School of Earth and Planetary Science

## The Geologic Record of Two Proterozoic Supercontinents within the Belt Basin Region of Western North America

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This thesis is presented for the Degree of Doctor of Philosophy of Curtin University

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## **Declaration**

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### **Acknowledgment of Country**

I acknowledge that during my time at Curtin University, I lived and worked on the traditional lands of the Wadjuk people of the Nyungar Nation. The fieldwork conducted and geologic samples collected for this scientific inquiry are from the traditional lands of the Kalispel, Coeur d'Alene, and Nez Perce people. I wish to pay my deepest respects to the ancestors and community members, past, present, and emerging of these First Nation peoples. While I strove to honor the geologic significance of the North American study region, I acknowledge and appreciate that the value and meaning of these lands surpass metrics measurable by scientific inquiry.

#### Abstract

The cyclical amalgamation and dispersal of most of Earth's continents, a process known as the supercontinent cycle, has been operable for at least the last 1.8 billion years. Many consider the supercontinent cycle to be the first-order control on the nonuniform spatial and temporal distribution of Earth's resources, and to have played a governing role in the environmental and biologic evolutionary changes that facilitated life. Early attempts at reconstructing Precambrian supercontinents often relied upon simplified correlations of singular geologic entities such as paired rift margins. However, more recent attempts to reconstruct ancient supercontinent configurations require multidisciplinary studies considering an even broader set of geologic entities such as basement provinces, orogenic histories, basin histories, paired rift margins, plume events, global plate kinematics, and paleomagnetic data. As a result, reconstructions have become more detailed, but the compounding effect of regional tectonic disagreements is still evident in wildly variable proposed global paleogeographic configurations. The Belt Basin region of western Laurentia has long been recognized to contain a key, yet debated, geologic record of the timing and configurations of the first supercontinent Nuna (1.6–1.3 Ga; also called Columbia), and its successor Rodinia (0.9-0.7 Ga). This study addresses some of the most significant of the Proterozoic magmatic, stratigraphic and metamorphic tectonic debates in this region, including A) the origin of localized North American Magmatic Gap magmatism, B) the tectonostratigraphic framework of Proterozoic strata, and the occurrence, timing, source, and implications of allegedly non-Laurentian derived detrital zircon within these strata, and C) the tectonic implications of enigmatic ca. 1.3–1.0 Ga metamorphism reported in this region. By bolstering field observations with U/Pb geochronology (zircon, monazite, apatite), additional zircon isotopic data (Lu/Hf, O-), and metapelite phase equilibria modelling, the results of this study strengthened commonly advocated ties between southeastern Australia and the Belt Basin region (USA) within supercontinent Nuna. However, the results also identified discrepancies between the Belt Basin region and commonly favored conjugate blocks (southeastern Australia or South China) within popular "SWEAT" or "Missing-Link" Rodinia configurations. Consequently, this work supports the accuracy of recently proposed Nuna configurations but advocates the need for more work on Rodinia reconstructions.



### **Author Acknowledgments**

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## Publications during the course of this thesis

## **Peer-reviewed journal articles:**

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## **Chapter 1: Introduction**

## **1.1. The Supercontinent Cycle**

One of the paradoxes of living on a tectonically active planet is that the same geologic processes responsible for exposing ancient rocks making them available for study also commonly obscures their original nature (Fig. 1.1). Consequently, there is regularly a correlation between the ambiguity in our understanding of tectonic events and their antiquity. During the late 20<sup>th</sup> and into the 21<sup>st</sup> century, the development of analytical methods to measure a variety of geochemical and isotopic systems within rocks and minerals, revolutionized the field of geology (e.g., Holmes, 1946; Goldschmidt, 1954; Stacey and Kramers, 1975; Frost et al., 2001; Hawkesworth and Kemp, 2006). Not only do geochemical and isotopic methods facilitate absolute dating of geologic and tectonic events, they can also be utilized as tracers/recorders of geologic and tectonic processes in situations where the original context has been obscured by younger events (e.g., Faure, 1977). When combined with field methods, the advent of geochemical and isotopic analytical methods has opened entirely new frontiers in the study of Earth systems.



**Fig. 1.1:** Panoramic photograph (looking northeast) of Belt Supergroup strata in Glacier National Park, Montana USA. The striking exposures of these Mesoproterozoic rocks results mostly from Late Cretaceous thrusting and uplift, followed by Pleistocene glacial incision. While these processes exposed these rocks for study, they also contributed to regional debates over particular stratigraphic correlations for decades. Photography by Brennan in 2018.

Prior to the availability of robust isotopic analytical methods, limited outcrop exposure, extensive tectonic over-printing, and the lack of absolute chronologic constraints made interpreting the geologic record of Precambrian rock assemblages particularly troublesome. As such, our knowledge of the 88% of earth's history that constitutes the Precambrian has only recently begun to be comparable with our

knowledge of younger Phanerozoic events. However, 20<sup>th</sup> century advancements in our understanding of geochemical and isotopic systems within rocks and minerals have gradually revealed that Earth's geosphere has an ancient and geologically active past.

Congruent with the proliferation of geochemical and isotopic studies was a growing scientific acceptance of plate tectonic theory (e.g., MeKenzie and Parker, 1967; Dewey and Horsfield, 1970). Not only was this theory consistent with modern geologic phenomena, most notably it also offered a testable mechanism for the movement of earth's continents allowing evaluation of Wegner's (1912) assertion that most of Earth's continents may have once been assembled into a singular landmass or "supercontinent." Wegner (1912) called this landmass Pangea (derived from the ancient Greek 'pan' meaning all, and 'gaea' meaning land). It didn't take long before others proposed that similar geologic processes likely occurred deeper, in the pre-Pangea, geologic past.

In 1970, Valentine and Moores were the first to officially propose the occurrence of a pre-Pangea, late Precambrian supercontinent subsequently named Rodina (from the Russian word 'rodit' meaning 'to beget' or 'to give birth'; McMenamin and McMenamin, 1990). The origin of this name is particularly suitable, as it was within the nutrient rich extensive shallow seas that resulted from globally widespread rifting associated with the breakup of Rodinia, that the proliferation of lifeforms during the Neoproterozoic–Cambrian "explosion" took place (e.g., Marshall, 2006; Peters and Gaines, 2012; Brocks et al., 2017; Hoffman et al., 2017). The concept and configuration of this late Precambrian "Rodinia" supercontinent has been long debated since the early 1990's (e.g., Moores, 1991; Dalziel, 1991; Hoffman, 1991). These disagreements are often based on conflicting correlations of ca. 1300–1000 Ma "Grenville-age" orogens along which the supercontinent breakup.

In the late 1990's and early 2000's, the recognition of widespread ca. 2100– 1800 Ma orogens led to the suggestion of the occurrence of an even older, pre-Rodinia supercontinent called "Nuna" (an Inuktitut term meaning "the land" or "all land", Hoffman, 1997) and/or "Columbia" (Rogers and Santosh, 2002; Zhao et al., 2002). As expected, the configuration of this Paleo-Mesoproterozoic supercontinent has also attracted much attention and debate within the geologic community. In particular, many geologic models favour similar configurations for both Rodinia and Nuna (e.g., Cawood and Hawkesworth, 2014; Li et al., 2019 and references within). This has raised discussions on whether they should be considered fully separate individual supercontinents (e.g., Condie et al., 2002) and consequently highlights the relatively poor understanding of the breakup and ensuing assembly processes of Earth's allegedly first and second supercontinents.

Despite intensive debate on the details, it has nonetheless generally been accepted that the assembly and subsequent dispersal of most of Earth's continents into supercontinents was a recurrent process for at least the past 1.8 billion years (Fig. 1.2; Condie, 2002; Nance et al., 2014; Evans et al., 2016; Li et al., 2019; Mitchell et al., 2021). The widespread recognition of long-term global cyclicity in tectonic processes is perhaps one of the most important developments in our understanding of the Earth since the acceptance of plate tectonic theory itself. Although it is now known that the supercontinent cycle was one of the first-order controls on the unequal spatial and temporal distribution of earth resources (e.g. Cawood and Hawkesworth, 2014), the drivers and mechanisms of tectonic cyclicity associated with these processes have many unanswered questions. For example, some argue that mantle-convection patterns are the predominate control on the style and evolution of Earth's tectonic cyclicity (Li et al., 2019), while others advocate that surficial erosion driven changes in subduction patterns are the primary first order control (Sobolev and Brown, 2019). An important first step in addressing these ongoing disagreements is the establishment of reliable, accurate and testable paleogeographic tectonic framework reconstructions throughout Earth's history.



**Fig. 1.2:** Timeline of supercontinents through time with paleogeographic reconstructions of Nuna at ca. 1300 Ma (also called Columbia), Rodinia at ca. 800 Ma, and Pangea at ca. 200 Ma (from Mitchell et al., 2021).

# **1.2.** A multidisciplinary approach to evaluating Precambrian supercontinent tectonics

Early attempts at Precambrian global paleogeographic tectonic reconstructions often relied heavily on correlation of singular geologic entities such as paired rift margins (e.g., Eisbacher, 1985). However, as Precambrian datasets grew, the correlation of multiple geologic entities such as paired rift margins and paleomagnetic data (Bell and Jefferson, 1987); and paired rift margins, paleomagnetic data, and orogenic histories (Dalziel, 1991; Moores, 1991; Hoffman, 1991) quickly became commonplace. More recently, it is generally accepted that robust paleogeographic reconstructions must be consistent with even broader set of geologic entities such as basement provinces, orogenic histories, basin histories, paired rift margins, plume events, global plate kinematic models, and paleomagnetic data (Fig. 1.3; e.g., Li et al., 2008). As such, the increasing consideration of multiple complementary datasets has aided in the generation of more detailed (e.g., Merdith et al., 2021) and hopefully more accurate reconstructions. However, these more detailed reconstructions have also highlighted how even minor disagreements and/or varying interpretations of what some may consider regional geologic discrepancies can be compounded into significant disagreements between global paleogeographic tectonic reconstructions. For example, disagreements on the Neoproterozoic geologic history of South China has led it to be placed centrally (Li et al., 2008), on the periphery (Wang et al., 2020), or perhaps even completely removed from Rodinia (Park et al., 2021).

### Solution = intersections of lines of evidence



Fig 1.3: A schematic diagram illustrating the importance of а multidisciplinary approach reconstructing and to evaluating palaeography (from Li et al., 2008). Note how when only a single line of geologic evidence is considered, there are often many non-unique solutions.

Consequently, regions where Precambrian basement, orogenic, basin, rift, and/or plume geologic records are present in close proximity often warrant detailed study, as robust tectonic models of these regions are a prerequisite for accurate and testable global paleogeographic tectonic models. Comparison of the tectonic records of these regions allows them to be linked in the past with other currently far afield regions containing similar histories, thus acting as geologic "piercing points." As a result, solving global-scale tectonic and paleogeographic disagreements is impossible as long as notable regional geologic debates persist.

# **1.3.**The Belt basin region – A critical Nuna and Rodina piercing point

As discussed, "Nuna" is a term in Inuktitut (the language of the indigenous people of the North American Arctic region) meaning "the land," or "all land," and Hoffman (1997) deserves credit for its first use to describe the Paleoproterozoic assembly of Laurentia and Baltica. Zhao et al. (2002) presented an extensive overview of global ca. 2100–1800 Ma orogens, and demonstrated that most other major Archean cratonic blocks such as those of North China, Australia, Siberia, India, South Africa, West Africa, and South America assembled along ca. 2000-1800 Ma orogens, suggesting synchronicity with Laurentia and Baltica's assembly. Following Rogers and Santosh (2002), Zhao et al. (2002) correlate these widespread ca. 2100-1800 Ma collisional orogens to reflect the assembly of a Paleo-Mesoproterozoic supercontinent they call Columbia. The Columbia name was first proposed by Rogers and Santosh (2002) who state that "the key evidence for its existence is the relationship between eastern India and the Columbia region of North America" (pg. 5). However, within the same Gondwana research volume, Meert (2002) presents the first paleomagnetic constraints for the Columbia Paleoproterozoic supercontinent, and in slight disagreement with the ca. 2100–1800 Ma assembly of Columbia advocated by Rogers and Santosh (2002), Meert notes that Paleomagnetic constraints suggest supercontinent assembly occurred primarily between ca. 1770–1500 Ma.

Consequently, an enduring controversy over the past two decades is not only whether the "Nuna" or "Columbia" name is better suited for the potential supercontinent that assembled in the late Paleoproterozoic (e.g., Meert, 2012), but if this supercontinent assembled coevally with widespread ca. 2000–1800 Ma "TransHudson" age orogens (e.g., Zhao et al., 2002), or if final assembly occurred later, probably after ca. 1800 Ma but prior to ca. 1500 Ma (e.g., Meert, 2002). In regards to the first (nomenclature) controversy, various arguments have been made recently to support both names. Harrison and St.-Onge (2022) note that the meaning of "Nuna" being "the land," or "all land," (in Inuktitut) is a more appropriate supercontinent name as it is akin to the meaning of Pangea (derived from the ancient Greek 'pan' meaning all, and 'gaea' meaning land). A sentiment shared by this author, and reflected by the preferred usage throughout this work. While others (e.g., Wang et al., 2021) suggest that the name Columbia, based off the "Columbia" region of western North America (namely Washington State) is more appropriate as it was the name used by the authors that first attempted global-scale reconstructions of this purported supercontinent (e.g., Rogers and Santosh, 2002; Zhao et al., 2002). While, naming preferences between myself and Rogers and Santosh (2002) differ, I do concur that the "Columbia" (which essentially comprises the western portion of Belt basin) region of western North American is critically understudied considering its long-recognized importance for global scale paleogeographic reconstructions (Fig. 1.4).



**Fig. 1.4**: Simplified geologic map of the northwestern United States, and southwestern Canada. The main Proterozoic tectonostratigraphic packages of this region, within the Columbia River drainage basin, consists of the extensive Mesoproterozoic Belt Supergroup (shown in brown), and Neoproterozoic Windermere Supergroup strata (and its correlatives, shown in green) which have both be integral in development of early Rodinia and Nuna paleographic reconstructions (e.g., Bell and Jefferson, 1982; Rogers and Santosh, 2002).

In fact, a growing body of paleomagnetic, geochronologic, and sedimentary provenance data has made the original "eastern India and the Columbia region of North America" correlation of Rogers and Santosh (2002) fall out of favor. Instead most recent models suggests links between the eastern margin of the North Australian craton (NAC) and the northwestern margin of Laurentia during assembly of supercontinent Nuna based on shared provenance, metamorphic and magmatic histories (Thorkelson et al., 2001; Ross and Villeneuve, 2003; Pisarevksy et al., 2014; Nordsvan et al., 2018; Pourteau et al., 2018; Volante et al., 2020, 2022). A lesser constrained southwest Laurentia-Mawson continent (Gawler Craton of South Australia and the Terre Adelie Craton of East Antarctica; Payne et al., 2009) connection is also suggested for this time (Mulder et al., 2015; Verbaas et al., 2018; Goodge et al., 2017). Based on similarities between crustal provinces in the Cathaysia Block of South China and southern Laurentia, Li et al. (1995), Yao et al. (2017) and others instead have proposed that the Cathaysia Block was between western Laurentia and Australia during Nuna time.

However, paleomagnetic constraints have demonstrated that the proposed Australia-Laurentia connection within Nuna could not have persisted uninterrupted during evolution to the subsequent supercontinent, Rodinia. Paleomagnetic constraints advocate that Australia and Laurentia separated between ca. 1300 and 1200 Ma (Pisarevsky et al., 2003; Kirscher et al., 2020), which suggests the occurrence of a complete Wilson cycle along the western Laurentia margin during the Nuna to Rodinia transition (Betts and Giles, 2006). However, a regional geologic record of this purported event is historically poorly recognized in western Laurentia.

The ensuing configuration of continents west of Laurentia within the supercontinent Rodinia (at ca. 1000 Ma) is an enduring (and perhaps endearing) controversy. Several original models are over 20 years old and continue to be revised and favoured by recent publications without a clear scientific consensus (see Fig. 1.5). Some of these leading models include a southwest U.S.–East Antarctic connection (SWEAT; Moores, 1991, Hoffman, 1991; Dalziel, 1991; Merdith et al., 2017; Zhao et al., 2018), possibly with a Rodinia-forming Grenville-age (Sibao) orogeny between (the Laurentia-connected) Cathayasia and the incoming Yangtze blocks of South China (Missing-Link; Li et al., 1995; Li et al., 2013), or with Australia located along the southwestern U.S. (AUSWUS; Karlstrom, 1999; Eyester et al., 2020) or Mexico (AUSMEX; Wingate et al., 2002). Completely different western Laurentia conjugates such as Tarim (Wen et al., 2017; 2018; Jing et al., 2021), or the North China Craton

(Ding et al., 2021) have also been suggested. However, at least one early model, the Siberian Connection (Sears and Price, 2000), which suggests that Siberia was conjugate to western Laurentian within Rodinia has generally fallen out of favor due to its inconsistency with most paleomagnetic data (Li et al., 2008; Pisarevsky et al., 2021; Evans, 2021).



**Fig. 1.5:** Variable Rodinia reconstruction models including the original models (top row), more recently proposed "updated" interpretations that share strong similarities with the original models, and alternative recently proposed models that have general similarities with original models. The location of the Belt basin region, the focus of this study area, is indicated by the black star in each reconstruction. Note that in relation to the pertinent regions of this study, most of these models differ in the location of Australia/Antarctica (in dark red) relative to western Laurentia, and the occurrence (or not) of small intervening blocks between Laurentia and Australia/Antarctica. Figure adapted from Evans (2021 and references within). Abbreviations include: Am, Amazonia; Au, Australian cratons including Antarctic Mawsonland; Ba, Baltica; Co, Congo; In, India; Ka, Kalahari; Laur, Laurentia; NC, North China; RP, Rio Plata; SC, South China; SF, Sa<sup>~</sup>o Francisco; Sib, Siberia; Ta, Tarim; WAf, West African craton.

## **1.4.** Regional debates with global implications

Several unique and debated geologic records within the Belt basin of western Laurentia make this region a distinctive Laurentian piercing point for Precambrian paleogeography (Fig. 1.6). Addressing these regional debates will allow for the evaluation of many of the competing global models presented above, and thus have the potential to significantly influence our understanding of Proterozoic supercontinent processes.

Within the Priest River and Clearwater metamorphic complexes (Fig. 1.4) within the Belt Basin region, 2670 to 2650 Ma Neoarchean and 1880 to 1840 Ma Paleoproterozoic magmatic rocks of the Clearwater block are exposed (Vervoort et al., 2016). Interestingly, the ca. 1480–1380 Ma Belt Supergroup strata that overlie these basement rocks have long been known to lack detrital zircon ages consistent with this Laurentian basement and instead contain abundant ca. 1700–1500 Ma detrital zircon grains (Ross and Villeneuve, 2003; Lewis et al., 2010). Many of these grains have ages that fall within the ca. 1610–1490 Ma "North American Magmatic Gap" (NAMG), a time interval during which magmatism was rare in Laurentia, but common in Australia. Consequently, this relationship is often used to justify the proximal relationship of Australia with western Laurentia during the Mesoproterozoic (e.g., Ross and Villeneuve, 2003). However, the presence of NAMG-age magmatism in South China (Xu et al., 2019) has also brought into question the uniqueness of this interpretation.

In the Priest River complex (Fig. 1.4), a thrust bounded ca. 1580 Ma granite (Evans and Fischer, 1986) represents one of the only ca. 1610–1490 Ma magmatic rocks in Laurentia. Its occurrence may negate the necessity of any non-Laurentian sources for the NAMG-age zircon grains in the Belt Supergroup. Within the Priest River complex, a thin coarse quartzite unit is either the basal unit of the Belt Supergroup, or is unconformably overlain by lower Belt Supergroup strata. Limited geochronology results suggest this unit lacks these unique ca. 1610–1490 Ma detrital zircon grains (Doughty et al., 1998).

Most of the metamorphism along western Laurentia is usually attributed to the late Mesozoic and younger Cordilleran orogeny (Dickinson, 2004). However, in the Clearwater complex, metasedimentary Belt Supergroup strata contain an enigmatic spread of pre-Cordilleran ca. 1380–1000 Ma Lu/Hf garnet ages (Zirakparvar et al., 2010; Nesheim et al., 2012). The older range of these garnets may correspond with ca.

1380–1350 Ma bimodal plutonism within the Belt Basin. This magmatism could be associated with the East Kootenay "orogeny" (McMechan and Price, 1982; Evans and Zartman, 1990; Doughty and Chamberlain, 1996; McFarlane and Pattison, 2000). The significance of the East Kootenay orogeny is contentious, but instead of an actual orogeny, it may represent a period of renewed subsidence along the western margin of Laurentia (in the Belt-Purcell basin) and potentially reflect the rifting of Australia from western Laurentia (Doughty and Chamberlain, 1996).

The tectonic context of the younger "Grenville" ca. 1150–1000 Ma metamorphic ages (Zirakparvar et al., 2010; Nesheim et al., 2012) are also debated. Some interpret a static thermal disturbance in the Belt region driven by magmatism at depth during this time interval (Doughty and Chamberlain, 2008). However, others advocate that the ca. 1100 Ma garnet growth requires crustal thickening (Zirakparvar et al., 2010) suggesting the presence of a Grenville-age orogen along western Laurentia during Rodinia assembly. Several global models propose either a ca. 1100 orogeny correlatable with the orogeny in the potentially adjacent South China (Sibao orogeny in the Missing-Link model, Li et al., 2008b) or a significant dextral transpressional margin (Wen et al., 2008, Mulder at al., 2018b) along western Laurentia that could account for this debated western Grenville-age orogenic event.

Along the northwestern edge of the Belt Basin, just west of the Priest River complex, the Buffalo Hump Formation and underlying Deer Trail Group strata crop out (Fig. 1.4). These rocks comprise the western-most exposures of Mesoproterozoic (and possibly Neoproterozoic) rocks in Laurentia. The entire Buffalo Hump Formation and Deer Trail Group were initially correlated with ca. 1470–1380 Ma Belt Supergroup to the east and across a significant thrust fault (the Jumpoff Joe Thrust), based on broad overall lithological similarities and the fact that they are overlain by the < 720 Ma Windermere Supergroup (Evans, 1987; Miller and Whipple, 1989). However, limited U-Pb analysis of detrital zircons from the Buffalo Hump Formation suggests a maximum depositional age of ca. 1100 Ma (Ross et al., 1992), indicating that it is too young to be part of the ca. 1380 Ma and older Belt Supergroup. This relationship requires either a significant unconformity between the Buffalo Hump Formation and the underlying allegedly Belt Supergroup correlative Deer Trail Group, or that the entire Deer Trail Group, which lacked any geochronologic constraints at the onset of this work, has also been miscorrelated.

The identification of ca. 1100 Ma detrital zircon grains within the Buffalo Hump Formation, and the relative absence of ca. 1100 Ma magmatism in western Laurentia, led Ross et al., (1992) to speculate that either: (a) The zircon grains were far-travelled or recycled, or (b) the grains record the former presence of Grenvillian orogenic activity within western Laurentia. However, the absence of a widespread Grenillian-orogenic belt in western Laurentia, and subsequent evidence for far-travelled Laurentia-sourced ca. 1100 Ma detrital zircon grains in northern and western Laurentia (e.g., Rainbird et al., 1992; Yonkee et al., 2014) tends to support the first hypothesis of Ross et al., (1992). Nevertheless, others (e.g., Yao et al., 2017) have continued to advocate that the necessity of a proximal, non-Laurentian source of ca. 1100 Ma zircon grains for the Buffalo Hump Formation requires South China, and its ca. 1100 Ma Sibao orogeny, adjacent to the Belt Basin region within Rodinia.

In the 30 years since Ross et al., (1992) published the first detrital zircon results from the western Belt Basin region, ca. 1100 Ma detrital zircon grains have been found to actually be quite common in the mostly Cryogenian and Ediacaran Windermere Supergroup and correlative strata along the western margin of Laurentia (e.g., Gehrels et al., 1995; Yonkee et al., 2014; Matthews et al., 2018; Box et al., 2020). Windermere Supergroup strata are generally younger than ca. 720 Ma, and record the onset of widespread rifting along western Laurentia associated with the breakup of Rodinia (e.g., Ross, 1991). Several occurrences of ca. 780–720 Ma, pre-Windermere Supergroup, strata within localized basins (Chuar, Pahrump, and Uinta groups) may record localized earlier rifting (e.g., Dehler et al., 2010). However, so far these ca. 780–720 Ma basins are only identified south of the Belt basin region, which has led to proposals (e.g. Haldari et al., 2021) that the Belt basin segment of the margin, specifically the St. Mary-Moyie fault zone (Fig. 1.4), reflects a notable Neoproterozoic boundary along the rift margin.

The St. Mary-Moyie fault zone (Fig. 1.4) roughly aligns with a basement structure called the Vulcan zone and was likely active during Mesoproterozoic Belt Supergroup deposition (e.g., McFarlane and Pattison, 2000). A segment of the St. Mary-Moyie Fault zone may also be reactivated as the Mesozoic thrust fault that currently separates exposures of Deer Trail Group strata, from Belt Supergroup rocks to the east (Miller and Whipple, 1989). Consequently, there are disagreements on if the exact timing, style, and number of Neoproterozoic rifting events differed for the segments south and north of the St. Mary Moyie structure, which has significant

implications for Rodinia breakup processes in this region (e.g., Colpron et al., 2002; Lund et al., 2003; Hadlari et al., 2021).



**Fig. 1.6:** Time-space diagram for the key debated Paleo–Neoproterozoic geologic and tectonic "tiepoint" events of the western Belt basin region (northeastern Washington and northern Idaho, USA), prior to the onset of this work in 2018.

## **1.5.Research Objectives**

The main objective of this work is to provide insights into several regional tectonic debates in the Proterozoic geologic history of the northwestern United States, notably along the western extent of the Mesoproterozoic Belt Basin (Fig. 1.6). Recalibrating the geologic record of this important Laurentian "piercing point" region allows evaluation of debated Nuna and Rodinia supercontinent tectonic reconstructions. Broken down into individual objectives, this task was accomplished through:

- Investigation of the origin of ca. 1.58 Ga North American Magmatic Gap Magmatism (NAMG) within the Clearwater Block, and further characterization of the isotopic composition of the nearby Archean– Proterozoic magmatic rocks. These results provided insights into the Proterozoic tectonic history of the region, and the provenance of overlying sedimentary units.
- 2) Geochronology and metamorphic study to resolve the timing, conditions, and origin of Meso–Neoproterozoic (Grenville-age) metamorphic events previously reported in the Clearwater region, and evaluate their relationship to similar events reported elsewhere along the western extent of the Belt Basin, and in potentially conjugate blocks.
- 3) Determination of the age, stratigraphic framework, and provenance of the Paleoproterozoic to Neoproterozoic strata of northeast Washington and northern Idaho (USA). Link these sedimentary rocks to potential source regions either within and/or outside Laurentia and determine the likely tectonic mechanisms for their deposition and provenance signatures.

Finally, these findings were integrated with the available Laurentian and non-Laurentian data to evaluate Nuna and Rodinia models focusing on the evolution of the western Laurentian margin in comparison to proposed conjugate regions, such as southeastern Australia, East Antarctica and South China during this time interval.

## **1.6.** Thesis Structure

This thesis is presented as a series of four published papers and a manuscript prepared for submission to a peer-reviewed journal. After peer review and publication, a data processing error was identified that affected the publications presented in Chapters 2 and 3. Corrigendum's to correct both publications were issued and Chapters 2 and 3 have been updated to reflect this correction and consequently vary slightly from their original published form. The text and figures of the published works (Chapters 2, 3, 5 and 6) and work currently in preparation for submission (Chapter 4) are reproduced in full and have been reformatted for consistency in the thesis. Thus, there is some unavoidable repetition between these chapters, particularly regarding the geological background and methods sections as each chapter is intended to read as standalone document.

Chapter 2: Closing the "North American Magmatic" Gap: Crustal evolution of the Clearwater Block from multi-isotope and trace element zircon data presents new U/Pb, Lu/Hf, O-, and trace element data from ca. 2.67 Ga, 1.86 Ga, and 1.58 Ga "North American Magmatic Gap" igneous rocks within the Clearwater Block. These data provide insights into the magmatic record of western Laurentian during the assembly of supercontinent Nuna. This data allows assessment of prior speculations that North American Magmatic Gap magmatism in the Clearwater Block may be associated with long recognized similar-age magmatism in the Gawler Craton of South Australia, or more recently identified similar-age magmatism in East Antarctica or the Hainan Island of South China.

Chapter 3: Detrital zircon U-Pb and Hf signatures of Paleo-Mesoproterozoic strata in the Priest River region, northwestern USA: A record of Laurentia assembly and Nuna Tenure investigates the provenance of the Paleoproterozoic Gold Cup Quartzite, Mesoproterozoic Belt Supergroup, and likely late Mesoproterozoic Deer Trail Group in the northwestern USA. This work provides the first laser-ablation split stream U/Pb and Lu/Hf data from detrital zircon grains within these sequences, and provides insights into the source and stratigraphic extent of North American Magmatic Gap detrital zircon grains recognized within these sequences.

**Chapter 4: Grenville-age metamorphism within the Belt basin of western Laurentia** examines the cryptic late Mesoproterozoic metamorphism reported within the Clearwater Complex. This work provides the first Pressure-Temperature-time constraints for this event based on U/Pb monazite and apatite geochronology, and thermocalc thermodynamic modelling.

**Chapter 5: Recalibrating Rodinian rifting in the northwestern United States** presents new detrital zircon U/Pb and Lu/Hf data from the Buffalo Hump Formation. The Buffalo Hump Formation was previously alleged to have a ca. 1.0 Ga depositional age. However, utilizing a rapid laser-ablation analysis methodology, a minor but significant ca. 760 Ma detrital zircon population was identified. This revised depositional age constraint has important ramifications for the occurrence of ca. 1.0 Ga (Grenvillian) tectonism in western Laurentia and the timing of Rodinian rifting.

Chapter 6: A tectonic model for the Transcontinental Arch: Progressive migration of a Laurentian drainage divide during the Neoproterozoic–Cambrian Sauk Transgression provides a new perspective on tectonic provenance models for ca. 1.1 Ga detrital zircon grains in western Laurentia. This new tectonic model is supported by two-dimensional quantitative comparison of a compilation of published U/Pb and Lu/Hf datasets from Neoproterozoic to early Paleozoic strata in western Laurentia, and potential eastern/southeastern Laurentian igneous sources.

**Chapter 7: Synthesis and conclusions: The role of northwestern Laurentia in understanding global supercontinent processes.** In this chapter the refined Proterozoic history of the Belt basin region of western Laurentia is synthesized, and the consistency of global Proterozoic supercontinent models with the regional geologic record of this key revised piercing point is assessed. In particular, this chapter summarizes how this work revises our understanding of:

 The Paleoproterozoic history of western Laurentia and how it relates to Nuna assembly, in particular was there evidence of Nuna assembly by ca. 1.85 Ga, or was it a later ca. 1.65 Ga process?

- 2) The Mesoproterozoic history of western Laurentia and how it relates to the Nuna to Rodinia transition, specifically what evidence is there for a ca. 1.1 Ga "western Grenville" orogenic event?
- 3) The Neoproterozoic history of western Laurentia and how it relates to Rodinia breakup, in particular what is the timing and style of rifting in western Laurentia? How does it relate to other suggested conjugate blocks?

In answering these questions, Chapter 7 brings the work presented in the individual chapters together and presents a revised Proterozoic tectonic model for the Belt basin region of western Laurentia. This regional tectonic model is then used to evaluate the feasibility of inherently more speculative global tectonic reconstructions, and the implications are discussed. As always, all scientific knowledge is conjectural, and while this work answers some questions, it also raises many more. Consequently, an important part of this concluding chapter is to emphasize uncertainties with the tectonic models resulting from this work and to highlight questions for future investigation.

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# Chapter 2: Closing the "North American Magmatic" Gap: Crustal evolution of the Clearwater Block from multi-isotope and trace element zircon data

## Abstract

Along the west-central margin of Laurentia, within the Priest River and Clearwater complexes, rare exposures of crystalline basement rocks of the Clearwater Block include "North American Magmatic Gap" (NAMG, ca. 1.61–1.49 Ga) ages. Elsewhere in this region, crystalline basement rocks are buried beneath thick deposits of the overlying Mesoproterozoic Belt Supergroup and younger sequences. The unique combination of magmatic basement ages and the detrital zircon components (which also include NAMG detrital ages) within the overlying Mesoproterozoic Belt Supergroup strata, has led researchers to identify the Clearwater Block region as a key tie-point for Proterozoic paleogeographic reconstructions. Some researchers even speculated that Proterozoic supercontinent events stranded exotic (possibly Australia, Antarctica or South China associated) basement terranes within the Clearwater Block. However, no comprehensive multi-isotopic data exist on the Neoarchean to Mesoproterozoic Clearwater Block crystalline basement leaving many of these speculations untested. We report new U-Pb, Lu-Hf and O isotopic data and trace element results of zircon grains for these rocks. Collectively, along with existing data these new results indicate a crustal evolution for the Clearwater Block that consists of: 1) ca. 2.67 Ga juvenile mantle-derived crustal growth as evident by mantle-like  $\delta 180$ and slightly supra-chondritic (+4 to 0)  $\varepsilon$ Hf<sub>t</sub> values, 2) ca. 1.87 to 1.83 Ga melting and metamorphism of this ca. 2.67 Ga crust as recorded by ca. 1.86 Ga samples containing zircon with low (<0.1) Th/U ratios and retention of mantle-like  $\delta$ 180 values, and similar-age ca. 1.87–1.83 Ga samples containing zircon with higher (>0.1) Th/U ratios, and 3) ca. 1.58 Ga "NAMG" magmatism that records mantle-like  $\delta$ 180 but subchondritic (-5.5 to -9.5) EHft values. We interpret the ca. 1.58 Ga NAMG magmatism to be consistent with (perhaps plume-driven) reworking of the Clearwater Block's ca. 2.67 Ga lower crustal reservoir. Consequently, these results support a Laurentian origin for NAMG-age magmatism within the Clearwater Block, but confirm the

necessity of non-Laurentian sources for juvenile ( $+\epsilon Hf_t$ ) NAMG-age detrital zircon grains in the overlying ca. 1.47 Ga lower Belt Supergroup strata, thus providing important constraints for western Laurentia's conjugate during the early Mesoproterozoic.

### 2.1. Introduction

The North American Magmatic Gap (NAMG) is an apparent tectono-magmatic lull from ca. 1.61 to 1.49 Ga within Laurentia (Van Schmus et al., 1993). This period of relative magmatic quiescence occurred after the culmination of the Paleoproterozoic Trans-Hudson (ca. 2.0–1.8 Ga) and Yavapai-Mazatzal-Mojave orogens (ca. 1.65 Ga), and prior to the start of extensive anorogenic magmatism within the Transcontinental Granite-Rhyolite Province at ca. 1.48 Ga (Ross and Villeneuve, 2003; Whitmeyer and Karlstrom, 2007). The NAMG coincides with the final assembly (at ca. 1.6 Ga; Thorkelson et al., 2001; Pourteau et al., 2018) and the following period of relative tectonic stability within the supercontinent Nuna (also called Columbia), and likely reflects Laurentia's central location within the supercontinent (Kirscher et al., 2021). Accordingly, the predominance of NAMG-age detrital zircon grains within western Laurentian strata such as the Mesoproterozoic, ca. 1.47-1.38 Ga Belt (Purcell in Canada) Supergroup (Fig. 2.1A; Ross et al., 1992; Ross and Villeneuve, 2003; Lewis et al., 2010; Box et al., 2020; Brennan et al., 2021), the ca. 1.49–1.44 Ga Hess Canyon Group in southwestern Laurentia (and correlative Trampas basin strata; Doe et al., 2012, 2013; Jones et al., 2015), and the ca. 1.46–1.42 Ga PR1 basin in northwestern Laurentia (Medig et al., 2014), is often interpreted to require non-Laurentian source terranes. Potential source terranes with evidence of NAMG-age magmatism include western Tasmania (Halpin et al., 2014; Mulder et al., 2015), Australia (Reid and Payne, 2017), Antarctica (Goodge et al., 2017) and/or parts of south China (Hainan Island with or without the Cathaysia Block; Li et al., 1995; Xu et al., 2019; Cawood et al., 2020). Consequently, these terranes are commonly located adjacent to western Laurentia within Nuna supercontinent reconstructions.

However, within the Priest River and Clearwater complexes in the northwestern United States of America, the westernmost pre-Belt Supergroup rocks of the Clearwater Block are exposed (Fig. 2.1B), including a small sliver of ca. 1.58 Ga (NAMG-age) granitic gneiss (the Laclede Gneiss; Evans and Fischer, 1986). The ca. 1.58 Ga Laclede Gneiss is the only NAMG-age granitoid in western North America. It has been interpreted as a (i) stranded block of a Proterozoic conjugate continent from Australia, Antarctica, or South China (Ross et al., 1992; Doughty et al., 1998; Goodge et al., 2017; Xu et al., 2019) or (ii) a remnant of a circum- Laurentian orogenesis during the assembly of supercontinent Nuna (Furlanetto et al., 2013). Others (Lewis et al., 2010; Rogers et al., 2018) have also suggested that the Laclede Gneiss might represent a Laurentian source for the ca. 1.7–1.5 Ga detrital zircon grains within parts of the Belt Supergroup, negating the necessity for a western, non- Laurentian source in paleographic reconstructions.

However, apart from U–Pb geochronology studies (Evans and Fischer, 1986; Doughty et al., 1998; Vervoort et al., 2016), Neoarchean-Paleoproterozoic Lu-Hf datasets, and some whole-rock geochemistry (Buddington et al., 2016), a multiisotopic, integrated comparison of the Neoarchean-Mesoproterozoic Clearwater Block crystalline basement and overlying Paleoproterozoic-Mesoproterozoic strata does not exist. Consequently, many speculations about the Clearwater Block's paleogeographic importance remain untested. Here, we present the results of sensitive high-resolution ion microprobe (SHRIMP) U-Pb, secondary ionization mass spectrometry (Cameca SIMS 1280) 818O, and laser-ablation inductively coupled mass spectrometry (LA-ICP-MS) Lu-Hf and trace element analyses for zircon from ca. 2.67, 1.86 and 1.58 Ga igneous rocks from the Clearwater Block. These new results, along with existing constraints (Evans and Fischer, 1986; Doughty et al., 1998; Lewis et al., 2010; Buddington et al., 2016; Vervoort et al., 2016), provide robust characterization of the westernmost exposed basement beneath the Mesoproterozoic Belt Basin. These rocks include a unique record of NAMG-age magmatism and allow evaluation of competing models for western Laurentia's assembly and supercontinent Nuna's configuration/evolution.

### 2.2. Geologic Background

#### 2.2.1. The Priest River complex: American or Australian?

Along much of western North America, within the hinterland of the Cordilleran fold and thrust belt, Paleogene orogenic collapse and development of metamorphic core complexes have exhumed rare exposures of deeply buried crystalline basement beneath thick sequences of Mesoproterozoic to Mesozoic strata (e.g. Dickinson, 2004 and references therein). Within the Priest River complex, along the western extent of the Mesoproterozoic Belt Basin in northern Idaho and southern British Columbia (Fig. 2.1), granitic gneisses were among the first Precambrian rocks in the northwestern Cordillera to be dated by U–Pb geochronology (Clark, 1973; Evans and Fisher, 1986; Doughty et al., 1998). In part, these basement rocks drew early attention because of their sharp contrast with the surrounding extensive, siliciclastic and carbonate strata of the ca. 1.47–1.38 Ga Mesoproterozoic Belt (Purcell in Canada) Supergroup that had long been recognized for its economic and tectonic importance (Harrison, 1972; Ross et al., 1992).



**Fig. 2.1:** A) Simplified tectonic map of western Laurentia (after Vervoort et al., 2016 and references within) showing the extent and general age of basement provinces, the limit of Belt Supergroup exposures, location of ca. 1.59 and 1.55 Ga mafic dykes in southern Montana (Tobacco Root Mountains; Rogers et al., 2018) and location of sampling areas. B) Geologic map of the northern extent of basement rock exposure within the Priest River complex where samples of the Pend Oreille Gneiss (36DTB19) and Laclede Gneiss (37DTB19) were collected. C) Geologic map of the southern extent of basement rock exposure within the Priest River complex where a sample of the Coeur d'Alene Gneiss (46DTB19) was collected. D) Geologic map of the southeastern extent of the Clearwater complex where a sample of the Moses Butte Amphibolite (52DTB19) and Black Canyon Gneiss (67DTB19) were collected. Geologic maps B, C, and D adapted from Lewis et al. (2012).

Early geochronological analyses on these basement exposures were characterized by analyses showing considerable U–Pb discordance (Table 1). Discordia regression calculations hinted that the western "Belt basement" within the Priest River complex consisted of Neoarchean orthogneiss (ca.  $2650 \pm 21$  Ma) which was unconformably overlain by Belt or possibly pre-Belt strata (Doughty et al., 1998). In addition, the data suggested that the NAMG-age "Laclede Gneiss" ( $1576 \pm 13$  Ma by Evans and Fischer, 1986; ca. 1577 Ma by Doughty et al., 1998) was in fault contact with mylonitized lower Belt Supergroup equivalent strata (Doughty et al., 1998; Lewis et al., 2010; 2020; Fig. 2.1B, 2.1C). Based on the similarity of these ages to existing geochronological constraints for eastern Australia (notably the Gawler Craton), it was suggested that the basement rocks of the Priest River complex could be a remnant of eastern Australia left behind during late Proterozoic rifting (Ross et al., 1992; Doughty et al., 1998; Evans et al., 2000).

Within the Priest River complex, a thin (~300 m thick) quartzite (the Gold Cup Quartzite) unconformably overlies Neoarchean and Paleoproterozoic crystalline basement and is overlain by Mesoproterozoic Belt Supergroup strata (Doughty and Chamberlain, 2008; Buddington et al., 2016; Lewis et al., 2020). The Gold Cup Quartzite lacks detrital zircon grains younger than ca. 1.74 Ga, and records a Laurentian provenance (Brennan et al., 2021) suggesting deposition prior to the ca. 1.6 Ga final assembly of supercontinent Nuna (Nordsvan et al., 2018; Pourteau et al., 2018; Kirscher et al., 2019; Volante et al., 2020). Basin-wide studies of the overlying Belt Supergroup suggest that the Belt Basin received sediment from both Laurentian and disputed western non- Laurentian sources (e.g. Ross and Villeneuve, 2003). Within Belt Supergroup strata, a Laurentian signature is characterized by major agepeaks at ca. 2.7, 1.8–1.7, and 1.45 Ga, whereas a possible non- Laurentian signature is characterized as having a broad range of detrital zircon ages from ca. 1.9-1.4 Ga, including significant zircon grains with ages that fall within the ca. 1.61–1.49 Ga North American Magmatic Gap (Ross et al., 1992; Ross and Villeneuve, 2003; Box et al., 2020).

However, others (e.g. Lewis et al., 2010) have questioned if exotic sources are necessary to provide the NAMG-age zircon grains within Belt strata, citing the ca. 1.58 Ga Laclede Gneiss within the Priest River complex as a potential source. Rogers et al. (2018) also advocated that the ca. 1.59 Ga (1590  $\pm$  3 Ma) Mammoth and ca. 1.55 Ga (1551  $\pm$  5 Ma) Ramshorn Creek mafic dykes, located nearby in southern Montana,

may have potentially eroded felsic equivalents that could have been additional Laurentian detrital zircon sources. Rogers et al., (2018) correlated the plume-related chemistry of the ca. 1.59 Ga Mammoth dykes to geochemically similar, coeval rocks in the Gawler Craton and Curnamona Province of southeastern Australia, which they consider connected as one single large igneous province (LIP) within Nuna.

# 2.2.2. The Clearwater Block: A Priest River and Clearwater complex connection

Approximately 150 km south/southeast of the the Priest River complex, pre-Belt Supergroup crystalline basement rocks are also exposed in the Clearwater complex (Fig. 2.1D; Reid et al., 1973; Doughty and Chamberlain, 2007; Vervoort et al., 2016). Early work on Clearwater complex crystalline basement rocks (Table 1) gave discordant geochronology results suggesting ca. 2.1–1.8 Ga crystallization ages (Reid et al., 1973). Follow-up geochronology (Doughty and Chamberlain, 2007) also showed significant Pb-loss, but supported the presence of ca. 1.8 Ga igneous (anorthosite) rocks within the Clearwater complex. Limited geochronology results from an amphibolite exposed within the granitic basement also hinted at the occurrence of ca. 1.59 Ga mafic magmatism based on the two oldest, slightly reverse discordant analyses out of six total analyses, with the younger four analyses suggesting ca. 1.38 Ga metamorphic growth (Doughty and Chamberlain, 2007). Overall, these results reflect the similar timing of pre-Beltian magmatism within the Priest River and Clearwater complexes.

Subsequent extensive geochronological study of the Priest River and Clearwater complexes by Vervoort et al. (2016) further solidified the similarity between the ages of basement rocks exposed within the complexes. Vervoort et al., (2016) dated 18 orthogneiss exposures across the Priest River (n = 2) and Clearwater (n = 16) complexes. All samples yielded ages that fall into two tightly defined age ranges of ca. 2.67 to 2.65, and 1.88 to 1.84 Ga, indicating two main periods of crustal formation beneath the western portion of the Belt Basin. Based on the similarity of these ages, Vervoort et al. (2016) suggested that the Priest River and Clearwater complexes expose crystalline basement of the same crustal block, which they named the Clearwater Block. The relationship between the Clearwater Block and the adjacent Medicine Hat Block to the east is not well known (Vervoort et al., 2016; Gifford et al., 2020).

Paleoproterozoic xenocrystic zircons within Phanerozoic plutonic rocks led Foster et al., (2006) to speculate that a separate ca. 2.4–1.5 Ga "Selway" terrane comprises the southern portion of the Clearwater Block. However, additional studies of the xenocrystic zircon cargo of Phanerozoic plutons (Gaschnig et al., 2013) and exposed basement rocks in the region (Vervoort et al., 2016) did not support this speculation. Consequently, Gaschnig et al. (2013) and Vervoort et al. (2016) refrained from delineating a separate terrane in the southern portion of the Clearwater Block. In addition, geophysical results do not support the interpretation of a separate terrane in the southern portion of the Clearwater Block (e.g. Bedrosian and Feucht, 2014).

#### 2.2.3. Adjacent Laurentian basement framework

Western Laurentia is a complicated mosaic of igneous, metamorphic and sedimentary rocks that range in age from Archean to present and are the result of this region being at or near a continental margin periodically for the past 2.6 billion years (Hoffman, 1988; Whitmeyer and Karlstrom, 2007; Vervoort et al., 2016). East of the Clearwater Block, the Medicine Hat Block contains a mix of Archean (ca. 3.1–2.6 Ga) and Paleoproterozoic (ca. 1.81–1.75 Ga) crust (Gifford et al., 2018, 2020; Ross et al., 1991; Villeneuve et al., 1993). The Paleoproterozoic magmatism within the Medicine Hat block has an evolved Lu–Hf signature indicating reworking of the older Meso- to Neoarchean rocks (Gifford et al., 2020).

The Archean Wyoming Craton and Grouse Creek Block are separated from each other by the Farmington Zone and neighbor the Clearwater and Medicine Hat blocks to the south (Whitmeyer and Karlstrom, 2007; Mueller et al., 2011). The Wyoming Craton includes rocks as old as 3.6 Ga and detrital zircon ages as old as 4.0 Ga (Chamberlain et al., 2003; Mueller and Frost, 2006). The Grouse Creek Block in southcentral Idaho and northern Utah may also contain rocks as old as ca. 3.6 Ga preserved only as xenoliths within younger Snake River Plain volcanic rocks (Leeman et al., 1985), but has exposures of ca. 2.67–2.50 Ga felsic and ca. 1.85 Ga mafic magmatic rocks (Strickland et al., 2011; Link et al., 2017). The Farmington Zone contains ca. 2.45 Ga magmatism and ca. 1.67 Ga metamorphism, and likely records the final juxtaposition of the Wyoming Craton, Grouse Creek Block and Mojave Province (Mueller et al., 2011).

Paleoproterozoic (Trans-Hudson-age; ca. 1.9–1.7 Ga) suture/collisional zones separate the main Archean blocks of western Laurentia. The boundary between the Medicine Hat Block and the Wyoming Craton to the south (Mueller et al., 2002) is

delineated by the broad Great Falls Tectonic Zone. The Great Falls Tectonic Zone records major ca. 1.86–1.73 Ga Paleoproterozoic convergent events including the Great Falls Orogeny and the more temporally and spatially restricted Big Sky Orogeny. Generally, Great Falls Tectonic Zone rocks indicate northwest-dipping subduction, closure of an intervening ocean and eventual amalgamation of the Medicine Hat Block to the Wyoming Craton (Gorman et al., 2002; Mueller et al., 2002; Foster et al., 2006; Condit et al., 2015; Gifford et al., 2014; 2018; 2020).

The Clearwater and Medicine Hat blocks are bordered to the north by the subsurface Vulcan structure. The Vulcan structure is likely another Trans-Hudson age feature that may reflect the collision of the southwestern margin of the ca. 2.7–1.8 Ga Hearne Province (the Lovera Block) with the northern margin of the Medicine Hat Block along a north-dipping subduction zone (Ross et al., 1991; Nieuwenhuis et al., 2014). However, differing geophysical interpretations have also resulted in Paleoproterozoic rift (Kanasewich et al., 1969), or south-dipping subduction/collision zone models (Eaton et al., 1999) for the Vulcan structure. North of the Lovera Block, limited geochronologic studies indicate ca. 2.24, 2.03 and 1.84 Ga basement rocks are exposed within the Monashee complex (Crowley et al., 1999).

Following the assembly of the main Archean blocks of western Laurentia during Trans-Hudson-age events, a long-lived accretionary boundary resulted in the addition of the ca. 1.84–1.70 Ga Mojave province, which comprises a mixture of juvenile and evolved components (suggesting the presence of crust as old as ca. 2.5 Ga; Wooden et al., 2012), and the juvenile ca. 1.90–1.70 and 1.65–1.60 Ga Yavapai and Mazatzal provinces along the southern/southwestern margin of Laurentia (Bowring and Karlstrom, 1990; Holland et al., 2020). Collectively, the Mojave-Yavapai-Mazatzal provinces may record progressive accretion of separate, predominantly juvenile arc systems (Whitmeyer and Karlstrom, 2007), or may represent an extensive arc-backarc system that developed along the Australia–Antarctica margin at ca. 1.8 Ga before their accretion to Laurentia at ca. 1.65 Ga (Gibson and Champion, 2019). Mueller et al. (2011) interpreted the ca. 1.67 Ga metamorphism within the Farmington Zone to record collision of Mojave-Yavapai provinces to the southern margin of the Wyoming craton.

#### 2.3. Methods

#### **2.3.1.** Sample preparation

Samples were collected in the context of 1:100,000 scale geologic mapping of the Priest River and Clearwater complexes (Lewis et al., 2007; 2020). Petrographic thin sections were made by Wagner Petrographic, Utah USA. Zircon grains for isotopic analysis were separated from approximately 1 kg individual hand samples using standard techniques consisting of SEL-Frag fragmentation followed by Frantz magnetic and heavy liquid separation at Curtin University, Australia. Unknown zircon grains along with reference zircons OGC, 610, M257, 91500, and Z1 were mounted in epoxy resin within 6 mm of the center of 25 mm diameter disks and were polished to expose grain centers. Prior to analysis, all mounts were imaged in reflected and transmitted light on a Zeiss Axio Imager.M2m optical microscope and cathodoluminescence (CL) imaged using a MIRA3 variable-pressure field-emission scanning electron microscope (SEM) at the Microscopy and Microanalysis Facility at the John de Laeter Centre (JdLC), Curtin University for analysis targeting.

# 2.3.2. A threefold analytical approach: Measurement of U–Pb, $\delta^{18}$ O, Lu–Hf, and trace element zircon values

U-Pb dating was carried out on the SHRIMP II at Curtin University. A 25 µm diameter spot size was used for all the analysed grains with a primary beam current of 2.5–3.0nA. Data for each spot were collected in sets of 6 scans through the mass range of <sup>196</sup>Zr<sup>2</sup>O+, <sup>204</sup>Pb+, background, <sup>206</sup>Pb+, <sup>207</sup>Pb+, <sup>208</sup>Pb+, <sup>238</sup>U+, <sup>248</sup>ThO+, <sup>254</sup>UO+. The measured isotopic ratios were corrected for common Pb based on the measured <sup>204</sup>Pb and using the common Pb evolution curve of Stacey and Kramers (1975). U-Pb ages were normalized to the M257 zircon standard accepted value of 561.3 Ma (Nasdala et al., 2008). In addition to primary standard M257, secondary reference standard (OGC) analyses were interspersed between unknown analyses during each session (one standard every three to five unknowns). The weighted mean of 18 OCG analyses yielded a date of  $3466.6 \pm 3.1$  (MSWD = 1.6) which is indistinguishable from accepted OGC reference age of  $3465.4 \pm 0.6$  Ma (Stern et al., 2009). All isotopic measurements were reduced, processed and interpreted using SQUID II, and IsoplotR programs (Vermeesch, 2018; Bodorkos et al., 2020; Ludwig, 2003). All uncertainties reported within this text are at  $2\sigma$  and include errors from U-Pb calibration based on the reproducibility of U–Pb standard measurements, counting statistics and the common-

Pb correction. Throughout the text, <sup>207</sup>Pb/<sup>206</sup>Pb dates are used for all analyses besides sample 52DTB19 (Moses Butte Amphibolite). For sample 52DTB19, the <sup>206</sup>Pb/<sup>238</sup>U and Concordia age values are also considered due to the ambiguity in the best isotopic ratio for dates between ca. 1.5 and 1.0 Ga (Ludwig, 1998), which is discussed further in the results.

1998

(2016)

(2016)

1998

this work

this work

this work

Doughty and Chamberlain, 2007

this work

this work

this work

#### Table 2.1

SIMS

LA-SS-ICPMS

SIMS-SHRIMP

SIMS-SHRIMP

SIMS

LA-ICPMS

LA-ICPMS

Moses Butte Amphibolite GM-01 -2

52DTB19

O- isotopes (n = 20)

abundances (n = 20)

Lu-Hf (n = 20)

trace element

U-Pb (n = 6)

U-Pb (n = 27)

trace element

O- isotopes (n = 20)

abundances (n = 20)

Geologic Unit	Analysis method	Isotopic data	Values reported	Results	Reference
Pend Oreille					
Gneiss					
PR-93-7478	Dissolution TIMS	U-Pb (n = 3)	discordia upper intercept	2651 ± 21 Ma	Doughty et al., 19
36DTB19	SIMS-SHRIMP	U-Pb (n = 20)	discordia intercept estimates	ca. 2.7 Ga crystallization, ca. 1.8 Ga metamorphism, or a possible paragneiss origin	this work
Black Canyon					
08RAB025	LA-ICPMS	U-Pb $(n = 20)$	weighted mean of 20 ananlyses	2663 ± 8 Ma	Vervoort et al., (2)
67DTB19	SHRIMP	U-Pb $(n = 20)$	weighted mean of 11 concordant analyses	2665 ± 4 Ma	this work
	SIMS	O- isotopes (n = 20)	weighted mean of 17 robust analyses	$\delta 18O \ = \ 5.42 \ \pm \ 0.08 \ \%$	this work
	LA-SS-ICPMS	Lu-Hf (n = 20)	three most concordant analyses	$\epsilon Hft$ = +3.5 to $-0.5$	this work
	LA-ICPMS	trace element abundances ( $n = 20$ )	abundances (ppm)	see Fig. 8A	this work
Coeur d'Alene					
Gneiss					
09RMG07, 07RMG22	LA-ICPMS	U-Pb (n = 20)	weighted mean of 20 ananlyses	1862 ± 3, 1867 ± 4 Ma	Vervoort et al., (2)
67DTB19	SIMS-SHRIMP	U-Pb (n = 20)	weighted mean of 5 concordant analyses	1857 ± 5 Ma	this work
	SIMS	O- isotopes (n = $20$ )	weighted mean of 17 robust analyses	$\delta 18O~=~5.47~\pm~0.07~\%$	this work
	LA-ICPMS	trace element abundances (n = $20$ )	abundances (ppm)	reported in supplementary	this work
Laclede Gneiss					
Not assigned	Dissolution TIMS	U-Pb $(n = 3)$	discordia upper intercept	ca. 1540 Ma	Clark, 1973
Not assigned	Dissolution TIMS	U-Pb $(n = 4)$	discordia upper intercept	1576 ± 13 Ma	Evans and Fischer, 1986
PR-93 -731	Dissolution TIMS	U-Pb $(n = 3)$	single most concordant analysis	1577.4 ± 2.3 Ma	Doughty et al., 19
37DTB19	SIMS-SHRIMP	U-Pb (n = 24)	weighted mean of 22	1581 ± 3 Ma	this work

concordant analyses

range of 18 analyses

excluding 2 outliers

weighted mean of 2 voungest analyses

abundances (ppm)

weighted mean of 2 oldest

various metrics discussed in

abundances (ppm)

analyses

analyses

text

analyses

weighted mean of 17 robust  $\delta 180 = 5.15 \pm 0.13 \%$ 

weighted mean of 17 robust  $\delta 180 = 4.52 \pm 0.31 \%$ 

 $\epsilon$ Hft = -5.5 to -9.7

(metamorphic growth)

reported in supplementary

1587  $\pm$  9 Ma (crystallization) 1361  $\pm$  13 Ma

ca. 1417 to 1350 Ma metamorphic growth

see Fig. 8B

Abbreviations:	TIMS-Thermal	lonization	Mass Spectroscopy,	LA-Laser	ablation,	SS-Split	stream,	ICPMS-Iductively	Coupled	Plasma	Mass	spectrometry,	SHRIMP-
Sensitive Hiah	Resolution Ion	Micro Prob	e, SIMS-Secondary	lonization	Mass Spe	ctroscopy.							

After SHRIMP analysis, the sample mounts were thoroughly cleaned, and briefly repolished with a 3 µm diamond paste, prior to being coated with an approximately 30-nm-thick Au coating. Subsequent zircon oxygen isotopic compositions were measured using a Cameca IMS 1280 at the Centre for Microscopy, Characterization and Analysis (CMCA) facility at the University of Western Australia following procedures described by Hartnady et al., (2020). Oxygen analysis spots were placed within the same crystal domain as the SHRIMP analysis spots as identified by CL imaging but did not overlap and generally an approximately 10  $\mu$ m gap or larger was left between analysis spots where feasible. Oxygen results were processed with a CMCA in-house excel macro. Oxygen isotope compositions are reported in the conventional delta notation; expressed as  $\delta$ 180, reflecting the permil (‰) deviation in the (180/160) isotope ratio of the sample relative to average seawater (Vienna Standard Mean Ocean Water; VSMOW; Baertschi, 1976).

Instrumental drift and fractionation were determined through analysis of reference zircon 91,500 with OGC and M257 as secondary reference standards. During our first of two analytical runs, unknown samples 67DTB19, 46DTB19 and 37DTB19 were analysed with an approximately 20 µm diameter, 2.5nA, Cs+ ion-beam. During this run primary reference standard 91,500 (n = 14) yielded a  $\delta$ 180 weighted mean of  $9.94 \pm 0.08\%$  (MSWD = 0.63) which is indistinguishable from the accepted value of  $9.90 \pm 0.30\%$  (Wiedenbeck et al., 2004) and consequently did not require application of any drift correction. Secondary reference standards yielded  $\delta$ 180 weighted means of  $5.68 \pm 0.21\%$  (OGC) and  $13.99 \pm 0.06\%$  (M257) which are also indistinguishable from the accepted values of  $5.88 \pm 0.06\%$  and  $13.93 \pm 0.22\%$  (Nasdala et al., 2008; Petersson et al., 2019).  ${}^{16}O^{1}H/{}^{16}O$  values were also monitored to evaluate secondary water update facilitated by radiation damage within the zircon (e.g. Liebmann et al., 2021). Reference standard  ${}^{16}O^{1}H/{}^{16}O$  values ranged from 0.0006 to 0.0010. Only 5/60 analyses of the unknowns exceeded this range with no obvious effect on  $\delta$ 180 values. Nevertheless, these five analyses are disregarded due to their elevated <sup>16</sup>O<sup>1</sup>H/<sup>16</sup>O values recording possible alteration of their oxygen isotopic compositions.

Due to smaller zircon size, sample 46DTB19 was analysed during a separate run with a more targeted, approximately 10 µm diameter, 1.0nA, Cs+ ion-beam. Slight sample topology observed within the 91,500 reference material (and inability to polish further without removing the unknown grains) rendered it unfavourable as a primary standard (e.g. Kita et al., 2009), and consequently M257 was utilized as the primary reference standard. M257 yielded a  $\delta$ 180 weighted mean (n = 6) of 13.99 ± 0.12‰ (MSWD = 0.62) which is indistinguishable from the accepted value of 13.93 ± 0.22‰ (Nasdala et al., 2008) and consequently no drift correction was applied. Secondary reference standard OGC yielded a  $\delta 180$  weighted mean of  $5.86 \pm 0.18\%$  which is also indistinguishable from the accepted values of  $5.88 \pm 0.06\%$  (Petersson et al., 2019). All unknown analyses (n = 8) fell within the  ${}^{16}O^{1}H/{}^{16}O$  range given by the standards (0.0009 to 0.0013).

Final analysis consisted of measuring U–Pb, Lu–Hf, and trace element isotopes using laser ablation (single and) split-stream inductively coupled mass spectroscopy (LA-SS-ICP-MS) at the GeoHistory Facility in the John de Laeter Centre at Curtin University, Perth Australia across two analytical sessions. The first analysis session consisted of ablation with 38-µm analysis spot generated by a Resonetics RESOlution M50-A excimer laser. From this ablated material, U–Pb isotopes were measured on an Agilent 7700 s quadrupole ICP-MS for age determination, while Lu–Hf isotopes were simultaneously measured on a Nu Instruments NP II MC-ICP-MS. During this session, 38 µm analysis spots were placed over both the SHRIMP and SIMS analysis spots where possible.

Subsequently, during a second laser ablation analytical session (LA-ICP-MS), trace elements abundances were measured on an Agilent 8900 QQQ ICP-MS using a 20 µm spot generated by a Resonetics RESOlution M50-A excimer laser which was placed over the same zircon crystal domain as the prior analyses. Following analysis, data reduction was performed using the software Iolite v.3.6 (Paton et al., 2011). MudTank zircon standard was utilized as the primary standard for Lu–Hf results, while GJ-1 was utilized as a primary reference standard for the trace element results.

To evaluate the necessity of non-Laurentian sources for strata in the region, new trace element data from detrital zircon grains within overlying Paleoproterozoic Gold Cup Quartzite and Mesoproterozoic lower Belt Supergroup strata are reported. This analytical session also utilized a Resonetics RESOlution M50-A excimer laser paired with an Agilent 7700 s quadrupole and Nu Instruments NP II MC-ICP-MS at the GeoHistory Facility in the John de Laeter Centre at Curtin University for simultaneous measurement of U–Pb, Lu–Hf, and trace element abundances. Brennan et al. (2021) report the U–Pb and Lu–Hf results from this detrital zircon analytical session. Additional SHRIMP, SIMS, and LA-ICP-MS analytical details are included in the supplementary information.

#### 2.4. Results

#### 2.4.1. Sample 36DTB19 – Pend Oreille Gneiss

Within the core of the Priest River complex, the structurally lowest unit exposed is the Pend Oreille Gneiss (Lewis et al., 2020). Doughty et al., (1998) reported U–Pb (thermal ionization mass spectroscopy) data from five chemically abraded zircon grains from this unit that are variably discordant. Their discordia regression suggests a  $2651 \pm 21$  Ma crystallization age, disturbed by an early Paleozoic (ca. 495 Ma) Pb-loss event.

To further evaluate this probable Neoarchean basement within the Priest River complex, sample 36DTB19 was collected from a heterogeneous migmatitic biotite gneiss outcrop of the Pend Oreille Gneiss in a similar location (Fig. 2.1B) to Doughty et al. (1998). The zircon grains separated from sample 36DTB19 show concentric zoning in CL imaging consistent with magmatic growth. Thin ( $<5 \mu m$ ) metamorphic rims are present on some grains but their small size precluded analysis (Fig. 2.2A). Twenty SHRIMP U-Pb analytical results from these grains yielded complex (8% to 90%) discordant results with <sup>207</sup>Pb/<sup>206</sup>Pb ages ranging from ca. 2824 Ma to 1634 Ma (Fig. 2.3). The extensive Pb-loss in this sample precluded calculation of a geologically meaningful weighted mean age. A range of Th/U ratios (approximately 0.7 to 0.007) and U (2350 to 350 ppm) abundances were measured (Fig. 2.4). More radiogenic (higher U) grains yielded younger <sup>207</sup>Pb/<sup>206</sup>Pb ages. Due to the complexity of this sample, which is discussed further in section 5.1 and 5.2 of the discussion, we also present a more detailed concordia diagram and a thin section microphotograph (Fig. 2.5). The mineralogy observed within this sample (Fig. 2.5B) is relatively simple consisting of abundant lamellar twinned plagioclase, quartz, and biotite.



**Fig. 2.2:** Field photos of the sampled outcrops and cathodoluminescence (CL) images of representative zircon grains from the samples with analytical spots and results indicated. Labeled ages are based on  $^{207}$ Pb/ $^{206}$ Pb ratios. Note the scale card in the field photos is approximately 8.5 by 5.4 cm and shows a cm scale bar on the top and inch scale bar on the bottom. Analytical spot key and zircon grain scale bar is in the bottom right.

#### 2.4.2. Sample 67DTB19 – Black Canyon Gneiss

To compare the Archean isotopic composition of the Clearwater Block with the adjacent Medicine Hat Block and Wyoming Craton, the southern and easternmost exposure of Neoarchean Clearwater crust with a previously reported crystallization age of  $2663 \pm 8$  Ma (Vervoort et al., 2016) was resampled from along Black Canyon near the southeastern extent of the Clearwater complex (Fig. 2.1D). The Black Canyon Gneiss, sample 67DTB19, was collected from this Neoarchean biotite augen gneiss, and yielded zircon grains with concentric zoning in CL imaging consistent with magmatic growth (Fig. 2.2). Most grains also show bright (low U; e.g. Hanchar and Miller, 1993) overgrowths interpreted as metamorphic rims, which likely reflect late Mesozoic or younger metamorphism within the Clearwater complex (e.g. Doughty et al., 2007). Twenty analyses of the oscillatory zoned zircon cores yielded <sup>207</sup>Pb/<sup>206</sup>Pb ages (21 to 0% discordant) ranging from ca. 2688 Ma to 2373 Ma (Fig. 2.3), with a relatively limited range of Th/U ratios (0.54 to 0.28; Fig. 2.4). Eleven of these twenty analyses overlap with concordia (within 2 $\sigma$  uncertainties) and yield a weighted mean age of 2665 ± 4 Ma (MSWD = 6.6) which is indistinguishable from the age reported by Vervoort et al. (2016). The relatively high MSWD value of the weighted mean age indicates that the calculated weighted mean uncertainty is likely an underestimation of the true imprecision (e.g. Spencer et al., 2016).

Sixteen robust analyses (2 rejected for elevated  ${}^{16}O^{1}H/{}^{16}O$  values, another 2 rejected as outliers from the weighted mean calculation) of  $\delta$ 18O within the cores of these zircon give a weighted mean of  $5.42 \pm 0.08\%$  (MSWD = 3.1; Fig. 2.6), which is indistinguishable from accepted  $5.3 \pm 0.6\%$   $\delta$ 18O value of mantle derived zircons (Valley et al., 1998; Valley, 2003). Eighteen of the twenty Lu–Hf measurements give  $\epsilon$ Hf<sub>t</sub> values from +4.2 to +0.2 when calculated using the preferred 2665 Ma crystallization age, indicating a Lu/Hf composition overlapping and slightly above CHUR (Chondritic Uniform Reservoir; Blichert-Toft et al., 1999; Bouiver et al., 2008). Two additional analyses give outlier  $\epsilon$ Hf<sub>t</sub> values at approximately +6.9 and +13.4 (Fig. 2.7).

#### 2.4.3. Sample 46DTB19 – Coeur d'Alene Gneiss

To further evaluate the alleged (e.g. Doughty et al., 1998) southeastern Australian affinity of the basement rocks within the Priest River complex, the westernmost exposure of the late Paleoproterozoic Coeur d'Alene Gneiss, within the Priest River complex was sampled along the western shore of Lake Coeur d'Alene (Fig. 2.1C). Vervoort et al. (2016) sampled this same outcrop and report  $1862 \pm 3$  and  $1867 \pm 4$  Ma crystallization ages (LA-ICP-MS). The leucogranite lithology of the Coeur d'Alene Gneiss we sampled yielded zircon grains with poorly preserved and/or absent zoning, rather heterogenous mottled textures and small localized bright (in CL) patches (Fig. 2.2). Twenty analyses of the most uniform interior regions of these grains yielded <sup>207</sup>Pb/<sup>206</sup>Pb ages from 1864 to 1694 Ma, with many of the analyses discordant and a plot along a Pb-loss line with an  $1852 \pm 13$  Ma upper intercept and a ca. 155 Ma lower intercept (Fig. 2.3A). This lower intercept is similar to the timing of nearby late Jurassic terrane accretion (e.g. Schwartz et al., 2011). Five of the twenty total analyses overlap concordia within  $2\sigma$  uncertainties and yield a weighted mean age of  $1857 \pm 5$  Ma (MSWD = 0.9; Fig. 2.3B), which again is indistinguishable from the ages reported by Vervoort et al. (2016). The zircon grains from sample 46DTB19 yielded the highest U abundances (4472 to 1844 ppm) of all samples, with relatively consistent and low Th/U ratios (0.063 to 0.034; average of concordant grains = 0.051; Fig. 2.4).



**Fig. 2.3:** A) Wetherill concordia diagram of SHRIMP U–Pb results for the sampled units. Dashed analyses are omitted from discordia calculations. B) Weighted Mean calculations for analyses that overlap with concordia. All uncertainties indicated at  $2\sigma$  level. <sup>207</sup>Pb/<sup>206</sup>Pb ratios are used for samples 67DTB19, 46DTB19, and 37DTB19. Initial plots and discordia regressions generated with ISOPLOTR (Vermeesch, 2018). MSWD – mean standard weighted deviation.

Seventeen robust analyses of  $\delta 180$  from the same zircon domains as the SHRIMP analyses range from 4.54 to 5.61‰ and give a weighted mean of 5.47 ± 0.07‰ (MSWD = 3.1; Fig. 2.6), which is indistinguishable from the accepted 5.3 ± 0.6‰  $\delta 180$  value for mantle derived zircon (Valley et al., 1998; Valley, 2003). Interestingly, in addition to high U values, the average phosphorous (P), yttrium (Y), and lutetium (Lu) content of these grains (measured during LA-SS-ICP-MS analysis) is over twice that of samples 67DTB19 (Black Canyon Gneiss) and 37DTB19 (Laclede Gneiss). This suggests that the order of magnitude larger ablation volumes during LA-SS-ICP-MS analysis incorporated xenotime (YPO4), that was likely present within the zircon grains as either secondary overgrowth along fractures or inclusions. These

contaminant phases were likely avoided during smaller volume U–Pb (SHRIMP) and  $\delta$ 18O (SIMS) analyses but contributed to the spurious (LA-SS-ICPMS) Lu–Hf measurements.

#### 2.4.4. Sample 37DTB19 – Laclede Gneiss

Within the Priest River complex, a tabular body of megacrystic augen gneiss, the Laclede Gneiss, crops out over<9 km2 and lies in fault contact with surrounding metasedimentary strata of the lower Belt Supergroup (Clark, 1973; Doughty et al., 1998; Doughty and Chamberlain, 2008; Lewis et al., 2020). The Laclede augen gneiss is strongly foliated, with layering defined by biotite-rich and -poor zones, and contains conspicuous, subhedral to euhedral orthoclase megacrysts (3–6 cm in length) within a matrix of orthoclase (30–70%), plagioclase (5–35%), quartz (10–15%), biotite (3–7%), along with minor accessory minerals, such as apatite, zircon, epidote, and sphene (Clark, 1967). Prior geochronologic study of the Laclede Gneiss was on exposures north of the Oreille River and indicated disturbance in the U–Pb system resulting from recent Pb-loss (Evans and Fischer, 1986; Doughty et al., 1998). In an effort to minimize the likelihood of similar discordant results, a Laclede Gneiss sample was collected further from the nearby Cretaceous and Paleogene intrusions along the southeastern portion of the outcrop (Fig. 2.1B; Lewis et al., 2020).

This Laclede Gneiss sample yielded zircon grains that in CL imaging showed well-defined oscillatory zoning, with bright (low U) relatively homogenous metamorphic overgrowths (Fig. 2.2). Twenty-three SHRIMP analyses of the most uniform, oscillatory zoned interior regions of these grains yielded <sup>207</sup>Pb/<sup>206</sup>Pb ages from 1595 to 1566 Ma (Fig. 2.3), with U values from 2800 to 220 ppm and Th/U values>0.24 consistent with magmatic crystallization (Fig. 2.4). Twenty-two of these analyses overlap concordia within 2 $\sigma$  uncertainties and yield a weighted mean age of 1581 ± 3 Ma (MSWD = 0.73). This weighted mean value is interpreted as the crystallization age and overlaps with the existing discordia-calculated upper-intercept age-constraint of 1576 ± 13 Ma (Fig. 2.3; Evans and Fischer, 1986). A single analysis on the metamorphic rims yielded a ca. 58 Ma (<sup>206</sup>Pb/<sup>238</sup>U) date, which falls between the crystallization age of the nearby 50 ± 6 Ma Paleogene pluton (Whitehouse et al., 1992) and ca. 64 Ma peak metamorphism with the Priest River complex (Stevens et al., 2015).

Twenty robust analyses of  $\delta$ 180 from the same zircon domains as the SHRIMP analyses give a weighted mean of 5.15 ± 0.13‰ (MSWD = 3.4; Fig. 2.6), which is

also indistinguishable from accepted  $5.3 \pm 0.6\%$   $\delta$ 18O value of mantle-derived zircon (Valley et al., 1998; Valley, 2003). Seventeen Lu–Hf measurements give  $\epsilon$ Hf<sub>t</sub> values from -5.4 to -9.3, while three additional analyses give slight outlier  $\epsilon$ Hf<sub>t</sub> values of approximately -5.1, -4.5 and -4.2 (Fig. 2.7).

#### 2.4.5. Sample 52DTB19 – Moses Butte Amphibolite

Doughty and Chamberlain (2007) reported six zircon analyses from a strongly lineated garnet-hornblende amphibolite collected near Moses Butte within the central portion of the Clearwater complex. Three of these analyses yielded concordant dates of 1520, 1589, and 1584 Ma, which they interpret to record a 1587  $\pm$  9 Ma crystallization age of the mafic protolith. The additional three analyses yielded slightly discordant results suggesting 1361  $\pm$  13 Ma metamorphism. To further evaluate the presence of NAMG-age magmatism within the Clearwater complex, we collected another sample (sample 52DTB19) of the Moses Butte Amphibolite.

Zircon grains recovered from this sample were sparse and small. Most grains showed very faint to absent zoning in CL imaging (Fig. 2.2). Only one recovered grain showed a faint oscillatory zoned core, with a smaller metamorphic overgrowth in CL imaging. Twenty of twenty-six individual SHRIMP U–Pb analyses yielded concordant ages. Nineteen concordant ages on the predominant zircon grains with faint to absent zoning showed Concordia ages from ca. 1440–1229 Ma (Fig. 2.3) with Th/ U ratios from 0.19 to 0.002 (Fig. 2.4). The single oscillatory zoned core yielded a concordant ca. 1546 Ma ( $^{207}$ Pb/ $^{206}$ Pb) age with the highest measured Th/U value within this sample of 0.22. The  $^{207}$ Pb/ $^{206}$ Pb ratios from the nineteen grains with faint to absent zoning yield a 1396 ± 10 Ma (MSWD = 2.46) weighted mean age. Alternative weighted mean calculations based on Concordia ages suggest a 1381 ± 8 Ma (MSWD = 3.68, 1/19 analyses rejected) or 1350 ± 14 Ma (MSWD = 2.26, 1/19 analyses rejected) age using  $^{206}$ Pb/ $^{238}$ U ratios. The MSWD values of these weighted mean ages suggest underestimated errors, or multiple ca. 1400–1350 Ma populations within in the dataset (e.g. Spencer et al., 2016).

Eight robust analyses of  $\delta$ 180 from the same zircon domains as the SHRIMP analyses range from 5.01 to 4.17‰ and give a weighted mean of 4.52 ± 0.31‰ (MSWD = 23; Fig. 2.6). This is lower than, but slightly overlapping with, the 5.3 ± 0.6‰  $\delta$ 180 value of mantle derived zircon (Valley et al., 1998; Valley, 2003). It is also below the usual 5 to 17‰ value of metabasic metamorphic zircon (Cavosie et al., 2011). The tiny size of these grains precluded robust LA-ICP-MS analysis.



**Fig. 2.4:** Age (Ma) vs. Th/U (left) and U (ppm) vs. Th/U (right) scatterplots for individual SHRIMP U–Pb analyses. Background shading indicates a Th/U ratio of 0.1, which is the lower limit commonly found in igneous zircon (Yakymchuk et al., 2018). Note the vertical (Th/U) axis is logarithmic.

#### 2.5. Discussion

#### 2.5.1. Neoarchean growth of the Clearwater Block

The Neoarchean was a time of globally widespread continental growth as evident by the prevalence of ca. 2800–2500 Ma magmatic rocks within many other cratons (e.g. Slave, Yilgarn, Wyoming, etc.; Ivanic et al., 2012; Mole et al., 2019, 2021) as well similar age-peaks within the global detrital zircon record (e.g. Roberts and Spencer, 2015). The proposed mechanisms of crustal generation during the Archean are diverse but are generally placed into two end-member categories. These include modern plate tectonic style plume, rift or subduction processes (e.g. Frieman et al., 2021; Mole et al., 2021), and processes that do not require modern plate tectonics such as delamination, mafic reworking, and so-called "drip tectonics" (e.g. Johnson et al., 2014; B´edard, 2018; Mole et al., 2019). Our study of the Neoarchean crust within the Clearwater Block allows us to evaluate several of these potential mechanism for the generation of ca. 2670 Ma crust in this region.

Our sampling (sample 36DTB19) of the Neoarchean Pend Oreille Gneiss within the Priest River complex revealed more difficult to interpret U/Pb results than those reported by Doughty et al., (1998). When our results are viewed in Wetherill concordia space, they are consistent with an original ca. 2700 Ma crystallization event, and at least two Pb-loss events, one ancient at ca. 1800 Ma and one more recent in the latest Jurassic to early Cretaceous at ca. 165 Ma (Fig. 2.5A). The relationship between the Th/U ratio and the <sup>207</sup>Pb/<sup>206</sup>Pb date of the individual zircon grains within sample 36DTB19, also suggests that the higher U grains, which likely experienced more radiation damage, were preferentially reset during these Pb-loss events (Fig. 2.4). This could indicate that the ca. 495 Ma discordia lower intercept (an age not commonly associated with metamorphism in this region) calculated by Doughty et al., (1998) for the Pend Oreille Gneiss is actually a mixing age between Paleoproterozoic and Cretaceous Pb-loss. However, given the complexity of the sampled gneiss outcrop (Fig. 2.2), it is also possible that our sample 36DTB19 represents a high-grade paragneiss phase containing ca. 2700 and 1800 Ma detrital zircon populations that experienced latest Jurassic to early Cretaceous Pb-loss. The lamellar twinned plagioclase feldspar, quartz, and biotite mineralogy observed within this sample is generally permissible with either a para- or orthogneiss interpretation (Fig. 2.5B).



**Fig. 2.5:** A) Wetherill concordia diagram of SHRIMP U–Pb results for sample 36DTB19 indicating the complexity observed. B) A thin-section microphotograph of sample 36DTB19 in cross polarized light showing the main mineral modes of plagioclase (pl), quartz (q), and biotite (bi).

Within the ca. 2670 Ma Black Canyon Gneiss (sample 67DTB19), the augen texture (Fig. 2.2) and analytical results (Figs. 3, 4) are all consistent with a *meta*-igneous (orthogneiss) origin. The measured zircon  $\delta$ 180 value of 5.42 ± 0.08‰ from this sample indicates that the southwestern-most region of Archean crust within the

Clearwater Block did not undergo fractionation of O- isotopes since mantle extraction (Fig. 2.6). With some exceptions (e.g. Smithies et al., 2021), most Archean crust gives similar mantle-like  $\delta$ 180 values (Fig. 2.6; Spencer et al., 2014), indicating relatively limited intracrustal recycling of surface materials into magma by melting or contamination (Valley et al., 1998; 2003). The EHft values of these same zircon grains range from +4.2 to +0.2, indicating an overall slightly supra-chondritic (above CHUR; Bouvier et al., 2008) Lu-Hf composition (Fig. 2.7). These EHft values are approximately 3 EHf units below the value of the traditionally applied depleted mantle (DM) evolution line at ca. 2670 Ma. However, this traditional depleted mantle evolution line requires early (ca. 4560 Ma) widespread depletion of the mantle (e.g. Vervoort et al., 1996). If a later timing of widespread mantle depletion, such as widespread mantle extraction at ca. 3800 Ma (e.g. Vervoort and Kemp, 2016; Mole et al., 2021; Mulder et al., 2021) or the proposed new crust evolution curve (Dhuime et al., 2011) is accepted, then the  $\varepsilon$ Hft values within the Black Canyon Gneiss are much closer ( $<2 \text{ }\varepsilon\text{Hf units}$ ) from overlapping the expected value of the mantle reservoir at ca. 2670 Ma (Fig. 2.7).



Fig. 2.6: SIMS  $\delta 180$  results from the sampled units shown in violin plots. A violin plot includes both a box plot which indicates the min, max, median and quartiles of the dataset, and a mirrored density plot that shows the spread of the data. See explanation in the top left. On the vertical axis next to each sample's violin plot is a kernel density estimate plot of  $\delta 180$  zircon values extracted from the global compilation of Spencer et al. (2014). The global compilation was filtered to include zircon with crystallization ages within 50 million years of each individual Clearwater Block sample, and is plotted with 1‰ bin and band widths. Range of mantle zircon  $\delta 180$  values from Valley et al. (2008).

Consequently, our Lu-Hf data alone indicates that genesis of the Black Canyon Gneiss could have been derived directly from an only slightly depleted mantle reservoir at ca. 2670 Ma, or via reworking of older crust that was derived from a more depleted mantle reservoir during the Mesoarchean (ca. 3200–2800 Ma). The mantlelike  $\delta$ 18O values for the Black Canyon Gneiss (sample 67DTB19) indicate an absence of O- fractionation from mantle values by either tectonic or hydrothermal processes. The low (<0.3) Eu/Eu\* [Chondrite normalized Eu/(Sm\*Gd)^0.5] ratios from the Black Canyon Gneiss zircon grains (Fig. 2.8) also indicate considerable plagioclase fractionation, and minimal garnet fractionation within the melt during zircon crystallization. This is inconsistent with crystallization within thickened/hydrated continental crust, and suggests crystallization within shallower/drier crust (e.g. Lu et al., 2016; Tang et al., 2021). Based on these constraints alone, generation of the oldest crust within the Clearwater Block does not require crustal reworking of older Mesoarchean crust within a modern plate-tectonic style subduction setting. Consequently, we suggest that the Clearwater Block represents juvenile, mantlederived, Neoarchean crustal growth.



**Fig. 2.7:**  $\epsilon$ Hf<sub>t</sub> values vs. (<sup>207</sup>Pb/<sup>206</sup>Pb) Age plot for the Black Canyon Gneiss (67DTB19) and Laclede Gneiss (37DTB19). The colored box plots indicate the range of  $\epsilon$ Hf<sub>t</sub> values calculated for each gneiss based on the measured Lu/Hf, and the interpreted crystallization age of the sample. Here and in subsequent  $\epsilon$ Hf<sub>t</sub> vs. Age diagrams, we include three mantle evolution models including the classic Depleted Mantle (Bennett et al., 1993) assuming early mantle depletion at ca. 4560 Ma, the late extraction (LE) depleted mantle model (Vervoort et al., 2016; Fisher and Vervoort, 2018) assuming mantle depletion at ca. 3800 Ma, and the new crust model (Dhuime et al., 2011) which assumes Lu/Hf values of new juvenile crust is best represented by the average of oceanic arc values. CHUR–Chondritic Uniform Reservoir (Blichert-Toft et al., 1999; Bouvier et al., 2008).

However, the adjacent Medicine Hat Block contains both Mesoarchean rocks and locally preserves a sub-chondritic, Lu-Hf, and Sm-Nd, record of Neoarchean crustal growth reworking/recycling older Mesoarchean crust (Gifford et al., 2014; 2018; 2020). The thick deposits of Belt Supergroup strata between the Clearwater Block and the Medicine Hat Block prevent the detection of any clear geophysical or geological signature of either a suture/collisional zone or an Archean crustal continuity between the Clearwater and the Medicine Hat blocks (Bedrosian and Feucht, 2014; Gu et al., 2018). Consequently, it would be possible that the Clearwater Block was not associated with the Medicine Hat Block prior to the late Paleoproterozoic assembly of Laurentia via modern plate-tectonic subduction/collisional processes (Whitmeyer and Karlstrom, 2007; Weller and St-Onge, 2017; Wan et al., 2020). After ca. 1800 Ma, the continuity and similar provenance of strata across the Medicine Hat and Clearwater blocks indicate that they had achieved their near-current relative configuration (McMechan et al., 2021; Brennan et al., 2021). Consequently, we only advocate for the usage of a unified Medicine Hat-Clearwater Block (cf. Vervoort et al., 2016; Gifford et al., 2020) terminology for time after ca. 1800 Ma.

#### 2.5.2. Paleoproterozoic Tectonism within the Priest River complex

As previously discussed, the Pend Oreille Gneiss (sample 36DTB19) within the Priest River complex records a composite ca. 2700, 1800, and 165 Ma tectonic history (Fig. 2.5). Within the nearby Coeur d'Alene Gneiss, zircons with low Th/U ratios (0.063 to 0.034), high U abundances (approximately 1800 to 4500 ppm) and rather heterogeneous mottled zircon textures (sample 46DTB19) yield a weighted mean age of 1857  $\pm$  5 Ma and also record a similar timing of recent Pb-loss (ca. 155 Ma). Globally, high  $\delta$ 180 zircon values are common in ca. 1900–1800 Ma rocks (Fig. 2.6) due to widespread crustal reworking associated with Trans-Hudson age orogens (e.g. Spencer et al., 2014). However, the relatively robust  $\delta$ 180 isotopic results from the ca. 1860 Ma Coeur d'Alene Gneiss (sample 46DTB19) record similar mantle-like  $\delta$ 180 values to the ca. 2670 Ma Black Canyon Gneiss (sample 67DTB19). Consequently, we interpret the 1857  $\pm$  5 Ma age for the Coeur d'Alene Gneiss (sample 46DTB19) to record the complete resetting of the U–Pb system of the existing ca. 2670 Ma crust within the Clearwater Block (Vervoort et al., 2016).

The proximity of the Priest River complex to the Vulcan structure suggests that the ca. 1860 Ma event recorded within the Coeur d'Alene Gneiss could be related to the collision of the Medicine Hat-Clearwater Block with the Lovera Block (the southwestern region of the Hearne Province) along the enigmatic Vulcan structure (Eaton et al., 1999; Nieuwenhuis et al., 2014). Tectonic models for the Vulcan structure include a Paleoproterozoic rift (Kanasewich et al., 1969), and a north- (Ross et al., 1991; Nieuwenhuis et al., 2014) or south-dipping (Eaton et al., 1999) subduction/collision zone. However, mantle-like  $\delta$ 18O isotopic values and the general absence of juvenile magmatism associated with this Paleoproterozoic tectonism within the Priest River complex or in the northern portion of the Medicine Hat Block (Gifford et al., 2020) are most consistent with the model of a north-dipping (away from the Medicine Hat-Clearwater Block) collisional zone within the Vulcan structure.

If our speculation that the ca. 1860 Ma tectonism within the Coeur d'Alene Gneiss reflects a collision (and perhaps collisions induced melting) along the Vulcan structure, it occurred coevally with magmatism within the ca. 1900–1700 Ma Great Falls Tectonic Zone (Mueller et al., 2002) but prior to the 1830–1800 Ma terminal phase of the Trans- Hudson orogeny (Corrigan et al., 2009). This is similar to the relative order of events indicated by geophysical cross cutting relationships (Nieuwenhuis et al., 2014). However, more extensive work is needed to evaluate the tectonic relationship of the ca. 1860–1830 Ma metamorphism and magmatism within the Priest River and Clearwater complexes (Buddington et al., 2016; Vervoort et al., 2016), with nearby similar late Paleoproterozoic events recorded in the Vulcan Structure, Great Falls Tectonic Zone, and Monashee Complex (e.g. Ross et al., 1991; Crowley, 1999; Mueller et al., 2002).

#### 2.5.3. NAMG-age magmatism within the Clearwater Block

The results from sample 37DTB19 refine the crystallization age for the Laclede Gneiss from  $1576 \pm 13$  Ma (Evans and Fischer, 1986) to  $1581 \pm 3$  Ma. The Laclede Gneiss clearly falls within the ca. 1610 to 1490 Ma North American Magmatic Gap (Fig. 2.2; NAMG; Ross and Villeneuve, 2003). However, it does not overlap in age with the  $1590 \pm 5$  and  $1551 \pm 5$  Ma mafic dykes in southern Montana (Rogers et al., 2018). Of regional interest, it also confirms that the larger, augen gneiss outcrop south of the Pend Oreille River is correlative to the smaller dated bodies (Fig. 2.1B; Evans and Fischer, 1986; Doughty et al., 1998) on the northern side of the river as mapped (Lewis et al., 2020). The well-preserved oscillatory zoning, Th/U ratios above 0.2, absence of a U (ppm) vs. age trend (Fig. 2.4), and overall mineralogy including large K-spar augen (Fig. 2.2) indicates an igneous/magmatic origin for sample 37DTB19.

The new Lu–Hf and  $\delta$ 18O results also yield additional insights into the origin of this unique Laurentian magmatic event.

The  $\epsilon$ Hf<sub>t</sub> values of the Laclede Gneiss range from -5.1 to -9.3, which indicates an isotopically evolved signature consistent with recycling of Neoarchean or Paleoproterozoic crust. Although this sample records evolved Lu–Hf values, the  $\delta$ 180 results are consistent with mantle-like values signifying limited intracrustal recycling of surface materials into the magma by melting or contamination. These Lu–Hf and  $\delta$ 180 results indicate that ca. 1580 Ma magmatism within the Clearwater Block was unlikely subduction or arc-related as previously speculated (e.g. Furlanetto et al. 2013). The zircon trace element results from the Laclede Gneiss also show higher (>0.3) Eu/Eu\* ratios than the nearby Neoarchean basement (Fig. 2.8). This higher Eu/Eu\* ratio suggests limited plagioclase and signification garnet fractionation within the melt during zircon crystallization, and thus is consistent with derivation from thickened continental crust (e.g. Lu et al., 2016; Tang et al., 2021).



Fig. 2.8: A) Chondritic normalized trace element results for the ca. 2670 Ma (sample 67DTB19; shown in brown) igneous rocks of the Clearwater Block, and the same age (overlapping within  $2\sigma$  error) detrital zircon grains from the overlying Cup Gold Ouartzite (grey). B) Chondritic normalized trace element results for the ca. 1580 Ma (sample 37DTB19, shown in blue) igneous rocks of the Clearwater Block, and the same age within (overlapping  $2\sigma$ error) detrital zircon grains from the overlying lower Belt Supergroup strata (grey). Inset charts highlight the Eu anomaly calculated as [Chondrite normalized Eu/(Sm\*Gd)^0.5].

#### 2.5.4. Crustal Evolution of the Clearwater Block

A Lu–Hf 'rewoking array' (e.g., Payne et al., 2016) fit through the 2670 and 1580 Ma Clearwater complex samples intersects with the main ca. 1860–1800 Ma detrital zircon population within the overlying Gold Cup Quartzite (Brennan et al., 2021; Figs. 2.7, 2.9). We interpret these Lu/Hf results to be consistent with a continuous crustal evolution trend recording limited input from a depleted mantle source, at least in the Priest River region, during the ca. 1860 and 1580 Ma events. The slope of this line yields an approximate 176Lu/177Hf = 0.022 evolution ratio that is higher than the generally suggested value for bulk felsic continental crust (176Lu/177Hf = 0.018 to 0.012) and results in a shallower  $\varepsilon$ Hf vs. time evolution. As mentioned, the available  $\delta$ 180 results from the igneous samples used to define this array are consistent with limited fractionation of O- isotopes from expected mantle values, indicating limited magmatic interaction with low temperature meteoric or high temperature hydrothermal water (Valley et al., 1998), suggesting that a subduction origin for these rocks is not required.

Consequently, the 176Lu/177Hf = 0.022 ratio suggested by the fit of a reworking array of both the igneous basement and proximally derived overlying detrital zircon samples is plausible given that lower continental (more mafic) crust generally yields higher 176Lu/177Hf values (0.025 to 0.017) than the often assumed values for the bulk or more-felsic upper continental crust (Payne et al., 2016; Spencer et al., 2020). Comparable 176Lu/177Hf ratios (e.g. 176Lu/177Hf = 0.022, Amelin et al., 1999; 176Lu/177Hf = 0.024, Næraa et al., 2012; 176Lu/177Hf = 0.022-0.020, Mole et al., 2019) have previously been calculated based on reworking arrays of other Archean provinces. This crustal evolution array suggests that the oldest, ca. 2670 Ma magmatism in the Clearwater Block represents the main crustal growth event within the block, and the subsequent events at ca. 1860 Ma and 1580 Ma likely reworked this Archean lower crustal reservoir, perhaps without the involvement of arc-magmatism. Given the plausibility of this crustal evolution model, the isotopic evidence does not require an Australian origin for the ca. 1580 Ma Laclede Gneiss as speculated by previous studies (e.g. Ross et al., 1992; Doughty et al., 1998).

#### 2.5.5. Ca. 1.4 Ga metamorphism within the Clearwater complex

The results from the Moses Butte Amphibolite (sample 37DTB19) show no clear evidence for NAMG-age magmatism as most grains yielded textures, Th/U, and  $\delta$ 18O results consistent with metamorphic zircon growth in a hydrothermally affected

environment (Figs. 2.3, 2.4, 2.6). A single grain showed an oscillatory zoned core (Fig. 2.2), which had the highest Th/U value of 0.22 and yielded a concordant ( $^{207}Pb/^{206}Pb$ ) date of  $1546 \pm 17$  Ma. This single grains supports speculations (Doughty and Chamberlain 2007), that the amphibolite's protolith may fall within the NAMG age interval and could be related to the nearby  $1551 \pm 5$  Ma mafic dykes (Rogers et al., 2018). However, the remainder of the dates are interpreted to record metamorphic/hydrothermal zircon growth. The metamorphic event(s) recorded by these grains occurred between ca. 1416 and 1350 Ma, as determined by the oldest discordia upper-intercept age, and the youngest (<sup>206</sup>Pb/<sup>238</sup>U) weighted mean age. Magmatism (and associated metamorphism) of this age is well documented within the Belt Basin (Evans et al., 2001; Doughty and Chamberlain, 2008; Zirakparvar et al., 2010; Nesheim et al., 2012; McFarlane, 2015), which likely provided heat for the hydrothermal zircon growth documented here. This period of magmatism is correlated with rifting near the end of Belt Basin subsidence and is suggested to correspond to global events linked to the initial breakup of supercontinent Nuna/ Columbia (Ross and Villeneuve, 2003; Box et al., 2020; Brennan et al., 2021).

#### 2.5.6. Constraints on detrital zircon provenance

In addition to providing insights into the genesis of Clearwater Block basement, our results allow evaluation of proposed detrital zircon provenance patterns for the overlying Paleo-Mesoproterozoic strata. In particular, within the Priest River complex, younger than ca. 1800 Ma coarse strata of the Gold Cup Quartzite overlie Clearwater Block Basement (Lewis et al., 2020). Detrital zircon U-Pb and Lu-Hf components from the Gold Cup Quartzite consist of two main age components. An older ca. 2670 Ma population with CHUR-like  $\varepsilon$ Hf<sub>t</sub> values concentrated around +1, and younger ca. 1900–1750 Ma grains, with main age-peaks at ca. 1860 and 1800 Ma. These Paleoproterozoic zircon grains have a wide range of EHft values with the greatest density showing evolved EHft values between -4 and -8 (Fig. 2.9; Brennan et al., 2021). These isotopic results from the detrital zircon grains, including the trace element constraints for sample 67DTB19, are a good match for the basement rocks within the Clearwater Block and are consistent with our suggested crustal evolution trend. These similarities support prior interpretations that the Gold Cup Quartzite was sourced from proximal Laurentian basement sources primarily within the Clearwater and Medicine Hat Blocks (Doughty and Chamberlain, 2008; Buddington et al., 2016; Brennan et al., 2021).

In the Priest River region, finer-grained strata of the ca. 1480–1380 Ma Belt Supergroup overlie strata of the Gold Cup Quartzite. Brennan et al. (2021) sampled Prichard and Ravalli Group strata from the stratigraphically lower portion of the Belt Supergroup approximately 50 km to the west of the Priest River complex basement exposures. These samples contained a spread of ca. 1750-1470 Ma detrital zircon grains, including a significant portion of grains with ages within the ca. 1610–1490 Ma NAMG. These NAMG-age grains have predominately juvenile ( $+\epsilon Hf_t$ ) values. Consequently, the evolved  $\varepsilon$ Hf<sub>t</sub> = -5.1 to -9.3 values within the ca. 1580 Ma Laclede Gneiss, make it a poor Lu–Hf match for the NAMG-age detrital grains within nearby Belt Supergroup strata (Fig. 2.9). In addition to the Lu–Hf mismatch, the trace element data from the Laclede Gneiss (sample 37DTB19) also match poorly with that of the detrital grains (Figs. 2.8, 2.9). Consequently, interpretations of an exotic source for these detrital grains (Ross and Villeneuve, 2003; Fanning et al., 2009; Box et al., 2020; Brennan et al., 2021) remains a valid hypothesis. Additionally, the non-Laurentian source for the similar, juvenile (+EHft) NAMG-age detrital zircon populations found in coeval ca. 1450 Ma Hess Canyon, Trampas basins in southwestern Laurentia also remains valid (Doe et al., 2012, 2013; Jones et al., 2015).

Southeastern Australia, notably the Gawler Craton, records widespread magmatism in pulses from ca. 1900 to 1500 Ma, which include: 1) the ca. 1850–1790 Ma Donington–Myola Suite (Fanning et al., 1988; Reid et al., 2008), 2) the ca. 1770–1740 Ma McGregor Volcanics and associated suites (Fanning et al., 1988), 3) the 1620–1605 Ma St Peter Suite (Swain et al., 2008), 4) the 1600–1575 Ma Gawler Range Volcanics–Hiltaba suite (Fanning et al., 2009), and 5) granites as young as ca. 1500 Ma in the Spilsby Suite (Fanning et al., 2009). The ca. 1620–1605 Ma St Peter Suite (Fanning et al., 2009). The ca. 1620–1605 Ma St Peter Suite (Fanning et al., 2009), and 5) granites as young as ca. 1500 Ma in the Spilsby Suite (Fanning et al., 2009). The ca. 1620–1605 Ma St Peter Suite (+ $\epsilon$ Hf<sub>t</sub>) compositions (Swain et al., 2008; Reid and Payne, 2017) and are consequently a much better source match for the detrital zircon grains within Belt Supergroup strata than the Laclede Gneiss. Thermochronology (40Ar/39Ar) studies also indicate that the northern Gawler Craton was actively exhumed at ca. 1480–1440 Ma, the same time as the deposition of the lower Belt Supergroup strata in Laurentia (Reid and Forster, 2021).



**Fig. 2.9:** Paleo–Mesoproterozoic stratigraphy and U–Pb/Lu–Hf detrital zircon results from the Priest River Region (Doughty and Chamberlain, 2008; Box et al., 2020; Lewis et al., 2020; Brennan et al., 2021) and the range of robust  $\epsilon$ Hf<sub>t</sub> values (samples 67DTB19 and 37DTB19) from the underlying ca. 2670 and 1580 Ma igneous basement. The red box indicates the age range (ca. 1.88–1.83 Ga) of Paleoproterozoic tectonism/magmatism within the Clearwater Block (Vervoort et al., 2016). Inferred crustal evolution line (Lu/Hf = 0.022) for the Clearwater Block indicated. We note that the main ca. 1860 Ma detrital zircon population within the Gold Cup Quartzite contains  $\epsilon$ Hf<sub>t</sub> values of -3 to -8, which are consistent with our suggested crustal evolution trend of the Clearwater Block. DM–Depleted Mantle, LE–Late Extraction, NC–New Crust, CHUR–Chondritic Uniform Reservoir. See Fig. 7 for explanation of mantle evolution lines.

# 2.5.7. Insights into the evolution and configuration of supercontinent Nuna

As previously discussed, with the exception of eastern Australia, notably the Gawler Craton, NAMG magmatism is relatively limited in the global geologic record (Figs. 2.10, 2.11). Thus, the Australian ca. 1600–1500 Ma magmatism is often considered a significant tie-point for locating eastern Australia-East Antarctica against western Laurentia during the early Mesoproterozoic (e.g. Goodge et al., 2017; Kirscher

et al., 2019, 2021). In some reconstructions Hainan Island, including all or some of the Cathaysia Block of South China (cf. Yao et al., 2017; Xu et al., 2019; Cawood et al., 2020), is also placed in close proximity to western Laurentia in Nuna. Within southeastern Australia, NAMG-age magmatism is predominately juvenile ( $+\epsilon$ Hf<sub>t</sub>) and is episodic with two main pulses at ca. 1620–1575 Ma and ca. 1525 Ma, respectively (Fig. 2.10; Reid and Payne, 2017; Chapman et al., 2019; Hartnady et al., 2020). Granitic glacial clasts sampled from East Antarctica also contain a similar, two-pulsed magmatic record of NAMG-age magmatism (Goodge et al., 2017), consistent with East Antarctica being part of the Mawson continent together with the Gawler Craton for most of the Proterozoic (e.g., Payne et al., 2009). However, the ca. 1570 Ma magmatism in East Antarctica is more evolved than the mostly juvenile similar-age magmatism within the Gawler craton (Fig. 2.10). Compared to the East Antarctica constraints, the Laclede Gneiss (sample 37DTB19) is a slightly better age-match for Gawler craton NAMG magmatism but is not an ideal Lu–Hf match due to its more evolved composition.

The ca.  $1551 \pm 12$  Ma felsic magmatism recently recognized within Hainan Island of south China (Xu et al., 2019) is perhaps the worst age-match for magmatism within the Gawler Craton and East Antarctica, as it falls between the two main pulses of magmatism. It is also ~ 30 Myr younger than the Laclede Gneiss but is similar to nearby  $1551 \pm 5$  Ma mafic dykes in Laurentia (Rogers et al., 2018). Admittedly, the ca. 1550 Ma magmatism in Hainan Island does have the least evolved (most juvenile) Lu–Hf values, making it a slightly better Lu–Hf match for the Gawler Craton than other discussed ca. 1580–1550 Ma rocks (the Laclede Gneiss and East Antarctica glacial clasts). Interestingly, northeastern Australia (Mount Isa Inlier; Fig. 2.11B) also contains poorly studied ca. 1550–1500 Ma felsic magmatism (Page and Sun, 1998; Li et al., 2020) that appear to be a better age match with Hainan Island than the Gawler Craton. These ca. 1500 Ma granitoids in northern Australia likely provided the detrital zircon grains found within the ca. 1460–1400 Ma PR1 basin in northwestern Laurentia (Medig et al., 2014).

Genesis models for the prevalent NAMG-age magmatism in southeastern Australia are complex. However, the ca. 1600–1500 Ma magmatism has generally been associated with the final assembly of Australia and East Antarctica with western Laurentia to form Nuna (Betts et al., 2008; Payne et al., 2009; Kirscher et al., 2019). Most models emphasize mantle plume activity that may have modified subductionrelated arc-magmatism, localized back-arc extension and/or continental collision orogenic processes (Betts et al., 2009; Payne et al., 2009; Forbes et al., 2011; Tiddy et al., 2020). Given the absence of a clear subduction-related isotopic signature in the Clearwater Block at this time, we suggest that a mantle plume, perhaps centered beneath southeastern Australia, supplied the heat to melt the (likely) adjacent Archean lower continental crust within the Clearwater Block (Fig. 2.11B), resulting in the generation of the evolved ca. 1580 Ma Laclede Gneiss. This proposed petrogenesis explains the predominantly juvenile NAMG magmatism in southeastern Australia, indicative of a location above the plume head, as well as the plume related geochemistry for the ca. 1590 Ma dykes in western Laurentia (Rogers et al., 2018) and our results for the Laclede Gneiss. This model is also consistent with paleomagnetic reconstructions of Nuna (Fig. 2.11B) which place the Gawler Craton adjacent to the Clearwater Block at ca. 1580 Ma (e.g. Kirscher et al., 2019, 2021; Pisarevsky et al., 2014).



**Fig. 2.10:** A) Individual  $\epsilon$ Hf<sub>t</sub> vs. <sup>207</sup>Pb/<sup>206</sup>Pb ages for the Clearwater Block (including the inferred crustal evolution trend), Medicine Hat Block (Gifford et al., 2020) and the suggested Non-Laurentian conjugate blocks of Hainan Island (South China; Xu et al., 2019), East Antarctica (Goodge et al., 2017), and the Gawler Craton of southeastern Australia (Reid and Payne, 2017 and references therein; Hartnady et al., 2020). Inferred crustal evolution line (Lu/Hf = 0.022) for the Clearwater Block indicated. B)  $\epsilon$ Hf<sub>t</sub> vs. <sup>207</sup>Pb/<sup>206</sup>Pb values for ca. 1610–1490 Ma, North American Magmatic Gap magmatism. For comparison, the abundant magmatism of the Gawler Craton is plotted in a two-dimensional kernel density estimate plot with 1  $\epsilon$ Hf and 5 Ma bandwidths (Spencer et al., 2020) and individual NAMG-age granites sampled in Hainan Island (Xu et al., 2019), East Antarctica (Goodge et al., 2017) and the Clearwater Block (this work) shown in box and whisker plots, where the width of the box corresponds to the <sup>207</sup>Pb/<sup>206</sup>Pb age uncertainty. Note that the evolved ca. 1580–1550 Ma magmatism in the Clearwater Block, East Antarctica, and Hainan Island are not a particularly good match for similar-age, juvenile magmatism within the Galwer Craton. DM–Depleted Mantle, LE–Late Extraction, NC–New Crust, CHUR–Chondritic Uniform Reservoir. See Fig. 2.7 for explanation of mantle evolution lines.



Fig. 2.11: A) Timing of Paleoarchean to early Mesoproterozoic magmatism for the main Archean blocks of western Laurentia and proposed conjugate blocks within Nuna shown in kernel density estimate plots with 25 Ma bandwidths. The main ca. 2670, 1860 and 1580 Ma ages of Clearwater Block magmatism are indicated in orange. Age peak labels are rounded to the nearest 5 Ma. Sources are compiled in the supplementary but include: Grouse Creek (Link et al., 2017); Farmington Zone (Mueller et al., 2011); Great Falls Tectonic Zone (Mueller et al., 2002; Foster et al., 2006; Gifford et al., 2018); Wyoming Craton (Frost and Fanning, 2006; Frost et al., 2006; 2017; Mueller et al., 2010); Medicine Hat Block (Gifford et al., 2020); Clearwater Block (Vervoort et al., 2016; this work); Monashee complex (Crowley et al., 1999); Gawler Craton (Reid and Payne, 2017 and references within; Hartnady et al., 2020); East Antarctica (Goodge and Fanning, 2016; Goodge et al., 2017); the Cathaysia Block of South China (Zhang et al., 2021 and references within); and Hainan Island of South China (Xu et al., 2019). B) Paleogeographic reconstruction of Nuna (after Goodge et al., 2017; Kirscher et al., 2019, 2021; Pisarevsky et al., 2014) with the extent of our proposed ca. 1580 Ma plume, NAMG-age (North American Magmatic Gap) felsic magmatism (indicated by star symbols), and Laurentian basins containing NAMG-age detrital zircon (indicated by tetragonal crystal symbol; for Hess Canyon and Trampas basins, see Doe et al., 2012; 2013; Jones et al., 2015, for PR1 basin see Medig et al., 2014) shown. A more detailed map of western Laurentia's basement framework is shown in Fig. 2.1A.

#### 2.6. Conclusions

This work presents zircon U–Pb geochronological and comprehensive isotopic (Lu–Hf,  $\delta$ 18O, and trace element) study of Mesoproterozoic and older crystalline basement rocks within the Clearwater Block of western Laurentia, a key Proterozoic supercontinent tie-point that contains a unique record of NAMG-age magmatism. In addition to providing robust source terrane characterization for utilization by future provenance studies, the main findings from our study of the Clearwater Block crystalline basement are the following:

1) The juvenile Lu–Hf, mantle-like  $\delta$ 18O, and trace element results from the oldest, ca. 2670 Ma, granitic basement rocks indicate that Neoarchean crustal growth within the Clearwater Block did not involve significant reworking or assimilation of older crust, nor that it requires modern-style subduction processes. The isotopic record therefore does not necessitate that of the Clearwater Block was built onto the edge of the Mesoarchean Medicine Hat Block (or the Wyoming Craton either) in a modern plate-tectonic arc setting. Rather, we suggest that ca. 2670 Ma rocks within the Clearwater Block represent either juvenile crustal growth through direct mantle extraction without subduction-related processes, or remelting of an older Mesoarchean mafic lower crust.

2) The Neoarchean crust in the Priest River complex (northern Clearwater Block) was metamorphosed and melted (see Vervoort et al., 2016) during a ca. 1860 Ma event. We suggest this event likely records collision related to the assembly of Laurentia. Results from the Priest River complex are consistent with models involving north-dipping subduction within the Vulcan Structure.

3) The new 1581  $\pm$  3 Ma crystallization age for the Laclede Gneiss supports prior assertions of NAMG-age magmatism within the Priest River complex based on discordia regression-age calculations (e.g. Evans and Fischer, 1986; Doughty et al., 1998). The evolved Lu–Hf, mantle-like  $\delta$ 18O, and trace element zircon values from the Laclede Gneiss are difficult to reconcile with a subduction or rift origin. Consequently, we favour a plume genesis, as is suggested for the nearby Laurentian 1590  $\pm$  5 Mammoth dykes (Rogers et al., 2018). Similar-age magmatism in southeastern Australia also has plume-related genesis models (e.g. Reid and Payne 2017; Chapman et al., 2019). The proposed Lu–Hf 'reworking array' and O- isotope values from the Clearwater Block indicate that reworking of a nearby Neoarchean lower continental crustal reservoir is the likely origin for the Laclede Gneiss. Consequently, we propose that the Laclede Gneiss is a crustal-derived, distal manifestation of a ca. 1580 Ma plume event beneath southeastern Australia.

4) The new geochronology and isotopic constraints from the Clearwater Block lend further support to interpretations (e.g. Brennan et al., 2021) that the overlying Gold Cup Quartzite and lower Belt Supergroup strata record a provenance shift from proximal Laurentian, to non-Laurentian sources sometime between ca. 1800 and 1480 Ma. This provenance shift likely corresponds to the final assembly of supercontinent Nuna/Columbia during this interval.

5) The Clearwater complex may contain NAMG-mafic magmatism. However, if present, the record of this event was overprinted by ca. 1410–1350 Ma hydrothermal metamorphism, likely associated with magmatism and rifting within the Mesoproterozoic Belt Basin.

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# Chapter 3: Detrital zircon U–Pb and Hf signatures of Paleo-Mesoproterozoic strata in the Priest River region, northwestern USA: A record of Laurentia assembly and Nuna tenure

# Abstract

Rocks of the Gold Cup Quartzite, Belt Supergroup and Deer Trail Group crop out in the Priest River region of northeastern Washington and northern Idaho (USA). As these sequences represent the westernmost exposures of Paleoproterozoic-Mesoproterozoic strata between New Mexico (USA) and the northern Yukon (Canada), they are key to understanding the assembly of Laurentia and evaluating the duration and configuration of the supercontinent Nuna/Columbia. Here, we present detrital zircon U–Pb and Lu–Hf isotope data from these sequences. The results indicate that the <1.73 Ga Gold Cup Quartzite contains similar detrital zircon components to other widespread late Paleoproterozoic units that record final assembly of the main Archean blocks of western Laurentia; as such, they do not require any non-Laurentian source. Prominent ca. 1.7–1.5 Ga, isotopically juvenile zircon grains form the main component of the overlying ca. 1.47 Ga Lower Belt Supergroup. Some of these detrital zircon components lack a Laurentian source and are instead consistent with derivation from the Gawler Craton in southeastern Australia. The >1.38 Ga upper Belt Supergroup strata are structurally overlain by <1.3 Ga Deer Trail Group rocks that contain detrital zircon components consistent with mixed Laurentian sources. The paucity of any syndepositional volcanic detrital zircon in Deer Trail Group strata along with its fine siliciclastic and carbonate nature suggest deposition within a tectonicallyquiescent basin coeval with breakup of Nuna.

# **3.1.** Introduction

The cyclic amalgamation and dispersal of continents has punctuated Earth's history for at least the past two billion years in a process known as the supercontinent cycle (e.g. Li et al., 2019; Mitchell et al., 2021; Nance et al., 2014). Similarities in stratigraphy, sedimentary provenance and crustal evolution between western Laurentia

(all directions expressed in modern-day coordinates), East Antarctica, and Australia have been used to argue that they were probably connected during most of the Proterozoic, a configuration referred to as the southwest-U.S.–East Antarctic, or SWEAT, connection (Moores, 1991).

Early models suggested the existence of a SWEAT-like connection from as early as 1.9 Ga, and that this configuration may have remained relatively stable until eventual breakup during the late Neoproterozoic (Moores, 1991; Dalziel, 1991; Hoffman, 1991). However, paleomagnetic-based paleogeographic reconstructions indicate that although a SWEAT-like configuration is permissible for most of the early Mesoproterozoic and Neoproterozoic, Australia and Laurentia appear to have been widely separated at ca. 1.25 Ga (Kirscher et al., 2019; Pisarevsky et al., 2014a,b; Kirscher et al., 2020). This suggests that some of the long recognized geological similarities between western Laurentia and Australia-East Antarctica (Moores, 1991; Bell and Jefferson, 1987) may instead provide evidence for the existence of two separate, but perhaps similarly configured, supercontinents—an older, predominately late Paleoproterozoic to Mesoproterozoic supercontinent called Nuna (or Columbia), and a younger, predominately Neoproterozoic, supercontinent called Rodinia (Zhao et al., 2002, 2004; Li et al., 2008a; Meert, 2012; Zhang et al., 2012; Kirscher et al., 2019; Li et al., 2019; Pisarevsky et al., 2014a; Kirscher et al., 2020). This SWEAT-like paleogeography during the late Paleoproterozoic to Mesoproterozoic between Australia, Antarctica and western Laurentia has been called a "proto-SWEAT" configuration (Fig. 3.1; Payne et al., 2009; Kirscher et al., 2019; 2020).

The main assembly of Laurentia occurred during ca. 1.92–1.77 Ga amalgamation of the Archean Rae, Slave, Hearne, Wyoming, Superior, and Medicine Hat cratons along the Trans-Hudson orogen and associated structures including the Great Falls Tectonic zone and Vulcan structure (Fig. 3.2A; Eaton et al., 1999; Mueller et al., 2002; Whitmeyer and Karlstrom, 2007). Similar-age ca. 2.1–1.8 Ga orogens also separate many Archean–Paleoproterozoic blocks in Australia, Siberia, North China, Antarctica, Africa and Baltica, which has led to suggestions that global assembly of Nuna occurred by ca. 1.8 Ga (Rogers and Santosh, 2002; Zhao et al., 2002). However, paleomagnetic (Pisarevsky et al., 2014b; Kirscher et al., 2019; 2020 and references therein) and geological (e.g. Betts et al., 2016; Furlanetto et al., 2013; Li et al., 2020; Nordsvan et al., 2018; Volante et al., 2020a; Volante et al., 2020b) constraints have suggested that an ocean existed between northern Australia and northwestern

Laurentia from ca. 1.8 to 1.6 Ga. Thus, whether Nuna assembly occurred at ca 1.8 Ga coeval with widespread Trans-Hudson events in Laurentia (e.g. Zhao et al., 2002), or rather involved a more protracted and complex, perhaps two-stage process, lasting from ca. 1.9 to 1.6 Ga (e.g. Kirscher et al., 2019), are debated. In the two-stage model, initial supercontinent amalgamation began with the assembly of a unified Laurentia–Baltica–Siberia landmass by ca. 1.8 Ga, but a final proto-SWEAT configured Nuna was not reached until ca. 1.6 Ga following closure of a small ocean between the Laurentia–Baltica–Siberia and Antarctica–Australia landmasses (Betts et al., 2016; Kirscher et al., 2019; Pourteau et al., 2018; Wang et al., 2020; Kirscher et al., 2020; Nordsvan et al., 2018).



**Fig. 3.1.** Configuration of proto-SWEAT Nuna including its core constituents of Laurentia, Mawson (East Antarctica and Gawler Craton), Australia (NAC–North Australian craton, SAC–South Australia craton, WAC–West Australia craton), North China Craton (NCC), Siberia, and Baltica (adapted from Kirscher et al., 2020). The North China Craton, Siberia, and Baltica are not pertinent to this study and thus only outlines are shown. Paleomagnetic constraints (Kirscher et al., 2020 and references therein) suggest this configuration was stable (albeit underwent counterclockwise rotation) from ca. 1.6–1.3 Ga, and is shown here at ca. 1.3 paleolatitude. Extent of Fig. 3.2A, the Belt Basin, and generally coeval Trampas and Yankee–Joe Blackjack and PR1 basins (Doe et al., 2013; Jones et al., 2015) indicated. Additional abbreviations: L–Laurentia, M–Mawson, A–Australia, C–North China Craton, S–Siberia, B–Baltica.

Regional tectono-stratigraphic evaluation of the proposed two-stage model for Nuna assembly along the Laurentian margin has so far neglected an approximately 3000 km section of the margin (Fig. 3.1) between the PR1 Basin in northwestern Laurentia (Medig et al., 2014; Verbaas et al., 2018), and the Mojave province in southwestern Laurentia (Holland et al., 2015, 2018). The Priest River region (Fig. 3.2) contains one of the most complete records of the Neoarchean to Mesoproterozoic tectonic history of the west-central margin of Laurentia and thus offers a unique opportunity to evaluate the timing, duration and credibility of proposed relationships with Australia/Antarctica.

Here, we use existing U–Pb detrital zircon datasets and new U–Pb and Lu–Hf detrital zircon data from three unconformity-bounded sequences in the Priest River region of Laurentia, including the < 1.73 Ga Gold Cup Quartzite, the ca. 1.47–1.38 Belt Supergroup, and the < 1.3 Ga Deer Trail Group. These new data record changes in the provenance of western Laurentia stratigraphy, which can be related to the timing of amalgamation of Laurentia, and the timing of amalgamation then breakup of Nuna.



**Fig. 3.2.** A) General tectonic map of western Laurentia showing Laurentian basement terranes, the limit of Belt Supergroup exposures and geographic areas mentioned in text (after Foster et al., 2006; Whitmeyer and Karlstrom, 2007; Vervoort et al., 2016 and references therein). The extent of regional geologic map in Fig. 3.1B indicated. The 87Sr/86Sr < 0.706 line approximates the western edge of Laurentia generated during Neoproterozoic rifting (Armstrong et al., 1977; Elison et al., 1990). B) Geologic map of the Priest River region showing the extent of Proterozoic rocks and sample locations (map modified from Miller, 2001; Schuster, 2005 and Lewis et al., 2012).

### **3.2.** Geological Setting

# **3.2.1.** The Archean–Paleoproterozoic basement framework of western Laurentia

In the Priest River and Clearwater complexes (Fig. 3.2A) of northeastern Washington and northern Idaho (USA), exposures of ca. 2.67–2.61 and 1.88–1.84 Ga orthogneisses are considered to belong to the same Archean–Paleoproterozoic Clearwater Block (Vervoort et al., 2016). The Clearwater Block, which represents the westernmost exposures of Laurentian crust beneath the Belt Basin (Foster et al., 2006; Vervoort et al., 2016; Gifford et al., 2020), abuts, or is possibly an extension of, the Medicine Hat Block. The Medicine Hat Block is not exposed, but based on limited borehole and xenolith data is thought to be a mix of Archean (3.1–2.6 Ga) and Paleoproterozoic (ca. 1.81–1.75 Ga) crust (Gifford et al., 2018, 2020; Ross et al., 1991; Villeneuve et al., 1993). Highly evolved ( $\epsilon$ Hft = –8 to –23) ca. 1.8 Ga magmatism within the Medicine Hat Block suggests that the younger Paleoproterozoic period of crustal growth reworked an older Meso- to Neoarchean component (Gifford et al., 2020).

The Archean Wyoming Province and Grouse Creek Block are the southern neighbors of Clearwater and Medicine Hat blocks (Fig. 3.2A; Whitmeyer and Karlstrom, 2007). The Wyoming Province consists of temporally and geochemically distinct sub-provinces, including rocks as old as 3.6 Ga and detrital zircon ages as old as 4.0 Ga (Chamberlain et al., 2003; Mueller and Frost, 2006). The Grouse Creek Block in central Idaho contains ca. 2.67–2.50 felsic and ca. 1850 Ma mafic magmatic rocks (Link et al., 2017).

Paleoproterozoic (Trans-Hudson-age; ca. 1.9–1.7 Ga) suture/collisional zones separate the main Archean blocks of western Laurentia. The boundary between the Medicine Hat Block and the Wyoming Province to the south (Mueller et al., 2002) is delineated by the broad Great Falls Tectonic Zone, which records major ca. 1.86–1.73 Ga Paleoproterozoic convergent events including the Great Falls Orogeny and the more temporally and spatially restricted Big Sky Orogeny. Generally, Great Falls Tectonic Zone rocks indicate northwest-dipping subduction, closure of an intervening ocean and eventual amalgamation of the Medicine Hat Block to the Wyoming Province (Mueller et al., 2002; Cheney et al., 2004; Harms et al., 2004; Foster et al., 2006; Alcock et al., 2013; Condit et al., 2015; Gifford et al., 2014; 2018; 2020).

The Vulcan Zone is a Paleoproterozoic collisional belt that records northdipping subduction between the Archean Medicine Hat–Clearwater block(s) and the southwestern Hearne Province (Eaton et al., 1999; Nieuwenhuis et al., 2014). The Loverna Block, which represents the most southwestern exposures of the Hearne Province, consists of ca. 2.71, 1.82, and 1.78 Ga rocks that are bordered to the north by the ca. 1.85–1.79 Ga Rimbey Arc (Ross et al., 1991).

The Farmington Zone in northeastern Utah contains primarily ca. 2.45 Ga *meta*-igneous rocks and < 2.42 Ga metasedimentary rocks that record upper amphibolite to granulite facies metamorphism at ca. 1.67 Ga (Link et al., 2017; Mueller et al., 2011; Nelson et al., 2011). Although the extent and tectonic significance of the Farmington Zone is uncertain, it likely: (i) separates the Archean Wyoming Province from the Grouse Creek Block to the west, and (ii) records the ca. 1.67 Ga collision of the predominantly late Paleoproterozoic Mojave province with the southern margin of the Grouse Creek–Wyoming provinces (Mueller et al., 2011).

Following assembly of the main Archean blocks of western Laurentia, a longlived accretionary boundary resulted in the addition of the ca. 1.84-1.70 Ga Mojave province, which comprises a mixture of juvenile and evolved components, and the juvenile ca. 1.80–1.70 and 1.65–1.60 Ga Yavapai and Mazatzal provinces along the southern/ southwestern margin of Laurentia (Bowring and Karlstrom, 1990; Holland et al., 2020). The more evolved isotopic signatures of the Mojave province rocks suggest reworking of a Neoarchean crustal component, which may suggest an early association with East Antarctica (Holland et al., 2018; Wooden et al., 2013). Collectively, the Mojave-Yavapai-Mazatzal provinces may record progressive accretion of separate, predominantly juvenile arc systems (Whitmeyer and Karlstrom, 2007), or represent an extensive arc-backarc system that developed along the Australia–Antarctica margin at ca. 1.8 before their accretion to Laurentia after ca. 1.65 Ga (Gibson and Champion, 2019). Detrital zircon (U/Pb and Lu/Hf) data from the ca. 1.79–1.74 Ga Vishnu basin in the Mojave province shows similar detrital zircon ages with coeval Australia–Antarctica strata and igneous sources, supporting an early (ca. 1.8 Ga) Mojave-Australia-Antarctica connection (Holland et al., 2015, 2018). Additionally, recognition of ca. 1.6–1.5 Ga metavolcanic rocks is increasing in the southwestern U.S., including a preliminarily dated  $1505 \pm 6$  Ma ash fall tuff within the Yankee Joe basin (Doe and Daniel, 2019), and the 1588 ± 7 Ma Blue Springs metarhyolite within the nearby Manzano group (Holland et al., 2020).

Several unconformity-bounded Paleo–Mesoproterozoic sequences (Fig. 3.3), including: 1) the Paleoproterozoic Gold Cup Quartzite (Doughty and Chamberlain, 2008); 2) the Mesoproterozoic (ca. 1.47–1.38 Ga) Belt Supergroup and; 3) the ca. <1.37 Ga Deer Trail Group (refined to <1.30 Ga by this work; Ross et al., 1992; Box et al., 2020) overlie basement rocks of the Clearwater Block in the Priest River region. Within the Priest River metamorphic complex, metamorphosed Belt Supergroup strata host a small (<3 km<sup>2</sup>) tectonically interleaved slice of ca. 1.58 Ga orthogneiss (the Laclede Gneiss) whose petrogenesis is poorly understood but represents the only known ca. 1.6–1.5 Ga granitoid in western Laurentia. As such, the Laclede Gneiss is suggested to be a piece of Australia that was stranded during Nuna breakup (Doughty and Chamberlain, 1996, 2008; Lewis et al., 2010; Lewis et al., 2020).



(Previous page) **Fig. 3.3.** Composite stratigraphic diagram of Paleo–Mesoproterozoic rocks from the Priest River region. Approximate stratigraphic thicknesses from Miller et al., (1999) and Lewis et al., (2020), and are only shown to scale on the far left of the diagram. Sampled and photographed intervals indicated. Field photographs include A) A conglomerate bed in the ca. 760 Ma Buffalo Hump Formation, and quartzite cobble (34DTB19) that has a likely eroded Deer Trail Group provenance (Brennan et al., 2021a), B) Fine-grained sandstone bed present in the Togo Formation (basal Deer Trail), C) Laminated mudstone showing soft-sediment deformation that is common in the Togo Formation, D) Ripples in Ravalli Group sandstones (Belt Supergroup), E) Laminated sandstone of the Gold Cup Formation. Photograph G is not from the Priest River region but rather shows coarse-grained to pebbly sandstone of the pre-Belt Supergroup Neihart Formation. The Neihart Formation crops out along the eastern edge of the Belt Basin, ~500 km east of the Priest River region (see Fig. 3.2A).

### **3.2.2.** Proterozoic sequences in the Priest River region

### 3.2.2.1. Paleoproterozoic Gold Cup Quartzite and potential correlatives

An approximately 100 m-thick coarse pebbly quartzite ('Quartzite of Gold Cup Mountain', hereafter referred to as the Gold Cup Quartzite) unconformably overlies ca. 2.67 Ga Neoarchean and ca. 1.87 Ga Paleoproterozoic orthogneisses in the Priest River complex (Fig. 3.2B). Although its upper contact with the overlying lower Belt Supergroup equivalents is mylonitized, it is likely a tectonized unconformity (Fig. 3.3; Doughty et al., 1998; Doughty and Chamberlain, 2008; Lewis et al., 2010; Lewis et al., 2020). Doughty and Chamberlain (2008) analyzed 18 detrital zircon grains from the Gold Cup Quartzite and found ca. 2.65 Ga and ca. 1.8–1.93 age components. Based on these data, Doughty and Chamberlain (2008) favored correlation of the Gold Cup Quartzite with the Paleoproterozoic Neihart Formation that crops out along the eastern margin of the Belt Basin, consistent with the lithostratigraphic correlation proposed by Winston et al. (1989).

The ~ 300 m-thick Neihart Formation (the Neihart Quartzite) crops out in westcentral Montana (Fig. 3.2A), and unconformably overlies ca. 1.87 Ga basement of the Great Falls Tectonic Zone (Mueller et al., 2002). The Neihart Formation was part of a widespread fluvial-nearshore sand sheet that was deposited prior to deposition of the Belt Supergroup (Freeman and Winston, 1987; Schieber, 1989). Detrital zircon provenance study indicated that the Neihart Formation contains primarily 1.9–1.7 Ga, and ca. 2.6 Ga detrital zircon components that do not support early correlations with lower Belt Supergroup strata from the main part of the basin further west (Mueller et al., 2016). Rather, these results suggest that deposition of the Neihart Formation occurred sometime after ca. 1.7 Ga, possibly during extensional collapse of the Great Falls Orogen, approximately 200 million years prior to onset of Belt Basin subsidence at ca. 1.47 Ga (Mueller et al., 2016). Other possibly pre-Belt Supergroup quartzites crop out ~250 km southwest of the Little Belt Mountains, near Argenta Montana, where a ~150 m-thick mature quartzite (the quartzite of Argenta) is overlain by Cambrian strata in a shallow, westdipping, angular unconformity (Sears et al., 2010). The base of the quartzite of Argenta is not exposed. Approximately 150 km southeast of the Priest River complex, along the western edge of the Clearwater complex, another suggested pre-Beltian quartzite, the Marble Creek Quartzite, unconformably overlies ca. 1.86 Ga orthogneiss and is overlain by Lower Belt Supergroup rocks in a likely faulted relationship (Baldwin et al., 2016).

In southeastern British Columbia, ~500 km northwest of the Little Belt Mountains, quartz arenite of the Fort Steele Formation occurs below Mesoproterozoic Belt Supergroup strata (Hoy, 1992; Ross and Villeneuve, 2003). However, the Fort Steele Formation is much thicker (>2000 m) than the other suggested pre-Belt Supergroup quartzites and shows a more varied composition. Generally, quartzite of the Fort Steele Formation fines upwards into deeper water facies siltstones and mudstones, possibly of the basal Belt Supergroup, and likely records an extensive fluvial system that flowed predominantly to the north-northwest (Hoy, 1992).

## 3.2.2.2. Mesoproterozoic Belt–Purcell Supergroup

The relatively fine-grained siliciclastic and carbonate rocks comprising the thick (up to 18 km) Mesoproterozoic (ca. 1.47–1.38 Ga) Belt Supergroup (known as the Purcell Supergroup in Canada) crop out over a large area (>200,000 km<sup>2</sup>) throughout Montana, Idaho, eastern Washington, and southern British Columbia (Fig. 3.2A; Sears, 2007; Lonn et al., 2020; Mueller et al., 2016). The Belt Basin stratigraphy consists of the Lower Belt, Ravalli, Piegan, and Missoula groups (e.g. Link et al., 1993; Sears, 2007; Winston 2007; Fig. 3.3). In the Priest River region, the Lower Belt Group consists of the Prichard Formation, a >6 km-thick sequence of turbidities intruded by ca. 1469 Ma mafic sills that exhibit textures suggesting they were emplaced into unconsolidated sediments (Anderson and Davis, 1995; Sears et al., 1998; Schandl and Davis, 2000).

The Lower Belt Group grades upwards into the Ravalli Group, which shows different western and eastern facies. In the Priest River region, the western facies of the Ravalli Group consist of the Burke, Revett, and St. Regis formations (Lewis et al., 2020; Miller et al., 1999), which are generally fine-grained quartzites that extend eastward and represent a broad alluvial apron formed by massive sheet floods.

Overlying the Ravalli Group, the Piegan Group includes the Wallace and Helena formations. The Helena Formation consists of carbonates containing stromatolitic horizons. Sand-carbonate cycles that commonly include hummocky cross-stratification characterize the overlying Wallace Formation (Winston, 2007).

The stratigraphically highest, Missoula Group marks a return to dominantly siliciclastic facies with widespread fluvial-alluvial fan deposition (Sears, 2007). A localized  $1401 \pm 6$  Ma tuff (the "Libby tuff"; all uncertainties given at  $2\sigma$ ) occurs ~1.7 km from the top of the Missoula Group, and constrains the depositional age of upper Belt Supergroup rocks to ca. 1.4 Ga (Evans et al., 2000). Strata in the southwestern part of the Belt Basin (in the Lemhi Subbasin of east-central Idaho), are termed the Lemhi Group and mostly contain Missoula Group equivalents (Winston et al., 1999; Link et al., 2007). In central Idaho (approximately 80 km west of Argenta, Montana; Fig. 3.2A), Lemhi Group rocks are intruded by ca. 1370 Ma granites and contain detrital zircon grains as young as ca. 1380 Ma (Doughty and Chamberlain 2008; Stewart et al., 2010; Link et al., 2016). Collectively, sedimentary features of Belt Supergroup rocks record their deposition within a vast, intracratonic, epeiric sea or lake. This sea may have opened to the ocean to the northwest, and likely experienced intermittent fluvial, playa, and lacustrine depositional systems (Winston, 2016; Winston and Link, 1993; Pratt, 2001).

Strata of the Lower Belt, Ravalli, and Piegan groups are interpreted to record provenance from both eastern (Laurentian) and western (non- Laurentian) sources (Ross and Villeneuve, 2003; Lewis et al., 2007). Specifically, these rocks contain ca. 1610–1490 Ma "North America Magmatic Gap" (NAMG) detrital zircons, which do not have igneous sources within Laurentia (e.g. Ross and Villeneuve, 2003). Consequently, these NAMG-grains are thought to record provenance from non-Laurentian terranes likely now located in Australia (Ross and Villeneuve, 2003; Fanning and Link, 2003) or possibly Antarctica or South China (e.g. Goodge et al., 2017; Xu et al., 2019; Li et al., 2008b).

Box et al. (2020) contended that NAMG zircon grains within the westernmost Missoula Group suggest a connection to a non-Laurentian source until at least ca. 1390 Ma. In rocks of the Missoula Group to the east of the Priest River Complex, NAMG zircon grains are absent and detrital populations comprise mostly juvenile (positive  $\epsilon$ Hft) ca. 1770–1640 Ma zircon grains interpreted to reflect sources from southwestern Laurentia (e.g. Ross and Villeneuve, 2003). Correlative strata in the Lemhi Subbasin contain similar age-populations, and paleocurrent indicators suggest a source to the south (Stewart et al., 2010; Link et al., 2016). The absence of NAMG grains in upper Belt Supergroup rocks, including the Missoula Group and Lemhi Group strata, is commonly interpreted to suggest a switch to sources in southern Laurentia and reorganization of drainage patterns associated with Nuna rifting (Ross and Villeneuve, 2003) and/or onset of the Picuris orogeny in southern Laurentia (Daniel et al., 2013).

Generally contemporaneous ca. 1.45 Ga Laurentian basin formation is noted ~1,500 km to the north of the Priest River region within the (1460–1420 Ma) PR1 basin (Medig et al., 2014) and ~1,000 km to the south of the Priest River region in the (1475–1450 Ma) Trampas and (1488–1436 Ma) Yankee Joe–Blackjack basins and correlatives (Doe et al., 2013; Daniel et al., 2013; Jones et al., 2015; Fig. 3.1). Collectively, Medig et al. (2014) interpreted the formation of these approximately contemporaneous basins to suggest a ca. 1.47–1.40 Ga period of Nuna extension, likely without full continental separation, along a north–south axis.

3.2.2.3. Late Mesoproterozoic Deer Trail Group

An estimated 2.5 km-thick package of argillite, siltite, quartzite and dolomite of the poorly-exposed Deer Trail Group consisting of the Togo, Chamokane, Wabash-Detroit, McHale, and Stensgar formations crops out in northeastern Washington State (Fig. 3.2B; Miller, 2000). The basal Togo Formation consists of >650 m of chiefly grey argillite, with a few coarser quartzose beds within the Togo Formation (Fig. 3.3B). Finer-grained intervals of the Togo Formation contain sub-millimeter- to 10 cm-thick bedding, sometimes graded and/or with erosional bases that range from wavy to parallel except where they are disturbed by soft-sediment deformation (Fig. 3.3C). Miller and Whipple (1989) reported syneresis cracks and fluid escape structures within this unit. The lower contact of the Togo Formation is faulted everywhere (Miller, 2000).

The Chamokane Creek Formation overlies the Togo Formation, and is perhaps the least exposed unit of the Deer Trail Group. The Chamokane Creek Formation is comprised of ~600 m of fine-grained sandstone interbedded with minor palegrey/green argillite. Overlying the Chamokane Creek Formation is the Wabash-Detroit Formation, which is an approximately 400 m-thick, predominantly dolomitic unit with minor argillite and siltite. Overall, the Wabash-Detroit Formation bears an overall lithological similarity to the Togo Formation, but locally contains stromatolitic beds. The McHale Slate stratigraphically overlies the Wabash-Detroit Formation, and includes ~370 m of dark-grey, green and lavender-gray argillite and shale/slate. The McHale Slate also includes extensive soft-sediment deformation that may increase in abundance toward the northeast (Miller and Whipple, 1989).

The Stensgar Dolomite is the uppermost unit of the Deer Trail Group and consists of ~250 m of dolomite with sparse algal structures (Fig. 3.3), oolites, and nodular chert. Near the inferred top of the unit, Miller and Whipple (1989) reported probable salt casts. Evans (1987) identified no major unconformities within the Deer Trail Group but documented a significant unconformity beneath the (<760 Ma; Brennan et al., 2021a) overlying Buffalo Hump Formation that locally thins the underlying Stensgar Dolomite.

Deer Trail Group strata crop out only in the hanging-wall of the northwestdipping Jumpoff Joe Fault (Fig. 3.2B; Miller, 2000). This fault was most recently active as a Mesozoic thrust fault. However, the absence of Deer Trail Group rocks in the footwall (to the east) of this fault, and the presence of reworked cobbles of the Deer Trail Group in the <760 Ma Buffalo Hump Formation strata, suggest that this Mesozoic thrust fault is a reactivated Neoproterozoic normal fault (Miller, 2000; Brennan et al., 2021a).

3.2.2.3.1. Detrital zircon provenance. Initially, the Deer Trail Group was correlated with the upper Piegan Group and lower Missoula Group of the Belt Supergroup, that only crop out east (in the footwall) of the Jumpoff Joe Fault based on similarities in sedimentary facies (Fig. 3.2B, 3; Miller and Whipple, 1989). However, subsequent detrital zircon provenance analysis (Box et al., 2020) suggested a 1364  $\pm$  35 Ma maximum depositional age (MDA) for the lower Deer Trail Group (Togo Formation), indicating that the entire Deer Trail Group is likely younger than the upper Belt Supergroup. The remainder of the detrital zircon ages within the Deer Trail Group consist primarily of ca. 1.9 to 1.6 Ga and ca. 1.4 Ga age components (Box et al., 2020).

The ~500 m-thick, interbedded siltstone and coarse (locally conglomeratic) quartzite of the Buffalo Hump Formation unconformably overlies upper Deer Trail Group rocks (Fig. 3.3; Evans, 1987; Brennan et al., 2021a). Sandstones from the Buffalo Hump Formation are dominated by ca. 1.2–1.0 Ga detrital zircon grains (Box et al., 2020), but contain a small population of ca. 760 Ma detrital zircon grains, indicating deposition during rifting related to early Rodinia breakup (Brennan et al., 2021a). Quartzite cobbles from conglomerate channels within the Buffalo Hump Formation have a proximal upper Deer Trail Group source based on their large size

and similarity of detrital zircon ages (Box et al., 2020; Brennan et al., 2021a). This suggests removal of an unknown thickness of Deer Trail Group strata during the late Tonian–Ediacaran breakup of Rodinia.

The late Tonian Buffalo Hump Formation is unconformably overlain by <720 Ma Windermere Supergroup correlative strata (Miller, 2000; Brennan et al., 2021a). Cryogenian and Ediacaran rocks of the Windermere Supergroup are widespread in this region of the Cordilleran margin (e.g. Lund et al., 2010; Yonkee et al., 2014; Brennan et al., 2020) and record "Snowball Earth" glacial intervals and poorly-dated rift-related magmatism (Lund and Cheney, 2016).

# 3.2.3 The East Kootenay event: Termination of Belt Supergroup deposition

A variety of geo- and thermochronometers applied to Belt Supergroup rocks from along the western extent of the Belt Basin record an enigmatic ca. 1.38–1.3 Ga tectono-thermal event, which is commonly associated with Pb–Zn–Ag and Co–Cu  $\pm$ Au strata-hosted mineralization (Doughty and Chamberlain, 1996; McFarlane and Pattison, 2000; Zirakparvar et al., 2010; Nesheim et al., 2012; McFarlane and Corfu, 2015; Pattison and Seitz, 2012; Slack et al., 2020; Bookstrom et al., 2016). Early work in southern British Columbia suggested that Belt Supergroup strata must have undergone a period of tilting, gentle folding, erosion, and bimodal intrusion prior to deposition of unconformably overlying late Neoproterozoic and Cambrian strata. Some workers considered these observations to represent an East Kootenay "orogeny", reflecting a (oblique?) collision between Laurentia and a western terrane that terminated deposition of the Belt Supergroup at ca. 1.38-1.30 Ga (McFarlane and Corfu, 2015; McMechan and Price, 1982). Conversely, others have suggested that the ca. 1.38–1.30 Ga East Kootenay event was rather a period of basin rifting, renewed subsidence, and bimodal magmatism that shortly preceded the end of deposition within the Belt Basin (Doughty and Chamberlain, 1996; Pattison and Seitz, 2012).

### **3.3.** Field relations and sample descriptions

To evaluate correlations and provenance interpretations of Paleo- to Mesoproterozoic strata in the Priest River region, existing detrital zircon U–Pb datasets were compiled and additional samples were collected from target stratigraphic intervals for further detrital zircon analysis (U–Pb and Lu–Hf isotopes; Table 1). The stratigraphically-lowest sampled interval was from the core of the Priest River Complex (Lewis et al., 2020). This sample (38DTB19; Fig. 3.3F) was collected from poorly-exposed, coarse-grained, locally pebbly, Gold Cup Quartzite on the east side of Gold Cup Mountain. Here, the Gold Cup Quartzite overlies Archean igneous basement rocks and is approximately 120 m thick. In turn, a probable unconformity separates the Gold Cup Quartzite from overlying metamorphosed Lower Belt Supergroup strata (Miller et al., 1999; Doughty et al., 1999; Doughty and Chamberlain, 2008; Lewis et al., 2020). To evaluate the regional extent of potential pre-Belt Supergroup units, approximately 500 km east of the Priest River region within the Little Belt Mountains, a sample (82DTB19) of the Neihart Quartzite, a potentially Gold Cup Quartzite correlative (e.g. Doughty and Chamberlain, 2008; Lonn et al., 2020; Mueller et al., 2016), was collected from shallowly-dipping, coarse-grained to pebbly, thickly-bedded, cross-stratified quartzite (quartz arenite) (Fig. 3.3G).

West of the Newport Fault, a relatively intact stratigraphic section of Belt Supergroup rocks dips to the west and is offset by small-scale faults (Lewis et al., 2020). These rocks progress up section to the west (Miller, 2000), where upper Belt Supergroup rocks (or perhaps lowermost Deer Trail Group equivalent rocks; Box et al., 2020) are unconformably overlain by lower Paleozoic strata. In stratigraphic order, a fine-grained sandstone from the Lower Belt Supergroup (Prichard Formation; Fig. 3.3E; 10DTB19) was sampled. Approximately 8 km west of the Prichard Formation sample, medium-grained quartzite of the Revett Formation of the Ravalli Group, was sampled (Fig. 3.3D; 12DTB19). Approximately 3 km southwest of the Revett Formation sample, and ~800 m below the overlying sub-Cambrian unconformity that likely removed most Deer Trail Group strata here (Box et al., 2020; Brennan et al., 2021a), a fine-grained cross-laminated sandstone bed (sample 14DTB19) was sampled from within the predominately argillite sequence of the Snowslip Formation of the Missoula Group.

Deer Trail Group rocks are only mapped west (in the hanging wall) of the Jumpoff Joe Fault (Miller, 2000; Fig. 3.2B). Approximately 20 km southwest of the sampled Belt Supergroup section, an extensively faulted but relatively complete stratigraphic section of the Deer Trail Group is present. In this region, two samples (21JBM18 and 01DTB19; Fig. 3.3B) were collected (~15 km apart but broadly along strike) from the coarsest, medium-grained quartzite interval of the basal Deer Trail Group (Togo Formation) based off the mapping of Evans (1987) and Campbell and Raup (1964).

We also report new Lu–Hf detrital zircon data from a quartzite cobble within the ca. 760 Ma Buffalo Hump Formation that unconformably overlies upper Deer Trail Group. Brennan et al., (2021a) reported the U–Pb ages of the same detrital zircon grains from these cobbles (34DTB19) that are very similar in age to those in upper Deer Trail Group rocks (Box et al., 2020). This suggests that the cobbles were likely reworked from now eroded upper Deer Trail Group, probably during Neoproterozoic rifting (Brennan et al., 2021a).

### Table 3.1

Paleo-Mesoproterozoic compiled and original detrital zircon samples from the Priest River region & potential Laurentian correlatives.

Geologic Unit	Sample number	Location		Analysis	Isotopic	Reference	Figure shown
		Latitude ( <sup>⊠</sup> )	Longitude ( <sup>⊠</sup> )	method	data		
Now eroded (?) Mesoproterozoic Deer Trail							
Group							
Buffalo Hump	34DTB19	48.1312	-117.9977	LA-SS-ICPMS	U-Pb, Lu-Hf	Brennan et al. (2021a) ; this	Fig. 7; Fig. 8A*; Fig. 9A
conglomerate						work	
Mesoproterozoic Deer Trail Group							
Wabash-Detroit	07SB303A	48.1654	-117.9185	LA-ICPMS	U-Pb	Box et al. (2020)	Fig. 8A*
Wabash-Detroit	07SB302A	48.1596	-117.9264	LA-ICPMS	U-Pb	Box et al. (2020)	Fig. 8A*
Togo Formation	Togo3	48.1526	-117.9087	LA-ICPMS	U-Pb	Box et al. (2020)	Fig. 8A*
Togo Formation	01DTB19	48.0488	-118.0775	LA-SS-ICPMS	U-Pb, Lu-Hf	this work	Fig. 6, 8A*, Fig. 9A
Togo Formation	21JBM18	48.1619	-117.9272	LA-ICPMS	U-Pb	this work	Fig. 6, 8A*
Mesoproterozoic Belt Supergroup							
Snowslip	14DTB19	48.2713	-117.6567	LA-SS-ICPMS	U-Pb, Lu-Hf	this work	discussed in text
Snowslip	08SB203A	48.2740	-117.6573	LA-ICPMS	U-Pb	Box et al. (2020)	Fig. 8A*
Revett	12DTB19	48.2909	-117.6284	LA-SS-ICPMS	U-Pb, Lu-Hf	this work	Fig. 5, 8A*, Fig. 9B, 13*
Revett	07SB306A	48.1247	-117.5834	LA-ICPMS	U-Pb	Box et al. (2020)	Fig. 8A*
Prichard	10DTB19	48.2958	-117.5196	LA-SS-ICPMS	U-Pb, Lu-Hf	this work	Fig. 5, 8A*, Fig. 9B, 13*
Prichard	04RL213	47.4796	-116.2178	LA-ICPMS	U-Pb	Lewis et al., 2010	Fig. 8A*
Prichard	04RL175	48.3747	-116.1934	LA-ICPMS	U-Pb	Lewis et al., 2010	Fig. 8A*
Paleoproterozoic							
Quartzites							
Gold Cup Quartzite	GC-01-03	48.1772	-116.8646	SHRIMP	U-Pb	Doughty and Chamberlain	Fig. 8A*; Fig. 10*
						(2008)	
Gold Cup Quartzite	38DTB19	48.1908	-116.7945	LA-SS-ICPMS	U-Pb, Lu-Hf	this work	Fig. 4; Fig. 8A*; Fig. 9;
							Fig. 10*, 11*
Neihart Formation	84DTB19	46.9077	-110.6898	LA-SS-ICPMS	U-Pb, Lu-Hf	this work	Fig. 4; Fig. 8A*; Fig. 9;
							Fig. 10*, 11*
Neihart Formation	VN-98-01	Stop 1-2 of W	inston et al.,	SHRIMP	U-Pb	Ross and Villeneuve (2003)	Fig. 10*
1989							
Neihart Formation	NQ98-2	46.9130	-110.6983	SHRIMP	U-Pb	Mueller et al. (2016)	Fig. 10*
Quartzite of Argenta	07PL7	45.2977	-112.9126	LA-ICPMS	U-Pb	(Sears et al. (2010)	Fig. 10
Fort Steele Formation	RAR-98-FS	49.74088	-115.74255	SHRIMP	U-Pb	Ross and Villeneuve (2003)	Fig. 10

Note: All Locations converted to datum WGS84.

\*data shown compiled with other correlative units

Abbreviations: LA-Laser ablation, SS-Split stream, ICPMS-Iductively Coupled Plasma Mass spectrometry, SHRIMP-Sensitive High Resolution Ion Micro Probe

# **3.4.** Methods

#### **3.4.1** Detrital zircon analysis

Samples for detrital zircon analysis were collected and separated using standard techniques (chipmunk, disc mill or SEL-Frag, Frantz magnetic and heavy liquid separation) at Curtin University, Australia or the University of Wisconsin-Eau Claire, USA. Zircon grains were mounted in epoxy resin, and hand polished to expose grain centers. Cathodoluminescence (CL) or backscatter electron (BSE) images were taken of all zircon grain mounts. All "DTB" samples were imaged using a MIRA3 variable-pressure field-emission scanning electron microscope (SEM) coupled to a CL

detector and analyzed for U–Pb, and Lu–Hf isotopes using split-stream laser ablation inductively coupled mass spectroscopy (ICPMS) at the GEOHistory Facility in the John de Laeter Centre at Curtin University, Perth Australia. U–Pb isotopes were measured on an Agilent 7700 s quadrupole ICP-MS for age determination, whereas Lu–Hf isotopes were measured on a Nu Instruments Plasma II MC-ICP-MS to further constrain the provenance and character of the source terranes. Following analysis, data reduction was performed using Iolite v.3.6 software (Paton et al., 2011).

Backscattered electron (BSE) images of sample 21JBM18 were collected at University of Wisconsin – Eau Claire using a Hitachi S-3400 N Variable Pressure SEM and then analyzed for U–Pb isotopes at the University of Arizona Laserchron center with a Photon Machine Analyte G2 Excimer laser paired with a Thermo Element2 single-collector ICPMS. Following analysis, data reduction for 21JMB18 was performed with an Arizona Laserchron python decoding routine and an Excel spreadsheet (E2agecalc).

Detrital zircon age spectra are shown in kernel density estimate (KDE) plots generated with DensityPotter 8.5 (Vermeesch, 2012) with 25 Myr band and bin widths. Peak age labels were rounded to the nearest 5 Ma. For zircon grains with ages younger than 1500 Ma, the <sup>206</sup>Pb/<sup>238</sup>U age was used, whereas for zircons older than 1500 Ma the <sup>207</sup>Pb/<sup>206</sup>Pb age was used (Spencer et al., 2016). For samples, 10DTB19 and 12DTB19 which have depositional ages of ca. 1470 Ma, the <sup>207</sup>Pb/<sup>206</sup>Pb ages are  $(^{207}\text{Pb}/^{206}\text{Pb})$ with discordance (calculated plotted. Only analyses as  $(^{238}\text{U}/^{206}\text{Pb}))/(^{207}\text{Pb}/^{206}\text{Pb}))$  <10% to –5% are interpreted as robust and are included in the uni and bivariate KDE plots. Maximum depositional age constraints only use grains that met these criteria and also showed <sup>206</sup>Pb/<sup>207</sup>Pb and <sup>206</sup>Pb/<sup>238</sup>U ages that overlapped the concordia within  $2\sigma$  uncertainties (e.g. Spencer et al., 2016). Maximum depositional ages are presented for samples 38DTB19 (Gold Cup Quartzite) and 10DTB19 (Prichard Formation) based on the youngest population with a mean square weighted deviation (MSWD) of ~1 (Coutts et al., 2019; Herriott et al., 2019). Concordia plots and ages were calculated with Isoplot 3.70 (Ludwig, 2008) and IsoplotR (Vermeesch, 2018). The  $\varepsilon$ Hf<sub>(t)</sub> values calculated for all data used the <sup>176</sup>Lu decay constant =  $1.865 \times 10-11$  yr<sup>-1</sup> proposed by Scherer et al. (2001). Chondritic values are after Bouvier et al. (2008):  ${}^{176}$ Hf/ ${}^{177}$ Hf CHUR = 0.282785 and  ${}^{176}$ Lu/ ${}^{177}$ Hf CHUR = 0.0336, where CHUR is the chondritic uniform reservoir. Depleted mantle values are after Griffin et al. (2002):  ${}^{176}$ Hf/ ${}^{177}$ Hf = 0.28325 and  ${}^{176}$ Lu/ ${}^{177}$ Hf = 0.0384.

Where possible, all published (U–Pb and Lu–Hf) data included were recalculated/reselected using the same criteria.

Bivariate kernel density estimates (2DKDEs) were employed to visualize U– Pb/Lu–Hf data distribution and density with 1  $\epsilon$ Hf<sub>t</sub> and 45 Ma bandwidths using the methods and MATLAB code of Spencer et al., (2019). To further assess tectonostratigraphic correlations, and objectively evaluate the relative similarity between datasets, two-dimensional (U–Pb/Lu–Hf) statistical comparison of zircon density distributions utilizing the MATLAB program of Sundell and Saylor (2021) was also employed also using 1  $\epsilon$ Hf<sub>t</sub> and 45 Ma bandwidths. See data repository for additional details.



# 3.5. Detrital Zircon U–Pb and Lu–Hf results

**Fig. 3.4.** Detrital zircon U–Pb/Lu–Hf for the Neihart Quartzite (82DTB19) and Gold Cup Quartzite (38DTB19) shown in KDE plots, and Wetherill concordia diagrams. In the Wetherill concordia diagram the purple analyses fit within our concordance limits and are reported in the KDE plots. The grey analyses are outside our concordance limits and are omitted from the KDE plots. The concordia inset shows the five youngest concordant analyses (purple) and their 1739  $\pm$  30 Ma Concordia age (red) from sample 38DTB19. Representative zircon CL-images and individual analysis results are shown on the bottom right for sample 38DTB19. Approximate average crustal evolution (Lu/Hf = 0.015) indicated. Abbreviations: DM–depleted mantle, CHUR–chondritic uniform reservoir.

Detrital zircon grains (Fig. 3.4) from the Gold Cup Quartzite (38DTB19) and Neihart Quartzite (82DTB19) are similar in size, shape and appearance. Zircon grains from both samples are generally 80 to 250 µm long, with median aspect ratios (long axis/short axis) around ~1.85 but sometimes exceeding 3. In CL imaging grains from both samples show mostly concentric zoning, with some thin (<10  $\mu$ m) bright metamorphic rims. U/Pb results show similar age-components with ca. 2.7–2.6 Ga and ca. 1.95–1.7 Ga grains common. Both samples lack zircon grains younger than ca. 1.7 Ga.

In the Gold Cup Quartzite, a ca. 2.67 Ga age-component yields a tight cluster of  $\varepsilon$ Hft values from -2 to +3, indicating a CHUR-like Neoarchean source. The younger detrital component shows main age-peaks at 1850 and 1790 Ma and  $\varepsilon$ Hft values that mostly range from -10 to +10, suggesting similar-aged but isotopically discrete sources. Deposition of the Gold Cup Quartzite occurred after  $1731 \pm 29$  Ma based on a Concordia age constrained by the five youngest concordant analyses with similar  $\varepsilon$ Hft values that range from -0.9 to 3.9 (Fig. 3.4).

In the Neihart Quartzite, the ca. 2.68 Ga age-component exhibits  $\varepsilon$ Hf<sub>t</sub> values ranging from -12 to 0. This is a greater variation in  $\varepsilon$ Hf<sub>t</sub> than the similar-aged component in the Gold Cup Quartzite, which contain a tight cluster of  $\varepsilon$ Hf<sub>t</sub> values ranging from -2 to +3. The ca. 1.95–1.7 Ga component in the Neihart Quartzite shows a main age-peak at 1835 Ma and contains a similar range of  $\varepsilon$ Hf<sub>t</sub> values (approximately -17 to +9) to the temporally equivalent component in the Gold Cup Quartzite.

Detrital zircon grains from the Lower Belt Supergroup (Prichard Formation; 10DTB19), and Ravalli Group (Revett Formation; 12DTB19) are also similar in size, shape and appearance. Zircon grains from both samples are generally 40 to 90 µm long, with median aspect ratios (long axis/short axis) around ~1.9 but sometimes as high as 3, indicating preservation of elongate grains. In CL imaging grains from both samples show mostly faint concentric zoning. U-Pb zircon results show dominant ~1.8–1.5 Ga age-components that contain a significant number of grains with ages within the ca. 1.61-1.49 Ga North American Magmatic Gap ("NAMG"; Ross and Villeneuve, 2003). In the Prichard Formation (Fig. 3.5), the main 1610 Ma age-peak shows a tightly clustered range of  $\varepsilon$ Hf<sub>t</sub> values between +4 and +9. It also contains two shoulder age-peaks, at ca. 1805 Ma and ca. 1500 Ma. The older ca. 1805 agecomponent shows more evolved  $\varepsilon$ Hf<sub>t</sub> values concentrated between -6 to +3, whereas the younger ca. 1500 Ma age-peak shows juvenile  $\varepsilon Hf_t$  values (+6 to +10). A Concordia age of the six youngest (<ca. 1500 Ma) concordant analyses yields an age of  $1472 \pm 17$  Ma (MSWD = 0.9), which overlaps within  $2\sigma$  uncertainty with the 1468  $\pm$  2 and 1469  $\pm$  3 Ma age of mafic sills within the Prichard Formation that likely intruded unconsolidated sediment and approximate the depositional age (Anderson and Davis, 1995; Sears et al., 1998). These six youngest concordant analyses have similar  $\epsilon$ Hf<sub>t</sub> values from +5.3 to +9.8.

In the Ravalli Group sample (Fig. 3.5), the main age-components are at 1720 Ma and 1570 Ma. Both these age components contain mostly positive  $\varepsilon$ Hf<sub>t</sub> values. Detrital zircon grains from the Missoula Group (Snowslip Formation; 14DTB19) experienced significant Cretaceous lead loss and are mostly discordant precluding further interpretation.



**Fig. 3.5.** Detrital zircon U–Pb/Lu–Hf for Belt Supergroup samples from the Prichard Formation (10DTB19) and Ravalli Group (12DTB19) shown in KDE plots, and Wetherill concordia diagrams. The concordia inset shows the five youngest concordant analyses (blue) and their  $1486 \pm 17$  Ma Concordia age (red) from sample 10DTB19. In the Wetherill concordia diagram the blue analyses fit within our concordance limits and are reported in the KDE plots. The grey analyses are outside our concordance limits and are omitted from the KDE plots. Representative zircon CL-images and individual analysis results are shown on the bottom right for sample 10DTB19. Approximate average crustal evolution (Lu/Hf = 0.015) indicated. Abbreviations: DM–depleted mantle, CHUR–chondritic uniform reservoir.

Detrital zircon grains from the lower Deer Trail Group (Togo Formation; samples 01DTB19 and 21JBM18) are again similar in size, shape and appearance. Zircon grains from both samples are generally 30 to 80 µm long, with median aspect ratios (long axis/short axis) around 1.4, which indicates overall more equant zircon grains than observed within the Belt Supergroup and Gold Cup Quartzite samples. In CL imaging grains from sample 01DTB19 show mostly faint, darker, concentric

zoning. Geochronology results from the Togo Formation indicate an absence of NAMG-age grains, and the presence of age-components younger than ca. 1380 Ma (Fig. 3.6). The Togo Formation samples both show broad-age components from ca. 1.9–1.6 Ga. Sample 21JBM18 shows a single 1710 Ma age-peak, which probably is the amalgamation of several age-populations. In sample 01DTB19, this broad ca. 1.9–1.6 Ga population suggests several discrete subpopulations (Fig. 3.6) with an older age-peak at ca. 1815 Ma characterized by more evolved  $\varepsilon$ Hft values (–7 to +1), and two younger populations at ca. 1705 and 1660 Ma. These younger populations contain more CHUR-like/juvenile  $\varepsilon$ Hft values around +1 to +10. The next youngest main age-component at ~1450 Ma, is present in both samples. In sample 01DTB19, these grains show mostly juvenile  $\varepsilon$ Hft values (+2 to +8). These main age-components are similar to Missoula and Lemhi Group samples from further east/southeast (e.g. Stewart et al., 2010; Link et al., 2016).



**Fig. 3.6.** Detrital zircon U–Pb/Lu–Hf results for Deer Trail Group samples from the Togo Formation (01DTB19 and 21JBM18) shown in KDE plots, and Wetherill concordia diagrams. In the Wetherill concordia diagram the green analyses fit within our concordance limits and are reported in the KDE plots. The grey analyses are outside our concordance limits and are omitted from the KDE plots. The concordia inset shows the three youngest concordant analyses (green) and their 1299  $\pm$  12 Ma Concordia age (red) from sample 21JBM18, interpreted as the maximum depositional age of the Deer Trail Group. Representative zircon CL-images and individual analysis results are shown on the bottom right for sample 01DTB19. Approximate average crustal evolution (Lu/Hf = 0.015) indicated. Abbreviations: DM–depleted mantle, CHUR–chondritic uniform reservoir.

We favor a maximum depositional age of  $1299 \pm 12$  Ma for the Deer Trail Group based on a Concordia age of the youngest three overlapping grains in sample 21JBM18 (Fig. 3.6), which was collected from near the base of the group. The other lower Deer Trail Group sample presented here (01DTB19) also contains grains that contain similar <sup>206</sup>Pb/<sup>238</sup>U dates of  $1324 \pm 41$  and a youngest single grain date of  $1234 \pm 38$  Ma. A similar sample from the lower Deer Trail Group reported by Box et al., (2020) also contains a single concordant youngest grain at  $1264 \pm 29$  Ma. Therefore, we interpret the Deer Trail Group to be younger than ca. 1.30 Ga.

The U–Pb results from the Buffalo Hump conglomerate cobble (34DTB19) that likely represents eroded upper Deer Trail Group also contain concordant grains with ( $^{206}Pb/^{238}U$ ) crystallization dates of 1188 ± 34, and 1235 ± 39 Ma (Brennan et al., 2021a). These zircon grains are generally larger (lengths of 80 to 200 µm) than the grains found within the stratigraphically lower Deer Trail Group samples but also contain mostly lower aspect ratios (~1.4) and concentric zoning in CL-imaging. Here we present new Lu–Hf data from this cobble (Fig. 3.7) that complement the U-Pb data which indicates the presence of ca. 1.9–1.6 Ga and ca. 1.4 Ga age-components first reported by Brennan et al. (2021a). The ca. 1.9–1.6 Ga component shows a range of  $\epsilon$ Hft values (from –5 to +10) suggesting at least two discrete similar-age but different  $\epsilon$ Hft populations. The youngest single grain analysis date of 1188 ± 34 Ma from the Buffalo Hump Cobble overlaps with the youngest concordant grains reported by Box et al., (2020) from the upper Deer Trail Group and yields a  $\epsilon$ Hft value of +0.2.

Detrital zircons grains within all samples show varying levels of lead-loss. Generalized Discordia lines (calculated in IsoplotR; Vermeesch, 2018) for the Gold Cup Quartzite (38DT19), Belt Supergroup (12DTB19), and Deer Trail Group (21JBM19) samples yield lower intercepts from ca. 138 to 78 Ma. These Cretaceous ages likely reflect the timing of burial during the Sevier orogeny, and are generally consistent with peak metamorphism and magmatism within the Priest River Complex (Stevens et al., 2015, 2016).



**Fig. 3.7.** Detrital zircon U–Pb/Lu–Hf results for the Buffalo Hump cobble (34DTB19) shown in a KDE plot and Wetherill concordia diagram. This cobble was collected from the <760 Ma Buffalo Hump Formation and was likely sourced from eroded upper Deer Trail Group (Brennan et al., 2021a). In the Wetherill concordia diagram the green analyses fit within our concordance limits and are reported in the KDE plot. The grey analyses are outside our concordance limits and are omitted from the KDE plot. The concordia inset shows youngest analyses that fit our concordance limits. Solid lines indicated the analyses overlapped with concordia. Representative zircon CL-images and individual analysis results are shown on the right. Approximate average crustal evolution (Lu/Hf = 0.015) indicated. Abbreviations: DM–depleted mantle, CHUR–chondritic uniform reservoir.

# **3.6.** Discussion 3.6.1. The Gold Cup Quartzite: A record of Laurentia assembly prior to

#### final Nuna amalgamation

The relatively high zircon grain aspect ratios within the Gold Cup and Neihart quartzite samples indicate the preservation of elongate grains, suggesting comparably low levels of mechanical abrasion during erosion and transport (e.g. Markwitz and Kirkland, 2018). The detrital zircon spectrum within these samples are dominated by relatively bimodal age distributions at ca. 2.8–2.5 and 1.95–1.7 Ga (Fig. 3.4). These ages are common in the Medicine Hat/Clearwater block, and the Great Falls Tectonic Zone (Fig. 3.8B; Gifford et al., 2020; Vervoort et al., 2016). The Lu–Hf crustal evolution trends suggest sourcing from predominately Meso- and Neoarchean crust that was reworked in the late Paleoproterozoic, but which also received broadly coeval juvenile mantle input. The Neihart quartzite sample (82DTB19) contains significantly evolved ca. 1.8 Ga grains with  $\varepsilon$ Hf<sub>t</sub> values that range from approximately –10 to –18 (Fig. 9A). Considering that juvenile ca. 1.9–1.6 Ga sources are widespread in Laurentian Trans-Hudson-age arcs and Yavapai–Mazatzal–Mojave terranes in southwestern Laurentia (e.g. Whitmeyer and Karlstrom, 2007), the most evolved

grains within this age range may yield more unique provenance constraints. Many of these most evolved ca. 1.8 Ga grains yield  $\epsilon$ Hf<sub>t</sub> values similar to those in ca. 1.8 Ga rocks from the Medicine Hat Block (Fig. 3.9A; Gifford et al., 2020). Collectively, the zircon grain shape and U–Pb/Lu–Hf analytical results suggest a proximal provenance from the underlying Medicine Hat–Clearwater Block, and the Great Falls Tectonic Zone. Additional inputs from adjacent similar-age sources such as the Wyoming Craton, and poorly characterized (lacking Lu-Hf data) sources such as the Vulcan Structure, Hearne Province (Lovera Block), and the Rimbey Arc are also possible.

Sears et al. (2010) reported a detrital zircon sample (n = 95) from the Precambrian quartzite of Argenta, along the southern/southeastern margin of the Belt Basin. This sample also shows a bimodal age distribution, with broad peaks at ca. 2.8 to 2.5 and 2.0–1.7 Ga. Based on these ages Sears et al. (2010) favored a correlation to the Neihart Quartzite, an interpretation supported by our new data. The ca. 1.87 and ca. 2.59 Ga age-peaks in the quartzite of Argenta may reflect input from the Grouse Creek Block (Link et al., 2017; Fig. 3.2A). Comparable zircon ages are present in the Gold Cup and Neihart Quartzite, albeit less prevalent (Fig. 3.10).

A single sample in which detrital zircons were analyzed (n = 22) from a stratigraphic interval of the Fort Steele Formation that (probably conformably) underlies lower Belt Supergroup strata at the northern extent of the Belt Basin also shows ca. 1850 and 2.7–2.6 Ga age-peaks (Fig. 3.10; Ross and Villeneuve, 2003). However, the Fort Steele Formation is significantly thicker and contains finer-grained intervals than the Gold Cup and Neihart Quartzite. Additionally, the Fort Steele Formation contains a single concordant ca. 1635 Ma zircon grain, approximately 100 Myr younger than the youngest grains identified in the Gold Cup, Neihart, and Argenta units.



**Fig. 3.8.** A) Detrital zircon U–Pb and Lu–Hf data for Paleo–Mesoproterozoic strata from the Priest River region including our new U–Pb/Lu–Hf data and compiled U–Pb data. Average crustal evolution trends (Lu/Hf = 0.015) indicated. Data sources are in Table 1. B) Complied zircon U–Pb/Lu–Hf data for proposed igneous basement sources. Data source are in the supporting information, any omission of applicable data is non-intentional. Lu–Hf data is plotted using the bivariate kernel density estimate method of Spencer et al. (2020), note that warmer colors (red) indicate greater data density, while cooler colors (blue) indicate lesser data density. Abbreviations: DM–depleted mantle, CHUR–chondritic uniform reservoir, N = number of samples, n = total individual analyses.
Consequently, based on the lithologies and detrital zircon populations of these units, the Gold Cup, Neihart, and Argenta quartzites were likely deposited during a basin-forming event after ca. 1.74 Ga but prior to formation of the main Belt Basin at ca. 1.47 Ga. This period of Neihart–Gold Cup–Argenta sedimentation possibly occurred during final collision and post-collisional collapse of the Great Falls Orogen (e. g. Mueller et al., 2016) and other contemporaneous adjacent collisional zones (such as the Vulcan structure or the Rimbey Arc), and sourced detritus primarily from proximal Laurentian basement. Widespread sedimentation across the Medicine Hat–Clearwater Block and an inferred source from proximal basement rocks and bounding suture zones suggests that the Paleoproterozoic and Archean basement blocks in this region of Laurentia (e.g. Wyoming, Grouse Creek, Medicine Hat, Clearwater, and Hearne) were close to their current configuration by ca. 1.73 Ga. Importantly, in a broader context, these results indicate a widespread Laurentian provenance for the Priest River region between ca. 1.73–1.48 Ga.



**Fig. 3.9.** A) U–Pb and Lu–Hf values for the most evolved ca. 1.8 Ga detrital zircon grains in the Gold Cup (dark purple; 38DTB19) and Neihart Quartzite (light purple; 84DTB19), lower Deer Trail Group (light green; Togo Formation; 01DTB19), upper Deer Trail Group (dark Green; Buffalo Hump cobble; 34DTB19), their likely Medicine Hat Block source (Gifford et al., 2018). B) U–Pb and Lu–Hf values for the ca. 1.9 to 1.45 Ga detrital zircon grains from the Lower Belt (light blue; 10DTB19; Prichard Formation), Ravalli Group (dark blue; 12DTB19; Revett Formation) and compilation of magmatic sources from the Gawler Craton of southeastern Australia (Reid and Payne, 2017; Hartnady et al., 2020).



Fig. 3.10. Detrital zircon age-spectra for the Fort Steel Formation (Ross and Villeneuve, 2003), Quartzite of Argenta (Sears et al., 2010), Neihart Quartzite (Mueller et al., 2016; this study), and Gold Cup Quartzite (Doughty and Chamberlain, 2008; this study), and their main age-peaks highlighted indicated. These main age-peaks are consistent with proximal sourcing from the Medicine Hat Block and adjacent Paleoproterozoic collisional zones.

However, for this same general time interval, ca. 1.79–1.74 Ga strata in the Mojave province of southwestern Laurentia (e.g. Vishnu Schist), have been suggested to record a non-Laurentian, East Antarctica and Gawler Craton (southeastern Australia) provenance (Holland et al., 2015; 2018). During the Proterozoic, the East Antarctica and Gawler cratons were connected to form a larger continent called Mawson (Cawood and Korsch, 2008; Payne et al., 2009; Fig. 3.1). To evaluate Paleoproterozoic correlation of the Mawson Continent with Laurentia, statistical analysis of the detrital zircon U–Pb/Lu–Hf data from the Vishnu Schist, ca. 1.7 Ga southeastern Australian units, our studied Neihart–Gold Cup units and Mawson (combined East Antarctica-Gawler Craton) igneous sources was conducted. The statistical results (Fig. 3.11B) indicate that Mawson igneous sources show comparable similarity values with the ca. 1.7 Ga Gawler Craton strata and strata of the Vishnu basin in Mojave province. This similarity supports prior correlations of the Mojave province with the Mawson continent (Goodge et al., 2017; Goodge and Fanning, 2016;

Holland et al., 2015, 2018). However, the Gawler Craton igneous sources indicate a much weaker similarity with the Neihart–Gold Cup units. Notably, the presence of the CHUR-like (in regards to Lu–Hf) ca. 2.67 Ga populations within in the Neihart–Gold Cup, that are likely diagnostic of a Laurentian provenance, are not well represented in Mawson rocks.

Fig. 3.11. A) U-Pb and Lu-Hf values for (bottom to top): < 1.73 Ga studied western Laurentian strata (Gold Cup, Neihart Quartzite), ca. 1.79 - 1.74 strata in southwestern Laurentia (Vishu basin strata; Holland et al., 2015, 2018; Wooden et al., 2013), ca. 1.7 Ga strata from the Gawler Craton (Howard et al., 2009, 2011; Szpunar et al., 2011), Mawson Continent (southeastern Australia and East Antarctica) igneous sources (Reid and Payne, 2017 and references within). Results of B) twodimensional (Lu-Hf/U-Pb) statistical comparison (Sundell and Saylor, 2021) of the datasets, with a value of 1 indicating the most similar and 0 the least similar, between Mawson continent igneous sources, and southeastern Australian strata, strata of western Laurentia (Gold Cup and associated units) and southwestern Laurentia (strata of the Vishu basin). See Sundell and Saylor (2021) for further discussion of the Cross-correlation (C.-correlation), Likeness, and Similarity metrics. Please note that only zircon grains with both U-Pb and Lu-Hf values are included in the compilation and statistical comparison, any omission of applicable data is non-intentional.



Consequently, the U–Pb/Lu–Hf detrital zircon data from ca. 1.79–1.74 Ga Vishnu basin strata of the Mojave province are similar to coeval Australia–Antarctica strata and igneous sources. However, there is no evidence that the Priest River region and the surrounding main Archean blocks (Wyoming, Clearwater, Medicine Hat, Hearne, and Grouse Creek) of western Laurentia were exchanging sediments with Australia–Antarctica during the late Paleoproterozoic. As such, Paleoproterozoic strata in the main Archean blocks of western Laurentia do not support a final assembly of Nuna by ca. 1.8 Ga. Instead, we suggest that the Mojave province had an Australia–Antarctica origin and subsequently joined Laurentia during final Nuna assembly at ca. 1.65–1.6 Ga (Gibson and Champion, 2019). Alternatively, the assembly of Australia–Antarctica with Laurentia may have been a prolonged process that generally propagated from north to south along the western margin of Laurentia (modern coordinates) from ca. 1.75 to 1.6 Ga (c.f. Betts et al., 2011; Furlanetto et al., 2013; Kirscher et al., 2019; Pisarevsky et al., 2014a; Nordsvan et al., 2018).

#### **3.6.2.** NAMG-age magmatism within the Clearwater Block

The detrital zircon spectrum of the two analyzed Belt Supergroup samples (Prichard Formation and Ravalli Group) along with existing data (Fig. 3.5; 8A) compiled from the Priest River region, contain a large-proportion of grains that fall within the ca. 1610–1490 Ma NAMG, supporting a western non-Laurentian source. These samples were sourced primarily from juvenile ( $\varepsilon Hf_t = +5$  to +7) ca. 1600 Ma and more evolved ( $\varepsilon$ Hf<sub>t</sub> = -5 to +4) ca. 1720 Ma rocks. The only Laurentian sources, the ca. 1580 Ma Laclede Gneiss in the Priest River Complex (Evans and Fischer, 1986), and the recently identified  $1588 \pm 7$  Ma meta-rhyolite (the Blue Springs metarhyolite) in the Mazatzal province of southwestern Laurentian (Holland et al., 2020) are localized and do not span the entire age-range present in Belt Supergroup strata. Although there is no Lu-Hf isotopic data available for the Blue Springs metarhyolite, the Laclede Gneiss has a relatively evolved  $\varepsilon Hf_t$  (approximately -6; Goodge et al., 2017). Thus, non-Laurentian sources are required to satisfy the range of detrital zircon ages (as previously noted; e.g. Ross and Villeneuve, 2003; Jones et al., 2015; Lewis et al., 2010) and Lu–Hf compositions identified within western Belt Supergroup rocks.

The Gawler Craton of southeastern Australia records widespread magmatism in pulses from ca. 1.9 to 1.5 Ga, which include: 1) the ca. 1850–1790 Ma Donington– Myola Suite (Fanning et al., 1988; Reid et al., 2008), 2) the ca. 1770–1740 Ma McGregor Volcanics and associated suites (Fanning et al., 1988), 3) the 1620–1605 Ma St Peter Suite (Swain et al., 2008), 4) the 1600–1575 Ma Gawler Range Volcanics– Hiltaba suite, and 5) granites as young as ca. 1500 Ma in the Spilsby Suite (Fanning et al., 2007). The ca. 1620–1605 Ma St Peter Suite and ca. 1600–1575 Ma Hiltaba Suite and Gawler Range Volcanics all show distinctly juvenile compositions with average  $\epsilon$ Hf<sub>t</sub> values up to +4 (Fig. 3.8B; Swain et al., 2008; Reid and Payne, 2017).

The juvenile, NAMG-age magmatism of the St. Peter Suite, and Hiltaba and Gawler Range Volcanics are predominately A-type, mantle-derived melts (Chapman et al., 2019) consistent with the U–Pb, and Lu–Hf results for NAMG zircons in the westernmost Belt Supergroup (Fig. 3.9B). Additionally, (<sup>40</sup>Ar/<sup>39</sup>Ar) thermochronology data records widespread exhumation of the Galwer Craton from ca. 1460–1415 (Reid and Forster, 2021), which is the same as the main timing of Belt Supergroup deposition. This strengthens interpretations of a Belt Supergroup–Gawler Craton connection similar to that proposed by Ross et al. (1992), Ross and Villeneuve (2003), Fanning et al. (2009) and Box et al. (2020), within a proto-SWEAT configured Nuna from at least ca. 1.5 to 1.4 Ga (Fig. 3.12B).

# 3.6.3. Provenance and age of the Deer Trail Group: A ca. 1.3–1.2 Ga sequence deposited after Nuna breakup but likely prior to Grenville-age tectonism

Upper Belt Supergroup strata (Missoula and Lemhi groups) are intruded by ca. 1370 Ma granites in east-central Idaho and lack detrital zircon grains younger than ca. 1380 Ma (Doughty and Chamberlain 2008; Stewart et al., 2010; Link et al., 2016). Thus, the  $1299 \pm 12$  Ma maximum depositional age for the basal Deer Trail Group falsifies initial correlations of the Deer Trail Group to Piegan and lower Missoula group strata of the Belt Supergroup (Miller and Whipple, 1989). Furthermore, the ca. 80 Myr gap between depositional age constraints on the ca. 1.38 Ga upper Belt Supergroup rocks and the younger basal Deer Trail Group is similar in age and duration to the enigmatic East Kootenay tectono-thermal event. This may suggest that the East Kootenay event separated (or spanned) these two basin-forming intervals. Grenvillian (ca. 1.2–1.0 Ga) detrital zircons are common in nearby Neoproterozoic

strata (e.g. Yonkee et al., 2014; Matthews et al., 2018; Box et al., 2020; Brennan et al., 2020; 2021a; 2021b) but are absent in the Deer Trail Group. Consequently, we suggest that deposition of the Deer Trail Group likely occurred prior to the ca. 1.1 Ga main collisional phase of Grenville orogeny in eastern/southeastern Laurentia (e.g. Tollo et al., 2004; Mulder et al., 2017). Alternatively, the Deer Trail Group could be a younger (<1.1 to 0.76 Ga) basin that was not fed by a Grenvillian-source but this is less likely given the relative abundance of Grenville-age detrical zircon grains in strata of this age.

The overall fine-grained siliciclastic and interbedded carbonate character of the Deer Trail Group stratigraphy is consistent with deposition in a shallow intracratonic basin or marine continental shelf depositional environment (Box et al., 2020). The prevalence of soft-sediment deformation may also signify slumping, perhaps influenced by seismically-induced slope instability (e.g. Bose et al., 2012; Pratt and Ponce, 2019; Pratt and Rule, 2021). The broad ca. 1.9–1.6 Ga and 1.45 Ga detrital zircon populations in the Deer Trail Group are similar in age to those found in the Missoula Group (and the correlative Lemhi Group) of the Belt Basin. However, the range of Lu–Hf values of the ca. 1.9–1.6 Ga detrital zircon grains within the Deer Trail Group are a poor match for any single basement source (Fig. 3.8). Consequently, to satisfy the range of ages and Lu–Hf values of the ca. 1.9 to 1.6 Ga zircon grains from Deer Trail Group strata, a mixed provenance from the Medicine Hat Block, Mojave province, and/or recycling from ca. 1.7 Ga Gold Cup/Neihart or ca. 1.4 Ga Lemhi Group strata is required (Figs. 3.8 and 3.12C).

The ca. 1.5–1.3 Ga grains within the Deer Trail Group samples contain  $\varepsilon$ Hf<sub>t</sub> values mostly between 0 to +12, with a few grains containing evolved ( $-\varepsilon$ Hf<sub>t</sub>) values. The ca. 1.5–1.3 Ga Laurentian midcontinent granite–rhyolite province in southwestern Laurentia contains sources of similar ages with mostly juvenile  $\varepsilon$ Hf<sub>t</sub> values, consistent with crustal melts sourced from the late Paleoproterozoic juvenile Yavapai–Mazatzal–Mojave provinces they intrude (Bickford et al., 2015). Generally, the most evolved ca 1.45 Ga midcontinent granites intrude along the southeastern edge of the Superior province, in the midcontinent region (Bickford et al., 2015). However, the few detrital zircon grains with particularly evolved  $\varepsilon$ Hf<sub>t</sub> values (below –5) within the Deer Trail Group, despite still being within our discordance filter, show a higher level of discordance (generally >5% discordant), suggesting these grains may not provide robust provenance constraints. Consequently, the Deer Trail Group detrital zircon

components may indicate a mixed distal Laurentian and proximal recycled provenance. Notably, *syn*-depositional magmatism is limited or absent within the Deer Trail Group, and the fine-grained nature of these strata likely precludes significant proximal uplift.



Fig. 3.12. Proposed sedimentary transfer systems (indicated by arrows) to the Priest River region during the A) early assembly, B) tenure, and C) breakup of Nuna with global paleogeographic reconstruction cartoons adopted from Kirscher et al. (2020). At ca. 1.7 Ga (A) during deposition of the Gold Cup Quartzite, and likely coeval Neihart Quartzite, Quartzite of Argenta, and perhaps Fort Steele Formation, proximal Paleoproterozoic suture zones (Great Falls Tectonic Zone; Vulcan Zone, Rimbey Arc) likely supplied sediment into a basin(s) that likely extended across most of the Medicine Hat-Clearwater Block. Abbreviations: A-Ouartzite of Argenta, N-Neihart Quartzite, G-Gold Cup Quartzite, S-Fort Steele Formation. (B) At ca. 1.45 Ga during deposition of Belt Supergroup strata. Belt Supergroup strata in the Priest River region are characterized by NAMG detrital zircon populations consistent with sources from Australia-Antarctica, notably the Gawler craton. Belt strata along the eastern and southern extent of the basin, generally lack NAMG zircon grains, and contain ages reflecting southwestern Laurentia (SWL; e.g. Ross and Villeneuve, 2003; Ronemus et al., 2020) or perhaps E. Antarctica sources (Stewart et al., 2010; Link et al., 2016). (C) At ca 1.3 Ga during deposition of Deer Trail Group strata. These rocks generally indicate a mixed Laurentian provenance, and are consistent with depositional during the final interval of the ca. 1.38-1.30 Ga East Kootenay tectono-thermal event. We propose the East Kootenay orogeny recognized in this region, is consistent with Doughty and Chamberlain's (2008) model of renewed rifting, and subsidence in the Priest River area. This event likely resulted in the end of Belt Supergroup deposition and shortly preceded deposition of the Deer Trail Group coeval with the proposed timing of widespread Nuna breakup (Pisarevsky et al., 2014a,b; Kirscher et al., 2020).

At first order, these stratigraphic observations are less consistent with collisional models for the ca. 1.38–1.30 Ga East Kootenay "orogeny" (McFarlane and Corfu, 2015; McMechan and Price, 1982). Instead, these stratigraphic constraints are more consistent with the East Kootenay "orogeny" as a period of basin rifting and renewed subsidence that marked the end of deposition within the Belt Basin (Doughty and Chamberlain, 2008). We suggest this event shortly preceded deposition of the Deer Trail Group coeval and was coeval with the proposed timing of widespread Nuna breakup at ca. 1.3 Ga (Pisarevsky et al., 2014b; Kirscher et al., 2020). If correct, this implies a late-rift to passive margin setting for deposition of the Deer Trail Group. However, given the relatively limited minimum depositional age-constraints, this is currently speculative. It is unclear how extensive the Deer Trail sequence may have been, although vestiges of its original extent may be present in central Idaho (Isakson, 2017; the "?" basin in Fig. 3.12C).

### 3.6.4. Smaller block within "proto-SWEAT" reconstructions

Various smaller crustal blocks, notably Hainan Island (with or without the entire Cathaysia Block; Li et al., 1995; 2008a; b; Xu et al., 2019; Yao et al., 2017) and Tasmania (Halpin et al., 2014; Mulder et al., 2015) are suggested to have occupied the region between western Laurentia and East Antarctica/Australia in a proto-SWEAT configured Nuna. The "Missing-Link" model proposes that the Cathaysia Block of South China was an extension of western Laurentia from ca. 1.8 Ga until Rodinia breakup (Li et al., 1995; 2008a). In particular, this model suggests that ca. 1.4 Ga juvenile granites on Hainan Island (Li et al., 2008b; Yao et al., 2017) represent a continuation of the A-type granitic province of southwestern Laurentia (e.g. Bickford et al., 2015). Additionally, the Baoban Complex metasedimentary rocks (including the generally coeval Shilu Group) that also contain NAMG-age detrital zircon agecomponents (Xu et al., 2019; Yao et al., 2017) are suggested correlatives to Belt Supergroup strata of western Laurentia. However, the Proterozoic configuration of South China, including whether Hainan Island was separate from or part of the Cathaysia or proto-Yangtze Block prior to the mid-Paleozoic is debated (c.f. Yao et al., 2017; Cawood et al., 2020; Liu et al., 2020; Xu et al., 2019). Consequently, Hainan Island may not be a reliable constraint for the location of the larger South China blocks.

On Hainan Island, the ca. 1.4 Ga paragneiss (the Gezhencun "succession") of the Baoban complex contains ca. 1.9-1.4 Ga detrital zircon grains, including some ca. 1.6-1.5 Ga NAMG grains. Based on limited Lu–Hf data (n = 21; Xu et al., 2019), these

ca. 1.9–1.5 Ga detrital zircon grains show  $\varepsilon$ Hf<sub>t</sub> values less than +5 (Fig. 3.13A). Consequently, the juvenile ( $\varepsilon$ Hf<sub>t</sub> = +5 or greater) ca. 1.9 to 1.5 Ga grains that comprise approximately 50% of the total detrital zircon cargo in Belt Supergroup strata within the Priest River region are not recognized in coeval rocks on Hainan Island (Yao et al., 2017).

The identification of NAMG-age detrital zircon components in the lowermiddle Rocky Cape Group of Tasmania led Halpin et al. (2014) and Mulder et al. (2015) to correlate the lower-middle Rocky Cape Group of Tasmania to the Belt Supergroup and Deer Trail Group of Laurentia. This interpretation has Tasmania located central position between western Laurentia in a and East Antarctica/southeastern Australia within Nuna (Halpin et al., 2014; Mulder et al., 2015). The juvenile ( $\varepsilon$ Hft = +5 or greater) ca. 1.8 to 1.5 Ga grains that characterize Belt Supergroup strata in the Priest River region, and coeval strata in southwestern Laurentia (Doe et al., 2013) are present within the lower Rocky Cape Group (Fig. 3.13; Mulder et al., 2015), consistent with similar proposed Gawler Craton-East Antarctica (Mawson continent) sources. Consequently, Tasmania's proposed location adjacent to southwestern/western Laurentia (e.g. Halpin et al., 2014; Mulder et al., 2015; Fig. 3.1) at ca. 1.5 Ga is consistent with existing provenance constraints.

Statistical analysis of the detrital zircon (U–Pb/Lu–Hf) data from these ca. 1.45 Ga basins in Laurentia, Tasmania, Hainan Island and their proposed Gawler Craton source (Fig. 3.13B) allows objective evaluation of these proposed correlations. Overall, the statistical results indicate that the similarity of detrital zircon components in the Belt Basin and coeval southwestern Laurentian basins (Trampas, Yankee Joe-Blackjack basins) is the strongest as they consistently yield the greatest (closest to 1) comparison values (Fig. 3.13B). Thus, it is probable that the ca. 1.45 Ga Yankee-Joe Defiance Basin (Doe et al., 2013) in southwestern Laurentia and the Belt Basin, ~1500 km to the north, received sediment from a similar (non-Laurentian) source. This source was likely the Gawler Craton of southeastern Australia, and perhaps associated rocks in East Antarctica (Jones et al., 2015).

The next strongest statistical resemblance to the Belt Supergroup detrital zircon dataset is coeval strata of the lower Rocky Cape Group in Tasmania (Mulder et al., 2015). Gawler Craton igneous sources also generally show statistical similarity values (to the Belt Supergroup detrital zircon dataset) that are comparable to the values given by the Tasmanian strata (Fig. 3.13B). Consequently, the new data from the Belt

Supergroup is consistent with prior interpretations that Tasmania occupied a central position between western Laurentia and East Antarctica/southeastern Australia within Nuna (Halpin et al., 2014; Mulder et al., 2015). Based on the relatively limited detrital zircon Lu/Hf available from the Gezhencun succession of Hainan Island (Xu et al., 2019), the weakest correlation is between Belt Supergroup strata and coeval strata on Hainan Island. This weak statistical correlation likely reflects to the absence of juvenile ( $\epsilon$ Hf<sub>t</sub> = +5 or greater) ca. 1.6–1.5 Ga detrital zircon grains in the Hainan Island strata which are present in the Laurentian and Tasmanian strata, and the Galwer Craton igneous sources. Consequently, prior assertions of the correlation between Belt Supergroup rocks and coeval rocks on Hainan Island (e.g. Xu et al., 2019; Yao et al., 2017) are the least justified.



**Fig. 3.13.** A) Detrital zircon U–Pb and Lu–Hf data from ca. 1.45 Ga strata from Hainan Island, South China (the Gzehencun succession, Xu et al., 2019), Western Tasmania (lower Rocky Cape Group; Mulder et al., 2015), southwestern Laurentia (the Blackjack Formation and Defiance Quartzite; Doe et al., 2013), and Belt Supergroup strata of the Priest River region (Prichard and Revett formations). B) Results of two-dimensional (Lu–Hf/U–Pb) statistical comparison (Sundell and Saylor, 2021) of the datasets above, with a value of 1 indicating the most similar and 0 indicating the least similar between Belt Supergroup strata of the Priest River region, and strata of southwestern Laurentia, Tasmania, Hainan Island, and igneous sources within the Gawler Craton. See Sundell and Saylor (2021) for further discussion of the Cross-correlation (C.-correlation), Likeness, and Similarity metrics.

### **3.7.** Conclusions

U–Pb and Lu–Hf detrital zircon provenance data from the (<1.73 Ga) Gold Cup Quartzite, (ca. 1.47–1.38 Ga) Belt Supergroup and overlying (<1.3 Ga) Deer Trail Group of the Priest River region (northern Idaho, and northeastern Washington state, USA) give insights into the regional tectonostratigraphy of western Laurentia, and yield important constraints on the assembly of western Laurentia and the evolution of supercontinent Nuna. Our major findings are the following:

1) The Gold Cup Quartzite, Neihart Quartzite, and the quartzite of Argenta show similar detrital zircon age spectra that suggests sourcing from proximal Neoarchean and Paleoproterozoic Laurentian basement. Such similarities, and the general absence of zircon grains younger than ca. 1.73 Ga within these units, suggest that assembly of the main Archean–Paleoproterozoic blocks of western Laurentia (Wyoming, Clearwater, Medicine Hat, Hearne, and Grouse Creek) was likely complete by ca. 1.73 Ga.

2) The Laurentian < 1.73–1.48 Ga, Gold Cup and Neihart quartzites do not have require non-Laurentian sources. Thereby, this data does not compel a proto-SWEAT configured Nuna by ca. 1.8 Ga as previously suggested (e.g. Rogers and Santosh, 2002; Zhao et al., 2002; Holland et al., 2018), and instead favors a protracted, perhaps two-stage assembly of Nuna from ca. 1.8 to 1.6 Ga (e.g. Kirscher et al., 2019).

3) Ca. 1.47 Ga strata in the western extent of the Belt Basin contain juvenile ca. 1610–1490 Ma "North American magmatic gap" zircon grains that lack a Laurentian source. The Gawler Craton contains igneous sources that span the required age and Lu–Hf compositions of these grains, and experienced active exhumation at ca. 1.47 Ga. Consequently, our new constraints are consistent with suggestions that southeastern Australia was a source of sediment for Belt Supergroup strata. This data supports proto-SWEAT reconstructions for Nuna that place the Gawler Craton of southeastern Australia adjacent to the Priest River region of Laurentia by at least ca. 1.47 Ga.

4) Deposition of the Deer Trail Group occurred after ca. 1.3 Ga, perhaps coeval with the end or latter part of the enigmatic East Kootenay tectono-magmatic event. The ages and range of Lu–Hf values recorded by the main detrital zircon components within the Deer Trail Group suggest a mixed provenance from several Laurentian sources, including the Mojave Province, Trans-Hudson Orogen, and perhaps the

Medicine Hat Block. Many of these grains could have been recycled from nearby older strata, such as the Lemhi Group of the Belt Basin. The fine-grained siliciclastic and carbonate lithology and the lack of significant *syn*-depositional magmatic detrital zircon components in Deer Trail Group strata are consistent with their deposition during a period of regional subsidence within the Priest River region that coincides with purported Nuna breakup at ca. 1.3 Ga (Kirscher et al., 2020).

Collectively, these new provenance constraints are most consistent with paleogeographic models that advocate widespread assembly of the main Archean blocks of western Laurentia from ca. 1.9 to 1.7 Ga, and indicate that the Priest River region does not record sedimentation from non-Laurentian source terranes until after ca. 1.5 Ga. Consequently, the Paleo–Mesoproterozoic tectonostratigraphic record of the Priest River region is consistent with models that indicate the main assembly of western Laurentia was a precursor to, and not necessarily synchronous with, the final assembly of a proto-SWEAT configured Nuna supercontinent.

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# Chapter 4: Grenville-age metamorphism within the Belt Basin of western Laurentia

# Abstract

The presence or absence of ca. 1100-1000 Ma "Grenville-age" tectonism in western Laurentia is long debated and has significant implications for the assembly of supercontinent Rodinia. Recently, identification of ca. 1350-1020 Ma garnet-grade metamorphism within the Clearwater complex of the Belt Basin has renewed this debate. However, the tectonic implication of such cryptic metamorphic records is uncertain due to regional structural and thermal overprinting by younger Cordilleran processes. Here, we present new monazite and apatite U-Pb results from metapelites within the western region of the Clearwater complex. Although monazite ages overlap with existing garnet ages, some apatite records ca. 680 Ma ages associated with nearby rift-related magmatic rocks that formed during Rodinia breakup and indicate that locally Cordilleran conditions did not exceed ~450–550°C in the western Clearwater complex. Consequently, the mineral assemblages within these rocks most likely reflect the peak metamorphic event recorded by the youngest ca. 1100-1020 Ma garnet Lu-Hf and monazite U–Pb ages. Thermodynamic modeling of these assemblages indicates P/T conditions of 5–7.5 Kbar and 620–670°C, suggesting burial depths of at least ~17– 22 km along a moderately-high average geothermal gradient of ~23–36°C/km. These ca. 1100-1020 Ma metamorphic conditions are difficult to satisfy with thermal upwelling/heating within the Belt Basin alone, and thus advocate for western tectonism and localized Grenville-age structural inversion and crustal thickening within the Belt Basin, likely along inherited structures. Consequently, global geologic models should account for ca. 1100-1020 Ma Grenville-age tectonism in continental blocks adjacent to the western margin of Laurentia within supercontinent Rodinia.

### 4.1. Introduction

The Mesoproterozoic Era (1600–1000 Ma) records the transition from Earth's first supercontinent Nuna (also called Columbia; ca. 1600–1300 Ma) to its successor, Rodinia (ca. 1100–800 Ma; e.g. Li et al., 2019). However, researchers have suggested that the global transition from Nuna to Rodinia may have significant geodynamic differences from the previous assembly of Nuna, and the ensuing Rodinia to Pangea supercontinent transition. Notably, the geologic record suggests evidence for a different style of plate tectonics associated with systemically higher thermobaric (temperature/pressure; T/P) conditions during metamorphism (Brown et al., 2020), a warmer upper mantle and the presence of hot, low and thin "Grenville-age" mountain belts (Spencer et al., 2021; Zhu et al., 2022), and/or the closure of "young" interior oceans, rather than older exterior oceans during this supercontinent transition (e.g. Li et al., 2019). Consequently, the Nuna to Rodinia supercontinent cycle is considered to be a perplexing geological time interval dubbed the "Boring Billion" (Cawood and Hawkesworth, 2014; Sobolev and Brown, 2019).

The ca. 1480–1380 Ma Belt Supergroup outcrops along the western margin of Laurentia and represents one of the largest Mesoproterozoic sedimentary sequences in the world, containing an immense thickness of strata (>15 km), covering >200,000 km<sup>2</sup> (Lonn et al., 2020). The monotonous lithology of Belt Supergroup stratigraphy records its deposition in an intracratonic rift basin near the center of the Nuna supercontinent landmass (Winston and Link, 1993; Box et al., 2020). Enigmatically, after deposition, despite paleogeographic models calling for globally widespread tectonism associated with the subsequent breakup of Nuna and assembly of Rodinia, most Belt Supergroup strata remained largely undisturbed for the next 1 billion years until the late Mesozoic Cordilleran (Sevier/Laramide) orogeny. Consequently, the general ca. 1300–900 Ma tectonic quiescence in this region, notably the absence of ca. 1100–1000 Ma Grenville-age tectonism, may indeed lend credence to the assertion that the Nuna to Rodinia transition was "boring", at least in this region.

Then again, isotopic studies along the western portion of the Belt Basin, particularly within strata recently buried deep within Cordilleran metamorphic core complexes (notably the Matthew Creek metamorphic zone and associated Priest River metamorphic complex, the Clearwater metamorphic core complex and the Bitteroot metamorphic core complex) have revealed a growing body of evidence for tectonism within this interval. This evidence includes indications of ca. 1115–1065 Ma Grenville-age metamorphism (e.g. Doughty and Chamberlain, 2008; Zirakparvar et al., 2010; Nesheim et al., 2012; Slack et al., 2020) that has notable implication for conflicting collisional (e.g. Li et al., 1995; 2013; Yao et al., 2017), transpressional (e.g. Merdith et al., 2020; Mulder et al., 2018) and/or apparently tectonically quiescent (e.g. Eyster et al., 2018) models of Rodinia assembly along western Laurentia (Fig. 4.1). However, interpretations of the importance of the Grenville-age isotopic ages within the Belt Basin, and consequently evaluation of proposed global geodynamic models are often in disagreement. Reaching a consensus on their importance is likely hampered by difficulties in separating the younger, Cordilleran record of metamorphism from the older, Grenville-age record. Some workers interpret the Grenville-age metamorphism to simply reflect static magmatic heating at depth (e.g. Doughty and Chamberlain, 2008; Slack et al., 2020), while others have suggested that the ages require tectonic thickening (Zirakparvar et al., 2010; Neishem et al., 2012).



**Fig. 4.1:** Leading models with differing for Rodinia configurations and assembly mechanism. These models include: Missing-Link collisional (Li et al., 1995; 2013; Yao et al., 2017), SWEATlike (Southwest U.S.–East Antarctica; Moores, 1991) transpressional (e.g. Mulder et al., 2018; Merdith et al., 2020) and/or apparently AUSWUS-like (Australia–Southwestern U.S.; Karlstrom et al., 1999) tectonically quiescent (e.g. Eyster et al., 2018) mechanism of Rodinia assembly along western Laurentia. Abbreviations include: Am, Amazonia; Au, Australian cratons including Antarctic Mawsonland; Ba, Baltica; Co, Congo; In, India; Ka, Kalahari; Laur, Laurentia; NC, North China; RP, Rio Plata; SC, South China; SF, Sao Francisco; Sib, Siberia; Ta, Tarim; WAf, West African craton.

Here, we present new laser-ablation inductively coupled mass spectroscopy (LA–ICPMS) monazite and apatite U–Pb geochronology, electron probe microanalysis (EPMA) of mineral compositions and phase equilibrium P–T modeling of metapelitic strata from the Clearwater complex. These rocks contain a record of ca. 1350–1000 Ma garnet growth under unknown conditions (Zirakparvar et al., 2010; Neishem et al., 2012), which is variably overprinted by younger ca. 130–55 Ma

Cordilleran metamorphism that reaches as high as lower granulite facies (Doughty et al., 2007). Collectively, our results were able to constrain a portion of the complex that was not buried deeply within the Cordilleran orogeny and thus preserves a critical record of amphibolite-grade Grenville-age metamorphism in this region. These results reveal important insights into the Nuna to Rodinia transition in western Laurentia, and provide additional constraints on evaluating global tectonic and metamorphic processes during the late Mesoproterozoic.

### 4.2. Geologic Overview

The North American Cordillera is a sinuous mountain belt that runs for ~6500 km along the western edge of Laurentia, from Alaska to Mexico. The orogen records prolonged subduction of oceanic lithosphere beneath western North America since the early Mesozoic. Along most of the Cordillera, Late Cretaceous to Paleogene overthickening of the orogenic wedge and/or changing subduction boundary conditions (e.g. flat slab subduction) resulted in the formation of metamorphic core complexes (Dickinson, 2004; Fig. 4.3). These core complexes expose rocks formerly buried deep within the hinterland of the Cordilleran orogen due to late Mesozoic or younger crustal thickening (e.g. Wernicke, 1981; Stevens et al., 2015; Howlett et al., 2021). Although the Cordillera is an archetypal natural laboratory to study modern orogenic processes, overprinting by Cordilleran processes commonly obscures the record of older events along the western margin of Laurentia. Unfortunately, the western margin of Laurentia occupies a critical, central, position along which most models advocate the final assembly of Proterozoic supercontinents Nuna and Rodinia occurred. As a result, difficulty in deciphering the regional pre-Cordilleran record of western Laurentia has made evaluation of conflicting global models challenging.

Following a tectonic lull during the ca. 1610–1490 Ma North American Magmatic Gap associated with final Nuna assembly (Ross and Villenavue, 2001; Brennan et al., 2022), juvenile terranes and arcs were accreted along most of the southern margin of Laurentia from ca. 1480–1350 Ma. Accretion was associated with widespread bimodal 'A-type' granite and anorthosite magmatism within the Granite-Rhyolite province (e.g. Bickford et al., 2015; Fig. 4.2). In southwestern Laurentia, magmatism was contemporaneous with the ca. 1460–1400 Ma Picuris orogeny (Karlstrom et al., 2001; Daniel et al., 2013) then, from ca. 1380–1320 Ma, development of an extensive backarc system (Mulder et al., 2017).



Fig. 4.2: Simplified geologic map of Laurentia (adapted from Greenman et al., 2021) indicating the relevant ca. 1480-1080 Ma geologic provinces including the ca. 1480-1380 Ma Belt basin, ca. 1480-1320 Ma Granite Rhyolite province, ca. 1380-1330 Ma Hart and Salmon River Large Igneous Provinces (LIP), ca. 1270 Mackenzie LIP and the ca. 1100-1080 Midcontinent Rift/LIP, Pikes Peak Batholith, Southwestern Laurentian LIP (SWLLIP), and Arctic Bylot Basins. The extent of the North American Cordillera shown in Fig. 4.3 is indicated.

The ca. 1470–1380 Ma Belt Basin is an extensive intracratonic basin that formed within the supercontinent Nuna, concurrent with the aforementioned more widespread tectonomagmatic activity in southern Laurentia, and contains over 15 km thick of shallow water and subaerially deposited strata, that record intermittent, localized syndepositional magmatism (Lonn et al., 2020 and references within). Following Belt Basin deposition, continental-arc magmatism occurred in southern Laurentia from ca. 1250–1230 Ma due to continued subduction beneath the southern margin of Laurentia that predated onset of the main episode of Grenvillian orogenesis.

Grenville-aged tectonism in southern Laurentia peaked at ca. 1140–1100 Ma (Mulder et al., 2017), broadly coeval with slab break-off and/or delamination beneath southern Laurentia (Mosher et al., 2008). Subsequent impingement of a mantle plume beneath the Laurentian midcontinent resulted in formation of the ~3000-km long Midcontinent Rift (Cannon and Hinze, 1992; Stein et al., 2015) and emplacement of ca. 1094–1080 Ma diabase dykes of the Southwestern Laurentian large igneous province (SWLLIP) (Bright et al., 2014). The record of magmatism at ca. 1080 Ma extends as far northwest as central Colorado, where the ca. 1115–1065 Ma Pikes Peak batholith intruded along crustal sutures within the Yavapai province, and likely records lithospheric delamination and/or plume activity (Guitreau et al., 2016). In northern Laurentia, intracratonic basins (the Bylot basins) developed from ca. 1090 Ma to 1050

Ma (Fig. 4.2; Gibson et al., 2019; Rainbird et al., 2020; Greenman et al., 2021). Collectively, the data are consistent with a widespread episode of thermal upwelling and localized extension across Laurentia around ca. 1120–1050 Ma, in a period otherwise dominated by Grenvillian orogenesis associated with assembly of Rodinia. Grenville-age (ca. 1300–1000 Ma) orogens are recognized on many continental blocks (such as Laurentia, South China, Australia, Kalahari and Baltica) and have long been known to reflect the widespread assembly of supercontinent Rodinia (e.g. Moores, 1991; Li et al., 2008; Mulder et al., 2017; Johansson et al., 2022).

The Clearwater complex is the central of three main core complexes that occur along the western edge of the Belt Basin, including the Priest River complex and associated Matthew Creek metamorphic zone ~150 km to the north, and the Bitterroot complex ~150 km to the southeast (Fig. 4.3). These complexes all record an enigmatic record of ca. 1400–1000 Ma tectonism, which is variably overprinted by younger Cordilleran processes, but is generally attributed to two main events. These two events consist of an older ca. 1380–1300 Ma East Kootenay "Orogeny" (McMechan and Price, 1982) and a younger poorly understood ca. 1115–1060 Ma Grenville-age event (e.g. Neishem et al., 2012).

The ca. 1380-1300 Ma East Kootenay tectono-magmatic event was contemporaneous with the final stages of tectonism and magmatism within the Granite-Rhyolite province in southern Laurentia, and largely records high-T, low-P regional metamorphism (McFarlane and Pattison, 2000; McFarlane, 2015) and bimodal magmatism within the Salmon River sills and associated Elk City Domain within the Belt Basin (Doughty and Chamberlain, 1996, 2008; Gaschnig et al., 2013). Consequently, the East Kootenay tectono-magmatic event has been interpreted as a period of either orogenic collapse (McMechan and Price, 1982; McFarlane, 2015) or volcanism and renewed subsidence near the end of deposition of the Belt Supergroup (Doughty and Chamberlain, 2010; McFarlane and Pattison, 2000; Pattison and Seitz, 2012). Some 1000 km further north, Verbaas et al., (2018) correlate the ca. 1380 Ma Hart River sills with the Salmon River sills, and suggests that the bimodal magmatic provinces may record rifting in western Laurentia. Ernst et al., (2008) considers the Hart River and Salmon River sills to comprise a single large igneous province (LIP) that may record rifting of Nuna. Recently, an  $\geq 2.5$  km thick package of fine-grained and carbonate rocks (the Deer Trail Group) has been shown to be younger than ca. 1300 and may record deposition during the final stages of this East Kootenay tectonomagmatic event (Box et al., 2020; Brennan et al., 2021b). Remnants of Deer Trail Group strata are likely present elsewhere along the western edge of the Belt Basin (Pearson and Link, 2021), suggesting that a substantial thickness of sedimentary rocks may have been removed from atop the Belt Basin prior to Rodinian rifting after ca. 760 Ma (Brennan et al., 2021a).



The younger event is often attributed to ca. 1115–1060 Ma, Grenville-age, tectonothermal activity. This Grenville-age metamorphism has been suggested to simply reflect static magmatic heating at depth, perhaps suggesting a relation to coeval, deep (possibly plume related) magmatism within the Midcontinent Rift, and Southwest Laurentian Large Igneous Province (e.g. Doughty and Chamberlain, 2008; Slack et al., 2020). However, no magmatism of this age has been directly identified within the Belt Basin, while it is relatively widespread in these other coeval provinces. Others have

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instead suggested that the ca. 1100 Ma ages instead require tectonic thickening (Zirakparvar et al., 2010; Neishem et al., 2012), similar to the peak of Grenville orogenic burial in southern Laurentia at ca. 1140–1100 Ma (Mulder et al., 2017). Recently, the only suspected ca. 1100 Ma strata in this region, the Buffalo Hump Formation (e.g. Ross et al., 1992), was shown to contain ca. 760 Ma detrital zircon grains. These ages indicate that the Buffalo Hump Formation was actually deposited during Rodinia breakup, not assembly (Brennan et al., 2021a). Consequently, no magmatism or stratigraphy associated with this Grenville-age event within the Belt Basin is identified.

Most Belt Supergroup strata east of the Priest River, Clearwater and Bitterroot complexes record greenschist or lower-grade metamorphism and thus have not been examined by metamorphic studies. However, the enigmatic spread of ca. 1400–1000 Ma ages variably overprinted by younger ca. 130–50 Ma metamorphism recorded within the amphibolite-grade metamorphic assemblages of the within the Priest River, Clearwater and Bitterroot complexes have been investigated. In the Priest River and Bitteroot complexes, metamorphism has mostly been interpreted to relate to late Mesozoic and younger Cordilleran events, consistent with monazite U–Pb ages (Stevens et al., 2015; Aleinikoff et al., 2012). However, structures related to deposition of the Belt Supergroup and ca. 1380–1060 Ma U–Pb cassiterite (SnO2 ore; Slack, 2020), monazite (McFarlane, 2015) and xenotime (Aleinikoff et al., 2012) ages are known to occur.

Within the Priest River complex, Mesoproterozoic lower Belt Supergroup metapelitic rocks record peak metamorphic conditions of ~785–790 °C and ~9.6–10.3 kbar (constrained by phase equilibria modelling) between ca. 74 and 54 Ma as recorded by U–Pb monazite ages (Stevens et al., 2015). However, approximately 100 km north of the Priest River complex, in a similar structural position within the Cordilleran orogenic belt, lower Belt Supergroup strata in the Matthew Creek metamorphic zone (Fig. 3) are intruded by  $1365 \pm 5$  and  $1335 \pm 5$  Ma peraluminous granites and have an older, pre-Cordilleran metamorphic record. Lower Belt Supergroup metapelites in the Matthew Creek metamorphic zone contain layer-parallel foliation fabrics and peak metamorphic conditions of ~580–650 °C and ~3.5 kbar (also constrained by phase equilibria modelling) that occurred from ca. 1365–1335 Ma, as recorded by U–Pb monazite ages (McFarlane and Pattison, 2000; McFarlane, 2015). Some 10 km to the northeast, ca. 1468 Ma casserite hosted within metapelitic rocks of the lower Belt

Supergroup records thermal events (of unknown P/T conditions) at ca. 1380 and 1075 Ma (Slack, 2020).

Along the southern region of the Belt Basin, the Bitteroot complex records peak metamorphic conditions of ~700–750 °C and ~7–8 kbar (based on early garnet and amphibole composition thermobarometry methods; House et al., 1997) between ca. 64 and 56 Ma (Aleinikoff et al., 2012; Howlett et al., 2021). Monazite from Mesoproterozoic rocks in the Bitteroot complex generally record Cretaceous (ca. 110–92 Ma) U–Pb ages that are similar in age to the intrusion of nearby granites from the Idaho Batholith (Aleinikoff et al., 2012; Bookstrom et al., 2016). However, rocks in the Bitteroot complex also record evidence for pre-Cordilleran metamorphism, particularly within the Blackbird mineralized district that contains ca. 1370 Ma bimodal magmatism, ca. 1370–1320 Ma U–Pb xenotime ages, and ca. 1060 Ma hydrothermal xenotime ages (Aleinikoff et al., 2012). Mesoproterozoic metamorphism in this region is estimated to require pressures of 4–6 kbar (based on garnet thermobarometry methods) equating to ~14–20 km of burial (Doughty and Chamberlain, 2010; Bookstrom et al., 2016).

The Clearwater complex (Fig. 4.4) also records peak metamorphic conditions of ~700–750 °C and pressures as high as ~9 kbar (based on garnet thermobarometry methods) between ca. 82 and 64 Ma constrained by U–Pb ages of metamorphic zircon rims (Doughty et al., 2007). Doughty et al. (2007) only looked at the internal zone of the complex, which was likely buried the deepest in the Cordilleran orogeny, and suggests that the Clearwater complex experienced similar Cordilleran metamorphism as the previously described complexes to the north and south. However, early workers (Lang and Rice, 1985) recognized that metamorphism within the internal zone overprinted an early regional metamorphic event that is better preserved in the external (marginal) zones of the complex (Fig. 4.4; Doughty et al., 2007; Baldwin et al., 2016). Subsequent Lu–Hf garnet geochronology on metapelitic rocks primarily within these external zones revealed an enigmatic spread of ca. 1400–1000 Ma ages (Zirakparvar et al., 2010; Neishem et al., 2012) with no record of late Mesozoic to early Paleogene metamorphism (Doughty et al., 2007). These results suggest that the external zone of the Clearwater complex may contain a better preserved record of these Mesoproterozoic metamorphic events than amphibolite-grade regions to the north (Priest River complex and Matthew Creek metamorphic zone) or south (Bitterroot complex and Blackbird district).



**Fig 4.4:** Geologic map of the Clearwater complex (modified from Lewis et al., 2012), including the published ca. 1350–1020 Ma garnet Lu–Hf ages in this region (Zirakparvar et al., 2010; Neishem et al., 2012), and the location of our samples along the western external region of the complex (49, 50, 51DTB19), center (52DTB19), and eastern external region (59DTB19). Schematic core complex cross section cartoon (A–A') after Doughty et al., (2007).

## 4.3. Methods

### 4.3.1 Mineralogy

From selected rock billets, Wagner Petrographic cut and polished (30 μm thick) thin sections for petrographic investigation. The thin sections were investigated using standard transmitted light microscopy and TESCAN integrated mineral analyzer (TIMA) at the John de Laeter Centre at Curtin University, Perth Australia. TIMA mapping of polished thin sections provided detailed X-ray and back-scattered electron (BSE) maps for mineralogical characterization, including quantification of mineral modes and the identification of accessory phases for subsequent dating. TIMA analyses used a 15mm working distance, a 2500eV beam intensity and a spot size of 50-μm. Full thin section photomicrographs were taken with a Zeiss Axio Imager 2 imaging system. A JEOL 8530F electron probe microanalyser (EPMA) at the Centre for Microscopy, Characterization and Analysis, University of Western Australia was
used to measure semi-quantitative garnet mineral compositions. EPMA parameters included a 15kV accelerating voltage, 20 nA beam current, 100-ms dwell time and utilized natural and synthetic standards. Garnet formula were calculated stoichiometrically based on 12 oxygen following Droop (1987).

#### 4.3.2 Phase equilibrium modelling

Material from the same hand sample as used for the thin sections was analyzed for bulk rock geochemistry by the Bureau Veritas Laboratory, in Perth, Western Australia using X-Ray Fluorescence (XRF). Isochemical P-T phase diagrams (pseudosections) were generated for the major element oxide compositions using THERMOCALC 3.50 (Holland and Powell, 2011) and the activity–composition models of White et al., (2014a, 2014b) within the MnO–Na<sub>2</sub>O–CaO–K<sub>2</sub>O–FeO–MgO– Al<sub>2</sub>O<sub>3</sub>–SiO<sub>2</sub>–H<sub>2</sub>O–TiO<sub>2</sub>–O (MnNCKFMASHTO) system. Calculations used an Fe<sup>3+</sup>/Fe<sup>2+</sup> ratio of 0.2 (Johnson et al., 2021).

#### 4.3.3 Laser-ablation mass spectroscopy

Monazite and apatite grains were targeted in-situ within the thin sections for measurement of U–Pb isotopes. During this analysis, material ablated by a Resonetics RESOlution SE 193nm laser incorporating a dual volume S155 sample cell was sent to an Agilent 8900 triple-quadrupole inductively coupled mass spectroscopy (LA-QQQ-ICPMS) which measured <sup>202</sup>Hg, <sup>204</sup>Pb (and <sup>204</sup>Hg), <sup>206</sup>Pb, <sup>207</sup>Pb, <sup>208</sup>Pb, <sup>232</sup>Th, and <sup>238</sup>U masses. All data was collected across two analytical sessions at the GeoHistory Facility in the John de Laeter Centre at Curtin University, Perth Australia. In Iolite 3.5, the monazite time-resolved mass spectra were reduced using the U\_Pb\_Geochronology4 data reduction scheme (Paton et al, 2011). Due to the presence of common-Pb bearing standards, apatite time-resolved mass spectra were reduced using VizualAge UcomPbine reduction scheme (Chew et al., 2014 and references within). The VizualAge\_UcomPbine reduction scheme applies a common-Pb correction to the primary standard before applying a drift correction to the unknowns; otherwise, no common (or non-radiogenic) Pb-correction was applied. Based on the long term-reproducibility of U-Pb standard analysis at the GeoHistory Facility an additional 2% error was propagated to individual analyses.

Due to the variable common-Pb content of apatite, the uncorrected U–Pb apatite data was plotted on Terra-Wasserburg Concordia diagrams ( $^{207}$ Pb/ $^{206}$ Pb vs.  $^{238}$ U/ $^{206}$ Pb), and the apatite age was calculated as the lower Concordia intercept age of a free-regression Discordia line, with the common Pb-component represented by the

y-intercept on the <sup>207</sup>Pb/<sup>206</sup>Pb axis (Chew et al., 2011; Kirkland et al., 2018). This approach assumes that the U–Pb data are concordant and equivalent. To a lesser degree, monazite can also sometimes include a component of common Pb. Where a common-Pb component was apparent within some monazite analyses, a similar approach was employed which is covered further in the discussion. All data was calculated and plotted using IsoplotR (Vermeesch, 2018).

For monazite U–Pb analysis, monazite grains were targeted with a 10  $\mu$ m laser spot. Monazite 44069 was utilized as the primary standard and gave a weighted mean age of 424.1 ± 4.6 Ma (mean square weighted deviation or MSWD = 0.02) which is the same as the accepted value (424.9 ± 0.4 Ma; Aleinikoff et al., 2006). Analysis of secondary reference standards, Manangotry (558 ± 3 Ma; Horstwood et al., 2003) and Stern (511.7 ± 1.2 Ma; Palin et al., 2013) gave weighted mean ages (562.4 ± 7.6, MSWD = 0.3; 509.9 ± 5.42, MSWD = 0.38) within uncertainty of accepted values. Only monazite U–Pb analyses that overlap Concordia within 2 $\sigma$  uncertainties are defined as concordant (e.g. Spencer et al., 2016).

Apatite U–Pb analyses used a 30  $\mu$ m laser spot and data were calibrated against the Madagascar apatite standard, which gave a weighted <sup>238</sup>U/<sup>206</sup>Pb mean age of 472.8 ± 5.1 Ma (MSWD = 0.06) which is the same as the published value (474.25 ± 0.85; Thomson et al., 2012). Secondary reference standards Forest Center–FC (1094 ± 34; Thomson et al., 2012) and McClure Mountain–MMC (523.5 ± 1.47 Ma; Schoene and Bowring, 2006), when treated as unknowns and allowed free regression on a discordia line in Tera-Wasserburg space yielded lower concordia intercept ages (1098.9 ± 34.2, MSWD = 0.39 and 522.8 ± 17.3, MSWD = 0.92, respectively), also consistent with published values.

#### 4.4. **Results**

#### 4.4.1 Field and petrographic observations

The metapelitic samples (49, 50, 51, and 59DTB19) were all collected from the Wallace Formation of the Belt Supergroup (Fig. 4.4; Lewis et al., 1999; 2001; 2005). To the north and east, where the Wallace Formation is only weakly metamorphosed, it consists mostly of fine sandstone and siltstone, commonly in graded couplets, with dolomite and carbonate intervals, and is overlain by at least 8 km of upper Belt Supergroup strata (Lonn et al., 2020). Approximately 250 km northeast of the study area within the Clearwater complex, a volcanic tuff from a similar stratigraphic position yielded a  $1454 \pm 9$  Ma age, and a stratigraphicallyhigher rhyolitic lava an age of  $1443 \pm 7$  Ma age (Evans et al., 2000), consistent with a ca. 1450 Ma depositional age for the protoliths of the metapelitic rocks discussed below.

#### Western extent of Clearwater Complex–Samples 49, 50, and 51DTB19

Sample 49DTB19 is a garnet–muscovite–staurolite–biotite– quartzofeldspathic schist with relict (4 to 20 mm thick) graded bedding (Fig. 4.5). This location was previously sampled (sample 05JV07) by Zirakparvar et al., (2010). They report a Lu–Hf garnet age of  $1064 \pm 10$  (MSWD = 4.5) from this locality. In our collected sample (49DTB19), a foliation is mostly defined by alignment of feldspar and micas and is mostly subparallel to bedding. Staurolite porphroblasts are up to 4 cm long and may be twinned. Garnet forms small (mostly <1 mm) porphyroblasts containing apparently randomly-oriented inclusions (primarily quartz) that are preferentially concentrated in the cores of grains. There is no observed deflection in (i.e. wrapping of) the foliation around garnet or staurolite porphroblasts (Fig. 4.5A, inset i, inset ii; Fig. 4.6A). Monazite and apatite are present within the matrix but neither occur as inclusions within garnet, and neither garnet, monazite or apatite are found as inclusions within staurolite.

Sample 50DTB19 is a staurolite–muscovite–garnet–biotite–sillimanite– quartzofeldspathic schist from the same location of sample 08HL-04 of Neishem et al., (2012), who report similar lithologies and Lu–Hf garnet dissolution ages of 1347  $\pm$  10 Ma (MSWD = 4.6; garnet cores) and 1102  $\pm$  43 Ma (MSWD = 42; garnet rim). Sillimanite comprises both large prismatic porphyroblasts (up to 30 mm long; Fig. 4.5B, inset i), and as fibrolite (Fig. 4.5B, inset ii). The foliation is defined primarily by matrix micas, and sillimanite porphyroblasts. In thin section, thin veinlets filled primarily with K-feldspar crosscut the prismatic sillimanite porphyroblasts (Fig. 4.6B). Small, euhedral to subhedral staurolite crystals are found along the margins of sillimanite (Fig. 4.6B). Garnet grains within 50DTB19 are mostly euhedral, up to 3 mm in diameter, and are clearly wrapped by the foliation, locally exhibiting evidence for dissolution and quartz strain shadows. Garnet grains generally show an inclusionrich (mostly quartz) core. Monazite grains occur within the matrix and as inclusions within garnet.

Sample 51DTB19 is a quartzofeldspathic muscovite–garnet–biotite– sillimanite schist. Sillimanite is present as small (up to 2 mm long) clusters of

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fibrolite that are preferentially alinged parallel a subtle foliation and are crosscut by K-feldspar (Fig. 4.6C). The mica- and quartz-defined foliation within this sample is less strongly developed and wraps large ( $\geq$ 5 mm in diameter) garnet porphyroblasts (Fig. 4.5Ci). This sample is from the same location as sample 05JV03 of Zirakparvar et al., (2010), who report similar lithologies and a Lu–Hf garnet dissolution age of 1018 ± 25 Ma (MSWD = 113). Based on the high MSWD of the Lu–Hf isochron including all five garnet fractions analysed, Zirakparvar et al., (2010) propose discrete Lu–Hf isochron model ages of 1024 ± 3 Ma (MSWD = 1.5) and 1081 ± 20 Ma (MSWD = 45) based on inclusion-richer and inclusion-poorer garnet fractions.

#### Core of Clearwater Complex–Sample 52DTB19

Sample 52DTB19 is a strongly-lineated mylonitic ilmenite- and apatitebearing garnet amphibolite from the central portion of the Clearwater complex. In thin-section, interstitial quartz is abundant, suggesting alternation by hydrothermal fluids (Fig. 4.5D), and consequently this sample was not utilized for thermodynamic modelling, but was previously analyzed for zircon U/Pb and O- isotopes (Brennan et al., 2022), which we supplement with new apatite U/Pb results in this study.

#### Eastern extent of Clearwater Complex-Sample 59DTB19

Sample 59DTB19 is a quartzofeldspathic monazite- and apatite-bearing muscovite–garnet–biotite schist, collected along the eastern extent of the complex. Although no garnet ages are reported from this specific outcrop, 10 to 22 km to the north, Neishem et al., (2012) reports Lu–Hf garnet ages that range from ca. 1315 to 1085 Ma (see Fig. 4.4). In this sample, the foliation is mostly defined by quartz, feldspar and micas. Garnet grains have inclusion-rich (mostly quartz) cores and exhibit dissolution textures. Garnet grains locally show core/rim geometries and exhibit development of strain shadows that are filled with biotite, muscovite, and quartz (Fig. 4.5E inset i and ii; Fig. 4.6DE). Monazite and apatite grains are present within the matrix. A couple of monazite grains are also present as inclusions within garnet.



**Fig. 4.5:** Representative thin section mineralogy (produced by TESCAN integrated mineral analyzer; TIMA) and important mineralogical relationship highlighted inset boxes (i) and (ii). Mineral abbreviations from Whitney and Evans (2010).



**Fig. 4.6:** Additional mineralogy of the metapelitic samples shown in plane polarized light microphotographs, and interpretative sketches. (A) Sample 49DTB19 garnet-muscovite-staurolite-biotite-quartzofeldspathic schist. (B) Sample 50DTB19 staurolite-muscovite-garnet-biotite-sillimanite-quartzofeldspathic schist, highlighting the two generations of sillimanite and their association, but non-cross cutting or inclusion, relationship with staurolite. (C) Sample 51DTB19 muscovite-garnet-biotite-sillimanite-quartzofeldspathic schist, showing the fibrolite sillimanite present, and large garnets. (D) Sample foliated monazite and apatite bearing muscovite-garnet-biotite-garnet-biotite-sillimanite and muscovite-rich region that is perhaps a pseudomorph of an earlier higher-grade assemblage. Mineral abbreviations from Whitney and Evans (2010).

#### 4.4.2 U–Pb Geochronology

Western extent of Clearwater Complex (samples 49, 50, and 51DTB19)

Monazite from the analyzed samples (Fig. 4.7A) yielded concordant U–Pb dates between ca. 1400 and 1060 Ma (Fig. 4.8). Apatite U–Pb results indicated younger dates, and generally fall into either a Cryogenian (ca. 676 Ma) or late Paleogene-early Eocene (ca. 58–54 Ma) population.

Monazite within sample 49DTB19 only occurs within the matrix. A free Discordia regression line fit through 15 analyses yields a  $1074 \pm 14$  (MSWD = 0.6) age, with a  $^{207}$ Pb/ $^{206}$ Pb common Pb upper intercept of ~0.9. Ten of the 15 analyses are concordant, and together yield a concordia age of  $1087 \pm 10$  (MSWD = 1.9). A free Discordia regression line fit through 38 analyses of matrix apatite in sample 49DTB19 (Fig. 4.7B) yields a lower intercept age of  $676 \pm 13$  Ma (MSWD = 2.8), and an upper  $^{207}$ Pb/ $^{206}$ Pb common Pb intercept of ~0.9 (Fig. 4.9). Zirakparvar et al.,

(2010) report a 1064  $\pm$  10 Ma (MSWD = 4.5) garnet Lu–Hf age for the same outcrop.



**Fig. 4.7** (A) Representative back-scattered electron (BSE) images of U–Pb analyzed monazite with concordant ages labelled. Note that samples 50DTB19 (shown) and 51DTB19 contained monazite grains as inclusions within garnet that yielded older ca. 1365–1320 Ma ages. Of the limited monazite grains present in 59DTB19, a single grain able to fit two analyses spots yielded both ca. 1321 and 1075 Ma ages. (B) Representative back-scattered electron (BSE) images of U–Pb apatite grains with individual analyses spots indicated that correspond to the "Spot ID" within the supplementary tables. Note individual Pb-corrected apatite grain ages were not calculated and consequently not labelled here.

In sample 50DTB19, monazite occurs both in the matrix and as inclusions within garnet. Five of six monazite grains analyzed as inclusions within garnet show concordant dates (Fig. 4.7A; 4.8) that yield a concordia age of  $1365 \pm 17$  Ma (MSWD = 0.1). Twenty-one analyses of matrix monazite yield 11 concordant dates ranging from  $1358 \pm 15$  to  $1060 \pm 14$  Ma (all individual spot ages reported as single spot concordia ages; Ludwig, 1998), the two youngest of which are  $1079 \pm 13$  and  $1060 \pm 14$  Ma. The two youngest concordant analyses, and the five youngest discordant grains with a common Pb anchor (of 0.9, e.g. Albarede and Martine, 1984) define a Discordia with an intercept age of  $1056 \pm 19$  Ma (Fig. 4.8). Sample 50DTB19 does not contain any apatite. Neishem et al., (2012) microdrilled (rim and core zones) garnets from this same sampled outcrop and found Lu–Hf ages of  $1347 \pm 10$  Ma (MWSD = 4.6; isochron from garnet cores) and  $1102 \pm 43$  Ma (MSWD = 42; isochron from garnet rims).

Sample 51DTB19 contains monazite within the matrix and as inclusions within garnet (Fig. 4.7A). Seven of nine monazite grains were analyzed as inclusions within garnet yielded concordant dates that range from  $1392 \pm 20$  to  $1269 \pm 19$  Ma, and collectively give a concordia age of  $1318 \pm 14$  Ma (MSWD = 0.3). A single inclusion monazite grain sufficiently large for two analytical spots yields different concordant ages ( $1392 \pm 20$  and  $1280 \pm 14$  Ma; Fig. 4.7). Twenty-six of 30 concordant matrix monazite grains yield dates that range from  $1379 \pm 21$  to  $1007 \pm 21$  17 Ma. The three youngest monazite analyses yield a weighted mean age of  $1021 \pm 20$  Ma (MSWD = 3.7; Fig. 4.8). For this location, Zirakparvar et al., (2010) reported a 1018 ± 25 Ma (MSWD = 113) Lu–Hf isochron age based on five garnet fractions (i.e. five fractions of a single garnet). Given the high MSWD, Zirakparvar et al., (2010) speculate their data may represent two stages of garnet growth at  $1081 \pm 20$  (MSWD = 45, three garnet fractions) and  $1024 \pm 3$  (MSWD = 1.4, two garnet fractions). Analyses of 32 matrix apatite grains (Fig. 4.7B) define a free Discordia regression with a lower intercept age of  $56 \pm 7$  Ma (MSWD = 22), and an upper  $^{207}$ Pb/ $^{206}$ Pb common Pb intercept of ~ 0.48 (Fig. 4.9). The high MSWD of the Discordia regression indicates complexity in the dataset, such as potentially multiple age-populations, which will be explored further in the discussion.

#### Core of Clearwater Complex (sample 52DTB19)

Sample 52DTB19 lacks monazite but contains abundant apatite (Fig. 4.7B). A free Discordia regression line fit through 91 apatite analyses yields a lower intercept age of  $54 \pm 2.7$  Ma (MSWD = 1.3), and an upper  $^{207}$ Pb/ $^{206}$ Pb common Pb intercept of ~ 0.50 (Fig. 4.9). Brennan et al., (2022) report zircon U–Pb and O-isotope data from this sample that indicate metamorphic/hydrothermal zircon growth at ca. 1396–1350 Ma.

#### Eastern extent of Clearwater Complex–Sample 59DTB19

Sample 59DTB19 contains rare, both garnet and matrix hosted, monazite (Fig. 4.7A). Six of eight concordant analyses give dates that fit into two agepopulations, one at around 1337 Ma and another at around 1119 Ma (Fig. 4.8A). A single grain sufficiently large for two spot analyses yields concordant ages of ca. 1321 and 1075 Ma. The older two concordant analyses give dates of  $1321 \pm 25$  and  $1346 \pm 19$  Ma, that together define a concordia age of  $1337 \pm 30$  Ma (MSWD = 1.2). The younger four concordant analyses dates range from  $1150 \pm 20$  to  $1075 \pm 17$  Ma, and give a concordia age of  $1119 \pm 18$  Ma (MSWD = 0.5; Fig. 4.8). A discordia through 80 analyses of matrix apatite (Fig. 4.7B) define a lower intercept age of  $58 \pm 9$  Ma (MSWD = 1.4), and an upper  $^{207}$ Pb/ $^{206}$ Pb common Pb intercept of ~ 0.8 (Fig. 4.9).



**Fig. 4.8:** Monazite U–Pb geochronology results from samples 49, 50, 51, and 59DTB19. Results are show in (A) Terra-Wasserburg plots, please note the legend for these plots beneath sample 59DTB19 and (B) Kernel Density Plots (plotted with a 25 Myr band and binwidth) which include the corresponding published garnet Lu–Hf dissolution ages (Zirakparvar et al., 2010; Neishem et al., 2012). Only analyses that overlap Concordia within  $2\sigma$  uncertainties are plotted. Monazite grains hosted along cracks within garnet are plotted here as matrix hosted but are indicated in Appendix D4.4.





**Fig. 4.9:** Apatite U–Pb geochronology results from samples 49, 51, 52, and 59DTB19 shown in Terra-Wasserburg plots. Apatite U–Pb ages are obtained using a Terra-Wasserburg lower concordia intercept based on a unique, non-anchored, upper (<sup>207</sup>Pb/<sup>206</sup>Pb) of a relevant non-radiogenic Pb regression line.

#### 4.4.3 Mineral Compositions and Phase Equilibrium Modelling

Pressure–temperature pseudosections for the four modelled samples are shown in Fig. 4.10, which the inferred peak assemblage fields are highlighted. For clarity, we show the stability of garnet (at P/T above the thick red line) and staurolite (at P/T above the thick yellow line).

#### Western extent of Clearwater Complex

The three samples collected along the western region of the Clearwater have similar major oxide bulk compositions and, consequently, similar calculated phase equilibria. None of the samples preserves evidence for partial melting, restricting peak metamorphic conditions to temperatures below the H<sub>2</sub>O-saturated solidus (< or << 680 °C; Fig. 4.10).

Sample 49DTB19 contains an interpreted peak assemblage of garnet– muscovite–staurolite–biotite–plagioclase–ilmenite (+quartz, and H2O), consistent with conditions of ~570–670 °C and 5.5–9.0 kbar. Garnet within this sample shows flat major element profiles with around 3 mol.% spessartine, 5 mol.% grossular (Ca<sub>3</sub>Al<sub>2</sub>), 11 mol.% pyrope, and 80% mol. almandine, and an Fe# = 89% (where Fe# = Fe<sup>2+</sup>/[Fe<sup>2+</sup> + Mg]; Fig. 4.11). As Ca is usually the slowest diffusing major cation (Carlson, 2006), we use the calculated 5 mol. grossular isopleth to more tightly constrain peak *P–T* conditions to 6.5–7.5 kbar, and 640–665 °C (Fig. 4.10).

#### 49DTB19

g ep mu chl bi lm ab sp

ep mu chl bi

10

8

Pressure (Kbar)

SiO2 Al2O3 CaO MgO FeO K2O Na2O TiO2 MnO O 73.870 9.185 0.311 2.676 3.592 2.363 0.895 0.481 0.036 0.359 MNCKFMASHTO (+H2O, qz)

#### MNCKFMASHTO (+H2O, qz) chl ilm g ep m chl bi ilm sph drated a mu bi ilm st lidus 9 g ep mu bi chl ilm g ep mu chl bi ilm plc mu bi 8 ilm g st and g mu bi chl ilm m plc mu bi ilm g and g mu bi ilm st mt 7 -plc mu bi ilm g sill Pressure (Kbar) g ep mu bi chl ilm m g plc mu chl bi ilm g plc mu chl bi ilm sph APSISE bi chl g plc mu chl bi ilm r plc mu bi ilm st sill plc mu b ilm sill plc mu bi ilm mt sill ilm sill k olc ksp bi plc mu bi chl bi ilm m 3 plc mu bi ilm mt and plc mu bi ilm and plc ksp b >plc mu chl bi st ilm mt and Ic ksp co 2 550 600 Temperature (°C) 650 700

51DTB19

59DTB19

#### 50DTB19

SiO2 Al2O3 CaO MgO FeO K2O Na2O TiO2 MnO O 70.823 10.912 0.303 2.685 4.248 2.572 0.701 0.450 0.035 0.425 MNCKFMASHTO (+H2O, qz)



Fig. 4.10: Pressure-temperature pseudosections calculated for 49, 50, 51, and 59DTB19. The garnetin isopleth is indicated in red, staurolite-in isopleth is indicated in yellow, and aluminosilicate triple point fields indicated in blue. Fields containing the observed mineral assemblages are highlighted with thick lines and the interpreted peak paragenesis is indicated by the red field. Please note for sample 50DTB19, the observed mineral assemblage falls within the narrow field labelled by the red box, while the stability field indicated by the garnet chemistry are shown in the red ovals. Mineral abbreviations from Whitney and Evans (2010). H2O and quartz (qz) were considered in excess for all calculations.

600 Temperature (°C)

SiO2 Al2O3 CaO MgO FeO K2O Na2O TiO2 MnO O 64.953 10.214 0.437 5.442 7.714 2.762 0.578 0.540 0.101 0.771 MNCKFMASHTO (+H2O, qz)

SiO2 Al2O3 CaO MgO FeO K2O Na2O TiO2 MnO O

64.721 13.383 0.238 2.507 4.975 3.414 0.913 0.475 0.036 0.497

Hydrated Solidus

a plc mu bi

plc ksp bi mt ilm sill

plc ksp bi mt ilm and

n mt sill

bi mt bi mt

700

Sample 50DTB19 contains the interpreted peak assemblage garnet– muscovite–staurolite–biotite–plagioclase–ilmenite–sillimanite (+H2O and quartz; Fig. 4.5), which is predicted to be stable within a thin field from ~620 °C and 5 kbar, to ~680 °C and ~6.8 kbar (Fig. 4.10). The core of the garnets, dated at 1347  $\pm$  10 Ma (Zirakparvar et al., 2010) show ~3–4.5% grossular (Fig. 4.11), which is broadly consistent with a modelled lower-pressure assemblage of garnet–muscovite–biotite– plagioclase–ilmenite–magnetite–sillimanite (+H2O and quartz) stable from ~620 °C and ~5.2 Kbar to ~680 °C and 7 Kbar (Fig. 4.10). The garnet rims, dated at 1102  $\pm$ 42 Ma (Zirakparvar et al., 2010), show a slight increase in percent grossular to perhaps as high as 9% grossular (Fig. 4.11). This compositional change in garnet is consistent with slightly higher-pressure garnet growth, and the assemblage of garnet– muscovite–staurolite–biotite–plagioclase–ilmenite–magnetite (+H2O and quartz), which is stable from ~6.8–7.8 Kbar and ~650–670 °C, indicating a very similar P/T condition to sample 49DTB19.

Sample 51DTB19 contains the interpreted peak assemblage garnet– muscovite–biotite–plagioclase–ilmenite–magnetite–sillimanite (+quartz, and H2O). The absence of staurolite is consistent with slightly lower pressure conditions than recorded within samples 49DTB19 and 50DTB19. Sillimanite and garnet are only predicted to be stable together in a small field between ~620 °C and 5 kbar to ~680 °C and ~6.8 kbar (Fig. 4.10).



**Fig. 4.11:** Garnet compositional profiles of major elements for samples 49, 50, and 59DTB19 including back-scattered electron (BSE) images of analyzed traverses.

#### Eastern extent of Clearwater Complex

The calculated stability field for garnet in sample 59DTB19, from the eastern extent of the Clearwater complex, is significantly expanded compared to the other samples (Fig. 4.10), reflecting a threefold increase in the Mn content (e.g. White et al., 2014b). A small triangular garnet-absent field is also present related to the stability of staurolite and biotite at the expense of garnet and chlorite. Distinct rim and core domains (Fig. 4.11) suggest at least two stages of garnet growth. The preserved assemblage in this sample lacks staurolite, any aluminosilicate minerals, and contains significant potassium feldspar and muscovite agglomerates, that may have replaced an earlier higher-grade assemblage. Consequently, we interpret significant overprinting by lower (sub-garnet) grade metamorphism in this sample and do not assign a peak assemblage field.

#### 4.5. Discussion

## 4.5.1 Chronological constraints on Metamorphism within the Clearwater

#### region

Within the external regions (three samples from the western region, one from the eastern) of the Clearwater complex, the ages of 71 concordant monazite U–Pb analyses range from 1397 to 1007 Ma (Fig. 4.12), similar to the range of Lu–Hf garnet ages from the same rocks (1379 to 1018 Ma; Zirakparvar et al., 2010; Neishem et al., 2012). Lu–Hf dates from garnet are usually interpreted to represent its growth, which in metapelitic rocks generally requires pressures greater than 5 kbar, but can occur at temperatures as low as ~450 °C (Yakymchuk et al., 2017). Net diffusive gain or loss of Lu or Hf from garnet is thought to negligible at *T* < 800–900 °C (Smit et al., 2013; Bloch et al., 2020). Monazite in metapelitic rocks can also grow at temperatures as low as ~450 °C (Parrish, 1990) or higher (e.g. Cherniak, 2010). The U–Pb in apatite system is thought to have a much lower closure temperature of 450–550 °C, making it a valuable tool for constraining middle-*T* (mid-crustal) processes (Kirkland et al., 2018; Jepson et al., 2021).

The concordant monazite U–Pb analyses from the four studied samples indicate two age-peaks at 1352 Ma and 1083 Ma (Fig. 4.12), consistent with growth during the ca. 1380–1300 Ma East Kootenay and ca. 1115–1065 Ma Grenvillian tectono-thermal events (Zirakparvar et al., 2010; Neishem et al., 2014). On an

individual sample basis, the northwestern most sample (49DTB19) records the strongest Grenville-age signature with a monazite U–Pb Concordia age of  $1091 \pm 9$  Ma (MSWD = 1.7), slightly older than the  $1064 \pm 10$  Ma (MSWD = 4.5) Lu–Hf garnet age (Zirakparvar et al., 2010; Fig. 4.8B). Interestingly, this is the only sample to contain a robust pre-Cordilleran U–Pb apatite age of  $676 \pm 13$  Ma (MSWD = 2.8), contemporaneous with significant rift-related volcanism within the ca. 685-650 Ma Edwardsburg volcanics and Big Creek plutonic suite some 150 km to the south (Lund et al., 2003; 2010). Importantly, the absence of Phanerozoic ages indicates that this sample was largely unaffected by Cordilleran metamorphism (implying *T* < 450 °C).



Fig. 4.12: All concordant monazite U-Pb ages from the Clearwater complex, plotted with a 25 Myr band and binwidth. The ages of corresponding southwestern Grenville stages (Mulder et 2017), and al notable Laurentian Large Igneous Provinces (LIPS; Ernst et al., 2008 and references within) are indicated.

Sample 50DTB19 records a wider spread of monazite U–Pb dates, with five monazite grains armored as inclusions in garnet yielding a  $1365 \pm 17$  Ma (MSWD = 0.1) concordia age, with the youngest seven grains defining a  $1056 \pm 19$  Ma (MSWD = 1.0) discordia intercept age. These ages are in good agreement with the Lu–Hf garnet ages in rocks from the same outcrop, which records two stages of garnet growth at  $1347 \pm 10$  Ma (garnet core, MSWD = 4.5) and  $1102 \pm 42$  (garnet rim, MSWD = 42).

In sample 51DTB19, concordant U–Pb monazite ages between ca. 1400 and 1200 Ma are significantly older than the existing Lu–Hf garnet ages of ca. 1081-1024 Ma (Zirakparvar et al., 2010). Seven concordant monazite inclusions in garnet yield a  $1318 \pm 14$  Ma concordia age (MSWD = 0.1), consistent with monazite (but not garnet) growth during the ca. 1380-1300 Ma East Kootenay tectono-thermal event. The

youngest three concordant matrix monazite yield a  $1021 \pm 20$  Ma concordia age that corresponds well with the Lu–Hf garnet age. Collectively, the data suggest this rock experienced lower-pressure conditions (under which garnet was not stable) during the East Kootenay event than during the Grenville age event.

The apatite U–Pb data from this sample yield an age of  $56 \pm 7$  Ma (MSWD = 32; Fig. 4.8). The high MSWD of the Discordia regression suggests this sample contains more than one apatite age-population. The ~0.48  $^{207}$ Pb/ $^{206}$ Pb common-Pb intercept of this age is also much lower than predicted by common-Pb evolution models (Albarede and Juteau, 1984). Consequently, we suggest that apatite within sample 51DTB19 grew during partial breakdown (dissolution) of an older radiogenic Pb-bearing phase, likely a population of older Cryogenian apatite similar to the ca. 676 Ma apatite within nearby sample 49DTB19 (Fig. 4.9). The preservation of some likely Cryogenian apatite within this sample indicates that the Cordilleran processes this rocks experienced were within the U–Pb partial retention (or growth/dissolution) zone of apatite which is around 450–550 °C (Kirkland et al., 2018).

In the internal zone of the Clearwater complex, the Eocene  $54 \pm 2.7$  Ma (MSWD = 1.3) apatite U–Pb age from sample 52DTB19 (Fig. 4.9) records cooling and exhumation of the Clearwater complex, and is contemporaneous with existing ca. 64–55 Ma metamorphic zircon rims and ca. 53 to 47 Ma <sup>40</sup>Ar/<sup>39</sup>Ar mica ages (Doughty et al., 2007). These data indicate that rocks in the internal zone of the complex were buried deeper during Cordilleran processes than the external flanking zones (e.g. Lang and Rice, 1985; see Fig. 4.4). However, the internal zone does preserve a record of hydrothermal metamorphic zircon growth at ca. 1396–1350 Ma within this sample (Brennan et al., 2022). Apatite within sample 52DTB19 gave an upper <sup>207</sup>Pb/<sup>206</sup>Pb common Pb intercept of ~0.50, which again is much lower than predicted by common-Pb evolution models (Albarede and Juteau, 1984). Consequently, it is likely that the apatite in this sample also grew during the breakdown/dissolution of an older unknown radiogenic Pb-bearing phase perhaps also apatite, consistent with Cordilleran conditions that exceeded the U–Pb partial retention zone of apatite (~550 °C; Kirkland et al., 2018).

Along the eastern flanking region of the Clearwater Complex, U–Pb monazite ages of  $1337 \pm 30$  Ma and  $1119 \pm 18$  Ma are present in sample 59DTB19 (Fig. 4.8). The apatite U–Pb results record a  $58 \pm 9$  Ma (MSWD = 1.4) age (Fig. 4.9) that is also consistent with Cordilleran burial and Eocene core complex formation. No apatite

record of an older Proterozoic component present in rocks further to the west (in samples 49DTB19 and likely 51DTB19) was found. Interestingly, the  $58 \pm 9$  Ma U–Pb apatite age in sample 59DTB19 gives an upper <sup>207</sup>Pb/<sup>206</sup>Pb common Pb intercept of ~0.83, which is similar to values predicted by common-Pb evolution models (Albarede and Juteau, 1984). Consequently, the apatite in this sample does not record breakdown/dissolution of an older common-Pb bearing phases, perhaps indicating that the Cyrogenian apatite growth present along the western external zone did not occur in the eastern zone.

#### 4.5.2 Linking the timing and conditions of metamorphism

Integrating existing garnet Lu–Hf (Zirakparvar et al., 2010; Neishem et al., 2012) with U–Pb monazite and apatite data and phase equilibrium modelling allows the timing and conditions of metamorphism within the Clearwater region to be constrained, particularly along the western external zone of the complex. Along the western edge of the complex, monazite U–Pb ages (samples 49, 50, and 51DTB19) indicate that the rocks were affected by high-T processes during the older ca. 1380-1300 Ma East Kootenay tectono-thermal event. However, only one sample (50DTB19) records similar, ca. 1350 Ma, Lu-Hf garnet (core) ages (Neishem et al., 2012). While in these same three samples, younger ca. 1115-1065 Ma Grenville ages are ubiquitously recorded in monazite U-Pb and Lu-Hf garnet ages (Zirakparvar et al., 2010; Neishem et al., 2012). The presence of East Kootenay garnet ages in only one sample, while Grenville-age garnets are present in all samples, suggests that along the western, external, region of the Clearwater complex garnet did not grow in most rocks during the earlier Kootenay event, but was a common product of subsequent Grenvilleage metamorphism. This relationship is consistent with higher pressures during the latter, Grenville-age event.

#### East Kootenay metamorphism

Determining metamorphic conditions for the older ca. 1380–1300 Ma East Kootenay tectonothermal event is difficult due to extensive overprinting by Grenvillian metamorphism. Near the northern extent of the Belt Basin, within the Matthew Creek metamorphic zone and nearby St. Eugene deposit, ca. 1350 Ma metamorphism of lower Belt Supergroup strata is constrained to ~580–650 °C and 3.0–4.0 kbar (McFarlane and Pattison, 2000) and 490–510 °C and 3.6–4.0 kbar (Pattison and Seitz, 2012), consistent with 'warm' average geothermal gradients of

 $\geq$ 35 °C/km (e.g. Tucker et al., 2015). These relatively low-*P* conditions identified within the northern extent of the Belt Basin, are consistent with our inference of limited garnet growth within the western Clearwater complex. The relatively low pressures, and warm geotherms are more characteristic of Buchan rather than Barrovian metamorphism (e.g. Pattison and Spear, 2018; Pattison and Goldsmith, 2022 and references within). Consequently, the P-T conditions of the East Kootenay event are broadly consistent with sedimentary burial and heating due to coeval bimodal intrusions into the Belt Basin at this time (Doughty and Chamberlain, 1996).

The scattering of older ca. 1400–1200 Ma Lu–Hf garnet ages further east in the Clearwater complex (Neishem et al., 2012), suggest that this event may be better preserved, or that pressures of East Kootenay metamorphism were greater, further to the east. In sample 50DTB19, the thermodynamic modeling and mineral assemblages suggest that ca. 1350 Ma garnet core growth requires conditions of at least 620 °C and ~5 kbar. However, only a few kilometers in either direction, there is no evidence for garnet growth at this time. Thus, we speculate that the localized garnet growth within the western portion of the Clearwater complex at ca. 1350 Ma could reflect localized higher T/P conditions from documented nearby ca. 1380–1330 Ma magmatism within the Belt Basin (e.g. Doughty and Chamberlain, 1996; Lewis et al., 2007; Pearson and Link, 2021).

#### Grenville-age metamorphism

Rocks in the western portion of the Clearwater complex mostly preserve ca. 1115–1065 Ma metamorphic ages and Barrovian metamorphic assemblages that provide robust *P*–*T* constraints. Sample 49DTB19, which preserves ca. 1090–1070 Ma U–Pb monazite and ca. 1060 Ma Lu–Hf garnet ages (Fig. 4.8B), has an assemblage consistent with peak metamorphic conditions of 6.5–7.5 kbar and 640–654°C (Fig. 4.9). Sample 50DTB19 records ca. 1100 Ma garnet Lu–Hf rim ages and ca. 1060 Ma monazite U–Pb ages (Fig. 4.7B), and also records similar metamorphic conditions of ~6.8–7.8 kbar and ~650–670°C (Fig. 4.9). Sample 51DTB19, contains ca. 1080–1020 Ma Lu–Hf garnet ages, ca. 1020 Ma U–Pb monazite ages (Fig. 4.7B) and a mineral assemblage that suggests metamorphic conditions of ~620–680 °C and ~5.0–6.8 kbar (Fig. 4.10). Collectively, these values suggest that the rocks along the western region of the Clearwater complex were buried to a depth of ~17–22 km or greater (assuming isostatic pressures and an average crustal density of 3.0-2.7 g/cm<sup>3</sup>) around ca. 1080–

1020 Ma (Fig. 4.13). These results also imply a moderately-high average geothermal gradient (~23–36°C/km; e.g. Tucker et al., 2015).

In the central portion of the Clearwater complex, Doughty et al. (2007) assign peak metamorphic conditions of ~9–10 kbar and approximately 650°C at ca. 82–72 Ma, followed by a significant clockwise P-T path associated with core complex formation and exhumation from ca. 64 to 54 Ma (Fig. 4.13). These conditions suggest burial to a depth of ~31–38 km, along a geothermal gradient notably cooler (17– 21°C/km) than recorded by the rocks in the western external zone of the complex. The well-defined 54 ± 3 Ma (MSWD = 1.3) and 58 ± 9 Ma (MSWD = 1.4) apatite U–Pb ages reported here in the central and eastern portions (samples 52 and 59DTB19; Fig. 4.9) of the complex are in good agreement with this Cordilleran P-T-t pathway, and support Clearwater core complex exhumation in the late Paleocene to early Eocene (Fig. 4.13).

The 676  $\pm$  13 Ma (MSWD = 2.8) apatite U–Pb age within sample 49DTB19, and the over-dispersed 56  $\pm$  7 Ma (MSWD = 22) age recorded in sample 51DTB19 (Fig. 4.9), which we interpret to record partial resetting/recrystallization of an older Cryogenian apatite population, indicates that the western external region likely did not exceed ~550°C (the apatite U/Pb partial retention zone) during Cordilleran orogenesis. As discussed, within these same samples the higher temperature Lu–Hf garnet or U– Pb monazite systems notably record no indication of this Cryogenian event, which is previously not identified regionally in other mid-temperature thermo-chronometers. Given that the Cryogenian apatite ages are the same as nearby (well-agreed upon) riftrelated volcanism (the ca. 685–650 Ma Edwardsburg volcanics and Big Creek plutonic suite; Lund et al., 2003; 2010), which are not associated with any known supergreenschist facies metamorphism in this region, the Cryogenian apatite ages likely reflect a fluid-flow/thermal event associated Rodinian rifting. The absence of Cryogenian Lu–Hf garnet and U–Pb monazite ages indicate that this event did likely not result in re-equilibrium of the metamorphic assemblages from peak conditions at ca. 1115–1065 Ma (Fig. 4.13).

Interestingly, sample 49DTB19 contains the strongest signal of the ca. 1080 Ma Grenvillian event with complementary ca. 1090–1060 Ma U–Pb monazite and Lu– Hf garnet ages (Fig. 4.8), as well as the clearest ca. 676 Ma U–Pb apatite age of this Cryogenian rifting event (Fig. 4.9). Consequently, sample 49DTB19 is likely located proximal to a crustal/basin-scale structure that preferentially facilitated localized recording of these tectono-thermal events. The presence of Cryogenian apatite populations (samples 49 and 51DTB19) and/or more radiogenic than expected common-Pb values suggesting breakdown of an older apatite population (sample 52DTB19) along the central and western region of the complex, while no indication of an Cryogenian apatite population (or breakdown of an older more radiogenic population) in the eastern region of the complex (59DTB19; see Fig. 4.4 and 4.9) could also perhaps reflect a Proterozoic structure (with a Cryogenian history) between these two regions.



**Fig. 4.13:** Pressure–temperature–time pseudosection interpretations for the internal zone of the Clearwater complex (Doughty et al., 2007) that reflect Cordilleran conditions from ca. 82–54 Ma, and the western external zone (this work) that reflect the ca. 1080–1020 Ma "Grenvillian" conditions recorded in the corresponding samples.

#### 4.5.3 A revised regional tectonic model

Rocks of the western Clearwater complex yield important new constraints that allow for a revised tectonic model for the Belt Basin region of western Laurentia during the Nuna to Rodinia transition. Insights into the absolute P/T conditions of ca. 1380–1300 Ma East Kootenay tectono-magmatic event in the studied region are limited due to overprinting by higher-grade ca. 1115–1065 Ma metamorphism. However, we note that the relatively extensive monazite growth, but only localized garnet crystallization identified during this event are consistent with high temperature, lower pressure, Buchan-style metamorphism similar to what workers (e.g. McFarlane and Pattison, 2000; Pattison and Seitz, 2012) identify coevally within similar rocks in the northern portion of the Belt Basin, and attribute to extension and magmatism within the basin.

From the investigated samples, the peak metamorphic event along the western extent of the Clearwater complex give more robust insights into the ca. 1115–1065 Ma Grenvillian event within the Belt Basin. Tectonic models for this event within the Belt Basin region must now account for burial of Belt Supergroup rocks to a depth of ~17–22 km or greater along a moderately-high average geothermal gradient (~23–36°C/km) at ca. 1100–1065 Ma. The most recent model to explain this period of Barrovian-style Grenville-age metamorphism within the Clearwater complex advocates for continental collision and crustal thickening mechanisms at ca. 1090–1070 Ma based primarily on Lu–Hf garnet ages, and the generalized metamorphic grade/fabric suggested by the accompanying mineral assemblages (Neishem et al., 2012). However, recent documentation of metamorphism of pelitic rocks to conditions of ~680–660°C and 5.5–10.5 kbar, within a deep intraplate rift-basin (Tucker et al., 2015) caution against the ubiquitous attribution of compressional tectonic thickening to explain medium-pressure metamorphism unless supported by other lines of regional geologic evidence.

The Stenian Period (ca. 1200–1000 Ma) is admittedly predominantly a time of orogenesis and crustal thickening across southern Laurentia, associated with development of the Grenville province (e.g. Mulder et al., 2017). However, during this period of generally widespread crustal thickening, there is a distinctive period of continent-wide mantle/thermal upwelling, intraplate volcanism, reactivation of crustal weaknesses, and extension from ca. 1110–1040 Ma within Laurentia. Manifestations of this event are found in the 1110–1085 Ma Midcontinent Rift (e.g. Swanson-Hysell et al., 2018), 1115–1078 Ma Pikes Peak batholith (Guitreau et al., 2016), 1094–1080 Ma Southwestern Laurentian Large Igneous Province (Timmons et al., 2001; Bright et al., 2014), and 1090-1040 Ma Bylot and correlative basins in northern Laurentia (Greenman et al., 2021; see Fig. 4.2). However, although located <500 km from the Grenville orogenic front, this period of mantle upwelling and extension within the Midcontinent rift was punctuated by localized ca. 1090-1030 Ma (Cannon et al., 1993; Cannon, 1994), and ca. 1010-980 Ma; Swanson-Hysell et al., 2019; Hodgin et al., 2022) structural basin inversion, associated with the Ottawan and Rigolet phases of the Grenville orogeny. This punctuated inversion of the Midcontinent Rift indicates that Grenville orogenic deformation propagated far into the Laurentian continental

interior, often associated with inherited rift structures in regions weakened by recent thermal upwelling.

Consequently, the possibility of the ca. 1100–1065 Ma metamorphism within the Clearwater complex and Belt Basin to reflect similar processes (e.g. thermal upwelling and/or inversion of inherited structures) as is recognized coevally within the Midcontinent Rift is worth exploring. The work of various other geologists over the past couple of decades has demonstrated that significant syn-depositional, but commonly reactivated (with most reactivation generally attributed to Neoproterozoic rifting, and Mesozoic and younger Cordilleran deformation), crustal-scale faults break the Belt Basin up into segments with varying subsidence/exhumation histories (e.g. Winston, 1991; Sears, 2007; Lydon, 2010; Lonn et al., 2020 and references within). From north to south, the most significant of these crustal-scale structures consist of the St. Mary-Moyie and associated Rocky Mountain Trench fault-systems, the Showshoe fault and Jocko Line that border an intrabasin sydepositional high called the Central horst, and to the south, the Perry Line (Fig. 4.14A; Winston, 1986; Sears, 2007; Lydon, 2010). Some workers (e.g. Bookstrom, 2016) have suggested that the ca. 1380–1300 Ma East Kootenay and ca. 1115–1065 Ma Grenvillian events are generally pervasive along the western margin of the Belt Basin. However, alternatively we argue that it is only locally within the vicinity of these significant syn-depositional Belt Basin structures, that a clear record of ca. 1380-1330 Ma "East Kootenay" magmatism and metamorphism, and ca. 1115–1065 Ma "Grenville" metamorphism is identified.

In the northern region of the Belt Basin, adjacent to significant syndepositional structures of the northeast-southwest trending, St. Mary-Moyie Fault system, the Matthew Creek metamorphic zone and nearby world class Sullivan Pb-Zn-Ag deposit are present (Fig. 4.14A). Within the Matthew Creek metamorphic zone, sillimanite-grade amphibolite facies rock of the lower Belt Supergroup are of notably higher metamorphic grade than nearby greenschist facies Belt Basin rocks (McFarland and Pattison, 2000), and are intruded by the ca. 1365 Ma Hellroaring Creek and ca. 1335 Ma Matthew Creek stocks (Aleinikoff et al., 2015). These sillimanite-grade amphibolite facies rocks yield a spread of U–Pb monazite ages from ca. 1380–1000 Ma, with two distinct age-peaks at ca. 1350–1340 and 1080 Ma (Fig. 4.15; McFarlane, 2015). Associated with significant syn-depositional faults, casserite (tin-ore, SnO<sub>2</sub>) from the nearby Sullivan SedEx deposit yields U–Pb ages with a major ca. 1470 Ma age-peak associated with the timing of mineralization, and two significant overprinting

events at ca. 1380 and 1075 Ma that reflect dissolution-reprecipitation processes associated with localized thermal perturbations (Slack, 2020). Proterozoic structures of the St. Mary-Moyie Fault system also extend further southeast into the Priest River region, where rare ca. 1100 Ma metamorphic zircon rims are present (Doughty and Chamberlain, 2008).

The southernmost syn-depositional fault-system of the Belt Basin occurs along the east-west trending, down to the north, Perry Line (Fig. 4.14A; Winston, 1986; Link et al., 2007). The trend of the Perry Line extends west (e.g. Sims et al., 2004), into the Blackbird Co-Cu-Au district, where strata of the Lemhi Subgroup of the Belt Basin hosts Mesoproterozoic mineralization (Aleinikoff et al., 2012; Bookstrom et al., 2016). Ca. 1370 Ma diabase, diorite, and migmatites are also associated with the mineralized Belt Basin strata in the Blackbird district. Metamorphic barometry on these migmatites suggest initial pressures equivalent to ~14 km of burial, and subsequent pressure increases equivalent to ~20 km of burial (Doughty and Chamberlain, 2010). Monazite and xenotime U–Pb geochronology indicates that initial mineralization formed at ca. 1360 Ma, and experienced a subsequent Mesoproterozoic thermal event at ca. 1060 Ma (Fig. 4.15; Aleinikoff et al., 2012).

Within the central portion of the Belt Basin, the region investigated by this study, syndepositional basin-scale structures include a central horst block bounded to the north by the Snowshoe fault and to the south by the Jocko Line. Associated with the Snowshoe and Jocko syn-depositional structures are world-class Pb-Zn-Co-Ag deposits of the Coeur d'Alene and associated districts (e.g. Hobbs et al., 1965). The Jocko Line is of particular interest to this study, as it is a down to the south, significant syn-depositional Belt Basin fault that is an antecedent to the Lewis and Clark fault zone (Fig. 4.14; Winston, 1991; Sears, 2007). Notably, Lewis and Clark fault zone structures accommodated formation/exhumation of the Clearwater metamorphic complex during Cordilleran deformation (Doughty et al., 2007). As discussed, U–Pb monazite ages from the Clearwater complex contains distinct ca. 1380–1340 and 1080–1060 Ma bimodal age-peaks, that are similar to those found adjacent to other major syn-depositional Belt Basin structures (Fig. 4.15). Consequently, Grenville-age ca. 1080–1060 Ma metamorphism within the Belt Basin is associated with significant pre-existing crustal-scale structures. These structures were likely active in a normal-sense during the main ca. 1470–1380 Ma interval of

Belt Basin subsidence and were conduits for magmatism and mineralization during ca. 1370–1330 Ma East Kootenay metamorphism within the Belt Basin (Fig. 4.14A).

Importantly, the record of Grenville-age metamorphism is also associated with these major Belt Basin syn-depositional normal-fault structures. The sampled metapelitic units are from the Wallace Formation which occupies a middle-stratigraphic position of the Belt Supergroup, with an estimated ~9 km of underlying strata (Winston, 2016). The possibility that the sampled Wallace Formation is actually miscorrelated, lower Belt strata, is unlikely as the sampled unit contains consistent carbonate horizons absent in nearby lower Belt units, and also lacks the syndepositional mafic sills common in nearby lower Belt strata (e.g. Lewis et al., 2001; 2005; 2007). Maximum thickness estimates for Belt Supergroup are generally ~20 km



**Fig 4.14:** Generalized map (adapted from Sears, 2007 and Lonn et al., 2020), and schematic cross section cartoons of significant Belt basin syndepositional faults/fault zones at (A) the suggested occurrence of ca. 1380–1330 Ma East Kooteney, Buchan-style, metamorphism due to high heat flow, mineralization and magma intrusion into the Belt basin, and at (B) the suggested occurrence of ca. 1110–1060 Ma Grenville-age, Barrovian-style, metamorphism due to high heat flow and localized inversion of the Belt basin due to rejuvenation of inherited fault zones. Various mechanisms are worth investigating for this apparent Grenville-age tectonism, including a predominately compressional stress-field resulting in reverse-sense activation (shown by black faults) of inherited weaknesses, or an predominately transpressional stress-field resulting in some localized reverse sense, and perhaps some nominal or normal activation sense structures (alternative fault type shown in green) associated with restricting or releasing bends in the margin.

(Harrison, 1972) and re-correlation of the overlying Deer Trail Group strata (Box et al., 2020) may indicate at least another ~2.5 km (Miller and Whipple, 1989) of poorly preserved strata atop upper Belt strata. Consequently, at ca. 1080 Ma, the preserved stratigraphy can only account depositional burial of the Wallace Formation to depths of about 12–14 km, while the thermodynamic modelling results indicate pressures requiring at least 17–22 km of burial. It is possible that the stratigraphic thicknesses are underestimates due to subsequent erosion.

Nevertheless, the results presented in this work lend further support to earlier interpretations (Zirakparvar et al., 2010; Neishem et al., 2012) that Grenville-age tectonism in the Clearwater region of the Belt Basin requires a component of tectonic thickening or structural burial. Given the basin-wide association of this metamorphism with crustal-scale structures, and coeval timing to similar events elsewhere within Laurentia, we suggest this localized Grenville-age metamorphism within the Belt Basin was facilitated by enhanced heat flow and localized structural burial along inverted rift structures. This interpretation suggests that at ca. 1100–1020 Ma the Belt Basin experienced a period of mantle/thermal upwelling (e.g. Doughty and Chamberlain, 2008) and localized structural inversion (Fig. 4.14B), perhaps partially analogous/correlative to coeval processes recognized within the Midcontinent Rift and Southwest Laurentian large igneous province (e.g. Cannon, 1994; Bright et al., 2014; Swanson-Hysell, 2019; Hodgin et al., 2022). However, these processes in the Belt Basin differ notably from coeval Midcontinent and Southwest Laurentian processes. In particular, this time interval was amagmatic within the Belt Basin and there is no recognized associated sedimentation (Link et al., 1993; Brennan et al., 2021a; 2021b).

Identification of field-based relationships revealing this probable localized Grenville-age inversion of the western Belt Basin may be hampered by the fact that these same inherited structures were subsequently reactivated multiple times during Neoproterozoic rifting, and Mesozoic and younger Cordilleran orogenesis (e.g. Doughty et al., 2007; Lund et al., 2010; Bookstrom et al., 2016). During Neoproterozoic rifting the Belt Basin segment of the margin also experienced less subsidence and more exhumation than adjacent segments (Lund, 2008; Link et al., 2017; Brennan et al., 2020), which could have eroded a limited Grenville-age sedimentary record if it was ever present. However, as the geochronology and thermodynamic modeling results indicate, Grenville-age tectonism is indeed present

in western Laurentia. The substantiation of this finding has significant implications for global models of supercontinent Rodinia formation.



Fig. 4.15: Kernel Density U-Pb age spectra (plotted with 25 Myr band and binwidth) from amphibolite Belt Supergroup grade within metapelites the Matthew Creek metamorphic zone (Casserite, Slack, 2020; Monazite, McFarlane, 2015). Clearwater the complex (Monazite, this work), and the Blackbird district (Xenotime, Aleinikoff et al., 2012). The corresponding ages of southwestern Grenville stages (Mulder et al., 2017), lower Belt syndepositional mineralization, and notable Laurentian Large Igneous Provinces (LIPS; Ernst et al., 2008 and references within) are indicated. Note all three locations contain a age-distribution bimodal with 1380-1340, and 1080-1060 Ma age-peaks.

# 4.5.4 Global Implication of Grenville-age Barrovian metamorphism within the Belt Basin

Most paleographic reconstructions favor the assembly of continents along western Laurentia at ca. 1100–900 Ma associated with the greater amalgamation of supercontinent Rodinia (e.g. Li et al., 2008; Mulder et al., 2018; Merdith et al., 2020). Consequently, the presented evidence for ca. 1110–1020 Ma Barrovian metamorphism within the Belt Basin presents several new constraints to refine these global models.

Firstly, these results suggest that the onset of amalgamation of continents west of the Belt Basin region initiated around 1110 Ma, and concluded by ca. 1020 Ma. Given the absolute absence of recognized tectonism in the Belt Basin region from ca. 1020–780 Ma (e.g. Brennan et al., 2021a), we suggest this ca. 1020–780 Ma interval was the stable duration of Rodinia in this region. Notably, this timeframe is longer than suggested by most leading global models (e.g. Li et al., 2008; Merdith et al., 2020) that instead suggest the main amalgamation of Australia, Antarctica, western Laurentia, and perhaps South China occurred primarily between ca. 1040–900 Ma, and began breaking up around ca. 830–820 Ma. This discrepancy could indicate that the Belt Basin region only records the initial onset of this assembly process and lacks a record of the initial onset of breakup processes, or perhaps the absolute timing of these global models require refinement.

Importantly, the Clearwater region is ~1800 km from the nearest Grenvilleorogenic front in southwest Laurentia (see Fig. 4.2). This distance is over three times further than the ~500 km from the Grenville orogenic front in eastern Laurentia and the reactivated/inverted structures of the Midcontinent Rift. Thus, it is doubtful that Grenville orogenic stresses in southern and eastern Laurentia could solely result in the far-field inversion of the Belt Basin, especially since the record of structural inversion appears concentrated more in the western extent of the basin. Consequently, Rodinia models with continental blocks exhibiting tectonism adjacent to western Laurentia at ca. 1110–1020 Ma should be favored over those that lack a satisfactory mechanism to account for the Grenville-age metamorphic record of the Clearwater complex.

One such model that provides a satisfactory Grenville-age mechanism is the "Missing-Link" model (Li et al., 1995). In this model, final Rodinia assembly may have occurred along the ca. 1040–900 Ma Sibao orogen in South China, which is suggested to have been located between western Laurentia and Australia/Antarctica (Fig. 4.16). Additionally, the "Missing-Link" model also has several other strengths. Notably, South China also provides a satisfactory Neoproterozoic plume and rifting record that could account for discrepancies in corresponding records of western Laurentia and eastern Australia (e.g. Li et al., 2008). However, the absence of any non-Laurentian derived Grenville-age sedimentation in (or along) the Belt region (see Brennan et al., 2021a; 2021b), contradicts a long-held prediction of this model (Li et al., 1995; 2002; 2008; Yao et al., 2017). Others have also utilized paleomagnetic constraints (Park et al., 2021; Chang et al., 2022), and the presence of moderately

widespread ca. 950–830 Ma magmatism (Yao et al., 2019) in South China to instead argue that South China was located along the periphery, not center, of Rodinia. Based primarily on paleomagnetic data and broadly similar Neoproterozoic histories, alternative "Missing-Link" blocks with records of Grenville-age tectonism such as Tarim have also been proposed (Wen et al., 2017; 2018).



**Fig. 4.16:** Geologic timeline of the Nuna to Rodinia supercontinent transition, the relevant Laurentianscale geologic events and local events within the Clearwater region. Below the timeline are two competing tectonic models for the Nuna to Rodinia transition along western Laurentia that could account for the ca. 1110–1020 Ma metamorphic record of the Clearwater complex. The upper model proposes a "SWEAT-like" (e.g. Moores, 1991) assembly of Rodinia along a large dextral transform boundary (after Mulder et al., 2018; Meredith et al., 2020). The lower "Missing-Link like" model proposes that the assembly of Rodinia occurred along the intervening Cathaysia and Yangtze blocks which contain a ca. 1100–900 Ma collisional (Sibao) orogen (after Li et al., 1995; 2008; 2013; Yao et al., 2017).

Alternative models besides the "Missing-Link" also warrant consideration. The most notable of which are those that advocate for the final assembly of western Laurentia and Australia/Antarctica along a dextral transpressional/transtensional boundary perhaps better recorded in smaller intervening blocks, such as Tasmania and the Western South Tasman Rise (Fig. 4.16). A strength of these models, is that Tasmania and the Western South Tasman Rise contain ca. 1300–1080 Ma metamorphism and provenance ties to western Laurentia (Halpin et al., 2014; Mulder et al., 2018; Merdith et al., 2020; Brown et al., 2022). It is also worth noting, that some alternative Missing-Link models, such as those that favor Tarim between western Laurentia and Australia/Antarctica (Wen et al., 2018) also advocate for dextral transpressional assembly of Rodinia along the western Laurentian margin.

In these models of transpressional Rodinia assembly, the observed ~6 km discrepancy between calculated burial depths and estimates for the thickness of overlying strata in the Clearwater region at ca. 1080 Ma, suggest that the Clearwater region (and the Jocko Line; see Fig. 4.14) could have acted as a localized restraining bend boundary along the western edge of the Belt Basin during this period (Fig. 4.14B; 4.16), consistent with the proposed dextral motion. If correct, based on the orientations of the Perry Line, and St. Mary-Moyie fault zones, the dextral assembly models predict these regions would have been predominantly releasing bends along the margin. This relationship may suggest nominal Grenville-age inversion and limited related Barrovian-style metamorphism, but perhaps still a record of thermal upwelling and/or subsidence, in these areas. Consequently, dextral transpressional models could explain why the ca. 1380–1330 Ma East Kooteney metamorphism along the Perry Line and St. Mary-Moyie Fault zone regions (Matthew Creek metamorphic zone and Blackbird district) appears to have a weaker Grenville-age overprint (e.g. Pattison and Seitz, 2012; Bookstrom et al.., 2016) compared to the Clearwater complex.

#### **4.6 Conclusions**

A key record to solving debates on the style and mechanism of the Nuna to Rodinia transition lies in the ca. 1100 Ma Grenville-age tectonic record of western Laurentia. Within the Clearwater complex of the Belt Basin in western Laurentia, existing Lu–Hf garnet geochronology (Zirakparvar et al., 2010; Neishem et al., 2012) and new monazite and apatite U–Pb results and Thermocalc (pressure-temperature) constraints from ca. 1450 Ma Belt Supergroup metapelitic strata record ca. 1350 and 1080 Ma metamorphism, and thus may contain a rare record of this supercontinent transition. However, variable overprinting by younger Mesozoic and Cordilleran orogenic processes has previously hindered interpretation of these older events. In the western external region of the Clearwater complex, metapelitic strata retain, or partially retain, Cryogenian apatite U–Pb ages associated with nearby rift-related magmatism during Rodinia breakup. These ages indicate that Cordilleran conditions did not exceed ~450–550°C (the U/Pb closure temperature of apatite) in this region. Consequently, the mineral assemblages within these rocks likely reflect an upper amphibolite grade, Barrovian-style, metamorphic event recorded by ca. 1100–1070 Ma garnet Lu–Hf and monazite U–Pb ages. Thermodynamic modeling of these metamorphic assemblages indicate they are consistent with pressures of 5–7.5 kbar and temperatures of  $620-670^{\circ}$ C, suggesting burial to a depth of ~17–22 km or greater around along a moderately-high average geothermal gradient of ~23–36°C/km.

These ca. 1100–1070 Ma metamorphic conditions are difficult to satisfy with static heating within the Belt Basin alone. Thus, these conditions advocate that thermal upwelling/heating and western tectonism facilitated rejuvenation of crustal-scale riftstructures which resulted in localized Grenville-age structural inversion, and crustal thickening within the Belt Basin. Manifestations of this critical period of thermal upwelling/heating, rejuvenation of crustal-scale structures, and sometimes localized structural rift inversion associated with Rodinia assembly may be recognized Laurentian-wide such as within the 1110-1085 Ma Midcontinent Rift (e.g. Swanson-Hysell et al., 2019), 1115–1078 Ma Pikes Peak batholith (Guitreau et al., 2016), 1094– 1080 Ma Southwestern Laurentian Large Igneous Province (Timmons et al., 2001; Bright et al., 2014), and perhaps the 1090–1040 Ma Bylot and correlative basins in northern Laurentia (Greenman et al., 2021). Consequently, global geologic models must account for ca. 1100-1020 Ma Grenville-age tectonism in blocks adjacent to the western margin of Laurentia within supercontinent Rodinia. Future work should evaluate the viability of Grenville-age collisional or transpressional/transtensional settings along the western margin of Laurentia and alleged conjugates such as Australia/Antarctica, South China and/or Tarim.

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# Chapter 5: Recalibrating Rodinian rifting in the northwestern United States

### Abstract

A lack of precise age constraints for Neoproterozoic strata in the northwestern United States (Washington State), including the Buffalo Hump Formation (BHF), has resulted in conflicting interpretations of Rodinia amalgamation and breakup processes. Previous detrital zircon (DZ) studies identified a youngest ca. 1.1 Ga DZ age population in the BHF, interpreted to reflect mostly first-cycle sourcing of unidentified but proximal magmatic rocks intruded during the amalgamation of Rodinia at ca. 1.0 Ga. Alternatively, the ca. 1.1 Ga DZ population has been suggested to represent a distal source with deposition occurring during the early phases of Rodinia rifting, more than 250 m.y. after zircon crystallization. We combined conventional laser-ablation splitstream analyses of U-Pb/Lu-Hf isotopes in zircon with a method of rapid (8 s per spot) U-Pb analysis to evaluate these opposing models. Our study of  $\sim$ 2000 DZ grains from the BHF identified for the first time a minor ( $\sim 1\%$ ) yet significant ca. 760 Ma population, which constrains the maximum depositional age. This new geochronology implies that the BHF records early rift deposition during the breakup of Rodinia and correlates with sedimentary rocks found in other late Tonian basins of southwestern Laurentia.

### 5.1. Introduction

Correlation of pre-rift and rift strata across purportedly paired margins, such as Neoproterozoic strata of the Adelaide rift complex (southeastern Australia) and the Windermere Supergroup (western Laurentia), has long been used to define key piercing points for reconstructing supercontinents (e.g., Bell and Jefferson, 1987; Dalziel, 1991; Brookfield, 1993). In the northwestern United States, strata of the ca. 1.47–1.38 Ga Belt Supergroup, the ca. 1.3 Ga Deer Trail Group, the <1.1 Ga Buffalo Hump Formation (BHF), and the ca. <720 Ma Windermere Supergroup provide key constraints in the reconstructions of the supercontinents Nuna (ca. 1.6–1.3 Ga) and Rodinia (ca. 900–700 Ma; Fig. 5.1A; Ross et al., 1992; Ross and Villeneuve, 2003; Li et al., 2008; Kirscher et al., 2020). However, uncertain provenance and depositional ages of these key strata have resulted in varying proposed configurations, timings, and identities of alleged Laurentian conjugates such as Australia, Antarctica, and/or South China during the Proterozoic (e.g., Li et al., 2008; Box et al., 2020).



**Fig 5.1:** (A) Geologic map and time line of the North American Cordillera, and the northwestern United States study area, where Proterozoic rocks of the Belt Supergroup, Deer Trail Group, Buffalo Hump Formation, and Windermere Supergroup outcrop adjacent to the edge of Lau- rentia. Extent of the Grenville Province is shown on the inset map. Neoproterozoic rift geometry and structures are indicated (after Lund et al., 2010). (B) Stratigraphy of the study region (after Box et al., 2020) and photo of the cobble analyzed. Paleocurrent measurements indicate a mean vector to the northwest, roughly perpendicular to the Jumpoff Joe thrust fault. Abbreviations: ChUMP—Chuar–Uinta Mountain–middle Pahrump Group; BSG—Belt Supergroup, DTG—Deer Trail Group, BHF—Buffalo Hump Formation; GB—Gun Barrel, WSG—Windermere Super- group, PM—passive margin; C—Cambrian. State/province abbreviations: BC—British Columbia, Canada; WA—Washington; MT—Montana; OR—Oregon; ID—Idaho; NV—Nevada; WY—Wyoming; UT—Utah; CO—Colorado; AZ—Arizona; NM—New Mexico

Approximately 10 km west of the westernmost Belt Supergroup in northeastern Washington State, coarse-grained quartzite and locally feldspathic siltite of the BHF and finer-grained argillite and carbonate rocks of the underlying Deer Trail Group crop out. An initial study suggested these rocks comprise a relatively continuous sequence that was correlative to the Piegan and Missoula Groups of the Belt Supergroup (Miller and Whipple, 1989). Ross et al. (1992) dated six detrital zircon (DZ) grains from the BHF and found four ca. 1.2–1.0 Ga grains and two older ca. 1.8 Ga grains. Because the BHF is coarser than Belt Supergroup rocks to the east, Ross et al. (1992) advocated a western source of ca. 1.1 Ga detritus into the BHF basin. More recent geochronology and field work have demonstrated that the Belt Supergroup and Deer Trail Group are characterized by DZ populations ca. 1.3 Ga and older, signifying deposition before the onset of the Grenville orogeny and Rodinia amalgamation (Ross and Villeneuve, 2003; Box et al., 2020). West of the Mesozoic Jumpoff Joe thrust fault (Fig. 5.1A), Deer Trail Group rocks are unconformably overlain by BHF strata containing abundant ca. 1.1 Ga (Grenvillian) DZs (Box et al., 2020).

Despite these developments, the original interpretation of a western ca. 1.1 Ga DZ source for the BHF (Ross et al., 1992) remained an important constraint for the reconstruction of Rodinia during its assembly (e.g., Li et al., 2008; Yao et al., 2017). However, others have argued that the youngest ca. 1.1 Ga DZ population does not represent the age of deposition, and instead the BHF may be the basal unit of the overlying Windermere Supergroup that constraints early Rodinia breakup (Box et al., 2020).

We adopted an integrated approach combining a rapid laser-ablationinductively coupled plasma-mass spectrometry (LA-ICP-MS) U-Pb technique with standard split-stream ICP-MS U-Pb and Lu-Hf analyses of DZ from the BHF. Our approach identified a minor and previously unrecognized DZ age population that permits recalibration of a key piercing point for Rodinia reconstructions.

### 5.2. Geologic setting and methodology

The >350-m-thick BHF is characterized by alternating mudstone and sandstone strata that experienced regional lower-greenschist-facies metamorphism. Locally, the sandstone intervals include monolithic quartzite conglomerate beds containing cobbles >20 cm in diameter. The sandstone intervals decrease in thickness

and grain size up section, recording an overall fining-upward trend at the formation scale (Fig. 1B).

To reassess the depositional age and evaluate conflicting sources for the BHF detritus, DZ grains separated from four sandstone intervals and one quartzite cobble were mounted and imaged. Approximately 120 grains from each sample were analyzed by conventional laser-ablation split-stream ICP-MS (LA-SS-ICP-MS) methods for U-Pb and Lu-Hf isotopes at the GeoHistory Facility in the John de Laeter Centre at Curtin University (Perth, Australia) using a 38 µm spot. This approach identified a single concordant  $756 \pm 30$  Ma ( $\varepsilon$ Hf<sub>t</sub> =  $3.4 \pm 1.5$ ; all uncertainties reported at  $2\sigma$ ) zircon grain. An additional U-Pb session (~400 unknowns), utilizing a 20 µm spot, identified two additional ca. 760 Ma grains. To further characterize this age, the remaining DZ grains from all four sandstone sample mounts (~1200 unknowns) were analyzed using a technique involving rapid (8 s each) LA-ICP-MS analysis. This analysis rate was achieved by bypassing the aerosol homogenization device tubing, omitting "cleaning pulses," and reducing ablation and washout times (Chew et al., 2019). Rapid analysis identified additional ca. 760 Ma DZ grains in all four samples. Reanalysis of these grains via conventional U-Pb LA-ICP-MS methods provided robust age constraints. Age-population plots and maximum depositional age calculations only include zircon analyses with discordance less than 10% (Fig. 5.2).

### 5.3. Detrital zircon U-Pb and Lu-Hf isotope data

The U-Pb/Lu-Hf LA-SS-ICP-MS analysis of DZ grains from all four BHF sandstone samples showed older components at ca. 2.8–2.4 Ga and ca. 1.9–1.6 Ga, along with two broad younger age peaks at ca. 1450 Ma and 1105 Ma that had mostly juvenile Lu-Hf ( $\epsilon$ Hf<sub>t</sub> = +5 to +10) values (Fig. 2). Laurentian sources such as the Grenville Province (Fig. 1A, inset), the midcontinent (A-type) Granite-Rhyolite Province, the Yavapai-Mazatzal-Mojave Province, and Archean provinces to the east/southeast (e.g., Wyoming craton) are consistent with these age components (Whitmeyer and Karlstrom, 2007).

A juvenile ( $\epsilon$ Hf<sub>t</sub> = +5 to +10) ca. 1380 Ma component may represent detritus derived from plutonic rocks that intrude the Belt Supergroup (Brennan et al., 2020). A minor ca. 1.1 Ga component with an evolved ( $\epsilon$ Hf<sub>t</sub> = 0 to -5) signature indicates an additional source inconsistent with juvenile Grenville sources in southeastern Laurentia (Howard et al., 2015; Thomas et al., 2017). The 1.07 Ga Pike's Peak batholith of central Colorado is of similar age and isotopic composition ( $\epsilon$ Hf<sub>t</sub> of 2 to -3; Howard et al., 2015) and was also undergoing rapid exhumation during the late Tonian (Flowers et al., 2020), indicating it could be a first-cycle source for this DZ component.



Fig 5.2: (A) Detrital zircon (DZ) U-Pb/Lu-Hf results for the Buffalo Hump Formation (BHF; Washington State, USA) sandstones and the BHF cobble. Age spectra are kernel density estimates (KDEs) with 25 m.y. bandwidths, which are also used for the histograms, and exclude repeated measurements on the targeted young grains. Lu-Hf data shown in the bivariate KDE plot also have 25 m.y. and 1  $\epsilon$ Hf bandwidths. Average crustal evolution (Lu/Hf = 0.015) is indicated. The  $\epsilon$ Hf and age fields are from Thomas et al. (2017) and Brennan et al. (2020). CHUR-chondritic uniform reservoir; -depleted mantle; MCGR-Midcontinent Granite-Rhyolite; NAMG-North American magmatic DMgap; Y-M-Mo-Yavapai-Mazatzal-Mojave. (B) Cumulative distribution function highlights the similarity between the BHF cobble sample (orange) and the Deer Trail Group (dashed orange; Box et al., 2020), and BHF conventional sandstone (blue) and rapid sandstone (dashed gray) analyses (see the Supplemental Material). (C) Terra-Wasserberg concordia plot of ca. 760 Ma DZ grains, which yielded a Concordia age of  $758 \pm 7$  Ma ( $2\sigma$ ). Images (cathodoluminescence and reflected light) of grain BH1-154 in inset. Four analyses of this grain yielded similar (238U/206Pb) ages and a Concordia age of 760  $\pm$  12 Ma (2 $\sigma$ ), indicating this grain experienced minimal Pb loss. MSWD—mean square weighted deviation. (D) KDE plot of young analyses with individual analysis bars ( $2\sigma$ ) and preferred 758 ± 7 Ma maximum depositional age shown.

Twenty-eight (28) conventional U-Pb spot analyses on 21 ca. 760 Ma grains yielded a Concordia age of  $758 \pm 7$  Ma (mean square weighted deviation [MSWD] = 1.7, all given as a measure of concordance plus equivalence; Figs. 5.2C and 5.2D). All analyses overlapped with concordia at  $2\sigma$  and yielded alpha-doses and calculated densities (conservatively assuming damage accumulation initiated at crystallization) indicative of closed-system behavior of U-Pb (Murakami et al., 1991). Multiple robust analyses of single DZ grains allows better evaluation of potential Pb loss. Five individual zircon grains were large enough for multiple robust analyses. Four had similar concordia ages of  $762 \pm 10$  Ma (n = 4; MSWD = 0.25; Fig. 2C),  $762 \pm 17$  Ma

(n = 2, MSWD = 0.16), 766  $\pm$  16 Ma (n = 2, MSWD = 0.19), and 770  $\pm$  12 Ma (n = 3, MSWD = 0.34). The fifth multi-analysis grain gave a Concordia age of 736  $\pm$  14 Ma (n = 2, MSWD = 0.28).

The DZ ages from the quartzite cobble from the BHF conglomerate contain ca. 1.7 Ga and ca. 1.4 Ga components, with no grains younger than ca. 1.2 Ga (Figs. 2A and 2B).

### 5.4. Recalibrating rifting of Rodinia in western Laurentia

### 5.4.1 New constraints from the Buffalo Hump Formation

Based on the Concordia age of the young (ca. 760 Ma, n = 28) analyses, we favor a 758 ± 7 Ma (MSWD = 1.7) maximum depositional age for the BHF. This age is a purely descriptive measure of the youngest ages present (Figs. 2C and 2D). The single 736 ± 14 Ma multi-analysis grain was found in the stratigraphically highest sampled interval (BH1) and may support a maximum depositional age that decreases up section from ca. 760 to 735 Ma, and a continued connection to the source of these ca. 760 Ma grains throughout BHF deposition. While ca. 760 Ma magmatic sources were present in eastern Laurentia (e.g., MacLennan et al., 2020), similar-aged source rocks are unknown from western Laurentia. Non-Laurentian source rocks with ca. 760 Ma ages occur in Tasmania (760 ± 12 Ma; Turner et al., 1998), Western Australia (755 ± 3 Ma; Wingate and Giddings, 2000), and the Yangtze block of South China (768 ± 7 Ma to 751 ± 10 Ma; Li et al., 2003).

The large size of the BHF cobble (Fig. 1B) and the ages of the DZ it contains (Fig. 2A) suggest it was sourced from the underlying Deer Trail Group. To the east of the Mesozoic Jumpoff Joe thrust fault, BHF rocks are absent, and Deer Trail Group strata are ~3 km thinner than they are west of the fault (Box et al., 2020). However, Cambrian rocks are continuous across the fault (Lindsey and Gaylord, 1992). These relationships suggest that the Mesozoic Jumpoff Joe thrust fault may have been an ancestral down-to-the-northwest Neoproterozoic normal fault during BHF deposition. The fault is parallel to the Paleoproterozoic boundary between the Archean Hearne and Medicine Hat blocks (Fig. 1A), and likely exhumed Deer Trail Group rocks on the footwall to its east, interpreted as a rift shoulder, providing a proximal source for the cobbles that were recycled into the adjacent hanging-wall BHF rift basin.

### 5.4.2 A "ChUMP-B" Correlation and Implications

Detrital zircon grains with ca. 760 Ma ages are rare in western Laurentia and only known to occur in the Uinta Mountain Group (Fig. 1A). The Uinta Mountain Group has the same maximum depositional age (766  $\pm$  5 Ma; Dehler et al., 2010) as the BHF and is also unconformably overlain by younger than 720 Ma Windermere Supergroup strata. A south-dipping, syndepositional fault is inferred to have bounded the Uinta Mountain Group basin to the north. The fault is parallel to, and likely related to, the east-west-trending Paleoproterozoic suture zone along the southern margin of the Archean Wyoming craton (Fig. 1A; Dehler et al., 2010). The orientations of the BHF and Uinta Mountain Group syndepositional faults suggest north-south to northwest-southeast extension along preexisting boundaries.

The Uinta Mountain Group is correlative to the Chuar and middle Pahrump Groups in southwestern Laurentia (Fig. 5.1A). These three coeval (Chuar–Uinta Mountain–middle Pahrump) groups comprise the "ChUMP" correlation (Dehler et al., 2017, and references therein). Similar to the BHF, ChUMP strata contain significant ca. 1.90–1.65 Ga, ca. 1.45 Ga, and ca. 1.3–1.0 Ga DZ age components (Fig. 3). A few late Tonian (ca. 800–720 Ma) DZ grains in ChUMP rocks constitute a comparable (<1.5%) component of the total DZ population. Basal rocks of the more southern Chuar and middle Pahrump Groups have ca. 780 Ma maximum depositional ages (<782 ± 7 Ma and <775 ± 18 Ma, respectively; Dehler et al., 2017; Mahon et al., 2014). Upper Chuar Group strata contain a 742 ± 6 Ma interbedded tuff and are unconformably overlain by Cambrian rocks (Karlstrom et al., 2000, 2018). Middle Pahrump Group strata are overlain by younger than 720 Ma Sturtian diamictites (Mahon et al., 2014; Dehler et al., 2017).

ChUMP strata record an interval of intracratonic rift-basin formation that occurred after intrusion of the ca. 780 Ma Gunbarrel dike swarms (Harlan et al., 2003) but prior to widespread Laurentian rifting at ca. 720 Ma (Yonkee et al., 2014). The stratigraphic position, DZ ages, and tectonic setting of the BHF indicate that it is likely a correlative to ChUMP group strata in an expanded "ChUMP-B" (Chuar, Uinta Mountain, middle Pahrump Groups–Buffalo Hump Formation) correlation. The absence of ca. 900–800 Ma DZ grains in ChUMP-B strata (Fig. 5.3) likely reflects tectono-magmatic quiescence in western Laurentia during that interval due to its central location within Rodinia (e.g., Li et al., 2008).



**Fig. 5.3:** Normalized U-Pb detrital zircon kernel density estimate (KDE) plots and main age components for late Tonian strata in western Laurentia.

The proposed ChUMP-B correlation extends the <780 to ca. 720 Ma interval of rift-basin development northward to the Belt segment (central Idaho to southeastern British Columbia) of the Cordilleran margin. In this region, intermittent Cryogenian–Cambrian Windermere Supergroup deposition and magmatism record predominately northeast-southwest extension, recurrent margin-parallel exhumation (e.g., the Lemhi arch; Fig. 1A), and accompanying breakup in the late Ediacaran–early Cambrian (Lund et al., 2010; Lund and Cheney, 2016; Brennan et al., 2020). Thus, it appears that the orientations of the BHF and Uinta Mountain Group syndepositional faults require earlier extension oblique to the main extension direction during deposition of the Windermere Supergroup. Southwestern Laurentia also likely experienced similar complex multiphase extension during this time (Timmons et al., 2001).

This history of rifting is difficult to reconcile with a single event between southeastern Australia (the Gawler craton) and western Laurentia (e.g., Yonkee et al., 2014). Southeastern Australia contains ca. 830–790 Ma synrift magmatism (Preiss, 2000), of which there is no record in the Belt region. Additionally, high-quality paleomagnetic constraints indicate Australia was widely separated or significantly offset from western Laurentia at ca. 750 Ma (Eyster et al., 2020). Thus, our proposed ChUMP-B correlation and the younger Windermere Supergroup strata support a

scenario with multiple rifting events west of Laurentia during Rodinia breakup (see Fig. 4). Intervening blocks, likely including western Tasmania, occupied the region between western Laurentia and Australia within Rodinia.



**Fig 5.4:** Simplified Neoproterozoic tectono-stratigraphy (and inferred rift/faulting, sag/thermal subsidence, lithospheric breakup, and passive margin phases) for west-central Laurentia (Belt segment) and suggested conjugate margins, and proposed paleographic cartoon (adapted from Preiss, 2000; Li et al., 2003; Mulder et al., 2020; Brennan et al., 2020, and references therein). In addition to being a magmatic source of ca. 780–720 Ma zircon, western Tasmania also contains a Neoproterozoic history (Mulder et al., 2020) similar to the Belt region (Lund et al., 2010; Brennan et al., 2020). This correlation is consistent with a multiple-rift scenario. Chuar, Uinta Mountain, middle Pahrump Groups–Buffalo Hump Formation (ChUMP-B) strata may have formed in localized inboard rift basins generated from the breakup of Australia-Antarctica and Laurentia. Younger Windermere Supergroup records the rifting of additional intervening blocks, likely including western Tasmania, into an already open paleo–Pacific Ocean.

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### Chapter 6: A tectonic model for the Transcontinental Arch: Progressive migration of a Laurentian drainage divide during the Neoproterozoic– Cambrian Sauk Transgression

### Abstract

A widespread provenance shift recorded by passive margin strata of western Laurentia, from predominant Stenian (1.2–1.0 Ga) detrital zircon age components to their absence, occurred during the Neoproterozoic–Cambrian Sauk transgression and is commonly used as a ca. 540 Ma chronostratigraphic marker throughout the west/south-western United States. However, in Neoproterozoic–Cambrian strata of this region, we identify a probable shift from distal to more proximal Stenian-age zircon sources before a diachronous loss of Stenian detrital zircon age components. We suggest these provenance patterns reflect progressive subsidence of the passive margins surrounding Laurentia and concomitant relative uplift of the Transcontinental Arch, a broad and segmented northeast–southwest trending topographic high across the Laurentian midcontinent possibly due to lithospheric flexure. The Transcontinental Arch segments align with transverse rift structures of the Neoproterozoic–Cambrian Iapetan margin and the Mesoproterozoic Midcontinent Rift, perhaps reflecting rejuvenation of midcontinent lithospheric weaknesses during the Sauk transgression and final Rodinia breakup.

### 6.1. Introduction

Many detrital zircon datasets from extensional (rift, post-rift passive margin and intracratonic) basins show provenance shifts which are commonly interpreted to represent the effects of far-field tectonics that result in reorganization of continental drainage divides (Cawood et al., 2012; Gehrels & Pecha, 2014). Several detrital zircon provenance studies of western Laurentian Neoproterozoic and early Palaeozoic strata deposited during the Sauk transgressions (Sloss, 1963) propose that uplift of a northeast to southwest (all directions in modern coordinates) continental drainage divide across the midcontinent of Laurentia (the Transcontinental Arch; TCA; Fig. 6.1) resulted in the transition from Stenian (ca. 1.2–1.0 Ga) source terranes east of the TCA (Llano Uplift/Wichita province and/or Grenville) for Neoproterozoic strata, to more proximal, predominantly late Palaeoproterozoic source terranes west of the TCA for middle Cambrian through pre-Carboniferous strata (e.g. Amato & Mack, 2012; Gehrels & Pecha, 2014; Linde et al., 2014; Matthews et al., 2018; Mueller et al., 2007; Rainbird et al., 2017; Yonkee et al., 2014). The proposed timing of the initial uplift of the TCA varies from early Neoproterozoic (Craddock et al., 2017), late Neoproterozoic (Gehrels & Pecha, 2014), Cambrian (Linde et al., 2014; Saylor & Sundell, 2021), to Devonian (Myrow et al., 2003). Others (e.g. Howard et al., 2015; Karlstrom et al., 2018) have advocated that a combination of localized factors, predominately (Neoproterozoic-Cambrian) rift-related exhumation and reworking of underlying strata during the Sauk Transgression, require further consideration as potential mechanisms for this provenance shift. Here, we evaluate these competing models with a two-dimensional (U-Pb/Lu-Hf) quantitative comparison (Saylor & Sundell, 2021; Sundell & Saylor, 2021) of ca. 1.3-1.0 Ga detrital zircon components in Neoproterozoic to Cambrian strata of south-western Laurentia and Stenian-age sources to the east (e.g. Llano Uplift/Wichita province, Pikes Peak Batholith and/or Grenville province). We also revisit the timing of the provenance shift in question considering revision of the depositional ages of Cambrian strata in south-western Laurentia (Karlstrom et al., 2018, 2020; Spencer et al., 2014). Collectively, the results suggest a probable progressive shift in Stenian-age sources during the Cryogenian–Ediacaran, prior to a diachronous transition to predominantly late Palaeoproterozoic detrital zircon age components during the Cambrian. We suggest this provenance pattern reflects progressive northeast to southwest uplift (or relative uplift) of a segmented TCA, which correlates with the geometry and timing of the Neoproterozoic–Cambrian rift-drift transition along the Iapetan margin.

### 6.2. Laurentian Rifting and the Sauk Transgression

Sloss (1963) recognized that an extensive latest Precambrian to early Ordovician, unconformity-bounded stratigraphic "Sauk" transgressive mega-sequence occurred across most of Laurentia. The Neoproterozoic to early Ordovician Sauk mega-sequence has been further subdivided into three Sauk sub-sequences (or supersequences; Keller et al., 2012; Palmer, 1981). These three sub-sequences (Sauk I, Sauk II and Sauk III) progressively onlap the cratonic platform and are separated by two regional unconformities, likely relating to relatively short-lived eustatic events at ca. 515 and 495 Ma respectively (Fig. 6.2; Burgess, 2019; Karlstrom et al., 2020; Keller et al., 2012; Palmer, 1981). However, a young and rapid ca. 505 to 501 Ma Sauk II transgression proposed for south-western Laurentia (Karlstrom et al., 2018) implies diachroneity both in the onset times of Sauk sequence transgressions and in drift-phase subsidence of the Laurentian rift margin, which may indicate important local tectonic influences in addition to global eustasy.



Fig. 6.1: Timeline for the Proterozoic and Early Palaeozoic major tectonic events for Laurentia with suggested palaeogeographic reconstructions at (a) ca. 640 Ma, showing the continental divide following the Grenville Belt along eastern Laurentia inferred from detrital zircon populations in Cryogenian-Ediacaran strata along the western margin and (b) at ca. 500 Ma, after relative uplift of the Transcontinental Arch and resulting westward migration of the continental divide resulting in a switch to more proximal source terranes for western Laurentia strata. Cambrian regional facies belts of the Sauk sequence are from Myrow et al., (2012). Numbered locations refer to locality of stratigraphic time-space diagrams in Fig. 6.2. The position of Sonora is restored along the Mojave mega-shear as per Stewart (2005) and Precordillera restored within the Ouachita embayment of per Martin, Collins, et al., (2020). Palaeogeographic reconstructions modified from Gehrels and Pecha (2014)and Ron Blakev are (http://jan.ucc.nau.edu/rcb7/nam.html), which are artistically rendered.

It is now recognized that the Sauk transgressive mega-sequence is likely related to the final breakup of Rodinia (Bond et al., 1984; Dalziel, 2014; Valentine & Moores, 1970). Palaeogeographic models of supercontinent Rodinia (e.g. Li et al., 2008) indicate a diachronous breakup, beginning along the western Laurentian margin with the emplacement of the ca. 780 Ma Gunbarrel magmatic event (Harlan et al., 2003). Related localized sedimentation occurred shortly after (Brennan et al., 2021; Dehler et al., 2017; Lund et al., 2003; Karlstrom et al., 2000) and along most of the western margin by ca. 720 Ma (e.g. Yonkee et al., 2014), coeval with the emplacement of the Franklin large igneous province (Macdonald et al., 2010). The western margin of Laurentia also records a younger (Ediacaran–Cambrian) phase of extension, breakup and syn-to post-breakup magmatism (Beranek, 2017; Bond et al., 1985; Prave, 1999; Ross, 1991).



Fig. 6.2: Generalized stratigraphic time-space diagram representative of the Neoproterozoic to Ordovician sedimentary units along the Laurentian margin adapted from Spencer et al., (2014). The ages of the reported maximum depositional ages (in Ma) are plotted as additional depositional constraints. Uncertainties are  $2\sigma$ . See Fig. 6.1 for generalized stratigraphic section locations. Red zircon symbols indicate the stratigraphic positions of compiled samples in Fig. 6.5. Various rock types, general depositional settings and indicated rift-drift intervals are per the following references: Southern British Columbia and Southeast Idaho (Colpron et al., 2002; Link et al., 1987; Yonkee et al., 2014); rift-related igneous rock age (Colpron et al., 2002); Worm Creek Quartzite detrital zircons (Link et al., 2017); Death Valley stratigraphy (Corsetti & Kaufman, 2003; Heaman & Grotzinger, 1992; Hogan et al., 2011; Prave, 1999); Death Valley detrital zircons (Stewart et al., 2001); Sonora stratigraphy (Farmer et al., 2005; Sour-Tovar et al., 2007; Stewart, 2005; Stewart et al., 2002); Grand Canyon stratigraphy (Karlstrom et al., 2000, 2018, and references therein); southeast Arizona stratigraphy (Hayes, 1972); south-central and southeast Arizona detrital zircons (Stewart et al., 2001); southern New Mexico stratigraphy (Hayes, 1972); southern New Mexico detrital/igneous zircons (Amato & Mack, 2012); west Texas stratigraphy (Hayes, 1972; LeMone, 1969); west Texas detrital zircons (Spencer et al., 2014); Precordillera stratigraphy (Finney et al., 2005); southern Appalachians stratigraphy (Chakraborty et al., 2012; Tull et al., 2010); central Appalachians stratigraphy (Astini, 1995; Burton & Southworth, 2010; Southworth et al., 2009; Tollo 2010); central Appalachians rift-related zircons (Aleinikoff et al., 1995, recalculated by Burton & Southworth, 2010; Southworth et al., 2009) and northwest Vermont stratigraphy (Brink et al., 2019; Landing et al., 2009; Shaw, 1958). Sauk sequence after Palmer (1981). Geologic time scale is after Peng et al., (2020) with Early, Middle and Late Cambrian divisions from the United State Geologic Survey time-scale (U.S. Geological Survey Geologic Names Committee, 2010).

Neoproterozoic to lower Palaeozoic strata preserved along the Laurentian margins were likely deposited within the proximal margin domain (e.g. Brennan et al., 2020; Yonkee et al., 2014). While precise timing is often difficult to determine, in proximal margin domains, the lithospheric breakup surface (i.e. rift-drift transition) is typically recorded as an unconformity (Soares et al., 2012). Evidence for a rift-drift transition at ca. 540 Ma in south-eastern Idaho (Linde et al., 2014; Yonkee et al., 2014) is recognized as an unconformity within the upper Brigham Group, where the feldspathic Ediacaran–Cambrian Camelback Mountain Quartzite disconformably overlies the quartzose Ediacaran Mutual Formation, delineating the base of the Sauk I super-sequence (Link et al., 1987). Further south, an interpreted rift-drift transition in the Grand Canyon region occurred at ca. 505 Ma, recorded as an unconformably between the coarse Cambrian Tapeats Sandstone and the underlying cherty siltstone and sandstone of the Ediacaran–Cambrian Sixtymile Formation. This unconformity is interpreted to coincide with the Sauk I/Sauk II boundary (Amato & Mack, 2012; Karlstrom et al., 2018; Spencer et al., 2014).

Provenance studies document an abundance of distal Stenian detrital zircons in Neoproterozoic strata and a provenance shift to more proximal, predominantly older sources in Cambrian strata (Linde et al., 2014; Matthews et al., 2018; Yonkee et al., 2014). The loss of Stenian detrital zircon populations in Cambrian strata has been interpreted as ca. 540–530 Ma chronostratigraphic indicator in Nevada, Utah, Idaho and Montana (Brennan et al., 2020; Gehrels & Pecha, 2014; Linde et al., 2014; Matthews et al., 2018; Yonkee et al., 2014), generally coinciding with initiation of the Sauk I transgression. However, the absence of biostratigraphic markers, and relatively limited radiometric age control due to the scarcity of syn-depositional volcanism, implies that the depositional ages of these clastic rocks may be poorly constrained and so the inferred synchroneity of the provenance changes remains an open question.

#### **6.2.1 Evaluating the Stenian sources**

Until recently, quantitative assessment of detrital zircon distributions and potential source similarities/dissimilarities was limited to one-dimension, often (U-Pb) age-only, statistical comparison methods (e.g. Nordsvan et al., 2020; Saylor & Sundell, 2016; Vermeesch, 2012, 2013, 2018). However, it is difficult to differentiate between separate source regions with similar magmatic histories using these methods. Consequently, we compiled bivariate (U-Pb and Lu-Hf) datasets (Gehrels & Pecha,

2014; Howard et al., 2015; Martin, Spencer, et al., 2020; Spencer et al., 2012; Wooden et al., 2013 and references therein) of ca. 1,300 to 900 Ma detrital zircon components in late Tonian (<760 Ma) to Cambrian strata of western/south-western Laurentia. These strata are compared to potential source regions in eastern Laurentia (Grenville province), south-eastern Laurentian (Llano and Wichita province) and central Laurentia (Pikes Peak Batholith; Fig. 6.3) utilizing recent two-dimensional quantitative comparison methods (DZstats2D MATLAB code; Sundell & Saylor, 2021). Cross-correlation coefficient results (Fig. 6.4) indicate that north-eastern Stenian-age sources (Grenville) show the strongest statistical correlation with the detrital zircon components in the oldest Tonian–Cryogenian strata, and generally show decreasing similarity with younger Ediacaran and Cambrian strata. Conversely, the similarity of south-western Laurentian strata with south-eastern Stenian-age sources (Llano and Wichita province) increases up-section and is strongest in Cambrian strata. Both the Ediacaran and Cambrian strata show a second strongest similarity with their immediately underlying (older) Tonian-Cryogenian or Ediacaran strata respectively. Additional comparison metrics (Similarity, Likeness, K-S Test D and Kuiper Test V) all show the same trend as the Cross-correlation metric (see supplementary information).

Fig. 6.3: Approximately 1.3–0.9 Ga detrital zircon U-Pb/ Lu-Hf values from (ca. 760-640 Ma) Tonian-Cyrogenian, (ca. 630-550 Ma), Ediacaran (ca. 540-530 Ma) and Cambrian strata in south-western Laurentia and potential ca. 1.3-0.9 Ga eastern source provinces including the Grenville (eastern Laurentia), Pikes Peak (central Laurentia) and Llano/Wichita province (south-eastern Laurentia; see Fig. 6.6). Age (U-Pb) data are shown in kernel density estimation plots with 10 m.y. bandwidths generated with DensityPlotter (Vermeesch, 2012). Lu-Hf data are shown in with individual analysis scatter plots, and bivariate kernel density estimation plots with 25 million-year bin-and 1.5 EHf bandwidths generated with the MATLAB code of Spencer et al., Abbreviations: (2020).DM. depleted mantle; N, number of samples; n, number of analyses.



### 6.2.2 A diachronous loss of Stenian zircon grains?

In south-eastern Idaho and northern Utah (location 2 in Figs. 6.1, 6.2, 6.5 and 6.6), the provenance shift from Stenian sources to predominantly older sources occurs within the Camelback Mountain Quartzite that spans the Ediacaran–Cambrian boundary (Link et al., 1987; Yonkee et al., 2014). Approximately 2,500 meters stratigraphically above where this provenance shift occurs, feldspathic sandstones deposited within a predominately carbonate sequence mark the Sauk II/Sauk III sequence boundary (Armstrong & Oriel, 1965). These feldspathic sandstones (Worm Creek Quartzite Member of the St. Charles Formation) have a late Cambrian (Furongian) age of ca. 495 Ma (detrital zircon maximum depositional age of ca. 497 Ma and Dunderbergia and Elvinia trilobite zones from 495.2 to 493 Ma; Link et al., 2017).

Fig. 6.4: Multi-dimensional scaling (MDS) plot of two-dimensional (U-Pb and Lu-Hf) cross-correlation comparison results for ca. 1.3 to 0.9 Ga zircon components. MDS plots are used to visualize the similarity of datasets, where similar datasets plot closer together in Cartesian space, and less similar datasets plot further apart (see Nordsvan et al., 2020; Saylor & Sundell, 2021; Vermeesch, 2013, for further discussion of MDS plots as applied to zircon datasets). Statistically nearest (or most similar) sources (solid arrow) and second nearest (dashed arrow) geologically feasible sources are Geologically indicated. feasible indicating that it is available as a source at the time of the units' deposition (e.g. Ediacaran strata cannot be sourced from recycling of younger Cambrian strata). Note that Tonian–Cryogenian strata show the greatest similarity to a Grenville source, while Ediacaran and Cambrian strata show a greatest similarity to a Llano and Wichita source, with a second greatest similarity to Tonian-Cryogenian and Ediacaran strata respectively. Similarity, Likeness, Kolmogorov-Smirnov Test D and Kuiper Text V comparison metrics were also calculated and all show the same statistically nearest and second nearest sources indicating reliability of the results. Comparison matrices for all metrics were generated with the DZstats2D MATLAB script of Saylor and Sundell (2021).



In Arizona and west of the TCA (location 5 in Figs. 6.1, 6.2, 6.5 and 6.6) within similar-age strata (Spencer et al., 2014), deposition of the ca. 540–512 Ma Sixtymile Formation spans the Sauk I transgression and contains significant Stenian detrital zircon age components throughout its various stratigraphic intervals (Karlstrom et al., 2018). The provenance shift from dominantly Stenian detrital zircon sources to proximal, dominantly older, sources is not observed in this sequence until the younger (<508 Ma) Tapeats Sandstone, which was deposited during the second major Sauk II transgression (Karlstrom et al., 2018, 2020). The recognition of Cambrian-age detrital zircon in these rocks allowed precise maximum depositional age constraints via tandem dating: laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS) of a large number of grains, followed by chemical abrasion–isotope dilution–thermal ionization mass spectrometry (CA-TIMS) of the youngest grains (Karlstrom et al., 2018, 2020).

East of the TCA in south-eastern New Mexico and western Texas (location 7 in Figs. 6.1, 6.2, 6.5 and 6.6), rocks coeval with the Sixtymile Formation and Tapeats Sandstone that are also interpreted to span the Sauk I/Sauk II boundary contain significant Stenian detrital zircon populations (Amato & Mack, 2012; Spencer et al., 2014). Also east of the TCA, in the central Appalachian region (location 11 in Figs. 6.1, 6.2, 6.5 and 6.6), the Weverton Formation and the overlying Rome Sandstone also contain significant Stenian detrital zircon components. These rocks are interpreted to record the basal Sauk I transgression, suggesting they are mostly similar in age to the upper Brigham Group of southeast Idaho, i.e. Camelback Mountain Quartzite and Gibson Jack Formation (Fig. 6.2). The lower Cambrian Weverton Formation is generally interpreted to record provenance from proximal Grenvillian basement. The overlying Rome Sandstone contains Stenian detrital zircon in addition to older ages typical of the Laurentian craton (including the Granite-Rhyolite, Trans-Hudson, Penokean and Superior provinces), consistent with an Early-Middle Cambrian drainage system that originated in central Laurentia and flowed eastward (Thomas et al., 2004). Similar detrital zircon patterns are found further north in strata of comparable age along the rifted margin of Laurentia in Newfoundland (Cawood & Nemchin, 2001).

Although prolonged rifting started at ca. 750 Ma, continental break-up along the eastern Laurentian margin occurred later than along the western margin (Li et al., 2008; Merdith et al., 2021). Rift-to-drift magmatism indicates continental separation along a north-to-south propagating rift, or distributed rift system, from ca. 615 to 510 Ma, resulting in the opening of the Iapetus Ocean and/or removal of further blocks into an already open Iapetus Ocean (Bond et al., 1984; Cawood et al., 2001; Dalziel, 2014; Mitchell et al., 2011). The rift-drift transition initiated in the central Appalachians at ca. 545 Ma and propagated southward to West Texas by ca. 510 Ma (Fig. 2.2; Martin et al., 2020; Spencer et al., 2014). Iapetan-associated rifting propagated far into the craton, forming intra-continental rift basins (or aulacogens), including the Reelfoot Rift and the Southern Oklahoma aulacogen (Fig. 6.6; Thomas, 2011).

### 6.2.3 The Transcontinental Arch

Initial isopach maps suggested that the Transcontinental Arch (TCA) was a southwest-trending elevated linear feature during Cambrian time (Sloss, 1988). However, stratigraphic compilations and further isopach mapping (Carlson, 1999; Poole et al., 1992) indicate that the TCA was likely a composite, broad and discontinuous plateau dissected by several smaller northwest-striking, laterally persistent, basement-controlled structures of the Mazatzal-Yavapai province highs that served as local sources of detritus for small intervening basins, resulting in a broad, yet segmented TCA (Carlson, 1999).

## 6.3. Tectonic Model: Progressive uplift of an arch between two young passive margins

Bond et al., (1989) advocate that flexural bending of the Laurentian margin and long-term eustasy is responsible for the retreat of the siliciclastic shoreline during the Sauk transgression and have calculated broad flexural uplifts of 100–200 m located over 600 km inboard from the Cordilleran continental margin. These results suggest that sediment loading, thermal densification and post-rifting lithospheric rigidity increase along the craton margin could result in broad uplift of the midcontinent region. Widespread denudation occurred during the Neoproterozoic associated with the formation of the "Great Unconformity" (Flowers et al., 2020; Keller et al., 2018). This denudation, along with the lateral continuity in sedimentary thickness and facies of the Sauk sequence (Sloss, 1963), suggests that the sub-Sauk depositional surface across Laurentia exhibited rather low relief. For example, the Cambrian basal transgressive unit in Wyoming and Montana (the Flathead Quartzite) shows a remarkably uniform average thickness of approximately 35 meters over a region in excess of 90,000 square kilometres (Deiss, 1935). Thus, we propose that a regionally extensive uplift (or relative uplift) of any significant magnitude would have had a notable influence on sedimentary transport systems.



**Fig. 6.5:** Proposed timeline for the widespread provenance shift from dominant Stenian (ca. 1.2–1.0 Ga) detrital grains to older dominantly Palaeoproterozoic detrital grains. In Idaho, northern Utah and Nevada (location 2), this shift has been previously stratigraphically recognized to take place during the Sauk I transgression at ~540–530 Ma (Linde et al., 2014; Yonkee et al., 2014). To the south in the Grand Canyon region (location 5), this shift is precisely placed (by 508.6  $\pm$  0.8 TIMS max depositional age on youngest detrital zircon in Sixtymile Formation) to the Sauk I transgression at ~508 Ma (Karlstrom et al., 2018). Red dashed lines indicate the approximate timing of the provenance shift. East of the Transcontinental Arch at location 7 (Amato & Mack, 2012; Spencer et al., 2014), in a stratigraphic section similar in age to the Grand Canyon section, no loss of Grenville detritus is observed. Also east of the Transcontinental Arch at location 11 (Thomas et al., 2004; Satkoski, 2013), in a stratigraphic section generally similar in age to the Idaho section, no loss of Stenian detrital zircons and possibly a shift to Laurentian midcontinent sources is observed. Data are shown in normalized kernel density estimation plots with 10 m.y. bandwidths. Full sample list can be found in supplementary material A. DZ, detrital zircon; *N*, number of samples; *n*, number of analyses.

At first order, comparison of bivariate (U-Pb and Lu-Hf) datasets suggests that Neoproterozoic–Cambrian strata in south-western Laurentia record a decrease in the contribution of Stenian zircon from north-eastern sources (Grenville) with time and a corresponding increase in the contribution of south-eastern Stenian sources (Llano and Wichita provinces), with recycling from proximal underlying strata being a secondary contributor. Furthermore, the stratigraphic interval that contains the switch from predominantly Stenian zircon components to older Palaeoproterozoic components is variable. In south-eastern Idaho/northern Utah, the shift occurred during the Sauk I transgression at ca. 540 Ma, whereas in south-eastern New Mexico/western Texas Stenian zircon components are present throughout Sauk I strata, and the shift does not occur until ca. 510 Ma within Sauk II transgressive strata. These trends appear to be consistent with progressive (northeast to southwest) west-stepping migration of a significant continental drainage divide resulting from Ediacaran to Cambrian uplift of the TCA. This drainage divide migration probably cut off westward transport of distal Grenville sourced zircon to western/south-western Laurentia at ca. 540 Ma, while northern/north-western transport of more proximal Llano and Wichita sourced zircon appears to have persisted until ca. 510 Ma. This provenance pattern likely reflects progressive (northeast to southwest) formation of the TCA during the Ediacaran–Cambrian resulting from the subsidence of passive margins (and perhaps intracontinental rift basins such as the Reelfoot Rift) surrounding Laurentia, and the resulting lithospheric flexure during the breakup of Rodinia.



(Previous page) Fig. 6.6: Map of the tectonic structures suggested to be interrelated and have influenced the uplift of the Transcontinental Arch (TCA). Laurentian basement provinces and structures adapted from Whitmeyer and Karlstrom (2007), Gehrels and Pecha (2014), Marshak et al., (2017) and Stein et al., (2018). The ca. 1.1 Ga Midcontinent Rift (Stein et al., 2018), the Iapetus rift margin (Thomas, 2014), the western Laurentian margin (Lund, 2008) and uplifted regions of the TCA (Carlson, 1999) all show geometric affinities with each other. Cambrian plutons/dikes/localized detrital zircon age components from Lund (2008); Amato and Mack (2012); Hanson et al., (2013); Link et al., (2017) and references within. Iapetan transform faults bisect segments of the Midcontinent rift and the TCA. Although precise timing of the rift-drift transition along the Iapetan margin is difficult to determine, generally it is thought to have progressively opened from north to south at ca. 615 to 500 Ma (Dalziel, 2014); with rift-drift transitions in the central Appalachians at ca. 545 Ma, and west Texas at ca. 510 Ma (Spencer et al., 2014), consistent with our proposed timing of northwest to southeast progressive uplift of the Transcontinental Arch. The proposed geometry of the Laurentian margin is consistent with an oceanic triple-junction located off south-western Laurentia. AZ, Arizona; BC, British Columbia; IL, Illinois; OK, Oklahoma; NV, Nevada; NM, New Mexico; MT, Montana; ID, Idaho; UT, Utah; WY, Wyoming; TX, Texas; LS, Lake Superior.

The major transverse faults and fault zones of the Iapetan margin (New Jersey, Virginia-Tennessee, Georgia, Alabama-Oklahoma and Texas; Thomas, 2014) align with segments of the Midcontinent Rift and the proposed north-eastwardtrending tectonic units of the TCA (Fig. 6.6). Localized Cambrian deformation, dike swarms and associated magmatism are identified more than 800-1400 km inwards from the continental margin, adjacent to these major transverse fault zones in Colorado, northern New Mexico and perhaps central Illinois (Fig. 6.6; Brueseke et al., 2016; Freiburg et al., 2020; Hanson et al., 2013; Thomas, 2014). These observations lead us to link these Laurentian structures and suggest that the segmented geometry of the Mesoproterozoic Midcontinent Rift acted as a genetic control of the segmentation of the Neoproterozoic Iapetan rifted margin and influenced the geometry of alternating broad highs and intervening lows of the TCA. These transverse fault zone/transverse fault zone-parallel structures initially formed during Midcontinent rifting ca. 1.1 Ga, and we suggest were rejuvenated during Neoproterozoic-Cambrian opening of the Iapetus Ocean and (relative) uplift of the Transcontinental Arch, prior to probable reactivation during Ordovician closure of the Iapetus and subsequent late Palaeozoic closure of the Rheic Ocean (e.g. Craddock et al., 2017). Our analysis suggests that intra-continental transverse riftstructures are long-lived regions of lithospheric weakness.

### 6.4. References

Terra Nova reference style

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# **Chapter 7: Synthesis and Conclusions**

#### 7.1 Introduction

The geologic focus of this thesis spans over 2,000 million years, from the Neoarchean Era to the Cambrian Period. During this time span, Earth underwent numerous cyclical, secular and stepwise modifications. To espouse the preamble quote of this thesis, there are many "horizons" during these 2,000 million years where the geological evidence, and consequently our knowledge of these Earth modifications is missing or incomplete. This work aimed to reduce the extent and uncertainty of several key tectonic/geologic horizons within the key piercing point of the Belt Basin region of western Laurentia, and thus increase the completeness of the Paleoproterozoic to early Paleozoic knowledge of this critical area in many tectonic reconstructions. In doing so, this work provides a more robust regional geologic history against which inherently more speculative larger scale global Nuna and Rodinia tectonic models must be compared, evaluated and redefined.

In the following chapter, the work of this thesis is synthesized and discussed within the context of three general time intervals that correspond to significant global plate-tectonic reorganization events. These time intervals include: ca. 2000–1350 Ma (section 7.2.1) during which supercontinent Nuna assembled, ca. 1350–900 Ma (section 7.2.2) during which supercontinent Nuna broke apart and subsequent supercontinent Rodinia assembled, and finally from ca. 800–500 Ma (section 7.2.3) during which Rodinia broke apart. In a way, these three delineations are a Belt Basin regionally focused update to the unconformity bounded successions A (~1700–1200 Ma), B (1200–800 Ma), and C (800–570 Ma) defined by Young et al., (1979) in northern Laurentia, and subsequently applied southward to most of the western Laurentian margin (Link et al., 1993).

#### 7.2 Summary and significant findings

#### 7.2.1 Paleoproterozoic Laurentia and Nuna assembly

As introduced in Chapter 1, a main controversy surrounding global Paleoproterozoic paleogeography is whether the final assembly of supercontinent Nuna was primarily a ca. 1800 Ma process coeval with the main assembly of Laurentia (e.g. Zhao et al., 2002), or if final Nuna assembly was primarily a later, ca. 1600 Ma process (e.g. Kirscher et al., 2021). In northwestern Laurentia and northeastern Australia, ca. 1750–1550 Ma strata record final Nuna assembly at ca. 1600 Ma

(Furlanetto et al., 2016; Nordsvan et al., 2018). However, ~1500 km further south in the Belt Basin region, the focus area of this study, previous provenance studies have primarily focused on the ca. 1470–1380 Ma Belt Supergroup (e.g. Ross and Villenaeuve, 2003; Lewis et al., 2007) and neglected the significance of potential pre-Belt Supergroup units, such as the Gold Cup and likely correlative Neihart quartzites (Doughty and Chamberlain, 2008) to constrain the tectonostratigraphic record of this region prior to ca. 1470 Ma.

As discussed in Chapter 3 (section 3.2.1) the Mesoproterozoic Belt Basin traverses at least two significant Paleoproterozoic sutures associated with the assembly of Laurentia, which include the Great Falls Tectonic Zone and the Vulcan Structure. The better exposed, and thus better studied of these structures is the Great Falls Tectonic Zone which records ca. 1860-1730 Ma convergent events associated with northwest dipping subduction and amalgamation of the Medicine Hat and likely Clearwater block(s) to the Wyoming province (e.g. Mueller et al., 2002; Foster et al., 2006; Gifford et al., 2020). In Chapter 2, existing (Vervoort et al., 2016) and new zircon geochronology from the Clearwater Block indicates that crustal growth in this region occurred primarily at ca. 2670 and ca. 1880-1840 Ma, with localized magmatism at ca. 1581 Ma. New zircon Lu/Hf and O- isotope data, also suggest that the younger interval of Paleoproterozoic crustal growth primarily records remelting of older lithosphere, as opposed to significant juvenile mantle contributions. However, additional constraints on this period of ca. 1880-1840 Ma crustal growth in the Clearwater block have been published (Wang et al., 2022) following the publication of Chapters 2 and 3. Thus, we include these new results here (Fig. 7.1).



**Fig. 7.1:**  $\epsilon$ Hf<sub>t</sub> values vs. (<sup>207</sup>Pb/<sup>206</sup>Pb) Age plot for the Clearwater Block (Chapter 2; Wang et al., 2022). The colored box plots indicate the range of  $\epsilon$ Hf<sub>t</sub> values calculated for each gneiss based on the measured Lu/Hf, and the interpreted crystallization age of the sample. See Fig. 2.7 for explanation of Mantle evolution curves. The red boxes are from the Coeur d'Alene Gneiss in the Priest River complex near the Laclede Gneiss outcrop (Wang et al., 2022). Wang et al., (2022) also reports Lu/Hf data from ca. 1900–1830 Ma orthogneiss located further south in the Clearwater complex, which show a slightly wider range of  $\epsilon$ Hf<sub>t</sub> values from approximately –8 to +8 (Wang et al., 2022). CHUR–Chondritic Uniform Reservoir (Bouiver et al., 2008).

In Chapter 3, additional U/Pb (prior limited n-analyses presented by Ross and Villeneuve, 2003; Doughty and Chamberlain, 2008; Mueller et al., 2016) and the first Lu/Hf detrital zircon results from the oldest, younger than ca. 1750 Ma strata that unconformably overlie the Clearwater and Medicine Hat/Great Falls Tectonic Zone basement terranes, the Gold Cup Quartzite and Neihart Quartzite, was presented. The objective of this data was to evaluate whether these likely pre-Belt Supergroup units require non-Laurentia sources or not, and thus assess competing models on the timing of Nuna assembly. The detrital zircon components of both the Gold Cup and Neihart quartzites consist of primarily two age distributions at ca. 2670 Ma and ca. 1860–1780 Ma. The Neoarchean grains contain CHUR-like Lu/Hf values, and consequently are similar in age and Hf composition to the nearby Clearwater Block basement. However, the Paleoproterozoic grains contain a wider range of Lu/Hf values that are generally concentrated around three  $\varepsilon$ Hf ranges, +8 to +4, -3 to -7, and -14 to -18 (Neihart Quartzite only), suggesting perhaps mixing of at least three possible sources. Suitable sources for these grains are found within ca. 1800 Ma ( $\varepsilon$ Hf = -10 to -20) rocks of the

Medicine Hat block (Gifford et al., 2020), ca. 1880–1840 Ma ( $\epsilon$ Hf<sub>t</sub> = +8 to -8) rocks of the Clearwater complex (Vervoort et al., 2016; Wang et al., 2022), the extensive ca. 1860-1780 Ma Trans-Hudson orogen, and perhaps ca. 1880–1740 Ma ( $\epsilon$ Hf<sub>t</sub> = +10 to -5) rocks of the Mojave-Yavapai-Mazatzal provinces (Whitmeyer and Karlstrom, 2007; Holland et al., 2018 and references within). Consequently, the tectonostratigraphic record of the Belt region does not require any non-Laurentian sources during Laurentian assembly, and thus is broadly consistent with the ca. 1800 Ma assembly of the main Archean blocks (Wyoming, Medicine Hat, Clearwater, Hearne) of western Laurentia prior to a later ca. 1650–1600 Ma assembly of Nuna. In western/southwestern Laurentia, a record of this later assembly may be associated with ca. 1670 Ma metamorphism in the Farmington Zone (Mueller et al., 2011), and the ca. 1650–1600 Ma Mazatzal Orogeny (Gibson and Champion, 2019; Holland et al., 2020).

In Chapter 2, the  $1581 \pm 3$  Ma Laclede Gneiss within the Priest River complex contains evolved Lu–Hf ( $\varepsilon$ Hf = -6 to -10) and mantle-like  $\delta$ 18O zircon values, suggesting remelting of a Neoarchean lower continental lithosphere source. The evolved values of this gneiss makes it a poor direct match for coeval, mostly juvenile, magmatism in the Gawler Craton of southeastern Australia (Reid and Payne, 2017). Thus, I advocated that the Laclede Gneiss is not a stranded fragment of Australian crust. However, as Wang et al., (2022) note, Antarctica and southeastern Australia do have similar age (ca. 1580 Ma) evolved (negative  $\varepsilon H f_t$ ) magmatism that could be a non-Laurentian source for the Laclede Gneiss. Nevertheless, the evolved (negative ɛHft) values for the Laclede Gneiss importantly demonstrate that a non-Laurentian source for the similar-age evolved (positive EHf) detrital zircon grains within the surrounding Belt Supergroup is required. This zircon source is likely the Gawler Craton of southeastern Australia, as it contains magmatic rocks with the same age and Hf values as the juvenile ca. 1600 Ma detrital zircon grains within the overlying Belt Supergroup (Fig. 7.2). Ca. 1630-1580 Ma St. Peters Suite and Gawler Range Volcanics in southeastern Australia have plume and/or back-arc genesis models (e.g. Reid and Payne 2017; Chapman et al., 2019). Consequently, as discussed in Chapter 2 (section 2.5.4), the Laclede Gneiss may be a crustal-derived, distal manifestation of a ca. 1580 Ma mantle up-welling (perhaps plume) event beneath southeastern Australia. Therefore, the Belt Basin regional geologic record does not require the assembly of Australia/East Antarctica with western Laurentia within Nuna at ca. 1800

Ma, and rather the first indirect evidence of this association may be recorded in the 1581 Ma Laclede Gneiss.



**Fig. 7.2:** Paleo–Mesoproterozoic stratigraphy and U–Pb/Lu–Hf detrital zircon results from the Priest River Region (Doughty and Chamberlain, 2008; Box et al., 2020; Lewis et al., 2020; Brennan et al., 2021) and the range of robust  $\epsilon$ Hf<sub>t</sub> values (samples 67DTB19 and 37DTB19) from the underlying ca. 2670 and 1580 Ma igneous basement. The red box indicates the age and  $\epsilon$ Hf<sub>t</sub> range (ca. 1.88-1.83 Ga) of Paleoproterozoic magmatism in the northern extent of the Clearwater Block (Vervoort et al., 2016) and the Lu–Hf values of Wang et al., (2022) for the Coeur d'Alene Gneiss. Wang et al., (2022) also reports Lu/Hf data from ca. 1900–1830 Ma orthogneiss located further south in the Clearwater complex, which show a slightly wider range of  $\epsilon$ Hf<sub>t</sub> values from approximately –8 to +8, which could be the source of the more juvenile ca. 1860–1830 Ma grains in the Gold Cup Quartzite. (Wang et al., 2022). Inferred crustal evolution line (Lu/Hf = 0.022) for the Clearwater Block indicated. LE–Late Extraction, NC–New Crust, CHUR–Chondritic Uniform Reservoir. See Fig. 2.7 for explanation of mantle evolution lines.

#### 7.2.2 Mesoproterozoic Laurentia and the Nuna to Rodinia transition

In Chapters 2 and 4, it was demonstrated that the ca. 1600 Ma detrital zircon grains within Belt Basin strata were not sourced from the Laurentian ca. 1581 Ma Laclede Gneiss, as its evolved (negative  $\epsilon$ Hf<sub>t</sub>) values could not have supplied the juvenile (positive  $\epsilon$ Hf<sub>t</sub>) detrital grains. Other workers (e.g. Yao et al., 2017; Xu et al., 2019; Goodge et al., 2017) have suggested that ca. 1570–1510 Ma magmatic rocks in Hainan Island (south China) or East Antarctica could have contributed detritus to the

Belt Basin. However, zircon grains from these magmatic rocks also exhibit evolved (negative  $\epsilon$ Hf<sub>t</sub>) values (see Fig. 2.10), and thus are also poor matches for the grains in Belt Basin strata. Consequently, the mostly juvenile ca. 1630–1580 Ma magmatism within the Gawler craton of southeastern Australia is the best match for these detrital grains, adding further support to long-standing correlations between these two regions during the Mesoproterozoic (Ross et., 1992; Ross and Villeneuve, 2003).

A long-standing controversy in Belt Supergroup geology, is whether the ca. 1470-1380 Ma Belt Basin is a rift to passive margin sequence that records Nuna breakup at ca. 1400 Ma, or whether the Belt Basin was completely intracratonic and preceded Nuna breakup (e.g. Evans et al., 2000; Ross and Villeneuve, 2003; Lonn et al., 2020 and references within). In fact, paleomagnetic data indicates that Australia and western Laurentia were likely in a stable configuration from ca. 1600-1300 Ma suggesting that the Belt Basin may have been completely intracratonic and preceded ca. 1300–1200 Ma Nuna breakup (Kirscher et al., 2021). Limited (n = 29 within their applied -5 to 20% discordant filter) U/Pb detrital zircon results from upper Belt Supergroup strata in northeastern Washington reported by Box et al., (2020) also suggests that the exotic, likely Australian, ca. 1630–1580 Ma source terrane shared sediments with Laurentia until ca. 1390 Ma. The limited geochronology results (of Box et al., 2020) from upper Belt Supergroup, Missoula Group strata (Snowslip Formation) in the Priest River region require substantiating, particularly due to the notable Pb-loss in this sample. It is worth noting that I analyzed a similar upper Belt Supergroup, Missoula Group (Snowslip Formation) sample (14DTB19; see Chapter 3), which yielded almost entirely discordant ages consistent with ca. 95 Ma Pb-loss. Nevertheless, the Missoula Group results of Box et al., (2020) do suggest an Australian-Laurentian connection within Nuna until at least ca. 1390 Ma. However, until recently (Chapter 3; Box et al., 2020), no strata between the ca. 1380 Ma upper Belt Supergroup and ca. 720 Ma basal Windermere Supergroup, were identified in the Belt Basin region. Consequently, there was a limited regional geologic record to compare against paleomagnetically constrained models of ca. 1300-1200 Ma Nuna breakup.

Early work on the Deer Trail Group in northeastern Washington State (Miller and Whipple, 1989) correlated these rocks with ca. 1450–1380 Ma Belt Supergroup strata, suggesting they were the western-most exposures of Belt strata. In Chapter 3 new detrital zircon U–Pb results from the Deer Trail Group were presented. These results support interpretations like those recently presented by Box et al., (2020), and indicate that the Deer Trail Group is mostly younger than 1300 Ma, and thus not correlative to older Belt Supergroup strata further east. The ages and Lu/Hf values of the detrital zircon components in the Deer Trail Group indicate a mixed Laurentian provenance. Notably, Deer Trail Group strata do not record any non-Laurentian sources, and thus indicate a provenance shift from the sources recorded in the underlying Belt Supergroup. The fine-grained siliciclastic and carbonate lithology, and lack of significant syn-depositional magmatic detrital zircon components in Deer Trail Group strata are consistent with their deposition during a period of regional subsidence within the Priest River region that coincides with purported Nuna breakup at ca. 1300-1200 Ma (Kirscher et al., 2020). These stratigraphic and provenance observations suggest the Deer Trail Group may have been deposited during final rifting and passive margin subsidence associated with Nuna breakup. While the only minimum depositional age constraint on the Deer Trail Group is the maximum depositional age of the overlying, < 760 Ma, Buffalo Hump Formation, it is possible that the Deer Trail Group is much younger than ca. 1200 Ma. For example, it is possible that the Deer Trail Group was instead deposited during the assembly and/or early tenure of Rodinia. However, given the absence of ca. 1200–1000 Ma "Grenville-age" zircon grains in the Deer Trail Group, despite their prevalence in Neoproterozoic strata in the region lends credence to a likely ca. 1300–1200 Ma age for the Deer Trail Group.

During this same general time interval, prior workers identified a tectonomagmatic event that may have terminated deposition of the Belt Supergroup. McMechan and Price (1982) delineated the East Kooteny orogeny as a ca. 1350 Ma period of regional folding, metamorphism, and magmatism within the northern extent (southeastern British Columbia) of the Belt Basin. However, in the more southern extent of the Belt Basin (north central Idaho) Doughty and Chamberlain (1996) instead assert that the East Kooteny "orogeny" was not an orogen but rather a ca. 1380–1330 Ma pulse of bimodal magmatism, basin rifting, and renewed subsidence and sedimentation that shortly preceded the end of the deposition in the Belt Basin.

New results from ca. 1400–1350 Ma metamorphic zircon from a mafic sill within the Clearwater complex (presented in Chapter 2) contain  $\delta$ 180 values consistent with hydrothermal zircon growth. In Chapter 4, metapelitic rocks from the western portion of the Clearwater complex are also shown to contain ca. 1350 Ma and younger ca. 1070 Ma monazite U/Pb ages. Interestingly, within the three studied

samples from the western Clearwater complex, all three-record garnet growth associated within the younger ca. 1070 Ma monazite ages. However, only one sample recorded garnet growth (Zirakparvar et al., 2010; Neishem et al., 2012) associated within the older ca. 1350 Ma monazite ages, suggesting lower pressure (below approximately 6 kbar) metamorphism for this older event. Consequently, the occurrence of hydrothermal zircon growth and apparently high temperature, lower pressure metamorphism, as well as the absence of any coarse-grained strata possibly associated with this event, suggests that the "East Kootenay Orogeny" is more consistent with a period of bimodal magmatism and basin rifting within the Clearwater complex, then tectonic thickening.

#### 7.2.3 Neoproterozoic Laurentia and Rodinia breakup.

The correlation of ca. 1200–1000 Ma "Grenville-age" orogens have been critical in the construction of various Rodinia models (e.g. Dalziel et al., 1991; Karlstrom et al., 2000; Li et al., 1995). Consequently, the absence, or presence of a poorly preserved/recognized, Grenville-age orogen in western Laurentia is a significant constraint that accurate paleogeographic models must account for. Within this work, the metamorphic (Chapter 4) and tectonostratigraphic (Chapters 3 and 5) record of a potential Grenville-age orogen in the Belt Basin region was investigated. We note that no direct record of ca. 1250–800 Ma magmatism in the Belt Basin region was found by this, or any previous studies.

In Chapter 4, existing Lu/Hf garnet geochronology (Zirakparvar et al., 2010; Neishem et al., 2012) and new monazite and apatite U-Pb results and Thermocalc (pressure-temperature) constraints from ca. 1450 Ma Belt Supergroup metapelitic strata within the western portion of Clearwater complex (notably within the Piegan Group of the Belt Supergroup) indicate that Phanerozoic Cordilleran conditions did not exceed ~550–450°C in this region. Consequently, the mineral assemblages within these rocks likely reflect a high-grade, Grenville-age, metamorphic event recorded by ca. 1100–1060 Ma garnet Lu/Hf and monazite U/Pb ages. Thermodynamic modeling of these mineral assemblages indicate they are consistent with pressures of 7.5–5 Kbar, and temperatures of 670–620°C, suggesting burial to a depth of ~22–17 km or greater around along a moderately-high average geothermal gradient of ~36–23°C/km. Elsewhere in the Belt Basin, and I suggest spatially associated with inherited lithospheric-scale faults, similar ca. 1100–1070 Ma metamorphic events are noted

(McFarlane and Pattison, 2000; Aleinikoff et al., 2012; Pattison and Seitz, 2012; Bookstrom et al., 2016).

At ca. 1100 Ma Laurentia was undergoing a period of widespread extension and thermal upwelling. Manifestations of this event are found in the 1110–1085 Ma Midcontinent Rift (e.g. Swanson-Hysell et al., 2019), 1115–1078 Ma Pikes Peak batholith (Guitreau et al., 2016), 1094–1080 Ma Southwestern Laurentian Large Igneous Province (Timmons et al., 2001; Bright et al., 2014), and 1090–1040 Ma Bylot and correlative basins in northern Laurentia (Greenman et al., 2021). Despite the evidence for Laurentian-wide extension and thermal upwelling at this time, it is indeed difficult to account for pure depositional burial of the Piegan Group (of the Belt Supergroup) to a depth ~22–17 km, when the preserved thicknesses of overlying Belt strata are >10 km, and Deer Trail Group strata are ~3.5 km thick. Therefore, the ca. 1110–1060 Ma period of continent-wide thermal upwelling and reactivation of crustal weaknesses, may have indeed combined with localized inversion of the Belt Basin to produce the metamorphism present in the Clearwater complex.

Importantly, as demonstrated in Chapter 5, if there was indeed any Grenville-age localized inversion of the Belt Basin, and the stratigraphic record of this event was preserved, it must be reflected in the Deer Trail Group, whose fine-grained lithology and recycled detrital zircon provenance signature is a better match for an extensional basin than typical convergent or collisional sequences (Fig. 7.3). Alternatively, no strata was deposited during local inversion of the Belt Basin, or it was subsequently eroded, likely prior to Cryogenian rifting.

Previously, the only possibly suspected Grenville-age (ca. 1000 Ma) strata in western Laurentia was the Buffalo Hump Formation. Prior workers had suggested it required a western Grenville-age source based in part on its erroneous correlation to finer-grained Belt Supergroup strata further east (Miller and Whipple, 1989), and that the Buffalo Hump Formation contained ca. 1100 Ma detrital zircon grains (Ross et al., 1992). However, in Chapter 5, the identification of a small, yet significant, ca. 760 Ma detrital zircon population in the Buffalo Hump Formation indicates that it was deposited during Rodinia breakup, not assembly. The presence of large (20+ cm) reworked Deer Trail Group cobbles in the Buffalo Hump Formation, and the absence of the Buffalo Hump strata along with thinned to absent Deer Trail Group strata east of a regional thrust fault (the Jumpoff Joe Fault) suggests that the thrust is a reactivated Neoproterozoic normal fault. Consequently, the Buffalo Hump Formation records

early ca. 760–720 Ma Rodinia fault-controlled rift-basin formation similar to coeval deposits further south in the Uinta, Chuar and Pahrump basins. These results constrain the onset of rifting in the Belt Basin region to after ca. 760 Ma and thus about 70 Myrs later then in the Adelaide Superbasin of the Gawler craton in southeastern Australia (Preiss, 2000; Lloyd et al., 2020). This time difference makes it difficult for the Belt Basin region (western Laurentia) and the Adelaide Superbasin region (Gawler craton) to be direct conjugate margins as is suggested by Rodina SWEAT models (e.g. Moores et al., 1991).



**Fig. 7.3:** Cumulative proportion curves of the general fields the variation of the difference between the measured crystallization age for a detrital zircon grain, and the depositional age of the succession in which it occurs for convergent, collisional, and extensional basins (from Cawood et al., 2012). Plotted curves show the strata investigated in this work, with the Gold Cup Quartzite in purple, Belt Supergroup in dark blue, Deer Trail Group in green, and Buffalo Hump Formation in light blue. For the Gold Cup Quartzite and Deer Trail Group, whose depositional ages are only broadly constrained, the maximum depositional age approximated by the youngest detrital zircon population is the thicker line, and potential younger minimum depositional ages are plotted as the same color but thinner lines.

Importantly, deposition of the Buffalo Hump Formation during Rodinia rifting, not assembly, along with the accompanying detrital zircon populations in the Buffalo Hump Formation indicates that its detrital zircon components came from eastern/southeastern Laurentia including the Grenville and intervening provinces. This detritus was likely carried via pancontinental fluvial systems that drained the Grenville orogeny as is suggested for other Neoproterozoic western, and northern Laurentia strata that contain similar detrital zircon age-components (e.g. Rainbird et al., 1992; 2017, Yonkee et al., 2014). During the Neoproterozoic–Cambrian Sauk transgression, many stratigraphic sections along the western U.S. Laurentian margin, record a provenance shift (often roughly correlated with the Neoproterozoic/Cambrian boundary, e.g. Linde et al., 2014) involving abundant ca. 1200–1000 Ma detrital zircon grains to their absence. Despite the widespread nature of this provenance shift, a tectonic mechanism and an understanding of how these Laurentian-wide provenance trends relate to Rodinia breakup processes was lacking.

In Chapter 6, a compilation of Stenian (ca. 1200–1000 Ma) zircon (detrital and igneous) U/Pb and Lu/Hf values were compiled and statistically compared. The results indicated that while eastern Laurentian Grenville province sources are the most likely source for Stenian detrital zircon grains in Tonian and Cyrogenian strata (like the Buffalo Hump Formation), more southern Llano Inlier and Wichita province sources are a better match for Stenian detrital zircon grains in Ediacaran strata. The trends also suggest that the eventual loss of far-travelled Stenian detrital zircon age-components progressed from north to south (Idaho to Arizona) from ca. 540 to 510 Ma. Consequently, these new results suggest that the generally north to south opening of the Iapetus Ocean along the eastern margin of Laurentia (near the center of Rodinia) results in the migration of a drainage divide from eastern to southern to the midcontinent of Laurentia, known as the Transcontinental Arch (e.g. Sloss, 1988). Importantly, this tectonic model provides a mechanism for the signification continentscale shifts in Laurentian sedimentary systems during Rodinia breakup, and further emphasizes that the eastern and western margins of Laurentia not only differed in character during the assembly of Rodinia (see Chapter 5) but that these margins also differed (perhaps influenced by inheritance of older assembly related features) in character during the breakup of Rodinia.

# 7.3 From Laurentia assembly to Rodina breakup: A revised early tectonic evolution of the Belt Basin region and its importance for global models

This work provides several important updates to the timing, importance, and correlation of Proterozoic geologic events in the Belt Basin region, some of which were foundational in the proposal of various Precambrian paleographic models and thus have importance that ranges well beyond western Laurentia.

Almost thirty years ago, Link et al., (1993) wrote:

"First, the Neihart Quartzite at the base of the Belt (Schieber, 1989a) may be part of a supermature discontinuous quartz sand body (Freeman and Winston, 1987) that blanketed the craton after the Early Proterozoic assembly of Laurentia (about 1,900 to 1,700 Ma; Hoffman, 1989) and before faulting and subsidence of the Belt Basin (about 1,450 Ma). If the Neihart is a genetically distinct unit, it should be removed from the Belt."

In 1998, Doughty et al., suggested that the Gold Cup Quartzite in the Priest River complex is a western equivalent to the Neihart Quartzite based on similarity in detrital zircon U/Pb ages. Mueller et al., (2016) presented further arguments for an approximately 200 m.y. "pre-Belt" age for the Neihart Quartzite based on additional detrital zircon age result differences between the Neihart Quartzite and the Prichard Formation (lower Belt Supergroup). In the simplest stratigraphic sense, Walter's Law of stratigraphic succession (i.e. any vertical progression of facies is the result of a succession of depositional environments that are laterally juxtaposed to each other; Middleton, 1973) dictates a disconformity between the coarse, pebbly fluvial to nearshore Goldcup Quartzite and the overlying lower slope deposits of the basal (member A) Prichard Formation (Cressman, 1985). This relationship is consistent with the tectonized unconformity contact identified by Doughty and Chamberlain (1998) in the field. The additional detrital zircon U/Pb and Lu/Hf data presented in Chapter 3 further support both these findings, and thus I tend to support the suggestion that the Neihart and Gold Cup quartzites both be "removed from the Belt" indicating that the unconformity between lower Belt strata and these pre-Belt quartzites may represent a significant ~300–200 Myr duration. I encourage further work on the physical, temporal and tectonostratigraphic relationships of the allegedly lower Belt equivalents within the Helena embayment (see Mueller et al., 2016). None of the detrital zircon components within these units suggest a non-Laurentian provenance, and consequently the strata in the Belt Basin region do not require Nuna assembly prior to ca. 1750 Ma, and are permissible with models (e.g. Nordsvan et al., 2018) of a later 1650–1600 Ma final Nuna assembly.

It has been long recognized that the source region of the western Belt Basin lay to the west of the basin and was removed by subsequent rifting (Ross et al., 1992). Detrital zircon studies of western Belt Basin strata revealed that this source terrane was primarily comprised of ca. 1700–1500 Ma rocks, including ca. 1610–1490 Ma "North American Magmatic Gap" ages, which are rare in Laurentia, but abundant in southeastern Australia, establishing early ties between these two regions during the Mesoproterozoic (Ross and Villeneuve, 2003). However, identification of other ca. 1590–1550 Ma "North American Magmatic Gap" granitoids in East Antarctica (Goodge et al., 2017), south China (Xu et al., 2019), and within the Belt Basin region itself (e.g. Evans and Fischer, 1986) brought into doubt the uniqueness of the western Belt Basin, southeastern Australia provenance tie. However, currently only the Gawler Craton of southeastern Australia contains ca. 1590–1550 Ma granitoid sources (Reid and Payne, 2017) that match the juvenile Lu/Hf values of the similar-age zircon grains found within the western Belt Basin (Fig. 7.2; see Chapters 2 and 3). Further testing of this relationship by other detrital phases (e.g. rutile, monazite) may yield interesting results into the tectonic setting of this relationship (e.g. Pereira et al., 2020). The similar timing, and proposed genetic relationship between ca. 1580 Ma magmatism in the Priest River region, and coeval magmatism in southeastern Australia, suggest that these two regions may have been adjacent to each other within Nuna by ca. 1580 Ma, consistent with paleomagnetic constraints (see Fig. 7.5; Kirscher et al., 2019).

The absence of juvenile ( $\epsilon$ Hf > +5) ca. 1700–1500 Ma detrital zircon grains within ca. 1450 Ma successions on Hainan Island of south China, means that the detrital zircon provenance rationalization for featuring Hainan Island (Xu et al., 2019), and sometimes the entire Cathasia block (e.g. Yao et al., 2017) between the Belt Basin and SE Australia within Nuna is not strongly justified. However, the sample size (21 zircon grains, Xu et al., 2019) from ca. 1450 Ma Hainan Island strata that include Lu/Hf data is relatively small and additional analysis may refine this assertion. Other evidence commonly used to justify the central location of Hainan Island and the Cathaysia block in Nuna, such as correlating ca. 1450 Ma felsic magmatism on Hainan Island with the ca. 1500–1350 Ma Granite-Rhyolite province of southern Laurentia (Li et al., 2008b) is permissible. Magmatism at this time was generally widespread along the margin of Nuna, with coeval magmatism recognized in other cratons like Baltica, Amazonia, and India (e.g. Johansson et al., 2022; Sequeira et al., 2022).

Many of the Paleoproterozoic to early Mesoproterozoic correlations discussed above and in prior chapters of this work were incorporated into early reconstructions of supercontinent Rodinia (e.g. Bell and Jefferson, 1987; Moores et al., 1991; Dalziel, 1991; Hoffman, 1991). Thus, at least some of the evidence for a Neoproterozoic SWEAT-like **Rodinia** connection was, in fact, evidence of a Mesoproterozoic (proto-) SWEAT-like **Nuna** connection. In part, the apparent absence of Young et al.'s (1979) "succession B" or Grenville-age (ca. 1200–1000 Ma) strata between ca. 1480–1380 Ma Belt and < 720 Ma Windermere Supergroup strata in the Belt Basin region (see Link et al., 1993), led many of these early models to advocate a long-lived relative tectonic relationship between Australia and western Laurentia during the Mesoproterozoic to Neoproterozoic. However, other subsequent models (such as the missing-Link; Li et al., 1995; 2002; 2013) rather advocated for a complete Wilson cycle (e.g. opening and closing of an ocean basin) along western Laurentia during Grenville-time. One line of reasoning to support this model was the alleged presence of "succession B" or Grenville-age (ca. 1200–1000 Ma) orogenesis and foreland basin strata recorded within the Buffalo Hump Formation along the western edge of the Belt Basin. Consequently, this thesis took a critical look at the geologic record of a potential western Grenville-age orogen within the Belt Basin region, which until this work (Chapter 3, 4, and 5) was not vigorously tested.

In Chapter 5, the speculated South China-derived ca. 1100–1000 Ma foreland basin deposit within the Buffalo Hump Formation (Li et al., 1995; 2002; Yao et al., 2017) was investigated. While, the Buffalo Hump Formations' coarse nature, and conglomeratic horizons did indeed suggest proximal uplift during its deposition, the small yet significant ca. 760 Ma detrital zircon population, and regional stratigraphic relations, indicated that the Buffalo Hump Formation was not an exotically derived Grenville-age orogenic deposit. Instead, the Buffalo Hump Formation is a Laurentian sourced ca. 760–720 Ma rift basin deposit. The unconformably underlying Deer Trail Group strata (see Chapter 3), could possibly be ca. 1200–1000 Ma in age, given that they contain a ca. 1300 Ma youngest detrital zircon population. However, Deer Trail strata lack Grenville-age detritus but otherwise exhibit a clear Laurentian provenance signature. Additionally, their fine-grained siliciclastic and carbonate nature precludes adjacent significant uplift. Thus, if the Deer Trail Group is Grenville in age, they are also inconsistent with a proximal orogen and rather suggest a period of extension within the region.

In Chapter 4, the ca. 1400–1000 Ma garnets reported from the Clearwater complex (Zirakparvar et al., 2010; Neishem et al., 2012) and their potential record of a Grenville-age orogen was also investigated. The new monazite U/Pb results support the occurrence of two main metamorphic events, an older ca. 1380–1330 Ma event, and younger ca. 1100–1060 Ma event. The older event was widely recorded in monazite U/Pb ages but only locally resulted in garnet growth, consistent with a lower pressure, higher temperature event. This event likely relates to similar-age hydrothermal zircon growth (see section 2.5.6) and magmatism within the Belt Basin.

These results are consistent with previous interpretations of ca. 1380–1330 Ma being a period of magmatism and renewed rifting within the Belt Basin (Doughty and Chamberlain, 1996) and do not require orogenic thickening. However, the Pressure-Temperature-time constraints suggest that the younger ca. 1100–1060 Ma event recorded burial of middle Belt Supergroup strata (Piegan Group) to depths of at least ~17–22 km along a moderately-high average geothermal gradient. Elsewhere in Laurentia at this time, similar age geology records mantle/thermal upwelling, intraplate volcanism, reactivation of crustal weaknesses and extension such as within the 1110–1085 Ma Midcontinent Rift (e.g. Swanson-Hysell et al., 2018), 1115–1078 Ma Pikes Peak batholith (Guitreau et al., 2016), 1094–1080 Ma Southwestern Laurentian Large Igneous Province (Timmons et al., 2001; Bright et al., 2014), and 1090–1040 Ma Bylot and correlative basins in northern Laurentia (Greenman et al., 2021; see Fig. 4.2).

Consequently, thermal upwelling and reactivation of crustal weaknesses within the Belt Basin likely contributed to the ca. 1100–1060 Ma metamorphism. However, there is an approximately 6 km discrepancy between the calculated burial depth, and the preserved thickness of overlying units, suggesting either A) a component of tectonic burial, likely through localized inversion of the Belt Basin, and related burial of Belt strata in the Clearwater region or B) miscalculation of Belt Supergroup and perhaps Deer Trail Group stratigraphic thickness and/or subsequent erosion. However, if calculated pressures do reflect tectonic burial, this tectonism was amagmatic, localized, associated with syndepositional Belt Basin structures, and produced very little (to no) preserved sedimentation. Thus, of the multiple working models presented in Chapter 4, transpressional/transtensional mechanism, rather than subduction-driven continent-continent collisional orogenic tectonic mechanism may be more likely. Importantly, after the termination of this metamorphic event around ca. 1060 Ma, there is no record of any magmatism and/or tectonism in the Belt Basin region until the intrusion of the Gun Barrel dyke swarm around 780 Ma (Harlan et al., 2003). In the Belt Basin region, recalibration of the Buffalo Hump Formation (see Chapter 5) indicates that ca. 780 Ma dyke intrusion was followed by widespread but localized riftbasin development from ca. 760-720 that correlates to other localized Laurentian basins. Collectively, these "CHUMP-B" basins reflect early Rodinia breakup (e.g. Dehler et al., 2017; Chapter 5). As discussed in Chapters 5 and 6, in the Belt Basin region, intermittent Cryogenian-Cambrian sedimentation was likely influenced by local rift structure/timing as well as Laurentian-scale drainage divide migrations associated with circum-Laurentia rifting. Importantly, Neoproterozoic–Cambrian strata in the Belt Basin region record final rifting and breakup in the late Ediacaran–early Cambrian (Lund et al., 2010; Lund and Cheney, 2016; Brennan et al., 2020; 2022).

This revised geologic record (Fig. 7.4) is difficult to reconcile with a SWEATlike (e.g. Moores, 1991; Merdith et al., 2017) configuration which places southeastern Australia, and its record of mantle plume and rifting activity as early as 830 Ma, as a direction conjugate to Belt region within Rodinia. A Missing-Link configuration (Li et al., 1995; 2013) which was initially proposed to alleviate some of the same discrepancies with a SWEAT configured Rodinia, highlighted above, instead places South China, and its significant ca. 1300–900 Ma Grenville-age orogenesis (Li et al., 1995; 2007), widespread ca. 950–830 Ma volcanism (Yao et al., 2019), and record of rifting as early as 850 Ma (Li et al., 2008) directly conjugate to the Belt region within Rodinia. Thus, a Missing-Link configuration, with South China adjacent to the Belt Basin region of Laurentia near the center of Rodinia, is also not a perfect fit for allegedly adjacent regional geologic histories. Recently, an external or peripheral location of South China within Rodinia is often advocated due to South China's Neoproterozoic tectonostratigraphic similarity with India (e.g. Cawood et al., 2013) and some paleomagnetic constraints (Park et al., 2021; Chang et al., 2022).

As a result, the regional geologic constraints discussed and redefined throughout this thesis highlights issues with both of the most commonly applied Rodinia models, and echos the ethos of recent paleomagnetic reconstructions that also indicate a tight-fitting SWEAT or Missing-Link configuration may be untenable within Rodinia (Eyster et al., 2020; Park et al., 2021; Swanson-Hysell, 2021; Chang et al., 2022). Consequently, perhaps neither southeastern Australia, nor South China were directly adjacent to the Belt Basin region within Rodinia. As speculated in Chapter 5, widespread, perhaps multiphase ca. 760–540 Ma rifting and passive margin sequences along most of western Laurentia may instead reflect the rifting of other smaller blocks (recent work suggests Tasmania or Tarim may be suitable candidates) or yet-to-be identified ribbon continents (e.g. Mulder et al., 2020; Jing et al., 2021), rather than a single protracted rifting event between Laurentia and eastern Australia or Laurentia and South China (see Fig. 7.5).



**Fig. 7.4:** Left: Time-space diagram for the Paleo–Neoproterozoic geology and corresponding tectonic events of the western Belt basin region (northeastern Washington and northern Idaho, USA), and major western Laurentian tectonic events (ca. 2018) prior to the onset of this work. Center: The revised Time-space diagram for the western Belt basin region resulting from the data and conclusions presented in this work. Right: Summary of the tie-point relationships of the Belt basin region and their importance for paleogeographic tectonic reconstructions.

Although hardly proven, reconsidering the "Missing-Link" model (Li et al., 1995) for a more a peripheral location of South China within Rodinia does imply significant geodynamic implications for Rodinia breakup. Importantly, Li et al., (1999; 2008) speculate that Rodinia breakup began around ca. 825 Ma via a superplume centered beneath the supercontinent. In this model, the superplume event was best recorded in the ca. 830–820 Ma plume and rifting record of a centrally placed South China block. Thus, alternative models that argue for a peripheral location of South China within Rodinia (e.g. Park et al., 2021; Chang et al., 2022; Wang et al., 2020) instead suggest that supercontinent breakup initiated mostly along the margins of the supercontinent subduction processes, such as subduction retreat and more localized mantle upwelling were more key drivers of Rodinia breakup than a proposed central superplume event (c.f. Cawood et al., 2016; Li et al., 2008).



**Fig. 7.5:** Growing consensus Nuna and debated Rodinia models. The location of the Belt basin region is indicated by the black star in each reconstruction. Figure adapted from Evans (2021 and references within). Abbreviations include: Am, Amazonia; Au, Australian cratons including Antarctic Mawsonland; Ba, Baltica; Co, Congo; In, India; Ka, Kalahari; Laur, Laurentia; NC, North China; RP, Rio Plata; SC, South China; SF, Sao Francisco; Sib, Siberia; Ta, Tarim; WAf, West African craton.

Collectively, the redefined tectonic history of the Belt Basin region strengthens models of a (proto-) SWEAT configured Nuna supercontinent from ca. 1600-1300 Ma (Kirscher et al., 2020) but identified tectonostratigraphic issues with these same regions as directly conjugate rift margins within subsequent supercontinent Rodinia (Fig. 7.5). I also emphasize that some of the original SWEAT correlations made in support of early Rodinia models (Moores, 1991; Dalziel, 1991; Hoffman, 1991), such as western derived detritus in the Mesoproterozoic Belt Basin, instead support a (proto) SWEAT-like relationship during Nuna-time. On the other hand, several of the foundational assertions that the Missing-Link model relied upon, such as the shared provenance between Hainan Island and the Belt Basin and Buffalo Hump Formation, (Li et al., 1995; 2008; Yao et al., 2017), considering new data are worth re-evaluating. However, it is worth noting that a Missing-Link configuration, notably the significant ca. 1300–900 Ma Grenville-age orogenesis and Neoproterozoic plume record in South China (e.g. Li et al., 1995; 2008), does perhaps provide the most compatible geologic record to reconcile the aforementioned differences with a SWEAT-like configured Rodinia.

Consequently, while the value and importance of global tectonic models for understanding and predicting fundamental earth processes is undeniable, it is clear that after more than 30 years of focused research, a clear consensus on Proterozoic paleogeography is still lacking. Thus, I respectfully submit that the work of this thesis espouses the foundational tenet that scientific progress requires that all viable models remain open to observation-driven modification and refinement. With anticipation, openness, and humility, I look forward to new observations testing, refining and perhaps refuting the interpretations I present here.

#### 7.4 References

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Appendix A: Statements of Co-Authorship and Copyright Permissions

# Appendix A1: Statement of Co-Authorship for Chapter 2

Chapter 2: Closing the "North American Magmatic" Gap: Crustal evolution of the Clearwater Block from multi-isotope and trace element zircon data *published in Precambrian Research* 

	Conceptualization and Design	Data Acquisition and Method	Data processing and Visualization	Interpretation and discussion	Total contribution (%)	
Co-author 1						
Daniel T.	75	75	80	70	75	
Brennan						
Co-author 1 ackno I acknowledge that research output	wledgement: t these represent my contr	ibution to the above	Signed:			
<b>Co-author 2</b> Paul K. Link	15	-	5	10	7.5	
Co-author 2 ackno I acknowledge that research output	wledgement: t these represent my contr	ibution to the above	Signed:			
Co-author 3						
Zheng- Xiang Li	10	-	5	10	6.25	
Co-author 3 acknowledgement: Signed: I acknowledge that these represent my contribution to the above research output.						
<b>Co-author 4</b> Laure Martin	-	15	5	-	5	
Co-author 4 ackno I acknowledge that research output	wledgement: t these represent my contr	ibution to the above	Signed:			
Co-author 5						
Tim E.	-	-	-	10	2.5	
Johnson						
Co-author 5 acknowledgement: Signed: I acknowledge that these represent my contribution to the above research output.						
Co-author 6						
Noreen J. Evans	-	5	5	-	2.5	
Co-author 6 acknowledgement: Signed: I acknowledge that these represent my contribution to the above research output.						
<b>Co-author 7</b> Jiangyu Li	-	5	-	-	1.25	
Co-author 7 ackno I acknowledge that research output	wledgement: these represent my contr	ibution to the above	Signed:			
Total%	100	100	100	100	100	

### Appendix A2: Statement of Co-Authorship for Chapter 3

Chapter 3: Detrital zircon U-Pb and Hf signatures of Paleo-Mesoproterozoic strata in the Priest River region, northwestern USA: A record of Laurentia assembly and Nuna Tenure *published in Precambrian Research* 

	Conceptualization and Design	Data Acquisition and Method	Data processing and Visualization	Interpretation and discussion	Total contribution (%)		
<b>Co-author 1</b> Daniel T. Brennan	50	85	85	60	70		
Co-author 1 ackno I acknowledge tha research output	wledgement: t these represent my cont 	ribution to the above	Signed:				
<b>Co-author 2</b> J. Brian Mahoney	20	10	10	10	12.5		
Co-author 2 acknowledgement: I acknowledge that these represent my contribution to the abores earch output.			Signed:				
C <b>o-author 3</b> Zheng- Xiang Li	20	-	-	15	8.75		
Co-author 3 ackno I acknowledge tha research output	wledgement: t these represent my cont	ribution to the above	Signed:				
<b>Co-author 4</b> Paul K. Link	10	-	-	10	5		
Co-author 4 acknowledgement: Signed: I acknowledge that these represent my contribution to the above research output.							
<b>Co-author 5</b> Noreen J. Evans	-	5	5	-	2.5		
Co-author 5 acknowledgement: Signed: I acknowledge that these represent my contribution to the above research output.							
<b>Co-author 6</b> Tim E. Johnson	-	-	-	5	1.25		
Co-author 6 acknowledgement: Signed: I acknowledge that these represent my contribution to the above research output.							
Total	100	100	100	100	100		

## Appendix A3: Statement of Co-Authorship for Chapter 5

Chapter 5: Recalibrating Rodinian rifting in the northwestern United States *published* in Geology

	Conceptualization and Design	Data Acquisition and Method	Data processing and Visualization	Interpretation and discussion	Total contribution (%)
Co-author 1	70	60	70	60	65
Co-author 1 acknowledgemen contribution to the above res	t: I acknowledge that earch output.	these represent my	Signed:		
<b>Co-author 2</b> Zheng-Xiang Li	20		-	15	8.75
Co-author 2 acknowledgemen contribution to the above res	t: I acknowledge that earch output.	these represent my	Signed:		
<b>Co-author 3</b> Kai Rankenburg	5	15	10	-	7.5
Co-author 3 acknowledgemen contribution to the above res	t: I acknowledge that earch output.	these represent my	Signed:		
<b>Co-author 4</b> Noreen Evans		15	10	-	6.25
Co-author 4 acknowledgemen contribution to the above res	t: I acknowledge that earch output.	these represent my	Signed:		
<b>Co-author 5</b> Paul K. Link	5			10	3.75
Co-author 5 acknowledgemen contribution to the above res	t: I acknowledge that earch output.	these represent my	Signed:		
<b>Co-author 6</b> Adam Nordsvan			5	5	2.5
Co-author 6 acknowledgemen contribution to the above res	t: I acknowledge that earch output.	these represent my	Signed:		
<b>Co-author 7</b> Christopher L. Kirkland	-	5	5	-	2.5
Co-author 7 acknowledgemen contribution to the above res	t: I acknowledge that earch output.	these represent my	Signed:		
<b>Co-author 8</b> J. Brian Mahoney	-	-		5	1.25
Co-author 8 acknowledgemen contribution to the above res	t: I acknowledge that earch output.	these represent my	Signed:		<u> </u>
<b>Co-author 9</b> Tim_Johnson	-	-		5	1.25
Co-author 9 acknowledgemen contribution to the above res	t: I acknowledge that earch output.	these represent my	Signed:	<u> </u>	
<b>Co-author 10</b> Bradley J. McDonald	-	5	-	-	1.25
Co-author 10 acknowledgeme contribution to the above res	nt: I acknowledge that earch output.	at these represent my	Signed:	L	
Total%	100	100	100	100	100

## Appendix A4: Statement of Co-Authorship for Chapter 6

Chapter 6: A tectonic model for the Transcontinental Arch: Progressive migration of a Laurentian drainage divide during the Neoproterozoic–Cambrian Sauk Transgression *published in Terra Nova* 

	Conceptualization and Design	Data Acquisition and Method	Data processing and Visualization	Interpretatio n and discussion	Total contribution (%)
<b>Co-author 1</b> Daniel T. Brenn an	50	80	80	50	65
Co-author 1 acknow I acknowledge that research output.	vledgement: these represent my con	tribution to the above	Signed:		
C <b>o-author 2</b> Ross N. Mitchell	30	10	15	15	17.5
Co-author 2 acknow I acknowledge that research output.	vledgement: these represent my con	tribution to the above	Signed:		
<b>Co-author 3</b> Christopher J. Spencer	10	10	5	15	10
Co-author 3 acknow I acknowledge that research output.	vledgement: these represent my con	tribution to the above	Signed:		
C <b>o-author 4</b> J. Brendan Murphy	10	-	10	10	7.5
Co-author 4 acknow I acknowledge that research output.	vledgement: these represent my con	tribution to the above	Signed:		
<b>Co-author 5</b> Zheng-Xi an g Li	-	-	-	10	2.5
Co-author 5 acknow I acknowledge that research output.	vledgement: these represent my con	tribution to the above	Signed:		
Total%	100	100 100	100	100	100
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# Appendix B: Conference Abstracts presented during this Doctoral Thesis

## Appendix B1: 2022 Geological Society of Australia Earth Science Student Symposium Abstract



# An ancient Australian-American Alliance: a multi-isotope investigation of western N. America relations within Proterozoic supercontinents

<u>Daniel T. Brennan<sup>1</sup></u>, Zheng-Xiang Li<sup>1</sup>, Paul K. Link<sup>2</sup>, Tim Johnson<sup>3</sup>, Noreen Evans<sup>4</sup>

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Along the west-central margin of Laurentia (North America), within the Priest River and Clearwater metamorphic complexes, rare exposures of "North American Magmatic Gap" (NAMG, ca. 1.61-1.49 Ga) crystalline basement rocks of the Clearwater Block are present. Overlying these crystalline basement rocks are ca. 1.47–1.38 Ga Belt Supergroup strata that also contain NAMG-age detrital zircon grains. This unique igneous and detrital record of NAMG-magmatism stands in contrast to other regions of North America that generally lack a record of any ca. 1.61-1.49 Ga tectono-magmatic activity. These differences led some early researchers to speculate that Proterozoic supercontinent events may have stranded exotic, perhaps Australia associated basement terranes within the Clearwater Block and that Australia (or perhaps Antarctica or South China) may have supplied the NAMG zircon grains within the overlying Belt Supergroup. If true, the rocks that now constitute some of the most scenic mountains in the northwestern United States were actually once part of Australia. Here, we report new U-Pb, Lu-Hf and O isotope data from Neoarchean and Proterozoic igneous and sedimentary rocks within the Priest River and Clearwater regions of western N. America. Our isotopic results indicate that ca. 1.58 Ga "NAMG" magmatism within the Clearwater block records mantle-like δ18O values but subchondritic (-5.5 to -9.7) εHft values in zircon, suggesting (perhaps plume-driven) reworking of the Neoarchean country rock. The overlying Belt Supergroup strata contain similar-age detrital zircon grains but with more juvenile suprachondritic (positive)  $\epsilon$ Hft values that are similar to igneous sources in southeastern Australia. Collectively, these zircon results suggest that the Clearwater Block does have a North American origin, and that detrital zircon grains in the overlying sedimentary rocks of the Belt Supergroup record non-North American sources consistent with rocks in southeastern Australia. Consequently, these new results lend further support for an ancient Australian-American geological alliance.

## **Appendix B2: 2021 Australian Earth Sciences Convention Abstract**

which point to a global increase in thermal gradients that intersected granite genesis. We suggest these changes occurred as the secular cooling of the mantle and crust was reversed by a net increase in the spatial extent of continental crust between 2–1.8 Ga, resulting in thermal insulation of the mantle. The following 1.2 billion years on Earth was dominated by a warm, insulated mantle and crust, maintained by stable continental volumes, which eventually cooled to allow the second emergence and widespread preservation of eclogites from *ca* 0.8 Ga until present. While novel, this idea combines unrelated global petrological and geochemical datasets to explore the sensitivity of switches in the thermal evolution of the solid Earth.

## When did Australia's Cratons come together?

Gorczyk, Weronika, Tyler, Ian, Aitken, Alan, & Kohanpour, Fariba

Centre of Exploration Targeting, School of Earth Science, University of Western Australia, Perth, Australia

Assembly of Australian cratons as part of Nuna assembly has been a subject of debates for decades. Especially within Australian geoscience community the timing and style of Western Australia Craton (WAC) with Norther Australian Craton (NAC) collision causes a lot of controversy. The dispute arises mostly due to sparsity of data available. As the Proterozoic knowledge of Australian cratons, as well as others grew new models for Nunan assembly were proposed, and the literature become overcrowded with variable models, based on localised and limited data.

Here, without presenting any new data, an attempt is made to analyse existing models in an unbiased style, questioning and correlating all the tectonic and sedimentation events across WAC, NAC and SAC (Southern Australia Craton). The position and interactions with Laurentia and North China – which are believed to be proximal to Australia at the time of paleo– meso Proterozoic, as also considered.

To achieve this task, plate reconstruction software (GPlates) is used. Publicly available geological data that describe tectonic and sedimentary events affecting WAC, NAC and SAC, as well as paleomagnetic data to are taken into account to support or contradict conceptual models. The immense advantage of this approach is continuous space and time visual representation of the plate interactions and occurrence of events.

Three (with variations) time models of WAC and NAC collision are shown with different subduction polarity: (1) 1800-1765 Ma, (2) 1590-1550 Ma, (3) ca 1300 Ma. Essentially, in the first model one can correlate all the tectonic events across WAC an NAC and SAC with one another post-collision, but spatial problem arises between the cratons and events that follow. In the second model the collision of WAC and NAC can be correlated with metamorphic and magmatic events in Arunta region, as well as in Mt Isa, but does not allow for correlation of previous events across WAC and NAC. The third model with subduction under WAC combines the tectonic evolution of Paterson region, Wankanki Arc and Stage I of Albany Fraser in a very elegant way, but again keeps WAC on a separate palate prior 1300 Ma and does not allow for correlation of events across the cratons of with similar styles and timings. Pros and cons for all models will be presented, and the verdict will be left to you.

## Detrital zircon record of Proterozoic strata in the Priest River region of western Laurentia: Evaluating "SWEAT" relationships for supercontinents Nuna and Rodinia

# Brennan, Daniel T.<sup>1</sup>, Li, Zheng-Xiang<sup>1</sup>, Link, Paul K.<sup>2</sup>, & Johnson, Tim<sup>3</sup>

<sup>1</sup>Earth Dynamics Research Group, School of Earth and Planetary Sciences, Curtin University, WA, Australia; <sup>2</sup>Department of Geosciences, Idaho State University, Pocatello, ID, USA; <sup>3</sup>School of Earth and Planetary Sciences, The Institute for Geoscience Research (TIGeR), Curtin University, WA, Australia

Correlation of rocks across purportedly paired margins, such as Proterozoic strata (notably the Belt-Purcell and Windermere Supergroups) of western Laurentia with coeval rocks and/or magmatic sources in and around the Gawler Craton, have long been used as a key piercing point for SWEAT-like reconstructions of supercontinents Nuna and Rodinia. Here we evaluate the nature and timing of the proposed correlations through U–Pb and Lu–Hf analysis of detrital zircon (DZ) from the Proterozoic Gold Cup Quartzite, Belt-Purcell Supergroup, Deer Trail Group, and Buffalo Hump Formation of the Priest River region, northwestern USA.

The <1.7 Ga Gold Cup quartzite contains mostly ca 2.6 and 1.8 Ga DZ grains, indicating it is likely a western equivalent of the Neihart Formation. Lu-Hf values from these grains suggest that the younger ca 1.8 Ga population ( $\varepsilon$ Hft = -9 to -3) resulted from a reworking event on the ca 2.6 Ga crust involving juvenile mantle input ( $\epsilon$ Hft = -2 to 4). This is consistent with the sediments being sourced from proximal Neoarchean Laurentian terranes such as the Clearwater/Medicine Hat block, that were intruded by Paleoproterozoic magmatism associated with the collision of the Wyoming and Medicine Hat blocks. Thus, these units do not require a SWEAT configuration (or the existence of Nuna) at ca 1.7 Ga. In the overlying western (ca 1.48–1.37 Ga) Belt Supergroup units, significant juvenile ( $\epsilon$ Hft = 2 to 8) ca 1.6 Ga DZ grains are present. These grains fall within the North American Magmatic Gap and likely indicate provenance from the Gawler Craton, supporting a proto-SWEAT configuration for Nuna during ca 1.5-1.4 Ga as in most Nuna reconstructions. The overlying <1.3 Ga, fine-grained and carbonate Deer Trail Group is interpreted as a passive margin succession and contains mostly ca 1.9-1.65 Ga DZ grains with a wide range of Lu-Hf values  $(\varepsilon Hf_t = -6 \text{ to } 9)$ , notably ca 1.6 Ga DZ grains are absent. This provenance shift could be indicative of Nuna breakup, removal of the Gawler Craton from its Nuna position along western Laurentia, and a southwestern Laurentia provenance or recycling from underlying rocks of the Lemhi group of the Belt-Purcell Supergroup.

Coarse, locally conglomeratic, rocks of the Buffalo Hump Formation unconformably overly Deer Trail group strata. Prior small-n DZ study of the Buffalo Hump Formation identified a *ca* 1.1 Ga youngest DZ population, which was suggested to record deposition at *ca* 1.0 Ga during Rodinia amalgamation. However, our large-n study of the Buffalo Hump Formation identified for the first time a minor (~1%) yet significant *ca* 760 Ma DZ population, which constrains the maximum age of deposition. These geochronology results redefine the onset of Rodinia rift-related sedimentation to after *ca* 760 Ma in this region. Additionally, the Buffalo Hump Formation lacks any *ca* 900–790 Ma DZ grains. Such a DZ age-spectrum, and inferred rift history, is difficult to reconcile with an immediate neighbourhood between Laurentia and Australia in Rodinia as the latter had an earlier start of continental rifting (with *ca* 830–750 Ma rifting and synrift magmatism).

## Review of SHRIMP zircon ages for the Eastern Succession of the Mount Isa and Etheridge Provinces and their provenances

#### Withnall, Ian

Geological Survey of Queensland, Brisbane, Australia

The migration of zircon geochronology data collected by Geoscience Australia (GA) and Geological Survey of Queensland (GSQ) from the Mount Isa Province into the Online Geochron Delivery System, an important repository maintained by GA, provided an opportunity to review the data and replot it using a consistent approach. This included data for which only preliminary plots of had been available to GSQ and never published.

The review highlighted that the main magmatic events that would have contributed zircon to the Eastern Succession sedimentary rocks occurred at 1850–1870 Ma, 1790–1800 Ma, 1780 Ma, 1760 Ma, 1735–1745 Ma, 1725 Ma, 1705–1715 Ma and 1670–1680 Ma and volumetrically smaller events at 1770 Ma, 1755 Ma, 1655–1660 Ma and 1650 Ma.

The Soldiers Cap Group in the easternmost part of the Mount Isa Province and extending under cover to the east is younger than most of the eastern succession. It consists of Llewellyn Formation, Mount Norna Quartzite and Toole Creek Volcanics in ascending stratigraphic order. The Kuridala Group comprises the Starcross Formation and Hampden Slate.

Samples of the two lowermost units of the Soldiers Cap Group and Starcross Formation have similar maximum depositional ages. A closer comparison has been made of their respective provenances by pooling analyses for units in each group. These provenances are similar, indicating a minor, very old source around the Archean-Proterozoic boundary and then almost none up to ca 1900 Ma (the Barramundi Orogeny). Except for minor components from the Kalkadoon-Leichhardt basement (1850–1870 Ma) and Argylla Formation (1780 Ma), by far the major sources appear to be the Wonga-Burstall-Gin Creek plutonic suites at ca 1740 Ma and Fiery Creek Volcanics or Weberra Granite at ca 1710 Ma. They also both have a significant younger component (slightly older in the Soldiers Cap Group at ca 1685 Ma, and ca 1675 Ma in the Starcross Formation). Pooling analyses from the Hampden Slate indicates that apart from the youngest component being ca 1655 Ma, other components are almost identical to those in the Starcross Formation.

By contrast the provenance of the Toole Creek Volcanics is dissimilar to the other units. It shows an *ca* 1795 Ma, *ca* 1850 Ma, and *ca* 2680 Ma.

Comparing the provenance spectra of the lower part of

the Soldiers Cap and Kuridala Groups with those of the lower part of the Etheridge Group in the Etheridge Province (Georgetown region) suggests that they were probably deposited at about the same time, but the provenance patterns are strikingly different. The Etheridge Group shows a large Archean component as well as almost continuous spread of data points throughout the Paleoproterozoic including peaks around 1900–2000 Ma. This dissimilarity has been cited as evidence that the Georgetown rocks were not distal to Mount Isa and were part of Laurentia until welded to the Australian craton during the assembly of Nuna. The provenance of the upper part of the Etheridge Group, however, is like that of the Toole Creek Volcanics.

#### Partial melting, granulites, retrogression and their control on late orogenic exhumation processes

Cenki-Tok, Bénédicte<sup>1,2</sup>, Rey, Patrice F.<sup>2</sup>, & Arcay, Diane<sup>1</sup>

<sup>1</sup>Géosciences Montpellier, Université de Montpellier, CNRS, 34095 Montpellier Cedex 5, France; <sup>2</sup>Earthbyte Research Group, School of Geosciences, University of Sydney, NSW 2006, Sydney, Australia

Orogenesis drives the differentiation of the continental crust through metamorphic and magmatic processes, the exhumation of deep metamorphic terranes and the concomitant formation of sedimentary basins. A major consequence of prograde metamorphism following a typical orogenic thermal gradient is the dehydration and partial melting of buried rocks leading to the formation of migmatites and granulites. Partial melting and granulitisation are often intertwined and primarily linked to the availability of fluids. Here, we consider the thermal and mechanical consequences of coupled partial melting, granulitisation and strain-rate dependent retrogression during the orogenic cycle, in particular during the recovery phase when the crust's thickness and geotherm re-equilibrate. We explore through 2D thermo-mechanical modelling how the interplay between mechanical weakening due to partial melting and mechanical strengthening due to granulitisation impacts the formation and preservation of crustal roots, the exhumation of the partially molten crust in gneiss domes, the formation of HT/UHT terranes and the partitioning of deformation through the crust.

Our results show that the survival of granulites, which strengthen the lower crust and decrease its capacity to flow under gravitational stresses, impedes the formation of migmatite-cored gneiss domes, and controls the formation and preservation of thick and strong granulitic roots. These are strong enough to stay immune to gravitational stresses and persist over hundreds of million years. These can be actually compared with stable intracontinental regions where the presence of localized crustal roots explains the remarkable variability - from 25 to 65 km - of crustal thickness. Finally, our results highlight the importance of an elevated radiogenic heat production in the upper crust in order to form the long-lived HT/UHT terranes often resulting from supercontinents amalgamation. Our experimental results explain as well why some ancient orogenic domains expose at the Earth's surface dominantly granulitic terranes (e.g., South India, Sri

# Appendix B3: International Geoscience Programme 648 Virtual Seminar Series Abstract

UPERCONTI	NENT CYCL	ES & GLO	DBAL	GEODTIN	AMIC	5						
Home IGCP 648	Group members	Research	News	Contact Us	Links	PhD Opportunities	Australian palaeo-/rock-magnetism work					
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geologic mapping (2019 USGS Student Geologic Map 1 <sup>st</sup> place winner) redef         sequence of Neoproterozoic and lower Paleozoic strata. Dan is scheduled to         his PhD in January 2022.         Abstract         Supercontinent Rodinia assembled through widespread (Grenvillian) orogenia         events between 1300 Ma and 900 Ma, and much like its assembly experience         diachronous break up, perhaps recorded by localized rifting as early as 825 M         The western margin of Laurentia (North America) occupied a critical, central         location within Rodinia. Despite its important location and its relatively well-st         nature, the evolution of these processes in western Laurentia and the identity         conjugate margins is a subject of long-standing debate. Here, we present res         from the northwestern United States (Washington State), including the Buffald         Hump Formation. The Buffalo Hump Formation unconformably overlies ca. 1.         strata, and was previously interpreted by some to be a ca. 1.0 Ga "Grenvilliar         deposit formed during Rodinia assembly. Our study of ~2000 detrital zircong         from the Buffalo Hump Formation identified for the first time a minor (~1%) by significant ca. 760 Ma population, which constrains the maximum age of         deposition. This indicates an absence of Grenville-age sedimentation and a c												

## **Appendix B4: 2019 Geological Society of America Annual Meeting**



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## GSA Annual Meeting in Phoenix, Arizona, USA - 2019

Paper No. 127-4 Presentation Time: 9:00 AM-6:30 PM

DETRITAL ZIRCON U/PB AND LU/HF ANALYSES OF THE BUFFALO HUMP FORMATION AND UNDERLYING DEER TRAIL GROUP: INSIGHTS INTO THE PROTEROZOIC TECTONOSTRATIGF

BRENNAN, Daniel T.<sup>1</sup>, LI, Zheng-Xiang<sup>2</sup>, NORDSVAN, Adam<sup>2</sup>, LINK, Paul K.<sup>3</sup>, MAHONEY, J. Brian<sup>4</sup>, YAO, Weihau<sup>2</sup> and PARKER, Stuart D.<sup>5</sup>, (1)Department of A<sub>J</sub> Australia; Geology, University of Wisconsin - Eau Claire, Eau Claire, WI 54703, (2)Department of Applied Geology, Curtin University of Techology, Department 6845, Australia; (3)Geosciences, Idaho State University, Pocatello, ID 83209, (4)Geology, University of Wisconsin - Eau Claire, WI 54703, (5)Idaho St

Significant uncertainties regarding the Proterozoic tectonic history of the western margin of Laurentia hampers our understanding of the timing, geometry, the occurrence of a complete Wilson cycle along the western margin of Laurentia during the Nuna to Rodinia transition has been suggested, substantiating the sedimentary, metamorphic, and structural record of the region.

The Deer Trail Group and the overlying Buffalo Hump Formation constitute a -3km thick siliciclastic and dolomitic sequence that are typically thought to be Belt Supergroup. Early work suggested a possible exotic western provenance for some of the units. Here we present new detrital zircon data that revise the predominantly argillaceous and dolomitic Deer Trail Group (Togo Fm.) has a maximum depositional age (MDA) of -1365 Ma, but consist mostly of a -1.6 to 1 younger than, but shares similar sources with, the upper Belt Supergroup equivalent strata in the Lemhi sub-basin. Up-section, detrital zircon spectra from : Ga and a dominant Stenian (1.2–1.0 Ga) population that shows juvenile Lu-Hf isotopic values (eHf of +2 to +12). Several tectonic models propose the existent western margin of Laurentia, offering a proximal, non-Laurentian source for this detritus at ca. 1.0 Ga. However, nearby (<780 Ma) Windermere Supergroup zircon populations that are interpreted to have been sourced from distal Laurentian Grenville provinces.

This new data corroborates Box et al.'s (2019; GSA Cordillera abstract) that the Buffalo Hump Formation likely unconformably overlies the Deer Trail Group, including paleocurrent analysis, is required to evaluate their potential for constraining the late Proterozoic tectonic evolution of western Laurentia and its protection of the second secon

#### Session No. 127--Booth# 324

T50. Structure and Tectonic Studies, from Outcrop to Supercontinent (Posters): In Honor of Ian Dalziel Monday, 23 September 2019: 9:00 AM-6:30 PM

Hall AB, North Building (Phoenix Convention Center)

Geological Society of America Abstracts with Programs. Vol. 51, No. 5

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Back to: T50. Structure and Tectonic Studies, from Outcrop to Supercontinent (Posters): In Honor of

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## Appendix C: Non Peer-Reviewed Science Outreach Articles

## Appendix C1: A Short Hike on the Edge of Ancient North America: Out There Outdoors Magazine, 2021



## HIKING

**Quartzite Mountain** A Short Hike on the Edge of Ancient North America By Daniel T. Brennan



THE CHEWELAH VALLEY, like any good valley, is flanked on both sides by mountain ranges. To the east is the Selkirk Range and to the west are the Huckleberry Mountains. However, these mountains are relatively young geologically—we are talking only tens of millions of years.

#### GEOLOGIC HISTORY OF THE CHEWELAH VALLEY

Long before the rocks that make up the Selkirks and Huckleberry Range were uplifted into mountains, geologists have suggested western North America was connected to an unidentified continent, perhaps Australia, around 1 billion years ago. Scientists consider ancient configurations such as this one as a "supercontinent," this one being called "Rodinia," which comes from the Russian word "to give birth" since geologists once thought all subsequent continents spawned from the breakup of Rodinia. You may be more familiar with the most recent supercontinent called Pangea that existed approximately 300 million years ago.

Around 780 million years ago, tectonic forces broke apart supercontinent Rodinia, and a new pre-Pacific Ocean formed. Since the rocks that make up the western portions of Washington State and Oregon are significantly younger than 780 million years old, this suggests that the ancient edge of North America, that formed during breakup of supercontinent Rodinia, lies unidentified somewhere in the mountains of eastern Washington.

Research, by myself and other colleagues that was recently published in the peerreviewed scientific journal "Geology," suggests that this supercontinent breakup process occurred directly beneath the Chewelah Valley about 760 million years ago. All it takes is a short but steep hike up Quartzite



Mountain, just east of Chewelah, to get an awesome view from what was once the edge of this ancient world.

#### SOLVING AN ANCIENT GEOLOGIC MYSTERY

On Quartzite Mountain, the oldest sedimentary rocks are called the Belt Supergroup and are made of silt, sand, and limestone that were deposited approximately 1.4 billion years ago, likely within a huge ancient lake in the center of supercontinent Rodinia. As you start the steep incline near the Quartzite Mountain trailhead, these are the poorly exposed rocks you are hiking over. However, at the top of Quartzite Mountain, orange blocky outcrops of hard quartzite rocks create a striking cliff. These rocks are only about 540 million years old, indicating a complete absence of the approximately 780-600 million year-old rocks that are thought to have been deposited when supercontinent Rodinia was breaking apart.

However, west across the valley in the Huckleberry Mountains, beneath the same approximately 540-million-yearold quartzite rocks, very different rock layers, or stratigraphy, is present. These different rock layers include small quartzite boulders in a unit called the Buffalo Hump Formation. The nature of the sand and silt layers in the Buffalo Hump indicated to us that it was likely deposited in ancient river channels, deltas, or a shallow basin. By measuring uranium and lead isotopes of certain minerals in these different rock layers, our geologic study revealed that an ancient river deposited these small boulders approximately 760 million years ago, and the boulders were sourced from the approximately 1.3-billion-year-old rocks exposed across the valley, near the top of Quartzite Mountain

This suggests uplift and erosion of the eastern side of the modern Chewelah valley, and subsidence of the western side sometime around 760 million years ago. We proposed that the simplest way to explain the ancient topography suggested by these rocks is the existence of an ancient fault, or fracture in the earth's crust, underneath the Chewelah Valley. This fault likely lowered the western portion of the valley and uplifted the eastern portion. Such faults commonly form when continents are pulled apart in a process known as rifting. All of this suggests that the edge of ancient North America was forming directly below Chewelah about 760 million years ago.

#### HIKING QUARTZITE MOUNTAIN

There you go. Take a hike up Quartzite Mountain and contemplate that. You are a human living on a 4.6 billion-year-old planet currently standing on the 760 million-yearold edge of ancient North America. If you are fortunate, you may live for 100 years—an infinitesimally small quantity in comparison. Don't waste it. Go for a hike. Get out there! This moderate hike is 3 miles roundtrip with 800 feet of elevation gain.

To get there from Chewelah, Wash., take Howery Trail road east, then turn south onto Mud Lake Road. About 2.5 miles up Mud Lake Road, you will spot the Quartzite Mountain trailhead on the west (right) side of the road.

Daniel T. Brennan is a PhD student at Curtin University in Perth, Australia. This is his first article in Out There.





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## Appendix C2: When the Mountains Were Made: A New Geological Discovery, Idaho Magazine, 2020





Being footloose has always exhilarated us. It is associated in our minds with escape from history and oppression and law and irksome obligations, with absolute freedom, and the road has always led west.

- Wallace Stegner, The American West as Living Space

LEFT: Dolomite cliffs near Bayhorse in the Salmon River Mountains.

ABOVE: Dan Brennan in the mountains with Blue. On Easter of 2016, I sat in the living room with my grandfather, whom we all called Papa, when he unknowingly echoed Stegner's phrase "the road has always led west." I had just shared my plan to leave our home in Wisconsin and head to Idaho for graduate school, which had spurred his comment. "If you move west, you won't move back," Papa said nonchalantly, and quickly delved into to his own story of adventures out West on a road trip as a much younger man. He was that kind of guy, one with a story for every situation—a quality I now realize is likely the hard-earned result of a life well-lived. Between the chaos of family gatherings, Papa would share his stories to those who would listen, usually sitting in his recliner, the one with armrests worn thin from his signature way of slapping his hands when he reached a particularly exciting part, or was upset with the current politics on TV. But Papa (and Wallace Stegner) were right: the West was calling me. The day after I graduated with a bachelor's degree, my prone-to-overheating little truck was loaded down with gear and the rising sun glinted off the rearview mirror as I headed out to start the first chapter of my own western story.



Actually, I had been a full year in Idaho before I was introduced to the writing of the author that Papa had unknowingly echoed. On a visit to my field area in the Salmon River Mountains, one of my professors gave me a tattered secondhand copy of Stegner's book Angle of Repose, which I read during the cold evenings in camp. To be honest, I spent most of that first year unsure of what I was doing ... with both my research project and my life. I'm a geologist, and although there is no better place for young geologists to gain experience than Idaho, the billions of years of Earth's history recorded in the rocks can be daunting to a green scientist. But I knew one thing: I liked to make geologic maps, and under the tutelage of my

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professors, Idaho was the place to learn. Eventually, as I had hoped, map-making became the main task of my master's research project, thanks to a bit of funding from the United States Geologic Survey (USGS). I had one summer to complete a geologic map of about a thirty-five-square-mile region in the Salmon River Mountains just west of Challis.

Short of actual hunting or gathering, I think geologic mapping is as close to the activities of our hunter-gather ancestors as a scientist can get. Maybe that's why most field geologists find something primordially satisfying about it. If you're not familiar with the premise of geologic mapping, it's relatively straightforward. Before you begin, you must lace up your hopefully ABOVE: Dan shows off his battered copy of the novel. broken-in boots, equip yourself with a topographic map, a rock hammer, a hand lens (which is small magnifying glass for identifying minerals), a notebook, a good compass, and as much food and water as necessary. If you have a trusty field dog, let it out of the truck. (I didn't have a dog at first, but that changed after a few weeks of isolated hikes, cold toes at night, and one trip "just to look" at dogs for adoption.) With your pack loaded—and the dog you just adopted eagerly leading the way—you start walking. The joke goes that geologic mapping is ninety percent intentional walking, but I don't think that's far from the truth.

All joking aside, geologic mapping is a scientifically rigorous activity. As I traverse any mapping area, I constantly develop, test, and alter a 3D conceptual model of the rocks beneath my feet. This geologic model is visualized in my head, sketched in my notebook, and drawn on my map.

In preparation for my Idaho field season, I poured through the literature and found I was far from the first young person who had aimed to find fame and fortune in the craggy peaks and glaciated meadows of the Salmon River Mountains. I uncovered the labor of souls kindred to mine in reading about 18th Century Shoshoni hunters who drove buffalo off the steep cliffs south of Challis, in photos of the still-standing but dilapidated late 19th-Century ruins of failed gold and silver mines at the Bayhorse ghost town, and in several late-1980s publications by a USGS geologist named Warren Hobbs. Although I was fortunate to collaborate with current Idaho Geological Survey mappers, I never got the chance to meet Warren, who died before my time. Luckily, if you're a young person driving a truck with a university logo in Challis, you open yourself up to some good-natured questioning by the locals. On a particularly warm late-summer afternoon,

one provider of such questioning happened to be an old friend of Warren's. Unfortunately, I did not catch the oldtimer's name, but with a sparkle in his eye, he made sure the university was not paying for the burger and cold drink I was scarfing down. He said Warren would have been happy to know that young geologists were still out scampering around the Salmon River Mountains, just as he had spent many a summer doing.

As I traversed the field area with my supervisors, we began to decipher something that I'm sure Warren knew all too well. In those mountains, as with most other central Idaho ranges, the original layer-cake stratigraphy of sedimentary rocks that formed in ancient lakes, rivers, and oceans was long gone. The orderly



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I had one summer to figure out what the original configuration was, and decipher the sequence, geometry, and eventually the tectonic forces that resulted in the mangled puzzle in my little region of the mountains.

configuration of the sedimentary rocks had been erased and deformed by younger igneous rocks, crystallized from molten material. Adjacent to where these igneous melts had intruded, the pressures and temperatures were great enough to alter the minerals in the rocks that didn't melt, a process called metamorphism. To muddy the story even more, the rocks had been displaced across a series of faults or fractures, which created a complex three-dimensional pattern. As I have learned in my travels since then, these complexities are not unique to the Salmon River Mountains, but rather are a paradox of many mountain ranges. In such cases, exposure of the ancient earth record comes at a cost: the same processes that can make the rocks available for

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geologic study can mask their original identity.

I had one summer to figure out what the original configuration was, and decipher the sequence, geometry, and eventually the tectonic forces that resulted in the mangled puzzle in my little region of the mountains. I would have to piece it together one rock description at a time, and I quickly found that the secrets of ancient geologic processes entrusted to these mountains would not be shared easily. After about ten weeks of camping, hiking, eating more hot dogs than I'd like to admit, and of Blue (my newly adopted dog) terrorizing every chipmunk in Custer County, our team arrived at a hypothesis. Our geologic mapping suggested that the original geologic mapping ABOVE: Idaho State geology class in the Pioneer Mountains.

OPPOSITE, CLOCKWISE FROM TOP LEFT: Blue in the Salmon River Mountains; the author and his dog in the Pioneers; Dan in the Pioneers; Lost River Valley sunset.





done by Warren and his colleagues had incorporated a slight misunderstanding in how the rocks were configured. They had postulated a large thrust fault or fracture across which rocks were displaced. This supposed structure required that the rocks on top be older and shoved above the allegedly younger rocks they now overlaid. However, our geologic mapping suggested that instead, the rocks on top were indeed younger than those beneath, and there was very little evidence for a thrust fault.

Armed with this hypothesis, we took several kilograms of specifically chosen rock samples to the lab. We prepared the samples in our lab at Idaho State University in Pocatello but for additional analysis, we then traveled to the University of Arizona and shipped other samples off to collaborators in Wyoming, California, and





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Australia. This analysis consisted of measuring particular isotopes of elements such as uranium and lead in the carefully chosen minerals zircon and baddeleyite. Our results indicated that the majority of rocks thought to be about 450 million years old were actually millions of years older, and had formed mostly between 660 and 600 million years ago. As you can imagine, this was quite an exciting discovery.

The data suggested a new origin for rocks in the Salmon River Mountains. Geologists had already proposed that the shores of an ancient pre-Pacific ocean once ran through what is now Idaho. During that time, Idaho was at the edge of North America, and the majority of rocks that make up Oregon and Washington had not

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yet formed. The prevailing theory for the rocks we studied in the Salmon River Mountains was that they were deposited on the shores of this wide ancient ocean. However, our data indicated that instead these rocks were deposited when the ocean was just beginning to open. Back then, other continents that were connected to the western margin of North America were in the process of slowly moving, or being rifted, away, which created an ocean. Our discovery showed that this rifting process was taking place in central Idaho more than six hundred million years ago, and this ancient ocean formed in a fashion similar to the creation of better-understood modern oceans such as the North Atlantic. Much later in

ABOVE: Hamming it up.

geological terms, a series of processes deformed the rocks of this ancient ocean shoreline into the Salmon River Mountains we see today. Warren and his colleagues had gotten in some good punches early, and had set us up for the knockout. At last, the mystery of at least some of the rocks in the Salmon River Mountains was solved.

Our uncovering of these geologic secrets would soon give me another reason to continue my westward movement. Papa seemed to have known a thing or two when he predicted that my ticket west would not be a round trip. After two years in Idaho, another geologic challenge led me across an ocean to begin a PhD program in Perth, Australia. Other geologists have suggested that Australia was one of the continents originally west of North America, whose removal might be recorded in the rocks of the Salmon River Mountains. So, I'm now doing research into that question, and although I am now on the other side of the world, geologically, it feels like home.

Unfortunately, Papa is not around anymore to let me know if my westward trajectory is destined to continue after I finish my PhD in a couple of years. But as a good mate of mine likes to say, "Life is all about stories." Wherever I go, I hope to make a few of my own and find more rocks that reveal stories of Earth's ancient past. One thing I know: at this point, if I go any farther west, I'll be headed towards home.

The author encourages anyone interested in studying geosciences to visit Idaho State University at **isu.edu/ geosciences/undergrad**, or get a book on geology from the local library. He recommends *Timefulness: How Thinking Like a Geologist Can Help Save the World*, by Marcia Bjornerud.

To learn more about the research Daniel and colleagues conducted, their geologic map can be downloaded at **idahogeology.org/product/t-20-01** 

For their recent scientific paper, visit agupubs. onlinelibrary.wiley.com/doi/ abs/10.1029/2020TC006145

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# Appendix D: Supplementary Datatables

# Appendix D2.1: SHRIMP U/Pb Results

	Spot Fundamentals					SQUID OUT	PUTS 27.01	.2021							ISC	PLOT R AG	E CALCS			DTB Calcs
		u	Th	232Th		4-corr 208*		4-corr 238		4-corr 207*		207/235	,	06/238		207/206		Concordia Age		Discordance
Fraction	Date/Time	(ppm)	(ppm)	/238U	+/-1sigma	/232	+/-1sigma	/206*	+/-1sigma %	/206*	+/-1sigma	2017233	1sigma Ma	1724 7	1sigma Ma	2700 4	1sigma Ma	201001010 / 160	1sigma Ma	26.12
36DB-1 36DB-10	2/12/2020 13:15 2/12/2020 18:25	1095.304	343.061/ 10.57142	0.626853	0.205623	0.078952	5.421301 12.08252	3.26006 4.178825	5.226450083 4.988562229	0.185327 0.113849	1.651189 0.702957	1583.1	49.4 40.4	1/24./ 1383.1	/9.1 62.1	2700.4 1860.9	27.3	2646.5 1849.44	1/./ 9.26	36.13 25.68
36DB-11 36DB-12	2/12/2020 19:16 2/12/2020 19:40	447.532 648.4096	157.3846	0.363421	0.448084	0.099173	5.076978	3.726518	4.560969582	0.174226	0.429122	2038.2	40.3 38.8	1532.4 1408.4	62.2 56.8	2597.91 2385.3	7.15	2592.59 2362.98	3.91 7.89	41.01
36DB-13	2/12/2020 20:05	1122.702	31.69806	0.029177	4.361709	0.035316	15.58424	6.451223	4.99077178	0.128779	1.169421	1342.4	38.2	929	43.2	2080.6	20.6	126.2	18.3	55.35
36DB-14 36DB-15	2/12/2020 20:29 2/12/2020 21:41	1012.067 1554.344	26.49559 14.46448	0.027054 0.009617	0.843339 0.564892	0.036368 0.056772	14.80102 24.41126	5.332994 7.919583	4.799380855 4.523285841	0.112864 0.15347	0.469114 0.804088	1386.2 1320.4	36.5 33.9	1107.9 766.5	48.9 32.7	1845.22 2384.2	8.49 13.7	1836.66 50.44	4.89 9.23	39.96 67.85
36DB-16	2/12/2020 22:05	1623.908	62.30459	0.039649	0.993335	0.002313	62.53068	37.02228	7.103949844	0.11658	2.07416	366	22.7	171.8	12	1903.6	37.3	33.57	5.47	90.97
36DB-17 36DB-18	2/12/2020 22:51	1359.535	11.10534	0.008441	0.672572	0.003934	37.20921	6.459103	4.480721669	0.125497	0.96616	1322.3	33.9	927.9	38.7	2472.5	5.65	111.1	15.4	49.37
36DB-19 36DB-2	2/12/2020 23:48 2/12/2020 13:47	331.905 537.0556	29.29865	0.091223	5.857506	0.117791	11.14903	2.977206	4.498198886	0.162512	1.074375	2175.7	41.4	1866.8 2317.7	72.9	2481.2	18.1	2458.5	13.4	24.76 13.32
36DB-20	3/12/2020 0:12	264.5509	291.1166	1.137181	0.403984	0.13818	4.546927	2.018498	4.500491713	0.199835	0.376815	2725.3	42.7	2594.1	96.1	2824.12	6.15	2823.31	5.54	8.14
36DB-3 36DB-4	2/12/2020 14:1/ 2/12/2020 15:30	2101.508 2320.623	13.84426 23.74115	0.006808	1.008327 0.88547	0.020077 0.054379	82.4959 35.54229	10.84803 10.25757	6.392827842 4.928608451	0.101411 0.100584	1.1142/2 0.864882	840.6 868.2	37.1 29.2	568.4 599.7	34.8 28.2	1649.3 1634.1	20.7	57.9	12.1	65.54
36DB-5	2/12/2020 15:53	982.9611	7.898468	0.008304	0.774796	0.034148	29.56924	5.10963	4.775584996	0.11279	0.41944	1418.3	36.6	1152.2	50.4	1844.03	7.59	1837.54	4.55	37.52
36DB-7	2/12/2020 16:25 2/12/2020 17:14	1995.923	23.38719	0.013741	0.322273	0.02518	29.53344	9.891748	4.506307013	0.139237	0.766487	920.9	27.7	620.8	26.7	1730.6	8.56	23.29	8.84	64.13
36DB-8 36DB-9	2/12/2020 17:37 2/12/2020 18:01	804.4948 2338.375	97.86889 15.82643	0.125717 0.006994	4.626751 0.536074	0.133027 0.024691	8.336318 54.95312	3.57489 9.247654	5.164520521 4.543529281	0.154353 0.105013	1.462755 0.489822	1968.6 956.5	46.7 28.3	1590 661.9	72.8 28.6	2394 1713.72	24.9 9.01	2347.9	16.8	33.58 61.38
37DB-10	3/12/2020 4:54	1181.736	770.3403	0.673649	0.350263	0.080938	4.510497	3.673563	4.47965956	0.097498	0.3261	1562.2	35.8	1552	61.8	1575.96	6.1	1575.74	5.98	1.52
37DB-11 37DB-12	3/12/2020 5:39	515.7931	193.9921	0.388669	0.398131	0.078464	4.56852	4.015264	4.492954361 4.488701285	0.098036	0.573793	1558.3 1492.1	36.1 35.4	1537.8 1433.6	61.5 57.7	1586.3 1576.3	11.6 10.7	1584./ 1572.23	11 9.63	9.05
37DB-13 37DB-14	3/12/2020 6:02 3/12/2020 6:26	682.8437 222.8164	357.9954	0.541786	0.468089	0.079163	4.543286	3.636832	4.484133033	0.09774	0.414077	1572.2	36	1566	62.3 61.1	1580.6 1588.6	7.75	1580.38	7.61	0.92
37DB-15	3/12/2020 6:48	1164.219	557.24	0.494629	0.338542	0.080372	4.517951	3.668401	4.480233469	0.098387	0.334844	1570.6	35.9	1554	61.9	1592.94	6.25	1592.56	6.06	2.44
37DB-16 37DB-17	3/12/2020 7:40 3/12/2020 8:04	792.8298 1064.285	370.1856 301.6876	0.482515 0.292935	0.162915 2.280893	0.076156 0.069427	4.581816 5.431522	3.734862 4.148861	4.483176358 4.560787014	0.098481 0.097901	0.405957	1557 1469.7	35.8 35.5	1529.4 1392	61 57.1	1594.72 1583.68	7.58 6.49	1593.8 1581.75	7.2	4.10
37DB-18	3/12/2020 8:31	1839.119	678.4218	0.381208	0.364722	0.079408	4.510999	3.620998	4.477821118	0.097567	0.257513	1574.3	35.9	1572	62.5	1577.29	4.82	1577.26	4.79	0.34
37DB-19 37DB-2	3/12/2020 9:04	2095.712	1033.705	0.509726	0.28404	0.081176	4.542251	3.472564	4.483772468	0.097348	0.240156	1574.3	36.2	1631.4	64.5	1576.9	4.49	1631.39	10.8	-3.26
37DB-20 37DB-21	3/12/2020 9:32	339.4567	166.8197	0.507849	1.442636	0.068738	5.269801	4.603948	4.649055605	0.097738	1.893847	1388.6 1489.7	38 35.4	1267.1	53.5	1580.6 1579.7	35.4	1495.4 1575 31	30.3	19.83
37DB-22	3/12/2020 11:08	2799.094	1349.131	0.498091	0.614912	0.086196	4.770723	3.520802	4.524540959	0.097811	0.205747	1598.8	36.5	1611.6	64.5	1581.96	3.85	1611.61	3.59	-1.87
37DB-23 37DB-24	3/12/2020 11:56 3/12/2020 12:23	318.9183 1184.69	298.1252 309.6275	0.966031 0.270089	2.108519 0.163278	0.070451 0.083717	5.366321 4.580189	3.873448 3.801025	4.501028913 4.492945235	0.097003	0.904434 0.317187	1516.2 1533.7	36.1 35.6	1480.5 1505.6	59.5 60.3	1566.4 1572.62	17 5.94	1560.5 1572.03	15.6 5.64	5.48
37DB-3	3/12/2020 1:00	645.5069	376.0411	0.602013	1.213404	0.077627	4.689923	3.725024	4.486856851	0.097404	0.480346	1550.4	35.9	1533	61.2	1574.16	8.99	1573.33	8.66	2.61
37DB-4 37DB-5	3/12/2020 2:09	1339.09	422.6928	0.31447	0.304009	0.08504	4.65024	4.371237	4.637840659	0.097889	0.312623	1425.6	35.6	1328	55.7	1585.07	6.19	1572.26	5.13	15.65
37DB-6 37DB-7	3/12/2020 2:31 3/12/2020 2:55	1657.799 798.0581	694.2526 511.8584	0.43277	0.302863	0.080772	4.507358	3.672802	4.478209135	0.09759	0.476419	1563.1 1588.2	35.9 36.1	1552.3 1594	61.8 63.3	1577.73 1580.62	8.92 7.18	1577.23	8.68	1.61 -0.85
37DB-8	3/12/2020 3:18	366.9846	85.45325	0.240631	0.460027	0.075797	4.710276	3.887583	4.495978104	0.098128	0.606831	1522.4	35.8	1475.7	59.3	1588	11.3	1584.5	10.4	7.07
37DB-9 37DT-1	3/12/2020 3:41 2/12/2020 12:02	788.795 148.3967	252.0717 0.234376	0.330241 0.001632	0.850471 6.625215	0.080097 0.134285	4.740358 24.05571	3.64188 110.0595	4.523163937 5.362190765	0.09816	0.416527 9.610531	1574.5 75.93	36.3 8.05	1564 58.31	62.8 3.11	1588.62 673	7.78	1588.26 57.37	7.6 3.09	1.55 91.34
46DB-1	4/12/2020 2:06	1844.319	85.39201	0.047847	0.252532	0.088947	5.64358	3.400075	4.478882795	0.11252	0.247144	1742.1	37.4	1662	65.6	1839.7	4.47	1839.02	3.98	9.66
46DTB-20	9/12/2020 6:17	2268.106	85.86225	0.039121	0.711808	0.030540	5.389913	4.493789	2.451165882	0.1113505	0.387866	1508.6	19.5	1295.2	28.8	1822.4	7.04	1805.63	4.94	28.93
46DB-12 46DB-11	4/12/2020 8:02 4/12/2020 7:40	2318.336 2373.205	43.57549 108.9272	0.019424 0.047432	0.364942	0.088086	10.50418 4.770792	8.860194 3.508209	4.724638058 4.47651974	0.109252 0.111264	0.515628 0.22607	1008.3 1706.9	30.4 37	689.4 1616.7	30.9 64	1786.16 1819.35	9.4 4.1	25.54 1818.68	6.5 3.59	61.40 11.14
46DTB-18	9/12/2020 5:33	2418.746	110.9657	0.04741	0.370816	0.091915	3.066897	3.038671	2.197003032	0.113116	0.57639	1841.1	19.3	1834	35.1	1849.3	10.4	1848.03	9.93	0.83
46DB-7 46DB-8	4/12/2020 5:18 4/12/2020 5:40	25/3.923 2725.278	108.36 134.7398	0.043506	0.8/8165	0.073623	4.822237 4.793778	3.699499 3.126653	4.528250859 4.485945834	0.112451 0.113711	0.360927	16/1.9 1821.4	37.2	1542.4 1788.9	62.1 70.1	1838.59 1858.74	6.54 3.76	1836.23 1858.55	5.3/	16.11 3.76
46DTB-14	9/12/2020 3:43	2768.126	129.6287	0.048394	1.057864	0.083315	3.358161	3.416568	2.282372155	0.111139	0.472838	1727.9	19.4	1655	33.3	1817.31	8.58	1808.55	7.69	8.93
46DTB-15	9/12/2020 4:05	2802.311	112.148	0.041357	0.673067	0.079378	3.25672	4.187859	2.195150699	0.111512	0.335006	1564.8	17.7	1380.4	27.3	1823.39	6.08	1810.31	4.54	24.29
46DB-9 46DTB-19	4/12/2020 6:49 9/12/2020 5:55	2915.003 3088.718	157.9671 117.7191	0.056001 0.039386	0.882672	0.081301 0.051766	4.695901 5.015316	3.477712 6.121164	4.515754937 2.552458222	0.111941 0.103892	0.204847 0.399111	1719.1 1224.3	37.5 18.4	1629.3 975.5	65 23.1	1830.35 1693.95	3.71	1829.82 1667.54	3.25	10.98 42.41
46DTB-17	9/12/2020 5:12	3261.847	145.7118	0.046164	1.956519	0.062218	5.85413	5.274943	4.555043946	0.109619	0.362719	1372.5	34.4	1119.1	46.8	1792.27	6.61	1786.74	3.95	37.56
46DB-3 46DTB-13	4/12/2020 2:58 9/12/2020 3:20	3622.022 3638.352	168.17 206.9486	0.047981 0.05878	1.028491 0.288719	0.083218 0.096914	4.688376	3.258/24 2.94667	4.4/548//31 2.402539371	0.112543 0.113883	0.1/2346 0.248157	1///.8 1873.1	37.6	1725.3 1883.6	67.7 39.2	1840.07 1861.47	3.12 4.48	1839.85 1883.62	2.9 4.24	6.24 -1.19
46DB-6 46DB-10	4/12/2020 4:56	3641.74	120.7523	0.034266	2.732131	0.065176	6.257218	6.796978	5.541904137	0.108133	0.801068	1178.7	39	884.8	45.8	1767.4	14.6	59.4	13.4	49.94
46DB-2	4/12/2020 2:35	3690.679	226.4007	0.063393	0.402034	0.095987	4.548678	2.952485	4.475596531	0.11334	0.174287	1867.3	38.2	1880.4	73	1852.83	4.59	1775.84 1880.4	2.93	-1.49
46DB-4 52DB-26	4/12/2020 3:21 9/12/2020 1:47	4471.553 37.20119	174.627 1.419309	0.040358	0.579845 5.456007	0.097212	4.666487	2.98163 7.00703	4.561424487 4.09413988	0.113771 0.051864	0.34602 36.34414	1862.2 714	39 188	1864.4 860	73.9 33	1859.69 278	6.25 832	1864.44 857.5	6.16 32.8	-0.25 -209.35
52DB-5	8/12/2020 13:46	209.4101	0.549115	0.00271	4.533339	-0.54271	-61.715	4.214277	2.381697477	0.085441	2.108428	1354	23.8	1372.6	29.4	1324.7	40.8	1355.9	23.4	-3.62
52DB-24	9/12/2020 0:39	708.8787	2.556835	0.003727	2.289909	-0.12205	-90.6671	4.169126	2.255702318	0.087384	1.076555	1378.9	18.9	1465.6	29.8	1368.1	20.7	1374.4	11.5	-1.31
52DB-9 52DB-1	8/12/2020 16:37 8/12/2020 11:52	571.3648	124.192	0.224622	0.404615	0.081857	3.503273	3.64543	2.246415648	0.095937	0.916434	1555.5 1363.5	19.3 20.7	1562.7 1365.2	31.2 28.4	1545.7 1360.8	17.2 29.4	1549.7	15.1 20.4	-1.10
52DB-2	8/12/2020 12:16	384.8222	2.127013	0.005712	5.530937	-0.05384	-124.224	4.360624	2.28463463	0.085922	1.198355	1332.7	19.1	1331	27.5	1335.6	23.2	1333.6	17.7	0.34
52DB-10 52DB-16	8/12/2020 16:58 8/12/2020 20:28	399.5279 157.9184	0.390748	0.030191 0.002557	19.74394 5.339353	-0.61044	-70.1143	4.28878	2.2//191115 2.418050631	0.087061	0.920515	1354.9 1325.4	18.4 30.2	1351.1 1319.4	27.8 28.9	1361 1335.2	17.7 63.5	1358.1 1322	15 26.4	0.73
52DB-23	9/12/2020 0:17	1089.843	3.767556	0.003572	3.664115	0.001114	3925.351	4.217767	2.697486995	0.08884	1.741093	1382.7	24.2	1371.6	33.3	1399.9	33.4	1385.6	23.8	2.02
52DB-14 52DB-22	8/12/2020 23:52	421.0677	1.8962	0.004835	2.291555	0.03381	48.30641	4.424819	2.22817687	0.089404	0.882211	1332.4	17.9	1313.5	26.6	1362.8	14.9	1348.8	13.1	3.62
52DB-3 52DB-13	8/12/2020 12:38 8/12/2020 18:32	288.4589 292.7173	0.586933 2.205973	0.002103 0.007788	4.34218 8.595669	-0.03396 0.1321	-412.146 26.44721	4.341068 4.190819	2.310496003 2.30591972	0.088345	1.168443 1.079043	1356.8 1405.2	19.4 19.4	1336.4 1379.5	27.9 28.6	1389.1 1444.3	22.4 20.6	1368.5 1422.6	17.7 16.9	3.79 4.49
52DB-6	8/12/2020 14:30	496.5893	1.763365	0.00367	2.466938	0.101096	34.34994	4.297903	2.254706515	0.089454	1.374106	1373.7	19.9	1348.5	27.4	1413	26.3	1382	19.5	4.56
52DB-25 52DB-4	9/12/2020 1:24 8/12/2020 13:23	5/3.593 267.9808	47.91262	0.086321 0.003863	2.821867	0.06/3/8	6.339391 41.90041	4.386676	2.239963738 2.315876704	0.088/18 0.089687	0.776218	1352.1 1370.4	17.7	1323.8 1340.1	26.8 28	1397.2 1418	14.9 23.7	1380.6 1385.5	12.9 18.6	5.25
52DB-12 52DB-20	8/12/2020 18:07 8/12/2020 22:21	451.6426	1.2132	0.002776	3.05699	0.118377	23.21546	4.463232	2.426019123	0.088378	0.841157	1336.4 1349.4	19.1 20.6	1303.3 1309.9	28.6 30.4	1389.9 1412.4	16.1 19.2	1369.9 1384.3	14 16.3	6.23 7.26
52DB-7	8/12/2020 14:54	122.648	0.247554	0.002086	7.045035	0.258013	19.1938	4.495719	2.469442599	0.088957	1.612933	1335.8	21.9	1294.7	29	1402.4	30.9	1344.1	22.2	7.68
52DB-21 52DB-15	8/12/2020 23:28 8/12/2020 20:07	181.4178 251.0212	0.440016 0.798856	0.002506 0.003289	5.23243 3.845756	-0.14027 0.071735	-233.044 198.8932	4.872265 4.647919	2.41543082 2.342889221	0.08481 0.088152	2.328507 1.548334	1242.3 1304.5	24 20.6	1203.4 1256.2	26.5 26.7	1310.3 1384.9	45.2 29.7	1228.5 1312.1	24 21.2	8.16 9.29
52DB-19	8/12/2020 21:59	224.7205	0.375114	0.001725	5.400835	1.09478	31.3335	4.474447	2.339002305	0.092212	1.595866	1366.2	21.3	1300.3	27.5	1470.9	30.3	1374.4	22.2	11.60
52DB-18 52DB-8	8/12/2020 21:13	168.0152	0.476748	0.002292	5.25009	1.028206	17.50767	4.66793	2.405572895	0.090304	1.609213	1319.1	20.1	1255.9	20.8	1425.8	30.7	1338.5	20.3	12.56
52DB-17 52DB-27	8/12/2020 20:50 9/12/2020 2:08	231.6701	44.08737	0.19666	14.07474	0.069934	22.73261	5.121795	2.703578743	0.085436	2.05806	1212 1084.5	24 21.9	1149.7 1001.5	28.5 21.8	1324.6 1255.4	39.9 45	1202.9 1035.1	25.5 21.8	13.20
67DB-15	3/12/2020 21:37	642.1959	250.3499	0.402858	0.190425	0.134583	4.533157	2.048708	4.484698999	0.178804	0.281643	2606.6	42.1	2562.5	94.8	2641.06	4.68	2640.88	4.5	2.97
67DB-16 67DT-1	3/12/2020 21:59 2/12/2020 11:37	604.1588 8.469227	304.4647 0.08521	0.520784 0.010397	1.15354 12.7425	0.130398 3.461981	4.895947 61.46524	2.167543 37.28196	4.485531278 33.89979066	0.180569 0.598249	0.296882 14.30594	2563 1185	42 257	2445.5 <del>170.6</del>	91.3 57.1	2657.36 4503	4.92 <del>208</del>	2656.83 29.9	4.45 24.3	7.97 <del>96.21</del>
67DT-10	3/12/2020 17:45	526.7952 833 9079	189.0574	0.370872	0.426326	0.10454	4.562263	2.657475	4.488020756	0.176242	0.336241	2352.1	41.2	2059	79.1	2617.07	5.6	2615.27	4.22	21.32
67DT-12	3/12/2020 19:20	694.2542	183.464	0.273089	0.209839	0.141103	4.57092	2.035884	4.487191571	0.17948	0.519001	2005.4	42.7	2575.8	95.3	2647.33	5.92	2646.77	8.31	2.70
67DT-13 67DT-14	3/12/2020 20:12 3/12/2020 20:49	539.0461 836.1217	233.5866 290.5135	0.44781 0.359061	0.324534 0.176711	0.140733 0.138064	4.570809 4.514917	1.970398 1.959639	4.521813191 4.481876778	0.18223 0.181867	0.284812	2661.1 2664.3	42.7 42.3	2646 2657.9	98.1 97.6	2672.53 2669.22	4.71 3.85	2672.47 2669.21	4.65	0.99
67DT-17	3/12/2020 22:22	259.493	103.0268	0.410295	0.27054	0.138248	4.588678	1.980408	4.499898723	0.182121	0.409792	2655.7	42.5	2635	97.3	2671.54	6.78	2671.36	6.66	1.37
67DT-18 67DT-19	3/12/2020 22:45 4/12/2020 0:01	496.1401 346.7186	188.9795 118.4038	0.393624	0.211081 0.263552	0.133529 0.118312	4.56/471 4.631405	2.038536 2.496965	4.51818226 4.496893196	0.18048 0.171496	0.308027	2620 2384.2	42.5 41.5	2573 2171.3	95.9 82.9	2656.54 2571.55	5.11 7.6	2656.32 2569.08	4.91 6.23	3.14 15.56
67DT-2 67DT-20	3/12/2020 13:33	749.6213	338.3699	0.466468	0.868271	0.130972	4.755691	2.159261	4.647844213	0.175542	0.657023	2540.3	43.8	2453.3	94.8	2610.4	10.9	2608.6	10.1	6.02
67DT-21	4/12/2020 0:47	479.8055	252.7952	0.544472	0.762452	0.132654	4.650992	2.102577	4.551975995	0.181048	0.315101	2594	42.4	2508.1	94.6	2661.75	5.22	2661.33	4.86	5.77
67DT-3 67DT-4	3/12/2020 13:56 3/12/2020 14:19	309.9531 239.5415	87.81868 125.8077	0.292794 0.542746	0.284901 0.266184	0.133894 0.136374	4.612929 4.583914	2.091237 1.982257	4.496560491 4.504476108	0.181416	0.390178	2600.9 2664.4	42.3	2519.4	93.8 97.4	2665.11 2688.41	6.46 7.25	2664.49	6.03	5.47
67DT-5	3/12/2020 15:28	616.5366	188.978	0.316755	0.20855	0.133	4.547179	2.05161	4.485341902	0.180365	0.277132	2613.4	42.2	2559.5	94.8	2655.48	4.59	2655.27	4.39	3.61
67DT-6 67DT-7	3/12/2020 15:50 3/12/2020 16:14	612.9384 636.1915	269.3411 198.8545	0.454106	0.1913/7 0.848712	0.130067	4.501666 4.776571	2.162194 2.716658	4.522302945 4.619475307	0.179258	0.2927/3	2558.5 2201.4	42.3	2450.6 2020.5	92.2 80.1	2645.27 2374.34	4.86 6.54	2644.8 2372.59	4.43 5.42	7.36 14.90
67DT-8 67DT-9	3/12/2020 17:00 3/12/2020 17:22	297.2827 297.4659	117.909 79.25224	0.409873 0.275325	0.250482 0.718815	0.131856 0.126988	4.576745 4.803695	1.996345 2.189923	4.495623336 4.61313541	0.183837 0.177309	0.603986	2657 2536.5	42.7 43.2	2617.7 2424.7	96.7 93.2	2687.05 2627.11	9.98 6.88	2686.35 2626.16	9.64 6.24	2.58 7.70

# Appendix D2.2: SHRIMP U/Pb Standards

	Spot Fundamentals					SQUID OUT	PUTS 27.01	.2021							ISO	PLOT R AG	GE CALCS			DTB Calcs
Fraction	Date/Time	U (ppm)	Th (ppm)	232Th /238U	+/-1sigma	4-corr 208* /232	+/-1sigma	4-corr 238 /206*	+/-1sigma %	4-corr 207* /206*	+/-1sigma	207/235	2 1sigma Ma	06/238	1sigma Ma	207/206	1sigma Ma	Concordia Age	1sigma Ma	Discordance
0GC-1	2/12/2020 12:49	116.8504	77.20861	0.682821	0.336222	0.185055	4.622232	1.354281	4.529620718	0.298228	0.418792	3498.2	44.7	3565	124	3460.35	6.49	3564.64	5.44	-3.02
060-1	4/12/2020 10:46	161.1597	52.86415	0.82555	0.303085	0.188421	4.725698	1.382113	4.600009636	0.299881	0.406551	3402.1	45.3	3450.5	174	3453.49	5.8	3408.72	5.26	-1.61
0GC-11	4/12/2020 6:25	187.4651	154.7243	0.852922	0.278761	0.171291	4.587918	1.496572	4.517312592	0.301396	0.396712	3410.5	44.4	3299	117	3476.72	6.14	3476.27	5.74	5.11
OGC-2	2/12/2020 15:06	93.42488	60.90468	0.67369	0.889841	0.194051	4.728354	1.355634	4.539503293	0.300368	0.446708	3504.2	44.8	3562	124	3471.43	6.92	3561.91	5.93	-2.61
OGC-2	8/12/2020 11:07	257.6634	211.3093	0.847496	0.35187	0.182231	2.455159	1.407638	2.301618265	0.300919	0.427754	3469	23	3460	61.6	3474.26	6.62	3474.1	6.55	0.41
OGC-3	2/12/2020 21:17	56.1525	27.76209	0.510922	0.897618	0.187714	4.874294	1.355972	4.581727262	0.298531	0.57389	3498	45.4	3561	125	3461.92	8.89	3561.22	7.51	-2.86
OGC-3	8/12/2020 15:50	256.5092	219.6716	0.884998	0.351146	0.174733	2.477691	1.430895	2.306966564	0.298726	0.4372	3445.8	23	3416.3	61.2	3462.93	6.78	3462.38	6.63	1.35
OGC-4	3/12/2020 4:26	101.2382	52.86829	0.539663	0.390102	0.183882	4.689806	1.397894	4.540390371	0.302165	0.458757	3479.9	44.8	3479	122	3480.66	7.1	3480.65	7.08	0.05
OGC-4	8/12/2020 19:38	154.1068	134.7953	0.903909	0.428992	0.179552	2.6587	1.459878	2.387311615	0.297813	0.584039	3423.1	24.1	3363.5	62.6	3458.19	9.05	3456.33	8.68	2.74
OGC-5	3/12/2020 10:21	197.3397	155.0681	0.812044	0.253155	0.182014	4.555753	1.419381	4.507728419	0.299151	0.329236	3455.1	44.4	3438	120	3465.14	5.1	3465.09	5.05	0.78
OGC-5	8/12/2020 23:05	148.2808	84.3386	0.587778	0.473387	0.180363	2.832832	1.407987	2.379002542	0.299736	0.562848	3464.9	24	3459.3	63.7	3468.16	8.72	3468	8.61	0.26
OGC-6	3/12/2020 13:10	287.0915	245.0727	0.882158	0.2069	0.176792	4.611336	1.44555	4.536751368	0.298829	0.268484	3436.1	44.6	3389	120	3463.47	4.16	3463.38	4.04	2.15
OGC-6	9/12/2020 2:57	199.1519	92.10318	0.477927	1.224248	0.180312	3.10704	1.407321	2.342282411	0.29672	0.528268	3455.5	23.6	3460.6	62.7	3452.49	8.19	3460.61	8.01	-0.23
OGC-7	3/12/2020 15:04	171.0295	139.1057	0.840516	0.266356	0.178174	4.568067	1.444334	4.512676078	0.299662	0.703653	3439.7	44.8	3392	119	3467.8	10.9	3467.2	10.6	2.19
OGC-7	9/12/2020 7:01	88.31484	45.40984	0.531359	0.622478	0.191301	3.21373	1.416842	2.513854176	0.304488	0.71615	3474.2	25.7	3442.6	67.1	3492.5	11.1	3491.2	10.8	1.43
OGC-8	3/12/2020 18:51	161.6706	84.26102	0.538601	0.31652	0.183565	4.61469	1.376344	4.516208737	0.300984	0.375268	3491.3	44.5	3521	123	3474.6	5.81	3520.6	5.36	-1.34
OGC-9	3/12/2020 23:36	90.48369	60.67674	0.692985	0.719676	0.186127	4.736919	1.394378	4.560978392	0.297796	0.538906	3468.1	45.1	3485	123	3458.1	8.35	3485.42	7.94	-0.78

## Appendix D2.3: SIMS O- Results

A	Inalysis session 1 20 µm d	iameter, 2.5 nA, Cs <sup>+</sup> ion-beam						
Sample #	Analysis #	Raw Data from Cli	PS	SIMS correct	ed	Drift con	rected	Notes
bumple #	Anarysis in	180/160 1sigma err	or	d18O ± pe	r mil	OH/O ±	rel (%)	notes
37DTB19	OH-DB_09-DB20_37DTB19@01	0.002016266	3.06086E-07	5.51884379	0.151808103	0.000857162	0.3608533	
37DTB19	OH-DB_09-37DB19@02	0.002016441	3.32346E-07	5.606012346	0.164818147	0.000759828	0.1151747	
37DTB19	OH-DB_09-37DB19@03	0.002015946	2.81726E-07	5.359034772	0.139748723	0.000745774	0.1942408	
37DTB19	OH-DB_09-37DB19@04	0.00201548	2.88722E-07	5.126585291	0.143252387	0.000795772	0.4011484	
37DTB19	OH-DB_09-37DB19@05	0.002015897	3.39436E-07	5.334487305	0.168379672	0.00076661	0.2437459	
37DTB19	OH-DB_09-37DB19@06	0.002015423	2.99935E-07	5.098030075	0.148819812	0.000986084	0.2392039	
37DTB19	OH-DB_09-37DB19@07	0.002015292	2.84799E-07	5.032904143	0.141319191	0.000808253	0.567568	
37DTB19	OH-DB_09-37DB19@08	0.002016017	3.16431E-07	5.394603551	0.156958348	0.000861948	0.5737716	
3701819	OH-DB_09-37DB19@09	0.002015448	3.18059E-07	5.110554292	0.15781074	0.000858881	0.4914057	
3701819	OH-DB_09-37DB19@10	0.002014307	2.91251E-07	4.541453839	0.144591377	0.000766662	0.1029989	
37DTB19	OH-DB_09-37DB19@11	0.002014643	2.69003E-07	4./092/8356	0.133524047	0.000820311	0.5304983	
37DTB19	OH-DB_09-37DB19@12	0.00201529	3.03855E-07	5.031902205	0.150774969	0.000703465	0.1278924	
27DTB10	OH-DB_09-37DB19@13	0.002015438	2.030322-07	5.11550556	0.14143272	0.000752403	0.2239297	
37DTB19	OH-DB_09-37DB19@14	0.002015777	3.22489E-07	5.2/48/2029	0.159982353	0.000716048	0.4500809	
37DTB19	OH-DB_09-37DB19@15	0.002016213	2 81178F-07	5.492292449	0.139458705	0.000710048	0.363914	
37DTB19	OH-DB_09-37DB19@10	0.002015205	2.011/02-07	4 090210965	0.149044993	0.000304882	0.2559943	
37DTB19	OH-DB_09-37DB19@17	0.002015205	2 81848F-07	5 153637601	0.139837888	0.000792333	0.1219552	
37DTB19	OH-DB_09-37DB19@19	0.002014837	3.21374E-07	4.805965317	0.159503905	0.000902445	0.2574412	
37DTB19	OH-DB 09-37DB19@20	0.002015767	4.09255E-07	5.269862342	0.203027147	0.000745844	0.1927767	
46DTB19	OH-DB_09-46DB19@01	0.002015749	3.12402E-07	5.260844905	0.154980417	0.000791339	0.4824054	
46DTB19	OH-DB 09-46DB19@02	0.002016283	3.83631E-07	5.527360259	0.190266324	0.000756203	0.3999153	
46DTB19	OH-DB 09-46DB19@03	0.002016438	2.90515E-07	5.60450944	0.144073574	0.000774367	0.5494097	
46DTB19	OH-DB 09-46DB19@04	0.002016929	3.08165E-07	5.849483139	0.152788979	0.000770785	0.1987718	
46DTB19	OH-DB 09-46DB19@05	0.002017005	3.17804E-07	5.887055792	0.157562422	0.000821509	0.5677005	
46DTB19	OH-DB_09-46DB19@06	0.002016197	2.98799E-07	5.48427695	0.148199406	0.000786919	0.2243366	
46DTB19	OH-DB 09-46DB19@07	0.002015497	3.05506E-07	5.135101759	0.151578558	0.000867206	0.4198946	
46DTB19	OH-DB_09-46DB19@08	0.002015671	2.90978E-07	5.221769346	0.144358029	0.001003019	0.9196111	
46DTB19	OH-DB_09-46DB19@09	0.002017	2.71523E-07	5.884550948	0.134617258	0.001395404	1.015526	omitted high OH/O-
46DTB19	OH-DB_09-46DB19@10	0.002016567	3.27575E-07	5.668633435	0.162441742	0.000872832	0.1851135	
46DTB19	OH-DB_09-46DB19@11	0.002016368	2.9277E-07	5.56944163	0.145196642	0.000921191	0.5056991	
46DTB19	OH-DB_09-46DB19@12	0.002017166	2.95829E-07	5.967711754	0.146655891	0.002378079	2.745597	omitted high OH/O-
46DTB19	OH-DB_09-46DB19@13	0.002016505	2.66461E-07	5.638074343	0.132140071	0.001005206	0.217211	
46DTB19	OH-DB_09-46DB19@14	0.002016386	2.58765E-07	5.578459067	0.128331081	0.001186586	0.6217962	omitted high OH/O-
46DTB19	OH-DB_09-46DB19@15	0.002015347	3.72267E-07	5.060457422	0.184716174	0.000943951	0.7896001	
46DTB19	OH-DB_09-46DB19@16	0.002015323	3.03353E-07	5.048434173	0.150523469	0.001043421	0.4183532	
46DTB19	OH-DB_09-46DB19@17	0.002015864	2.98742E-07	5.317955338	0.148195591	0.000856083	0.2268726	
46DTB19	OH-DB_09-46DB19@18	0.002015603	3.30695E-07	5.188204442	0.164067722	0.000910641	0.2741711	
46DTB19	OH-DB_09-46DB19@19	0.002016272	2.71938E-07	5.521849603	0.134871544	0.000886009	0.1250535	
46DTB19	OH-DB_09-46DB19@20	0.002016962	3.23785E-07	5.865514137	0.16053106	0.000882343	0.2237801	
67DTB19	OH-DB_09-67DB19@01	0.002020957	3.92151E-07	7.857866694	0.194042027	0.001780457	4.975086	omitted high OH/O-
67DTB19	OH-DB_09-67DB19@02	0.002016982	2.74882E-07	5.875533511	0.136283737	0.00071295	0.5009309	
6/U1819 C7DT010	OH-DB_09-67DB19@03	0.002018159	2.84159E-07	6.462668839	0.14080088	0.001694431	4.486829	omitted nigh OH/O-
6701819	OH-DB_09-67DB19@04	0.002016811	2.8/526E-0/	5.790368831	0.142564532	0.000914548	1.120014	
67DTB19	OH DB 00 67DB10@05	0.002012857	2.90348E-07	3.818555991	0.144246603	0.000/10549	5.998934	
67DTB19	OH-DB_09-67DB19@06	0.002016347	3.10902E-07	5.020051094	0.15/155/52	0.000711805	0.1958074	
67DTB19	OH-DB_09-07DB19@07	0.0020160347	2.560546-07	5.330321207	0.14703004	0.000711893	2 224200	
67DTB19	OH-DB_09-67DB19@08	0.002016024	3.1/2002-07	5.451212015	0.19019/271	0.000708171	1 902922	
67DTB19	OH-DB_09-67DB19@09	0.002015131	2 90112E-07	5.431213013	0.139050290	0.00080887	0.21/0202	
67DTB19	OH-DB_09-67DB19@11	0.002015411	3 24853E-07	5.09201845	0.161184488	0.000703479	0 218183	
67DTB19	OH-DB 09-67DB19@12	0.002015411	3.24684E-07	5.642082093	0.161012678	0.000762307	0.2272872	
67DTB19	OH-DB 09-67DB19@13	0.002016064	3.34509E-07	5.41814908	0.165921817	0.000672457	0.3035271	
67DTB19	OH-DB 09-67DB19@14	0.002016162	2.81184E-07	5.466743045	0.139465173	0.00069224	0.2536313	
67DTB19	OH-DB 09-67DB19@15	0.0020153	3.536E-07	5.036911892	0.175457584	0.000701259	0.2124638	
67DTB19	OH-DB 09-67DB19@16	0.002015918	2.75734E-07	5.345007648	0.136778464	0.000690229	0.3118861	
67DTB19	OH-DB_09-67DB19@17	0.002012996	3.23452E-07	3.887689673	0.160681932	0.000759254	0.7287932	
67DTB19	OH-DB 09-67DB19@18	0.002015898	3.4336E-07	5.334988274	0.170326268	0.000774998	1.460556	
67DTB19	OH-DB_09-67DB19@19	0.0020153	2.66571E-07	5.036911892	0.132273386	0.000783027	0.1887783	
67DTB19	OH-DB_09-67DB19@20	0.002015229	3.4611E-07	5.001343114	0.171747071	0.000790339	0.5659688	
A	Inalysis session 2 10 μm d	iameter, 1.0 nA, Cs <sup>+</sup> ion-beam						

Sample #	Analysis #	Raw Data fr	rom CIPS	SIMS corre	ected	Drift co	rrected	Notes
sumple #	-1101300 <del>1</del>	180/160	1sigma error	d180 ± j	per mil	он/о	± rel (%)	EJ
52DTB19	OH-DB_52DTB19@1	0.00201456	3.65128E-07	4.667697953	0.181244599	0.000951835	0.187781	
52DTB19	OH-DB_52DTB19@2	0.002013571	3.23901E-07	4.174744744	0.160859222	0.001172443	0.5562904	
52DTB19	OH-DB_52DTB19@3	0.002014413	3.05061E-07	4.594556522	0.151439222	0.000997259	0.2089095	
52DTB19	OH-DB_52DTB19@4	0.00201449	3.20391E-07	4.633131113	0.15904311	0.000952211	0.2070688	
52DTB19	OH-DB_52DTB19@5	0.002012897	2.97348E-07	3.83859474	0.147721254	0.000975512	0.1273858	
52DTB19	OH-DB_52DTB19@6	0.002014484	3.00463E-07	4.6301253	0.14915154	0.000943785	0.1370374	
52DTB19	OH-DB_52DTB19@7	0.00201525	2.9129E-07	5.011863457	0.144542949	0.001173869	0.6260424	
52DTB19	OH-DB_52DTB19@8	0.002014478	3.40544E-07	4.627119488	0.169048024	0.001013108	0.2638681	

## Appendix D2.4: SIMS O- Standards

	Analysis session 1	20 μm diameter, 2.5 n	A, Cs⁺ion-be	am							
Samula #	Analysis #		Raw Da	ta from CIPS		SIMS cor	rected		Drift co	orrected	Natas
Sample #	Analysis #	180/160	1	sigma error	d1	80 ±	per mil		он/о	± rel (%)	Notes
91500	OH-DB 09-DB20 91500@4	0.0	02025401	2 73962E-07		10.07415226	0 135263313		0.000687249	0 5323319	
91500	OH-DB 09-DB20 91500@3	0.0	02025201	2 2001E-07		10.0601/1258	0 16729019		0.000656006	0.2116591	
01500	011-00_03-0020_51500@3	0.0	0020235351	2.041475.07		10.00514250	0.10730010		0.000050000	0.2110501	
51500	OH-DB_09-DB20_91500@2	0	.00202526	2.84147E-07		10.00401664	0.140301653		0.000661941	0.4074392	
91500	OH-DB_09-DB20_91500@14	0.0	02025039	2.95929E-07		9.893803528	0.14613504		0.000670406	0.1463796	
91500	OH-DB_09-DB20_91500@13	0.0	02025428	3.43505E-07		10.08767842	0.169596216		0.000652035	0.1458913	
91500	OH-DB_09-DB20_91500@12	0.0	02024792	3.19069E-07		9.770565226	0.157580972		0.000670077	0.3364866	
91500	OH-DB_09-DB20_91500@11	0.0	02025348	2.71902E-07		10.04810189	0.134249664		0.000676422	0.5313374	
91500	OH-DB 09-DB20 91500@09	0.0	02025177	3.48236E-07		9.962436241	0.171953366		0.000692961	0.5174865	
91500	OH-DB 09-DB20 91500@08	0.0	02024948	2 77273E-07		9 848215376	0 136928478		0.000662578	0 1474669	
91500	OH-DB_09-DB20_91500@007	0.0	0 0020252	2.914126-07		0 072058522	0.139955226		0.000677362	0.1964106	
91500	OH DB 00 DB20_01500@07	0.0	0.0020252	2.014122-07		0.065042022	0.130333230		0.000664564	0.1004150	
51500	OH-DB_09-DB20_91300@00	0.0	02023184	2.540172-07		9.903943022	0.1434/00//		0.000004304	0.3090403	
91500	OH-DB_09-DB20_91500@05	0.0	002024706	2.79989E-07		9.727481917	0.138286387		0.000694405	0.5311041	
91500	OH-DB_09-DB20_91500@010	0.0	002025113	3.50732E-07		9.930875213	0.173191217		0.000658301	0.1500499	
91500	OH-DB_09-DB20_91500@01	0.0	02024858	3.06937E-07		9.803629161	0.151584245		0.000665258	0.3946493	
OGC	OH-DB_09-DB20_OGC@13	0.0	02016687	3.08647E-07		5.72874968	0.153046334		0.001089232	0.140743	
OGC	OH-DB 09-DB20 OGC@12	0.0	02016559	3.1645E-07		5.664625685	0.156925875		0.001043832	0.1129922	
OGC	OH-DB 09-DB20 OGC@11	0	00201674	3.98285E-07		5,754800053	0.197489386		0.000948023	0.3038348	
060	OH-DB 09-DB20 06C@10	0.0	02016268	2.86055E-07		5 5109/15729	0 1/197255/		0.000991907	0 1120112	
000	011-00_03-0820_0406@10	0.0	02010208	2.000552-07		5.515045720	0.1410/3334		0.0000531507	0.1130113	
000	OH-DB_09-DB20_OGC@09	0.0	02016035	3.18542E-07		5.403620987	0.158003934		0.000957154	0.2112503	
UGC	OH-DR_09-DR50_OGC@08	0.0	002015189	2.91543E-07		4.981304365	0.1446/2/93		0.000915684	0.1470667	
OGC	OH-DB_09-DB20_OGC@07	0.0	002016805	3.18388E-07		5.787363019	0.1578676		0.00100767	0.209695	
OGC	OH-DB_09-DB20_OGC@06	0.0	002016358	2.90876E-07		5.564431943	0.144257908		0.000893493	0.1580112	
OGC	OH-DB_09-DB20_OGC@05	0.0	02016569	3.54759E-07		5.669635372	0.175921933		0.00083367	0.2175937	
OGC	OH-DB 09-DB20 OGC@04	0.0	02016356	3.43124E-07		5.563430006	0.170170348		0.000856599	0.2124317	
OGC	OH-DB 09-DB20 OGC@03		0.0020179	2.6318E-07		6.333418912	0.13042275		0.000925105	0.3843214	
OGC	OH-DB 09-DB20 0GC@02	0.0	02016758	3 14937E-07		5 763817489	0 156160053		0.000819279	0.4766153	
060	OH-DB_09-DB20_OGC@01	0.0	02010750	3 10541E-07		6.020922911	0 153030654		0.000025275	0.2255265	
M2E7	011-00_03-0020_0020001	0.0	02017255	2.002075.07		14.050055011	0.1355555004		0.0005300057	0.2235205	
11237	OH-DB_09-DB20_M257@4	0.0	02033391	2.982876-07		14.05885738	0.140094184		0.000643488	0.2676096	
M257	OH-DB_09-DB20_M257@30	0.0	02033596	3.25667E-07		14.16105499	0.16014357		0.000654028	0.195474	
M257	OH-DB_09-DB20_M257@3	0.0	02033235	2.78309E-07		13.98120723	0.136879808		0.000650297	0.1625557	
M257	OH-DB_09-DB20_M257@29	0.0	02033071	2.99631E-07		13.89954933	0.147378253		0.000662105	0.1113873	
M257	OH-DB_09-DB20_M257@28	0.0	002032616	3.08013E-07		13.6726105	0.151535136		0.0006703	0.3621382	
M257	OH-DB_09-DB20_M257@27	0.0	02033152	3.02482E-07		13.93962682	0.148774856		0.000638871	0.1699941	
M257	OH-DB 09-DB20 M257@26	0.0	02032675	3.33561E-07		13,70166669	0.164099626		0.000670975	0.398922	
M257	OH-DB_09-DB20_M257@25	0.0	02033107	3.07945E-07		13 91708323	0 151465412		0.000641157	0 1556723	
M257	OH-DB_09-DB20_M257@24	0.0	02033260	2 991925-07		12 70995462	0 1/1761172		0.000642864	0.2452297	
14257	011-06_03-06220_N257@24	0.0	02032005	2.001022-07		13.75005402	0.141/011/2		0.000042804	0.3452207	
IVI257	OH-DB_09-DB20_M257@23	0.0	002033209	3.02998E-07		13.96818204	0.149024494		0.000646363	0.2559461	
M257	OH-DB_09-DB20_M257@22	0.0	02033046	3.24747E-07		13.88702511	0.15973423		0.00067389	0.3661834	
M257	OH-DB_09-DB20_M257@21	0.0	02032833	3.28822E-07		13.78081974	0.161755516		0.000675872	0.255695	
M257	OH-DB_09-DB20_M257@20	0.0	02033173	3.3958E-07		13.95014717	0.167019848		0.000658617	0.2600312	
M257	OH-DB_09-DB20_M257@2	0	.00203327	2.98378E-07		13.99874113	0.14674806		0.000648604	0.1942788	
M257	OH-DB 09-DB20 M257@19	0.0	02033451	3.32724E-07		14.0889155	0.163625035		0.000651835	0.1603915	
M257	OH-DB_09-DB20_M257@18	0	00203246	2.72836E-07		13,59445938	0.134239145		0.000680224	0.2829176	
M257	OH-DB_09-DB20_M257@17	0	00203294	2 60471E-07		13 83392243	0 128125275		0.000667519	0 3641615	
M257	OH-DB_09-DB20_M257@16	0.0	020222294	2.004712-07		14 00425179	0.126500699		0.000658583	0.2896507	
14257	011-00_03-00220_N257@10	0.0	02033201	2.775442-07		14.00423173	0.150500000		0.000050505	0.2000007	
IVI257	OH-DB_09-DB20_M257@15	0.0	002033245	3.22523E-07		13.98621691	0.158624509		0.000642591	0.1161775	
M257	OH-DB_09-DB20_M257@14	0.0	002033524	3.00555E-07		14.12548622	0.147800214		0.000645779	0.2443702	
M257	OH-DB_09-DB20_M257@13	0	.00203345	3.36534E-07		14.08841453	0.165498782		0.000650669	0.1970071	
M257	OH-DB_09-DB20_M257@12	0.0	02034067	3.23027E-07		14.39600932	0.158808488		0.000647806	0.2153644	
M257	OH-DB_09-DB20_M257@11	0.0	02033583	3.03471E-07		14.1545424	0.1492296		0.000648651	0.2560871	
M257	OH-DB 09-DB20 M257@10	0.0	02033712	3.83584E-07		14.21916736	0.188612903		0.000667922	0.2456096	
M257	OH-DB_09-DB20_M257@09	0.0	02033519	3 1474E-07		14 12298137	0 154776226		0.000659663	0 2778733	
M257	OH-DB_09-DB20_M257@08	0.0	02033513	2 77601E-07		14 11007556	0 136512977		0.000667268	0.2003164	
M257	OH DR 00 DR20 M257@08	0.0	020202012	2.770012-07		14.11557550	0.130312077		0.00064254	0.2055104	
11/237	OH-DB_09-DB20_W257@07	0.0	02033804	3.00042E-07		14.29481364	0.175040050		0.00064654	0.2257004	
M257	OH-DR_09-DR50_W521@06	0.0	JU2U33357	3.57767E-07		14.04182444	0.175948953		0.000660983	0.2102762	
M257	OH-DB_09-DB20_M257@05	0.0	002033608	3.22347E-07		14.16706662	0.158509873		0.000624511	0.41315	
M257	OH-DB_09-DB20_M257@02	0.0	002033185	3.24303E-07		13.95615879	0.159504744		0.000643087	0.231571	
M257	OH-DB_09-DB20_M257@01	0.0	02033329	3.22878E-07		14.02779732	0.15879291		0.000660593	0.3742145	
M257	OH-DB_09-DB20_M257@01	0.0	02033259	3.25413E-07		13.99323048	0.160045095		0.000655022	0.2275834	
	Analysis session 2	10 um diameter. 1 0 n	A. Cs <sup>+</sup> ion-he	am							
		p diameter, 1.0 fi	,	ta from CIDS		SIMC	rested	-	Drift or	procted	
Sample #	Analysis #	100 //	ndw Dai			SIIVIS COP			Dint co	i l(a()	Notes
		180/160		15igma error	d1	80 ±	per mil		UH/0	± rel (%)	
M257	OH-DB_52DTB19_M257@7	0.0	002033513	3.46641E-07		14.11997556	0.170464127		0.0008626	0.2054075	
M258	OH-DB_52DTB19_M257@6	0.0	02033424	3.18243E-07		14.07538934	0.156505899		0.000900419	0.1926557	

								NOTOC
Sample #	Analysis #	180/160	1sigma error	d180 ± pe	er mil	он/о	± rel (%)	Notes
M257	OH-DB_52DTB19_M257@7	0.002033513	3.46641E-07	14.11997556	0.170464127	0.0008626	0.2054075	
M258	OH-DB_52DTB19_M257@6	0.002033424	3.18243E-07	14.07538934	0.156505899	0.000900419	0.1926557	
M259	OH-DB_52DTB19_M257@5	0.00203344	3.04378E-07	14.08340484	0.149686074	0.000975826	0.4281997	
M260	OH-DB_52DTB19_M257@4	0.002033133	2.98886E-07	13.93010842	0.147007435	0.000949523	0.3940813	
M261	OH-DB_52DTB19_M257@2	0.002033196	2.88108E-07	13.96166945	0.141702169	0.000946904	0.1929651	
M262	OH-DB_52DTB19_M257@01	0.002032816	3.45779E-07	13.77230328	0.170098706	0.000957122	0.1667874	
91500	OH-DB_52DTB19_91500@01	0.002025602	3.24555E-07	10.17434601	0.160226595	0.001010495	0.4473895	omitted sample topology
91500	OH-DB_52DTB19_91500@2	0.002025449	3.35421E-07	10.09819876	0.165603069	0.001012409	0.5280014	omitted sample topology
91500	OH-DB_52DTB19_91500@3	0.002025547	3.19891E-07	10.1472937	0.157928369	0.000988545	0.3153125	omitted sample topology
<del>91500</del>	OH-DB_52DTB19_91500@4	0.002025569	2.8907E-07	10.15831501	0.142710472	0.000825623	0.1556147	omitted sample topology
91500	OH-DB_52DTB19_91500@5	0.002025503	2.9946E-07	10.12525107	0.147844556	0.000823978	0.3675927	omitted sample topology
OGC	OH-DB_52DTB19_OGC@01	0.002017058	2.9771E-07	5.913607133	0.147596137	0.001304474	0.2429095	
OGC	OH-DB_52DTB19_OGC@03	0.002017023	3.38173E-07	5.896073229	0.167659562	0.001092478	0.1834291	
060	OH-DB 52DTB19 OGC@2	0.002016708	3 38891F-07	5 739270023	0 168041624	0.001308865	0 5039747	

TDMCrustal (Ga) HKCHUR(1) HFDM(t)	al., 2001, Science 293	2.24 2.630 0281791501 0.28209408	2.29 2.766 0.281791501 0.282115964 2.33 2.764 0.281791501 0.282115064	2.33 2.820 0.281791501 0.282112535	2.31 2.787 0.281791501 0.282105013	95201282.0 IDC19/182.0 188.2 75.2 75.2 10267195.0 102	2.25 2.672 0.281791501 0.282117247	2.18 2.595 0281791501 0.282115676	2.21 2.583 0.281791501 0.282081752	2.33 2.851 9.1501 0.252127302 2.826 0.16179150 0.252127302	2.29 2.740 0.281791501 0.282107277	2.31 2.778 0.281791501 0.282090665	2.32 2.800 0281791501 0.282106289	2.40 2.503 0281791501 0.282104873	2.32 2.797 0281791501 0.282109268	2.30 2.30 10229/1232 0.712 0.282130487	2.30 2.778 0.281799599 0.28211126	2.43 2.822 0.28161504 0.281897793	2.50 2.916 0.28161504 0.281897793	2.42 2.787 0.28161504 0.281897793	2.27 2.551 0.28161504 0.281897793	2017001001010101010101010101010101010101	56//691970 MOLTOTOTOTO VILL 80.7	ELL/20107/0 MOSTOTO7/0 15/17 05/7 05/7	2.26 2.537 0.2816150M 0.281897798	2.23 2.473 0.28161504 0.281897793	0.68 -0.099 0.28161504 0.281897793	1.68 1563 0.28161504 0.281897793	0.48 -0.471 0.28161504 0.281897793	50//60107/0 MC10107/0 76/0- 76/0- 76/0	1.76 1694 0.28161504 0.281897793	-0.10 -1451 0.28161504 0.281897798	2.36 2.696 0.28161504 0.281897793	-0.55 -2.188 0.28161504 0.281897799 2 39 0 2 732 0.28161504 0.281897799		2.92 3.000 1.0000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000	2 89 2 80 1081001820 0381061820 03812	2.90 3.086 0.281114242 0.281318556	2.85 3.003 0.281121004 0.281326379	2.86 3.025 0.281126095 0.281332267	2.96 3.177 0.281112785 0.281316872	2.34 3.112 0.221000000000000000000000000000000	2.80 2.924 0.281116609 0.281321294	2.82 2.962 0.281127883 0.281334335	2.70 2.766 0.281129547 0.281336259	2.88 3.064 0.281137048 0.281344935	2.8/ 3.054 0.281146/3/ 0.281390087 2.90 3.154 0.281176086 0.281390087	2.45 2.379 0.281159002 0.281370327	2.89 3.154 0.28119797 0.281415399	2.92 3.192 0.281189002 0.281405027	2.81 3.030 0.281214892 0.281434972
±20 TDM(Ga)	y 0.02 Scherer et	51 1.30	35 1.12	24 1.26	83 1.05	201 07	83 109	65 1.05	93 123	00 100 01 100	102	89 1.02	02 1.16	67 1.09	92 1.05		850 0.98	05 0.91	54 0.74	49 0.81	78 0.91	50 1.61	25 T-40	21.1 UB	56 0.77	45 0.84	80 7.70	58 1.79	35 1.82	20 3.4/	56 102	76 1.47	07 0.74	42 450 63 0.88			36 1.76	20 1.09	38 0.98	33 1.09	20 0.95	3/ 1.1/2	69 1.30	29 1.44	<u>9</u> 1.75	71 F	105	38 1.12	41 0.98	86 133 74 1.13	79 1.02
5H2	Hi Ludeca	0.28164 -5	0.28158 -7.	0.28156 -8	0.28157 -7	e- 82185.0	0.28163 -5	0.28166 -4	0.28165 -4	0.28156 -8	7- 65182.0	0.28157 -7	0.28157 -8	0.28152 -9.	0.28157 -7	7- 62182.0	2- 85182 0	0.28147 -5	0.28143 -6	0.28149 -4	0.28159 -0	0.28205	c 0/10710	C. 1018L0	0.28160 -0	0.28163 0.	0.28274 39.	0.28203 14	0.28289 45	0.28161 -0	0.28197 12	0.28330 59.	0.28153 -3	0.28360 70		0 011970	0.28113 1	0.28112 0	0.28116 1	0.28115 0.	0.28108 -1	0. 00180.0	0.28119 2	0.28118 1	0.28127 4	0.28114 0	0.28112 -2	0.28145 10	0.28113 -2	0.28111 -2	0.28119 -0
±2.0 INT		0.0018	0.0023	0.0008	0.0042	790000	0.0019	0.00023	00000	820000	0.0027	0.0017	0.001	0.00074	0.0011	/90000	0.00054	0.0001	0.0034	0.0014	0.00036	70000		470000	0.00038	0.00072	0.000	0.0013	90000	0.0009	0000	0.0005	0.00036	10000		10000	1000	0.0011	0.00029	0.000055	0.00028	10000	0.00033	0.00035	0.00092	0.00038	0.00039	0.00039	0.00029	0.0025	0.0002
176Yb/177Hf	2008 EPSL-273 002. Uthos-237	0.066	0.04992	0.03323	0.035	0.05852	0.0538	0.01808	0.04792	26/50.0 A5750.0	0.0426	0.0208	0.0256	0.05085	0.0272	0.04624	0.03206	0.01747	0.0344	0.03	0.02285	0.01354	111000	00100	0.02184	0.02862	0.03233	0.0264	0.01625	0.01118	0.02619	0.02042	0.03238	0.0321		0.04100	0.0369	0.0216	0.03041	0.039367	0.03635	1002761	0.03911	0.03512	0.04387	0.06505	0.03558	0.02643	0.04345	0.0506	196010
THE ±20 INT	160 Bouvier et al., 240 Griffin et al., 2	3 0.000052	0.0000049	8 0.000031	0.0001	9700000 F	3 0.000051	23 0.000062	0.0001	20000012	4 0.000067	2 0.000039	1 0.00003	2 0.000011	5 0.000034	2 0,000018	12 0.000008	6 0.000068	3 0.000039	0.00033	0.0000089	6000000 8	7100000	stronoon a	0.0000066	1 0.00013	5 0.00015	3 0.00028	0.000018	100000	0.00013	0.0001	0.00011	0.000025			100004	0.0003	M 0.000079	7 0.000043	4 0.000046	100000	1 0.0000049	9 0.000061	0.000025	00000	5000000 B	00000	8 0.000034	0.000067	0.00011
0.% 176W/177	ernal ±) 0.03	002671 0.00191	005664 0.000834	005668 0.00113	005662 0.00098	77100 695000	005665 0.00162	005664 0.000622	005669 0.00135	005662 0.0012/ 005664 0.00120	005662 0.00122	005661 0.00062	005665 0.00085	005662 0.00161	005662 0.00093	001000 00000	960000 995000	005656 0.000484	100000 000000	002653 0.00080	005658 0.000594	10000 / 19900	000000 0/0000	1900000 0129500	005654 0.00058	005657 0.00083	005875 0.00096	005692 0.00083	000021 0.000500	20000 00000 000000	6/0000 699500	005708 0.00057	005652 0.00094	000000 818500			2010010 995000	005654 0.0006	005652 0.000901	005655 0.001155	76000.0 25000	67T0010 059500	005662 0.001151	005666 0.000963	005677 0.00128	005657 0.00178	011000 659500	005662 0.00075	005652 0.001169	005662 0.00144	005654 0.00106
	to INF Ext	00037 0.	00032	00036	0000		00031	00003	00035	0 0000	000200	00029	00033 0.	00031 0.	0000	0.022	1200	00026 0.	00021	0.0023	00026	0 0000			00000	00024 0.	0022 0.	00051 0.	25000	0 11000	0 67000	00042	0.0021	0014 0			2000	0.0031	0.0028	0.0031 0.	2000	70000	0 20037	0.0041 0.	0000	00032	1000	00032 0	0.0028	0.038	- 67000
10Hf/JJJHf	0.282785 ±	0.281694 0.0	0.281609 0.0	0.281593 0.0	0.2816 0.	10 00 00 00 00 00 00 00 00 00 00 00 00 0	0.281675 0.0	0.281679 01	0.281694 0.0	0 109182-0	0.281629 0.0	0.281588 0.0	0.281591 0.0	0.281567 0.0	0.281596 00	10 27919270	0.281606 0.0	028149 0.0	0.281463 0.0	0.281517 0.0	0.281614 0.0	0.252065 0.0	0 0011070	10 2451070	028162 0.0	0.281657 0.0	0.28277 0.	0.282055 0.0	0.28291 0.0	0.281644 0.0	0 265182.0	0.283318 0.0	0.281562 0.0	0.28363 0.0		10 /viter 0	0.28118 0.0	028115 0.0	0.281205 0.0	028121 0.0	0.281128 0.0	0.021148	028125 0.0	0.281229 0.0	0.281332 0.	0.281229 0.0	0.281166 0.	0.281488 0.0	0.281186 0.0	0.281178 0.0	0.281243 0.0
11	002 * 3/1/(8/9:	8.33	8.8	45	10.6	12.51	12.82	19.00	10.85	20.55	5	14.69	30.29	6.66	12.79	24-25	75.2	19.34	26.90	30.55	32.89	32.90	5.65	0174	43.89	45.11	45.28	46.27	48.4	97.79	16.89	95-69	78.34	80.73 81.09		88	999	6.65	10.15	10.16	10.25	10.01	11.99	12.91	13.71	14.08	15.36	18.27	18.91	20.00	25.39
	20 PROP (7/	5.33	6.52	5.42	6.85	191	4.16	5.53	11.5	4.09	62 S	6.57	8.03	4.79	4.42	4.81	9	4.43	4.48	3.89	435	507 1	2.6	4.76	445	4.52	4.93	S.71	43	8.50	669	7.23	7.69	5/.6		2 G	117	6.19	4.8	3.91	3.85	292	4.11	3.77	5.33	3.61	3.65	5.5	4.17	48	4.67
f seal a sources a	1Pb/206Pb ±	1591.66	1561.92	1566.57	1576.77	2010/01	1560.18	1562.31	1608.3	1540.54	1573.7	1596.22	1575.04	1576.96	1571	1542.42	1568.3	1841.3	1738.33	1763.94	1780.95	125/10	21106/1	1005.25	1777.43	1782.62	1812.25	1827.25	1819.77	1597.16	1758.34	1751.02	1604.53	1588.81	10 1 201	2077007	04.720	2632.64	2622.24	2614.41	2634.88	10,0002	2629	2611.66	2609.1	2597.56 7687.66	2537.46	2563.77	2503.74	2517.56	2477.65
inatemin - ala	20 PROP 20	31.5	52 228	31.3	29	147	29.3	26.7	62 G	2.17	31.4	29.3	24.7	31.4	29.2	797	333	31.3	27	26.4	27.3	9	e 17	6 M	27.3	28	22	21.7	8 6	215	12	29.4	13.1	142		5	0.98	49.4	6.13	45.7	8.6 2 2		45.8	46.2	1.14	1	19	40.4	40.8	6 Q 2	37
u a poleto	38U/206Pb ±	1459.1	1422	1501.6	1434.3	0.0001	1360.1	1265.5	1433.8	1.8021	1477	1361.7	1098	1471.9	1370	120/.5	1605.4	1485.2	1270.8	1225.1	1295.2	1.8511	10001	1002 1	995.6	978.4	993.4	981.7	932.8	522.9	556.7	533	347.6	301.05	0.000	1027	2.092	2457.6	2356	2348.8	2364.9	0.000	2324.2	2274.5	2251.4	2232.3	2347.8	2095.4	2080.3	20115	1848.6
	rho 2	0.35039	0.30431	0.2 0395	0.16999	0.29769	0.10872	0.21143	0.46775	0.1545	1311600	-0.016695	0.16016	0.13002	0.23958	19/10	0.063 883	0.22.11	0.14562	0.0086911	0.27712	-0.0546Z	(See T.D	577 0000	-0.073122	0.35497	0.079 299	0.11213	-0.15406	0.7383	0.63735	0.82959	0.4016	0/57510		06/67D	0.14182	-0.6472	-0.48568	0.45454	0.25583	0.18655	-0.3597	-0.16158	0.47106	0.17465	0.27887	0.28569	-0.48056	-0.40395	0.26449
conse.	±20 PROP	0.0025164	0.0025954	0.0024902	0.002 6508	0.002 44444	0.0023536	0.0024958	0.003 184	0.002 3856	0.0025376	0.0026512	0.002769	0.002441	0.002 3948	79657000	0.002 552	0.000 5508	0.0005202	0.000459	0.0005202	89640000	000000000000000000000000000000000000000	1000000	000023000	0.0005405	0.0006018	0.0007038	0.0005304	8/06/0000	0.000816	0.0008466	0.000816	201000			0008060	0.001326	0.00102	0.0008262	0.0008262	000000000000000000000000000000000000000	0.0008772	0.0007956	0.001122	0.0007548	0.0007344	0.001122	0.000816	0.0009486	0.0008976
nutrinosi nui-	2079%/2069%	0.09832	0.096774	0.09701	0.09754	102800	0.09668	6/ 96010	0.0992	96565000 9226000	0.097.38	0.09856	0.09745	0.09755	0.097.24	e/ 66000	0.0971	0.11262	0.10643	0.10793	0.10894	65211.0	6460T10	76/0110	0.10873	0.109.04	0.11083	0.11175	011129	198800	0.1076	0.10717	0.099	0.097617		90.92.10	0.181.0	0.1779	0.17679	0.17596	0.17814	18081.0	0.17751	0.17567	0.1754	0.17419	0.16804	0.1707	0.1647	0.16606	0.162.17
~~~~	±20 PR OP	0.2 2394 448	12 1743 469	120999602	121326669	C085067-0	0.24002318	0.2533393	121343802	127527609	202 CM07 2 1	123941119	3 1073 675	1.2 1960033	123618687	NO/ 590871	19570912	0.1823252	0.2 1482 546	12 2585 697	124582051	108 0077 71	160047071	C34, 0070 C 1	135476355	137590448	0.2866453	0.2902412	0.30714668	01022000101	91518725	0.87854824	13 9582 206	2116/818		767097600	22901300	0.10418372	111003944	0.10556378	0.10385579	CICVERUIT	0.10825566	0.11395777	111091776	0.11318083	11743546	11753317	0.12652498	0.12930418	113872469
	238U/206Pb	3.937008	4.051864 5.094244	3.812429	4.012841	1 C18/17.8	4.257131	4.610207	4.014452	4. /b41/3 2 00675	3883495	4.251701	5.38503	3.898635	4.222973	1 M/CSU.C	3.536068	3.859514	4.589261	4.777831	4.90918	4. /438555	67TC/6'6	5. 502472	5.988024	6.101281	6.002401	6.079027	6.422608	0.0216.0	11.08647	11.60093	18.05054	200.7053		200/002	2118195	2.154708	2.266546	2274795	2.256318	161/677	2303617	2.363507	2.392344	2.416626	2.529084	2.603489	2.701243	2.730748	3.011141
±20 INT		19	L 2	18	8	8 ¥	ន	8.6	9 9	R =	1 12	1 12	5.7	R	22	8 2	1	4.8	e	13	= ;	Q ;	1 0	9 5	1	8	3.9	62	2:	5 5	1 22	13	120	R 8	;	25	3	12	4.3	6.8	84	° 6	89	3.7	84	5.6	13	12	2.7	82	8.7
232Th conc.	maa	6/8	55 BJ	69	369	25 (20)	1037	369.2	961 1	1411	164	232	158.6	921	517	262	252	99.5	221.5	198	184	2	120.3	200	132.1	498	113.4	62.7	8.03	246	187	621	720	200		5-10 C	2.082	147	177	300.6	246.5	786.3	269.2	177.5	299.9	480.9	257.6	104.9	353.9	442 745 5	193
±20 INT		100	91 01	44	7.5	55 64	65	36	54	55	5 2	25	13	43	86	77	26	91	8	2.10	9 <u>9</u>	<u>8</u>	2	3 5	22	220	8	8	6	8 2	952	380	220	1.705+03		9 9	1 2	12	16	24	23	11	20	8.2	19	12	19	ŝ	25	85	11
238U conc.	mag	1120	426	702	385	1416	1715	1063	245	1391	949	519	299	1174	13.78	1/2/1	451	2055	3910	39.70	35.30	6017	07.02	0.00	3407	3550	2700	1840	1759	016	6630	3660	9690	1.50E+04	-	340	174	327	433	646	673	816	635	491.7	583	882	88	3125	1122	696	L91
Soot ID		37DTB+L+1	37DTB-L-10 37DTB-L-11	37DTB-L-12	37DTB-L-13	3/D18-L-14 27D78-L-15	37DTB-L-16	37DTB-L-17	37DTB-L-18	3/DTB-L-19 37DTB-L-2	37DTB-L-20	37DTB-L-3	37DTB-L-4	37DTB-L-5	37DTB-L-6	3/DIB-L-/	37DT8-L-9	46DTB-L-10	46DTB-L-8	46DTB-L-12	46DTB-L-6	46D18-L-1	CT - 1-01/000	CT - 1-01/004	46DTB-L-4	46D TB-L-17	46DTB-L-19	46DTB-L-18	46DTB-L-16	46DTB-L-9	46DTB-L-14	46DTB-L-7	46DTB-L-20	46DTB-L-5 46DTB-L-5	a i unard	0/0/B-C-0	7.1.BT012	67DTB-L-16	67DTB-L-17	67DTB-L-12	67DTB-L-20	0/018-C-T2	67DTB-L-11	67DTB-L-19	67DTB-L-6	67DTB-L-4	67DTB-L-2	67DTB-L-18	67DT8-L-13	67DTB-L-1 670TB-L-0	67DTB-L-3
Analysis date-time		17/03/2021 (4)	17/03/2021 (4)	17/03/2021 (4)	17/03/2021 (4)	(#) 1202/S0// 1 (#) 1202/S0/2 1	17/03/2021 (4)	17/03/2021 (4)	17/03/2021 (4)	(#) 1202/20// 1 (#) 1202/20/2 1	17/03/2021 (4)	17/03/2021 (4)	17/03/2021 (4)	17/03/2021 (4)	17/03/2021 (4)	(#) 1707/20// T	17/03/2021 (4)	17/03/2021 (4)	17/03/2021 (4)	17/03/2021 (4)	17/03/2021 (4)	(*) 1707 /S0// 1	(#1 F202/2072 F	(w) 1202/20/21	17/03/2021 (4)	17/03/2021 (4)	17/03/2021 (4)	17/03/2021 (4)	17/03/2021 (4)	(#) 1202/20// T	17/03/2021 (4)	17/03/2021 (4)	17/03/2021 (4)	(4) 1202 /S0// 1 1 7/05/ 2002 (4)	(a) and a second s	(#1 F202/2072 F	(#) L2UC/2U/2 L	17/03/2021 (4)	17/03/2021 (4)	17/03/2021 (4)	17/03/2021 (4)	(#) 1707/00//1	17/03/2021 (4)	17/03/2021 (4)	17/03/2021 (4)	17/03/2021 (4)	17/03/2021 (4)	17/03/2021 (4)	17/03/2021 (4)	17/03/2021 (4)	17/03/2021 (4)
	Sample ID	37078 29	3701829 3701879	37018 29	37018 29	3701629	3707829	37DTB 29	37018 29	3701829	37DTB 29	37078 29	3701819	37018 19	3701829	3701629	37018 29	46DTB 29	46DTB 29	46DTB 29	46DTB 29	4601829	400.10.29	07 BL 01	46DTB 29	46DTB 29	4607829	46DTB 29	4601839	4607879	46DTB 29	46DTB 29	46078 29	4607879 4607879		0/01079	67018.19	67DTB 29	67018 29	6707839	67078.29	67018.92	6701829	6701819	6707829	6701829	6701829	67DTB 29	6701829	6701839	6701829

# Appendix D2.5: LA-ICPMS U/Pb-Lu/Hf Results

# **Appendix D2.6: LA-ICPMS Trace Element Results**

1725	38	s	<u>a</u> 2	<pre>k</pre>	N 00	s.	2 2	2		s.	N SS	E	2 2	s	3	: 3	N :	2 2	2	2 3	2	83	ť a	s	s 23	s.	8 4	1	2 a	3	è a	s.	2 2	N	5	1	s S	ŝa	1038	34	S a
90 Gd	9	2	23	32	- 2 2 3	2	2 Z 2 7	2 : N	~ 2	2	23 23	4	22	2	2 :	. 0	2 :	22		23	2 Z	0.0	32	2 0	2 3 P	2	~ ~	: 2 . 7	0 #	23	8 22 8 19	2	2 2 2 6	N 69	41	2 2	2 S	5 Z	88	88	8 m 2 s
an Gd_g	9	- 3	3.		- 3	200	6 		- 3	~	88	-	. 4	2		۰، ۱	~	3 *		-i -	4 14	in ,	4	9	2 F	~	N .	13		00	5 8 • •	~	8 8 * *	5		3	3,	- 3	88	3 ~	3-
n 6d_pg	78	6.1	. 655	- 6	3.11	24.3	2 2	2.7	37.6	12	102	15	2.8	29.	81	41.0	8	119	43	1	78	22	1 F2	370	68	128	292	ĩ	999	10.00	13	21.5	16.8	83	17.	4	290	1.2	22	12	4.8 29
EU.pp 11_m153	NaN	NaN	000	0012	NaN 0012	NBN	N UN	NeN	N EN	NeN	0012 NaN	0017	0012	NaN	NeN	NeN	NeN	N EN	NBN	Nev	0012	NaN of	NeN	NBN	NeN NeN	NBN	NeN .	NaN	NaN 0.012	NeN	NeN	NBN	N EN	NeN	NeN	002	NaN	NeN	NeN	N SN	NaN NaN
Eu_ppm m153_le 25E	0.88	0.094	0.076	110	0.097	0.14	0.056	0.13	6100	0.32	0.13	0.14	0.095	0.21	0.022	1	0.01	1000	0.013		0.022	0.044	0.038	0.077	0.056	0.033	0.028	-	4.9	0.047	0.044	0.14	0.057	0.045	0.12	80	0.027	0.036	0.057	0.31	0.038
Eu_ppm_ m153	674	672	619	8	660 9850	085	0.216	0.76	0207	54	126	113	0.621	2.55	0.048	0	0.00	0149	0014	• •	0036	0.129	0104	0.211	024	0.081	0055	•	30.4	5 5	0165	9.0	600	0.347	051	0201	0.055	0104	0.06	133	0.134 0.311
5m_ppm 10_L 00	NaN	NaN	NaN	NaN	N eN N eN	NaN	N N N	NaN	NBN	NaN	NaN NaN	NaN	N SN	0.046	NaN	NeN	NaN	Nev	NaN	0.035	NaN	NaN	NEN	NaN	N N N	NaN	NaN	NaN	NaN	NaN	NaN	NBN	Nev	NeN	NaN	NaN	NaN	NaN	NaN	0.035	NaN NaN
m_ppm mm	7.8	0.31	0.25	6.8	0.51	0.48	0.26	5	0.18	3	0.47	0.46	0.25	66.0	9.8	0.84	1	410	1	032	53	24	39	92	8 X	6.4	- 5	3	8 8	0.38	0.28	0.58	970	0.21	13	028	0.13	0.37	0.33	31	0.17 0.48
- 741m	454	5	141	18	356	332	0.89	219	5700	22.1	334	3.59	231	836	469	697	59	12.3	35	18	19.8	88 3	152	292	73 9 <u>1</u>	292	5 104	80	2.34	2.27	9 28	4.41	22	14	55	160	0.41	234	246	61	6 8 4 39
- 146_L 146_L 00	NE	N	NaN 1	N N	N N	N PI	z z	N	s s	N	N N	N	N N	N	Nei	N	N	N EL C	N	N N	N N	No.	NE	N	N N	N PI	N N	N	Nei	N	N N	Net	N N N	Net	Nei	65	10	10	N PI	N N	N N N N
46.1 md	0 0	12	2 : 8 :	12	2 S S	37 N	2 2 8 8	46	2 Z	8	2 2	31	2 S	21 2	2 ·	1 12	2	2 - 2 -	-	51 - 2 -		2 i	19	2	< 2 < 0	~	2 2	. z	8 9	28	 	31	2 Z Z	21 N	2 2 9 2	5 0 5 8		ະ 0 າ 23	2 N N	୧୧ ୧୦	4 2 2 2 2
46 mi 10 mi	2	, o	3 < # 4		0 0 8 8	0	3 0 3 8	9.0	5 0 1 12	4	ං ං ඉ ස	8	50	0		• 0	0	3 °	9	۰ ہ ب			5 4 2 m	0		~	900		~ o	80	 	0	20	8	- - - -	5 0 5 8	2	" 0 1 8	9 C	5 ® 8 m	00 88
و Nd ا	16	12	33	12	23	~	3.2	21	13	E.	23	2	3 5	5.5	K g	17	53	3 %	9	33		16	5 97	42	າ 	7	73	13	180	33	18	2	1.	0.0	33	13	2 :	12	513	38	82
nt m141 OD	NaN	NaN	NaN	NaN.	NeN NeN	NBN	NeN NeN	NaN	NEN .	NaN	NaN NaN	NaN	NaN NaN	NaN	NeN	NeN .	NBN		NaN	NaN	NeN NeN	NaN		NaN	N8N 0.00	NBN	84	NaN	NeN	NaN	NEN N	NaN		NaN	NaN	Nev N	NaN	N IN N	NeN NeN		NaN
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Pr_ppm m 141	25	0.091	0.026	0033	0.161	0.255	0.0023	0.437	0.025	1.42	0.203	0.107	0.03	0.52	15.2	0.584	0.328	2.60	2.18	0.042	ş ø	46	2.38	ĸ	1 22	1.35	0.56	0.067	511 0.046	0.068	80	0.265	0.003	0.085	2.56	0.173	0.026	0.071	0.083	s.s	0.048
Ce_ppm _m140_L OD	NaN	0.017	NaN	NaN	N RN N RN	ŝ	NeN NeN	NUN	STOD NWN	0.011	N IN	0.0075	NaN	0.0076	NRN	N N	NRN	z z	NBN	New	0.0081	NaN	0.015	NBN	N NSN	ŝ	N UN N	NaN	NRN NRN	0.0077	0.015	Nev	N NN	NBN	NtN	NBN	0.0077	0.0082	0.011 NaN	N N	0.0076 NaN
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" utto	317	69.4	1856	38	4424 47.13	47.6	46.8	48.2	25.19	335	48.7 373	314	3171	20.7	8	526	368	174	21.6	438	202	52	808	253	92 20	222	375	564	1970	1939	1635	2491	1251	1651	28.2	401	5	17.88	19.7	28	11.26 30.64
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opmm43	236+04	low LOD	low LOD	low LOD	low LOD	low LOD	low LOD	low LOD	10% LOD	low LOD	low LOD	low LOD	low LOD	low LOD	low LOD	low LOD	low LOD	510 N	low LOD	low top	low tob	3110	low LOD	550	001 MOI	low LOD	460 Iou I OD	low LOD	66E+05	low LOD	low LOD	low LOD		low LOD	50E+03	low LOD	low LOD	low LOD	low LOD	138 +04	low LOD
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", mqq_I2	3.10E+C	3.60€+0	4.506+0	2.906+0	3.20€+0	4.20€+0	3.706+0	3.60E+0	4.60£+0	3.90€+0	3.30E+C	3.30€+0	3.906+0	4.00E+C	3.40€+0	3.306+0	4.90€+0	3.105+0	4.10€+0	3.406+0	4.906+0	4.106+0	2.906+0	3.60E+C	3.602+0	3.50€+0	3.105+0	3.40€+0	4.806+0	3.40€+0	3.400.40	3.20£+0	3.105+0	3.20€+0	2.906+0	3.106+0	3.50E+C	4.005+0	4.40E+0 3.50F+0	2.60€+0	3.30£+0
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# Appendix D2.6 continued.

0		NSN	NBN	NaN	0.094	NEN	NaN 0.12	NaN	NBN	NBN	0.036	01	NaN	NaN 0.018	NEN	NeN	NSN	6100	NaN NaN	NeN	2.4 NaN	1	Nev	10	0.78	NBN	Nev	NaN NaN	0.011 New	NaN	N NN	NBN	0.047 NaN	NeN	NaN	0.48 NiN	NaN	NRN	New	0.012
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00 mga		142.9	394.6	235	164.6	249.3	482	22	5.55 192.5	61.9	222	402	323	442	805	781	826	598	192	1558	1399	569	1160	838	631	1108	673	304	615	263.4	561 615	592	585 586	19.2	200	566 410	385	019	122	541
206_LO		2000	0.075	000	0.025	0.02	500	0.019	0.021	0.019	0.016	0021	61010	0.016	0.022	0.019	00	0.019	0.018	0.021	200	0.027	0.026	0.018	0.066	0.018	0.032	0.022	0.036	0.018	0.018	0.023	0.018	0.016	0.017	0.016	0.023	0.024	0.024	0.017
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6_00_0		New	NaN	NaN	NeN	NaN	NaN	NaN	NeN	NaN	NaN	NaN	NeN	NaN NaN	NaN	NaN 1300	NaN	NeN 2027	0011	1800	NaN 650	610	610	NaN	NaN	NaN	410	NaN	490	230	081 081 081	190	130	220	88	52 082	410	150	28 F	260
ppm_m 1_mzsE	100	190	230	low LOD	low LOD	230	300	low LOD	Low LOD	low LOD	low LOD	low LOD	140 Iow I OD	170 Iow LOD	1400	206+03	low LOD	low LOD	206+03	30E+03	550 Iow I OD	99	910	low LOD	00E+03	200 +013	570	low LOD	530 Iow I OD	low LOD	180 180	180	130 low LOD	low LOD	Iow LOD	240	low LOD	low LOD	8 8 8	220
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Tbppm m159	100	2.32	2.36	3.19	3.72	3.52	4.79	9.27	28.2	1.33	13.77	4.06	4.92	3.53	15.9	26.7	11.54	2.25	17.6	67	18.5	52	9.58	2 R	818	42.3	23.6	3.88	125	4.96	7.01	7.75	7.02	3.21	6.8	1.81	13.1	456	742	10.29
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| 2_GU1_4<br>2_GU1_4<br>2_GU1_5<br>2_GU1_6<br>2_GU1_7<br>2_GU1_8                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         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| 2_G13_4<br>2_G13_5<br>2_G13_6<br>2_G13_6<br>2_G13_8<br>2_G13_9<br>2_G13_9<br>2_G13_10                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  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                                                                                                                         | 0.00572638<br>0.00572632<br>0.00572532<br>0.0057255<br>0.00572256<br>0.00571956<br>0.00572156<br>0.00572156<br>0.00572156<br>0.00572156<br>0.00572156<br>0.00572156                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           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0.00022319<br>0.00022211<br>0.0002256<br>0.000303056<br>0.00030240<br>0.00030214<br>0.00030214<br>0.00030274<br>0.00030274<br>0.00029801<br>0.00029801<br>0.00029802<br>0.00029802<br>0.00029802<br>0.00029802<br>0.00029802<br>0.00029802<br>0.00029802<br>0.00029802<br>0.00029802<br>0.00029802<br>0.00029802<br>0.00029802<br>0.00029802<br>0.00029802<br>0.00029802<br>0.00029802<br>0.00029802<br>0.00029802<br>0.00029202<br>0.00029202<br>0.00029202<br>0.0002920<br>0.0002920<br>0.0002920<br>0.0002920<br>0.000290<br>0.0002000<br>0.00002000<br>0.000020000000000                                                                                                                                                                                                                                                                                                                                                                                                                                                             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| 2, G11, 4<br>2, G11, 5<br>2, G11, 5<br>2, G11, 5<br>2, G11, 9<br>2, G11, 9<br>2, G11, 9<br>2, G11, 10<br>2, Phenoles, 1<br>2, Phenoles, 3<br>2, Phenoles, 3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            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| 2, Cut , 4<br>2, Cut , 4<br>2, Cut , 5<br>2, Cut , 6<br>2, Cut , 6<br>2, Cut , 8<br>2, Cut , 9<br>2, Cut                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 17/03/2021 (4)<br>17/03/2021 (4)                                                                                                                                                                                                                                                                                                                                    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2,201,4<br>2,01,5<br>2,01,5<br>2,01,7<br>2,01,7<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2,01,9<br>2 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2,201,4<br>2,201,4<br>2,201,5<br>2,201,7<br>2,201,7<br>2,201,7<br>2,201,7<br>2,201,9<br>2,200,00,1<br>2,200,00,1<br>2,200,00,1<br>2,200,00,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,1<br>2,200,0,0,0,0,0,0,                                                                                                                                                                                                                                                                         | 1/00/2021 (4)<br>7/00/2021 (4)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | <ul> <li>Ш1</li> <li>Ш1</li> <li>Ш1</li> <li>Ш1</li> <li>Ш4</li> <li>Ш4</li> <li>Ш1</li> <li>Ш1</li> <li>Ш1</li> <li>Ш1</li> <li>Ш1</li> <li>Ш1</li> <li>Ц1</li> <li>Ц1<!--</td--><td>1.46716<br/>1.46712<br/>1.46712<br/>1.46712<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46703<br/>1.46703<br/>1.46705<br/>1.46705<br/>1.46705<br/>1.46705<br/>1.46705<br/>1.46705<br/>1.46713<br/>1.46705<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.46713<br/>1.4671</td><td>0.00012<br/>0.00013<br/>0.00013<br/>0.000096<br/>0.00011<br/>0.00013<br/>0.00011<br/>0.00011<br/>0.00012<br/>0.00012<br/>0.00012<br/>0.00012<br/>0.00012<br/>0.00012<br/>0.00012<br/>0.00012<br/>0.00012<br/>0.00012<br/>0.00012<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00012<br/>0.00012<br/>0.00012<br/>0.00013<br/>0.00013<br/>0.00012<br/>0.00012<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00012<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00012<br/>0.00013<br/>0.00013<br/>0.00012<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00012<br/>0.00013<br/>0.00013<br/>0.00012<br/>0.00013<br/>0.00013<br/>0.00012<br/>0.00013<br/>0.00012<br/>0.00013<br/>0.00012<br/>0.00012<br/>0.00014<br/>0.00012<br/>0.00012<br/>0.00014<br/>0.00012<br/>0.00012<br/>0.00012<br/>0.00012<br/>0.00012<br/>0.00012<br/>0.00012<br/>0.00012<br/>0.00012<br/>0.00012<br/>0.00012<br/>0.00012<br/>0.00012<br/>0.00012<br/>0.00012<br/>0.00012<br/>0.00012<br/>0.00012<br/>0.00013<br/>0.00012<br/>0.00012<br/>0.00013<br/>0.00012<br/>0.00013<br/>0.00013<br/>0.00012<br/>0.00013<br/>0.00013<br/>0.00012<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013<br/>0.00013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                                                                                                               | 1/00/2021 (4)<br>17/00/2021 (4)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         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## **Appendix D2.8: Detrital Zircon Trace Element Results**



## Appendix D3.1: U/Pb-Lu/Hf Results

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# Appendix D3.1 continued.

	Analysis Notes	
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_	2380 conc. 120 WT 2327h conc. 1201 ppm ppm	
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Dutt of Indees in Dark snow motor	Sarrple D	

## Appendix D3.1 continued.

	Analysis Notes		nc ertainty xLON, included									rcertainty xL0%, included						ncertainty static, included																									Discontanti and hadred	D scordart, escholed	D scordart, escholed	Discondure, excluded Discondure, excluded	G scordare, eschaded D scordare, eschaded	Discondure, excluded Discondure, excluded	Discondure, excluded Discondure, excluded	G scordare, eschaded D scordare, eschaded	Discondure, excluded Discondure, eventualed	Discondure, excluded Discondure, excluded	Discontant, excluded Discontant are below	Discondure, excluded Discondure, eventualed	Discretizer, excluded	Discondure, excluded	O scordare, excluded	Discordant, each ded	Discondarty, end haded	D socrater, excluded D socrater, excluded	D scordare, escholed D scordare, escholed	Discondant, excluded Discondant, excluded	Discontant, excluded	Discondure, excluded	Discondent, excluded	O scordare, eschaded Di scordare, eschaded	Discordare, excholed Discordare, excholed	Discondure, excluded	Discretary, escholed	D scordart, escholed	D scordare, eschaded D scordare, eschaded
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Table 213BM18. U-Pb geochronologic analyses. University of Arizona Laserchron center				Measured ratios		Apparent ages (Ma) Pre		Preferred	ages	Discord							
Analysis	U 2051 (ppm) 2041	РЬ U/T РЬ	h 2	207Pb ± 235U 2	206P sig 238L	5* ± 2 sig	error corr.	2079b 235U	± (Ma) 3 sin	206Pb 238U	± (Ma)	206Pb 207Pb	± (Ma)	Bestage ± (Ma) (M	a)	(7/6-6/8)/7/6 *100	Analysis Notes
Note black text analyses were	included, red are exclu	uded, see analysis	note column	"S" for furth	er description.						2.00						
-21.8M18 Spot 3 -21.8M18 Spot 97	174.54 63.16	83934.63 150092.50	2.14 2.01	2.567 2.5627	0.067 0	2229 0.0049 0.221 0.0049	0.86	1291.3 1290.1	18.7 20.2	1297.2 1287.2	25.3 25.3	1281.5 1294.9	36.6 39.6	1281.5 1294.9	25.284 25.284	-0.76% 0.37%	Used for MDA calculation Used for MDA calculation
-21/8M18 Spot 20 -21/8M18 Spot 188 -21/8M18 Swot 99	203.67 481.84 195.10	94535.71 106470.62 77456.48	1.67 4.21 1.58	2.6681 2.7948 3.0753	0.075 0	2273 0.0055 2267 0.0095 2493 0.006	0.84	1319.7 1354.1 1426.6	20.4 34.1 21.0	1320.3 1317.2 1434.9	28.2 49.0 30.4	1318.6 1413.0 1414.2	40.0 66.8 41.1	1318.6 1413 1414 2	28.224 49 30.38	-0.08% 4.17% -0.88%	Used for MDA calculation
-21.8M18 Spot 39 -21.8M18 Spot 163	99.76 104.29	19554.94 74946.63	1.63 1.96	3.1549 3.2018	0.082 0	2555 0.0051 2586 0.0062	0.75	1446.2 1457.6	19.6 22.7	1466.8 1482.7	25.7 31.2	1416.1 1421.2	38.4 44.6	1416.1 1421.2	25.676 31.164	-2.13%	
-21/8M18 Spot 40 -21/8M18 Spot 9 -21/8M18 Spot 9	324.12 189.64	266324.70 138309.45	1.67	2.762 3.0848 3.0743	0.072 0	2229 0.0045 2487 0.006 2307 0.0062	0.8	1345.3 1428.9	19.1 21.0	1297.2 1431.8	23.3 30.4	1422.8	37.3 41.1	1422.8 1424.7	23.324 30.38	5.44%	
-21.8M18 Spot 185 -21.8M18 Spot 128	250.82 69.49	79777.47 34741.17	30.77	3.1428 3.1562	0.075 0	2527 0.0045 2531 0.0056	0.72	1443.2	18.0	1452.4	22.7 28.2	1429.8	35.3	1429.8	22.736 28.224	-0.94%	
-21/8M18 Spot 53 -21/8M18 Spot 100 -21/8M18 Spot 100	285.28 63.10	62673.02 94428.74 77154.74	2.24	3.086 3.1331 2.0110	0.086 0	2472 0.0059 2508 0.007	0.83	1429.2 1440.9	21.0 26.5 10.3	1424.0 1442.6	29.8 35.3	1437.0 1438.3	41.1 51.9	1437 1438.3	29.792 35.28	0.54%	
-21/8M18 Spot 27 -21/8M18 Spot 140	307.05 221.89	906891.88 624404.51	2.38	3.1177 3.1306	0.075 0	2494 0.0045 2503 0.0055	0.77	1437.1 1440.2	18.1 22.7	1435.4	22.7 27.8	1439.6 1440.6	35.5 44.6	1439.6 1440.6	22.736 27.832	0.18%	
-21.8M18 Spot 120 -21.8M18 Spot 143	115.43 103.20	41127.06 72460.99	1.93 2.14	3.031 3.2048	0.085 0	2421 0.0053 2559 0.0051	0.78	1415.5 1458.3	21.0 19.6	1397.6 1468.8	27.0 25.7	1442.4 1443.0	41.1 38.4	1442.4 1443	27.048 25.676	1.86% -1.06%	
-21/8/18 Spot 105 -21/8/18 Spot 158 -21/8/18 Spot 172	47.05 195.37	28572.40 66487.11	1.31 2.08	3.2344 3.2354	0.11 0.078 0	2532 0.0051 0.258 0.0062 2577 0.0052	0.74 0.83	1450.3 1465.4 1465.7	25.9 18.3	1479.6	31.2 26.1	1445.0 1447.8	41.5 50.7 35.9	1443.5 1445 1447.8	31.164 26.068	-1.41%	
-21.8M18 Spot 18 -21.8M18 Spot 98	205.34 215.50	279959.13 3902493.84	3.13 3.36	3.1079	0.099 0	2475 0.0054 2412 0.0058	0.73	1434.6 1415.2	23.9 22.5	1425.6 1392.9	27.4 29.6	1448.1 1448.9	46.9 44.2	1448.1 1448.9	27.44 29.596	0.93%	
-21/8/18 Spot 50 -21/8/18 Spot 127 -21/8/18 Spot 182	129.57 358.46	79170.72 196509.78	1.30 1.74 1.54	3.203	0.083 0	2541 0.0051 2271 0.0077	0.91	1457.9	19.6 25.7	1429.2 1459.6 1319.3	25.7 39.6	1455.4	38.4 50.3	1455.4 1458.8	25.676 39.592	-0.17%	
-21J8M18 Spot 167 -21J8M18 Spot 42	157.50 137.98	395356.36 108649.95	3.79 1.48	3.204 3.1552	0.083 0	2535 0.0051 2496 0.0055	0.75	1458.1 1446.3	19.6 21.2	1456.5 1436.4	25.7 27.8	1460.5 1460.8	38.4 41.5	1460.5 1460.8	25.676 27.832	0.16%	
-21/8M18 Spot 102 -21/8M18 Spot 82 -21/8M18 Spot 79	164.64 250.27 485.22	853430.63 102521.44 111635.12	0.81 4.03 4.65	3.1657 3.2069 3.1637	0.095 0	0.25 0.0055 2532 0.0056 2494 0.0075	0.75 0.83 0.87	1448.8 1458.8 1448.3	22.7 21.4 26.3	1438.5 1455.0 1435.4	27.8 28.2 37.8	1464.1 1464.5 1467.4	44.5 41.9 51.5	1464.1 1464.5 1467.4	27.832 28.224 37.828	1.05% 0.39% 1.30%	
-21.8M18 Spot 164 -21.8M18 Spot 72	134.42 215.11	2018745.93 62100.44	1.34 4.31	3.3137 3.2484	0.086	0.261 0.0057 2548 0.0066	0.79	1484.3 1468.8	19.8 21.4	1495.0 1463.2	28.6 33.3	1469.1 1476.9	38.8 41.9	1469.1 1476.9	28.616 33.32	-1.03% 0.55%	
-21/8M18 Spot 66 -21/8M18 Spot 134 -21/8M18 Spot 77	123.79 57.19 267.41	104775.96 131572.09 23728.64	2.22 1.42 1.72	3.2663 3.2767 3.2905	0.072 0 0.092 0 0.47 0	2559 0.0046 2559 0.0056 2567 0.036	0.8 0.76 0.98	1473.1 1475.5 1478.8	16.8 21.4 109.0	1468.8 1468.8 1472.9	23.1 28.2 180.9	1479.2 1485.2 1487.3	32.9 41.9 213.6	1479.2 1485.2 1487.3	23.128 28.224 180.908	0.42% 0.65% 0.57%	
-21.8M18 Spot 48 -21.8M18 Spot 149	235.97 201.77	64833.78 96788.45	1.08 0.68	3.0899 3.2019	0.099 0	2405 0.0063 2484 0.0045	0.86	1430.2 1457.6	24.1 18.2	1389.3 1430.2	32.1 22.7	1491.6 1497.8	47.3 35.7	1491.6 1497.8	32.144 22.736	4.12% 2.68%	
-21/8M18 Spot 22 -21/8M18 Spot 21 -21/8M18 Spot 33	78.96 174.92 97.56	78592.85 51157.50 59794.31	1.64 3.06 1.45	3.3274 3.2836 3.3342	0.087	0.258 0.0052 2544 0.0056 2623 0.0079	0.73	1487.5 1477.2 1489.1	20.0 21.4 27.6	1479.6 1461.1 1501.6	26.1 28.2 39.6	1498.8 1500.3 1471.3	39.2 41.9 54.2	1498.8 1500.3 1501.6	26.068 28.224 54.16656	0.75%	
-21/8M18 Spot 116 -21/8M18 Spot 16	259.77 224.24	72902.45 135710.56	4.18 2.52	3.7868 3.8575	0.11 0	2625 0.0053 2668 0.0059	0.73	1589.9 1604.8	22.9 20.6	1502.6 1524.5	26.5 29.4	1707.8 1711.9	44.9 40.3	1502.6 1524.5	44.94672 40.3368	6.90% 6.26%	
-21/8M18 Spot 197 -21/8M18 Spot 122 -21/8M18 Spot 6	223.32 360.82 384.21	196820.32 313918.35 71466.10	2.77 3.33 1.87	4.012 4.0169 4.2275	0.11 0	2771 0.0067 2802 0.0062 2805 0.0079	0.84 0.8	1636.6 1637.6 1689.0	21.8 21.8 26.5	1576.7 1592.4 1594.4	33.1 30.6 39.0	1714.5 1696.2 1808.6	42.6 42.6 51.9	1576.7 1592.4 1594.4	42.64176 42.64176 51.8616	4.54% 3.45% 6.61%	
-21/8M18 Spot 61 -21/8M18 Spot 121	154.39 244.85	85341.50 79573.11	1.26	4.0557 4.0553	0.11 0.12 0	0.281 0.0067 2819 0.0073	0.85	1645.4 1645.4	21.6 23.7	1596.4 1600.9	33.1 36.1	1708.7	42.3 46.5	1596.4 1600.9	42.2576 46.48336	3.70%	
-21.8M18 Spot 108 -21.8M18 Spot 175	389.76 473.47	191299.13 101048.77	3.00	4.1	0.18 0	2823 0.011 2842 0.011	0.91	1654.3	35.1 34.9	1602.9	54.1 54.1	1720.2	68.8 68.4	1602.9 1612.5	68.76464 68.38048	3.83% 3.57%	
-21,8M18 Spot 1/1 -21,8M18 Spot 196 -21,8M18 Spot 90	338.51 325.29 71.11	873708.13 47892.83	3.88 2.37 1.03	4.409 4.0387 3.9572	0.15 0	2863 0.011 2866 0.0069	0.85 0.92 0.84	1625.5	27.6 35.5 24.1	1623.0 1624.5	33.9	1666.5 1626.7	54.2 69.5 47.3	1616.5 1623 1624.5	47.25168	6.61% 1.47% 0.07%	
-21.8M18 Spot 64 -21.8M18 Spot 28 -21.8M19 Sect 127	253.05 451.24	190278.10 689133.95 160784.12	1.48	3.5794 4.1913	0.11 0	2592 0.0062 2892 0.01 2532 0.001	0.84	1545.0 1672.3	23.9 30.6	1485.7 1637.5	31.2 49.0	1627.0 1716.3	46.9 59.9	1627 1637.5	31.164 59.92896	5.04% 2.56%	
-21.8M18 Spot 37 -21.8M18 Spot 74	185.02 165.94	28491.68 85680.47	0.14 1.34 1.29	4.1927	0.44 0	2902 0.03 2923 0.0076	0.97	1672.6 1702.4	84.3 26.1	1642.5 1653.0	146.8 37.2	1710.5 1763.7	165.2 51.1	1642.5 1653	165.1888 51.09328	0.62% 2.22% 3.48%	
-21.8M18 Spot 68 -21.8M18 Spot 124 -21.8M18 Spot 124	83.27 154.30	863772.69 68282.65 76684.47	1.77 6.37	4.1065	0.11 0	2924 0.0064 2947 0.0065 2949 0.006	0.81	1655.6 1676.9	21.4 21.0 30.4	1653.5 1665.0	31.4 31.8 45.0	1658.2 1691.9	41.9 41.1 50.6	1653.5 1665	41.87344 41.10512 59.544*	0.16%	
-21,8M18 Spot 51 -21,8M18 Spot 8	377.69	146870.79 88192.69	3.67 1.96	4.3935 4.4687	0.12 0	2957 0.0071 2958 0.0059	0.84 0.85	1711.1 1725.2	22.1 20.0	1670.0 1670.4	34.7 28.8	1761.9 1792.2	43.4 39.2	1670 1670.4	43.41008 39.18432	1.19% 2.88% 3.74%	
-21JBM18 Spot 46 -21JBM18 Spot 105 -21JBM18 Spot 105	129.07 593.25 276 23	36336.83 43607.27 219236 **	2.53	4.2418 3.6367 4.2415	0.1	0.297 0.0053	0.77	1682.2 1557.6 1682.5	19.0 32.1 10.0	1676.4 1469.3	25.9 48.8 26.9	1689.3 1679.4	37.2 63.0	1676.4 1679.4	37.225104 48.804 37.23510-	0.42%	
-21,8M18 Spot 29 -21,8M18 Spot 136	181.85 125.68	75270.07 78594.34	2.45 1.58 2.73	4.3573 4.3104	0.15 0	2986 0.009 0.299 0.0054	0.86	1704.3	27.8 17.8	1684.4 1686.3	43.7 26.3	1728.9	54.6 34.9	1684.4 1686.3	54.55072 34.881728	0.07% 1.42% 0.65%	
-21.8M18 Spot 145 -21.8M18 Spot 78 -21.8M18 See 6*	208.86 200.85 247.99	7873954.05 62904.71 117595.9*	3.75 3.05 7 **	4.4032 4.2392 4.3791	0.11 0	2991 0.0054 2994 0.0066 2997 0.0000	0.77	1712.9 1681.6 1708 3	20.2 22.7 22.7	1686.8 1688.3 1689.9	26.3 32.1 37.8	1745.0 1673.3 1780.0	39.6 44.6 43.4	1686.8 1688.3 1694 9	39.56848 44.56256 43.41009	1.84%	
-21,8M18 Spot 15 -21,8M18 Spot 25	192.62 202.46	235880.62 95117.75	1.98 2.77	4.1708	0.1 0	3003 0.0054 0.259 0.0057	0.85	1668.3 1573.2	19.2 20.4	1692.8 1484.7	26.3 28.6	1637.6 1694.0	37.7 40.0	1692.8 1694	37.724512 28.616	-1.87% 7.13%	
-21.8M18 Spot 114 -21.8M18 Spot 144	346.25 101.16	498869.67 99071.48	4.12	4.2939	0.14 0	3006 0.0078 3008 0.0066	0.82	1692.2 1704.4	26.3	1694.3 1695.3	37.8 32.1	1689.6 1715.5	51.5 40.0	1694.3 1695.3	51.47744 39.95264	-0.15%	
-21/8/18 Spot 140 -21/8/18 Spot 62 -21/8/18 Spot 43	467.50	478619.78 67212.66	2.04	4.3347 3.7443 3.7583	0.13 0.11 0	0.261 0.0084 2619 0.0063	0.9	1580.9	27.2 22.9	1495.0	42.1 31.6	1697.5 1698.1	53.4 44.9	1696.3 1697.5 1698.1	42.14 31.556	6.87% 6.73%	
-21.8M18 Spot 189 -21.8M18 Spot 71	296.36 96 116.49	3373158.42 60824.47	2.07	4.3986	0.13 0	3022 0.0079 3023 0.006	0.83	1712.1 1700.3	23.9 20.6	1702.2	38.4 29.2	1724.2 1697.4	46.9 40.3	1702.2 1702.7	46.86752 40.3368	0.70%	
-21/8/18 Spot 70 -21/8/18 Spot 174 -21/8/18 Spot 47	165.04 184.75	105961.94 93583.29	3.24 3.89	4.3604 4.4557	0.13 0	0.303 0.0073 0.303 0.0079	0.88	1704.9 1722.8	20.4 23.7	1706.2	35.5 38.2	1753.3 1703.3 1743.0	40.0 46.5	1706.2 1706.2	46.48336 46.48336	-0.09%	
-21/8M18 Spot 11 -21/8M18 Spot 199 -21/8M18 Spot 92	240.17 216.20	65029.82 114360.60	3.25 4.03	4.34 4.4832	0.11 0	3035 0.0061 3041 0.0067	0.82	1701.0 1727.9	20.6 23.5 26.1	1708.6	29.6 32.5	1691.6 1747.6	40.3 46.1	1708.6	40.3368 46.0992	-0.56% 1.13%	
-21.8M18 Spot 87 -21.8M18 Spot 87	234.00 171.95	1218997.11 63673.30	1.13 5.82	4.3753 4.4298	0.11 0	3048 0.0061 3048 0.0073	0.74	1707.7 1717.9	20.4 22.0	1715.1 1715.1	29.6 35.3	1698.6 1721.4	40.0	1715.1 1715.1	39.95264 43.02592	-0.54% 0.20%	
-21/8M18 Spot 160 -21/8M18 Spot 148 -21/8M18 Spot 34	106.59 553.42 151.84	25687.58 196273.28 119059.60	3.05 4.75 3.03	4.4323 4.5364 4.3905	0.12 0 0.18 0.14 0	3048 0.0067 0.305 0.011 3051 0.0079	0.77	1718.4 1737.7 1710.6	22.0 32.3 25.9	1715.1 1716.1 1716.5	32.5 53.3 38.2	1722.5 1763.8 1703.2	43.0 63.4 50.7	1715.1 1716.1 1716.5	43.02592 63.3864 50.70912	0.24%	
-21/8M18 Spot 113 -21/8M18 Spot 190	102.30	155971.37 62874.91	1.80	4.4652	0.13 0	3051 0.0061 3056 0.0067	0.74	1724.5	23.7 22.3	1716.5	29.6	1734.2	46.5	1716.5	46.48336 43.79424	0.56%	
-21/8M18 Spot 187 -21/8M18 Spot 36 -21/8M18 Spot 36	54.30 140.81	28200.57 116491.88 62700.85	2.07	4.3399 4.3823	0.12 0.11 0	0.306 0.0061 3071 0.0061	0.73	1701.0	22.3 20.4	1721.0 1726.4	29.6 29.4	1676.4 1687.7	43.8	1721 1726.4	43.79424 39.95264 46.86783	-1.47%	
-21.8M18 Spot 133 -21.8M18 Spot 94	307.92 68.35	514200.61 63873.73	2.24	4.9524	0.15 0	3084 0.0074 3085 0.008	0.84	1811.2	25.1 25.3	1732.8	35.7 38.6	1902.7	49.2	1732.8 1733.8	49.17248 49.55664	4.81%	
-21/8M18 Spot 52 -21/8M18 Spot 110 -21/8M18 Spot 100	163.31 124.69	88750.32 281981.32 74945.71	0.96	4.9805	0.16 0	3087 0.008 3092 0.0068	0.79	1816.0 1735.1	26.7 23.5	1734.3 1736.8	38.6 32.7	1911.1 1733.1	52.2 46.1	1734.3 1736.8	52.24576 46.0992	4.98%	
-21/8/18 Spot 50 -21/8/18 Spot 179 -21/8/18 Spot 150	105.11 129.50	74305.71 80195.09 74151.85	1.61 4.00	4.563 4.4738	0.12 0	3102 0.0056 3102 0.0068 3103 0.0074	0.79	1742.5 1726.1	25.1 23.7	1730.8 1741.7 1742.2	32.7 35.7	1748.5 1743.6 1706.7	49.2 46.5	1730.8 1741.7 1742.2	49.17248 46.48336	0.06%	
-21.8M18 Spot 118 -21.8M18 Spot 142 -21.8M18 Spot 44	458.32 215.24 280.14	373753.17 105624.66	2.55	4.6256 4.4463	0.16 0	3105 0.0087 3108 0.0075	0.86	1753.9 1721.0	28.2 23.7 21.4	1743.7 1744.6	41.9 36.1	1766.1 1692.4	55.3 46.5	1743.7 1744.6	55.31904 46.48336	0.69%	
-21/8M18 Spot 54 -21/8M18 Spot 54	103.08 356.71	154220.58 127739.89	2.50	4.6175 4.6243	0.14 0	3109 0.0075 3109 0.0062	0.76	1752.4 1753.7	24.9 21.2	1745.1 1745.1	36.1 29.8	1761.2 1763.8	48.8	1745.1 1745.1	48.78832 41.48928	0.50%	
-21/8M18 Spot 186 -21/8M18 Spot 45 -21/8M18 Spot 45	244.87 342.31 157.07	76421.49 107429.76 20402.06	4.62	4.7761 4.667	0.13 0	3129 0.0075 0.313 0.0081	0.86	1780.7 1761.3	22.3 26.3	1755.0 1755.5	36.1 39.0	1811.0 1768.3	43.8 51.5	1755 1755.5	43.79424 51.47744	1.67%	
-21/8M18 Spot 91 -21/8M18 Spot 91	405.87	101967.64	19.10	5.1452 4.7399	0.16 0	3139 0.0094 3143 0.0063	0.89	1843.6	25.9	1759.9	45.3 30.4	1939.5 1789.1	50.7 40.7	1759.9 1761.8	50.70912 40.72096	4.94%	
-21.8M18 Spot 192 -21.8M18 Spot 73 -21.8M18 Spot 73	117.41 193.40	38730.69 257243.86	5.89 2.72	4.6528 4.857 4.723	0.15 0	3147 0.0082 3152 0.01	0.82	1758.8	26.5 30.6	1763.8	39.4 48.0	1752.9 1828.2	51.9 59.9	1763.8 1766.2	51.8616 59.92896	-0.34% 1.83%	
-21.8M18 Spot 129 -21.8M18 Spot 24	120.62	119777.53 509305.62	4.98	4.7714	0.14 0	3182 0.0076 3187 0.0064	0.8	1779.9	24.1 23.9	1780.9	36.5	1778.6	47.3 46.9	1780.9	47.25168 46.86752	-0.07% 0.49%	
-21.8M18 Spot 131 -21.8M18 Spot 176	85.02 94.87	7949647.45 68586.70	5.28 2.99	4.812 4.8212	0.13 0	3192 0.0064 3206 0.0077	0.75	1787.0 1788.6	22.3 22.1	1785.8 1792.7	30.6 36.8	1788.4 1783.9	43.8 43.4	1785.8 1792.7	43.79424 43.41008	0.08%	
-21/8M18 Spot 111 -21/8M18 Spot 132 -21/8M18 Spot 137	92.89 55.25 139.29	30810.94 17831.26 101687.86	2.84 3.63 4.19	4.8544 4.8298 4.8393	0.16 0 0.14 0 0.14 0	3218 0.0084 3221 0.0064 3232 0.0071	0.81 0.73 0.77	1794.4 1790.1 1791.8	27.2 23.9 23.9	1798.5 1800.0 1805.3	40.2 30.6 33.9	1789.6 1778.6 1776.0	53.4 46.9 46.9	1798.5 1800 1805.3	53.39824 46.86752 46.86752	-0.27% -0.65% -0.89%	
-21JBM18 Spot 49 -21JBM18 Spot 181	149.39 108.25	1721170.64 68539.56	5.39 1.50	4.8193 4.754	0.13 0	3234 0.0071 3239 0.0078	0.84	1788.3 1776.8	22.1 24.3	1806.3 1808.7	33.9 37.2	1767.3 1739.5	43.4 47.6	1806.3 1808.7	43.41008 47.63584	-1.19% -2.14%	
-21/8/18 Spot 201 -21/8/18 Spot 201 -21/8/18 Spot 95	155.87 71.17	46810.34 31933.99	2.64 3.01	5.1156 5.1293	0.13 0	3292 0.0079 3298 0.0079	0.81	1825.5 1838.7 1841.0	22.7	1823.3 1834.5 1837.4	37.6	1828.0 1843.5 1845.0	44.6	1823.3 1834.5 1837.4	44.56256 44.56256	0.26%	
-21.8M18 Spot 26 -21.8M18 Spot 166 -21.8M18 Spot 166	146.01 91.80	23422.54 78699.98 47032.63	2.20	5.185 5.0996	0.15	0.33 0.0059 3304 0.0059	0.69	1850.2 1836.0	24.1 16.3	1838.4 1840.3	28.0 28.0	1863.4 1831.2	47.3 32.0	1838.4 1840.3	47.25168 31.962112	0.71%	
-21.8M18 Spot 58 -21.8M18 Spot 204	125.59 289.82	77826.13 65602.70	4.59 5.77	5.3602 5.3451	0.13 0	3358 0.0067 3382 0.0054	0.8	1878.5 1876.1	20.4 18.8	1866.4	31.8 25.5	1891.9 1874.0	40.0 36.9	1866.4 1878	39.95264 36.87936	-1.12% 0.71% -0.11%	
-21.8M18 Spot 55 -21.8M18 Spot 10 -21.8M18 Seve 1 <sup>54</sup>	209.40 53.78 163.40	1509852.64 21724.70 820532.09	1.37 4.03 1.44	5.3285 5.437 10.0477	0.15 0	3393 0.0081 3446 0.0096 4589 0.012	0.83	1873.4 1890.7 2430 °	23.5 27.8 27.0	1883.3 1908.8 2434 7	38.2 45.1 51.9	1862.5 1870.9 2447 **	46.1 54.6 53.0	1883.3 1908.8 2494.2	46.0992 54.55072 53.01499	-0.59% -1.06%	
-21/8M18 Spot 85 -21/8M18 Spot 76	121.10 141.72	56191.13 3386916.91	2.84 2.39	10.2773	0.31 0	4618 0.011 4669 0.0093	0.81	2460.1 2479.0	27.4 23.3	2447.5	47.6	2470.5 2486.4	53.8 45.7	2447.5 2470	53.7824 45.71504	0.42%	
-21.8M18 Spot 88 -21.8M18 Spot 159 -21.8M18 Spot 5	148.43 163.60 1 125.46	318702.01 8455121.61 3015969.90	2.85 2.73 1.73	10.4526 10.5729 10.774	0.31 0 0.27 0 0.34 0	4697 0.011 4733 0.01 4738 0.01	0.8 0.84 0.79	2475.7 2486.3 2503.8	26.9 23.1 28.8	2482.2 2498.0 2500.2	47.2 42.9 47.2	2470.4 2476.8 2506 *	52.6 45.3 56.5	2482.2 2498 2500 2	52.62992 45.33088 56.47157	-0.21% -0.38% 0.15**	
-21.8M18 Spot 75 -21.8M18 Spot 115	166.09 174.64	149703.95 195409.97	1.88	10.4799 11.0657	0.27 0	4745 0.0085 4824 0.014	0.75	2478.1 2528.7	23.3 31.4	2503.3 2537.7	36.5 59.6	2457.6 2521.4	45.7 61.5	2503.3 2537.7	45.71504 61.4656	-0.83%	
-21.8M18 Spot 200 -21.8M18 Spot 2 -21.8M18 Spot 2	308.77 111.59 205.62	721832.69 107924.03 136831.9*	1.10	11.994 11.3072 11.49	0.34 0	4888 0.011 4893 0.011 4911 0.012	0.84	2603.9 2548.8 2575 *	26.1 23.5 26.7	2565.5 2567.6 2575.4	46.6 46.6 50.8	2634.0 2533.8 2574 *	51.1 46.1 51 *	2565.5 2567.6 2575.4	51.09328 46.0992 57.09***	1.14%	
-21.8M18 Spot 109 -21.8M18 Spot 96	129.87 100.91	150411.76 66657.32	2.07	11.8431 11.8535	0.33 0	4931 0.0089 0.5 0.009	0.66	2592.1 2592.9	25.5 23.9	2584.1 2613.8	37.6 37.8	2598.3 2576.6	49.9 46.9	2584.1 2613.8	49.9408 46.86752	0.24%	
-21JBM18 Spot 154 -21JBM18 Spot 184 -21JBM18 Spot 156	86.74 87.09 311 83	94538.14 65659.99 119383 M	1.38 2.12 2.77	12.4441 12.7152 12.2555	0.3 0	5034 0.01 5053 0.014 5056 0.01*	0.79	2638.5 2658.8 2624.2	22.1 29.8 27.8	2628.4 2636.5 2637.8	41.9 58.8 54.5	2646.3 2675.8 2613.7	43.4 58.4 54.6	2628.4 2636.5 2637.8	43.41008 58.39232 54.55072	0.29%	
-21JBM18 Spot 138 -21JBM18 Spot 123	148.23 11.20	4654025.77 76020.61	1.68 2.80	12.8556	0.39 0	5116 0.013 5171 0.013	0.9	2669.1 2712.5	28.0 31.6	2663.5 2686.9	54.3 54.1	2673.4 2731.7	54.9 61.8	2663.5 2686.9	54.93488 61.84976	-0.40% 0.16% 0.70%	
-21.8M18 Spot 12 -21.8M18 Spot 112 -21.8M18 Spot 112	147.42 78.07 109.14	238106.94 76085.48 1919768.90	1.07 1.11 4.0P	17.1381 18.469 35.4041	0.41 0.44 0	0.569 0.01 6004 0.012 7632 0.021	0.79	2942.6 3014.5 3650.0	22.5 22.5 32 7	2903.7 3031.4 3656.0	40.2 47.4 75.3	2969.3 3003.2 3646.7	44.2 44.2 64.7	2903.7 3031.4 3656	44.1784 44.1784 64.1547*	0.90%	
-21.8M18 Spot 203 -21.8M18 Spot 86	318.58 178.93	150281.34 105549.33	4.05	2.7217	0.098	0.21 0.0063 2339 0.0094	0.84	1334.4 1488.8	26.3 34.5	1228.8	32.9 48.2	1508.1 1685.1	51.5 67.6	1508.1 1685.1	32.928 48.216	11.52% 11.65%	> 10% Discordant, not plotted > 10% Discordant, not plotted
-21.8M18 Spot 202 -21.8M18 Spot 125 -21.8M18 Spot 165	610.68 63.74 331.37	18219.27 71646.24 188538.79	1.86 1.26 1.18	3.2591 7.4539 8.194	0.29 0.3 0 0.33 0	3296 0.011 3407 0.013	0.75 0.85 0.95	1471.3 2167.5 2252.7	67.8 35.3 35.7	1339.7 1836.4 1890.0	77.0 52.3 61.3	1666.7 2497.5 2600.6	132.9 69.1 69.9	1666.7 1836.4 1890	77.028 69.1488 69.91712	11.72% 13.21% 13.38%	> surv uticondiant, not plotted > 10% Discordiant, not plotted > 10% Discordiant, not plotted
-21.8M18 Spot 63 -21.8M18 Spot 135	465.05 159.68	18796.83 81448.12	1.93 1.35	2.6308 3.2653	0.1 0	2024 0.0073 2269 0.0059	0.91	1309.3 1472.8	27.4 22.9	1188.2 1318.2	38.4 30.4	1513.5 1703.3	53.8 44.9	1513.5 1703.3	38.416 30.38	13.49% 13.53%	> 10% Discordant, not plotted > 10% Discordant, not plotted
-21.8M18 Spot 169 -21.8M18 Spot 32 -21.8M18 Spot 84	558.95 488.42 344 %	50927.10 38274.69 114121.3*	2.63 1.31 1.99	3.0926 2.3292 2.88n8	0.11 0	2192 0.0075 1879 0.0056 2103 0.0075	0.9 0.88 0.89	1430.9 1221.2 1376.9	26.7 23.5 30.8	1277.6 1110.0 1230.4	38.8 29.8 37.6	1666.7 1423.5 1612.0	52.2 46.1 60.3	1666.7 1423.5 1619	38.808 29.792 37.632	14.15% 14.21% 14.5%	> zors uticondiant, not plotted > 10% Discondiant, not plotted > 10% Discondiant, not plotted
-21.8M18 Spot 65	218.83	48560.14 71956.25	1.64	9.7501 3.1287	0.47 0	3465 0.016 2165 0.0074	0.95	2411.4 1439.8	43.5 29.0	1917.9 1263.4	75.1 38.4	2859.1 1711.0	85.3 56.9	1917.9 1711	85.28352 38.416	14.56% 15.66% 15.85%	> 10% Discordant, not plotted > 10% Discordant, not plotted
-21.8M18 Spot 168 -21.8M18 Spot 81 -21.8M18 Swa 101	399.45 722.59 636.00	35163.51 88549.60 71418 #*	3.03 2.26 9.54	3.0153 2.8687 3.6322	0.13 0	2119 0.0081 2054 0.007 2282 0.000	0.91	1411.5 1373.7 1557 7	32.1 25.7 25.7	1238.9 1204.3 1325.1	42.1 36.7 34.9	1682.5 1648.0 1880 *	63.0 50.3 50.9	1682.5 1648 1884 3	42.14 36.652 34 000	16.11%	> 10% Discordant, not plotted > 10% Discordant, not plotted > 10% Discordant, not plotted
-21.8M18 Spot 157	378.25 183.23	12143.83 36915.68	154	3.0442	0.097 0	2094 0.005 1514 0.0033	0.76	1418.8	23.9 17.4	1225.6	26.1 18.1	1722.0	46.9 34.1	1722 1220.7	26.068 18.1104	17.55% 17.61% 17.68%	> 10% Discordant, not plotted > 10% Discordant, not plotted
-21.8M18 Spot 14 -21.8M18 Spot 41 -21.8M18 Swat 19	756.29 410.39 462.49	4990.48 7425.49 66641 **	2.02	2.7507 3.9921 3.1769	0.12 0.26 0	0.193 0.0077 2277 0.0096 2044 0.006	0.93	1342.3 1632.6 1451 °	31.8 51.7 26.9	1137.6 1322.4 1198.0	40.8 49.4 31.9	1685.5 2059.0 1843 *	62.2 101.4 51.5	1685.5 2059	40.768 49.392 31.049	20.36%	> 10% Discordant, not plotted > 10% Discordant, not plotted > 10% Discordant, not plotted
-21.8M18 Spot 4 -21.8M18 Spot 139	621.34 648.36	79887.23 16006.97	1.70	1.9173 5.3772	0.069 0	1576 0.005 2504 0.01	0.91	1087.1 1881.2	23.5 37.4	943.4 1440.5	27.2 50.6	1387.6 2410.0	46.1 73.4	1387.6 2410	27.244	21.66% 21.94%	> 10% Discordant, not plotted > 10% Discordant, not plotted
-21.8M18 Spot 153 -21.8M18 Spot 170 -21.8M18 Sect 17	1022.21 720.75	21444.36 26397.71 0421.07	2.12	2.6071 2.4644 2.0179	0.083 0	1828 0.0051 1775 0.0057 1601 0.017	0.91	1302.6 1261.7	22.9 25.5 8 <sup>4</sup> <sup>4</sup>	1082.3 1053.3 957.2	27.2 30.6	1686.7 1637.0	44.9	1686.7 1637	27.244 30.576	22.77% 22.93%	> 10% Discordiant, not plotted > 10% Discordiant, not plotted > 10% Discordiant, not plotted
-21,8M18 Spot 19 -21,8M18 Spot 57	577.22 576.61	8993.16 39213.77	1.35 1.28 1.30	8.9321 5.5522	0.43 0.2 0	0.281 0.013 2411 0.0077	0.95	2331.1 1908.7	43.1 30.4	1596.4 1392.4	64.1 39.2	3055.8 2528.0	84.5 59.5	1596.4 2528	98 84.5152 39.2	23.18% 23.72% 24.50%	> 10% Discordant, not plotted > 10% Discordant, not plotted
-21.8M18 Spot 180 -21.8M18 Spot 1 -21.8M18 Spot 1	575.27 773.53 848.00	31557.57 44960.40 3512.04	3.13 2.01 7.00	2.2348 2.3477 5.8454	0.076 0	1644 0.0049 1677 0.0064 2387 0.0004	0.88	1192.0 1226.9 1953 3	23.3 29.4 30.6	981.2 999.4 1379.9	26.7 34.7 38.8	1597.6 1652.3 2680 *	45.7 57.6 59.9	1597.6 1652.3 2699.9	26.656 34.692 38.000	25.39% 25.75%	> 10% Discordant, not plotted > 10% Discordant, not plotted > 10% Discordant, not plotted
-21,8M18 Spot 30 -21,8M18 Spot 38	1016.38 658.71	33416.88	1.13	2.0674	0.095 0	1567 0.0069 2018 0.0065	0.92	1138.1 1710.5	30.8 29.6	938.4 1185.0	37.6 34.1	1541.6 2432.0	60.3 58.0	1541.6 2432	37.632 34.104	25.75% 26.17% 29.67%	> 10% Discordant, not plotted > 10% Discordant, not plotted
-21.8M18 Spot 69 -21.8M18 Spot 35	1050.55 951.87	8162.56 3242.35	1.76	1.82	0.084 0	1397 0.0059 1683 0.0098	0.89	1052.7	29.6 46.6	843.0 1002.7	32.7 52.9	1517.9 1992.5	58.0 91.4	1517.9 1992.5	32.732 52.92	30.65% 31.41%	> 10% Discordant, not plotted > 10% Discordant, not plotted > 10% Discordant, not plotted
-21.00M18 Spot 147 -21.00M18 Spot 119 -21.00M18 Spot 80	810.49 1045.43 720.76	24068.81 3945.63 19400.11	1.57 1.08 1.05	3.0356 2.5703 4.1577	0.11 0 0.11 0 0.15	1609 0.0064 0.19 0.0065	0.83 0.91 0.91	1416.6 1292.2 1665.7	27.0 30.6 29.0	1025.3 961.8 1121.4	28.0 34.9 34.5	2086.6 1893.3 2441.9	53.0 59.9 56.9	2066.6 1893.3 2441.9	28.028 34.888 34.496	31.45% 31.75% 31.79%	> 20% Socordant, not potted > 20% Discordant, not plotted > 20% Discordant, not plotted
-21.8M18 Spot 152 -21.8M18 Spot 151	1209.71 1253.96	20758.61 23997.79	2.50 1.23	1.7596	0.074	0.134 0.0054 1165 0.004	0.94	1030.7 874.8	26.7 23.1	810.6 710.4	30.0 22.5	1532.8	52.2 45.3	1532.8 1317.7	29.988 22.54	32.76% 33.61%	> 10% Discordant, not plotted > 10% Discordant, not plotted > 10% Discordant, not plotted
-21.8M18 Spot 7 -21.8M18 Spot 7 -21.8M18 Spot 23	992.21 1034.76 1103.52	19797.13 11511.80	0.82 1.70 2.25	2.326 2.0001 1.8238	0.084 0	1388 0.0053 1319 0.0053	0.79 0.9 0.81	1220.3 1115.5 1054.1	25.1 29.2 31.0	assi.5 837.9 798.7	23.1 29.4 29.6	1849.3 1705.7 1629.4	49.2 57.2 60.7	1849.3 1705.7 1629.4	23.128 29.4 29.596	34.01% 34.60% 35.31%	> 10% Discordant, not plotted > 10% Discordant, not plotted > 10% Discordant, not plotted
-21.8M18 Spot 177 -21.8M18 Spot 178 -21.8M18 Spot 178	968.23 666.23	16655.01 1829.33	2.04	1.7711 3.081	0.064 0	1293 0.0039 1543 0.013	0.87	1034.9	22.9 117.0	783.9 925.0	21.8 71.1	1611.8 2286.0	44.9 229.3	1611.8 2286	21.756 71.148	35.79% 37.53%	> 10% Discondant, not plotted > 10% Discondant, not plotted > 20% Discondant, not plotted
-21,8M18 Spot 31 -21,8M18 Spot 31	1234.48 501.41 2340.74	27874.89 7221.21	2.00 0.91	1.6288 1.4383	0.16 0	1179 0.012 0.078 0.0027	0.9 0.98 0.91	981.4 905.0	60.6 22.5	718.5 484.2	67.8 15.8	1627.7 2147.6	44.2 118.7 44.2	1627.7 2147.6	67.816 15.8172	38.14% 39.71% 57.86%	> 10% Discordant, not plotted > 10% Discordant, not plotted > 10% Discordant, not plotted

Curtin University Geohistory center Sample 10	Spot ID	238U conc.	ala INT	232Th conc.	420 INT	228U/206Pb	123 980P	A-ICP-MS teatopic Rad	al ala PROP	nha ann ann an Ann	Appa 228U/205Pb	azo PROP	Isopiot R (Ma)	s2o PROP	er (Sneprer et al. 20**)	
	91500-1 91500-2 91500-3 91500-4 91500-4 91500-4 91500-4 91500-9 91500-9 91500-9 91500-9 91500-9 91500-9 91500-11 91550-11 91550-11 91550-11 91550-11 91550-11	80.1 7%9 7%15 7%3 7%3 80.4 7%4 80.4 7%4 80.2 7%4 80.2 7%3 80.3 7%3 80.3 7%3 80.3 7%3 80.3 7%3 80.3 7%3 80.3 7%3 80.3 7%3 80.3 7%3 80.3 7%3 80.3 7%3 80.3 7%3 80.3 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 80.4 7%3 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67.6 67.6 67	21.5 22.8 22.1 22.9 22.9 22.9 22.9 22.9 22.9 22.1 22.1		
Standard Results - U/Pb on 7700 -	PLSS - 3 PLSS - 4 PLSS - 5 PLSS - 5 PLSS - 6 PLSS - 7 PLSS - 10 Sample 38DTB19 - OGC	608 501.3 585 289 666.4 706 primary standard f	24 7.3 19 11 55 24 or unknown	98.9 45.00 96.5 21.6 41.8 78.2 > 1500 Ma, 1	13 0.0 15 1 0.78 41 errors prop	18.72659 18.47063 18.71267 18.31837 18.43218 18.02776	0.2314523 0.242266 0.2311059 0.2483656 0.231658 0.2346002 on long term r	00535 00522 00542 00542 00542 00551 00515	0.0017 0.0017 0.0015 0.0019 0.0019 0.0019 0.0019	0.41663 0.064403 -0.000445 0.2683 0.2683 0.2684 0.15773 r et al., 2016).	235.36 239.89 235.61 242.54 240.55 248.62	4.04 4.34 4.04 4.52 4.52 4.56 4.4	71.8 74.4 72.6 78.8 77 62.4	25.9 37.2 36.3 39.4 38.5 31.2		
	9520-1 9520-2 9520-3 9520-4 9520-4 9520-5 062-1 062-1 062-1 062-1 062-1 062-1 062-1 062-1 062-1 062-1 062-1 062-1 952-1 952-1 952-1 952-1 952-1 952-1 952-1	61.3 81.5 80.2 79 78.1 106.6 106. 106.9 400 420 401 401 401 401 401 401 401 401 401 40	211 212 229 229 229 229 229 229 229 229	29.2 21.3 21.3 29.1 28.6 150 100 527 203.5 11 150.77 203.5 11 20.29 203.5 11 20.29 203.5 203.5 204.6 20.22 201.7 20.42 20.2 20.2 20.2 20.2 20.2 20.2 20.	1.4 1.4 1.3 1.1 1.2 2.6 10 29 6.3 0.6 0.65 0.66 0.69 0.51 0.64 0.52 0.46 0.52 0.46 0.55 0.64 0.55 0.64 0.55 0.55 0.55 0.55 0.55 0.55 0.55 0.5	5.646527 5.553471 5.566500 5.415672 5.500642 1.434056 1.434056 1.434056 1.434056 1.434056 1.434056 1.4346421 20.55228 10.2459 8.640258 20.115228 10.2459 20.115228 10.2459 20.11122	0.1243448 0.5572237 0.3646471 0.3546471 0.3546471 0.35464745 0.05548569 0.0524855 0.0524855 0.0524855 0.3570685 0.3570685 0.3570685 0.352563 0.3570678 0.352563 0.352568 0.352568 0.352586 0.3257866 0.342585	0.0721 0.0736 0.0001 0.0736 0.0736 0.02367 0.0587 0.0587 0.0582 0.0555 0.0555 0.0555 0.0555 0.0555	0.0069 0.0055 0.0075 0.0065 0.0067 0.0067 0.0062 0.0052 0.0054 0.0052 0.0052 0.0052 0.0052 0.0052 0.0052 0.0052 0.0052 0.0052 0.0052 0.0055 0.0055	0.3433 0.2006 0.2505 0.01126 0.0225 -0.0225 -0.0225 -0.0225 0.2555 0.2555 0.2569 0.2555 0.2569 0.2555 0.2569 0.2555	1955.1 1957.5 1956.5 1957.7 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 1957.5 19	21.4 22.5 25.7 26.8 26.7 26.7 26.7 26.9 26.9 26.9 26.9 26.9 26.9 26.9 26.9	988 9228 1169 2024 2025 2025 2025 2025 2025 2025 2025	185 173 185 234 188 29.5 27.1 198 22.8 22.8 124 124 124 124 124 124 124 124		

### Appendix D3.2: U/Pb-Lu/Hf Standards

Curtin University Geo	history center					Lu-Hf Isotopic Ratios	from Iolite		1	
		170		176Hf/177Hf		1001 5	L76Lu/177Hfm	±2σ INT	176Yb/177Hf	±2σ INT
	Spot ID	178Hf/177Hf	±2σ INT	0.282785	±2σ INT	(2% External ±)	0.0336	U BOUVIER Et al., 2008	1951-273	
		1007010 100		0.283250			0.0384	0 Griffin et al., 2002, L	ithos-237	
Run 1: Standard Results - Lu/H	Ht on Nu Plasma II - samples	s 10DTB19, 12D	TB19, 14DTE	319 - MudTar	ik Primar	y Standard - er	rors propoga	ted within run a	ind are simila	ar to long term
		runnii	ng averages	(see Spencer	et al., 20	20).				
	FC 1	1 4675	0.00014	0 282202	0.000045	0.00568004	0.001833	0.000021	0.0775	0.0012
	FC - 2	1.46752	0.00014	0.282202	0.000043	0.0056874	0.0015052	0.0000017	0.06502	0.00012
	FC - 3	1.46762	0.00013	0.282169	0.000044	0.00568738	0.0010627	0.0000046	0.04379	0.00015
	FC - 4	1.46753	0.00015	0.282286	0.000036	0.00568172	0.001807	0.000031	0.07137	0.00068
	FC - 5	1.46747	0.00013	0.28227	0.000033	0.0056784	0.001857	0.000037	0.07218	0.00087
	FC - 5	1.46751	0.00015	0.282185	0.000036	0.0056797	0.0016159	0.000003	0.06984	0.00049
	FC - 8	1.46733	0.00014	0.282146	0.000035	0.00567892	0.00085855	0.00000059	0.03471	0.00026
	FC - 9	1.46744	0.00016	0.28219	0.000044	0.0056878	0.00141074	0.00000059	0.05874	0.00036
	FC - 10	1.46738	0.00014	0.282257	0.00003	0.00567514	0.0016104	0.0000063	0.06621	0.00067
	FC - 11	1.46729	0.00017	0.282203	0.000041	0.00568506	0.001545	0.0000065	0.06521	0.00056
	FC - 12	1.46735	0.00015	0.282252	0.000037	0.00568204	0.001637	0.000019	0.06753	0.00068
	GJ1 - 1	1.46762	0.00015	0.281992	0.000054	0.00569384	0.00034026	0.0000096	0.013194	0.000081
	GJ1 - 2	1.46768	0.00013	0.281963	0.000051	0.00569026	0.00033693	0.0000066	0.012847	0.000078
	GJ1 - 3 GI1 - 4	1.46768	0.00015	0.282029	0.000049	0.00568958	0.00033294	0.00000084	0.012669	0.000074
	GJ1 - 5	1.46753	0.00015	0.282006	0.000049	0.00568912	0.00032549	0.00000081	0.012247	0.000068
	GJ1 - 6	1.46751	0.00015	0.281969	0.000052	0.00569138	0.00033002	0.00000072	0.012347	0.000082
	GJ1 - 7	1.46751	0.00012	0.282029	0.000046	0.00568658	0.00032936	0.0000074	0.012266	0.000079
	GJ1 - 8 GI1 - 9	1.46749	0.00014	0.282079	0.000052	0.00569358	0.00032847	0.00000064	0.012166	0.000074
	GJ1 - 10	1.46742	0.00012	0.282006	0.000045	0.00569012	0.00032044	0.00000085	0.011804	0.000062
	GJ1 - 11	1.46752	0.00015	0.282021	0.000041	0.00568142	0.00032666	0.0000074	0.011931	0.000066
	GJ1 - 12	1.46747	0.00016	0.282	0.000043	0.005683	0.0003219	0.000007	0.011817	0.000066
	GJ1 - 13 GJ1 - 14	1.46752	0.00017	0.281998	0.00004	0.00569568	0.00032491	0.00000073	0.011934	0.000065
	GJ1 - 15	1.46749	0.00017	0.281995	0.000043	0.0056829	0.00031295	0.00000071	0.011472	0.000069
	GJ1 - 16	1.46743	0.00013	0.282057	0.000056	0.00569714	0.0003197	0.0000063	0.011659	0.00007
	GJ1 - 17	1.46752	0.00015	0.282026	0.000047	0.00568752	0.00031975	0.00000064	0.011692	0.000078
	GJ1 - 18 GJ1 - 19	1.4674	0.00017	0.282015	0.000043	0.0056843	0.00032387	0.00000073	0.011796	0.000071
	GJ1 - 20	1.46747	0.00016	0.282003	0.000039	0.00567906	0.00031987	0.00000079	0.011697	0.00008
	MUD - 1	1.4676	0.00013	0.282529	0.000038	0.00568858	0.00002452	0.00000039	0.001217	0.000015
	MUD - 3	1.46759	0.00015	0.282497	0.000044	0.00569394	0.00002601	0.00000051	0.001252	0.000024
	MUD - 4	1.46765	0.00014	0.282521	0.000035	0.00568542	0.00002353	0.00000045	0.001148	0.000015
	MUD - 5	1.4676	0.00013	0.282495	0.000035	0.0056849	0.0000246	0.0000035	0.001171	0.000019
	MUD - 6	1.46754	0.00012	0.282504	0.000042	0.00569208	0.00002843	0.00000044	0.001364	0.000016
	MUD - 7 MUD - 8	1.46759	0.00011	0.282492	0.000041	0.00569084	0.00002497	0.00000055	0.001194	0.000023
	MUD - 9	1.46749	0.00013	0.282524	0.000035	0.00568548	0.00002834	0.00000047	0.001374	0.000014
	MUD - 10	1.46752	0.00015	0.282522	0.000027	0.00567744	0.00002445	0.0000057	0.001158	0.000015
	MUD - 11	1.4675	0.00018	0.282487	0.000042	0.00569174	0.00002426	0.0000005	0.001153	0.000014
	MUD - 12 MUD - 14	1.46749	0.00015	0.282508	0.000037	0.00568688	0.00002417	0.0000004	0.001147	0.000013
	MUD - 15	1.46743	0.00016	0.282528	0.000034	0.00568456	0.00002751	0.00000041	0.001283	0.000014
	MUD - 16	1.46753	0.00013	0.28251	0.000037	0.0056872	0.00002586	0.0000057	0.001195	0.000023
	MUD - 17	1.46747	0.00016	0.282502	0.000042	0.00569204	0.00002524	0.00000049	0.001166	0.000015
	MUD - 18 MUD - 19	1.46735	0.00015	0.282485	0.000036	0.00568828	0.00002692	0.0000005	0.001234	0.000017
	MUD - 20	1.46736	0.00015	0.282514	0.000037	0.00568728	0.00002282	0.00000039	0.001053	0.00001
	PLES - 1	1.46762	0.00018	0.282458	0.000034	0.00568316	0.0001439	0.0000046	0.008489	0.000054
	PLES - 2 PLES - 3	1.46762	0.00014	0.282465	0.000033	0.0056823	0.00013141	0.00000038	0.007894	0.000054
	PLES - 4	1.46758	0.00016	0.282458	0.000039	0.00568878	0.00012936	0.00000044	0.007611	0.000053
	PLES - 5	1.46748	0.00016	0.282503	0.000037	0.00568706	0.00013587	0.0000039	0.007861	0.000043
	PLES - 6	1.46742	0.00018	0.282475	0.000036	0.0056855	0.00013753	0.00000045	0.007855	0.000045
	PLES - 7	1.46745	0.00013	0.282482	0.000032	0.00568164	0.00011909	0.00000077	0.006543	0.000024
	PLES - 8 PLES - 9	1.46748	0.00015	0.282468	0.000033	0.00568236	0.00012871	0.00000085	0.00704	0.000018
	PLES - 10	1.46743	0.00014	0.282493	0.000042	0.00569186	0.00013199	0.00000047	0.007285	0.000037
	PLES - 11	1.46739	0.00011	0.282464	0.000039	0.00568828	0.00011219	0.0000058	0.006106	0.000026
		4 40305	0 000/ -	0.0007	0.0000		0.000000	0 0000	0.000.00	0 0007-
	K33 - 1 P22 - 2	1.46768	0.00016	0.282741	0.000042	0.00569682	0.0013344	0.000085	0.05549	0.00079
	R33 - 3	1.4676	0.00015	0.282805	0.000034	0.0056901	0.001936	0.000021	0.0764	0.0018
	R33 - 4	1.46764	0.00014	0.282743	0.000033	0.00568786	0.001235	0.000018	0.04544	0.00053
	R33 - 5	1.4676	0.00017	0.282795	0.000046	0.0057019	0.003598	0.000033	0.15253	0.00055
	K33 - 6 R33 - 7	1.4676	0.00015	0.282755	0.000038	0.0056931	0.00209363	0.000016	0.0727	0.00011
	R33 - 8	1.46746	0.00013	0.282772	0.000039	0.00569444	0.002142	0.000046	0.0895	0.0025
	R33 - 11	1.4675	0.00015	0.282779	0.000043	0.00569858	0.001098	0.000089	0.0427	0.0033
	R33 - 12	1.46747	0.00014	0.282737	0.000039	0.00569374	0.0010988	0.0000054	0.04337	0.00043
	R33 - 13	1.46741	0.00016	0.28276	0.000038	0.0056932	0.002432	0.000026	0.0979	0.0016
	R33 - 15	1.46748	0.00014	0.282757	0.000045	0.005/0046	0.001081	0.000016	0.04231	0.00093
	R33 - 16	1.46749	0.00011	0.282742	0.000053	0.00570784	0.002291	0.000044	0.0943	0.0013
	R33 - 17	1.46744	0.00014	0.282707	0.000038	0.00569214	0.00132	0.00004	0.0508	0.0015
	R33 - 18	1.46743	0.00017	0.282732	0.000038	0.00569264	0.0011112	0.0000059	0.04263	0.00017
	R33 - 19	1.46747	0.00017	0.282753	0.00004	0.00569506	0.002054	0.000011	0.08185	0.00029
	155 * 20	1.40/35	0.00015	0.202744	0.000051	0.00500588	0.00133	0.000054	0.0311	0.0012
	91500 - 1	1.46751	0.00015	0.282294	0.000055	0.00570088	0.00031298	0.0000078	0.012524	0.000078
	91500 - 2	1.46756	0.00015	0.282271	0.000043	0.00568842	0.00030758	0.0000073	0.012144	0.000073
	91500 - 3	1.46762	0.00014	0.282258	0.000052	0.00569716	0.0003064	0.0000011	0.011946	0.000079
	91500 - 4 91500 - 5	1.40/64	0.00014	0,282304	0.000058	0.00570408	0.00031624	0.00000082	0.012322	0.000059
	91500 - 6	1.46759	0.00016	0.282335	0.000044	0.0056907	0.00030118	0.00000091	0.011583	0.000066
	91500 - 7	1.4676	0.00014	0.282326	0.000054	0.00570052	0.00030039	0.0000008	0.011477	0.000073
	91500 - 8	1.46753	0.00017	0.282331	0.000056	0.00570262	0.00029342	0.0000009	0.011097	0.000086
	91500 - 10 91500 - 12	1.46752	0.00018	0.282304	0.000053	0.00569908	0.00030244	0.00000084	0.011497	0.000072
	91500 - 12	1.46754	0.00015	0.282294	0.000058	0.00570432	0.00037391	0.00000078	0.014322	0.0001
	91500 - 14	1.46745	0.00013	0.282295	0.000057	0.0057029	0.00037119	0.0000009	0.014034	0.000098
	91500 - 15	1.46744	0.00018	0.282281	0.000058	0.00570362	0.00036531	0.0000085	0.013822	0.000085
	91500 - 16	1.46743	0.00017	0.282286	0.000057	0.00570272	0.00036507	0.00000089	0.013691	0.00008
	91500 - 17 91500 - 18	1.46737	0.00016	0.282294	0.000048	0.00569388	0.0003683	0,00000087	0.013/35	0.000077
	91500 - 19	1.46741	0.00014	0.282296	0.000057	0.00570292	0.00036967	0.00000078	0.01393	0.000092
	91500 - 20	1.46741	0.00019	0.282329	0.000055	0.00570158	0.00036813	0.0000085	0.01388	0.0001

Curtin University Geo					Lu-Hf Isotopic Ratios	from lolite	-			
			176Hf/177Hf			176Lu/177Hfm	±2σ INT	176Yb/177Hf	±2σ INT	
	Spot ID	178Hf/177Hf	±2σ INT	0.282785	±2σ INT	(2% External ±)	0.03360	0 Bouvier et al., 2008 El	PSL-273	
				0.283250			0.03840	0 Griffin et al., 2002, Lit	hos-237	
Dura 2. Chan dand Danisha Lud		2007040 04			Chan da		a sector al contata to		dente leve	
Run 2: Standard Results - Lu/	HT ON NU Plasma II - sample	es 3801B19, 84	101813 - Mino	a lank Primar	y Standar	a - errors prop	logated withir	n run and are sin	nilar to long	term running
		а	averages (see	Spencer et a	il., 2020).					
	EC1 1	1 4675	0.00013	0 282156	0.000038	0.001276	0.001276	0.000015	0.05064	0.00032
	FC1_2	1.46731	0.00013	0.282196	0.000039	0.000847	0.000847	0.000013	0.03236	0.00032
	FC1_3	1.46722	0.00016	0.282156	0.000043	0.000903	0.000903	0.000023	0.03438	0.00074
	FC1_4	1.46726	0.00012	0.282194	0.000045	0.001273	0.001273	0.000016	0.04913	0.00043
	FC1_5	1.46722	0.00015	0.282186	0.000048	0.001272	0.001272	0.000012	0.04971	0.0002
	FC1_6	1.46727	0.00015	0.282137	0.000045	0.001191	0.001191	0.000018	0.04701	0.00037
	FC1 8	1.46751	0.000099	0.282195	0.00004	0.0011722	0.0011722	0.0000048	0.04499	0.00041
	FC1_9	1.46723	0.00012	0.282145	0.000038	0.00074055	0.00074055	0.0000051	0.0276	0.00019
	FC1_10	1.46716	0.00013	0.282175	0.000038	0.001176	0.001176	0.000015	0.04558	0.00031
	FC1_11	1.46748	0.00014	0.282202	0.000043	0.00568704	0.001242	0.00005	0.0457	0.0016
	FC1_12 FC1_13	1.46759	0.00013	0.282175	0.000048	0.00568748	0.000758	0.0000018	0.02708	0.00014
	FC1_14	1.46749	0.00013	0.282156	0.00004	0.00568312	0.0008106	0.0000018	0.02957	0.00033
	Z_GJ1_1 Z_GI1_2	1.4675	0.00014	0.281998	0.000054	0.00028407	0.00028407	0.00000079	0.009863	0.000052
	Z_GJ1_2 Z_GJ1_3	1.46726	0.00010	0.282013	0.000054	0.00028533	0.00028533	0.00000085	0.009889	0.000063
	Z_GJ1_4	1.46733	0.00015	0.282042	0.000055	0.00028712	0.00028712	0.0000075	0.010002	0.000069
	Z_GJ1_5	1.46739	0.00015	0.282041	0.000048	0.0002856	0.0002856	0.0000068	0.009961	0.000057
	Z_GJ1_6	1.46734	0.00016	0.282026	0.000055	0.00028051	0.00028051	0.00000078	0.009715	0.000062
	Z GJ1 8	1.46754	0.00015	0.281972	0.00005	0.00028436	0.00028436	0.00000058	0.009819	0.000059
	 Z GJ1 9	1.46762	0.00014	0.282026	0.000043	0.00028626	0.00028626	0.0000006	0.009904	0.000062
	Z_GJ1_10	1.46745	0.00014	0.282064	0.000064	0.0002902	0.0002902	0.00000068	0.010024	0.000051
	Z_GJ1_11	1.46745	0.00013	0.282093	0.000049	0.00028669	0.00028669	0.0000082	0.009916	0.000055
	Z_GJ1_12	1.46716	0.00014	0.281996	0.000049	0.00028022	0.00028022	0.00000079	0.009679	0.00005
	Z_GJ1_13 Z_GJ1_14	1.46729	0.00012	0.282008	0.000048	0.00028/38	0.00028/38	0.0000006	0.00996	0.000054
	Z_GJ1_15	1.4672	0.00017	0.282006	0.000044	0.00028281	0.00028281	0.00000052	0.009801	0.000063
	7 1/7 1	1 4/754	0.00017	0.202044	0.000042	0.00003161	0.00000161	0.0000004	0.0000.40	0.000017
	2_MT_1 7_MT_2	1.46751	0.00016	0.282511	0.000035	0.00002161	0.00002161	0.0000004	0.000949	0.000017
	Z_MT 3	1.46733	0.00014	0.282514	0.000035	0.00001843	0.00001843	0.00000041	0.000813	0.000013
	Z_MT_4	1.46733	0.00013	0.282504	0.000039	0.00001925	0.00001925	0.00000041	0.000868	0.000015
	Z_MT_5	1.46726	0.00017	0.282506	0.000038	0.00002006	0.00002006	0.00000044	0.000868	0.000018
	Z_MT_6 7_MT_7	1.46732	0.00015	0.282507	0.000047	0.00002054	0.00002054	0.00000047	0.000906	0.000016
	Z MT 8	1.46726	0.00013	0.282506	0.000043	0.00002033	0.00002033	0.00000051	0.00092	0.000013
	Z_MT_9	1.46735	0.00012	0.282509	0.000042	0.00002409	0.00002409	0.0000033	0.001041	0.00002
	Z_MT_10	1.46756	0.00014	0.282503	0.000033	0.00002157	0.00002157	0.0000005	0.000932	0.00002
	Z_MT_11 Z_MT_12	1.46759	0.0001	0.282515	0.000038	0.00002395	0.00002395	0.00000048	0.001047	0.000017
	Z MT 13	1.4674	0.00015	0.282505	0.000035	0.00002218	0.00002218	0.00000042	0.000945	0.00002
	Z_MT_14	1.46725	0.00016	0.282511	0.00003	0.00002532	0.00002532	0.0000039	0.001081	0.000016
	Z_MT_15	1.46723	0.00013	0.282505	0.000041	0.00002663	0.00002663	0.00000042	0.001161	0.000017
	2_MT_16 7_MT_17	1.46733	0.00016	0.282507	0.000048	0.00002774	0.00002774	0.00000042	0.001212	0.000013
	-2									
	PLES_1	1.46733	0.0001	0.282503	0.000031	0.00006283	0.00006283	0.0000056	0.003264	0.000014
	PLES_2	1.46732	0.00014	0.282474	0.000039	0.00019877	0.00019877	0.00000099	0.01037	0.00013
	PLES 4	1.46727	0.00013	0.282474	0.000044	0.00021616	0.00021616	0.00000052	0.011238	0.000012
	PLES_5	1.46726	0.00017	0.282502	0.000038	0.0002133	0.0002133	0.0000012	0.011044	0.00002
	PLES_6	1.46738	0.00014	0.282484	0.000043	0.0001979	0.0001979	0.0000019	0.01028	0.000041
	PLES_7 DIES_9	1.46745	0.00012	0.28247	0.000029	0.00017293	0.00017293	0.00000037	0.008842	0.000058
	PLES 9	1.46746	0.00011	0.282471	0.000033	0.00020945	0.00020945	0.00000098	0.010899	0.000069
	PLES_10	1.46725	0.00015	0.282499	0.000044	0.000214	0.000214	0.0000014	0.011142	0.000062
	PLES_11	1.46721	0.00011	0.282483	0.000032	0.0002137	0.0002137	0.0000016	0.011141	0.000074
	Z R33 1	1.46742	0.00015	0.282744	0.000043	0.0011121	0.0011121	0.000003	0.03892	0.00017
	Z_R33_2	1.4674	0.00013	0.282804	0.000046	0.0017781	0.0017781	0.0000079	0.06848	0.00078
	Z_R33_3	1.46726	0.00015	0.282777	0.000049	0.0015899	0.0015899	0.0000099	0.05576	0.00021
	Z_R33_4 7 R22 5	1.4674	0.00017	0.282805	0.000045	0.0010866	0.0010866	0.0000091	0.03777	0.00013
	Z_R33_6	1.46726	0.0001	0.282768	0.000039	0.0017211	0.0017211	0.0000093	0.05775	0.00065
	Z_R33_7	1.46741	0.00012	0.282782	0.000034	0.001513	0.001513	0.000016	0.05853	0.00088
	Z_R33_8	1.46721	0.00012	0.282768	0.000045	0.0013796	0.0013796	0.0000081	0.05169	0.0006
	2_K33_9 7 R33 10	1.46729	0.00014	0.282724	0.000042	0.001171	0.001171	0.000011	0.042192	0.00063
	Z_R33_11	1.46746	0.00015	0.282715	0.000044	0.0023244	0.0023244	0.0000021	0.08921	0.00066
	Z_R33_12	1.46735	0.00011	0.28277	0.000033	0.001321	0.001321	0.000018	0.04911	0.00035
	Z_R33_13	1.46742	0.00015	0.282802	0.00003	0.0013815	0.0013815	0.000003	0.05045	0.00044
	Z_R33_14 7 R33 15	1.46723	0.00015	0.282787	0.000046	0.001739	0.001739	0.00014	0.06491	0.00098
	Z_R33_16	1.46722	0.00013	0.282736	0.000041	0.001342	0.001342	0.000028	0.051	0.0014
	Z_R33_17	1.46727	0.00015	0.282789	0.000045	0.0009841	0.0009841	0.0000027	0.03562	0.00019
	Z_91500_1	1.46755	0.00015	0.282272	0.000049	0.00027618	0.00027618	0.0000075	0.009809	0.000072
	Z_91500_2	1.46732	0.00018	0.282269	0.000063	0.00027121	0.00027121	0.0000085	0.009692	0.000064
	2_91500_3 7_91500_4	1.46727	0.00016	0.282268	0.000049	0.00026224	0.00026224	0.00000081	0.009252	0.000075
	Z_91500_5	1.46727	0.0002	0.282267	0.000067	0.00027693	0.00027693	0.00000093	0.009828	0.000051
	Z_91500_6	1.4672	0.00019	0.282278	0.000046	0.0002841	0.0002841	0.000001	0.010127	0.000055
	Z_91500_7	1.4673	0.00017	0.282289	0.000058	0.0002654	0.0002654	0.00000081	0.009372	0.00006
	Z 91500_8	1.46741	0.00012	0.282272	0.000056	0.0002625	0.0002625	0.0000011	0.009835	0.000053
	Z_91500_10	1.46745	0.00014	0.282264	0.000057	0.00027529	0.00027529	0.00000095	0.009737	0.000052
	Z_91500_11	1.46752	0.00017	0.282267	0.000069	0.00025405	0.00025405	0.0000096	0.008983	0.000083
	2_91500_12 7_91500_12	1.46753	0.00015	0.282307	0.000049	0.00028603	0.00028603	0.00000069	0.010192	0.000079
	Z_91500_14	1.46722	0.00015	0.282258	0.000043	0.0002551	0.0002551	0.0000011	0.009096	0.000032
	Z_91500 15	1.46728	0.00014	0.28227	0.000051	0.00026297	0.00026297	0.0000084	0.009292	0.000064
	Z 91500 16	1,46714	0,0002	0.282277	0.00004	0.00027668	0.00027668	0.00000052	0.009844	0.00007
	Z_91500_17	1.46714	0.00015	0.282294	0.000051	0.00027364	0.00027364	0.00000099	0.009714	0.000079

Curtin University Geo	bhistory center	LI				Lu-Hf Isotopic Ratios from Iolite				
	Spot ID	178Hf/177Hf	±2σ INT	176Hf/177Hf 0.282785	±2σ INT	(2% External +)	.76Lu/177Hfm 0.0336	±2σ INT 0 Bouvier et al., 2008 F	176Yb/177Hf PSL-273	±2σ INT
	Spot ib	1/300/1//00	220 1111	0.282785	120 101	(270 External I)	0.0336	0 Griffin et al., 2008 El	hos-237	
D	(115 N C)	- 01070-0		T 1					- 11	· · · · · · · ·
Run 3: Standard Results - Lu/	Ht on Nu Plasma II - sample	es 01DTB19, 34	DTB19 - Mud	Tank Primar	y Standar	d - errors propo	ogated within	n run and are sin	nilar to long	term running
		а	iverages (see	spencer et a	1., 2020).					
	Z_FC1_1	1.467254	0.000068	0.282218	0.000031	0.00567536	0.0011009	0.0000076	0.04489	0.00022
	Z_FC1_2	1.46732	0.000082	0.282185	0.00002	0.0056637	0.0007049	0.0000026	0.02746	0.00017
	Z_FC1_3 Z_FC1_4	1.467301	0.000073	0.282203	0.000021	0.00566944	0.0012061	0.000024	0.02683	0.0001
	Z_FC1_5	1.467227	0.000099	0.282356	0.000022	0.00566912	0.0030858	0.0000043	0.12093	0.00021
	Z_FC1_6	1.46718	0.000094	0.282323	0.000025	0.00567146	0.0033308	0.0000057	0.13137	0.00019
	Z_FC1_7 Z_FC1_8	1.4672	0.000084	0.282262	0.000018	0.0056763	0.00222	0.00018	0.0779	0.0083
	Z_FC1_9	1.467191	0.000078	0.282256	0.000028	0.00567312	0.00194	0.0001	0.0755	0.004
	Z_FC1_10	1.467243	0.00007	0.282406	0.000027	0.00567512	0.004539	0.000021	0.17949	0.00069
	Z GJ1 1	1.467397	0.000092	0.28201	0.000031	0.0056712	0.00035847	0.0000007	0.013153	0.000028
	Z_GJ1_2	1.467297	0.000078	0.282024	0.000024	0.00566448	0.00033509	0.0000036	0.012197	0.000038
	Z_GJ1_3 7_GI1_4	1.46741	0.00011	0.28203	0.000024	0.0056646	0.00032499	0.0000005	0.011779	0.000034
	Z_GJ1_4 Z_GJ1_5	1.46727	0.00011	0.282015	0.000027	0.0056693	0.00031846	0.00000043	0.011049	0.000023
	Z_GJ1_6	1.467389	0.000094	0.282025	0.000022	0.0056625	0.00032197	0.0000053	0.011541	0.000049
	Z_GJ1_7	1.467301	0.000081	0.281991	0.000034	0.00567382	0.00031978	0.00000055	0.011363	0.000028
	Z_GJ1_9	1.46725	0.0001	0.282017	0.000027	0.00566734	0.00031515	0.00000044	0.011095	0.000037
	Z_GJ1_10	1.467345	0.000083	0.282015	0.000021	0.0056613	0.00031233	0.0000055	0.010985	0.000029
	Z_GJ1_11 Z_GJ1_12	1.46727	0.00012	0.282021	0.000024	0.00566442	0.00031723	0.0000005	0.011202	0.000042
	Z_GJ1_13	1.467245	0.000096	0.28202	0.000028	0.0056684	0.00031188	0.00000054	0.010993	0.000021
	Z_GJ1_14	1.467295	0.000086	0.282012	0.000025	0.00566524	0.00032024	0.00000057	0.011242	0.000027
	Z_GJ1_15 Z_GJ1_16	1.467168	0.000092	0.282021	0.00003	0.00566646	0.00032256	0.00000043	0.011297	0.000023
	Z_GJ1_17	1.467268	0.000081	0.281987	0.000029	0.00566874	0.00031169	0.0000062	0.011018	0.000017
	Z_GJ1_18	1.467242	0.000076	0.282008	0.00002	0.00566016	0.0003323	0.000001	0.011743	0.000032
	2_001_17	1.4073	0.000005	0.202000	0.000020	0.00000010	0.00034473	0.00000007	0.012130	0.000020
	Z_MT_1	1.46734	0.0001	0.282512	0.00002	0.00567024	0.00002986	0.0000023	0.0013993	0.0000071
	Z_MT_2 7 MT 3	1.467462	0.000079	0.2825	0.000031	0.005681	0.00002819	0.00000026	0.0013011	0.0000051
	Z_MT_4	1.467287	0.000076	0.282522	0.000023	0.00567344	0.00002742	0.00000015	0.0012433	0.0000064
	Z_MT_5	1.467339	0.000068	0.282511	0.000023	0.00567322	0.00002822	0.0000019	0.0012875	0.000064
	Z_MT_6 7 MT 7	1.467273	0.000086	0.282519	0.000027	0.00567738	0.0000224	0.000001	0.000991	0.000045
	Z_MT_8	1.467319	0.000088	0.282507	0.000022	0.00567214	0.000025	0.00000018	0.0011341	0.0000049
	Z_MT_9	1.467303	0.000079	0.282504	0.000023	0.00567308	0.00002507	0.00000022	0.0011255	0.0000054
	Z_MT_10 Z_MT_11	1.467322	0.000076	0.282519 0.282514	0.00002	0.00567038	0.00002534	0.0000023	0.0011267	0.0000049
	Z_MT_12	1.467265	0.000075	0.282502	0.000013	0.00566304	0.00001442	0.00000029	0.000566	0.000012
	Z_MT_13	1.46723	0.0001	0.282517	0.000023	0.00567334	0.00002297	0.00000019	0.0010103	0.0000058
	Z_MT_14 Z MT 15	1.467213	0.000086	0.282504 0.282481	0.000024	0.00567408	0.00002398	0.00000022	0.0010762	0.0000072
	Z_MT_16	1.467232	0.000075	0.282535	0.000027	0.0056777	0.00002797	0.00000019	0.0012286	0.0000066
	Z_MT_17	1.467221	0.000074	0.2825	0.000023	0.005673	0.00002552	0.00000018	0.0011409	0.0000059
	2_MT_18 7_MT_19	1.467268	0.000074	0.282511	0.000025	0.00567522	0.00001299	0.00000048	0.000508	0.000018
	Z_Plesovice_1	1.467387	0.000097	0.282495	0.000024	0.0056739	0.0001091	0.0000012	0.00595	0.00005
	Z_Plesovice_2 Z Plesovice_3	1.467249	0.000067	0.282464	0.000028	0.00567028	0.0000838	0.0000032	0.00447	0.00017
	Z_Plesovice_4	1.467273	0.000063	0.282464	0.000024	0.00567328	0.0001002	0.0000024	0.00533	0.00013
	Z_Plesovice_5	1.46731	0.00011	0.282471	0.000018	0.00566742	0.0000571	0.00000072	0.003024	0.000045
	Z_Plesovice_0	1.467275	0.000084	0.282502	0.000023	0.00567304	0.0001849	0.0000039	0.00974	0.00019
	Z_Plesovice_8	1.467275	0.000068	0.282472	0.000029	0.00567844	0.0001867	0.0000042	0.00981	0.00023
	Z_Plesovice_9	1.46725	0.000085	0.282472	0.000024	0.00567344	0.0001792	0.0000039	0.00945	0.00023
	Z_R33_1	1.467374	0.000085	0.282826	0.000025	0.00568152	0.0024426	0.0000094	0.09872	0.00015
	Z_R33_2	1.46732	0.00011	0.282838	0.000024	0.00568076	0.002598	0.000071	0.1002	0.0024
	Z_R33_3 7 R33 4	1.46734	0.00011	0.282777	0.000028	0.00568354	0.0012962	0.0000012	0.04448	0.00014
	Z_R33_5	1.467386	0.000072	0.282804	0.000026	0.00568208	0.002551	0.000029	0.10173	0.0009
	Z_R33_6	1.467265	0.00008	0.282776	0.000024	0.00567952	0.002188	0.000046	0.0865	0.0021
	Z R33 8	1.46732	0.0001	0.282753	0.000031	0.00568006	0.001596	0.000012	0.0613	0.0014
	Z_R33_9	1.467287	0.000087	0.282729	0.000021	0.00567558	0.00088	0.000011	0.0306	0.00043
	Z_R33_10 7_R33_11	1.467431	0.000099	0.282703	0.000027	0.00568106	0.001	0.000017	0.03758	0.00059
	Z_R33_12	1.467251	0.000094	0.282739	0.000034	0.00568878	0.0010007	0.0000082	0.03604	0.00042
	Z_R33_13	1.467281	0.000098	0.282795	0.00002	0.0056759	0.002017	0.000076	0.078	0.0032
	Z_R33_14 7_R33_15	1.467324	0.000066	0.282777	0.000023	0.00567854	0.001965	0.00002	0.07705	0.00091
	Z_R33_16	1.467291	0.000086	0.282803	0.000027	0.00568306	0.001764	0.000017	0.06417	0.00098
	Z_R33_17	1.467269	0.000087	0.282846	0.000026	0.00568292	0.0034368	0.0000074	0.13439	0.00072
	Z_K33_18 Z R33 19	1.46725	0.000099	0.282813	0.000025	0.00567986	0.002386	0.000034	0.09017	0.00063
	Z_R33_20	1.46729	0.0001	0.282763	0.000027	0.00568226	0.00237	0.00017	0.0919	0.0066
	7 91500 1	1,467361	0.000092	0,282317	0,000031	0.00567734	0.0003918	0,0000064	0,014902	0,000046
	Z_91500_2	1.467384	0.000092	0.282302	0.000033	0.00567904	0.0003771	0.00000068	0.014198	0.000037
	Z_91500_3	1.46729	0.00011	0.282321	0.000037	0.00568342	0.00037321	0.00000091	0.013837	0.000032
	Z_91500_4 7_91500_5	1.46728	0.00012	0.282281	0.000034	0.00567962	0.00036631	0.00000062	0.013556	0.000027
	Z_91500_6	1.467337	0.000091	0.282301	0.00003	0.00567602	0.00036181	0.00000042	0.013352	0.000044
	Z_91500_7	1.46735	0.0001	0.282324	0.000027	0.00567348	0.00036676	0.00000047	0.013362	0.000028
	Z_91500_8 Z_91500_9	1.467356	0.000097	0.282272	0.000032	0.00567744	0.00036352	0.00000056	0.013194	0.000026
	Z_91500_10	1.46733	0.0001	0.2823	0.000021	0.005667	0.00035975	0.00000067	0.012975	0.000023
	Z_91500_11	1.467275	0.000074	0.282287	0.00003	0.00567574	0.00036395	0.00000048	0.013235	0.000041
	Z_91500_12 Z 91500 13	1.467357	0.000075	0.282335	0.000029	0.0056757	0.00035043	0.0000053	0.013113	0.00003
	Z_91500_14	1.467238	0.000086	0.282319	0.000037	0.00568338	0.00034322	0.00000057	0.012479	0.000023
	Z_91500_15	1.4673	0.000085	0.282315	0.000028	0.0056743	0.00034878	0.00000043	0.012555	0.000035
	2_91500_16	1.467236	0.000092	0.282294	0.000025	0.00567088	0.00036077	0.0000058	0.013017	0.000028
	Z_91500_17	1.467404	0.000098	0.282313	0.000038	0.00568426	0.00035423	0.0000053	0.012761	0.000034
	Z_91500_18 Z_91500_19	1.467278	0.000097	0.28233	0.000032	0.0056786	0.00036813	0.0000083	0.013268	0.000042
		1.40742	3.00011	0.202302	0.000000	0.0000/904	0.00007534	0.00000000	0.01000/	0.000031
	fc - 1	1.4675	0.00013	0.282156	0.000038	0.00568112	0.001276	0.000015	0.05064	0.00032
	fc - 2	1.46731	0.00012	0.282196	0.000039	0.00568292	0.000847	0.000014	0.03236	0.00034
	fc - 3	1.46722	0.00016	0.282156	0.000043	0.00568612	0.000903	0.000023	0.03438	0.00074
	fc - 5	1.46726	0.00012	0.282194	0.000045	0.00568888	0.001273	0.000016	0.04913	0.00043
	fc - 6 fc - 7	1.46722	0.00015	0.282186	0.000048	0.00569172	0.001272	0.000012	0.04971	0.0002
	fc - 9	1 46752	0.00014	0.282152	0.000045	0.00568204	0.001154	0.000011	0.04450	0.00077
	fc 0	1 46751	0.00014	0.202132	0.00004	0.00500504	0.001134	0.000011	0.04400	0.000//
	fc - 11	1.46723	0.00012	0.282195	0.000038	0.0056809	0.00074055	0.0000048	0.0276	0.00041
	fc - 12	1.46716	0.00013	0.282175	0.000038	0.0056815	0.001176	0.000015	0.04558	0.00031

Curtin University Geo		Lu-Hf Isotopic Ratios from Iolite											
				176Hf/177Hf			176Lu/177Hfm	±2σ INT	176Yb/177Hf	±2σ INT			
	Spot ID	178Hf/177Hf	±2σ INT	0.282785	±2σ INT	(2% External ±)	0.0336	0 Bouvier et al., 2008 E	PSL-273				
				0.283250			0.0384	0 Griffin et al., 2002, Li	thos-237				
Run 4: Standard Results - Lu/Hi	f on Nu Plasma II - sample	e 38DTB19 - Mud	Fank Primary	y Standard, er	rors prop	ogated based	on long term	running average	es (see Spend	er et al., 2020).			
	Z_FC1_1	1.46748	0.00014	0.282202	0.000043	0.00568704	0.001242	0.00005	0.0457	0.0016			
	Z_FC1_2	1.46752	0.00015	0.282199	0.000046	0.00568998	0.001058	0.00001	0.03982	0.00014			
	Z_FC1_3	1.46759	0.00012	0.282174	0.000044	0.00568748	0.000758	0.0000018	0.02708	0.00029			
	Z_FC1_4	1.46749	0.00013	0.282156	0.00004	0.00568312	0.0008106	0.0000018	0.02957	0.00033			
	Z_GJ1_1	1.4675	0.00012	0.28198	0.00005	0.0056896	0.00028214	0.0000076	0.009402	0.000061			
	Z_GJ1_2	1.46755	0.00014	0.282079	0.000048	0.00568958	0.00028185	0.0000095	0.009389	0.000072			
	Z_GJ1_3	1.46754	0.00012	0.28195	0.000055	0.005694	0.00028301	0.00000073	0.009457	0.000064			
	Z_GJ1_4	1.46752	0.00014	0.282029	0.00005	0.00569058	0.0002831	0.00000061	0.00942	0.000076			
	Z_GJ1_5	1.46753	0.00014	0.282049	0.000042	0.00568298	0.0002816	0.0000067	0.00929	0.000072			
				0 000540	0.000005	0.00550504							
	2_MI_1	1.4675	0.00013	0.282512	0.000035	0.00568524	0.00001927	0.00000053	0.000823	0.000022			
	2_M1_2	1.46753	0.00012	0.282496	0.000047	0.00569692	0.00002075	0.00000038	0.000912	0.000021			
	2_M1_3	1.46743	0.00012	0.282493	0.000049	0.00569886	0.00002006	0.0000054	0.000858	0.000016			
	2_M1_4	1.46752	0.00013	0.282531	0.000048	0.00569862	0.00002338	0.000006	0.000993	0.000021			
	2_M1_5	1.46/54	0.00013	0.2825	0.000045	0.005695	0.0000216	0.0000073	0.000919	0.00002			
	7 Plesovice 1	1 46751	0.00014	0.28253	0.000027	0.0056976	0.000162	0.000001	0.007093	0.000095			
	Z_Plesovice_1	1.46751	0.00014	0.282524	0.000037	0.00568768	0.000102	0.0000012	0.007500	0.000033			
	7 Plesovice 3	1 4675	0.00013	0.28244	0.000057	0.0056988	0.000130	0.00000012	0.007343	0.000034			
	Z_Plesovice_3	1.407.05	0.00012	0.282419	0.000039	0.00569639	0.00014702	0.00000000	0.006917	0.000034			
	2_110304100_4	1.40745	0.00011	0.202425	0.000000	0.00500050	0.0001000	0.0000011	0.000017	0.000024			
	7 833 1	1.467431	0.000098	0.282768	0.000042	0.00569736	0.001047	0.000019	0.03616	0.00048			
	Z R33 2	1.46755	0.00014	0.282796	0.000055	0.00571092	0.00223	0.00013	0.0848	0.0057			
	Z R33 3	1.46754	0.00012	0.282771	0.000055	0.00571042	0.001826	0.000026	0.0642	0.0015			
	Z R33 4	1.46758	0.00014	0.282741	0.000043	0.00569782	0.0015573	0.0000035	0.05245	0.00018			
	Z R33 5	1.46752	0.00013	0.282732	0.000043	0.00569764	0.0011273	0.0000025	0.03945	0.00031			
	Z_91500_1	1.46752	0.00014	0.282292	0.000058	0.00570384	0.00025983	0.0000082	0.008756	0.00007			
	Z_91500_2	1.46767	0.00014	0.282339	0.000059	0.00570578	0.00028391	0.00000097	0.009675	0.000075			
	Z_91500_3	1.46758	0.00015	0.282321	0.000065	0.00571142	0.0002791	0.000001	0.009504	0.000052			
	Z_91500_4	1.46738	0.00015	0.282304	0.000058	0.00570408	0.0002601	0.0000011	0.008873	0.000088			
	Z_91500_5	1.46752	0.00014	0.282323	0.000056	0.00570246	0.0002719	0.0000012	0.009287	0.000072			

Table 21J University	BM18. U-Pb of Arizona I	geochronol aserchron	ogic analyse center	2	Me	asured rat	ios		Apparent ages (Ma)					
Analysis	U (ppm)	206Pb 204Pb	U/Th	207Pb 235U	± 2 sig	206Pb 238U	± 2 sig	error corr.	207Pb 235U	± (Ma) 2 sig	206Pb 238U	± (Ma) 2 sig	206Pb 207Pb	± (Ma) 2 sig
Standar	d Results - U	/Pb on 7700 1500	0 - Samples ) Ma, errors	10DTB19, 1 propogated	2DTB19, 14 d within run	DTB19 - O( and are th	GC primary ne same as l	standard fo ong term ru	r unknowns Inning avera	> 1500 Ma ages (Spenc	, 91500 prii er et al., 20	mary standa 16)	ard for unkr	iowns >
FC -1	271	69015	2.21	1.98649	0.0572	0.18848	0.00422	0.78	1110.93	17.6904	1113.1	20.748	1106.6	32.76
FC -1	1139 501	1088577	1.50	1.93898	0.0671	0.18735	0.00596	0.92	1094.6	21.112	1107 1092 1	29.484	1070.2	24.752
FC -1	463	78941	1.76	1.91642	0.0567	0.18401	0.00484	0.80	1086.82	17.9634	1032.1	24.024	1085.0	24.57
FC -1	505	99066	1.44	1.93512	0.0716	0.18549	0.00612	0.90	1093.3	22.568	1096.9	30.212	1086.2	29.484
FC -1	543	154574	1.73	1.96775	0.0649	0.18805	0.00549	0.89	1104.5	20.202	1110.8	27.118	1092.2	27.482
FC -1 FC -1	681	795728	2.25	1.97903	0.0641	0.18777	0.00511	0.84	1108.8	19.858	1109.5	23.298	1107.2	27.846
FC -1	293	77021	1.74	1.94369	0.0439	0.18578	0.0031	0.74	1096.27	13.7774	1098.47	15.3426	1091.9	27.664
FC -1	244	72996	1.62	1.95376	0.0508	0.18621	0.00387	0.80	1099.74	15.8886	1100.8	19.11	1097.6	28.392
FC -1 FC -1	416 512	64822	1.69	1.96965	0.0741	0.18807	0.00582	0.91	105.2	23.114	1110.9	28.756	1093.9	28.392
FC -1	469	125055	1.74	1.95096	0.0831	0.18704	0.00729	0.92	1098.8	26.026	1105.3	36.036	1085.8	30.394
FC -1	230	65053	2.38	1.97984	0.0598	0.18677	0.00437	0.77	1108.7	18.564	1103.9	21.658	1118.1	34.944
FC -1 FC -1	358	105418	2.04	1.98232	0.0777	0.18834	0.00693	0.94	109.5	16.8714	1112.4	20.02	103.9	24.388
FC -1	229	122516	1.63	1.9057	0.048	0.18305	0.0035	0.76	1083.08	15.2698	1083.62	17.3628	1082	29.848
FC -1	305	1113304	1.90	1.95529	0.0567	0.18664	0.00463	0.85	1100.27	17.7268	1103.1	22.932	1094.6	27.846
FC -1 FC -1	239	1662322 91423	1.41	1.94098	0.0703	0.18492	0.0061	0.91	1095.3	14.9422	1093.8	30.212	1098.4	27.3
FC -1	300	178604	1.82	1.94924	0.0569	0.18533	0.00393	0.72	1098.19	17.8178	1096	19.474	1102.5	36.946
FC -1	669	278180	1.68	1.93533	0.0716	0.18444	0.00605	0.89	1093.4	22.568	1091.2	30.03	1097.8	30.758
FC -1 FC -1	168 291	52430 61211	2.46	1.96506	0.0491	0.18721	0.0036	0.77	1103.62 1111 31	15.3062 16.3618	1106.24 1109 1	17.7814	1098.4 1115 7	29.12
FC -1	145	110592	2.23	1.92675	0.0478	0.18295	0.0033	0.73	1090.41	15.0878	1083.07	16.3618	1105.1	30.758
FC -1	672	143084	1.77	1.94379	0.0568	0.18577	0.00498	0.92	1096.31	17.836	1098.4	24.57	1092.1	20.93
FC -1 FC -1	427	119544	1.85	1.94702	0.0794	0.1856	0.00709	0.93	1097.4	24.934	1097.5	35.126	1097.3	27.3
FC -1	247	79783	2.20	1.95554	0.0583	0.18555	0.00423	0.79	1100.4	17.3452	1097.2	21.658	1107.8	33.306
FC -1	1171	267399	1.38	1.94149	0.0652	0.18546	0.00553	0.89	1095.5	20.566	1096.7	27.3	1093.1	27.846
FC -1	234	45271	1.52	1.94998	0.0577	0.18693	0.00422	0.76	1098.44	18.0726	1104.7	20.93	1086	35.126
FC -1 FC -1	163	68111	1.96	1.99861	0.0447	0.19081	0.0034	0.80	1115.50	15.7956	1124.08	23.114	1091.3	33.852
FC -1	248	31892	1.56	1.95095	0.0511	0.18805	0.0035	0.71	1098.77	15.9978	1110.8	17.29	1075	33.67
FC -1	286	84360	1.72	1.96519	0.0542	0.1872	0.00393	0.76	1103.66	16.8896	1106.2	19.474	1098.7	32.578
FC -1 FC -1	478	69528	2.00	1.95255	0.0703	0.18633	0.00828	0.95	1104.29	15.3244	1101.5	17.3082	11110.8	30.03
FC -1	548	135063	1.74	1.9303	0.0683	0.18236	0.00558	0.86	1091.6	21.476	1079.9	27.664	1115.2	32.76
FC -1	295	106194	1.77	1.94821	0.0507	0.18452	0.00373	0.78	1097.83	15.8886	1091.6	18.382	1110.2	29.666
FC -1 FC -1	496 1284	1828515 671896	1.73	1.93/92	0.0651	0.18606	0.00554	0.89	1094.3	20.384	100	27.482	1082.9	28.028
FC -1	136	70296	2.21	1.95987	0.0564	0.18372	0.00408	0.77	1101.84	17.5994	1087.3	20.202	1130.7	33.306
FC -1	452	61153	2.46	1.94648	0.067	0.18594	0.0055	0.86	1097.2	20.93	1099.3	27.118	1093.1	32.032
FC -1 FC -1	233	666076 1071825	1.32	1.999996	0.0704	0.18926	0.00575	0.87	1115.5	21.658	1117.4	28.392	1111.9 1104.9	31.486
	200	107 1025	1.01	1.55155	0.0452	0.10552	0.0055	0.75	1050.57	15.5572	1055.57	17.5204	1104.5	50.554
R33	49	6239	1.52	0.51266	0.0252	0.06754	0.00142	0.43	420.24	15.3972	421.32	7.8078	414.3	90.272
R33	45	52106	2.41	0.55665	0.0233	0.07188	0.00178	0.59	449.34	13.832	447.47	9.737	458.9	68.25
R33	184	22396	1.32	0.51274	0.0157	0.06618	0.00142	0.70	420.29	9.5914	413.1	7.8078	459.9	44.044
R33	304	41050	1.15	0.51409	0.0155	0.0662	0.00146	0.73	421.2	9.464	413.22	8.0262	465.1	41.496
R33	961 84	287889	1.53	0.50794	0.0194	0.06614	0.00216	0.85	417.06	11.8846	412.86	11.8846	440.4	40.768
R33	667	1186073	1.82	0.51598	0.0219	0.06762	0.00253	0.88	422.46	13.3406	421.8	13.9048	426.1	40.95
R33	197	42202	1.21	0.51054	0.0147	0.06696	0.0012	0.64	418.81	8.9908	417.81	6.6066	424.3	44.954
R33	149	789391	1.33	0.52358	0.0175	0.0681	0.00174	0.76	427.54	10.6106	424.7	9.555	442.9	44.044
R33	200	18866	1.20	0.50945	0.0199	0.06563	0.00161	0.65	418.08	12.1758	409.77	9.0818	464.2	59.878
R33	94	35561	1.30	0.52117	0.0144	0.06881	0.0013	0.69	425.93	8.7542	428.98	7.1344	409.5	40.768
R33	204	67829	1.26	0.52115	0.0181	0.06774	0.00183	0.78	425.92	10.9928	422.53	10.0464	444.3	44.044
ro3	215	20283	1.23	0.31320	0.0105	0.00743	0.00169	0.78	421.98	10.0040	+20.05	9.282	429.2	40.380
SL2	857	69909	6.13	0.72722	0.0241	0.08888	0.00272	0.92	554.92	12.8856	548.91	14.651	579.7	25.662
SL2	385	31192	5.48	0.72586	0.0289	0.08967	0.00321	0.90	554.12	15.47	553.59	17.29	556.3	34.398
SL2	394 109	23762	5.38 13.15	0.75535	0.0235	0.09055	0.00241	0.84	571.32	14.1596	560.03	13.559	616.5	54.210 43.862
SL2	62	6358	9.15	0.74119	0.0283	0.0922	0.0021	0.59	563.1	15.015	568.54	11.284	541.2	61.334
SL2	572	88857	6.24	0.71753	0.0255	0.0887	0.00268	0.85	549.21	13.7228	547.84	14.4326	554.9	37.128
SL2	843 733	78553	5.79	0.72352	0.0243	0.08928	0.00264	0.88	553.78	12.0484	551.28	14.2142	558.8	28.028
SL2	706	270556	5.86	0.71451	0.025	0.08811	0.00266	0.86	547.42	13.468	544.35	14.3416	560.2	35.49
SL2	343	105312	1.18	0.77059	0.0205	0.09395	0.00188	0.75	580.1	10.7016	578.86	10.0828	585	34.762
SL2 SL2	844 150	352706 53742	6.13 10.41	0.73387	0.0227	0.0899 0.09093	0.00236	0.84 0.79	554.86 558 79	12.1394 11.8846	554.95 561 03	12.7036 11.6116	554.5 549 7	33.67 36.946
SL2	104	22060	13.24	0.73768	0.0243	0.09232	0.00209	0.68	561.05	12.922	569.24	11.2294	528	48.23
SL2	371	96604	5.35	0.73337	0.0167	0.09074	0.0015	0.73	558.53	8.8998	559.91	8.0626	552.9	30.94
SL2	64	23001	9.76	0.74293	0.0266	0.09031	0.00204	0.63	564.11	14.105	557.37	10.9746	591.4	54.782
SL2	558 804	180015	6.15	0.73915	0.0286	0.088996	0.00316	0.89	561.91	11.7936	555.3	12.2122	588.8	32.214
SL2	722	79717	5.84	0.71802	0.0213	0.08989	0.00237	0.89	549.5	11.4478	554.89	12.7582	527.2	26.936
SL2	680	110048	5.77	0.72298	0.0243	0.08849	0.00265	0.89	552.42	13.0312	546.6	14.287	576.5	30.394
SL2 SL2	105	515728 17031	6.46 12.79	0.7314	0.0221	0.09037	0.00233	0.86	557.37 560.02	12.7764	559.08	12.5398 11.4114	555.9 563.8	50.576 44.954
SL2	399	81881	5.36	0.72901	0.0242	0.09046	0.00264	0.88	555.97	12.9402	558.26	14.196	546.6	31.304
SL2	54	9206	9.06	0.74255	0.0306	0.09193	0.00213	0.56	563.89	16.2344	566.94	11.4478	551.6	67.886
SL2 SL2	559 830	35539 94929	6.20	0.7249	0.0245 0.0268	0.0886 0.08957	0.00276	0.91	548.24 553.56	13.195 14.3598	547.25 552.99	14.8694 15.9432	552.4 555.9	28.21 33.488
	000	2.525	0.10					5.05						

sample #	Lat	Long	Description
49DTB19	47.05626	-116.43749	staurolite gt mu qf schist
50DTB19	46.99916	-116.35958	gt mica qf schist
51DTB19	46.98515	-116.31361	gt mu qf schist
59DTB19	47.02315	-115.46378	gt ky schist
52DTB19	47.01509	-115.81738	gt amphibolite

Appendix D4.1: Sample locations

			49DTB19	50DTB19	51DTB19	59DTB19	52DTB19
Wt. %	TiO2	79.9	0.617	0.572	0.597	0.686	1.888
	Cr2O3	151.99	0.009	0.009	0.009	0.009	0.002
	SiO2	60.09	71.19	67.63	61.21	62.1	58.01
	AI2O3	101.96	15.02	17.68	21.47	16.57	13.53
	CaO	56.08	0.28	0.27	0.21	0.39	6.64
	MgO	40.31	1.73	1.72	1.59	3.49	3.24
	FeO	71.85					
	MnO	70.94	0.041	0.04	0.04	0.114	0.228
	Fe2O3	159.69	4.6	5.39	6.25	9.8	13.31
	K2O	94.2	3.57	3.85	5.06	4.14	0.262
	Na2O	61.98	0.89	0.69	0.89	0.57	2.53
	H2O (LOI)	18.015	1.8	1.96	2.5	1.86	-0.04
	Total		99.75	99.81	99.83	99.73	99.60
Moles	TiO2		0.008	0.007	0.007	0.009	0.024
	Cr2O3		0.000	0.000	0.000	0.000	0.000
	SiO2		1.185	1.125	1.019	1.033	0.965
	AI2O3		0.147	0.173	0.211	0.163	0.133
	CaO		0.005	0.005	0.004	0.007	0.118
	MgO		0.043	0.043	0.039	0.087	0.080
	FeO		0.006	0.008	0.009	0.014	0.019
	MnO		0.001	0.001	0.001	0.002	0.003
	Fe2O3		0.012	0.014	0.016	0.025	0.033
	K2O		0.038	0.041	0.054	0.044	0.003
	Na2O		0.014	0.011	0.014	0.009	0.041
	H2O		0.100	0.109	0.139	0.103	-0.002
	total		1.558	1.536	1.512	1.494	1.417
	NF		64.171	65.109	66.153	66.922	70.574
Normalized	TiO2		0.496	0.466	0.494	0.575	1.668
MOLAR %	Cr2O3		0.000	0.000	0.000	0.000	0.000
	SiO2		76.024	73.279	67.386	69.161	68.131
	AI2O3		9.453	11.290	13.930	10.876	9.365
	CaO		0.320	0.313	0.248	0.465	8.356
	MaO		2.754	2.778	2.609	5.794	5.673
	FeO		0.411	0.488	0.575	0.913	1.307
	MnO		0.037	0.037	0.037	0.108	0.227
	Fe2O3		0.739	0.879	1.036	1.643	2.353
	K2O		2,432	2.661	3,553	2,941	0.196
	Na2O		0.921	0.725	0.950	0.615	2.881
	H2O		6.412	7.084	9,180	6,910	-0.157
	total		100.000	100.000	100.000	100.000	100.000
MnNCKFMASHT	TiO2		0.50	0.47	0.49	0.57	1.67
	SiO2		76.02	73.28	67.39	69.16	68.13
	AI2O3		9.45	11.29	13.93	10.88	9.37
	CaO		0.32	0.31	0.25	0.47	8.36
	MgO		2.75	2.78	2.61	5.79	5.67
	FeO		3.37	4.00	4.72	7.48	10.72
	MnO		0.04	0.04	0.04	0.11	0.23
	0		0.74	0.88	1.04	1.64	2.35
	K2O		2.43	2.66	3.55	2.94	0.20
	Na2O		0.92	0.72	0.95	0.62	2.88
	H2O		6.41	7.08	9.00	6.91	-0.16
	total		102.96	103 52	104 14	106 57	109 41
			102.00	100.02	101.14	100.01	100.41

# Appendix D4.2: Bulk Rock Geochemistry

### Appendix D4.3: EPMA Garnet Geochemistry



Appendix	<b>D4.4</b> :	Monazite	U/Pb	Results
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						Instantis Battan					- lated in local at 0	(84-)	Discord		Constantin Los	Coloursed in Insulat D	
Spot ID	238U conc.	232Th conc.				Isotopic Ratios			Appari	int Ages - Calc	ulated in isopiot K	(Ma)	Discord	error %	Concordia Age - I	Calcuated in Isopiot R	Concordant
	ppm	ppm		238U/206Pb	±2σ PROP	207Pb/206Pb	±2σ PROP	rho	238U/206Pb	±2σ PROP	207Pb/206Pb	±2σ PROP	(7/6-6/8)/7/6*100		Age	±2σ PROP	uncertainties?
49DTB19 49DTB19-MM - 2 d	2816 309331	33990 37731	0.08285609	5 474705387	0 2525755	0.074157141	0.002183278	0 28683644	1081 5	23	1044.8	29.7	351	2 13%	1055.7		15.2 concordant
49DTB19-MM - 9.d	2267.561078	25819.78107	0.08782263	5.359452345	0.2479169	0.075347832	0.002729109	0.19815474	1102.9	23.4	1076.9	36.4	-2.41	2.12%	1094.3		17.6 concordant
49DTB19-MM - 20.d 49DTB19-MM - 12.d	1797.623773 2469.30557	31010.47406 63515.55195	0.057968278	5.618365495 5.433171686	0.2596695	0.07461643	0.002348951 0.002749404	-0.0073103 0.52877379	1056	22.5	1057.3	31.7 36.3	0.12	2.13%	1056.4		18.4 concordant 13.8 concordant
49DTB19-MM - 10.d	2154.371869	40445.09743	0.053266576	5.435789668	0.2436672	0.07612913	0.002202525	0.47081442	1088.6	22.5	1097.6	28.9	0.82	2.07%	1092.3		13 concordant
49DTB19-MM - 4.d 49DTB19-MM - 1.d	3941.956264	57416.59227 34889 95567	0.06865535	5.534090907	0.2473975	0.075547412	0.001940652	0.30627341	1070.8	22.1	1082.2	25.8	1.05	2.06%	1075.8		14 concordant 13.1 concordant
49DTB19-MM - 23.d	2176.286444	34968.54891	0.062235538	5.533001102	0.2438308	0.077665713	0.002082374	0.26018075	1071	21.7	1137.4	26.7	5.84	2.03%	1098.7		14.9 concordant
49DTB19-MM - 13.d	2615.925855	52807.65378	0.04953687	5.38058761	0.2498111	0.07885405	0.002165294	0.24152653	1098.9	23.5	1167.6	27.2	5.88	2.14%	1129		15.9 concordant
49DTB19-MM - 11.d	1976.822148	34317.91275	0.057603216	5.704223625	0.2414385	0.080433684	0.002302697	0.21840758	1041.3	20.3	1206.8	28.2	13.71	1.95%	1100		15.8 discordant
49DTB19-MM - 6.d	1901.771406	34400.07998	0.055283924	5.500441981 5.40997215	0.2475753	0.083860146	0.002286488	0.04554753	1076.8	22.3	1288.4	26.5	16.42	2.07%	1159.9		18.7 discordant
49DTB19-MM - 21.d	679.2227238	2028.879201	0.334777311	5.192162215	0.2459797	0.118714979	0.003829892	0.1218633	1135.4	24.7	1936.2	28.9	41.36	2.18%	1295.4		36.8 discordant
49DTB19-MM - 19.d	606.2022249	10324.21105	0.058716567	5.150346938	0.2369061	0.132511114	0.004806338	-0.1924004	1143.9	24.1	2130.7	31.7	46.31	2.11%	893.6		26 discordant
4901819-MM - 15.0 4901819 MM - 22.d with links	746.220626	5150.459905	0.103298414	3.539066707	0.1943381	0.406847213	0.010783379	0.19708424	1646.9	37	4223	19.6 24.6	53.14 62.00	2.42%	882.2		37 discordant
49DTB19-MM - 17.d	1037.941167	16738.06221	0.062010832	4.852891319	0.2265118	0.606108979	0.016197415	0.32892829	1207.8	25.7	4522.1	19.4	73.29	2.13%	251.3		18.3 discordant
50DTB19-MI - 1.d	508.5082855	13382.97134	0.037996666	4.146590598	0.1915089	0.088948197	0.002990278	0.16273922	1392.7	28.9	1402.2	32.2	0.68	2.08%	1397		19.8 concordant
50DTB19-MI - 2.d	1074.381297	25577.74912	0.042004529	4.208869389	0.1960854	0.084141858	0.002584784	0.33071445	1374.2	28.8	1295	29.9	-6.12	2.10%	1335.6		16.6 concordant
SODTB19-MIC - 4.d	1206.74968	42909.0351	0.02812344	4.308045822	0.1957678	0.086338214	0.002627124	0.0200513	1345.6	27.6	1344.9	29.4	-0.05	2.05%	1345.3		19.9 concordant
SODTB19-MIC - 5.d	1627.696309	46832.71601	0.034755539	5.072290157	0.2289621	0.082991223	0.002965691	0.52787073	1160	24	1268.1	34.9	8.52	2.07%	1200.8		14.2 concordant
50DTB19-MMC - 0.0	1625.230947	15102.27994	0.10761494	4.466833474	0.2046655	0.087969903	0.002595105	0.27380329	1302.3	27.1	1379.1	20.2	5.70	2.00%	1365.9		16.8 concordant
50DTB19-MM - 10.d	2560.013692	32882.96686	0.077852272	4.460701732	0.2125691	0.087139459	0.002395151	0.32805786	1303.9	28.1	1362.7	26.5	4.31	2.16%	1334.7		16 concordant
SODTB19-MM - 11.d with links SODTB19-MM - 12.d	3221.660428 2888.362767	32328.31965 40658.27702	0.099654435 0.07103997	5.484788338 4.472476836	0.3094314	0.08045656	0.002494653 0.002475397	-0.0157056 0.34705942	1079.6 1300.8	28 26.6	1207.3 1340.8	30.5 27.8	10.58	2.59%	1136.6		22.3 discordant 15.7 concordant
50DTB19-MM - 13.d	1853.923939	42064.72568	0.044073126	4.259817355	0.1793889	0.088014403	0.00273432	0.28361649	1359.4	25.8	1381.9	29.8	1.63	1.90%	1369.4		16.7 concordant
50DTB19-MM - 14.d 50DTB19-MM - 15.d	5449.197834 3947 877914	32754.74412	0.166363621	5.651493505 5.748599505	0.2691872	0.07674033	0.002020913	0.44611244	1050.3	23.1	1113.6	26.3	5.68 c ec	2.20%	1079.1		13.2 concordant 13.5 concordant
50DTB19-MM - 17.d	1546.298973	46543.60851	0.033222585	5.633788146	0.2585588	0.0860192	0.002491603	0.36940363	1053.3	22.3	1337.7	28	21.26	2.12%	1169.5		15.5 discordant
SODTB19-MM - 18.d	1281.177559	43193.0722	0.029661645	5.498165814	0.2675565	0.089812982	0.003807315	0.29905067	1077.2	24.1	1420.7	40.5	24.18	2.24%	1171.2		20.3 discordant
50DTB19-MM - 19.0 50DTB19-MM - 20.0	1248.959723	27277.87893	0.045786541	4.392146134	0.203221	0.091627834	0.002622856	0.03202808	1322.3	24.7	1458.8	27.2	9.36	2.09%	1390.8		20.2 discordant
50DTB19-MM - 21.d	1256.722059	26135.00229	0.048085783	4.824178275	0.2787532	0.086493443	0.002812151	-0.024235	1214.4	32	1348.4	31.4	9.94	2.64%	1281.8		24.1 discordant
50DTB19-MM - 22.d 50DTB19-MM - 23.d	1113.14/58 1086.575529	13400.91945 13465.13156	0.083065015	4.406054 <i>3</i> 64 5.594291096	0.2018019	0.088835137	0.002792114	0.27743894 0.36660062	1318.5	27.3	1399.7	30.1	5.80	2.07%	1355.8		17.7 concordant 15.6 discordant
50DTB19-MM - 24.d	1667.494576	31288.05416	0.053294927	4.743239486	0.2451099	0.083331005	0.002602491	0.07820985	1233.2	29	1276.1	30.4	3.36	2.35%	1253.6		20.5 concordant
50DTB19-MM - 25.d 50DTB19-MM - 4.d	1646.347118	48710.15023	0.033798851	4.573412886	0.2096654	0.086968685	0.002650611	0.42746681	1274.8	26.5	1358.9	29.4	6.19	2.08%	1313.8		15.2 concordant
SODTB19-MM - 5.d	1136.065558	40981.17005	0.027721648	4.436742794	0.2097329	0.086108746	0.002706487	0.45897149	1310.3	28	1339.8	30.4	2.20	2.14%	1324.2		15.3 concordant
50DTB19-MM - 6.d	884.3966102	19128.41369	0.046234707	4.836414094	0.2276647	0.085715562	0.002761247	0.06032845	1211.6	26	1330.9	31.2	8.96	2.15%	1259.6		20.5 discordant
SODTB19-MM - 8.d	1702.587633	13143.45588	0.12953881	5.140958645	0.2316597	0.078900528	0.00267989	0.19734399	1145.8	23.7	1168.7	33.6	1.96	2.07%	1154		17.6 concordant
SODTB19_MM																	
51DTB19_MM																	
51DTB19-MI - 7.d	1280.851104	28551.74114	0.0448607	4.217895357	0.189018	0.084674502	0.002491848	0.28112403	1371.5	27.7	1307.2	28.6	-4.92	2.02%	1340.1		16.6 concordant
51DTB19-MI - 1.d	1911.984162	24180.54686	0.079071171	4.436692096	0.2075336	0.08420216	0.002465183	-0.1411876	1310.3	27.7	1296.4	28.5	-1.07	2.11%	1303.5		21.1 concordant
51DTB19-MI - 6.d	771.4424008	68881.47006	0.011199564	4.214633743	0.1965736	0.086952243	0.002808762	-0.0393661	1372.5	28.8	1358.6	31.1	-1.02	2.10%	1366.1		21.4 concordant
51DTB19-MIL-9.d 51DTB19-MIL-4.d	1184.620448 1892.132911	28363.62093	0.038835961 0.06670985	4.23095/044	0.1914568	0.087599506	0.00245129	0.012632067	1367.7	27.9	13/2.9	26.9	0.38	2.04%	13/0.4		18.1 concordant 19 concordant
51DTB19-MIc - 10.d	2507.247867	21670.88877	0.115696587	4.53762172	0.2473718	0.084076426	0.002335137	0.0614161	1283.9	31.7	1293.4	27	0.73	2.47%	1289.4		20 concordant
51DTB19-Mic - 6.d 51DTB19-Mi - 4.d	3740.247221 3657 699839	25081.83906	0.14912173	4.531062463	0.1969124	0.084291767	0.00217786	-0.0392977	1285.6	25.3	1298.4	25.1	0.99	1.97%	1292		18.3 concordant 19 concordant
51DTB19-Mir - 2.d	6732.378369	21806.44468	0.308733426	6.002433481	0.2762309	0.073570986	0.001958195	0.00240785	993.3	21.2	1028.8	26.9	3.45	2.13%	1006.8		16.9 concordant
51DTB19-Mic - 2.d	1275.016638	20907.80446	0.060982809	4.345427809	0.2079884	0.088121859	0.002595401	-0.2442849	1335.2	28.9	1384.3	28.3	3.55	2.16%	1360.1		23.2 concordant
S1DTB19-MI - 5.d	1352.311006	57117.41999	0.023675982	4.610409964	0.2143991	0.085994331	0.002548066	0.27175722	1265.5	26.7	1337.2	28.6	5.36	2.11%	1299.3		17.1 concordant
51DTB19-Mic - 1.d	1706.477819	23206.99228	0.073532916	4.857756777	0.2617992	0.084372438	0.002996304	-0.2630748	1205.7	29.7	1300.3	34.5	7.20	2.46%	1241.6		27 concordant
51DTB19-MM - 1.d	2496.902823	51744.27278	0.04825467	4.197546876	0.1905833	0.087273951	0.002431613	0.28180578	1377.5	28.2	1365.7	26.8	-0.86	2.05%	1371.4		16.4 concordant
51DTB19-MM - 10.d	1157.692472	66781.05302	0.017335643	4.207370108	0.193013	0.086952741	0.002725437	0.38379298	1374.6	28.4	1358.6	30.2	-1.18	2.07%	1367		16.2 concordant
51DTB19-MM - 11.d 51DTB19-MM - 13.d with links	5253.346235	28549.68922	0.184007125	4.593131752	0.2215054	0.086584729	0.002236151	-0.0493787	1269.8	27.8	1313.2	25.5	3.30	2.15%	1293.4		19.6 concordant
51DTB19-MM - 14.d	4932.239261	24545.81964	0.200940092	4.596690881	0.2122059	0.083927069	0.002093207	0.38226486	1268.9	26.6	1290	24.3	1.64	2.10%	1280.2		14.2 concordant
51DTB19-MM - 15.d 51DTB19-MM - 16.d	1816.920232	62059.94373 53692 87755	0.029276859	4.126960881	0.1877297	0.088196169	0.002423598	-0.0179777	1398.7 1435.1	28.6	1385.9	26.4	-0.92	2.04%	1391.8		19.5 concordant
51DTB19-MM - 18.d	3724.147682	48117.34302	0.077397201	4.560595662	0.2300733	0.086994939	0.002433717	0.57637608	1278	29.2	1359.5	27	5.99	2.28%	1321.1		13.1 concordant
5101819-MM - 19.d 51DTB19-MM - 2.d with links	966.8692601 1134.7832	46662.33707 80929.58961	0.020720549 0.014021858	4.163780842 4.353901404	0.2065861	0.087290697 0.087857762	0.002397271 0.002663551	-0.1791609 -0.0466538	1387.6 1332.8	27.6 28.6	1366.1 1378.5	26.4 29.1	-1.57	1.99% 2.15%	1376.2 1355		20.5 concordant 21.3 concordant
51DTB19-MM - 21.d	1982.788675	29985.03999	0.066125931	4.195576016	0.179599	0.086073356	0.002300885	0.19475469	1378.1	26.6	1339	25.8	-2.92	1.93%	1358.1		16.4 concordant
5101819-MM - 24.d 510TB19-MM - 27.d	3118.428819 3602.351476	30919.63582 43621.98966	0.08258109	4.625682465	0.2220437	0.084892167	0.002176348	0.0575961	1261.7	26.9 30	1271.7	25.5	0.79	2.13%	1266.9		17.9 concordant 21.1 concordant
51DTB19-MM - 28.d	2722.676529	32916.08715	0.08271568	4.877917404	0.2298939	0.082705824	0.002215152	0.05807296	1202.2	25.8	1261.4	26.2	4.69	2.15%	1231.3		18.3 concordant
51DTB19-MM - 29.d	1032.847277	51343.10692	0.020116571	4.211684369	0.1989507	0.088126323	0.002661048	0.40616460	1373.3	29.2	1384.4	29	0.80	2.13%	1378.9		20.7 concordant
51DTB19-MM - 30.d	1708.048744	24822.82848	0.068809594	4.14371428	0.1868522	0.086029696	0.002264873	0.28309414	1393.6	28.3	1338	25.4	-4.16	2.03%	1363.6		15.8 concordant
51DTB19-MM - 4.d with links	4018.176374	24241.64649	0.165755093	5.83022153	0.2713176	0.073696022	0.001919273	0.09924935	1020.5	22	1032.2	26.3	1.13	2.16%	1025.4		16.1 concordant
51DTB19-MM - 5.d	1344.770045	64128.27298	0.020970003	4.282036192	0.1973912	0.087885987	0.00258371	-0.002953	1353	28.1	1379.1	28.4	-0.37	2.03%	1351.5		20 concordant
51DTB19-MM - 7.d	1818.978654	72207.76505	0.025190901	4.689473983	0.2297429	0.084078095	0.002733896	-0.0736903	1246.1	27.8	1293.5	31.6	3.66	2.23%	1266.2		22.1 concordant
51DTB19-MM - 8.0 51DTB19-MM - 9.0	1547.838499	42836.3971	0.036133723	4.149328849 4.194204358	0.1963/01 0.203672	0.0861/9029	0.002360076	-0.2051485	1391.9	29.6	1341.3	27.2	-3.77	2.13%	1356.4		21.5 concordant
51DTB19-MI - 3.d	1257.8509	31131.21133	0.040404817	3.898101841	0.1847832	0.085635686	0.002384689	-0.126796	1472.1	31.2	1329.1	26.9	-10.76	2.12%	1388.6		20.6 discordant
5101819-MIC - 1.0 51DTB19-MIC - 5.d	1122.161735 1321.533779	28322.10755 35753.52848	0.039621406	3.996/46568 4.054067338	0.1888/34	0.085255255	0.002383308	-0.1679885	1439.5 1421.3	30.5 29	1320.5 1313.5	28 27.2	-9.01 -8.21	2.12%	1375.2 1362.8		20.5 discordant
S1DTB19-MI - 2.d	4099.206822	29754.1479	0.137769256	4.941806142	0.2200011	0.083798193	0.002094717	0.07515324	1188	24.1	1287	24.3	7.69	2.03%	1236.8		17.2 discordant
51DTB19-MM - 17.d with links 51DTB19-MM - 20.d	4742.719108 2395.505639	20423.51481 8763.077393	0.232218556	5.693543598 6.282057731	0.2632091 0.3011351	0.07775683	0.002126859 0.002141651	-0.1069501 -0.0072584	1043.1 957 7	22.3	1139.8 1069.6	27.2	8.48 10.98	2.14%	1079		19.3 discordant 18.4 discordant
51DTB19-MM - 23.d	1925.16152	22704.97117	0.084790309	5.408332202	0.26041	0.081208279	0.002379313	0.04863146	1093.7	24.2	1225.6	28.8	10.76	2.21%	1147.1		19.3 discordant
51DTB19-MM - 25.d	1440.712916	22941.89088	0.062798351	5.389037894	0.2675691	0.085479281	0.002912519	0.44469717	1097.3	25	1348	32.5	18.60	2.28%	1198.9		16.2 discordant
59DTB19_MM 59DTB19-MI - 6.d	2484.180791	33880.19791	0.073322499	5.128918922	0.2321674	0.077280732	0.002305627	0.10398317	1148.3	23.8	1127.5	29.7	-1.84	2.07%	1139.9		17.5 concordant
59DTB19-MI - 4.d	2023.512188	32628.90473	0.06201594	5.121344424	0.2507564	0.078192134	0.002345858	0.00185867	1149.8	25.8	1150.9	29.8	0.10	2.24%	1150.3		19.5 concordant
59DTB19-MI - 2.d	2303.942419	28562.83071	0.08038084	5.289933418	0.239652	0.077770294	0.002238005	-0.0451755	1116.2	23.2	1140.1	42.5 28.6	2.10	2.08%	1125.5		18.7 concordant
59DTB19-MM - 1.d	2839.100394	30738.45859	0.092363135	5.603498191	0.2500553	0.076184182	0.002039504	0.03744231	1058.6	21.8	1099	26.8	3.68	2.06%	1074.6		16.9 concordant
59DTB19-MI - 5.0	1807.105302 1663.813151	41491.05454 9322.64991	0.043554094 0.178469981	*.410/63501 5.013153856	0.2514519	0.08/580481	0.002389291 0.002487585	-0.1347907	1317.3 1172.5	21.7	13/2.4 1317.5	26.2 28.3	4.01	2.10%	1346.2 1238		22.7 discordant
59DTB19-MM - 3.d	983.438299	25456.14626	0.038632646	5.425888002	0.2875774	0.101809905	0.003582696	0.34886193	1090.4	26.6	1656.5	32.6	34.17	2.44%	1312.4		21.4 discordant

# Appendix D4.5: Monazite U/Pb Standards

Seat ID	238U conc.	232Th conc.			Isotopic Ratios			Appar	ent Ages - Calc	ulated in Isoplot R	(Ma)	Discord		Concordia Ag	e - Calcuated in Isoplot R	Concordant	
aporto	ppm	ppm	238U/206Pb	±2d PROP	2079b/205Pb	±2d PROP	rho	238U/206Pb	±20 PROP	2079b/205Pb	±20 PROP	(7/6-6/8)/7/6*100	entorixe	Age	±2ø PROP	within uncertainties?	
MZ_44069new																	
44069 - 1.d	3243.518804	24978.56992	14.76711698	0.6645592	0.05476356	0.002258687	0.16386281	422.39	9.2	401.6	46.2	-5.18	2.18%		mean = 424.05±2.2	3   4.37 Ma (n=17/1	17)
44069 - 2.d	3251.196098	24977.28417	14.72054635	0.6778399	0.056093504	0.001722317	0.33528169	423.69	9.44	455.1	34.1	6.90	2.23%		MSWD = 0.0	$19, p(\chi^{*}) = 1.00$	
44069 - 3.d	3251.690787	24976.95095	14.69413699	0.6410222	0.054589327	0.001722874	0.19579051	424.42	8.96	394.4	35.4	-7.61	2.11%	-			
44069 - 4.d	3250.187346	24974.03055	14.7118746	0.6719385	0.054584742	0.002207566	0.28975646	423.93	9.37	394.2	45.4	-7.54	2.21%	3 7			
44069 - 5.d	3254.043414	24983.68745	14.74280857	0.6516427	0.055735617	0.001832215	0.36292596	423.07	9.05	440.9	36.6	4.04	2.14%				
44069 - 6.d	3249.089667	24961.08752	14.68803477	0.6672523	0.056028678	0.001954879	0.23786607	424.59	9.33	452.5	38.7	6.17	2.20%	8			
44069 - 7.d	3253.159618	25016.10892	14.61787127	0.6362738	0.054302245	0.001748718	0.40278567	426.57	8.98	382.6	36.2	-11.49	2.11%	¥ 7			
44069 - 8.d	3251.326617	24966.28887	14.76587432	0.6729929	0.055400366	0.001812094	0.04533965	422.43	9.32	427.4	36.5	1.16	2.21%				
44069 - 9.d	3250.328844	24985.30308	14.66056393	0.6182894	0.056064741	0.001834884	0.45623385	425.36	8.68	453.9	36.3	6.29	2.04%	8 -			
44069 - 10.d	3251.170187	24973.18726	14.74671192	0.6853422	0.055151767	0.002010633	0.39557211	422.96	9.51	417.4	40.7	-1.33	2.25%	*			
44069 - 11.d	3250.487202	24977.77486	14.69312724	0.6621168	0.055642112	0.002070614	0.33869222	424.45	9.26	437.1	41.4	2.89	2.18%				
44069 - 12.d	3251.483473	24975.1621	14.76443967	0.6843693	0.054871708	0.001759531	0.10402454	422.47	9.48	406	35.9	-4.06	2.24%	<u></u>			
44069 - 13.d	3250.527148	24980.60205	14.73255617	0.6445546	0.055623415	0.001999831	0.29631053	423.35	8.96	436.4	40	2.99	2.12%				
44069 - 14.d	3251.520411	24978.71231	14.66556404	0.6814878	0.055161611	0.001947405	0.24097567	425.22	9.56	417.8	39.4	-1.78	2.25%				
44069 - 15.d	3250.624466	24972.66919	14.69709028	0.6494291	0.055146073	0.001884323	0.39321707	424.34	9.07	417.1	38.2	-1.74	2.14%		12345678	9 11 13	15 1
44069 - 16.d	3251.079071	24978.82057	14.63180304	0.6489698	0.054626821	0.001927496	0.39673366	426.17	9.15	396	39.6	-7.62	2.15%				
44069 - 17.d	3250.971754	24974.27677	14.73968645	0.6530249	0.055849394	0.001802246	0.28591504	423.15	9.07	445.4	35.9	5.00	2.14%				
MZ_Managotry															mean - 502.36 + 3.82   7.49 Mile (h - 10 (10) Million - 5.10 (10) - 5.01		
manangotry - 1.d	2445.312646	156050.9537	10.90078637	0.492967	0.056578176	0.002116638	0.35592706	565.8	12.2	474.1	41.4	-19.34	2.16%	8 7			
manangotry - 2.d	1166.417887	93821.71826	11.10473644	0.4987602	0.059845837	0.00229602	0.0744909	555.8	12	597	41.6	6.90	2.16%	8-			
manangotry - 3.d	1131.701632	113970.2089	11.17939022	0.5366315	0.06125878	0.002942554	-0.0919098	552.3	12.7	647.4	51.6	14.69	2.30%	8.			
manangotry - 4.d	1308.763436	100317.2888	10.97415886	0.4495898	0.059474873	0.002211065	0.22781197	562.2	11	583.5	40.4	3.65	1.96%				
manangotry - 5.d	1039.194201	95102.89381	10.84982796	0.5057053	0.060194409	0.002352375	0.19378394	568.3	12.7	609.6	42.2	6.77	2.23%	s -			
manangotry - 6.d	1538.781399	97030.14176	10.71696787	0.4754001	0.057562647	0.002189983	0.26911434	575.1	12.2	512.2	41.8	-12.28	2.12%	3 -			
manangotry - 7.d	1415.802273	193833.1438	11.00542991	0.5013939	0.060754697	0.002237869	0.39214022	560.6	12.2	629.6	39.7	10.96	2.18%	8 -			
manangotry - 8.d	1286.34326	113460.9615	11.10733946	0.4862088	0.058595331	0.002180442	0.17325293	555.7	11.7	551.1	40.6	-0.83	2.11%	2.			
manangotry - 9.d	1455.920712	98267.54296	10.95049834	0.4984727	0.058776721	0.002248044	-0.0335608	563.3	12.3	557.9	41.7	-0.97	2.18%				
manangotry - 10.d	1406.031681	114848.756	10.91794175	0.4906137	0.055993257	0.002033949	0.28595143	564.9	12.2	451.1	40.3	-25.23	2.16%			1 1	
MZ_Stern															N		
stern - 1.d	4716.046586	66468.49277	11.96981284	0.5357428	0.056965475	0.001837118	0.21543503	517.2	11.1	489.2	35.6	-5.72	2.15%				
stern - 2.d	2695.972093	45306.58894	12.14514133	0.5385654	0.056889079	0.00183533	0.36780162	510.1	10.9	486.2	35.6	-4.92	2.14%				
stern - 3.d	3099.608252	48193.68877	12.02859804	0.5252223	0.057185912	0.001854031	0.26784599	514.8	10.8	497.7	35.7	-3.44	2.10%		mean = 509.51 ± 2.71   5.89 8	Ab (n=17/17)	
stern - 4.d	4784.554034	58795.04501	12.51354096	0.5471657	0.059371715	0.001993613	0.35571988	495.6	10.4	579.8	36.5	14.52	2.10%		MSHD = 0.38, p(g') -	-0.99	
stern - 5.d	2284.324366	55914.94354	12.24088752	0.5662068	0.057332485	0.001778314	0.3996708	506.2	11.3	503.4	34.1	-0.56	2.23%	3			
stern - 6.d	3922.771542	71201.66831	12.04932215	0.5560998	0.057977281	0.001847418	0.38769498	514	11.4	527.9	34.9	2.63	2.22%	8.			
stern - 7.d	2264.310716	39018.8655	12.20889671	0.5471817	0.057798501	0.001732318	0.46948958	507.5	10.9	521.1	32.9	2.61	2.15%				
stern - 8.d	2276.055191	53268.36894	11.94280232	0.5559893	0.056848146	0.001742985	0.30553073	518.4	11.6	484.7	33.8	-6.95	2.24%	8 -			
stern - 9.d	3179.408078	40554.60829	12.20205657	0.5491742	0.056639385	0.001821438	0.14391386	507.8	11	476.5	35.6	-6.57	2.17%				
stern - 10.d	3490.870842	46554.55204	12.01037183	0.5504661	0.056924917	0.001766215	0.19372435	515.6	11.4	487.6	34.2	-5.74	2.21%	š -			
stern - 11.d	4318.883506	58544.67977	11.97128549	0.546125	0.058113212	0.001946219	0.25752547	517.2	11.3	533	36.7	2.96	2.18%	8			
stern - 12.d	3071.227963	91315.0855	12.19984235	0.5754622	0.057421818	0.001913389	0.27396409	507.9	11.5	506.8	36.6	-0.22	2.26%	8 7			
stern - 13.d	4199.287745	64532.97244	12.37691231	0.5734718	0.058516	0.00181575	0.18724364	500.9	11.2	548.2	33.9	8.63	2.24%	8 -			
stern - 14.d	3293.235653	58119.96669	12.34411226	0.5587759	0.058570247	0.002039494	0.50838357	502.2	10.9	550.2	38	8.72	2.17%	-			
stern - 15.d	4037.241764	63071.78953	12.04590793	0.550722	0.057407196	0.001736523	0.24110713	514.1	11.3	506.2	33.3	-1.56	2.20%	8 -			
stern - 16.d	3463.582117	47747.9531	12.28313599	0.579812	0.056744284	0.001743046	-0.0269402	504.5	11.5	480.6	33.9	-4.97	2.28%				
stern - 17.d	3320.348842	55247.58251	11.95139021	0.5453493	0.05588305	0.001799791	0.25182869	518	11.4	446.7	35.8	-15.96	2.20%		2345678910	11 12 13 14 15 16 1	7

# Appendix D4.6: Apatite U/Pb Results

		238U conc.		232Th conc.				LA-ICP-MS Isotopic Ratios		
	Spot ID		±2σ INT		±2σ INT	238U/206Pb	±2σ PROP(2%)	207Pb/206Pb	±2σ PROP(2%)	rho
L		ppm		ppm						
	49DTB19-AM									
1	49DTB19-AM - 1.d	16.16910767	3.228772921	6.266060947	1.83720746	4.293569588	0.21663715	0.488298043	0.02127382	-0.167226571
1	49DTB19-AMI - 3.0 49DTB19-AMI - 4 d	35 1598577	7 146182393	37 5109583	7 157249245	4 950247987	0.224116394	0.412430588	0.042604669	-0.227660892
	49DTB19-AM - 5.d	24.23391162	11.39616167	44.62092556	28.20789548	3.402707272	0.164162408	0.534504057	0.019654907	-0.236544666
	49DTB19-AM - 6.d	24.86574051	5.69960188	17.43436269	3.145521581	4.161335316	0.179802944	0.48185622	0.017159251	0.380247864
	49DTB19-AM - 7.d	3.313193842	1.310232909	0.535579031	0.421344579	0.812581735	0.048005138	0.810603114	0.033549295	0.173599725
	49DTB19-AM - 8.d	41.5663909	5.399168233	62.71821622	10.36190696	4.953794319	0.207791613	0.405398136	0.01312726	0.206359263
	49DTB19-AM - 9.d	30.87608627	5.824303489	17.38068957	5.087780567	4.838783016	0.205660979	0.447947609	0.014795148	0.337125431
1	49DTB19-AM - 10.d	17.34533631	12.84427607	30.8301396	20.66744351	3.264803664	0.187252048	0.572643098	0.021605858	-0.390443628
1	49D1B19-AMI - 11.0 49DTB19-AMI - 16 d	4.422098035	4 958586231	0.093189284	1 482665242	1 102635150	0.14481904	0.742946516	0.023248280	-0.111916185
	49DTB19-AM - 17.d	4.46554985	1.154423546	0.925480296	0.495292322	1.474176564	0.076262964	0.775376638	0.028424385	0.353871563
	49DTB19-AM - 18.d	7.844615223	1.371272965	1.533876357	0.495189772	1.979072812	0.091506875	0.684435325	0.025028344	0.197917347
	49DTB19-AM - 20.d	55.40247874	3.366806374	26.59298814	2.167576033	6.488591998	0.276501034	0.31068006	0.011427432	0.18238594
	49DTB19-AM - 23.d	16.96791556	4.232193846	17.03223669	4.245602353	4.962218674	0.314781042	0.384645924	0.029005469	0.376476478
1	49DTB19-AM - 26.d	39.53071567	1.954011549	11.58922897	1.461058333	5.898956582	0.321502697	0.402990937	0.020328634	0.633787718
1	49DTB19-AM - 27.d	7.88623735	0.995867764	11.59720547	2.403037098	2.1919273	0.105474497	0.700490514	0.026869967	0.417499922
1	49DTB19-AW - 28.0 49DTB19-AM - 29 d	2 660713848	1.013370013	0.985311425	0.684239342	1.832010397	0.060641571	0.710425275	0.02441108	0.45440/31/
	49DTB19-AM - 34.d	40.40172903	26.76539095	34.61111615	18.00930045	5.329109297	0.274842196	0.37270256	0.015044608	-0.538995655
	49DTB19-AM - 35.d	97.54443104	27.82530835	89.90986547	17.28400687	7.531196467	0.317133765	0.255205325	0.009754442	0.012412085
	49DTB19-AM - 37.d	2.320421023	0.495235113	0.36166923	0.583560738	0.738672212	0.037259502	0.797675041	0.028653981	0.237336767
	49DTB19-AM - 38.d	5.20366824	1.615177416	9.566973263	3.875009661	1.405846019	0.071773112	0.741778976	0.026348777	0.14050001
1	49DTB19-AM - 39.d	4.134693337	1.69243573	0.435014242	0.251418593	1.00631578	0.08282848	0.76900225	0.037557042	0.224159471
1	49DTB19-AM - 40.d	3.977711821	0.970530998	1.669056205	0.376936679	1.579743305	0.087958993	0.709948434	0.042155589	0.363020091
1	49D1B19-AM - 42.0	2.759235582	0.56913/949	0.40528838	0.196136214	0.884217743	0.041836/14	0.797532582	0.029914831	0.404813914
1	49DTB19-AM - 44.d	2.189912805	0.331930743	0.202977389	0.117415242	0.711750247	0.032202278	0.825261038	0.029125107	0.466622987
	49DTB19-AM - 45.d	0.759742772	1.533187956	0.192473296	0.133839369	0.358722727	0.033403995	0.877364134	0.033199385	-0.023345483
	49DTB19-AM - 47.d	8.002808886	3.317626745	2.76381119	1.539251774	2.441126389	0.144055525	0.716564917	0.027652825	-0.192531677
	49DTB19-AM - 48.d	8.009797223	2.306173947	2.192078268	0.877541029	2.157780902	0.099991452	0.684090695	0.025348241	0.382758257
	49DTB19-AM - 49.d	2.21127492	0.490144441	0.188606164	0.112240316	0.708572015	0.033293332	0.813088479	0.02876897	0.458048492
1	49DTB19-AM - 51.d	5.650497929	3.531511664	2.286983497	1.879816372	1.618933328	0.098290714	0.710293608	0.026313466	-0.190383613
1	49D1B19-AM - 54.0	2.1380/1423	0.846693215	0.535140353	0.002214278	0.932605352	0.049256498	0.826568355	0.031603676	0.225986575
1	49DTB19-AM - 57 d	4 596504364	1.071078561	0.41573973	0.158629467	1 185474173	0.054529918	0.758515044	0.033137033	0.379857184
	49DTB19-AM - 59.d	1.448022703	1.190721116	0.171192939	0.146946523	0.74076446	0.148567505	0.789565486	0.052709707	0.252151135
	49DTB19-AM - 60.d	2.859299225	1.576529035	1.563867619	1.309063077	0.696500915	0.043383845	0.826239706	0.028438251	-0.031278173
1	51DTB19-AM									
ł	51DTB19-AM - 1.d	11.63337735	1.838209317	0.181500918	0.122528037	12.0360767	0.593185029	0.485117918	0.028135488	0.628914966
	51D1B19-AM - 2.0	11.08094902	1.519430046	0.166653133	0.112339602	10.75361512	0.55723492	0.484503926	0.020200115	0.53/198453
Ĵ	51DTB19-AM - 4 d	12 6407077	1 468906989	0 186399311	0 121181734	12 79876451	0.63722049	0.473141703	0.022447130	0.666565283
ł	51DTB19-AM - 5.d	12.38942254	1.749026887	0.188311922	0.136200604	12.40007895	0.665336755	0.468513512	0.026533946	0.648347781
ł	51DTB19-AM - 6.d	26.38524325	8.312223494	1.142003183	0.627447792	20.31769523	1.07999912	0.398411968	0.023442412	0.609023037
1	51DTB19-AM - 8.d	12.39909607	1.947046842	0.203632665	0.129524166	13.45942058	0.669176784	0.488435155	0.029163031	0.643008786
1	51DTB19-AM - 9.d	18.38178909	2.61017016	2.283947606	2.586075828	7.883203441	0.418303792	0.333204513	0.018003047	0.531279462
1	51DTB19-AM - 10.d	14.20209589	9.539038898	0.543876731	0.888421203	8.63300039	0.543252475	0.342459628	0.027423568	0.843829799
	51DTB19-AW - 11.0	53.07/36374	12.069/32/0	0.212722727	0.69140669	37.37880428	0.654577166	0.349380000	0.021180240	0.573507752
Ĵ	51DTB19-AM - 13.d	1.711416455	0.774491747	0.170134835	0.134644359	2.222645169	0.164614246	0.579811199	0.047098658	0.123485308
ł	51DTB19-AM - 14.d	14.41994248	4.017609207	0.277769654	0.151655781	13.85686583	0.686315639	0.383897829	0.023009017	0.522138555
1	51DTB19-AM - 15.d	13.19935902	2.196970995	0.332629224	0.166748703	8.977825711	0.434530803	0.390441418	0.019247796	0.201013219
1	51DTB19-AM - 16.d	12.6866107	1.648231646	0.246843115	0.12818073	14.17486392	0.738086297	0.52007184	0.029089544	0.686642329
ł	51DTB19-AM - 17.d	28.8411892	6.801183734	1.260383354	0.49938882	23.69730279	1.321194486	0.354471345	0.023700553	0.541465246
ł	51DTB19-AM - 18.d	6.828717745	0.89552495	0.141315931	0.114727492	6.355256257	0.5156394	0.368161124	0.039177434	0.654620991
	51DTB19-AWI - 19.0 51DTB19-AMI - 20 d	8 081757330	2.6/064/649	0.286778032	0.146762956	8.075610726	0.402010540	0.255306401	0.01296/921	0.415005779
Ĵ	51DTB19-AM - 21 d	17 17863222	4 708266543	0.324602344	0.230763209	18 08338159	1.001917432	0.429315223	0.041101585	0.482138384
į	51DTB19-AM - 24.d	16.79203442	3.363584913	0.79767868	0.847637425	15.93427279	0.91476153	0.487302844	0.030709424	0.572430237
1	51DTB19-AM - 25.d	18.50754991	13.62317765	0.660555221	0.892218897	16.57044916	1.134779324	0.427088332	0.026877877	0.115155444
ł	51DTB19-AM - 26.d	10.22652771	7.291678444	0.545941639	0.35214014	11.16766457	0.839485714	0.393858643	0.038657859	-0.151090845
1	51DTB19-AM - 28.d	16.33664943	6.905920978	0.440554824	0.479740606	16.36326173	0.993346494	0.422167628	0.029920958	0.4824416
1	51DTB19-AM - 29.d	13.74598607	1.21326282	0.198223237	0.109510322	12.75438979	0.670081852	0.449218785	0.030758927	0.681163106
ł	51DTB19-AM - 31.d	16.62415615	4.755789044	0.806267775	0.854156591	10.40401002	0.557560817	0.40469445	0.036437574	0.170377467
ł	51D1B19-AM - 33.0 51DTB19-AM - 34.d	13.72950283	2.140597483	0.217766906	0.132032192	13.02237063	0.656293837	0.326368788	0.02439631	0.3568/90/9
1	51DTB19-AM - 36 d	15 03464115	1 672356717	0.261657893	0.137185027	11 66321496	0 551145457	0.363930142	0.019253875	0.455978741
ł	51DTB19-AM - 37.d	1.265000302	1.358552664	0.021722665	0.067163283	3.040177231	0.815794597	0.381107432	0.086858799	0.026081922
ł	51DTB19-AM - 38.d	47.12964903	15.25501588	2.433907133	1.003145982	35.16015939	2.115814178	0.365981891	0.030990955	0.298301448
1	51DTB19-AM - 39.d	12.81661358	2.751097721	0.228797743	0.144948778	12.82533136	0.621650548	0.452619924	0.025836297	0.570939897
1	51DTB19-AM - 40.d	16.22657722	2.885202138	0.471525076	0.218719914	9.5074641	0.445135982	0.439264721	0.020897542	0.398327835
ł	51DTB19-AM - 41.d	13.60209683	1.144944532	0.221512102	0.116847447	12.62150377	0.678329886	0.489340136	0.027971801	0.565686273
1	5101819-AM - 42.d	13.03809892	5.284910361	0.29967095	0.296199856	11.0253274	0.594064809	0.406895751	0.02615181	0.677400475
ł	51DTB19-AM - 44.0 51DTB19-AM - 45.d	4.814738	2.208980842	0.106305979	0.091/92572	12 6220574	0.45/338003	0.494023457	0.036473013	0.330710004
1	51DTB19-AM - 46 d	0.676049109	1.05514255	0.05136091	0.1025249001	1 133825032	0.013214839	0.435483087	0.024603031	-0 25173157
į	51DTB19-AM - 47.d	12.26149109	4.711928402	0.226931774	0.256185495	10.79509505	0.677666891	0.430185313	0.031999288	0.744677358
1	51DTB19-AM - 48.d	11.2587776	2.012446058	0.193147292	0.181165804	11.15131982	0.582157978	0.474721271	0.027750062	0.616426628
1	51DTB19-AM - 49.d	13.97782694	2.07687475	0.281796315	0.249856205	11.917917	0.605264316	0.411505517	0.024624923	0.680593708
1	51DTB19-AM - 50.d	54.24670164	7.118104185	4.175505444	1.600073516	34.36735598	1.800224406	0.339190758	0.017111393	0.450993634

	238U conc.		232Th conc.				LA-ICP-MS Isotopic Ratios		
Spot ID	nom	±2σ INT	nom	±2σ INT	238U/206Pb	±2σ PROP(2%)	207Pb/206Pb	±2σ PROP(2%)	rho
								1	
52DTB19-AM - 1.d	9.2334247	0.877672555	0.792702702	0.271824098	28.56222961	1.891494129	0.372533945	0.033636146	0.487984445
52DTB19-AM - 2.d	9.993455638	1.918500267	0.51598314	0.19512351	30.14502133	1.88309213	0.381247465	0.03412088	0.593188928
52DTB19-AM - 3.d 52DTB19-AM - 4.d	13.93637541	1.015543538	0.673978474	0.234163708	41.15623592	2.418169924	0.345263111	0.028519859	0.443112367
52DTB19-AM - 5.d	12.33143219	1.017884323	0.616436866	0.188158581	38.65534223	2.372692547	0.351526204	0.032998715	0.60962933
52DTB19-AM - 6.d	15.08364696	4.44601778	0.590215746	0.241874836	63.18714115	4.382742217	0.29137007	0.033451983	0.54818956
52DTB19-AM - 7.d	12.10759867	1.848668388	0.59590315	0.167905257	33.94833266	2.042095154	0.371998128	0.033047152	0.666770984
52DTB19-AM - 9.d	10.61557295	1.567492737	0.604603355	0.18413502	31.54609219	1.868025865	0.377399068	0.033699574	0.511051274
52DTB19-AM - 10.d	14.77397792	2.6329433	0.77531378	0.22618509	52.57551215	3.284210254	0.312842399	0.028295198	0.4820629
52DTB19-AM - 11.d	11.38246415	1.062490536	0.666640384	0.207821439	31.34534789	1.891810413	0.355057211	0.030325233	0.61021669
52DTB19-AM - 13.d	10.33095822	1.877235825	0.503698151	0.216191683	29.75042128	1.789469667	0.396884655	0.033239531	0.499715699
52DTB19-AM - 14.d	10.53886729	1.028214256	0.50045118	0.192279581	31.54048077	1.815306544	0.409267632	0.034414626	0.544709323
52DTB19-AM - 15.d	9.766312854	1.671508976	0.431542228	0.182301053	33.14414061	2.068221328	0.360092843	0.03545698	0.61200745
52DTB19-AM - 17.d	21.6160379	3.294941681	1.967737097	11.30919197	75.72675294	6.724085072	0.201252551	0.024919808	0.532627088
52DTB19-AM - 19.d	10.42081702	2.358135627	0.676253874	0.254850284	31.35578875	1.930267556	0.402219126	0.034251164	0.538273947
52DTB19-AM - 20.d	3.250940763	2.165263618	1.257872147	1.159142558	23.61923107	2.918436487	0.376046511	0.075356774	0.423140235
52DTB19-AM - 22.d	15.05766222	1.071620741	1.390489416	0.403789706	49.56656355	3.05571659	0.304171262	0.029041018	0.333552228
52DTB19-AM - 23.d	2.037003353	0.91322981	0.243866534	0.407286397	22.99177448	4.477221573	0.467679578	0.10771887	0.683108189
52DTB19-AM - 24.d	13.45639553	2.515449506	0.853053305	0.651174534	38.85321525	2.347498756	0.336359356	0.025842321	0.306472868
52DTB19-AM - 25.d 52DTB19-AM - 26.d	9.996475126	2.252321129	0.353157794	0.186910535	31.38682224 72.90228271	2.484960805	0.341/39661	0.042139606	0.480937457
52DTB19-AM - 27.d	15.09203666	2.212345743	0.491982555	0.205491257	59.9515164	4.050876904	0.2818305	0.036481756	0.70518795
52DTB19-AM - 28.d	16.11843283	2.036075843	0.611740273	0.290152566	66.23714154	4.977305361	0.283194923	0.03847801	0.549941233
52DTB19-AM - 30.d 52DTB19-AM - 31.d	6.873751765 13 29875712	4.32970566 2.834915179	0.551310211	0.425882686	24.90241181 37 21654491	2.812278332	0.461450571 0.363560062	0.049325063	0.028137857
52DTB19-AM - 32.d	15.99974618	3.937639858	0.559892131	0.262968096	69.42649232	4.783253255	0.229616484	0.029853049	0.437737465
52DTB19-AM - 33.d	5.31283197	2.173215973	0.936256795	0.828975071	8.778095656	0.923337478	0.439543836	0.039872438	0.237761018
52DTB19-AM - 34.d 52DTB19-AM - 35.d	14.22112055	1.60076662	1.691191302	0.324619139	41.71554105 44.4459764	2.57813774	0.321358973	0.031296809	0.630468297
52DTB19-AM - 36.d	12.92414496	2.074602234	1.246647184	0.235069505	36.21619115	2.225823725	0.357404116	0.029971125	0.406062937
52DTB19-AM - 37.d	13.58231248	4.708640314	1.457616955	0.581775463	36.24408202	2.664398424	0.40376635	0.036916312	0.294656687
52DTB19-AM - 38.0 52DTB19-AM - 39.d	16.50824557	2.580938478	1.860994512	0.516558889	40.51516154 36.47648174	2.43/109138	0.356102723	0.029073919	0.426034051
52DTB19-AM - 41.d	9.769051414	0.85063816	0.928468733	0.261901792	40.42978373	3.438982894	0.322718438	0.039908895	0.451941183
52DTB19-AM - 43.d	13.94849741	4.981209542	0.536458953	0.255273048	44.78650055	3.00201414	0.295084326	0.03198353	0.411103112
52DTB19-AM - 44.d	12.29070431	2.043867717	3.371491702	1.155508795	23.41699546	1.521902717	0.369527496	0.032044114	0.23753612
52DTB19-AM - 46.d	19.57774547	1.254771835	1.624554614	0.544969704	55.37813025	3.320886141	0.270192151	0.024593983	0.240811828
52DTB19-AM - 47.d	10.21794226	2.157953091	0.441090124	0.195666675	37.70317874	2.620903615	0.332875216	0.040867343	0.362896294
52DTB19-AM - 48.d	14.25186057	1.535510315	0.888762798	0.308569286	51.26960286	3.528139759	0.288196346	0.028494356	0.604940888
52DTB19-AM - 50.d	15.54046019	4.846240467	1.015891329	0.396568686	45.89161013	3.40351671	0.368426115	0.041168881	0.108707805
52DTB19-AM - 51.d	17.65688662	2.641501693	1.230820348	0.292054067	52.35879463	3.214668691	0.293008466	0.026082925	0.503653475
52DTB19-AM - 52.d	8.592927503	1.049887857 3.780244211	0.506676051	0.224783178	28.46390753	2.569757639	0.372487508	0.045660341	0.48310271
52DTB19-AM - 54.d	17.77184571	1.936083787	1.09258078	0.32943298	53.82578677	3.439884359	0.311383173	0.03157276	0.675388326
52DTB19-AM - 55.d	27.03414982	4.153987777	0.710411775	0.261585977	70.96164164	4.056771103	0.200552838	0.020839029	0.467750322
52DTB19-AM - 56.d	10.57833113	1.957805269	0.656808566	0.213612356	40.42674122	2.57704149	0.349661356	0.031905751	0.485855907
52DTB19-AM - 58.d	12.85315122	2.451671413	1.009589341	0.33805063	40.08013812	2.465532183	0.330694489	0.027850703	0.359367157
52DTB19-AM - 59.d	14.7368052	2.975581515	1.155568703	0.321494547	45.6030354	2.896924236	0.319911126	0.030920485	0.631322852
52DTB19-AM - 60.d	14.15638012	2.174116663	1.072508571	0.315390133	43.4860699	2.768737341	0.342919687	0.03211931	0.605530153
52DTB19-AM - 62.d	13.39706582	3.696262232	0.520062126	0.248361937	39.07629306	2.269167489	0.318871961	0.029446431	0.483817186
52DTB19-AM - 63.d	15.9313156	2.137048389	0.853633032	0.283253361	50.06113536	3.1704549	0.321522397	0.030841886	0.587715327
52DTB19-AM - 64.d	17.4124595	9.861731999	1.151592453	0.720766028	52.14572672	3.418028573	0.288818256	0.02696854	0.186193441
52DTB19-AM - 66.d	12.22406094	2.260556534	0.95706091	0.389496461	37.08876818	2.356237906	0.34166081	0.03009866	0.438915039
52DTB19-AM - 67.d	10.04370437	1.913464627	0.33837073	0.182373348	31.0194734	2.009651274	0.384283542	0.033178821	0.491394632
52DTB19-AM - 68.d	12.31201767	1.700886071	0.60934692	0.199932621	35.06126885	2.220489507	0.408504633	0.034337426	0.691679299
52DTB19-AM - 70.d	5.827220574	1.224022736	1.382032073	0.465458147	17.66395114	1.056744708	0.465025761	0.031183047	0.618481781
52DTB19-AM - 71.d	7.934749121	5.155961367	1.334500585	0.901886987	34.00394194	2.430178665	0.348049847	0.03823278	0.218868956
52DTB19-AM - 77.d	10.64089223	2.757628826	0.500351178	0.253993507	39.47245931	6.052836197	0.406509956	0.068205099	-0.21158126
52DTB19-AM - 78.d 52DTB19-AM - 79.d	21.93/53409 14.12626035	7.134704803	3.2/269/55 8.625367951	5.242485838	61.37379597	4.339893666	0.2/36/9/35	0.050491233	0.423046731
52DTB19-AM - 80.d	23.90482362	3.168933173	0.995167923	0.271250137	63.46550104	3.681265604	0.261970492	0.022207133	0.4827701
52DTB19-AM - 81.d	13.43839409	3.959818333	0.631690297	0.20118973	41.82031549	2.694043752	0.344710647	0.029359258	0.515903423
52DTB19-AM - 82.d 52DTB19-AM - 83.d	10.72976581	1.469949115	0.554777925	0.223787349	32.36447125	2.003585523	0.341062523	0.028823437	0.471817465
52DTB19-AM - 84.d	10.85690483	1.665501714	0.825081752	0.233506877	29.02458146	1.624437218	0.40502342	0.030564226	0.583786991
52DTB19-AM - 85.d	10.01181902	1.611367754	0.750866516	0.212883416	28.67620273	1.678248343	0.402926012	0.032657918	0.470013746
52DTB19-AM - 86.d	11.22848694	1.819982572	0.947811856	0.279859757	31.25831413	1.838447563	0.36595696	0.029769755	0.649844787
52DTB19-AM - 88.d	9.938355436	1.913116819	0.64871938	0.231665877	26.01910893	1.602907981	0.400897445	0.030657475	0.409542897
52DTB19-AM - 89.d	9.007747073	1.39434909	0.572498309	0.210036857	22.68658491	1.312057857	0.443396646	0.03464436	0.522355768
52DTB19-AM - 90.d	8.971570661	1.393910632	0.65261358	0.443903977	21.61576053	1.300243038	0.481267503	0.038040899	0.652240265
52DTB19-AM - 92.d	8.522707452 9.3566715	1.60994921 1.406521153	0.638429274	0.217797173	23.205/3804 27.33476578	1.3/3486506	0.420387096	0.032374321	0.505990129
52DTB19-AM - 93.d	9.853922442	1.53296751	1.001438925	0.449550738	26.90217351	1.585983567	0.36325356	0.030520512	0.496233776
52DTB19-AM - 95.d	16.67735518	1.710541892	0.998276996	0.266586235	46.69040132	2.632095301	0.310194219	0.028567676	0.462100995
52D1819-AM - 96.d 52DTB19-AM - 97.d	13.6715593	1.616725007 0 806297889	0.975013406	0.282076254	39.24339604	2.297094731	0.355901169 0.480640649	0.031644555	0.495182874
52DTB19-AM - 98.d	21.53320033	2.258097755	0.256082663	0.126201071	76.46498198	5.000920462	0.226776066	0.025404803	0.37106181
52DTB19-AM - 99.d	20.27420168	2.702154089	0.432917653	0.181664561	76.16893603	4.783298102	0.239462829	0.027940744	0.337058698
52D1B19-AM - 100.d 52DTB19-AM - 101.d	16.68006645 10.13235631	3.529589471 3.02905677	1.976077239	0.379975364	60.11329772 54.52775483	4.962219	0.283315422	0.040031207 0.052375813	0.395098305 0.486798501

	238U conc.		232Th conc.				LA-ICP-MS Isotopic Ratios		
Spot ID	0000	±20 IN I	0000	±20 IN1	238U/206Pb	±2σ PROP(2%)	207Pb/206Pb	±2σ PROP(2%)	rho
	ppm		ppm						
59DTB19-AM	2 100375956	1.050520002	0 6695 29051	1 0/18/0255	0 573109155	0.031526071	0 846897153	0.037007102	0 342477266
59DTB19-AM - 5.d	47.55065696	23.83707049	16.17172008	10.69673197	11.10887785	0.577823247	0.761665099	0.027568245	0.262346465
59DTB19-AM - 6.d	15.69484452	2.871855547	3.328329292	0.883944859	3.694394325	0.197600528	0.812970557	0.038330247	0.395519931
59DTB19-AM - 7.d	14.94387542	1.958715543	4.579852699	1.091711434	4.51954255	0.218487203	0.798803624	0.030008436	0.488083952
59DTB19-AM - 8.d	9.029009032	4.305511732	3.165728834	0.731312707	1.783958999	0.109571796	0.788350605	0.02775008	-0.089138318
59DTB19-AM - 11.d	6.666859786	0.697130932	0.665011951	0.251452377	1.778215063	0.080232357	0.82656627	0.028753458	0.267134285
59DTB19-AM - 12.0	2 545658497	0.531219295	0.384815702	0.460232909	0.513058147	0.044304612	0.820260009	0.028/13/14	0.466900462
59DTB19-AM - 14.d	78.29558571	10.41425199	19.25764845	3.378092123	19.5289289	1.094774562	0.689921668	0.030118442	-0.039623436
59DTB19-AM - 15.d	12.83630764	14.34720823	1.982765261	2.575798053	3.603793216	0.438060508	0.797624094	0.030178089	-0.041251072
59DTB19-AM - 16.d	46.03631377	7.393884575	9.992639294	1.741484201	9.743742614	0.448662398	0.752425001	0.027315773	0.212548216
59DTB19-AM - 17.d	4.298995316	0.553136325	0.254690086	0.140991066	1.049594983	0.047766427	0.833266643	0.028777177	0.549898747
59DTB19-AM - 18.0 59DTB19-AM - 19.d	0.511552	0.844226246	0.709297832	1.0919/969/	0.514400825	0.03913179	0.804013373	0.041280477	0.027553655
59DTB19-AM - 20 d	4 464957326	0.64863078	1 187109923	1 241259423	1 150912866	0.051606481	0.820940169	0.028528637	0.495618119
59DTB19-AM - 21.d	4.397947328	0.97965997	1.349389922	0.581653537	1.076360913	0.049800528	0.837624853	0.02880475	0.603145481
59DTB19-AM - 22.d	4.041185783	0.586864661	0.293364875	0.151313877	1.143540304	0.05183013	0.826471737	0.029793766	0.534151675
59DTB19-AM - 23.d	0.25005604	0.287652444	0.60658225	0.601348799	0.185487016	0.015998377	0.825148301	0.030709649	0.280115199
59DTB19-AM - 24.d	0.140881417	0.115126337	0.308763203	0.174714698	0.548692384	0.051003792	0.867683466	0.05238088	0.306022853
59DTB19-AM - 25.0	8.270320497 A 70004616	9.511566/56	2./5/9162/2	3.2381/105	1.360028783	0.1/0/15895	0.811203/5/	0.028120355	-0.055955419
59DTB19-AM - 27.d	3.903283854	2.410472353	2.031855613	1.311597216	0.781287527	0.052448079	0.84226157	0.027716173	0.122227409
59DTB19-AM - 28.d	0.131286612	0.086395366	0.380625364	0.298682672	0.489951563	0.044494522	0.834389486	0.045139994	-0.053743422
59DTB19-AM - 29.d	4.196779027	0.931006125	1.482025228	0.403879699	0.948003064	0.044999791	0.818602528	0.027394478	0.385556599
59DTB19-AM - 30.d	0.25325408	0.298770623	1.447516222	2.439894533	0.425886064	0.035772299	0.802432189	0.038149568	0.311476695
59DTB19-AM - 31.d	3.220871208	0.436069104	0.42730885	0.193284591	1.228116646	0.062958494	0.844664426	0.038329103	0.683763642
59DTB19-AM - 32.0 59DTB19-AM - 33.d	58.91848568	0.980175184	9.420387672	1.88/58/9/4	12.1015058	0.560267077	0.750255768	0.032507869	0.477637411
59DTB19-AM - 34 d	0.137691971	0.095418681	0.336704008	0 1532724	0.475312623	0.040284676	0.827518569	0.043025197	0.069807996
59DTB19-AM - 35.d	0.146840053	0.097319341	0.376516113	0.207934338	0.482505705	0.0411005	0.860406536	0.04312096	0.088647212
59DTB19-AM - 36.d	4.24884379	0.897597861	0.300188462	0.156315654	1.235481119	0.05471758	0.847876471	0.030670716	0.476571727
59DTB19-AM - 37.d	12.68450787	3.595076342	2.669431605	0.866623493	3.164958866	0.157495997	0.811776436	0.029643987	0.292118023
59DTB19-AM - 38.d	0.180650755	0.124741281	0.272753959	0.203617272	0.985013968	0.17181587	0.830495729	0.048737807	0.133128098
59DTB19-AM - 39.d	13.28471129	13.64304071	2.129151559	3.002554293	3.462674263	0.399427293	0.825232171	0.029478126	-0.041045393
59DTB19-AM - 40.0 59DTB19-AM - 41 d	0.912220246	0.427250448	0.404320211	0.203466841	0.637893117	0.041937195	0.800111987	0.027506891	0.330419458
59DTB19-AM - 42.d	4.443705769	0.984843463	0.308603998	0.155502246	1.224172726	0.054959129	0.836579325	0.029520175	0.461686424
59DTB19-AM - 43.d	4.187447275	0.839757386	0.48005942	0.196109731	1.143278958	0.052232417	0.843791996	0.032175071	0.713764257
59DTB19-AM - 44.d	16.70765496	3.04767196	4.780379364	1.067062015	3.320918868	0.149182921	0.761976026	0.025179348	0.267852293
59DTB19-AM - 45.d	8.346940927	6.246589192	1.587926892	2.543656841	2.223735084	0.172908645	0.829767447	0.028122685	-0.028486738
59DTB19-AM - 46.d	3.40679711	1.870485595	0.664693028	0.93837602	0.828351697	0.055126988	0.837461763	0.029006884	0.073918256
59D1819-AM - 47.0 59D1819-AM - 48 d	42.86155954	22.1/585//3	7.9644111/7	4.429/1649/	10.04689499	0.713572496	0.778986717	0.027364663	-0.116631294
59DTB19-AM - 49 d	1 824342521	0.687271157	13 77197937	7 47092854	0.333785088	0.016606679	0.749885544	0.025799964	0.151806811
59DTB19-AM - 54.d	16.02916805	1.857272506	2.109981097	0.429272258	3.83702986	0.173087067	0.825514581	0.031987656	0.597227244
59DTB19-AM - 55.d	4.152565259	0.823835252	0.70761448	0.369796444	1.100003443	0.048073681	0.837252807	0.029806763	0.456663359
59DTB19-AM - 59.d	9.441586807	2.788138642	1.086815875	0.71010919	2.639250886	0.153223972	0.813825368	0.029644948	0.075487651
59DTB19-AM - 60.d	9.031587385	1.063698181	3.730986639	3.078036028	2.397326039	0.111538626	0.815859523	0.030381305	0.450063581
59DTB19-AM - 61.d	0.180122057	0.178747804	0.875109757	0.93564961	0.473729912	0.038029883	0.856614913	0.042359269	0.207910285
59DTB19-AM - 63 d	3 132496615	1 001669717	1 083413207	0.454104891	0.961694909	0.047723435	0.804291002	0.030613505	0.458086856
59DTB19-AM - 64.d	7.250240959	0.985259747	2.058456985	0.573862866	2.226032242	0.142741155	0.835883441	0.052183323	0.625261069
59DTB19-AM - 65.d	13.42213805	6.742080065	7.820794347	1.707079138	3.393130008	0.19540635	0.802778309	0.027023535	0.246808798
59DTB19-AM - 68.d	1.530799876	0.711948921	0.709147829	0.347083513	0.633211985	0.034737188	0.836247647	0.032091257	0.289906286
59DTB19-AM - 69.d	0.129353205	0.0731417	0.347305765	0.225203359	0.336720426	0.027655718	0.836316963	0.037248555	0.261286855
59DTB19-AM - 71.d	7.05764891	0.777176617	1.136987155	0.520161119	1.854814708	0.085942852	0.839645363	0.03116491	0.498295312
59DTB19-AM - 72.d	21.00667211	2.822012704	7.141012825	2.333753474	5.288156731	0.244434767	0.789301415	0.028710603	0.63923005
59DTB19-AM - 73.d	8.262478658	0.921417478	3.40385676	1.558953322	1.800278381	0.084128119	0.836752956	0.029637819	0.377866681
59DTB19-AM - 74.d	4.567096499	1.171361742	0.692787161	0.820825015	1.304007109	0.059286533	0.832726134	0.030947373	0.559769343
59DTB19-AM - 75.d 59DTB19-AM - 77.d	3.766132115	0.507597853	1.600273859	0.550885634	0.733018977	0.035700471	0.829443194	0.033827167	0.534867446
59DTB19-AM - 78.d	0.15551436	0.098079999	1.461715474	0.543331732	0.083551379	0.00656122	0.826393652	0.025460355	0.183551709
59DTB19-AM - 79.d	4.342184283	0.848626988	0.296737319	0.140226597	1.22579776	0.055184194	0.843192739	0.032283529	0.621324337
59DTB19-AM - 81.d	35.82400608	23.25131137	7.26168649	5.712474063	8.0182694	0.620216046	0.765277993	0.02661592	-0.290235701
59DTB19-AM - 83.d	3.684772445	1.250184684	1.311966332	1.162156724	1.170203312	0.053507378	0.82345435	0.033448424	0.591449037
59DTB19-AM - 85 d	19 29268404	6 477102169	4 358867761	2 007442257	4 909754659	0.037449948	0.811952043	0.046706797	0.354765224
59DTB19-AM - 86.d	12.7308871	3.632438153	1.935936469	1.023260184	3.253705384	0.163589478	0.819201717	0.033814491	0.327196928
59DTB19-AM - 87.d	2.841353388	1.310787551	1.025455281	1.095038305	0.936493173	0.045651831	0.808053279	0.033082185	0.474274373
59DTB19-AM - 88.d	14.51052175	2.413174415	4.238683997	1.085192145	3.480396615	0.155614684	0.800257445	0.027702583	0.489158839
59DTB19-AM - 90.d	0.12784369	0.156698516	0.427215271	0.467265514	0.097061165	0.009540303	0.839957096	0.028657413	0.09099413
59DTB19-AM - 94.d	5.110033181 4.43985575	0.954633/21	5.161104217 0 340918299	1.030315339	1 21546895	0.052550155	0.82008/264	0.028030281	0.40580/281
59DTB19-AM - 95.d	4.139260931	3.836975546	1.664372717	1.057826455	0.685256227	0.063517996	0.827135763	0.026333446	0.117455341
59DTB19-AM - 96.d	6.257231498	2.801581496	2.072982595	1.001806992	1.786250855	0.093878383	0.81523289	0.030958473	0.19672831
59DTB19-AM - 97.d	4.260430562	0.938270579	0.520444578	0.206287391	1.185726811	0.055448906	0.831078985	0.031737381	0.517221983
59DTB19-AM - 98.d	3.917890009	0.701868019	0.922389804	0.358481359	0.898743437	0.040681543	0.827525529	0.028205579	0.444790839
59DTB19-AM - 100.d	0.137960878	0.087887974	0.900952951	1.993791352	0.34871453	0.02485488	0.794626773	0.037306931	0.350965525

# Appendix D4.7: Apatite U/Pb Standards

6	238U conc.	-2-87	232Th conc.	-2-197			LA-ICP-MS Isotopic Ratios				
sporto	ppm	220 IN I	pom	220101	238U/206Pb	±20 PROP(2%)	2079b/2069b	±20 PROP(2%)	rho		
A_MAD - Primary Standard											
mad - 1.d	22.19194504	3.300208787	798.6316479	121.4714414	13.25124456	0.634467819	0.0571961	0.00114392	0.060950228		maan - 472.80 ± 2.55 ( 5.00 Ma (p-18/18)
mad - 2.d	22.2247748	3.41850828	799.8940407	138.3263063	13.13638824	0.613191313	0.0571961	0.00114392	-0.010117696	8	MSHD = 0.998, p(g') = 1.00
mad - 3.d	22.1629605	3.68275844	794.0417453	145.5407047	13.13507547	0.611170935	0.0571961	0.00114392	0.02281685		
mad - 4.d	22.25225884	3.34/2/4131	801.2371312	138.0209554	13.19399521	0.631346508	0.0571961	0.00114392	0.05/05/35/		
mad - 5.0	22.14058509	3.85450030	200 6075709	122 6022206	13.20034303	0.622776513	0.0571961	0.00114392	0.034300338	4	
mad - 0.0 mad - 7 d	22.23958998	3.529806283	293 5505745	149 3480518	13 17909901	0.641482198	0.0571961	0.00114392	0.05547993		
mad - 8.d	22.22606432	3.225848452	796.4664249	137.9933459	13.15415974	0.623253233	0.0571961	0.00114392	-0.013557697	8	
mad - 9.d	22.14382667	3.302072822	801.2086254	134.9880041	13.1011295	0.622711697	0.0571961	0.00114392	-0.01799102		
mad - 10.d	22.32525677	4.158773631	802.8012868	155.3704129	13.08696766	0.620433947	0.0571961	0.00114392	0.027170444		
mad - 11.d	22.13243755	3.829742527	795.5431653	153.4909703	13.18343031	0.653054003	0.0571961	0.00114392	0.039634266	4	
mad - 12.d	22.22066759	4.062598965	792.1238543	159.9584331	13.09971908	0.620742212	0.0571961	0.00114392	0.046271264		
mad - 14.d	22.19768723	3.360742921	797.4712336	142.9162994	13.26694991	0.629526419	0.0571961	0.00114392	2 0.014598319	ŝ	
mad - 15.0	22.20507379	3.403013036	202.0502024	143.3/33380	13.03082552	0.6121/19/8	0.0571961	0.00114392	0.0193050078		
mad - 17 d	22 17821758	3 653091279	794 4508213	188 555	13.05698558	0.60930642	0.0571961	0.00114392	0.0327634	2	
mad - 18.d	22.23753478	3.656656065	804.2115283	142.6435058	13.22808379	0.616542344	0.0571961	0.00114392	0.037118298		
mad - 19.d	22.17981889	3.587689378	794.3157041	142.2539654	12.98306448	0.615116828	0.0571961	0.00114392	0.041542782		1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
											N
A_MMC											agg = 522 76 ± 0.65   16.95 Ma (%19)
mmc - 1.d	15.86252134	2.132295456	55.92123559	7.735292905	10.44029568	0.483520706	0.176749879	0.01130529	0.367980901		(***Pb)***0.876 z 0.857 ( 0.113 MOWD + 0.92, p(g*) + 0.55
mmc - 2.d	12.54691565	2.240722085	57.66612081	10.77288455	9.349098731	0.426272686	0.228263535	0.01367554	0.411942208	17	
mmc-s.d	12.45078039	1.085726125	49.07403164	0.029889908	9.973249004	0.461842866	0.236028493	0.01473695	0.4128/7209		
mmc - 4.0	10.68087378	1.821465105	33 72325445	5 267499467	9 731285723	0.45900297	0.213810491	0.00936114	0 408547091	2	.000
mmc - 6.d	12.87155064	0.855142133	48,70721612	2.778937112	9.863815806	0.452719679	0.213312358	0.01292766	0.482870201		
mmc - 7.d	15.27503811	1.682356271	55,96818461	6.816366713	10.25408776	0.464423211	0.178236808	0.01129149	0.486508887	5	
mmc - 8.d	31.97149062	5.626542736	126.1041592	22.16616001	11.01743335	0.48529827	0.118650318	0.00652053	0.257409195	2	3000
mmc - 9.d	18.76155584	2.656672255	77.1396034	8.845073582	10.13714756	0.46517429	0.151273977	0.00893753	0.40591861	5.8	
mmc - 10.d	9.480452401	1.958560373	40.44370624	8.95945517	8.776325969	0.408014375	0.247913362	0.01544235	0.491565586	£ *	
mmc - 11.d	13.399272	2.44830086	74.15288507	10.5841035	8.935220231	0.416645385	0.242400728	0.01361518	0.442519175	1	. 1500
mmc - 12.d	16.848/2619	6.214095455	72.33171998	25.0435049	9.902017437	0.456089648	0.193418464	0.01315415	0.084800551	9	
mmc - 13.0	13.0000002	1.270173014	50.54/99211	6.298243449	9.048580493	0.420341347	0.23949094	0.01224639	0.4/458/128	2	· · · · · · · · · · · · · · · · · · ·
mmc - 15 d	17.69380848	3 428135339	183 3670701	53 99/54919	8 030373565	0.956091306	0 330247104	0.01420742	0.33895746	6	1907.0
mmc - 16.d	14.12692902	2.392668229	66.08297137	10.67945114	9.140967319	0.425210546	0.231665164	0.01340157	0.351317961	11	
mmc - 17.d	11.30695924	1.686794227	44.46761436	7.889541122	9.741614665	0.457257992	0.194113277	0.013360	0.350314856	6	2 4 6 4 10 1
mmc - 18.d	14.26977511	1.767796092	61.01150557	9.251472687	8.49279578	0.396989857	0.280651665	0.01704613	0.548654447		20132090
mmc - 19.d	15.42743353	2.300834034	71.51070962	10.736103	9.926339735	0.460897372	0.175643776	0.01118853	0.421825253		
A PC	r 03/000073	0.000304545	20 07022400	2 (777220030		0.007740744	0.000704074	0.01741427			epr = 1096.9 ± 17.1   33.4 Ma (n=19)
fc1 - 2 d	6 454415956	0.98478724	24 45923208	2 208840404	3.001167228	0.138082175	0.450585279	0.02021494	0.515198761		(""Pb/"P0),= 0.352 10.035   0.069 MSWD = 0.39, p0(") = 0.99
fc1 - 3.d	4.467696284	0.544899469	15.35404313	1.386493898	3.665106424	0.193474887	0.364496338	0.02268769	0.538244239		
fc1 - 4.d	5.077020482	0.783429799	15.91436854	2.250540405	2.581140639	0.118995035	0.534950345	0.02346553	5 0.477131705		
fc1 - 5.d	4.718805914	0.972346451	16.0145826	2.69828954	3.838586675	0.183742156	0.331004223	0.01857623	0.446430338	5	
fc1 - 6.d	5.065093018	0.793492481	16.50046447	2.612367349	4.33986582	0.210163232	0.267042589	0.01615625	5 0.489091962		
fc1 - 7.d	2.108689173	0.452144209	6.763939362	1.19254217	3.095412384	0.177159154	0.445569375	0.02987215	0.522828392	-	4000 %
fc1 - 8.d	5.027987124	1.286099091	22.54962493	5.607585409	4.392133687	0.213488395	0.236377041	0.01405286	0.403748033		
1c1 - 9.d	2.778572546	0.506107449	8.527869147	1.169010241	3.717933188	0.196331907	0.34318/391	0.02022079	0.316961209	E	
fc1 - 10.0	2 52694520	0.509720079	10.01411016	1 613961355	2 601301366	0.100600400	0.355350704	0.02001905	0.457796560	10	2000
fc1 - 12.d	5.373870286	0.950277158	17.08471625	2.581820308	4.335493296	0.211335485	0.268965855	0.01610164	0.491633517		
fc1 - 13.d	7.833323253	1.32428718	30.32473335	4.644880512	4.534002951	0.211797904	0.212680539	0.01184122	0.39259671		2000
fc1 - 14.d	5.598757015	1.161528709	21.4301717	4.17243638	4.089781839	0.19032162	0.27555278	0.01574236	0.303324824	02	
fc1 - 15.d	5.693623763	0.739129971	22.53223108	3.072480682	4.359812672	0.214874005	0.229780384	0.01337166	0.347159658		come and
fc1 - 16.d	6.718547939	0.877183137	26.0622378	2.518003987	4.295006935	0.201995542	0.273699841	0.01438507	8 0.424002937	2	1000
fc1 - 17.d	7.433982935	1.449799397	30.79623511	6.037685669	4.161527089	0.187551151	0.25452063	0.01322271	0.344970522		L,
1c1 - 18.d	5.811491747	1.03485646	19.03485391	2.934664406	4.159014917	0.194393421	0.264223956	0.01518536	0.464394443		1 2 3 4
101 - 19.0	6.815614616	0.964342659	22.89/8/482	3.482588556	4.149218585	0.19428/968	0.264467243	0.01402790	0.493168094		209U32069D

### Appendix D5.1: Sample Locations

#### TABLE S1. LOCATIONS AND DESIGNATIONS FOR SAMPLES ANALYZED IN THIS PAPER

Sample	Geologic Unit	Loc	ation	Elevation (m	Analysis	Location Description
number	Geologic Onic	Latitude (°N)	Longitude (°W)	asl)	Alidiysis	
BH1	Buffalo Hump	48.1952	117.91376	1335	LA-SS-ICPMS	Ridge E/SE. of Klein Meadows. Upper Ybq
03DTB18	Buffalo Hump	48.18471	117.93345	1323	LA-SS-ICPMS	Lower Ybq near Double eagle Quarry
04DTB18	Buffalo Hump	48.18413	117.93176	1320	LA-SS-ICPMS	Along road cut N of Double eagle Quarry. Mid-lower Ybq
05DTB18	Buffalo Hump	48.20175	117.9069	1070	LA-SS-ICPMS	Duplication of Ross 1992 locality
	Buffalo Hump conglomerate individual	40 40400	117 00775	4205		
34D1B19	copple sampled	48.13122	117.99775	1295	LA-SS-ICPIVIS	Congiomerate bed at 55.5-57m on measured section 1

Note: Locations are based on datum WGS84.

# Appendix D5.2: U/Pb Results

Sample ID	Ansheir data-tima	Spot ID <sup>1</sup>	238U conc.		232Th conc.			ŀ	sotopic Ratios	-		Appare	nt Ages - Calculate	ed in Isoplot R (Ma)		Discord	Perferred age	1500
Jampie ID	Analysis date-time	sporto	ppm	±2σ INT	ppm	±20 INT Analyses in b	238U/206Pb slue font are from	±2σ PROP retargeted grai	207Pb/206Pb ins after rapid ana	±2σ PROP lysis identificatio	rho	238U/206Pb	±2σ PROP 2	207Pb/206Pb ±	2a PROP	(7/6-6/8)/7/6 *100	Ma	20
8H1 8H1	2020-07-30 16:07:02.000 2020-07-30 16:08:48.000	IBH1-154b - 1.d IBH1-154c - 1.d	306 334	7	340 377	7	8.022557 8.012350	0.237716 0.233059	0.063809 0.064696	0.004110 0.004132	0.118118 0.223823	757 758	21 21	734 764	136 135	-3.11 0.70	757 758	21 21
BH1 BH1	2020-07-30 16:10:32.000 2020-07-30 16:12:11.000	IBH1-154d - 1.d IBH1q - 709 - 1.d	321 246	9 4	364 5787	10 137	7.976002 7.921050	0.240792 0.243288	0.064390 0.064355	0.004122 0.004151	0.017591 0.145446	761 766	22 22	754 752	135 136	-1.05 -1.86	761 766	22 22
8H1 8H1	2020-07-30 16:13:52.000 2020-07-30 16:15:35.000	IBH1q - 709b - 1.d IBH1q - 709c - 1.d	257 219	4	2685 2400	55 55	7.781355 7.959874	0.234054 0.257660	0.063674 0.066166	0.004211 0.004508	0.146663 0.234983	779 763	22 23	730 811	140 143	-6.78 5.90	779 763	22 23
8H1 8H1	2020-07-30 16:17:15.000 2020-07-30 16:18:56.000	IBH1q - 692 - 1.d IBH1q - 692b - 1.d	130	4	111 66	1	7.971016 7.916348	0.270111 0.255869	0.065862	0.004767	0.303211 0.160344	762	24	801 811	152	4.88	762	24
BH1 RH1	2020-07-30 16:20:40.000 2020-07-30 16:29:24.000 2020-07-30 16:31:13.000	IBH1q - 648b - 1.d IBH1q - 648b - 1.d	47 56 145	1	54	1	8.175774	0.318409	0.067506	0.006216	0.107191	762 744 732	27	853 805	191	3.04 12.74 8.98	744	27
BH1 BH1	2020-07-30 16:32:51.000 2020-07-30 17:00:21.000	IBH1q - 423 - 1.d IBH1q - 384 - 1.d	199 48	5	165 27	5	8.260927 7.514458	0.251205 0.384357	0.064184 0.071371	0.004347	0.297804 0.212671	737	21 39	747	143 202	1.36	737	21 39
8H1 8H1	2020-07-30 17:02:10.000 2020-07-30 17:03:48.000	IBH1q - 763 - 1.d IBH1q - 747 - 1.d	573 42	7	359 24	9 1	6.351496 4.775377	0.270383 0.181246	0.147526	0.016785	-0.828930 0.160520	943 1226	37 42	2317 1279	195 160	59.31 4.14	943 1226	37 42
8H1 8H1	2020-07-30 17:05:30.000 2020-07-30 17:14:15.000	IBH1q - 655 - 1.d IBH1q - 643 - 1.d	1372 402	40 17	498 226	13 14	6.739803 5.804436	0.227222 0.194641	0.081847 0.075485	0.004697	-0.001692 0.251428	892 1025	28 32	1241 1081	112 123	28.14 5.17	892 1025	28 32
8H1 8H1	2020-07-30 17:16:02.000 2020-07-30 17:17:46.000	IBH1q - 60 - 1.d IBH1q - 505 - 1.d	25 129	1	20 45	1	5.393805 4.669583	0.220218 0.151220	0.074082 0.087531	0.007499 0.005718	0.228531 0.072875	1096 1251	41 37	1043 1371	204 126	-5.14 8.78	1096 1251	41 37
8H1 8H1	2020-07-30 17:19:25.000 2020-07-30 17:21:07.000	IBH1q - 446 - 1.d IBH1q - 192 - 1.d	974 49	24 3	2144 37	69 2	7.577399 8.432193	0.216055 0.393522	0.081040 0.063251	0.004749 0.006104	0.391341 0.206552	799 722	21 32	1222 716	115 205	34.58 -0.94	799 722	21 32
8H1 8H1	2020-07-30 17:22:51.000 2020-07-30 17:24:29.000	IBH1q - 178 - 1.d IBH1q - 172 - 1.d	791 255	10 4	45 118	1 2	5.429986 2.942177	0.154281 0.090668	0.075815 0.128214	0.004409 0.007470	0.250696 0.259664	1090 1886	29 50	1089 2073	117 103	-0.03 9.01	1090 2073	29 103
8H1 8H1	2020-07-30 17:26:12.000 2020-07-30 17:27:55.000	IBH1q - 160 - 1.d IBH1q - 152 - 1.d	496	4	233	37	5.377492 8.125236	0.361377 0.283560	0.085000	0.005056	0.224969	1100	68 25	1315 809	115	16.37 7.45	1100	68 25
8H1 8H1	03/12/2018 (2) 13:50:02.00 03/12/2018 (2) 13:50:02.00	BH1-1	120	6	90	5	4.523342	0.173960	0.089302	0.005455	0.276460	1262	40	1410	117	0.03	1262	45
8H1 8H1	03/12/2018 (2) 13:52:08:00 03/12/2018 (2) 13:54:09:00 02/12/2018 (2) 13:56:14:00	BH1 - 3	426	10	335	44	4.403280 5.434783 4.150724	0.197306	0.101400	0.009628	0.420240	1089	35	1649	167	-9.81 33.97 5.17	1089	35
BH1 BH1	03/12/2018 (2) 13:58:15.00 03/12/2018 (2) 14:00:19.00	BH1-5 BH1-6	198	11	83 230	5	3.289474 4.833253	0.107990	0.104800	0.005396	0.194190	1711 1212	48	1710	93 99	0.06	1710	93 35
8H1 8H1	03/12/2018 (2) 14:02:20.00 03/12/2018 (2) 14:04:25.00	BH1 - 7 BH1 - 8	76 267	2 17	34 123	1 7	5.515720 3.932363	0.244176 0.128130	0.101400 0.090500	0.009028	0.256290	1074 1461	42 41	1649 1435	157 117	34.86 -1.77	1074 1461	42 41
8H1 8H1	03/12/2018 (2) 14:06:26:00 03/12/2018 (2) 14:08:31:00	BH1 - 9 BH1 - 10	122 217	5 8	12 76	1 3	5.455537 5.633803	0.219233 0.182503	0.074900 0.076100	0.007198 0.004922	0.330940 0.171300	1085 1053	39 31	1055 1097	183 125	-1.88 3.97	1085 1053	39 31
8H1 8H1	03/12/2018 (2) 14:10:31.00 03/12/2018 (2) 14:12:36.00	BH1 - 11 BH1 - 12	106 92	4	66 71	2	5.521811 5.032713	0.229349 0.204500	0.076600 0.077200	0.006132 0.007344	0.256360 0.147400	1073 1168	40 42	1110 1125	153 180	3.33 -3.85	1073 1168	40 42
8H1 8H1	03/12/2018 (2) 14:14:36.00 03/12/2018 (2) 14:16:48.00	BH1 - 13 BH1 - 14	68 255	4	31 91	4	4.302926 3.395586	0.193447 0.158999	0.085100	0.008302	0.261400	1347	53	1317	179 95	-2.29 3.38	1347	53 95
8H1 8H1	03/12/2018 (2) 14:18:50.00 03/12/2018 (2) 14:20:54.00 02/12/2018 (2) 14:20:54.00	BH1 - 15 BH1 - 16	212	6	139	3	4.290004	0.139172	0.074900	0.003098	0.153800	1057	29 38	1065	82 99	2.39	1057	38
8H1 8H1	03/12/2018 (2) 14:22:54.00 03/12/2018 (2) 14:24:59.00 03/12/2018 (2) 14:24:59.00	BH1 - 17 BH1 - 18	221	9	114	4	5.464481	0.195885	0.075300	0.005226	0.135610	1083	35	1070	161	1.71	1083	35
8H1 8H1	03/12/2018 (2) 14:29:06:00 03/12/2018 (2) 14:29:06:00 03/12/2018 (2) 14:31:07:00	BH1 - 20 BH1 - 21	220	10	121	5	4.955401	0.175232	0.078300	0.004966	0.287050	1185	37	1154	122	-2.72	1185	37
BH1 BH1	03/12/2018 (2) 14:43:41.00 03/12/2018 (2) 14:45:46.99	BH1 - 22 BH1 - 23	155 84	7	71	3	4.191115	0.141788	0.086500	0.005630	0.040185	1379 850	41	1349 1319	122	-2.29 35.53	1379 850	41 81
8H1 8H1	03/12/2018 (2) 14:47:52.00 03/12/2018 (2) 14:49:57.00	BH1 - 24 BH1 - 25	182 189	7 18	93 83	4 10	5.577245 4.073320	0.214194 0.139538	0.071400 0.088400	0.005128	0.192100	1063 1415	36 42	968 1390	141 111	-9.82 -1.79	1063 1415	36 42
8H1 8H1	03/12/2018 (2) 14:51:58.00 03/12/2018 (2) 14:54:05.00	BH1 - 26 BH1 - 27	564 350	5 7	215 97	4	4.574565 4.321521	0.137530 0.138722	0.084600 0.087500	0.003892 0.004850	0.025697	1275 1342	34 38	1306 1371	88 104	2.37 2.11	1275 1342	34 38
8H1 8H1	03/12/2018 (2) 14:56:06.00 03/12/2018 (2) 14:58:09.00	BH1 - 28 BH1 - 29	353 113	15 7	69 69	5	3.667033 6.293266	0.135197 0.288247	0.095400 0.074000	0.004228	0.101850 0.105980	1555 951	49 39	1555 1041	81 178	0.01 8.67	1555 951	81 39
8H1 8H1	03/12/2018 (2) 15:00:11:00 03/12/2018 (2) 15:02:16:00	BH1 - 30 BH1 - 31	257 120	17	169 117	32 5	3.628447 5.678592	0.131814 0.236108	0.101300 0.080600	0.005326	0.121600 0.168780	1569 1046	49 39	1647 1211	95 161	4.74 13.66	1647 1046	95 39
8H1 8H1	03/12/2018 (2) 15:04:17:00 03/12/2018 (2) 15:06:22:00	BH1 - 32 BH1 - 33	77	4 14	57 79	3 7	5.202914 5.602241	0.236703 0.218754	0.080800 0.075200	0.008316 0.005104	0.186560	1133 1059	45 37	1216 1073	191 132	6.80 1.31	1133 1059	45 37
8H1 8H1	03/12/2018 (2) 15:08:23.00 03/12/2018 (2) 15:10:27.00	BH1 - 34 BH1 - 35	208	12	112 325	11	4.543389 5.205622	0.146602 0.196247	0.081600	0.005232	0.358780	1282	36	1235	122	-3.83 5.10	1282	36
5H1 8H1	03/12/2018 (2) 15:12:28:00 03/12/2018 (2) 15:14:33:00 02/12/2018 (2) 15:37:14:00	BH1 - 35 BH1 - 37 BH1 - 39	43 64 247	2	46 58	1	5.515720 5.194805	0.255018	0.074500	0.001990	-0.019879	1074 1135 1277	49	1094 1054 1772	203	-7.68	10/4 1135 1277	49
8H1 8H1	03/12/2018 (2) 15:29:19:00 03/12/2018 (2) 15:29:19:00 03/12/2018 (2) 15:31:24:00	BH1 - 39 BH1 - 40	397	13	140	5	5.333333	0.183467	0.077500	0.004050	-0.017650	1108	34	1133	102	2.24	1108	34
BH1 BH1	03/12/2018 (2) 15:33:25.00 03/12/2018 (2) 15:35:30.00	BH1 - 41 BH1 - 42	143	8	73 101	5	4.486317	0.172247	0.082600	0.006052	0.196630	1297 828	44	1259	138 156	-3.03 34.88	1297 828	44
8H1 8H1	03/12/2018 (2) 15:48:08.00 03/12/2018 (2) 15:50:16.00	BH1 - 43 BH1 - 44	84 414	3 20	60 251	2 15	5.652911 5.643341	0.330355	0.084000	0.007180	0.159820 0.215990	1050 1052	54 38	1292 1181	158 95	18.73 10.96	1050 1052	54 38
8H1 8H1	03/12/2018 (2) 15:52:22.00 03/12/2018 (2) 15:54:22.00	BH1 - 45 BH1 - 46	413 117	11 2	142 137	3 4	4.793864 3.297066	0.144138 0.130078	0.081500 0.107000	0.003930 0.006340	-0.173430 0.060263	1221 1708	33 57	1233 1748	93 106	0.91 2.31	1221 1748	33 106
8H1 8H1	03/12/2018 (2) 15:56:27.00 03/12/2018 (2) 15:58:29.00	BH1 - 47 BH1 - 48	81 103	3 6	80 41	3 3	3.071253 5.157298	0.131226 0.222836	0.113700 0.077100	0.008274 0.006642	0.206620	1817 1143	65 44	1859 1123	127 164	2.24	1859 1143	127 44
8H1 8H1	03/12/2018 (2) 16:00:33.00 03/12/2018 (2) 16:02:35.00	BH1 - 49 BH1 - 50	1233 517	55 44	638 45	30 6	7.288630 5.330490	0.246708 0.163438	0.095900 0.074700	0.006118 0.003494	-0.415790 -0.046744	829 1108	26 30	1545 1050	116 92	46.36 -4.62	829 1108	26 30
8H1 8H1	03/12/2018 (2) 16:04:40.00 03/12/2018 (2) 16:06:40.00	BH1 - 51 BH1 - 52	156 231	5 8	71 163	2	2.223705 4.861449	0.082550 0.156313	0.155400 0.077200	0.007108 0.004844	0.246560 0.279470	2394 1206	72 34	2405 1126	77 121	0.48 -7.14	2405 1206	77 34
8H1 8H1	03/12/2018 (2) 16:08:45.00 03/12/2018 (2) 16:10:46.00	BH1 - 53 BH1 - 54	158 74	12 4	118 45	10 3	3.514938 3.527337	0.124660 0.147688	0.097800 0.103000	0.004956 0.008460	0.035174 0.267550	1614 1609	49 58	1582 1678	93 145	-2.04 4.11	1582 1678	93 145
8H1 8H1	03/12/2018 (2) 16:12:51.00 03/12/2018 (2) 16:14:51.00 03/12/2018 (2) 16:14:51.00	BH1-55 BH1-56	231 249	14	151	7	3.717472	0.114343	0.099300	0.005786	0.037848	1536	47	1656	106	4.63	1656	106
8H1 8H1	03/12/2018 (2) 16:16:57.00 03/12/2018 (2) 16:18:58.00 02/12/2018 (2) 16:18:58.00	BH1-57 BH1-58	144	4	100	8	5.339028	0.198141 0.183745	0.077500	0.005350	0.220400	1145	39 34	1065	144	-7.53 2.34	1145	39
8H1 8H1	03/12/2018 (2) 16:23:09:00 03/12/2018 (2) 16:23:09:00 03/12/2018 (2) 16:25:15:00	BH1 - 60 BH1 - 61	161	7	85	4	3.921569	0.139946	0.088300	0.005466	0.195900	1464	45	1388	115	-5.47	1464	45
BH1 BH1	03/12/2018 (2) 16:27:18:00 03/12/2018 (2) 16:27:18:00 03/12/2018 (2) 16:29:22:00	BH1 - 62 BH1 - 63	451 233	14	420 114	12 2	4.159734 5.614823	0.126453 0.184807	0.095500 0.074100	0.004610	0.170800	1389 1057	37	1537 1043	89 126	9.65	1389 1057	37
8H1 8H1	03/12/2018 (2) 16:41:58.00 03/12/2018 (2) 16:44:01.00	BH1 - 64 BH1 - 65	127 873	8 49	54 639	3 37	5.411255 5.882353	0.201926	0.071800 0.261000	0.005236	0.050968	1093 1012	36 74	979 3252	143 177	-11.65 68.88	1093 1012	36 74
8H1 8H1	03/12/2018 (2) 16:46:06.00 03/12/2018 (2) 16:48:06.00	BH1 - 66 BH1 - 67	227 75	15 5	76 70	6 7	4.357298 3.987241	0.151699 0.168774	0.084700 0.088000	0.005294 0.007460	0.236100 0.146830	1332 1443	41 53	1308 1382	118 155	-1.84 -4.38	1332 1443	41 53
8H1 8H1	03/12/2018 (2) 16:50:11.00 03/12/2018 (2) 16:52:18.00	BH1 - 68 BH1 - 69	34 78	2	33 66	2	1.757469 1.801153	0.084569 0.065220	0.204600 0.200500	0.010492 0.009710	0.406200 0.215450	2904 2847	108 81	2863 2830	82 78	-1.44 -0.61	2863 2830	82 78
8H1 8H1	03/12/2018 (2) 16:54:23.00 03/12/2018 (2) 16:56:23.00	BH1 - 70 BH1 - 71	93 672	5 24	64 371	4 14	3.174603 5.246590	0.517007 0.228802	0.209000 0.090200	0.054180 0.003604	-0.953280 0.078484	1765 1125	220 43	2897 1429	369 75	39.07 21.30	2897 1125	369 43
8H1 8H1	03/12/2018 (2) 16:58:28.00 03/12/2018 (2) 17:00:29.00	BH1 - 72 BH1 - 73	112	5	38 88	2 6	5.319149 3.473428	0.208239 0.135824	0.077000 0.101700	0.006740	0.155760 0.103100	1111 1631	39 54	1120 1655	167 117	0.85	1111 1655	39 117
BH1 BH1	03/12/2018 (2) 17:02:34.00 03/12/2018 (2) 17:04:35.00 02/12/2018 (2) 17:04:35.00	BH1 - 74 BH1 - 75	363 246	59	243	41 2	5.730659 3.254149	0.245975	0.077300 0.102800	0.004946	0.229670	1037	40 49	1128	123	8.08 -3.16	1037	40 87
8H1 8H1	03/12/2018 (2) 17:08:40:00 03/12/2018 (2) 17:08:40:00 02/12/2018 (2) 17:08:40:00	BH1 - 77 BH1 - 77	92	3	49	2	4.091653	0.185631	0.089900	0.006998	0.008848	1410	55	1423	149	0.95	1410	55
8H1 8H1	03/12/2018 (2) 17:12:46.00 03/12/2018 (2) 17:12:46.00 03/12/2018 (2) 17:25:29.00	BH1 - 79 BH1 - 80	190	9	207	11	4.844961	0.188446	0.080200	0.005504	0.282820	1210	41	1201	131	-0.72	1210	41
BH1 BH1	03/12/2018 (2) 17:27:38.00 03/12/2018 (2) 17:29:37.00	BH1 - 81 BH1 - 82	137	7 23	54 260	3	4.926108	0.193162	0.075500	0.005810	0.285760	1191 1081	41	1081	148 105	-10.21	1191 1081	41
BH1 BH1	03/12/2018 (2) 17:31:44.00 03/12/2018 (2) 17:33:45.00	BH1 - 83 BH1 - 84	96 151	6	50 108	1	1.501502	0.052575	0.267300	0.009946	0.251970	3290 1448	88	3290 1471	58	-0.03	3290 1448	58 45
8H1 8H1	03/12/2018 (2) 17:46:22.00 03/12/2018 (2) 17:48:29.00	BH1 - 85 BH1 - 86	147 493	15 31	55 191	6 12	5.030181 4.514673	0.199284 0.188128	0.078900	0.006278	0.031098 0.319970	1169 1290	41 47	1169 1319	151 94	0.01 2.23	1169 1290	41 47
8H1 8H1	03/12/2018 (2) 17:50:30.00 03/12/2018 (2) 17:52:34.00	BH1 - 87 BH1 - 88	194 91	6 4	138 90	5 4	4.901961 3.264773	0.179739 0.135643	0.080000 0.116100	0.005400 0.007422	0.001498 0.023686	1197 1723	39 61	1196 1896	129 112	-0.06 9.16	1197 1895	39 112
8H1 8H1	03/12/2018 (2) 17:54:41.00 03/12/2018 (2) 17:56:47.00	BH1 - 89 BH1 - 90	225 350	11 16	157 181	9 20	3.188776 5.643341	0.107499 0.310320	0.109800 0.074600	0.005396 0.004092	0.289140 0.519760	1758 1052	50 51	1795 1057	88 108	2.06 0.48	1795 1052	88 51
8H1 8H1	03/12/2018 (2) 17:58:48.00 03/12/2018 (2) 18:00:53.00	BH1 - 91 BH1 - 92	65 448	2 8	47 121	2	5.437738 5.411255	0.280255 0.175573	0.075400 0.073800	0.009008	0.089283 0.150540	1088 1093	49 32	1078 1035	224 101	-0.95 -5.60	1088 1093	49 32
8H1 8H1	03/12/2018 (2) 18:02:53.00 03/12/2018 (2) 18:04:59.00	BH1 - 93 BH1 - 94	170	8	223 64	5	4.812320 5.224660	0.174985 0.194574	0.082000	0.006040	0.132940	1217	39 37	1245	138 157	2.24	1217 1129	39 37
8H1 8H1	03/12/2018 (2) 18:07:00:00 03/12/2018 (2) 18:09:05:00 02/12/2018 (2) 18:11:06:00	BH1 - 96 BH1 - 97	212	8	93 70	4	2.156567	0.069641	0.156000	0.006320	0.302780	2456	59 64	2412	100 68 90	-1.82	2412	68
8H1 8H1	03/12/2018 (2) 18:11:00:00 03/12/2018 (2) 18:13:12:00 03/12/2018 (2) 18:15:12:00	BH1 - 98 BH1 - 99	176	7	115	4	5.875441	0.200359	0.073100	0.005562	0.225570	1013	31	1016	148	0.28	1013	31
8H1 8H1	03/12/2018 (2) 18:19:17:00 03/12/2018 (2) 18:19:17:00 03/12/2018 (2) 18:19:17:00	BH1 - 100 BH1 - 101	220	22	3	0	4.775549	0.154806	0.080500	0.004310	0.053783	1226	35	1208	103	-1.42	1226	35
BH1 BH1	03/12/2018 (2) 18:21:23.00 03/12/2018 (2) 18:23:24.00	BH1 - 102 BH1 - 103	67	4	43 84	2 5	5.081301 3.985652	0.186831 0.141666	0.078300	0.008466	0.128760	1158 1443	38 45	1154 1450	201 108	-1.47 -0.36 0.47	1158 1443	38 45
8H1 8H1	03/12/2018 (2) 18:25:35.00 03/12/2018 (2) 18:27:36.00	BH1 - 104 BH1 - 105	115 205	5 10	118 166	5 9	5.316321 4.796163	0.213727 0.167233	0.074500 0.077900	0.005590	0.208200	1111 1221	40 38	1054 1143	145 127	-5.42 -6.77	1111 1221	40 38
8H1 8H1	03/12/2018 (2) 18:40:13.00 03/12/2018 (2) 18:42:20.00	BH1 - 106 BH1 - 107	304 239	19 11	342 241	22 16	4.828585 5.175983	0.164186 0.183892	0.077100 0.074900	0.003842 0.004998	0.104150 0.252320	1213 1139	36 36	1123 1055	97 130	-8.05 -6.93	1213 1139	36 36
8H1 8H1	03/12/2018 (2) 18:44:21.00 03/12/2018 (2) 18:46:26.00	BH1 - 108 BH1 - 109	251 333	14 6	196 121	11 2	3.218539 5.417118	0.101663 0.196378	0.105800 0.077100	0.004916 0.004342	0.148950 0.403950	1744 1092	47 35	1727 1123	84 109	-0.97 2.74	1727 1092	84 35
8H1 8H1	03/12/2018 (2) 18:48:28.00 03/12/2018 (2) 18:50:33.00	BH1 - 110 BH1 - 111	199 128	5	129 78	2	5.810575 5.681818	0.207371 0.565599	0.076500 0.097400	0.005430 0.008448	0.189680 0.481710	1024 1045	33 88	1107 1574	137 155	7.52 33.60	1024 1045	33 88
8H1 8H1	03/12/2018 (2) 18:52:34.00 03/12/2018 (2) 18:54:41.00	BH1 - 112 BH1 - 113	190 156	4	89 75	3	5.249344 4.081633	0.204187 0.153269	0.078600 0.098900	0.005372 0.005578	0.428660 0.016688	1124 1413	39 46	1161 1603	131 103	3.19 11.86	1124 1413	39 46
BH1 BH1	03/12/2018 (2) 18:56:48.00 03/12/2018 (2) 18:58:53.00	BH1 - 114 BH1 - 115	458	22 9	193 146	3 10	4.024145 4.282655	0.120967 0.201202	0.090400 0.084100	0.003808	0.092846	1431 1353	38	1433 1294	79 129	0.17	1431 1353	38
BH1 BH1	03/12/2018 (2) 19:02:59:00 03/12/2018 (2) 19:02:59:00 03/12/2018 (2) 19:04:50:00	BH1 - 117 BH1 - 118	5/ 872 567	46 20	262 207	0 15 10	6.131208 4.657662	0.179012	0.074600	0.003392	0.154100	2618 974 1354	87 26 95	1057 1421	87 90 90	-0.53 7.84	974 1254	26
BH1 BH1	03/12/2018 (2) 19:07:04:00 03/12/2018 (2) 19:07:04:00 03/12/2018 (2) 19:07:04:00	BH1 - 119 BH1 - 120	225	20 7 17	207 87 199	3	5.387931	0.145/18 0.183236 0.205750	0.073200	0.004264	0.254050	1254 1098 012	35 33 27	1431 1019	89 115 100	-7.75	1254 1098 012	33 27
BH1 BH1	03/12/2018 (2) 19:11:11.00 03/12/2018 (2) 19:27:40.00	BH1 - 121 BH1 - 122	622 243	21 7	317	9	5.030181	0.171451 0.188591	0.080200	0.003304	0.135470	1169 1088	35 34	1201 1019	80 125	2.67	1169 1088	35 34
BH1 BH1	03/12/2018 (2) 19:29:44.00 03/12/2018 (2) 19:31:50.00	BH1 - 123 BH1 - 124	503 200	38 9	290 110	14 4	4.299226	0.171008	0.111200 0.083600	0.004624	0.013329 0.166510	1348 1338	47	1818 1282	74	25.86	1348 1338	47
BH1 BH1	03/12/2018 (2) 19:33:51.00 03/12/2018 (2) 19:35:57.00	BH1 - 125 BH1 - 126	276	16 7	266	14 7	4.444444 1.826150	0.286420	0.098400 0.193300	0.004768	0.051157	1308 2815	72	1593 2770	89 60	17.89	1308 2770	72 60
8H1 8H1	03/12/2018 (2) 19:48:31.00 03/12/2018 (2) 19:50:33.00	BH1 - 127 BH1 - 128	217 169	17 13	164 77	9 5	5.122951 4.990020	0.170595 0.184461	0.079500	0.005390	0.199620 0.274140	1150 1178	34 39	1184 1151	129 127	2.89	1150 1178	34 39
BH1 BH1	03/12/2018 (2) 19:52:39.00 03/12/2018 (2) 19:54:40.00	BH1 - 129 BH1 - 130	284 31	7 2	124 28	3 1	4.050223 5.564830	0.136779 0.328068	0.088400 0.069000	0.004168 0.012380	0.449520 0.339400	1423 1065	42 55	1390 898	89 333	-2.32 -18.63	1423 1065	42 55
8H1 8H1	03/12/2018 (2) 19:56:45.00 03/12/2018 (2) 19:58:51.00	BH1 - 131 BH1 - 132	299 186	21 12	113 267	7	3.920031 2.933412	0.126037	0.087300 0.114900	0.005046	0.053031 0.094041	1465 1891	41 55	1366 1878	108 92	-7.20 -0.72	1465 1878	41 92
8H1 8H1	U3/12/2018 (2) 20:00:56.00 03/12/2018 (2) 20:02:57.00	ыні - 133 ВН1 - 134	335 303	18	96 183	4	3.891051 5.202914	0.118700	0.089000	0.004680	0.296160	1475 1133	39 34	1403 1099	98 120	-5.07 -3.08	1475	39 34
5m1 8H1	03/12/2018 (2) 20:05:02:00 03/12/2018 (2) 20:07:03:00 02/12/2018 (2) 20:07:03:00	or(1 - 135 BH1 - 136 BH1 - 137	186	9	239 58	21	3.947888 5.213764	0.139742	0.075400	0.005808	0.134850	1456	45	1475	109 148	1.31 -4.93	1456	45 35
BH1	03/12/2018 (2) 20:09:08:00 03/12/2018 (2) 20:11:09:00	BH1 - 137 BH1 - 138	73 286	4	46 220	2 8	5.476451 5.382131	0.265485	0.072600	0.007252	0.465030	1081	46	1002	191 142	-7.90 38.93	1081 1099	46 47
8H1 8H1	03/12/2018 (2) 20:15:15:00 03/12/2018 (2) 20:15:15:00	BH1 - 140 BH1 - 141	007 147 105	3	97 47	3	7.122507 4.222972	0.558437	0.089900	0.007198	0.268080	716 847 1270	20 58	707 1423 1397	146 145	-1.25 40.48	847	58
8H1 8H1	03/12/2018 (2) 20:19:21:00 03/12/2018 (2) 20:19:21:00 03/12/2018 (2) 20:21:27:00	BH1 - 142 BH1 - 143	692 261	34 16	47 523 176	31 13	4.952947	0.148122 0.137430	0.075800	0.003216	0.030876	1370 1186 1694	40 32 59	1089	15/ 84 85	-0.45 -8.87 g.02	1186	32
BH1 BH1	03/12/2018 (2) 20:23:28.00 03/12/2018 (2) 20:25:34.00	BH1 - 144 BH1 - 145	227	11 7	70 40	4	3.206156 3.571429	0.105241	0.105400	0.005608	-0.046367	1750	49 326	1721	95 429	-1.71	1721	95 429
BH1 BH1	03/12/2018 (2) 20:27:34.00 03/12/2018 (2) 20:29:47 nn	BH1 - 146 BH1 - 147	127	6	77 120	4	5.184033	0.203115	0.076300	0.007126	0.198370	1137	39	1102	177	-3.19 0.01	1137	39 34
BH1	03/12/2018 (2) 20:42:23.00	BH1 - 148	82	2	66	ż	5.359057	0 236419	0.077000	0.007740	0 322300	1103	43	1120	190	1 53	1103	43

Sample ID	Analysis date-time	Spot ID <sup>1</sup>	238U conc. ppm	±2σ INT	232Th conc.	±2σ INT	238U/206Pb	±2σ PROP	207Pb/205Pb	±2σ PROP	rho	Appar 238U/206Pb	tent Ages - Calc ±2σ PROP	207Pb/206Pb	Ma) ±2σ PROP	Discord (7/6-6/8)/7/6 *100	Perferred age 1500 Ma cutoff Ma 2 o
BH1 BH1	03/12/2018 (2) 20:44:25.00 03/12/2018 (2) 20:46:30.00 02/12/2018 (2) 20:46:30.00	BH1 - 149 BH1 - 150	209 129	9	132 87	5	3.196931 5.515720	0.104820 0.256346	0.105600 0.079000	0.005812	0.309820	1755 1074	45	1724	99 142	-1.77 8.27	1724 99 1074 44
BH1 BH1 BH1	03/12/2018 (2) 20:48:32:00 03/12/2018 (2) 20:50:37:00 03/12/2018 (2) 20:52:38:00	BH1 - 151 BH1 - 152 BH1 - 153	39 618	1 17	29 438	1 7	4.933399 4.672897	0.273905 0.182985	0.085000 0.091000	0.011700 0.003720	0.340730 0.170270	1919 1190 1250	57	7 1315 3 1446	246 77	9.52	1190 57 1250 43
BH1 BH1	03/12/2018 (2) 20:54:44.00 03/12/2018 (2) 20:56:44.00	BH1 - 154 BH1 - 155	229 343	13 15	171 13	14 1	3.193868 5.002501	0.136303 0.160110	0.111700 0.075500	0.005134 0.004010	0.180400 0.005345	1756 1175	63 33	8 1826 8 1081	82 104	3.86 -8.69	1826 82 1175 33
BH1 BH1 BH1	03/12/2018 (2) 20:58:50.00 03/12/2018 (2) 21:00:56.00 02/12/2018 (2) 21:00:56.00	BH1 - 156 BH1 - 157 BH1 - 158	77 68 729	3 4 20	97 12	3	5.282620 2.092050 6.092845	0.245183 0.103114 0.177579	0.078000 0.179400 0.075500	0.008360	0.140520 0.101170	1118 2519	46	5 1146 9 2647	200	2.48 4.84	1118 46 2647 80 990 26
BH1 BH1	03/12/2018 (2) 21:05:01:00 03/12/2018 (2) 21:05:01:00 03/12/2018 (2) 21:07:07:00	BH1 - 159 BH1 - 160	598 540	52 78	589 394	61 79	5.356186 13.245030	0.282125 1.633262	0.087300 0.085500	0.004546	0.524630	1104 469	51	1 1366 0 1326	98 133	19.23	1104 51 469 50
BH1 BH1	03/12/2018 (2) 21:09:08.00 03/12/2018 (2) 21:11:13.00	BH1 - 161 BH1 - 162	296 172	18 9	153 71	9	5.924171 5.173306	0.244828 0.197137	0.081700 0.084500	0.006734	-0.374310 0.615900	1006 1139	37	7 1237 3 1303	155 126	18.71 12.58	1006 37 1139 38
BH1 BH1 BH1	03/12/2018 (2) 21:13:13:00 03/12/2018 (2) 21:25:48:00 03/12/2018 (2) 21:27:57:00	BH1 - 163 BH1 - 164 BH1 - 165	92 63 172	11 3 8	81 39 53	14 2 3	10.309280 5.617978 5.858231	1.268998 0.342760 0.213257	0.115000 0.085300 0.074000	0.016300 0.009306 0.006080	0.427920 0.216820 0.264420	597 1056 1016	63 56 33	8 1879 5 1321 8 1041	236 199 158	68.24 20.06 2.40	597 63 1056 56 1016 33
BH1 BH1	03/12/2018 (2) 21:29:57.00 03/12/2018 (2) 21:32:08.00	BH1 - 166 BH1 - 167	217 164	10 6	85 83	4	4.399472 4.496403	0.155733 0.160690	0.090400 0.084000	0.005008	0.170770	1320 1295	41	1433 1 1292	103	7.87	1320 41 1295 41
BH1 BH1	03/12/2018 (2) 21:34:10.00 03/12/2018 (2) 21:46:47.00	BH1 - 168 BH1 - 169	117 156	7	40 158	3	5.561735 4.746084	0.228780 0.295397	0.075300 0.089400	0.006606	-0.043739 0.159410	1066 1233	35	9 1076 5 1412	167 120	0.94 12.71	1066 39 1233 66
BH1 BH1 BH1	03/12/2018 (2) 21:48:53.00 03/12/2018 (2) 21:50:54.00 03/12/2018 (2) 21:50:54.00	BH1 - 170 BH1 - 171 BH1 - 172	362 309 269	33 47 10	148 213 734	19 45 11	5.390836 9.551098 3.107520	0.189188 0.647139 0.111399	0.076400 0.100300 0.113800	0.004228 0.008806 0.005676	0.136550 0.309270 0.338850	1097 642 1799	34	1105 1629 1860	108 156 88	0.70 60.60 3.32	1097 34 642 39 1860 88
BH1 BH1	03/12/2018 (2) 21:55:00.00 03/12/2018 (2) 21:57:05.00	BH1 - 173 BH1 - 174	98 433	9 29	72 204	5	6.013229 5.192108	0.293827 0.176629	0.074700 0.078000	0.008294 0.004060	-0.010710 0.123350	992 1135	43 34	8 1050 4 1146	209 101	6.44 0.92	992 43 1135 34
BH1 BH1	03/12/2018 (2) 21:59:06.00 03/12/2018 (2) 22:01:13.00	BH1 - 175 BH1 - 176	681 1175	7 56	447 345	14	4.599816 5.230126	0.178745	0.086700	0.003434	0.071783	1268 1128	43	8 1353 8 1171	75	6.27 3.70	1268 43 1128 28
8H1 8H1	03/12/2018 (2) 22:05:19:00 03/12/2018 (2) 22:05:26:00 03/12/2018 (2) 22:07:26:00	BH1 - 177 BH1 - 178 BH1 - 179	255 317 251	19 11 10	90 7	12	4.892368 5.903188 1.828154	0.330634 0.053608	0.093500	0.005970	0.320110 0.181000	1009 2813	50	1213 1497 5 2853	110	1.19 32.62 1.41	1009 50 2853 55
BH1 BH1	03/12/2018 (2) 22:09:32.00 03/12/2018 (2) 22:11:31.00	BH1 - 180 BH1 - 181	147 86	10 7	69 53	6	4.948046 5.688282	0.292378 0.246428	0.090900 0.073700	0.007018	0.067903 0.171250	1187 1044	61 40	L 1444 D 1032	141 196	17.83	1187 61 1044 40
BH1 BH1	03/12/2018 (2) 22:13:39.00 03/12/2018 (2) 22:15:39.00 03/12/2018 (2) 22:15:39.00	BH1 - 182 BH1 - 183	745	25 7	502 88	18	5.767013 7.122507	0.251700	0.122000 0.109900	0.019440 0.009498	-0.641230	1031 847	40	0 1985 1 1797	260	48.07 52.87	1031 40 847 34
BH1 BH1	03/12/2018 (2) 22:17:43:00 03/12/2018 (2) 22:19:44:00 03/12/2018 (2) 22:21:51:00	BH1 - 185 BH1 - 185 BH1 - 186	73	2 5	36 31	2	4.280822 2.028398	0.195569 0.098170	0.097000 0.185700	0.008440 0.010134	0.094177 0.234300	1719 1353 2584	54	1784 1566 2713	83 156 88	13.58 4.76	1353 54 2713 88
BH1 BH1	03/12/2018 (2) 22:23:51.00 03/12/2018 (2) 22:25:58.00	BH1 - 187 BH1 - 188	426 33	33 2	208 15	21 1	4.239084 4.761905	0.133300 0.247166	0.087400 0.083000	0.003748	0.250000 0.031825	1365 1229	38	8 1369 5 1268	81 253	0.23	1365 38 1229 55
BH1 BH1 BH1	03/12/2018 (2) 22:28:00.00 03/12/2018 (2) 22:40:40.00 03/12/2018 (2) 22:40:40.00	BH1 - 189 BH1 - 190 BH1 - 191	494 108 181	25 5 10	129	8 9	4.187605 5.157298 5.015045	0.230815 0.170723	0.090600	0.007052	-0.460380 0.236640	1381 1143 1177	45	L 2533 5 1437 5 1303	70 204 133	45.50 20.49	1581 61 1143 45 1172 35
BH1 BH1	03/12/2018 (2) 22:44:48.00 03/12/2018 (2) 22:46:53.00	BH1 - 192 BH1 - 193	170 610	14 10	244 409	20 13	4.468275 7.942812	0.169227 0.650945	0.085100	0.006102	0.302450	1302 764	43	3 1317 5 1473	134	1.15 48.10	1302 43 764 55
BH1 BH1	03/12/2018 (2) 22:48:54.00 03/12/2018 (2) 22:50:58.00	BH1 - 194 BH1 - 195	38 64	3	97 41	17	5.494505 3.061849	0.441976 0.124986	0.097000 0.112000	0.015940	0.112930 0.182030	1078 1822	74	1566 1831	281 138	31.17 0.50	1078 74 1831 138
BH1 BH1 BH1	03/12/2018 (2) 22:52:59:00 03/12/2018 (2) 22:55:05:00 03/12/2018 (2) 22:55:05:00	BH1 - 196 BH1 - 197 BH1 - 198	138	3 8 10	78 39 45	3	3.411805 3.131851 4.230118	0.146227 0.119526 0.181229	0.103600	0.006872 0.006318 0.006880	0.043171	1657 1786 1368	55	J 1689 3 1813 I 1403	118 101 142	1.88 1.49 7.49	1689 118 1813 101 1358 51
BH1 BH1	03/12/2018 (2) 22:59:11.00 03/12/2018 (2) 23:01:12.00	BH1 - 199 BH1 - 200	202	7 20	40 116	2	5.420054 7.072136	0.193594 0.551567	0.077400 0.107400	0.005748	0.283000 0.393890	1092 853	35	5 1131 3 1755	142 161	3.49 51.42	1092 35 853 58
BH1 BH1	13/07/2020 (2) 12:49:08.00 13/07/2020 (2) 12:50:44.00	BH1 - 139b BH1 - 139c	854 1313	12 12	892 2673	9 17	8.124797 9.174312	0.261514 0.326572	0.056600 0.073300	0.002532 0.002766	0.274600 -0.078192	748 667	22	2 824 2 1021	78 76	9.23 34.70	748 22 667 22
BH1 BH1	13/07/2020 (2) 12:52:10.00 13/07/2020 (2) 12:53:40.00	BH1 - 139d BH1 - 2.4	385	6 12	495	3 20	8.833922 7.535795	0.309343	0.073700	0.003474	0.279760	691 803	22	2 1032 5 834	93 87	33.04 3.65	691 22 803 25
BH1 BH1 BH1	13/07/2020 (2) 12:55:08:00 13/07/2020 (2) 12:56:39:00 13/07/2020 (2) 12:58:05:00	BH1 - 2.5 BH1 - 2.6 BH1 - 2.7	253 253	3	105	1	4.553754 5.353319 4.377540	0.151211 0.190175 0.156280	0.087100	0.003842 0.003952 0.004282	0.307920 0.392710 0.313820	1104	3/ 35 47	i 1362 5 1136 9 1405	84 99 90	5.02 2.80 5.53	1280 3/ 1104 35 1328 42
8H1 8H1	13/07/2020 (2) 12:59:34.00 13/07/2020 (2) 13:01:03.00	BH1 - 2.8 BH1 - 2.9	466	7	160 387	3	4.024145	0.130684 0.451451	0.094800	0.003596	0.489130	1431 941	40	1523	71	6.08	1431 40 941 58
BH1 BH1	13/07/2020 (2) 13:02:34.00 13/07/2020 (2) 13:04:01.00	BH1 - 2.10 BH1 - 2.11	321 434	9 14	180 387	5 20	3.866976 5.470460	0.285689 0.294950	0.101300 0.105500	0.003826	0.191940 0.116590	1483 1082	92	1647	69 71	9.99 37.16	1483 92 1082 51
BH1 BH1	13/07/2020 (2) 13:05:31.00 13/07/2020 (2) 13:06:59.00	BH1 - 2.12 BH1 - 2.13	256 112	16 2	93 72	5 2	3.927730 3.966680	0.131007 0.142272	0.095800 0.093100	0.004116	0.295560 0.292290	1462 1449	42 45	2 1543 5 1489	80 97	5.24 2.67	1462 42 1449 45
BH1 BH1	13/07/2020 (2) 13:08:31.00 13/07/2020 (2) 13:09:57.00	BH1 - 2.14 BH1 - 2.15	563 60	10	322 28	9	4.935834 5.192108	0.162059 0.208978	0.089000 0.083700	0.003480	0.406310	1189 1135	35	5 1403 0 1285	74	15.25 11.62	1189 35 1135 40
BH1 BH1	13/07/2020 (2) 13:11:26:00 13/07/2020 (2) 13:12:55:00 13/07/2020 (2) 13:14:26:00	BH1 - 2.10 BH1 - 2.17 BH1 - 2.18	438	20	126	5	5.464481 4.732608	0.173238	0.077000	0.003268	0.097225	1083 1236	32	2 1130 2 1120 7 1230	80	4.60 3.30 .0.45	105 52 1083 32 1235 37
BH1 BH1	13/07/2020 (2) 13:15:53.00 13/07/2020 (2) 13:17:21.00	BH1 - 2.19 BH1 - 2.20	638 141	8	421 54	5	5.291005 3.101737	0.170208	0.081300 0.112800	0.002926	0.353380 0.274150	1116 1801	32	2 1228 3 1844	70	9.11 2.32	1116 32 1844 78
BH1 BH1	13/07/2020 (2) 13:18:50.00 13/07/2020 (2) 13:20:21.00	BH1 - 2.21 BH1 - 2.22	132 614	2 11	40 208	0 3	5.279831 5.440696	0.185439 0.179857	0.078800 0.078700	0.004476 0.002974	0.087961 0.281610	1118 1088	35 32	5 1166 2 1164	109 74	4.12	1118 35 1088 32
BH1 BH1	13/07/2020 (2) 13:26:24.00 13/07/2020 (2) 13:27:55.00	BH1 - 2.23 BH1 - 2.24	738	13 6	373 194	6	4.088307 5.428882	0.135252 0.182260	0.094800	0.003296	0.227040	1411 1090	41	1 1523 8 1110	65 83	7.40	1411 41 1090 33
BH1 BH1	13/07/2020 (2) 13:29:24:00 13/07/2020 (2) 13:30:53:00 13/07/2020 (2) 13:32:53:00	BH1 - 2.25 BH1 - 2.26	108	10	220	3	4.351610	0.153310	0.085100	0.004522	0.316200	1333 1152	41	1340	99 67	0.46 6.94	1333 41 1152 34
BH1 BH1	13/07/2020 (2) 13:32:23:00 13/07/2020 (2) 13:33:52:00 13/07/2020 (2) 13:35:20:00	BH1 - 2.28 BH1 - 2.29	292	7	181 106	4	5.094244 5.402485	0.166763 0.183936	0.079800 0.080800	0.003296	0.132380 0.165200	1413 1155 1095	34	1432 1191 1216	80 107	3.00	1415 42 1155 34 1095 33
BH1 BH1	13/07/2020 (2) 13:36:49.00 13/07/2020 (2) 13:38:20.00	BH1 - 2.30 BH1 - 2.31	195 109	3	84 69	2	3.313453 4.737091	0.230954	0.110200	0.004504	0.354800	1700	98	3 1802 9 1357	73	5.64	1802 73 1235 39
BH1 BH1	13/07/2020 (2) 13:39:47.00 13/07/2020 (2) 13:41:16.00	BH1 - 2.32 BH1 - 2.33	266 243	4 4	190 88	2 1	5.571031 5.470460	0.189012 0.181231	0.078700 0.078900	0.003774 0.003978	-0.002818 0.317540	1064 1082	32 32	2 1164 2 1169	93 98	8.55	1054 32 1082 32
BH1 BH1	13/07/2020 (2) 13:42:44.00 13/07/2020 (2) 13:44:15.00	BH1 - 2.34 BH1 - 2.35	80 206	2 3	46 201	1 3	3.918495 2.856327	0.144395 0.203981	0.093600 0.124600	0.005172 0.004492	0.160010 0.128660	1465 1935	47	7 1499 2 2022	102	2.27 4.31	1465 47 2022 63
BH1 BH1	13/07/2020 (2) 13:45:42.00 13/07/2020 (2) 13:51:46.00 12/07/2020 (2) 13:52:21.00	BH1 - 2.36 BH1 - 2.37 BH1 - 2.37	675 222 242	12 5 6	383 586	6 16	6.082725 5.221932 5.305633	0.195654 0.180791	0.077400 0.078900	0.002748 0.003978	0.227740 0.204750 0.329660	981 1130 1133	28	8 1131 5 1169 1169	70 98	13.22 3.35	981 28 1130 35
BH1 BH1	13/07/2020 (2) 13:53:21:00 13/07/2020 (2) 13:54:50:00 13/07/2020 (2) 13:56:21:00	BH1 - 2.39 BH1 - 2.40	417	8 18	206 241	3 10	4.020909 4.436557	0.133772 0.153685	0.094600	0.003478 0.003492 0.003702	0.420860	1432	41	L 1519 1 1800	69 61	5.76	1432 41 1310 40
BH1 BH1	13/07/2020 (2) 13:57:48.00 13/07/2020 (2) 13:59:17.00	BH1 - 2.41 BH1 - 2.42	270 148	2	112 173	3 5	5.780347 3.918495	0.202479 0.133646	0.075000 0.093700	0.003700 0.004474	0.208550	1029 1465	32 43	2 1068 3 1501	97 89	3.65 2.40	1029 32 1465 43
BH1 BH1	13/07/2020 (2) 14:00:45.00 13/07/2020 (2) 14:02:16.00	BH1 - 2.43 BH1 - 2.44	510 180	4 11	292 155	3 13	4.244482 2.446184	0.138937 0.174584	0.091400 0.172300	0.003328	0.246450 0.225720	1364 2209	35 126	9 1454 5 2579	69 58	6.21 14.34	1364 39 2579 58
BH1 BH1	13/07/2020 (2) 14:08:21.00 13/07/2020 (2) 14:09:51.00	BH1 - 2.45 BH1 - 2.46	204	5	50 347	1 4	3.075031 5.577245	0.222249 0.192420	0.115400 0.093800	0.004608	0.403980	1815 1063 1066	108	3 1885 3 1503	71 73	3.72 29.27	1885 71 1063 33
8H1 8H1	13/07/2020 (2) 14:11:20:00 13/07/2020 (2) 14:12:48:00 13/07/2020 (2) 14:14:20:00	BH1 - 2.48 BH1 - 2.49	122	4	60 182	2	3.309067 4.894763	0.241380 0.172167	0.107100	0.004842	0.002900	1702	103	8 1750 7 1364	81 94	2.72	1000 31 1750 81 1198 37
BH1 BH1	13/07/2020 (2) 14:15:47.00 13/07/2020 (2) 14:17:16.00	BH1 - 2.50 BH1 - 2.51	233 330	3 6	237 188	3 3	5.125577 3.227889	0.191835 0.231266	0.090400 0.112900	0.004008	0.329340 0.270790	1149 1740	38 103	3 1433 3 1846	83	19.83 5.75	1149 38 1846 61
BH1 BH1	13/07/2020 (2) 14:18:45.00 13/07/2020 (2) 14:20:16.00	BH1 - 2.52 BH1 - 2.53	427 71	4 3	174 27	2 1	6.501951 2.921414	0.214590 0.212052	0.073100 0.119800	0.003362 0.006096	0.393180 0.361990	922 1898	28	8 1016 2 1952	91 89	9.21 2.80	922 28 1952 89
BH1 BH1	13/07/2020 (2) 14:21:42.00 13/07/2020 (2) 14:23:11.00	BH1 - 2.54 BH1 - 2.55	390 650	14 8	168 68	7	5.530973 5.246590	0.187099	0.078700 0.082400	0.003374	0.295700	1071 1125	32 34	2 1164 1 1254	84 81	7.94	1071 32 1125 34
BH1 BH1	13/07/2020 (2) 14:24:40:00 13/07/2020 (2) 14:26:11:00 13/07/2020 (2) 14:27:38:00	BH1 - 2.57 BH1 - 2.58	329 478	4 13	395 190	5	4.793864 3.772161 4.585053	0.274652 0.205224	0.095700 0.118800	0.003482 0.003514 0.004376	0.226150	1516	92	2 1541 2 1937	68	1.63 34.36	1541 68 1272 50
BH1 BH1	13/07/2020 (2) 14:29:07.00 13/07/2020 (2) 14:30:36.00	BH1 - 2.59 BH1 - 2.60	246 228	6 4	70 202	2 4	3.921569 3.186743	0.133795	0.094200 0.107000	0.003884 0.004140	0.310470 0.351960	1464 1759	43	8 1511 8 1748	77 70	3.12	1464 43 1748 70
BH1 BH1	13/07/2020 (2) 14:32:08.00 13/07/2020 (2) 14:33:35.00	BH1 - 2.61 BH1 - 2.62	99 418	3 4	58 513	2 33	5.307856 5.390836	0.204764 0.221155	0.084400 0.089500	0.005288 0.003390	0.181740 0.168330	1113 1097	38 40	8 1301 0 1414	118 72	14.47 22.42	1113 38 1097 40
BH1 BH1	13/07/2020 (2) 14:35:03.00 13/07/2020 (2) 14:36:33.00	BH1 - 2.63 BH1 - 2.64	209	5	161 33	4	4.332756 4.980080	0.148505	0.089200 0.094100	0.003884	0.269380	1339 1180	40	0 1408 8 1509	82 99	4.90 21.84	1339 40 1180 38
BH1 BH1	13/07/2020 (2) 14:39:30:00 13/07/2020 (2) 14:39:30:00 13/07/2020 (2) 14:45:34:00	BH1 - 2.66 BH1 - 2.67	129	2	24 56 39	1	4.723000 5.373455 5.783690	0.202753	0.075400	0.005074	0.304140	1238 1100 1028	37	7 1078 5 1110	124 121 141	-0.38 -2.03 7.37	1238 41 1100 37 1028 35
BH1 BH1	13/07/2020 (2) 14:47:06:00 13/07/2020 (2) 14:48:35:00	BH1 - 2.68 BH1 - 2.69	231	4	154	3	4.380201 5.633803	0.147081 0.198373	0.088600	0.003772	0.187760	1326 1053	35	9 1395 8 1021	80	4.96	1326 39 1053 33
BH1 BH1	13/07/2020 (2) 14:50:06.00 13/07/2020 (2) 14:51:32.00	BH1 - 2.70 BH1 - 2.71	86 149	3 3	53 123	2 2	5.122951 4.849661	0.191691 0.172255	0.075600 0.083800	0.005212 0.004276	0.298080 0.418200	1149 1209	38	8 1084 8 1287	133 97	-6.08 6.10	1149 38 1209 38
BH1 BH1 BH1	13/07/2020 (2) 14:53:02.00 13/07/2020 (2) 14:59:04.00 13/07/2020 (2) 14:59:04.00	BH1 - 2.72 BH1 - 2.73 PH1 - 2.74	457 823 215	11 13 c	235 342	7 3	5.760369 4.271679	0.194844	0.078200	0.003064	0.472090	1032	31 41	1151 1545	77 63	10.35 12.24	1032 31 1356 41 2444 57
BH1 BH1	13/07/2020 (2) 15:02:10:00 13/07/2020 (2) 15:02:10:00 13/07/2020 (2) 15:03:37 00	BH1 - 2.75 BH1 - 2.76	289 456	9 39	215 154	4 13	4.460303	0.158836 0.220415	0.110600 0.081500	0.004812	0.438300 0.073918	2409 1304 1063	41	. 2444 L 1809 7 1733	58 78 81	1.46 27.89 13.75	1304 41 1063 37
BH1 BH1	13/07/2020 (2) 15:05:05:00 13/07/2020 (2) 15:06:33:00	BH1 - 2.77 BH1 - 2.78	261 561	9 27	106 227	4	4.284490 4.382121	0.148103 0.172136	0.087200 0.098200	0.003644 0.004764	0.129470	1352 1325	41	L 1364	79	0.87	1352 41 1325 45
BH1 BH1	13/07/2020 (2) 15:08:04.00 13/07/2020 (2) 15:09:31.00	BH1 - 2.79 BH1 - 2.80	293 782	2 50	151 343	2 17	5.527916 5.917160	0.183897 0.608522	0.078100	0.003462	0.304470	1072 1007	32 87	2 1149 7 1610	87 116	6.67 37.49	1072 32 1007 87
BH1 BH1 BH1	13/07/2020 (2) 15:11:00.00 13/07/2020 (2) 15:12:29.00 13/07/2020 (2) 15:12:29.00	BH1 - 2.81 BH1 - 2.82 PH1 - 2.82	134 240 251	5 3 5	74 76 40	2	3.888025	0.135204 0.176328	0.091900 0.079200	0.003784	0.239900	1476	44	1465 1176	96 93	-0.75 2.41	1476 44 1148 35 1705 67
BH1 BH1	13/07/2020 (2) 15:14:01.00 13/07/2020 (2) 15:15:27.00 13/07/2020 (2) 15:16:55.00	BH1 - 2.83 BH1 - 2.84 BH1 - 2.85	251 252 613	2 12	08 104 158	1 3	3.410641 4.032258 5.485464	0.242700 0.137552 0.178917	0.093200 0.077900	0.003890 0.003864 0.002758	0.296910 0.220400	1658 1428 1080	98 42 31	, 1/05 2 1491 L 1)43	68 77 70	4.22	1428 42 1080 31
BH1 BH1	13/07/2020 (2) 15:18:24.00 13/07/2020 (2) 15:19:56.00	BH1 - 2.86 BH1 - 2.87	201 215	5	506 222	16 10	4.780115 3.734130	0.161866	0.080800 0.102100	0.003716	0.161500 0.271840	1225 1530	37	1216	89	-0.73	1225 37 1662 78
BH1 BH1	13/07/2020 (2) 15:21:22.00 13/07/2020 (2) 15:27:26.00	BH1 - 2.88 BH1 - 2.89	356 157	8 3	211 93	5 2	4.823927 3.264773	0.196541 0.235835	0.096700	0.003934 0.004594	0.446160 0.239230	1214 1723	43	1561 1794	75 75	22.18 3.96	1214 43 1794 75
BH1 BH1	13/07/2020 (2) 15:28:59:00 13/07/2020 (2) 15:30:27:00 12/07/2020 (2) 15:30:27:00	BH1 - 2.90 BH1 - 2.91	437 536	9	166 638	4	5.580357 3.909304	0.189458	0.076300	0.003226	0.173770	1063	32	1102	83 60	3.58 19.25	1063 32 1468 92
BH1 BH1	13/07/2020 (2) 15:31:59.00 13/07/2020 (2) 15:33:27.00 13/07/2020 (2) 15:34:54.00	BH1 - 2.92 BH1 - 2.93 BH1 - 2.94	245 311 875	5 19 32	167 119 577	4 6 12	3.980892 8.605852	0.222245 0.453549	0.108800 0.076800	0.003838 0.004176 0.003636	0.380430 0.062901 -0.214650	11/0 1445 700	35	, 1242 9 1779 1 2452	90 69 .12,45	5.82 18.77 71 **	1445 69 709 34
BH1 BH1	13/07/2020 (2) 15:36:23.00 13/07/2020 (2) 15:37:56.00	BH1 - 2.95 BH1 - 2.96	186	4	76 437	2	4.705882	0.160554	0.084400	0.003988	0.197580	1242 1292	37	7 1301 3 1435	-1143 90 63	4.52	1242 37 1292 38
BH1 BH1	13/07/2020 (2) 15:39:22.00 13/07/2020 (2) 15:40:51.00	BH1 - 2.97 BH1 - 2.98	61 259	1 3	73 104	1 2	3.992016 4.807692	0.145179 0.167807	0.090800 0.087000	0.006216 0.003540	0.172030 0.111950	1441 1218	46	5 1442 8 1360	126 77	0.03 10.40	1441 46 1218 38
BH1 BH1	13/07/2020 (2) 15:42:20.00 13/07/2020 (2) 15:43:51.00	BH1 - 2.99 BH1 - 2.100	317 355	6 12	440	8	3.841721 5.296610	0.125539	0.096000	0.003920	0.237780	1491 1115	41 34	1547 1 1181	76 85	3.59 5.62	1491 42 1115 34
BH1 BH1	13/07/2020 (2) 15:45:17.00 13/07/2020 (2) 15:46:47.00 13/07/2020 (2) 15:46:47.00	BH1 - 2.101 BH1 - 2.102 BH1 - 2.102	276 451 137	8 8 7	183 185 63	7 4 1	4.623209 5.917160 5.502577	0.152312 0.195371 0.194992	0.078600	0.003272	0.3/2000 0.235790 0.172540	1262 1007	37	1388 1161	78	9.07 13.31	1262 37 1007 30 1076 24
BH1 BH1	13/07/2020 (2) 15:49:46.00 13/07/2020 (2) 15:51:12 00	BH1 - 2.105 BH1 - 2.105	152	4	85 123	2	3.353454 3.898635	0.235754	0.107000 0.092900	0.004340	0.513470	1076 1682 1477	34 98 44	11/1 8 1748 1 1485	105 73 91	a.11 3.76 0.88	1748 73 1472 44
BH1 BH1	13/07/2020 (2) 15:52:41.00 13/07/2020 (2) 15:54:09.00	BH1 - 2.106 BH1 - 2.107	261 109	6	204 74	5	3.109453 5.197505	0.216888 0.184992	0.115600 0.082500	0.004312	0.351480 0.144030	1798 1134	103 36	1888 1257	67 121	4.81 9.72	1888 67 1134 36
BH1 BH1	13/07/2020 (2) 15:55:42.00 13/07/2020 (2) 15:57:07.00	BH1 - 2.108 BH1 - 2.109	145 133	2 3	108 178	2 4	5.197505 5.241090	0.182291 0.184482	0.080100 0.080500	0.004002 0.004510	0.358880	1134 1126	35	5 1199 5 1208	96 107	5.36 6.84	1134 35 1126 35
BH1 BH1	13/07/2020 (2) 15:58:37.00 13/07/2020 (2) 16:09:15.00	BH1 - 2.110 BH1 - 2.111	532 597	9 22	367	7	16.835020 6.644518	0.705144	0.193300	0.011266	-0.410070	372 904	15 34	5 2770 1065	93 79	86.57 15.13	372 15 904 34
BH1 BH1 BH1	13/07/2020 (2) 16:10:47.00 13/07/2020 (2) 16:12:16.00 13/07/2020 (2) 16:12:47.00	BH1 - 2.112 BH1 - 2.113 BH1 - 2.114	302 199 04	7 2	169 104 47	5	5.109862 2.470966 4.250108	0.170085	0.081400 0.167000 0.094200	0.003528	0.235460	1152 2191	34 126	1230 5 2527	84 56	6.34 13.31	1152 34 2527 56 1331 44
BH1 BH1	13/07/2020 (2) 16:15:14:00 13/07/2020 (2) 16:15:14:00 13/07/2020 (2) 16:16:44:00	BH1 - 2.115 BH1 - 2.115	389 673	* 8 20	+3 376 438	6 24	4.048583 5.747126	0.153092	0.188300	0.006166	0.212450	1331 1423 1034	41 47 23	7 2727 3 1887	10 54 به	-2.52 47.81 45.30	1423 47 1034 32
BH1 BH1	13/07/2020 (2) 16:18:14.00 13/07/2020 (2) 16:19:45.00	BH1 - 2.117 BH1 - 2.118	383 247	7 4	130 106	3	3.957262 3.940110	0.130823 0.134690	0.092400	0.003748	0.277650	1452 1458	41 43	1475 1483	76 76	1.52	1452 42 1458 43
BH1 BH1	13/07/2020 (2) 16:21:12.00 13/07/2020 (2) 16:22:41.00	BH1 - 2.119 BH1 - 2.120	41 93	2 2	32 43	2 1	5.643341 3.921569	0.249810 0.278354	0.074400 0.093500	0.006588	0.384930 0.450850	1052 1464	41 87	1 1051 7 1497	170 104	-0.03 2.20	1052 41 1464 87
BH1 BH1	13/07/2020 (2) 16:24:10.00 13/07/2020 (2) 16:25:40.00	BH1 - 2.121 BH1 - 2.122	144	2	37 60	1	4.655493 4.110152	0.162465	0.085200	0.004004	0.300480	1254 1404	35 44	) 1319 1501	89 92	4.92 6.49	1254 39 1404 44
BH1 BH1	13/07/2020 (2) 16:27:07.00 13/07/2020 (2) 16:28:35.00 13/07/2020 (2) 16:28:35.00	BH1 - 2.123 BH1 - 2.124 BH1 - 2.125	514 298 617	10	53 116 497	3 2 5	4./U8098 5.022602	0.160661	0.096600	0.003654	-0.385310 0.43854	1242 1170	37	1261 5 1559	85 151	1.56 24.90	1242 37 1170 35 1767 57
BH1	13/07/2020 (2) 16:31:35:00	BH1 - 2.125	210	5	96	2	4.380201	0.154756	0.085500	0.004010	0.294050	1326	98	1326	58	0.03	1326 41

Sample ID	Analysis date-time	Spot ID <sup>1</sup>	238U conc. ppm ±2	232Th conc to INT ppm	±2σ INT	238U/206Pb	±2σ PROP	sotopic Ratios 207Pb/205Pb	±2σ PROP	rho	Appare 238U/206Pb	ent Ages - Calcu ±2σ PROP	lated in Isoplot R (N 207Pb/206Pb	la) ±2σ PROP	Discord (7/6-6/8)/7/6 *100	Perferred age : Ma cutoff Ma 2	1500 2 σ
BH1	13/07/2020 (2) 16:33:01.00	BH1 - 2.127	141	3 106	3	3.544842	0.259385	0.099500	0.004390	0.311220	1602	97	1614	81	0.74	1614	81
BH1 BH1	13/07/2020 (2) 16:34:29.00 13/07/2020 (2) 16:36:00.00	BH1 - 2.128 BH1 - 2.129	202	4 104 8 359	8	2.152853 5.464481	0.154292 0.183941	0.171000	0.005620	0.153340	2459 1083	138	2567 1141	55	4.18	2567	33
BH1 BH1	13/07/2020 (2) 16:37:30:00 13/07/2020 (2) 16:38:57:00 13/07/2020 (2) 16:38:57:00	BH1 - 2.130 BH1 - 2.131	389 99	8 402 3 73	2	4.701457	0.134476	0.091400	0.003428	0.181/60	1438	42 41	1261	103	1.11 1.44 2.05	1438	41
BH1 BH1	13/07/2020 (2) 16:46:29:00 13/07/2020 (2) 16:46:29:00	BH1 - 2.133 BH1 - 2.134	126	2 80	1	5.205622	0.179988	0.077700	0.004654	0.161630	1133	35	1138	116	0.49	1133	35
BH1 BH1	13/07/2020 (2) 16:49:33.00 13/07/2020 (2) 16:51:00.00	BH1 - 2.135 BH1 - 2.136	351 301	16 152 3 412	8 4	5.344735	0.181167 0.153381	0.078900	0.003578	0.219770	1106 2466	33	1169 2458	88	5.39	1106	33 54
BH1 BH1	13/07/2020 (2) 16:52:30.00 13/07/2020 (2) 16:53:58.00	BH1 - 2.137 BH1 - 2.138	799 84	8 171 4 102	2 4	5.434783 3.298153	0.173677	0.083900 0.108000	0.003778	-0.313720 0.416410	1089 1707	31 103	1289 1765	86 100	15.56 3.28	1089 1765	31 100
BH1 BH1	13/07/2020 (2) 16:55:30.00 13/07/2020 (2) 16:56:56.00	BH1 - 2.139 BH1 - 2.140	83 165	2 57 4 89	2	3.170577 3.438790	0.224252 0.246155	0.109300 0.101200	0.004886	0.330940 0.244500	1767 1646	103 98	1787 1645	80 80	1.11 -0.01	1787 1645	80 80
BH1 BH1	13/07/2020 (2) 16:58:25.00 13/07/2020 (2) 16:59:53.00	BH1 - 2.141 BH1 - 2.142	287 202	7 262 5 89	10 3	2.405002 4.098361	0.169565 0.137396	0.186700 0.093100	0.005734 0.003762	0.254430 0.473300	2241 1407	126 41	2713 1489	51 75	17.37 5.48	2713 1407	51 41
BH1 BH1	13/07/2020 (2) 17:01:25.00 13/07/2020 (2) 17:02:52.00	BH1 - 2.143 BH1 - 2.144	119 129	4 55 3 111	2	5.681818 4.098361	0.210486 0.139076	0.075000 0.091800	0.004600 0.004136	0.345420 0.188140	1045 1407	35 42	1068 1462	119 84	2.11 3.76	1045 1407	35 42
BH1 BH1	13/07/2020 (2) 17:04:20.00 13/07/2020 (2) 17:05:49.00	BH1 - 2.145 BH1 - 2.146	852 207	7 470 5 105	5	7.092199 3.889537	0.237413 0.138305	0.079700 0.094900	0.002994 0.004298	0.029017 0.306570	850 1475	26 45	1189 1525	73 84	28.47 3.29	850 1475	26 45
BH1 BH1	13/07/2020 (2) 17:07:20.00 13/07/2020 (2) 17:13:23.00	BH1 - 2.147 BH1 - 2.148	379	8 526 5 181	23	5.534034 4.923683	0.205620	0.112900	0.004558	0.301710	10/1	35	1846	72	41.99	1071	35
BH1 BH1	13/07/2020 (2) 17:14:36:00 13/07/2020 (2) 17:16:25:00 12/07/2020 (2) 17:17:52:00	BH1 - 2.145 BH1 - 2.150 BH1 - 2.151	478	1 08 8 113 2 20	2	3.984064	0.130474	0.091500	0.004758	0.284900	1077 1444 1435	41	1456 1458	67	0.86	1444	41
BH1 BH1	13/07/2020 (2) 17:19:24.00 13/07/2020 (2) 17:20:51.00	BH1 - 2.152 BH1 - 2.153	273	7 148	4	5.070994	0.168279	0.081700	0.003734	0.277160	1160	34	1238	88	6.24	1160	34
BH1 BH1	13/07/2020 (2) 17:22:20.00 13/07/2020 (2) 17:28:23.00	BH1 - 2.154 BH1 - 2.155	304	5 347 5 73	6	7.892660	0.282441 0.146271	0.065800	0.003316	0.333320	769 2559	25 142	799 2523	103	3.77	769	25
BH1 BH1	13/07/2020 (2) 17:29:56.00 13/07/2020 (2) 17:31:27.00	BH1 - 2.156 BH1 - 2.157	40 373	1 34 21 96	1 7	5.232862	0.214189 0.196059	0.080400	0.007108	0.298570	1127 1103	41 36	1206 1120	166 92	6.52 1.50	1127	41 36
BH1 BH1	13/07/2020 (2) 17:32:55.00 13/07/2020 (2) 17:34:23.00	BH1 - 2.158 BH1 - 2.159	100 741	2 38 12 411	1 7	4.118616 5.025126	0.141743 0.161107	0.091800 0.091200	0.004736	0.342850 0.208470	1401 1170	42 33	1462 1450	96 67	4.18 19.31	1401 1170	42 33
BH1 BH1	13/07/2020 (2) 17:35:52.00 13/07/2020 (2) 17:37:23.00	BH1 - 2.160 BH1 - 2.161	100 425	2 66 8 243	1 3	4.875670 3.915427	0.175962 0.128899	0.085900 0.093600	0.004618 0.003472	0.247650 0.103850	1203 1466	38 42	1335 1499	101 69	9.92 2.20	1203 1466	38 42
BH1 BH1	13/07/2020 (2) 17:38:51.00 13/07/2020 (2) 17:40:20.00	BH1 - 2.162 BH1 - 2.163	590 195	7 185 5 101	2 3	4.930966 4.147657	0.161837 0.141444	0.083500 0.089800	0.003070 0.003996	0.258100	1190 1392	35 41	1280 1420	71 84	7.01 1.97	1190 1392	35 41
BH1 BH1	13/07/2020 (2) 17:41:49.00 13/07/2020 (2) 17:43:20.00	BH1 - 2.164 BH1 - 2.165	152 294	3 109 4 269	2 4	5.211047 5.546312	0.182970 0.187830	0.079300	0.004086	0.262450	1132	35	1179 1186	100	3.99 9.91	1132	35
BH1 BH1	13/07/2020 (2) 17:46:16:00 13/07/2020 (2) 17:46:16:00	BH1 - 2.167 BH1 - 2.169	110	2 95	2	3.606203	0.254190	0.102100	0.004942	0.408140	1578	93	1662	88	5.06	1662	88
BH1 BH1	13/07/2020 (2) 17:49:16.00 13/07/2020 (2) 17:50:42.00	BH1 - 2.169 BH1 - 2.170	166	3 56 2 78	1	4.422822 3.921569	0.153009	0.087400	0.004148	0.225380	1314 1464	40	1369 1515	90 86	3.98 3.37	1314	40
BH1 BH1	13/07/2020 (2) 17:52:10.00 13/07/2020 (2) 17:53:39.00	BH1 - 2.171 BH1 - 2.172	340 332	6 226 3 102	4	4.770992 4.734848	0.156878 0.157470	0.083800	0.003576	0.475610 0.314580	1227 1235	36 36	1287 1289	82 79	4.69 4.20	1227 1235	36 36
BH1 BH1	13/07/2020 (2) 17:55:11.00 13/07/2020 (2) 17:56:38.00	BH1 - 2.173 BH1 - 2.174	727 445	7 109 7 253	3 4	5.350455 4.192872	0.172852 0.138356	0.076900 0.097700	0.002738 0.004154	0.311300	1105 1379	32 40	1118 1580	70 78	1.18 12.72	1105 1379	32 40
BH1 BH1	13/07/2020 (2) 17:58:07.00 13/07/2020 (2) 17:59:35.00	BH1 - 2.175 BH1 - 2.176	274 314	6 121 6 134	3 2	3.367003 5.479452	0.237391 0.187652	0.105200 0.074200	0.003804 0.003384	0.223630 0.379230	1676 1081	98 33	1717 1046	66 90	2.36 -3.31	1717 1081	66 33
BH1 BH1	13/07/2020 (2) 18:05:39.00 13/07/2020 (2) 18:07:13.00	BH1 - 2.177 BH1 - 2.178	95 896	2 56 28 886	1 32	2.726281 5.482456	0.195745 0.184792	0.123800 0.085000	0.005276	0.280220 0.486030	2014	117 33	2011 1315	75 68	-0.17 17.85	2011 1080	75
BH1 BH1	13/07/2020 (2) 18:08:40.00 13/07/2020 (2) 18:10:09.00	BH1 - 2.179 BH1 - 2.180	124	2 49 11 192	1	5.035247 2.117298	0.184372 0.149937	0.082600	0.004552	0.303270	1168 2494	38 138	1259 2618	105	7.24	1168 2618	38
8H1 BH1	13/07/2020 (2) 18:11:37:00 13/07/2020 (2) 18:13:10:00 13/07/2020 (2) 18:14:26:00	BH1 - 2.181 BH1 - 2.182 BH1 - 2.192	384 65 171	2 149 2 74 9 70	3	+.050223 2.805049 5.765979	0.133498 0.197730 0.1879423	0.120200	0.003298 0.006604 0.003249	0.277280 0.187040 0.332150	1422 1966	41 113	1423 1958	69 96	0.00	1422 1958 1122	41 96 35
BH1 BH1	13/07/2020 (2) 18:20:40.00 13/07/2020 (2) 18:20:40.00 13/07/2020 (2) 18:22:14.00	BH1 - 2.184 BH1 - 2.185	369	11 152 3 150	4	5.678592	0.187739	0.075400	0.003108	0.229630	1046	31	1078	81	3.03	1046	31
BH1 BH1	13/07/2020 (2) 18:23:43.00 13/07/2020 (2) 18:25:13.00	BH1 - 2.186 BH1 - 2.187	72	2 52 2 77	1	2.964720	0.217507 0.154723	0.115900	0.005418	0.364440 0.263880	1874 1294	112 39	1893 1369	83	1.02	1893 1294	83 39
BH1 BH1	13/07/2020 (2) 18:26:39.00 13/07/2020 (2) 18:28:08.00	BH1 - 2.188 BH1 - 2.189	249 459	10 113 8 302	8 7	3.057169 10.090820	0.220030	0.122400 0.220000	0.004348	0.175630	1824 609	108 30	1991 2980	63 123	8.36 79.56	1991 609	63 30
BH1 BH1	13/07/2020 (2) 18:29:38.00 13/07/2020 (2) 18:31:09.00	BH1 - 2.190 BH1 - 2.191	242 107	10 128 4 176	6 4	5.711022 5.704507	0.195760 0.234493	0.074900 0.075100	0.003698 0.004402	0.269270 0.068727	1040 1041	32 38	1065 1070	97 114	2.32 2.72	1040 1041	32 38
BH1 BH1	13/07/2020 (2) 18:32:36.00 13/07/2020 (2) 18:34:05.00	BH1 - 2.192 BH1 - 2.193	456 1185	12 91 26 341	1 9	4.291845 5.882353	0.141097 0.190311	0.092400 0.077700	0.003148	0.155960 0.118930	1350 1012	39 29	1475 1138	64 63	8.45 11.09	1350 1012	39 29
BH1 BH1	13/07/2020 (2) 18:35:35.00 13/07/2020 (2) 18:37:04.00	BH1 - 2.194 BH1 - 2.195	150 351	4 66 6 92	2	5.347594 5.068424	0.192742 0.170729	0.078100 0.078200	0.004362 0.002964	0.113120 0.100170	1105 1161	35 35	1149 1151	108 74	3.78 -0.84	1105 1161	35 35
BH1 BH1	13/07/2020 (2) 18:38:32.00 13/07/2020 (2) 18:40:01.00	BH1 - 2.196 BH1 - 2.197	252 189	4 168 5 92	4	5.263158 3.677823	0.182825	0.079200 0.129100	0.003784	0.297790	1121	35	1176	93 154	4.66 25.64	1121 2085	35 154
BH1 BH1	13/07/2020 (2) 18:41:30:00 13/07/2020 (2) 18:47:34:00	BH1 - 2.198 BH1 - 2.199	382 427	8 1/2 5 56	1	5.279831	0.133884 0.175288	0.092500	0.003358	0.170050	1408 1118 747	40	14// 1143 1612	70	4.63	1408	33
BH1 BH1	13/07/2020 (2) 18:45:05:00 13/07/2020 (2) 18:50:35:00 13/07/2020 (2) 18:52:04:00	BH1 - 2.200 BH1 - 2.201 BH1 - 2.202	54 74 155	1 1895 3 50 4 237	2	4.918839 3.422313	0.195157	0.082400	0.005348	0.366140	1193	42	1254	139	4.88	1193	42
BH1 BH1	13/07/2020 (2) 18:53:35:00 13/07/2020 (2) 18:53:35:00 13/07/2020 (2) 18:55:05:00	BH1 - 2.203 BH1 - 2.204	387	7 222	4	5.184033	0.176241	0.077700	0.003454	0.118170	1137	34	1138 1257	87	0.11	1137	34
BH1 BH1	13/07/2020 (2) 18:56:32:00 13/07/2020 (2) 18:58:01:00	BH1 - 2.205 BH1 - 2.206	94 62	2 55 1 75	1	4.482295 5.546312	0.163982 0.215516	0.088300	0.004966	0.414340 0.221480	1298 1069	42	1388 1208	105 143	6.48 11.57	1298 1069	42
BH1 BH1	13/07/2020 (2) 18:59:29.00 13/07/2020 (2) 19:01:01.00	BH1 - 2.207 BH1 - 2.208	147 306	3 115 15 370	3 40	5.089059 3.588088	0.179477 0.252003	0.079500 0.103700	0.004190	0.170270 0.111310	1156 1585	36 93	1184 1691	102 68	2.30 6.25	1156 1691	36 68
BH1 BH1	13/07/2020 (2) 19:02:28:00 13/07/2020 (2) 19:03:57:00	BH1 - 2.209 BH1 - 2.210	818 344	24 779 5 154	31 4	8.520791 5.787037	0.279322 0.202814	0.054800 0.076000	0.002596	0.381990 0.461780	715 1028	22 32	767 1094	83 93	6.72 6.09	715 1028	22 32
BH1 BH1	13/07/2020 (2) 19:05:26.00 13/07/2020 (2) 19:06:57.00	BH1 - 2.211 BH1 - 2.212	210 101	3 136 5 152	2 10	3.957262 5.580357	0.135521 0.205028	0.094000 0.074600	0.004180 0.004592	0.389590 0.306440	1452 1063	43 35	1507 1057	83 120	3.64 -0.55	1452 1063	43 35
BH1 BH1	13/07/2020 (2) 19:08:24.00 13/07/2020 (2) 19:09:53.00	BH1 - 2.213 BH1 - 2.214	349 230	24 178 4 252	18	5.988024 4.123711 3.333600	0.550038 0.138591	0.086600	0.003832	0.153020	1400	78 41	1351 1425	84 81	26.29 1.76	996 1400	78
BH1 BH1	13/07/2020 (2) 19:11:21:00 13/07/2020 (2) 19:12:52:00 12/07/2020 (2) 19:14:19:00	BH1 - 2.215 BH1 - 2.216 BH1 - 2.217	238	4 50 6 176 1 179	4	2.126302	0.151034	0.172700	0.005254	0.263880	2485	105	2583	51	3.81	2583	51
BH1 BH1	13/07/2020 (2) 19:15:49.00 13/07/2020 (2) 19:15:49.00 13/07/2020 (2) 19:17:16.00	BH1 - 2.218 BH1 - 2.219	257	3 144 3 137	2 3	4.407228	0.205629	0.092600	0.003952	-0.191580	1318 1632	54	1479 1667	80	10.87	1318	54
BH1 BH1	13/07/2020 (2) 19:18:46.00 13/07/2020 (2) 19:29:24.00	BH1 - 2.220 BH1 - 2.221	174 485	3 104 10 220	2	3.380663	0.239046	0.110900	0.004918	0.101780	1670 1091	98 33	1813 1115	79 75	7.89	1813 1091	79 33
BH1 BH1	13/07/2020 (2) 19:30:58.00 13/07/2020 (2) 19:32:25.00	BH1 - 2.222 BH1 - 2.223	1100 124	10 883 3 46	8 1	6.027728 4.182350	0.215022 0.150117	0.085000 0.087700	0.002800 0.004054	0.377830 0.214290	989 1382	32 43	1315 1375	63 87	24.74 -0.50	989 1382	32 43
BH1 BH1	13/07/2020 (2) 19:33:55.00 13/07/2020 (2) 19:35:23.00	BH1 - 2.224 BH1 - 2.225	544 72	6 287 2 31	3 1	4.199916 5.219207	0.140444 0.188829	0.093200 0.079400	0.003264	0.291330 0.272840	1377 1130	40 36	1491 1181	66 123	7.66 4.33	1377 1130	40
BH1 BH1	13/07/2020 (2) 19:36:55.00 13/07/2020 (2) 19:38:21.00	BH1 - 2.226 BH1 - 2.227	249 107	3 551 2 34	6	5.803831 4.955401	0.190182	0.075600	0.003712	0.299920	1025 1185	30 38	1084 1115	96 122	5.43	1025	30 38
BH1 BH1	13/07/2020 (2) 19:39:51:00 13/07/2020 (2) 19:41:20:00	BH1 - 2.228 BH1 - 2.229	73	4 107 2 66	2	7.052186	0.208510	0.086300	0.003956	0.191190	998 855	31	1141 1344	128	12.50 36.40	855	31
BH1 BH1	13/07/2020 (2) 19:44:17:00 13/07/2020 (2) 19:44:17:00	BH1 - 2.231 BH1 - 2.232	333	4 157 3 78	2	5.356186	0.181714	0.082100	0.004142	0.000946	1103	33	1247	97	11.51	1103	33
BH1 BH1	13/07/2020 (2) 19:47:15.00 13/07/2020 (2) 19:48:45.00	BH1 - 2.233 BH1 - 2.234	102 74	3 76 1 84	2	3.043214 3.203075	0.218304 0.228217	0.112600 0.113600	0.005052	0.222140 0.423680	1832 1752	108 103	1841 1857	80 85	0.51 5.68	1841 1857	80 85
BH1 BH1	13/07/2020 (2) 19:50:12.00 13/07/2020 (2) 19:51:41.00	BH1 - 2.235 BH1 - 2.236	146 86	3 86 2 71	2	5.138746 4.058442	0.176714 0.145406	0.078800 0.090100	0.004376 0.005302	0.133840 0.162420	1146 1420	35 44	1166 1427	107 109	1.71 0.48	1146 1420	35 44
BH1 BH1	13/07/2020 (2) 19:53:10.00 13/07/2020 (2) 19:54:41.00	BH1 - 2.237 BH1 - 2.238	117 265	5 72 6 76	3 1	4.997501 5.128205	0.184865 0.170940	0.083400 0.077900	0.004368	0.374400 0.340170	1176 1148	38 34	1278 1143	100 92	7.97	1176 1148	38 34
BH1 BH1	13/07/2020 (2) 19:56:07.00 13/07/2020 (2) 19:57:37.00	BH1 - 2.239 BH1 - 2.240	629 1090	4 329 31 1030	16 35	4.918839 5.102041	0.187898 0.388380	0.091700 0.321000	0.003234 0.047420	0.324270	1193 1154	40 75	1460 3574	66 211	18.30 67.72	1193 1154	40 75
BH1 BH1	13/07/2020 (2) 19:59:05.00 13/07/2020 (2) 20:00:36.00	BH1 - 2.241 BH1 - 2.242	674 524	24 373 14 154	16 4	4.368720 4.033885	0.144632 0.129494	0.087300	0.002946	0.052571 0.289920	1329	39 40	1366	64 67	2.75	1329	39 40
BH1 BH1	13/07/2020 (2) 20:08:41:00 13/07/2020 (2) 20:08:10:00 12/07/2020 (2) 20:08:20:00	BH1 - 2.243 BH1 - 2.244 BH1 - 2.245	745	4 84 8 537	4	4.137360	0.135812	0.120500	0.004110	-0.060485	1396	98 40 26	1953 1963	60 120	2.02 28.90 -1.29	1396	40
BH1 BH1	13/07/2020 (2) 20:11:08.00 13/07/2020 (2) 20:12:40.00	BH1 - 2.246 BH1 - 2.247	278	5 124 4 136	3	2.730748	0.196298	0.129400	0.004288	0.188930	2012	117 45	2089	58	3.71	2089	58 45
BH1 BH1	13/07/2020 (2) 20:14:06.00 13/07/2020 (2) 20:15:34.00	BH1 - 2.248 BH1 - 2.249	231 791	4 84 17 426	2 25	5.959476 5.081301	0.211529 0.163593	0.075000 0.084400	0.003400 0.002988	0.132510 0.273760	1000 1158	32 33	1068 1301	89 68	6.33 10.98	1000 1158	32 33
BH1 BH1	13/07/2020 (2) 20:17:04.00 13/07/2020 (2) 20:18:35.00	BH1 - 2.250 BH1 - 2.251	259 232	7 104 5 180	3 4	3.220612 5.546312	0.230370 0.190906	0.108600 0.076200	0.004072 0.003924	0.100590 0.337160	1743 1069	103 33	1775 1099	68 101	1.80 2.80	1775 1069	68 33
BH1 BH1	13/07/2020 (2) 20:20:01.00 13/07/2020 (2) 20:21:31.00	BH1 - 2.252 BH1 - 2.253	241 133	2 303 3 52	9 1	5.611672 4.786979	0.194110 0.166777	0.077400 0.084100	0.003648 0.004182	0.160210 0.330310	1057 1223	33 38	1131 1294	92 95	6.50 5.49	1057 1223	33 38
BH1 BH1	13/07/2020 (2) 20:23:00.00 13/07/2020 (2) 20:24:31.00	BH1 - 2.254 BH1 - 2.255	163	5 125 5 96	2	5.144033 4.327131	0.221955 0.152077	0.080100	0.003902	0.021471 0.281760	1145	44	1199	94 86	4.46	1145	44
BH1 BH1	13/07/2020 (2) 20:25:58:00 13/07/2020 (2) 20:27:27:00	BH1 - 2.256 BH1 - 2.257	72	1 19 2 76	2	5.260389	0.21312/ 0.147540	0.081700	0.009514	-0.009169	2618	40	1238 3021 1492	154	9.34 13.35	3021	67
BH1 BH1	13/07/2020 (2) 20:28:33:00 13/07/2020 (2) 20:34:58:00 13/07/2020 (2) 20:36:33:00	BH1 - 2.259 BH1 - 2.260	483	10 186 5 115	4	4.845000 5.865103 4.830918	0.192981 0.161954	0.073300	0.003156	0.024617	1015	30 36	1021	78	0.63	1015	30
BH1 BH1	13/07/2020 (2) 20:38:00.00 13/07/2020 (2) 20:38:00.00 13/07/2020 (2) 20:39:30.00	BH1 - 2.261 BH1 - 2.262	285	14 181 18 1231	8	5.524862	0.189860	0.094800	0.003996	0.243830	1072	33	1523 2487	78	29.60	1072	33
BH1 BH1	13/07/2020 (2) 20:40:59.00 13/07/2020 (2) 20:42:31.00	BH1 - 2.263 BH1 - 2.264	188 80	4 84 2 23	2	4.945598 3.330003	0.169843 0.244023	0.085300	0.004306	-0.026926 0.347270	1187 1693	36 102	1322 1712	96 86	10.17	1187 1712	36 86
BH1 BH1	13/07/2020 (2) 20:48:35.00 13/07/2020 (2) 20:50:05.00	BH1 - 2.265 BH1 - 2.266	658 513	8 412 5 178	4	5.319149 4.060089	0.196922 0.132303	0.142600 0.091100	0.008752	-0.703320 0.329210	1111 1419	37 40	2258 1448	103 69	50.82 1.96	1111 1419	37 40
BH1 BH1	13/07/2020 (2) 20:51:33.00 13/07/2020 (2) 20:53:02.00	BH1 - 2.267 BH1 - 2.268	397 283	9 302 10 154	8 11	4.889976 5.083884	0.159970 0.205061	0.084600 0.112000	0.003492 0.005140	0.296280	1199 1158	35 41	1306 1831	79 82	8.12 36.79	1199 1158	35 41
BH1 BH1	13/07/2020 (2) 20:54:33.00 13/07/2020 (2) 20:56:00.00	BH1 - 2.269 BH1 - 2.270	222 211	4 116 4 124	2	4.048583 4.413063	0.141618 0.146687	0.091600	0.003932	0.277830	1423 1317	43 38	1458 1485	80 83	2.42 11.34	1423 1317	43 38
8H1 8H1 8W1	13/07/2020 (2) 20:57:28:00 13/07/2020 (2) 20:58:58:00 12/07/2020 (2) 20:58:58:00	BH1 - 2.271 BH1 - 2.272	214 133	5 93 3 46	2	5.227392 2.666667	0.189257 0.344889	0.081800	0.003936	0.017121	1128 2053	36 205	1240 1878	92 77	8.99 -9.34	1128 1878	36
8H1 8H1	13/07/2020 (2) 21:00:29:00 13/07/2020 (2) 21:01:56:00 13/07/2020 (2) 21:03:25 00	BH1 - 2.274 BH1 - 2.374	374	25 291	2 30 3	4.7/5124 6.493506 4.274455	0.551526	0.083800	0.003780	0.194560	1181 923	35 68	11/1 1287	93 86	-0.81 28.26	923	68
BH1 BH1	13/07/2020 (2) 21:06:25:00 13/07/2020 (2) 21:06:25:00 13/07/2020 (2) 21:07:51:00	BH1 - 2.275 BH1 - 2.277 BH1 - 7 778	876 113	20 254 3 47	5 6 1	+.3/4453 5.032713 5.291005	0.150637 0.166508 0.189804	0.107100	0.003742	0.283680	132/ 1168 1114	40 34 74	1397 1750 1072	80 63 117	4.99 33.23 .4 01	1168	34 35
BH1 BH1	13/07/2020 (2) 21:09:20:00 13/07/2020 (2) 21:10:49:00	BH1 - 2.279 BH1 - 2.280	199	6 465 1 178	15 1	2.996704	0.212598	0.117100	0.004542	0.304570	1856 1358	108 40	1073 1912 1429	69	2.89	1912	69 40
8H1 8H1	13/07/2020 (2) 21:12:20:00 13/07/2020 (2) 21:13:46:00	BH1 - 2.281 BH1 - 2.282	266	10 111 8 615	6	6.261741 2.354049	0.293835 0.168995	0.084100 0.160800	0.004182	0.010128	955 2282	40 130	1294 2463	95 57	26.19 7.35	955 2463	40 52
BH1 BH1	13/07/2020 (2) 21:15:15:00 13/07/2020 (2) 21:16:44.00	BH1 - 2.283 BH1 - 2.284	335 210	5 244 1 116	3	4.205214 4.885198	0.140693 0.164526	0.093100	0.003662 0.003958	0.067446 0.110520	1375 1201	40 36	1489 1266	74	7.65	1375 1201	40 36
BH1 BH1	13/07/2020 (2) 21:18:17.00 13/07/2020 (2) 21:19:42.00	BH1 - 2.285 BH1 - 2.286	722 279	36 431 5 114	25 1	6.430868 4.422822	0.343669 0.149097	0.106100 0.087500	0.003822 0.003650	-0.120500 0.022695	932 1314	44 39	1733 1371	66 79	46.23 4.13	932 1314	44 39
BH1 BH1	13/07/2020 (2) 21:25:48.00 13/07/2020 (2) 21:27:20.00	BH1 - 2.287 BH1 - 2.288	196 183	4 86 3 157	2	8.257638 5.417118	0.294711 0.184640	0.080300	0.004906	0.092420	737	24 33	1204	117 103	38.77 21.08	737	24 33
orii BH1 BH1	13/07/2020 (2) 21:28:48:00 13/07/2020 (2) 21:30:20:00 13/07/2020 (2) 21:30:20:00	BH1 - 2.289 BH1 - 2.290 BH1 - 2.200	120 272 1075	4 177 14 101 35 403	3	3.685957 5.277045 5.959233	0.177944	0.075700	0.003514	0.229710	1547 1119	93 34	1655	83 91	6.47 -2.99	1655 1119 1016	83 34 22
BH1 BH1	13/07/2020 (2) 21:33:14/.00 13/07/2020 (2) 21:33:16.00 13/07/2020 (2) 21:24:45 00	BH1 - 2.291 BH1 - 2.292 BH1 - 2.292	546 221	14 264 9 04	12 9 7	5.050505 4.048599	0.174982 0.139070	0.110000	0.007100	-0.038952 0.419050	1016 1165 1432	33 36	1113 1799 1462	/0 114	8.68 35.25	1165	35 36 43
8H1 8H1	13/07/2020 (2) 21:36:17.00 13/07/2020 (2) 21:42:20.00	BH1 - 2.294 BH1 - 2.295	112 141	3 60 2 88	2	4.418913 5.485464	0.158675	0.087900	0.004858	0.351180	1315	41 35	1379 1146	104 130	4.66 5,80	1315	41 35
BH1 BH1	13/07/2020 (2) 21:43:52.00 13/07/2020 (2) 21:45:21.00	BH1 - 2.296 BH1 - 2.297	104 385	2 49 6 292	1 2	4.516712 3.274394	0.165817 0.237034	0.088100 0.108500	0.004762 0.003670	0.234870 0.406350	1289 1718	42 103	1384 1774	101 61	6.83 3.13	1289 1774	42 61
BH1 BH1	13/07/2020 (2) 21:46:50.00 13/07/2020 (2) 21:48:21.00 12/07/2020 (2) 21:48:21.00	BH1 - 2.298 BH1 - 2.299 BH1 - 2.200	1122 216	40 191 4 237	29 5	6.146281 4.042037	0.258922 0.139658	0.090900	0.005218	0.866120	972 1425	37 43	1444 1625	106	32.69 12.31	972 1425	37 43 27

Sample ID	Analysis date-time	Spot ID <sup>1</sup>	238U conc.		232Th conc.				Isotopic Ratios			Appari	ent Ages - Calcu	lated in Isoplot R (	Ma)	Discord	Perferred age Ma cutof	1500 ff
			ppm	±2σ INT	ppm	±20 INT Analyses in	238U/206Pb	±2g PROP	207Pb/205Pb	±20 PROP	rho	238U/206Pb	±2σ PROP	207Pb/206Pb	±2σ PROP	(7/6-6/8)/7/6 *100	Ma	2σ
34DTB19-D	17/03/2020 (3) 17:06:51.00	34DTB19-D - 46	139	1	96	1	7.745933	0.292917	0.120700	0.004214	-0.278220	783	28	1966	62	60.18	783	28
34DTB19-D 34DTB19-D	17/03/2020 (3) 16:09:06:00 17/03/2020 (3) 17:40:26:00	34DTB19-D - 27 34DTB19-D - 63	96 221	2	139 81	3	5.213764 4.214075	0.185825	0.190700 0.201100	0.005414	0.008824 0.203960	1131 1373	37	2747 2834	47	58.83 51.57	1131 1373	37 63
34DTB19-D	17/03/2020 (3) 20:09:23.00	34DTB19-D - 118	140	6	207	17	4.585053	0.165281	0.149900	0.005098	-0.142240	1272	42	2344	58	45.74	1272	42
34DTB19-D 34DTB19-D	17/03/2020 (3) 19:13:54.00 17/03/2020 (3) 20:01:30.00	34DTB19-D - 95 34DTB19-D - 114	167 184	2	107	2 9	5.313496 4.484305	0.295433 0.371212	0.120000 0.140100	0.005400	0.532150	1112 1298	57	1955 2228	80 93	43.15 41.75	1112 1298	57 97
34DTB19-D 34DTB19-D	17/03/2020 (3) 17:32:31.00 17/03/2020 (3) 20:11:19.00	34DTB19-D - 59 34DTB19-D - 119	156	1	55	1	4.659832	0.171367	0.129300	0.004786	-0.227030	1253	42	2088	65 59	39.97 38.37	1253	42
34DTB19-D	17/03/2020 (3) 19:11:53.00	34DTB19-D - 94	35	2	48	4	5.797101	0.220122	0.100590	0.002992	-0.091675	1026	36	1634	55	37.22	1026	36
34DTB19-D 34DTB19-D	17/03/2020 (3) 16:28:50:00 17/03/2020 (3) 16:22:56:00	34DTB19-D - 37 34DTB19-D - 34	134 378	5 17	112 498	5 49	5.659310 4.775549	0.180445	0.102500	0.003850	0.312070 0.155280	1049 1226	31 50	1669 1833	70	37.15	1049 1226	31 50
34DTB19-D	17/03/2020 (3) 17:34:31.00	34DTB19-D - 60	51	1	60	2	6.093845	0.236995	0.091200	0.005024	0.224110	980	35	1450	105	32.44	980	35
34D1B19-D 34DTB19-D	17/03/2020 (3) 15:07:08:00 17/03/2020 (3) 15:47:15:00	34D1819-D - 26 34D1819-D - 21	214 170	2	309 84	3	4.130525	0.239574	0.092200	0.002844	0.165500	1007	34 73	14/1 1988	59	31.52 29.69	1007	34 73
34DTB19-D	17/03/2020 (3) 15:29:24.00	34DTB19-D - 12	128	2	141	7	3.933910	0.128200	0.127300	0.003846	0.414580	1460	43	2060	53	29.13	1460	43
34DTB19-D	17/03/2020 (3) 19:17:51.00	34DTB19-D - 97	126	1	98	2	4.168404	0.199784	0.117400	0.003748	0.480410	1386	60	1916	57	27.66	1386	60
34DTB19-D 34DTB19-D	17/03/2020 (3) 17:16:41.00 17/03/2020 (3) 19:03:59.00	34DTB19-D - 51 34DTB19-D - 90	163 181	2	121 203	1 2	4.081633 5.420054	0.248230 0.214158	0.118000 0.092300	0.004660	0.462280	1413 1092	77 40	1925 1473	71	26.63 25.88	1413 1092	40
34DTB19-D	17/03/2020 (3) 20:53:19:00	34DTB19-D - 130	83	1	111	1	4.210526	0.183490	0.113000	0.004060	0.271570	1374	54	1847	65	25.64	1374	54
34DTB19-D	17/03/2020 (3) 19:59:28:00	34DTB19-D - 113	72	3	69	3	4.098361	0.154192	0.114200	0.003820	0.312890	1472	48	1970	56	23.29 24.59	1408	48
34DTB19-D 34DTB19-D	17/03/2020 (3) 20:19:14.00 17/03/2020 (3) 17:18:43.00	34DTB19-D - 123 34DTB19-D - 52	264 85	4	168 105	3	3.971406 4.282655	0.252921 0.164520	0.117000 0.109000	0.004340 0.004380	0.589650	1448 1353	83 47	1910 1782	67 73	24.20 24.08	1448 1353	83 47
34DTB19-D	17/03/2020 (3) 18:30:03.00	34DTB19-D - 83	132	2	159	2	4.025765	0.177756	0.114000	0.004080	0.186450	1430	57	1863	65	23.24	1430	57
34DTB19-D	17/03/2020 (3) 20:25:12:00	34DTB19-D - 126	146	7	149	3	4.275331	0.187866	0.105100	0.003902	0.350580	1465	54	1715	68	21.19 21.01	1355	54
34DTB19-D 34DTB19-D	17/03/2020 (3) 20:47:17:00 17/03/2020 (3) 17:08:46:00	34DTB19-D - 127 34DTB19-D - 47	175	2	201	2	3.977725	0.228284 0.287184	0.111800	0.004036	-0.353530 -0.619190	1446 1521	74	1828 1915	66 86	20.92	1446 1915	74 85
34DTB19-D	17/03/2020 (3) 19:25:45.00	34DTB19-D - 101	92	10	125	17	3.581662	0.212745	0.122900	0.004058	0.567290	1587	84	1998	59	20.55	1998	59
34DTB19-D	17/03/2020 (3) 19:51:34.00	34DTB19-D - 109	263	14	130	15	2.112825	0.131537	0.240500	0.006110	-0.147070	2498	45	3123	40	20.48	3123	40
34DTB19-D 34DTB19-D	17/03/2020 (3) 20:23:12:00 17/03/2020 (3) 17:38:29:00	34DTB19-D - 125 34DTB19-D - 62	86 87	1	158 115	4	2.724796 4.198153	0.165864 0.143886	0.166100	0.005422	0.132830	2015 1377	105	2518 1710	55	19.96 19.45	2518 1377	55 43
34DTB19-D	17/03/2020 (3) 15:39:19.00	34DTB19-D - 17	112	5	132	12	3.636364	0.231405	0.119000	0.005980	0.737050	1566	89	1941	90	19.29	1941	90
34DTB19-D	17/03/2020 (3) 17:28:52:00	34DTB19-D - 98	135	4	88	3	5.420054	0.202407	0.087300	0.004348	-0.177010	1092	38	1360	50	18.50	1092	38
34DTB19-D 34DTB19-D	17/03/2020 (3) 16:38:44.00 17/03/2020 (3) 19:53:35.00	34DTB19-D - 42 34DTB19-D - 110	234	28	268 153	32	3.756574	0.230362	0.113300 0.111800	0.003866	0.067569	1522 1514	83 78	1852 1828	62	17.85 17.16	1852 1828	62 69
34DTB19-D	17/03/2020 (3) 17:26:36.00	34DTB19-D - 56	313	4	298	6	3.795066	0.234329	0.110900	0.003618	0.293960	1508	83	1813	59	16.86	1813	59
34D1B19-D 34DTB19-D	17/03/2020 (3) 17:24:56:00 17/03/2020 (3) 20:21:15:00	34D1819-D - 55 34DT819-D - 124	298	11	384	3	3.773585	0.1/5110	0.093800	0.003812	0.481930	1256	43	1503	114	16.45	1256	43 63
34DTB19-D 34DTB19-D	17/03/2020 (3) 18:26:05:00 17/03/2020 (3) 19:02:03:00	34DTB19-D - 81 34DTB19-D - 89	167 220	18 5	86 500	17	3.829950 5.246590	0.142607	0.107900	0.004458	0.396140	1496 1125	50 47	1763 1324	76 98	15.19	1496 1125	50 47
34DTB19-D	17/03/2020 (3) 20:07:22.00	34DTB19-D - 117	140	4	92	3	1.819174	0.109190	0.266000	0.007020	0.223990	2824	137	3282	42	13.96	3282	42
34D1B19-D 34DTB19-D	17/03/2020 (3) 17:36:29.31 17/03/2020 (3) 17:36:29.31	34D1819-D - 61 34DT819-D - 61	344	35	236	27	3.916960	0.231765	0.104200	0.004684	0.026379	1466	/8 67	1699	83	13.75	1466	78 67
34DTB19-D 34DTB19-D	17/03/2020 (3) 17:58:25.00 17/03/2020 (3) 18:54:05:00	34DTB19-D - 67 34DTB19-D - 85	125	3	161	3	3.658983	0.233838	0.109700	0.004094	0.269450	1558	88	1794	68	13.16	1794	68 58
34DTB19-D	17/03/2020 (3) 19:21:48.00	34DTB19-D - 99	68	1	101	1	3.489184	0.203702	0.113600	0.004172	0.310160	1625	84	1857	66	12.52	1857	66
34D1B19-D 34DTB19-D	17/03/2020 (3) 18:04:18:00 17/03/2020 (3) 18:58:07.00	34D1819-D - 70 34D1819-D - 87	111	2	83	3	3.556188	0.207775	0.112300	0.004046	0.114320	1608	84	1836	66	12.46	1836	66
34DTB19-D 34DTB19-D	17/03/2020 (3) 18:28:02.00 17/03/2020 (3) 17:54:29:00	34DTB19-D - 82 34DTB19-D - 65	452	18	242	15	3.371544	0.203839	0.116800	0.006336	-0.729320 0.187480	1674	89	1907	97 73	12.20	1907	97 73
34DTB19-D	17/03/2020 (3) 20:55:16.00	34DTB19-D - 131	408	8	430	22	4.411116	0.169946	0.093200	0.004364	0.199810	1317	46	1491	89	11.66	1317	46
34DTB19-D 34DTB19-D	17/03/2020 (3) 19:15:51.00 17/03/2020 (3) 16:30:50.00	34DTB19-D - 96 34DTB19-D - 38	444	2	600 115	4	3.571429 4.170142	0.211735 0.192960	0.109600 0.096100	0.004192	0.216820	1591 1386	84 58	1792 1549	70	11.19	1792 1386	70 58
34DTB19-D 34DTB19-D	17/03/2020 (3) 17:02:53.00 17/03/2020 (3) 15:11:05:00	34DTB19-D - 44 34DTB19-D - 28	77	4	133	20	3.417635	0.220196	0.112000	0.006840	-0.298140 0.204530	1655 1470	94 48	1831	111	9.65	1831	111
34DTB19-D	17/03/2020 (3) 18:02:23:00	34DTB19-D - 69	107	2	134	3	4.154549	0.141776	0.095400	0.003808	0.011862	1390	43	1535	75	9.43	1390	43
34DTB19-D 34DTB19-D	17/03/2020 (3) 16:01:11.00 17/03/2020 (3) 16:18:59.00	34DTB19-D - 23 34DTB19-D - 32	184 50	2	118 37	3	3.590664 4.006410	0.213635 0.145939	0.106900 0.097800	0.005038	0.311770 0.248960	1584 1436	84 47	1746 1582	86 70	9.31 9.19	1746 1436	85 47
34DTB19-D	17/03/2020 (3) 18:24:05:00	34DTB19-D - 80	199	6	147	5	3.415301	0.196613	0.111300	0.003626	0.078847	1656	84	1820	59	9.03	1820	59
34DTB19-D	17/03/2020 (3) 20:15:17:00	34DTB19-D - 121	152	3	118	2	3.262643	0.192991	0.114800	0.004496	-0.132080	1724	90	1876	71	8.12	1876	71
34DTB19-D 34DTB19-D	17/03/2020 (3) 17:20:38.00 17/03/2020 (3) 18:00:23.00	34DTB19-D - 53 34DTB19-D - 68	456 319	5 11	95 192	2	4.528986 2.376426	0.170575 0.143534	0.088800 0.160500	0.003476 0.004610	0.419220	1286 2264	44	1399 2460	75	8.07	1286 2460	44
34DTB19-D	17/03/2020 (3) 18:18:13:00	34DTB19-D - 77	127	2	187	6	3.483107	0.215247	0.108100	0.005262	0.348480	1627	89	1767	89	7.91	1767	89 72
34DTB19-D	17/03/2020 (3) 19:49:38:00	34DTB19-D - 108	378	29	220	13	3.696858	0.224271	0.102600	0.004152	0.347460	1543	83	1671	75	7.64	1671	75
34DTB19-D 34DTB19-D	17/03/2020 (3) 15:59:11.00 17/03/2020 (3) 20:17:18.00	34DTB19-D - 22 34DTB19-D - 122	66 121	3	71 115	5	3.379520 3.650968	0.193223 0.219645	0.110500 0.103400	0.003910 0.004668	0.216710 0.208840	1671 1561	84 83	1807 1685	64 83	7.52	1807 1685	64 83
34DTB19-D 34DTB19-D	17/03/2020 (3) 16:20:56.00 17/03/2020 (3) 19:57:32 00	34DTB19-D - 33 34DTB19-D - 112	380	14	236	16	3.877472	0.242932	0.098500	0.004070	-0.002632 0.369190	1479	83	1595	77	7.27	1479	83 68
34DTB19-D	17/03/2020 (3) 17:14:45.00	34DTB19-D - 50	128	2	108	1	3.299241	0.196605	0.112200	0.004144	0.241940	1707	89	1835	67	6.97	1835	67
34DTB19-D 34DTB19-D	17/03/2020 (3) 15:33:22.00 17/03/2020 (3) 16:34:47.00	34DTB19-D - 14 34DTB19-D - 40	127 406	4	340 44	8	3.486750 3.404835	0.203467 0.195619	0.106900 0.108700	0.003638	0.146790 0.276750	1626 1660	84 84	1746	62 60	6.92	1746	62 60
34DTB19-D 34DTB19-D	17/03/2020 (3) 16:15:03.00 17/03/2020 (3) 15:19:33.00	34DTB19-D - 30 34DTB19-D - 7	145 397	3 17	130 357	3 23	2.018163 3.418803	0.125896 0.208635	0.194000 0.108100	0.007880	0.159540	2594 1654	133 89	2776	67	6.53	2776	67 67
34DTB19-D	17/03/2020 (3) 18:14:15:00	34DTB19-D - 75	92	1	93	1	3.479471	0.214870	0.106500	0.003930	0.120810	1629	89	1740	68	6.38	1740	68
34DTB19-D	17/03/2020 (3) 20:51:18:00	34DTB19-D - 129	182	3	235	5	4.009623	0.149324	0.095000	0.005200	0.435870	1435	48	1540	103	6.01	1435	48
34DTB19-D 34DTB19-D	17/03/2020 (3) 15:27:28:00 17/03/2020 (3) 18:56:06:00	34DTB19-D - 11 34DTB19-D - 86	59 154	6	50 143	5	3.732736 3.254149	0.227921 0.192157	0.100100 0.111800	0.004302	0.000043	1530 1727	83 90	1625 1828	80	5.85 5.51	1625 1828	90 61
34DTB19-D	17/03/2020 (3) 15:07:39.00	34DTB19-D - 1	112	2	101	2	3.224766	0.189285	0.112600	0.004952	0.182320	1741	90	1841	80	5.42	1841	80
34DTB19-D	17/03/2020 (3) 15:35:22.00	34DTB19-D - 15	40	1	23	1	1.970055	0.117023	0.196200	0.005924	-0.148360	2646	129	2794	49	5.29	2794	49
34DTB19-D 34DTB19-D	17/03/2020 (3) 20:49:21.00 17/03/2020 (3) 16:26:53.00	34DTB19-D - 128 34DTB19-D - 36	87 200	5 16	316 171	50	3.502627 4.737091	0.205005	0.104600	0.003592	0.193570	1619 1235	84 39	1707	63 67	5.13	1707	63 39
34DTB19-D	17/03/2020 (3) 17:30:33.00	34DTB19-D - 58	505	27	277	19	1.950458	0.115095	0.198200	0.005964	0.256330	2668	129	2811	49	5.07	2811	49
34DTB19-D	17/03/2020 (3) 19:23:45:00	34DTB19-D - 100	40	0	39	1	4.299226	0.183946	0.089700	0.004594	-0.063333	1348	52	1418	98	4.95	1348	52
34DTB19-D 34DTB19-D	17/03/2020 (3) 15:25:27.00 17/03/2020 (3) 19:55:32.00	34DTB19-D - 10 34DTB19-D - 111	302 188	8	274	5	3.280840 3.445899	0.194784 0.199534	0.110000	0.004400 0.003710	0.054274 0.191490	1715 1643	89 84	1799	73	4.64	1799	73 65
34DTB19-D	17/03/2020 (3) 16:32:47.00	34DTB19-D - 39	67	1	148	2	3.355705	0.202243	0.107500	0.003850	0.104480	1681	89	1757	66	4.28	1757	66
34DTB19-D	17/03/2020 (3) 18:08:16:00	34DTB19-D - 72	213	4	369	6	3.204101	0.187277	0.111300	0.003826	0.040722	1751	90	1820	62	3.79	1820	62
34DTB19-D 34DTB19-D	17/03/2020 (3) 19:47:37.00 17/03/2020 (3) 17:12:44.00	34DTB19-D - 107 34DTB19-D - 49	250 110	9	424 89	47	1.451589 3.954132	0.085924 0.130679	0.306600 0.093900	0.009032	0.303660 0.028249	3378 1453	156 43	3503 1505	46	3.56	3503 1453	46 43
34DTB19-D	17/03/2020 (3) 15:43:16.00	34DTB19-D - 19	196	1	173	2	4.127115	0.148971	0.091100	0.003122	-0.014691	1399	45	1448	65	3.40	1399	45
34DTB19-D	17/03/2020 (3) 17:22:40.00	34DTB19-D - 54	112	3	177	4	3.258390	0.192573	0.108800	0.004516	0.352160	1725	43	1779	51	2.99	1334	60
34DTB19-D 34DTB19-D	17/03/2020 (3) 19:33:39.00 17/03/2020 (3) 19:00:03.00	34DTB19-D - 105 34DTB19-D - 88	131 34	6 4	108 44	6 2	3.345601 4.025765	0.201229 0.142101	0.105900 0.092000	0.003818	0.111380 0.343650	1686 1430	89 45	1729 1467	66 81	2.50	1729 1430	66 45
34DTB19-D	17/03/2020 (3) 19:09:57.00	34DTB19-D - 93	330	12	475	34	3.328895	0.199556	0.106300	0.003726	0.205110	1693	89	1736	64	2.47	1736	64 72
34DTB19-D	17/03/2020 (3) 15:15:36.00	34DTB19-D - 5	123	6	86	3	1.900418	0.110240	0.195800	0.005316	0.074372	2725	129	2791	45	2.34	2791	45
34DTB19-D 34DTB19-D	17/03/2020 (3) 20:57:17.00 17/03/2020 (3) 19:29:43.00	34DTB19-D - 132 34DTB19-D - 103	226	2	223 409	6	4.042037 3.216468	0.124954 0.188477	0.091600 0.108900	0.003532 0.004078	0.313740 0.302340	1425 1745	40 90	1458 1780	73	2.28	1425 1780	40 68
34DTB19-D 34DTB19-D	17/03/2020 (3) 15:17:32.00 17/03/2020 (3) 18:22:08:00	34DTB19-D - 6 34DTB19-D - 79	157	3	122	4	3.480682	0.202880	0.102000	0.003640	-0.139090 0.227830	1628 1765	84	1660	66	1.93	1660	66 61
34DTB19-D	17/03/2020 (3) 16:03:12.00	34DTB19-D - 24	183	1	150	3	3.438790	0.210679	0.102900	0.003958	0.173100	1646	89	1676	71	1.83	1676	71
34DTB19-D 34DTB19-D	17/03/2020 (3) 20:03:26.00 17/03/2020 (3) 16:36:43.00	34DTB19-D - 115 34DTB19-D - 41	115 241	5	119 233	9 2	3.567606 4.940711	0.211358 0.154959	0.099900 0.080400	0.003998	0.336890 0.428380	1593 1188	84 34	1621 1206	75	1.76 1.47	1621 1188	75 34
34DTB19-D 34DTB19-D	17/03/2020 (3) 15:31:25:00 17/03/2020 (3) 18:16:12:00	34DTB19-D - 13 34DTB19-D - 74	163	1	161 92	1	3.156566	0.182698	0.109800	0.003696	0.052161	1774	90	1795	61 94	1.18	1795	61 43
34DTB19-D	17/03/2020 (3) 15:41:16:00	34DTB19-D - 18	143	9	54	2	4.522840	0.166144	0.084400	0.004388	0.423270	13/1 1288	43	1301	101	1.08	1288	43
34DTB19-D 34DTB19-D	17/03/2020 (3) 19:45:37.00 17/03/2020 (3) 19:06:00.00	34DTB19-D - 106 34DTB19-D - 91	64 78	1	70 58	2	1.866716 4.185852	0.110512 0.132777	0.196000 0.088500	0.006220	0.221770 0.218840	2765 1381	133 39	2792 1393	52 77	0.97	2792 1381	52 39
34DTB19-D	17/03/2020 (3) 17:56:24.00	34DTB19-D - 66	601	11	681	15	3.310162	0.197689	0.104900	0.004198	0.271890	1702	89	1712	74	0.58	1712	74
34DTB19-D	17/03/2020 (3) 18:12:14.00	34DTB19-D - 74	178	4	192	3	2.153316	0.126528	0.160900	0.005218	-0.025219	2459	120	2464	55	0.35	2464	55
34DTB19-D 34DTB19-D	17/03/2020 (3) 15:13:35.00 17/03/2020 (3) 15:21:29.00	34DTB19-D - 4 34DTB19-D - 8	148 202	3	80 147	2	1.968117 2.115059	0.116832 0.122824	0.180200 0.164200	0.005204	0.260800	2649 2496	129 120	2654 2499	48 57	0.21 0.11	2654 2499	48 57
34DTB19-D 34DTB19-D	17/03/2020 (3) 19:31:39.00	34DTB19-D - 104 34DTB19-D - 2	139	4	158	7	3.220612	0.188880	0.106700	0.004134	0.007022	1743	90	1743	71	-0.01	1743	71
34DTB19-D	17/03/2020 (3) 18:20:08.00	34DTB19-D - 78	131	2	176	3	3.537319	0.208385	0.098800	0.004076	0.281040	1605	84	1601	77	0.26	1601	77
34DTB19-D	17/03/2020 (3) 16:05:06:00 17/03/2020 (3) 16:17:00:00	34DTB19-D - 25 34DTB19-D - 31	82 143	1	48 88	8	4.355401	0.094642	0.236600	0.006432	0.079229	3111 1332	145 39	3097 1324	43 80	-0.65	1332	39
34DTB19-D 34DTB19-D	17/03/2020 (3) 15:37:18.00 17/03/2020 (3) 15:45:14.00	34DTB19-D - 16 34DTB19-D - 20	142 59	1	96 115	1	3.208213 3.195909	0.187676	0.105300 0.105600	0.003206	0.258750 0.332620	1749 1755	90 90	1719 1774	56	-1.77 -1 sn	1719 1724	56 92
34DTB19-D	17/03/2020 (3) 15:23:30.00	34DTB19-D - 9	587	16	285	6	3.138732	0.180994	0.106900	0.003738	0.289200	1783	90	1746	64	-2.09	1746	64

Sample ID	Analysis date-time	Spot ID <sup>1</sup>	238U conc.	±2σ INT	232Th conc.	±2σ INT	238U/206Pb	±2σ PROP	207Pb/205Pb	±2σ PROP	rho	Appar 238U/206Pb	ent Ages - Calcu ±2σ PROP	lated in Isoplot R ( 207Pb/206Pb	Ma) ±2σ PROP	Discord (7/6-6/8)/7/6 *100	Perferred age Ma cutoff	/ 1500 ff
05DTB19	2020-07-30 17:46:53.00	005DTB19q - 34 - 1.d	52 67	1	58 56	1	7.900234	0.326350	0.071568	0.006914	0.381941	768	30	973	197	21.02	Ma 3 768 727	30
05DTB19 05DTB18	2020-07-30 16:58:40.00	005DTB19q - 3 - 1.d 05DTB18+ 100	44	1	36	1	7.899340	0.334711	0.065052	0.006816	0.267513	768	31	775	220	0.86	768	31
05DTB18 05DTB18	10/05/2019 (6) 04:22:40.00	05DTB18 - 30 05DTB18 - 1	317	9	68	2	4.545455	0.380165	0.151000	0.032020	-0.901520	1282	90	2357	323	45.61	1282	90
05DTB18 05DTB18	10/05/2019 (6) 07:24:37.00 10/05/2019 (6) 04:07:38.00	05DTB18 - 104 05DTB18 - 22	65 53	4	51 30	2	4.306632 3.669725	0.199270	0.131100 0.153400	0.010022	0.432390	1346 1554	54	2112 2383	129	36.27 34.82	1346 2383	54 107
05DTB18 05DTB18	10/05/2019 (6) 07:05:50.00 10/05/2019 (6) 05:17:52.00	05DTB18 - 94 05DTB18 - 51	131 499	4 53	56 50	2	7.153076	0.270978	0.081600	0.005232	0.261190	844 1042	29 42	1235 1467	122	31.70 28.98	844 1042	29 42
05DTB18 05DTB18	10/05/2019 (6) 05:38:35.00 10/05/2019 (6) 05:06:33.00	05DTB18 - 59 05DTB18 - 45	311 94	18 8	108 86	6 7	4.737091 5.356186	0.188990 0.213272	0.104800 0.094100	0.008996	-0.141370 0.173600	1235 1104	43 39	1710 1509	151 160	27.80 26.89	1235 1104	43 39
05DTB18 05DTB18	10/05/2019 (6) 05:08:27.00 10/05/2019 (6) 04:32:06.00	05DTB18 - 46 05DTB18 - 35	216 120	9 5	112 52	5	5.200208 5.120328	0.309525	0.093000	0.015860 0.013880	0.319070 0.376100	1134 1150	59 59	1487 1507	293 257	23.75 23.69	1134 1150	59 59
05DTB18 05DTB18	10/05/2019 (6) 05:12:12.00 10/05/2019 (6) 05:48:04.00	05DTB18 - 48 05DTB18 - 64	236 89	9 4	219 49	8 3	4.208754 4.409171	0.155030 0.265095	0.107400 0.103000	0.010048	0.202410 0.310250	1374 1318	44 68	1755 1678	163 249	21.69 21.47	1374 1318	44 68
05DTB18 05DTB18	10/05/2019 (6) 07:47:19.00 10/05/2019 (6) 05:51:48.00	05DTB18 - 113 05DTB18 - 66	137 189	6 11	70 118	4	3.736921 5.414185	0.159922 0.210881	0.118800 0.087700	0.006576	0.285930 0.393970	1529 1093	56 38	1937 1375	97 156	21.10 20.54	1937 1093	97 38
05DTB18 05DTB18	10/05/2019 (6) 05:46:07.96 10/05/2019 (6) 05:42:23.00	05DTB18 - 63 05DTB18 - 61	240 208	9 5	146 152	6 3	5.512679 5.527916	0.234851 0.260292	0.085000	0.007620	0.074597	1075 1072	41 45	1337 1324	163 238	19.64 19.04	1075 1072	41 45
05DTB18 05DTB18	10/05/2019 (6) 06:43:02.00 10/05/2019 (6) 05:15:57.00	05DTB18 - 86 05DTB18 - 50	564 216	8 8	523 88	10 4	3.477051 5.656109	0.148125 0.205898	0.122500 0.083400	0.007450 0.005868	0.349260 0.131870	1630 1049	59 34	1992 1278	105 132	18.21 17.86	1992 1049	105 34
05DTB18 05DTB18	10/05/2019 (6) 05:27:12.00 10/05/2019 (6) 06:03:20.00	05DTB18 - 56 05DTB18 - 68	323 707	11 29	137 208	5 8	6.265664 3.259452	0.309828 0.136370	0.078400 0.129100	0.009768	0.115780	955 1725	42	1156 2085	230 140	17.42 17.27	955 2085	42 140
05DTB18 05DTB18	10/05/2019 (6) 05:02:43.00 10/05/2019 (6) 03:44:51.00	05DTB18 - 44 05DTB18 - 14	85 437	6 13	62 228	6 7	3.849115 5.224660	0.173284 0.221871	0.107400 0.085600	0.011448 0.010412	0.349430 0.421900	1489 1129	58 42	1755 1328	184 220	15.16 15.00	1489 1129	58 42
05DTB18 05DTB18	10/05/2019 (6) 05:40:33.00 10/05/2019 (6) 08:23:21.36	05DTB18 - 60 05DTB18 - 127	960 212	63 10	612 73	50 4	3.680530 6.527415	0.126441 0.266891	0.111200 0.075400	0.007724 0.006208	0.070402 0.160230	1549 919	46 34	1818 1078	122	14.79 14.78	1818 919	122 34
05DTB18 05DTB18	10/05/2019 (6) 08:36:30.00 10/05/2019 (6) 03:52:23.00	05DTB18 - 134 05DTB18 - 18	78 272	2	49 145	2 4	5.070994 5.561735	0.345712 0.367978	0.086000 0.081000	0.017720	0.256850	1160 1066	68 61	1337 1221	355 339	13.22 12.70	1160 1066	68 61
05DTB18 05DTB18	10/05/2019 (6) 05:25:22.00 10/05/2019 (6) 03:48:37.00	05DTB18 - 55 05DTB18 - 16	994 101	54 4	134 78	12 3	5.437738 5.899705	0.392617 0.292027	0.082000 0.078100	0.018640 0.010462	-0.072093 0.198300	1088 1009	68 44	1245 1149	391 246	12.59 12.15	1088 1009	68 44
05DTB18 05DTB18	10/05/2019 (6) 08:15:52.00 10/05/2019 (6) 05:49:53.00	05DTB18 - 123 05DTB18 - 65	258 52	20	370 28	22	5.411255 3.173596	0.254634 0.124909	0.081800 0.122800	0.009436	0.131130 0.296400	1093 1766	45 59	1240 1997	212	11.84 11.56	1093 1997	45
05DTB18 05DTB18	10/05/2019 (6) 05:00:43.00 10/05/2019 (6) 05:19:43.00	05DTB18 - 43 05DTB18 - 52	92 163	6 7	63 85	4	5.112474 4.403347	0.185889 0.188892	0.084400 0.093000	0.005988	0.061501 0.312250	1152 1319	37 49	1301 1487	133 177	11.47 11.28	1152 1319	37 49
05DTB18 05DTB18	10/05/2019 (6) 05:14:04.59 10/05/2019 (6) 08:08:21.00	05DTB18 - 49 05DTB18 - 119	100 290	4	39 104	2	2.232143 5.073567	0.129345	0.184000	0.016680	-0.141060 0.318610	2386 1160	110	2689 1299	143	11.24	2689 1160	143
05DTB18	10/05/2019 (6) 05:10:21:00 10/05/2019 (6) 06:22:25:00	05D1B18 - 47 05DTB18 - 75	155	41	113	8	5.455537	0.189499	0.080100	0.005502	0.226950	1456	34	1616	197	9.89	1456	34
05DTB18	10/05/2019 (6) 05:21:38:00 10/05/2019 (6) 05:29:07:00	05D1B18 - 53 05DTB18 - 57	332	20	38	9	2.999400	0.110368	0.125600	0.013640	0.031923	1132	55	2037	112	9.10	2037	112
05DTB18	10/05/2019 (6) 08:28:58:00 10/05/2019 (6) 04:47:26:00	05DTB18 - 130 05DTB18 - 40	274	12	93	4	5.787037	0.199465	0.076800	0.005536	0.500720	1050	62 32	1146	333	8.42	1050	32
05DTB18	10/05/2019 (6) 08:34:39.00 10/05/2019 (6) 08:34:39.00	05DTB18 - 35 05DTB18 - 133	326	42	105	17	4.631774	0.233679	0.075600	0.006842	0.175410	1260	36	1352	145	7.46	1260	36
05DTB18	10/05/2019 (6) 05:23:27.00	05DTB18 - 54	87	10	220	2	4.488330	0.062111	0.285100	0.015302	0.305790	3213	53	1384	1/9	5.29	3390	82
05DTB18 05DTB18	10/05/2019 (6) 03:22:10:00 10/05/2019 (6) 07:00:08:00 10/05/2019 (6) 04:11:22:00	05DTB18 - 5 05DTB18 - 91 05DTB18 - 24	77	13	90 119	18 3 5	3.607504	0.127650 0.155440 0.282660	0.103600	0.010728	0.430130	1510	50	1689	11/ 185	4.5/ 4.36	1689 1649	117
05DTB18 05DTB18	10/05/2019 (6) 04:11:23:00 10/05/2019 (6) 05:30:58:00 10/05/2019 (6) 03:34:02 86	05DTB18 - 24 05DTB18 - 58	63	3	38	1	5.652911	0.253662	0.076000	0.013520	-0.012621	1050	42	1094	321	4.02	1050	42
05DTB18	10/05/2019 (6) 04:28:21.00 10/05/2019 (6) 04:28:21.00	05DTB18 - 33 05DTB18 - 77	59	2	26	2	1.652893	0.065843	0.239600	0.013692	0.438260	3050	94	3117	89	2.14	3117	89
05DTB18	10/05/2019 (6) 03:43:01.00 10/05/2019 (6) 04:36:36.00	05DTB18 - 13	339	23	303	21	2.070393	0.084273	0.172900	0.012458	0.440290	2540	83	2585	116	1.74	2585	116
05DTB18 05DTB18	10/05/2019 (6) 05:30:32:00 10/05/2019 (6) 05:33:41 00	05DTB18 - 17 05DTB18 - 81	107	5	121	5	5.299417	0.204282	0.077300	0.006546	0.138120	1114	38	1128	161	1.21	1114	38
05DTB18 05DTB18	10/05/2019 (6) 04:15:09:00	05DTB18 - 26 05DTB18 - 115	122	3	93 31	2	2.958580	0.164210	0.116000	0.013320	0.479220	1877	86	1895	194	0.93	1895	194
05DTB18 05DTB18	10/05/2019 (6) 06:50:33.23	05DTB18 - 90 05DTB18 - 87	307	12	210	19	2.100840	0.094979	0.165400	0.009408	0.300880	2510 1492	91	2511	93	0.04	2511	93
05DTB18 05DTB18	10/05/2019 (6) 04:30:11.00 10/05/2019 (6) 04:17:04.00	05DTB18 - 34 05DTB18 - 27	106	7	83 64	6	4.081633 4.870921	0.174927	0.089200	0.009284	0.285230	1413 1204	52	1408	188	-0.36	1413 1204	52
05DTB18 05DTB18	10/05/2019 (6) 04:24:35.00 10/05/2019 (6) 08:06:26.00	05DTB18 - 31 05DTB18 - 118	359 91	12 7	305 30	9 2	5.379236 3.060912	0.188606	0.076000 0.110900	0.006520	0.241950 0.250080	1099 1822	34 64	1094 1813	164 125	-0.45 -0.50	1099 1813	34 125
05DTB18 05DTB18	10/05/2019 (6) 04:35:52.00 10/05/2019 (6) 04:18:55.00	05DTB18 - 37 05DTB18 - 28	92 266	9 15	71 118	9 7	4.585053 5.078720	0.190508	0.082800 0.078200	0.007356	0.139560 0.219640	1272 1159	46 35	1264 1151	165 136	-0.65 -0.66	1272 1159	46 35
05DTB18 05DTB18	10/05/2019 (6) 03:10:35.00 10/05/2019 (6) 04:03:54.00	05DTB18 - 2 05DTB18 - 20	177 246	10 13	70 119	6 7	4.101723 5.476451	0.169520	0.088700 0.075200	0.008274 0.006704	0.169690 0.324330	1406 1081	50 37	1397 1073	170 170	-0.69 -0.77	1406 1081	50 37
05DTB18 05DTB18	10/05/2019 (6) 04:49:17.00 10/05/2019 (6) 04:20:50.00	05DTB18 - 41 05DTB18 - 29	116 112	6 3	50 71	3 3	4.861449 3.943218	0.255575 0.201701	0.080000	0.012600 0.009814	0.017481 0.161860	1206 1457	55	1196 1440	284 194	-0.83 -1.22	1206 1457	55 64
05DTB18 05DTB18	10/05/2019 (6) 08:30:54.00 10/05/2019 (6) 04:09:32.99	05DTB18 - 131 05DTB18 - 23	309 53	10 1	93 42	4	3.000300 2.087683	0.142823 0.085338	0.112000 0.163400	0.012240 0.009968	0.462550 0.281500	1854 2523	74 83	1831 2490	187 100	-1.26	1831 2490	187 100
05DTB18 05DTB18	10/05/2019 (6) 03:39:13.00 10/05/2019 (6) 08:10:11.00	05DTB18 - 11 05DTB18 - 120	353 126	19 5	527 42	28 3	5.151984 4.796163	0.201249 0.247744	0.077100 0.080100	0.007142 0.009502	0.298430	1144 1221	40 55	1123 1199	175 218	-1.84 -1.85	1144 1221	40 55
05DTB18 05DTB18	10/05/2019 (6) 06:31:46.00 10/05/2019 (6) 08:04:35.00	05DTB18 - 80 05DTB18 - 117	265 214	13 6	111 97	7	4.531038 5.797101	0.195325 0.203319	0.082700 0.072700	0.007354 0.004654	0.248180 -0.174400	1286 1026	48	1261 1005	165 126	-1.93 -2.11	1286 1026	48 32
05DTB18 05DTB18	10/05/2019 (6) 07:09:35.00 10/05/2019 (6) 07:20:52.00	05DTB18 - 96 05DTB18 - 102	123 496	7 21	57 234	4 10	2.114165 4.342162	0.085980 0.218824	0.158400 0.084500	0.012768	0.311320 0.098184	2497 1336	82 58	2438 1303	131 233	-2.41 -2.54	2438 1336	131 58
05DTB18 05DTB18	10/05/2019 (6) 07:30:17.00 10/05/2019 (6) 04:01:57.00	05DTB18 - 107 05DTB18 - 19	81 345	3 16	57 348	3 23	2.907822 3.401361	0.124954 0.183720	0.113500 0.099600	0.011770 0.010592	0.302500 0.153490	1905 1662	68 76	1855 1616	177	-2.69 -2.83	1855 1616	177 187
05DTB18 05DTB18	10/05/2019 (6) 06:46:48.00 10/05/2019 (6) 07:41:43.00	05DTB18 - 88 05DTB18 - 110	431 182	13 8	131 32	5	4.854369 3.197953	0.276181 0.113048	0.079000 0.104100	0.016580	0.298700 0.277770	1208 1754	60 53	1171 1698	369 121	-3.12 -3.32	1208 1698	60 121
05DTB18 05DTB18	10/05/2019 (6) 08:38:25.00 10/05/2019 (6) 08:12:06.00	05DTB18 - 135 05DTB18 - 121	110 168	4 5	59 70	2	4.083299 4.355401	0.148359 0.227482	0.087300 0.083900	0.006046	0.199990 0.065307	1412 1332	45 60	1366 1289	129 225	-3.35 -3.37	1412 1332	45 60
05DTB18 05DTB18	10/05/2019 (6) 08:19:37.00 10/05/2019 (6) 07:37:54.00	05DTB18 - 125 05DTB18 - 108	71 227	4 10	50 62	3	5.120328 5.293806	0.288553 0.220776	0.076500 0.075200	0.011330 0.007404	0.328020 0.344130	1150 1115	56 41	1107 1073	272	-3.88 -3.96	1150 1115	56 41
05DTB18 05DTB18	10/05/2019 (6) 06:24:15:00 10/05/2019 (6) 06:35:31:00	05DTB18 - 76 05DTB18 - 82	109 264	5	52 174	2 4	3.355705 5.370569	0.202243 0.208362	0.099500 0.074500	0.007990	-0.227800 0.411850	1681 1101	85 38	1614 1054	143 162	-4.18 -4.43	1614 1101	143
05DTB18 05DTB18	10/05/2019 (6) 08:13:57.00 10/05/2019 (6) 07:45:29.00	05DTB18 - 122 05DTB18 - 112	425	21 8	163 94	11 6	2.999400 3.163556	0.105870 0.113312	0.108600	0.007072	0.266290 0.173210	1855 1771	55 54	1775 1694	115	-4.48 -4.52	1775 1694	115
05D1818 05DTB18	10/05/2019 (6) 03:18:19.00 10/05/2019 (6) 03:25:55.00	05D1818 - 3 05DTB18 - 7	53 100	4	32 54	1	2.799552	0.087264	0.115000	0.019000	0.228070	1969 2961	65 116	1879 2826	154	-4.78 -4.80	1879 2826	154
05DTB18 05DTB18	10/05/2019 (6) 07:26:32:00 10/05/2019 (6) 08:02:40.00	05DTB18 - 105 05DTB18 - 116	281	3	93 39	4	3.990423 2.707826	0.164203	0.087600	0.008152	0.300890	1442 2026	51	1373 1928	170	-5.00	1442 1928	51 104
05D1818 05DTB18	10/05/2019 (6) 07:02:04.00 10/05/2019 (6) 06:41:12.00	05D1818 - 92 05DTB18 - 85	599 169	23 8	/31 126	23 6	1.852538 4.518753	0.192471	0.1/9400 0.081200	0.008124	0.288970	2783	78	2647	91 186	-5.14 -5.17	2647 1289	91 48
05D1818 05DT818	10/05/2019 (6) 03:29:40.00 10/05/2019 (6) 06:48:42.00 10/05/2019 (6) 06:25:12.00	05D7B18 - 9 05D7B18 - 89	194 118 27	6	62	в 3	3.189793	0.11/7632	0.102000	0.006872	0.202880	1468	57	1395	143	-5.24	1468	142
05DTB18 05DTB18	10/05/2019 (6) 08:32:44.00 10/05/2019 (6) 08:32:44.00	05DTB18 - 125 05DTB18 - 132 05DTB18 - 00	3/ 162 97	8	38 56 79	3	3.080715 5.762695	0.139600 0.117610 0.259130	0.104600	0.006544	0.181030	1446 1812 1024	44	1354	139	-6.19	1021	117
05DTB18 05DTB18	10/05/2019 (6) 07:15:18:00 10/05/2019 (6) 04:05:48:00 10/05/2019 (6) 06:18:28:00	05DTB18 - 21 05DTB18 - 21	274	14	96	5	3.891051	0.173205	0.087600	0.008752	0.255710	1475	56	1373	182	-7.40	1475	56
05DTB18	10/05/2019 (6) 03:46:47.00 10/05/2019 (6) 05:37:36:00	05DTB18 - 15	56	2	20	1	4.482295	0.222246	0.080400	0.008908	-0.044879	1298	56	1205	205	-7.65	1298	56
05DTB18	10/05/2019 (6) 06:57:28:00 10/05/2019 (6) 07:11:31:00	05DTB18 - 97	140	8	80	5	2.906977	0.113068	0.108100	0.008362	0.230690	1395	62	1757	136	-7.81	1393	136
05DTB18 05DTB19	10/05/2019 (6) 06:05:10:00	05DTB18 - 69 05DTB18 - 95	487	→ 58 7	176	19	4.456328	0.148703	0.080000	0.005900	0.194740	1305	38	1382	140	-9.11	1305	38
05DTB18 05DTB19	10/05/2019 (6) 05:07:05:00	05DTB18 - 70 05DTB18 - 10	+30 99 2/2	3	58	3	2.613013	0.107566	0.116900	0.009438	0.238720	2089	46	1909	154	-9.45	1909	139
05DTB18 05DTB18	10/05/2019 (6) 07:19:02:00 10/05/2019 (6) 07:19:02:00 10/05/2019 (6) 07:39:47:00	05DTB18 - 101 05DTB18 - 109	100	2	49	1 5	5.109862	0.177918	0.074400	0.005488	0.223190	1152	36	1051 1053	143	-9.59	1152	36
05DTB18 05DTB18	10/05/2019 (6) 07:13:21.00 10/05/2019 (6) 07:28:22.00	05DTB18 - 98 05DTB18 - 105	162 150	7	103 118	4	5.428882 4.017678	0.211732	0.072200	0.007544	0.358080	1090	38	991	200	-10.01	1090 1433	38 51
05DTB18 05DTB18	10/05/2019 (6) 06:20:30.00 10/05/2019 (6) 03:41:07.00	05DTB18 - 74 05DTB18 - 12	470	13 10	250 59	11 4	3.787879	0.194846	0.086800	0.008536	0.088670	1510	66	1355 1030	180	-11.44	1355 1151	180 52
05DTB18 05DTB18	10/05/2019 (6) 03:20:19.00 10/05/2019 (6) 04:37:42.00	05DTB18 - 4 05DTB18 - 38	181 203	8 23	162 52	7	5.260389	0.243566	0.072500	0.009550	0.207730	1122	46 70	999 1315	248	-12.30	1122	46 70
05DTB18 05DTB18	10/05/2019 (6) 06:14:49.00 10/05/2019 (6) 08:17:47 00	05DTB18 - 71 05DTB18 - 174	134	2	106	5 20	5.133470	0.345113	0.073000	0.016460	0.200780	1147	67 #4	1013	401	-13.26	1147	67 45
05DTB18 05DTB18	10/05/2019 (6) 08:21:28:00 10/05/2019 (6) 07:43:34 00	05DTB18 - 126 05DTB18 - 111	97	4	120	6	4.923683	0.176050	0.073800	0.005476	0.234300	1192 1091	-+0 38 90	1035	144	-15.15	1192	38
05DTB18 05DTB18	10/05/2019 (6) 06:28:01.00 10/05/2019 (6) 06:28:01.00	05DTB18 - 78 05DTB18 - 39	157	7	53	2 7	5.347594	0.269953	0.070800	0.008216	0.316110	1105	49	943 951 1175	222	-15.24	1105	49
05DTB18 05DTB18	10/05/2019 (6) 04:51:11:00 10/05/2019 (6) 08:27:08 00	05DTB18 - 42 05DTB18 - 179	*36 279	3 15	75 211	3	4.759638	0.183544	0.074500	0.006790	0.289450	1310 1229 1370	53 42 54	1054	261 174 202	-16.63 .17.72	1229	42
05DTB18 05DTB18	10/05/2019 (6) 07:22:47.00 10/05/2019 (6) 03:27:51.00	05DTB18 - 103 05DTB18 - 8	493	8	431	6	3.332223 5.184033	0.162136	0.090600	0.011112	0.320890	1692 1137	69	1437	218	-17.70	1437 1137	218
05DTB18 05DTB18	10/05/2019 (6) 06:16:44.00 10/05/2019 (6) 04:13:18.00	05DTB18 - 72 05DTB18 - 25	530 104	11 2	199 35	10 1	5.205622	0.193537 0.244294	0.070600	0.005812	0.184510	1133	37 38	945 843	161	-19.88	1133 1024	37 38
05DTB18 05DTB18	10/05/2019 (6) 06:29:56.00 10/05/2019 (6) 07:51:08.00	05DTB18 - 79 05DTB18 - 114	286	16 22	117 170	6	4.472272 5.434783	0.205453 0.259334	0.072800	0.007556	0.261410 0.094544	1301 1089	52	1008	198	-29.12	1301 1089	52 46

Sample ID	Analysis date-time	Spot ID <sup>1</sup>	238U conc.	±2σ INT	232Th conc.	±2σ INT	238U/206Pb	±2σ PROP	Isotopic Ratios 207Pb/206Pb	±2σ PROP	rho	Appari 238U/206Pb	ant Ages - Calcu ±2σ PROP	lated in Isoplot R   207Pb/206Pb	Ma) ±2σ PROP	Discord (7/6-6/8)/7/6 *100	Perferred age 1500 Ma cutoff Ma 2 σ
04DTB19 04DTB19	2020-07-30 17:50:21.00 2020-07-30 18:00:51.00	004DTB19q - 81 - 1.d 004DTB19q - 105 - 1.d	949 91	25 3	634 120	21 5	10.913784 7.916175	0.338738 0.276437	0.081224 0.073040	0.004798 0.006074	0.229592 0.135852	565 767	17 25	1226 1014	116 169	53.90 24.39	565 17 767 25
04DTB19 04DTB19	2020-07-30 16:51:48.00 2020-07-30 16:43:04.00	1004DTB19q - 178 - 1.d 1004DTB19q - 130 - 1.d	43 54	1	49 52	1	7.788034	0.317423 0.307937	0.072134 0.067890	0.007388	0.262568	779	30 29	989 864	208	21.24	779 30 773 29
04DTB19 04DTB19 04DTB19	2020-07-30 16:55:14.00 2020-07-30 16:53:32.00 2020-07-20 16:53:32.00	004DTB19q - 64 - 1.d 004DTB19q - 34 - 1.d	66 50	2	117 76 52	3	7.999056 7.734419 7.902501	0.296865 0.309947 0.205847	0.067140 0.067967 0.067388	0.005979 0.006692	0.270946 0.185005	759 784 777	27 30	841 867 940	185 204 204	9.73 9.55	759 27 784 30 777 39
04DTB19 04DTB19 04DTB19	2020-07-30 17:59:06.00 2020-07-30 17:59:06.00 2020-07-30 17:48:39.00	1004DTB19q - 123 - 1.0 1004DTB19q - 117 - 1.d 1004DTB19q - 91 - 1.d	388	13	290 32	11 2	8.231249	0.246160	0.065752	0.004189	0.236775 0.149369	739	29 21 39	798 1191	134	7.33	739 21 1145 39
04DTB19 04DTB18	2020-07-30 16:41:25.00 14/07/2020 (3) 03:00:43.00	004DTB19q - 130b - 1.d 04DTB18 - 2.172	60 939	1 19	58 1043	1 28	7.962577 7.434944	0.310366 0.353229	0.064635 0.227000	0.006098	0.119656	763 814	28 35	762 3030	199 132	-0.15 73.15	763 28 814 35
04DTB18 04DTB18	13/07/2020 (2) 23:01:38.00 14/07/2020 (3) 02:27:57.00	04DTB18 - 2.39 04DTB18 - 2.153	710 875	13 17	283 342	7	9.765625 4.308488	0.414658 0.173416	0.090700 0.189900	0.003514 0.005598	0.059785 0.322420	628 1346	24 47	1440 2741	73 48	56.34 50.90	628 24 1346 47
04DTB18 04DTB18	10/05/2019 (6) 00:48:05.51 13/07/2020 (2) 22:12:22:00	04DTB18 - 11 04DTB18 - 2.12	135	4	138 758	23	7.272727 6.341154	0.462810	0.103000	0.018060	0.316360	831 944	47	1678 1865	294 85	50.51 49.38	831 47 944 46
04D1818 04DT818	14/07/2020 (3) 01:17:47.00 14/07/2020 (3) 02:57:44.00 14/07/2020 (3) 02:57:44.00	04D1B18 - 2.115 04DTB18 - 2.170 04DTB18 - 2.196	492	1/ 56	967 893	24	6.807352	0.280842 0.219559 0.211001	0.102000	0.006398	0.412280	1499 884 980	92 26 20	2865 1660 1907	51	47.69 46.77 45.79	1499 92 884 26 980 20
04DTB18 04DTB18	14/07/2020 (3) 03:06:39:00 13/07/2020 (2) 21:52:49:00	04DTB18 - 2.176 04DTB18 - 2.2	537	6	468	6	3.496503	0.289990 0.321806	0.189000	0.006080	-0.082621 0.358150	1622 775	111 29	2733	53	40.66	2733 53 775 29
04DTB18 04DTB18	14/07/2020 (3) 01:31:17.00 13/07/2020 (2) 23:59:59:00	04DTB18 - 2.121 04DTB18 - 2.72	1088 475	28 13	284 643	11 47	4.187605 6.825939	0.138114 0.271640	0.146600 0.092000	0.004332 0.003640	0.080312 0.064468	1380 881	40 32	2306 1467	51 74	40.13 39.90	1380 40 881 32
04DTB18 04DTB18	14/07/2020 (3) 02:50:20.00 13/07/2020 (2) 21:55:47.00	04DTB18 - 2.165 04DTB18 - 2.4	474 261	4 18	168 207	1 13	4.230118 3.891051	0.143652 0.211055	0.141100 0.156000	0.004722 0.006320	0.219780 -0.185190	1368 1475	41 68	2240 2412	57	38.93 38.87	1368 41 1475 68
04DTB18 04DTB18	13/07/2020 (2) 23:46:20.00 14/07/2020 (3) 02:20:31.00	04DTB18 - 2.66 04DTB18 - 2.148	1047	17	171	3	4.230118 7.818608	0.138284	0.139200 0.079300	0.004284	-0.089296 0.278830	1368 776	39 24	2217	53	38.28 34.18	1368 39 776 24
04D1818 04DT818 04DT818	14/07/2020 (3) 01:43:09:00 13/07/2020 (2) 22:01:43:00 13/07/2020 (2) 22:19:45:00	04D1B18 - 2.129 04DTB18 - 2.8 04DTB18 - 2.17	259 526 525	3 8 16	194 136 38	7	5.428882 6.688963 4.904365	0.185207 0.254583 0.160625	0.086400	0.004224 0.003728 0.003934	0.015698	1090 898 1196	33 31 35	1645 1346 1743	76 82 67	33.76 33.29 31.37	1090 33 898 31 1195 35
04DTB18 04DTB18	14/07/2020 (3) 00:22:24.00 14/07/2020 (3) 02:59:15.00	04DTB18 - 2.84 04DTB18 - 2.171	127	3	103 438	1	8.097166	0.299628	0.075800	0.004816	0.292440	751	25	1089	123	31.06	751 25
04DTB18 04DTB18	14/07/2020 (3) 01:35:45.00 13/07/2020 (2) 23:49:17.00	04DTB18 - 2.124 04DTB18 - 2.68	474 470	3	834 784	13 16	6.226650 4.302926	0.205952 0.141604	0.086900 0.113900	0.003838 0.004178	0.146970 0.430680	960 1347	29 39	1357 1862	84 66	29.27 27.64	960 29 1347 39
04DTB18 04DTB18	14/07/2020 (3) 03:32:12.00 14/07/2020 (3) 01:29:50.00	04DTB18 - 2.187 04DTB18 - 2.120	1063 808	12 34	39 819	3 40	6.920415 5.073567	0.229403 0.160676	0.079700 0.097800	0.002794 0.003256	0.091172 0.303240	870 1160	26 33	1189 1582	69 62	26.81 26.68	870 26 1160 33
04DTB18 04DTB18	10/05/2019 (6) 01:43:02.00 14/07/2020 (3) 00:10:34.00	04DTB18 - 33 04DTB18 - 2.76	565 94	14	192 148	2	5.871991 3.310162	0.351906	0.087300 0.145100	0.008046	0.353950	1014 1702	53 103	1366 2288	169	25.80 25.63	1014 53 2288 84
04DTB18 04DTB18	14/07/2020 (3) 03:58:53:00 14/07/2020 (3) 02:23:31:00 14/07/2020 (3) 03:09:37:00	04DTB18 - 2.150 04DTB18 - 2.150 04DTB18 - 2.178	257	30 8 12	618 125	49	4.405286 8.857396	0.225892	0.107900	0.004358	0.110790	1319 690	29 58 37	1763	73	25.21 24.93	927 29 1319 58 690 37
04DTB18 04DTB18	14/07/2020 (3) 02:14:35.00 10/05/2019 (6) 03:03:00.00	04DTB18 - 2.144 04DTB18 - 63	206 187	13	328	33 2	4.297379	0.213373 0.211744	0.109000 0.096100	0.006380	0.614480 0.196440	1349 1186	58	1782	104	24.32 23.42	1349 58 1185 45
04DTB18 04DTB18	10/05/2019 (6) 02:30:41.00 10/05/2019 (6) 02:36:17.00	04DTB18 - 50 04DTB18 - 53	178 280	4 15	238 121	3 4	4.149378 5.643341	0.181126 0.326244	0.110500 0.087000	0.009010 0.012740	0.147880 0.021593	1392 1052	53 53	1807 1360	142 259	22.96 22.67	1392 53 1052 53
04DTB18 04DTB18	14/07/2020 (3) 00:58:18:00 13/07/2020 (2) 21:58:45:00	04DTB18 - 2.105 04DTB18 - 2.6	210 256	7	244 230	8	4.440497 4.918839	0.153879 0.166123	0.102900 0.095000	0.004658	0.186260	1309 1193	40	1676	82 74	21.89 21.88	1309 40 1193 36
04D1818 04DT818	13/07/2020 (2) 21:54:20:00 10/05/2019 (6) 02:13:34.79 10/05/2019 (6) 00:42:32.00	04D1B18 - 2.3 04DTB18 - 42 04DTB18 - 9	142	24 5 7	125	38	5.934718 3.831418 4.724949	0.196180 0.238106 0.242661	0.083300	0.003266	0.181460 0.524340 0.280710	1004 1495 1335	30	12/5 1895	75 180 202	21.29 21.10	1004 30 1495 79 1225 55
04DTB18 04DTB18	14/07/2020 (3) 03:08:08:00 10/05/2019 (6) 03:04:55:60	04DTB18 - 2.177 04DTB18 - 64	141	6	414	56	5.440696	0.336743	0.087000	0.004640	0.006618	1088	59	1360	100	20.00	1088 59 1309 56
04DTB18 04DTB18	14/07/2020 (3) 00:19:28.00 14/07/2020 (3) 02:47:23.00	04DTB18 - 2.82 04DTB18 - 2.163	539 540	10 23	540 1420	13 140	4.844961 3.995206	0.153236 0.135770	0.093800	0.003476 0.003786	0.226670	1210 1440	34 43	1503 1787	69 63	19.53 19.42	1210 34 1440 43
04DTB18 04DTB18	13/07/2020 (2) 22:49:38.61 10/05/2019 (6) 02:32:29.70	04DTB18 - 2.31 04DTB18 - 51	651 240	12 8	149 381	19 21	3.901678 4.568296	0.149582 0.235364	0.111400 0.097600	0.003728 0.011452	0.441210 0.143620	1471 1276	49 57	1822 1578	60 206	19.25 19.13	1471 49 1276 57
04DTB18 04DTB18	14/07/2020 (3) 03:29:15.00 14/07/2020 (3) 00:02:55.00	04DTB18 - 2.185 04DTB18 - 2.74	197	7	70	2	4.531038 3.837299	0.150159	0.097200	0.004244	0.317740	1286 1493	37	1570	81 73	18.13 17.82	1286 37 1493 88
04DTB18 04DTB18	10/05/2019 (6) 02:08:00.00 13/07/2020 (2) 23:06:09.00	04DTB18 - 39 04DTB18 - 2.42	96 341	3	62 217	3	5.691520 2.933412	0.327627 0.213557	0.083000 0.144300	0.012660	0.282100	1043 1891	53	1268 2279	273	17.71	1043 53 2279 65
04DTB18 04DTB18	13/07/2020 (2) 22:05:21:00 13/07/2020 (2) 23:18:01:00 13/07/2020 (2) 23:56:51:00	04DTB18 - 2.50 04DTB18 - 2.50	754	4	402	4	6.049607 3.772161	0.201507	0.079300	0.002986	0.329070	1337 986 1516	30 92	1005	74 74 70	16.33 16.33	1337 39 986 30 1812 70
04DTB18 04DTB18	13/07/2020 (2) 22:52:44.00 10/05/2019 (6) 02:19:17.00	04DTB18 - 2.33 04DTB18 - 45	552 405	20 16	338 337	22 13	4.506534 4.759638	0.155119 0.172217	0.095800 0.091300	0.003516 0.005926	0.160290 0.165870	1292 1229	39 39	1543 1452	68 120	16.27 15.33	1292 39 1229 39
04DTB18 04DTB18	10/05/2019 (6) 02:17:22.47 14/07/2020 (3) 03:02:11.00	04DTB18 - 44 04DTB18 - 2.173	191 294	7	92 99	4 2	3.862495 3.718855	0.142893 0.267995	0.107200 0.110200	0.006044 0.004404	0.434460 0.137260	1484 1535	47 92	1752 1802	101 72	15.26 14.80	1484 47 1802 72
04DTB18 04DTB18	14/07/2020 (3) 02:56:15:00 14/07/2020 (3) 01:38:42:00	04DTB18 - 2.169 04DTB18 - 2.126	827 369	20	1178	38	5.390836 4.149378	0.177563 0.141527	0.083700 0.099800	0.002974	0.139430 0.246550	1097 1392	32	1285	69 66	14.61	1097 32 1392 41
04D1818 04DT818	13/07/2020 (2) 22:15:17:00 13/07/2020 (2) 23:14:59:00 14/07/2020 (2) 01:28:17:00	04D1818 - 2.14 04DT818 - 2.48 04DT818 - 2.119	931 149 152	21	153	3	6.12/451 4.321521 2.916704	0.197640 0.146192 0.280387	0.096600	0.002550	0.082131	9/5 1342 1500	40	1133 1559 1740	90 92	14.00 13.91	9/5 28 1342 40 1740 83
04DTB18 04DTB18	13/07/2020 (2) 22:18:18:00 14/07/2020 (3) 03:03:41.00	04DTB18 - 2.16 04DTB18 - 2.174	746	26 1	518	11	4.975124	0.166333 0.131116	0.087300	0.002946	0.086033	1181	35	1366	64 72	13.58	1181 35 1807 72
04DTB18 04DTB18	14/07/2020 (3) 02:41:18:00 14/07/2020 (3) 01:04:18:00	04DTB18 - 2.162 04DTB18 - 2.106	180 413	5 8	172 184	6 2	2.677376 4.391744	0.189746 0.143768	0.151300 0.094800	0.005626	0.192100 0.492410	2046 1322	117 38	2360 1523	63 78	13.31 13.19	2360 63 1322 38
04DTB18 04DTB18	14/07/2020 (3) 01:10:20.00 13/07/2020 (2) 22:25:41.00	04DTB18 - 2.110 04DTB18 - 2.21	611 193	17 6	312 150	9 2	3.946330 3.538570	0.130319 0.258594	0.102300 0.111900	0.003546 0.004338	0.087251 0.164320	1456 1604	42 97	1665 1830	64 69	12.57 12.31	1456 42 1830 69
04DTB18 04DTB18	14/07/2020 (3) 01:52:02:00 14/07/2020 (3) 01:59:28:00	04DTB18 - 2.135 04DTB18 - 2.140	774 341	13 9	516 209	7	5.431831 2.541296	0.176498	0.081900	0.002738	-0.017580 0.069453	1089 2139	32	1242 2433	65 55	12.31 12.07	1089 32 2433 55
04DTB18 04DTB18	13/07/2020 (3) 01:41:41:00 13/07/2020 (2) 22:36:07:00 14/07/2020 (3) 00:15:01:00	04DTB18 - 2.28 04DTB18 - 2.29	364	11	194 118	5	2.452182	0.175321	0.164300	0.005286	0.285620	2205	98 126 43	2500	80 54 67	11.80 11.79 11.56	2500 54
04DTB18 04DTB18	13/07/2020 (2) 22:54:15.00 14/07/2020 (3) 01:19:14.00	04DTB18 - 2.34 04DTB18 - 2.116	218 151	6	219	5	3.885004	0.133545 0.163789	0.102400 0.175600	0.004448	0.374250 0.351750	1477 2317	44	1667 2611	79	11.44	1477 44 2611 57
04DTB18 04DTB18	10/05/2019 (6) 00:40:37.00 14/07/2020 (3) 03:23:10.00	04DTB18 - 7 04DTB18 - 2.184	84 87	3 2	90 139	3 1	5.934718 3.868472	0.231401 0.146209	0.077200 0.101800	0.004744 0.005536	0.142040 0.360670	1004 1482	35 48	1126 1656	119 98	10.81 10.52	1004 35 1482 48
04DTB18 04DTB18	13/07/2020 (2) 22:07:47.00 14/07/2020 (3) 03:12:34.00	04DTB18 - 2.9 04DTB18 - 2.180	79 318	1 6	84 286	1 5	3.633721 3.723008	0.257529 0.268511	0.107000 0.103900	0.005640 0.004078	0.143750 0.151430	1567 1534	93 92	1748 1694	94 71	10.35 9.47	1748 94 1694 71
04DTB18 04DTB18	13/07/2020 (2) 22:00:16:00 13/07/2020 (2) 23:30:04:00 12/07/2020 (2) 23:55:42:00	04DTB18 - 2.7 04DTB18 - 2.55 04DTB18 - 2.35	535 349	18 3 7	268 169	9	4.171882 4.222973 5.120826	0.133911 0.139743 0.171062	0.095100 0.094200	0.003502 0.003884	0.272640 0.293020 0.174580	1385 1370	39 40 24	1529	69 77	9.42 9.35	1385 39 1370 40 1149 24
04DTB18 04DTB18 04DTB18	13/07/2020 (2) 22:55:42:00 13/07/2020 (2) 23:50:46:00 14/07/2020 (3) 03:35:13:00	04DTB18 - 2.69 04DTB18 - 2.189	176 122 87	5	49	2	3.016591 4.533092	0.215029 0.162583	0.125100 0.089300	0.005702	0.113250 0.245720	1148 1846 1285	108 40	2029	90 79 106	9.33 9.06 8.84	2029 79 1285 40
04DTB18 04DTB18	14/07/2020 (3) 03:05:12.00 13/07/2020 (2) 23:40:24.00	04DTB18 - 2.175 04DTB18 - 2.62	89 321	3	50 502	1 8	3.985652 3.932363	0.141666 0.131223	0.097700	0.005454 0.003970	0.277220 0.063114	1443 1461	45	1580 1595	102 74	8.65	1443 45 1461 42
04DTB18 04DTB18	14/07/2020 (3) 01:47:38.00 14/07/2020 (3) 01:44:38.00	04DTB18 - 2.132 04DTB18 - 2.130	298 442	9 21	106 336	2 18	4.347826 4.116921	0.177694 0.167084	0.091400 0.095000	0.003928 0.003400	0.166310 0.184110	1335 1402	48 49	1454 1527	80 67	8.23 8.21	1335 48 1402 49
04DTB18 04DTB18	10/05/2019 (6) 00:31:07.50 14/07/2020 (3) 00:26:52.00	04DTB18 - 2 04DTB18 - 2.87	183 67	5	161 52	5 2	8.038585 4.666356	0.348166 0.169539	0.066500 0.087000	0.007530	0.208850 0.227180	756 1252	30 40	821 1360	221 113	7.96 7.94	756 30 1252 40
04DTB18 04DTB18	10/05/2019 (6) 02:42:02.00 10/05/2019 (6) 02:40:06.00	04DTB18 - 56 04DTB18 - 55	193 222	5	152 503	6 32	5.461496 4.201681	0.305094 0.152885	0.079200 0.093100	0.010984	0.091176	1084 1376	53	1176	253 116	7.83 7.58	1084 53 1376 44
04DTB18 04DTB18 04DTB18	10/05/2019 (6) 02:34:28:00 10/05/2019 (6) 01:44:58:00 14/07/2020 (3) 03:33:42:00	04DTB18 - 32 04DTB18 - 34 04DTB18 - 2.188	169	5	156	4	2.969121	0.131671 0.137689	0.124300	0.003848	0.344200	1264 1871 1479	40 69 45	2018	180	7.27	2018 161 1479 45
04DTB18 04DTB18	13/07/2020 (2) 23:58:28:00 14/07/2020 (3) 01:49:05:00	04DTB18 - 2.71 04DTB18 - 2.133	105 92	2	54 42	1	4.370629 2.091613	0.156181 0.151203	0.090300 0.186600	0.005306	0.303410	1328 2519	42 142	1431 2712	109	7.18 7.11	1328 42 2712 61
04DTB18 04DTB18	10/05/2019 (6) 01:22:14.00 14/07/2020 (3) 01:11:51.00	04DTB18 - 25 04DTB18 - 2.111	490 357	15 10	243 155	12 4	4.987531 5.035247	0.199252 0.166625	0.082900 0.082400	0.006758 0.003748	0.236370 0.308360	1178 1168	41 34	1266 1254	152 87	6.95 6.89	1178 41 1168 34
04DTB18 04DTB18	14/07/2020 (3) 01:37:12.00 13/07/2020 (2) 23:43:22.00	04DTB18 - 2.125 04DTB18 - 2.64	272	11 2	222 53	8	5.035247 5.042864	0.169160	0.082300	0.003346	0.192040	1168 1166	35	1252	78	6.71	1168 35 1166 37
04DTB18 04DTB18	10/05/2019 (6) 02:43:52.00 10/05/2019 (6) 01:24:03.50	04DTB18 - 57 04DTB18 - 26	120 529	4	72 345	7 26	4.275331 5.399568	0.167760	0.091200	0.008024	0.260020	1355	46	1450	160	6.55 6.46	1355 46 1095 49
04DTB18 04DTB18	10/05/2019 (6) 01:09:04.00 13/07/2020 (2) 22:22:44.00	04DTB18 - 18 04DTB18 - 18 04DTB18 - 2.19	723	26 4	568 309	31 4	3.937008	0.191890 0.222554	0.096500	0.011330 0.004216	0.477480 0.251360	1459	61 103	1557	206	6.27	1459 61 1892 65
04DTB18 04DTB18	14/07/2020 (3) 02:05:33.00 14/07/2020 (3) 02:35:23.00	04DTB18 - 2.141 04DTB18 - 2.158	433 393	11 4	303 123	14 1	3.431709 3.264773	0.245284 0.235835	0.107500 0.112200	0.003850 0.003944	0.242820 0.308270	1649 1723	98 103	1757 1835	65 63	6.15 6.11	1757 65 1835 63
04DTB18 04DTB18	14/07/2020 (3) 01:40:10.00 13/07/2020 (2) 21:57:15.00	04DTB18 - 2.127 04DTB18 - 2.5	330 278	5	126 249	3 5	5.216484 3.855050	0.169638 0.270299	0.080300 0.097700	0.003406 0.003754	0.154980 0.374800	1131 1487	33 88	1204 1580	82 71	6.06 5.89	1131 33 1487 88
04DTB18 04DTB18 04DTB12	13/07/2020 (2) 23:16:28.00 10/05/2019 (6) 02:45:47.00	04DTB18 - 2.49 04DTB18 - 58 04DTD10 - 2.45	74 375	2 8	74 404	2 13	4.625347 5.241090	0.169525	0.085100	0.005522	0.075457	1262	41 43	1340	120 211	5.81	1262 41 1126 43
04DTB18 04DTB18 04DTB18	13/07/2020 (2) 25:05:07.00 14/07/2020 (3) 00:29:52:00 13/07/2020 (5) 77:33:0F.00	04DTB18 - 2.40 04DTB18 - 2.89 04DTB18 - 7.74	193 55 215	3 1 0	93 98	2	+.5/4565 4.757374 3.331113	0.158457 0.178888 0.117117	0.084400	0.004330 0.005688 0.004788	0.191640	1274 1230 1693	39 41 40	1349 1301 1799	95 126 71	5.49 5.46 ç 20	1274 39 1230 41 1789 71
04DTB18 04DTB18	14/07/2020 (3) 02:33:52:00 14/07/2020 (3) 00:25:23:00	04DTB18 - 2.157 04DTB18 - 2.86	158 215	10 2	74 189	4	4.074980 4.248088	0.149582 0.142710	0.093300	0.004466	0.227010	1415	49 45 40	1493	89	5.25 5.19	1415 45 1363 40
04DTB18 04DTB18	13/07/2020 (2) 23:19:27.99 13/07/2020 (2) 22:27:10.00	04DTB18 - 2.51 04DTB18 - 2.22	512 271	11 3	398 95	10 1	4.127115 3.343363	0.137048 0.234538	0.092300 0.108600	0.003346	0.293670 0.461640	1399 1687	41 98	1473	68 71	5.03	1399 41 1775 71
04DTB18 04DTB18	14/07/2020 (3) 02:26:28.00 10/05/2019 (6) 02:15:31.00	04DTB18 - 2.152 04DTB18 - 43	448 122	9 4	359 70	5 3	4.868549 3.485535	0.161368	0.082900 0.104700	0.003258 0.006794	0.231420 0.298240	1204 1626	35 48	1266 1708	76 116	4.88 4.81	1204 35 1708 116
04DTB18 04DTB18 04DTP19	14/07/2020 (3) 00:09:00.00 14/07/2020 (3) 00:32:48.00 14/07/2020 (3) 00:32:48.00	04DTB18 - 2.75 04DTB18 - 2.91 04DTB18 - 2.91	178 698	4 25	81 217 262	3	4.875670 3.299241	0.180716 0.229260	0.082600	0.004052	0.116480	1203	39 98	1259	94 56	4.47	1203 39 1784 56 1295
04DTB18 04DTB18	10/05/2019 (6) 02:57:16:00 14/07/2020 (3) 01:22:12 00	04DTB18 - 60 04DTB18 - 60 04DTB18 - 7 119	581 175 305	14 6 9	203 60 82	3	+.535092 4.918839 3.304693	0.219352 0.229909	0.082000 0.108500	0.003224 0.008440 0.003570	0.264/40 0.197270 0.296780	1285 1193 1704	36 47 99	1542 1245 1774	71 190 م	4.23 4.15 3.01	1193 47 1774 60
04DTB18 04DTB18	14/07/2020 (3) 02:51:49.00 10/05/2019 (6) 02:28:46.00	04DTB18 - 2.166 04DTB18 - 49	230 101	4	120 16	2	4.627487 3.546099	0.154649 0.150143	0.084900 0.102300	0.003698	0.177470	1764 1261 1601	98 37 58	17/4 1312 1665	60 83 136	3.90 3.84	1261 37 1665 136
04DTB18 04DTB18	14/07/2020 (3) 00:38:44.00 13/07/2020 (2) 23:09:04.00	04DTB18 - 2.95 04DTB18 - 2.44	282 370	6 7	176 297	5 6	5.299417 3.607504	0.173390 0.254347	0.078400 0.100700	0.003668	0.060132 0.175910	1114 1577	33	1156 1636	91 66	3.61	1114 33 1636 66
04DTB18 04DTB18	13/07/2020 (2) 22:37:34.00 10/05/2019 (6) 02:47:38.00	04DTB18 - 2.29 04DTB18 - 59	436 73	13 2	295 93	10 3	4.430660 2.024291	0.145542 0.081463	0.087000 0.182900	0.003240 0.013458	0.230170	1312 2588	38 83	1360 2679	71 118	3.51 3.38	1312 38 2679 118
04DTB18 04DTB18	14/07/2020 (3) 00:01:26.00 14/07/2020 (3) 00:37:15.00	04DTB18 - 2.73 04DTB18 - 2.94	232 247	5	173 169	2	3.591954 3.441156	0.252469	0.100800	0.003916	0.283250	1583 1645	93 98	1638 1701	71 71	3.35 3.33	1638 71 1701 71
04D1818 04DTB18 04DTB18	14/07/2020 (3) 03:11:08.00 14/07/2020 (3) 03:18:36.00 10/05/2019 (6) 07:38:17:00	04D1818 - 2.179 04DTB18 - 2.181 04DTB18 - 54	354 247 263	7 7 11	345 219 136	6 8 6	3.718855 3.889537 4.308488	0.132253 0.171560	0.094900 0.088400	0.003862 0.003898 0.008668	0.338840	1535 1475 1344	92 44 47	1588 1525 1200	73 76 179	3.29 3.29 7.7	1588 73 1475 44 1346 47
04DTB18 04DTB18	14/07/2020 (3) 00:55:19.00 14/07/2020 (3) 01:55:00.00	04DTB18 - 2.103 04DTB18 - 2.137	584	18 5	371	7	4.494382	0.156546	0.085000	0.003120	0.157030	1295 1243	40 38	1330 1337 1282	69 104	3.16	1295 40 1243 38
04DTB18 04DTB18	10/05/2019 (6) 01:41:14.27 13/07/2020 (2) 22:57:11.00	04DTB18 - 32 04DTB18 - 2.36	258 275	19 7	94 348	5 3	5.096840 4.752852	0.182468 0.165085	0.079800 0.083000	0.005596	0.137630 0.241980	1155 1231	37	1191 1268	133 82	3.05	1155 37 1231 38
04DTB18 04DTB18	14/07/2020 (3) 02:22:00.00 10/05/2019 (6) 02:23:02.00	04DTB18 - 2.149 04DTB18 - 47	276 85	7 5	331 106	11 7	3.604903 4.541326	0.254033 0.158885	0.100000 0.085100	0.003800 0.005702	0.289800 0.187480	1578 1283	93 39	1623 1317	70 126	2.77	1623 70 1283 39
04DTB18 04DTB18	14/07/2020 (3) 00:16:30.00 13/07/2020 (2) 22:51:15:00	04DTB18 - 2.80 04DTB18 - 2.32	224	7	183 126	6 5	3.847634 3.926188	0.130248	0.095000	0.004000	0.089795	1489 1463	44 43	1527 1499	78 90	2.48	1489 44 1463 43
04DTB18 04DTB18 04DTB12	13/07/2020 (2) 21:51:16.00 14/07/2020 (3) 00:12:05.00	04DTB18 - 2.1 04DTB18 - 2.77 04DTB18 - 40	357	14 2	553 83	23	7.974482 3.495281 2.002000	0.267597 0.253161	0.055200 0.102000	0.003004	0.245160	762	23	780	95 81	2.35	762 23 1660 81
04DTB18 04DTB18 04DTB18	14/07/2020 (3) 02:39:47.00 13/07/2020 (2) 22:13:48 nn	04DTB18 - 2.161 04DTB18 - 2.13	250 353	39 4 9	763 126	12 2	2.092050 3.028468 2.086811	0.094361 0.216487 0.146251	0.115100 0.172000	0.015440 0.004402 0.005440	0.2/8190 0.201820 0.496950	2519 1839 2574	91 108 138	2576 1881 2576	143 68 53	2.19 2.19 2.04	2576 143 1881 68 2576 53
04DTB18 04DTB18	14/07/2020 (3) 02:24:59.00 14/07/2020 (3) 00:40:13.00	04DTB18 - 2.151 04DTB18 - 2.96	110 215	3 4	49 169	1 2	4.012841 3.581662	0.144668 0.251229	0.091800	0.004836	0.117370	1434	45	1462	98 74	1.92	1434 45 1618 74
04DTB18 04DTB18	14/07/2020 (3) 02:19:02:00 14/07/2020 (3) 02:11:35:00	04DTB18 - 2.147 04DTB18 - 2.142	342 129	10 5	191 147	7 4	4.260758 3.677823	0.139677 0.262926	0.088100 0.097600	0.003662 0.004652	0.251830 0.197720	1359 1550	39 93	1384 1578	79 87	1.79 1.74	1359 39 1578 87
04DTB18 04DTB18	14/07/2020 (3) 02:48:52.00 14/07/2020 (3) 02:13:06.00	04DTB18 - 2.164 04DTB18 - 2.143	192 94	3 1	179 33	2	5.022602	0.176132	0.079800 0.110200	0.003896	0.311310	1170 1773	36 103	1191 1802	94 87	1.74	1170 36 1802 87
04DTB18 04DTB18 04DTB18	14/07/2020 (3) 01:14:46.00 14/07/2020 (3) 01:50:34.00 13/07/2020 (2) 22:10:50 00	0401818 - 2.113 0407818 - 2.134 0407818 - 2.11	126 194 219	2 9 5	54 154 747	1 9 3	4.768717 3.588088 3.772161	0.252003	0.099300	0.004442 0.004086 0.004012	0.359550	1227 1585 1517	39 93	1247	103 76	1.59	122/ 39 1610 76 1539 ~~
04DTB18 04DTB18	13/07/2020 (2) 22:28:39.00 14/07/2020 (3) 02:53:21.00	04DTB18 - 2.23 04DTB18 - 2.167	336 273	8	180 256	4	2.681684	0.190271 0.251384	0.128300 0.099300	0.003966	0.253220 0.395320	2043 1587	117 93	2074	78 54 76	1.50	2074 54 1610 76

			22011		22275			b	sotopic Ratios			Appare	int Ages - Calcul	ated in Isoplot R (f	vla)	Discord	Perferred ag	ge 1500
Sample ID	Analysis date-time	Spot ID <sup>1</sup>	2380 CONC.	+20 INT	2321110016	+2a INT	238U/206Pb	+20 PROP	207Pb/205Pb	+2 a PROP	rho	23811/205Pb	+20 PBOP	207Pb/206Pb	+2g PROP	(7/6-6/8)/7/6 *100	Ma cuto	off
			ppm		ppm											(.)= 0)000	Ma	2σ
04DTB18	14/07/2020 (3) 00:56:48.00	04DTB18 - 2.104	335	7	301	7	4.273504	0.142085	0.087700	0.003354	0.391030	1355	39	1375	73	1.43	1355	39
04DTB18	14/07/2020 (3) 01:05:55:00	04DTB18 - 2.107	323	9	277	8	3.003003	0.213367	0.115000	0.004100	0.405490	1853	108	1879	64	1.39	1879	64
0401818	14/07/2020 (3) 01:57:57.00	0401818 - 2.139	284		192	4	3.4/5843	0.250739	0.101600	0.003632	0.245250	1630	98	1653	66	1.3/	1653	55
0401818	13/07/2020 (2) 23:07:33:00	04DTB18 - 2.54	391	8	677	14	3 173596	0.224619	0.109300	0.004086	0.178830	1766	103	1787	67	1.19	1787	67
04DTB18	13/07/2020 (2) 23:04:37.00	04DTB18 - 2.41	182	2	76	1	4.235493	0.143910	0.088000	0.004160	0.334680	1366	41	1382	89	1.10	1366	41
04DTB18	10/05/2019 (6) 02:06:06.00	04DTB18 - 38	96	5	85	3	4.789272	0.182947	0.081600	0.007332	0.085653	1222	41	1235	168	1.03	1222	41
04DTB18	13/07/2020 (2) 22:39:03.00	04DTB18 - 2.30	107	4	50	3	3.777862	0.275369	0.095100	0.004702	0.352190	1514	92	1529	91	1.01	1529	91
04DTB18	13/07/2020 (2) 23:10:32.00	04DTB18 - 2.45	440	4	438	3	3.832886	0.267641	0.094100	0.003482	0.453210	1494	88	1509	69	0.99	1494	88
04DTB18	13/07/2020 (2) 22:16:47.00	04DTB18 - 2.15	277	3	147	2	3.965107	0.131185	0.091800	0.003636	0.328780	1450	42	1462	74	0.86	1450	42
04DTB18	14/07/2020 (3) 00:28:21.00	04DTB18 - 2.88	128	1	104	1 20	5.678592	0.203862	0.074500	0.004490	0.236600	1046	34	1054	118	0.80	1046	34
0401818	14/07/2020 (3) 00:50:49:00	04DTB18 - 2 100	211	3	221	1	3 113325	0.217351	0.110500	0.004012	0.219560	1795	103	1809	65	0.71	1809	65
04DTB18	13/07/2020 (2) 22:58:40.00	04DTB18 - 2.37	216	3	130	2	4.222973	0.148560	0.087900	0.003858	0.153270	1370	42	1379	83	0.68	1370	42
04DTB18	14/07/2020 (3) 02:17:35.00	04DTB18 - 2.146	444	12	301	10	4.006410	0.136308	0.091000	0.003520	0.267850	1436	43	1446	73	0.64	1436	43
04DTB18	14/07/2020 (3) 02:32:23.00	04DTB18 - 2.156	451	9	215	4	4.861449	0.158677	0.080700	0.003014	0.278360	1206	35	1213	73	0.61	1206	35
04DTB18	14/07/2020 (3) 01:16:16:00	04DTB18 - 2.114	324	7	159	4	3.998401	0.132726	0.091100	0.003622	0.464980	1439	42	1448	75	0.61	1439	42
04DTB18	14/07/2020 (3) 02:16:04.00	04DTB18 - 2.145	231	3	130	1	5.146680	0.174452	0.078200	0.003864	0.289500	1145	34	1151	96	0.56	1145	34
0401818	13/07/2020 (2) 23:37:27:00	0401818 - 2.60	90	1	45	1	4.490346	0.160378	0.084500	0.005290	0.184/90	1296	41	1303	118	0.54	1296	41
0401818	10/05/2019 (6) 00:33:05:00	04DTR18 - 3	427	7	471	5	4 553734	0.219641	0.083700	0.010674	0.062781	1780	54	1285	231	0.40	1280	54
04DTB18	14/07/2020 (3) 02:54:48.00	04DTB18 - 2.168	244	3	224	7	3.006615	0.213808	0.113600	0.004172	0.165670	1851	108	1857	66	0.32	1857	66
04DTB18	14/07/2020 (3) 00:18:02.00	04DTB18 - 2.81	381	8	502	10	3.591954	0.252469	0.098100	0.003462	0.212740	1583	93	1588	65	0.26	1588	65
04DTB18	14/07/2020 (3) 00:52:18.00	04DTB18 - 2.101	221	5	240	4	3.920031	0.130647	0.092100	0.003942	0.160660	1465	42	1469	80	0.26	1465	42
04DTB18	10/05/2019 (6) 01:39:09.75	04DTB18 - 31	160	3	84	3	2.021836	0.074774	0.173900	0.009678	0.293190	2591	76	2595	91	0.17	2595	91
04DTB18	13/07/2020 (2) 23:00:11.00	04DTB18 - 2.38	117	1	78	1	3.958828	0.138731	0.091400	0.004528	0.131740	1452	44	1454	92	0.15	1452	44
0401818	12/07/2020 (2) 23:20:50:00	04D1B18 - 2.32	149	5	112	-	3.122075	0.105550	0.091900	0.004092	0.176990	1/91	51	1/92	67	0.04	1/52	67
0401818	14/07/2020 (3) 01:34:14:00	04DTB18 - 2 123	183	5	85	â	3 915427	0.128899	0.091900	0.004038	0.381950	1465	47	1465	82	-0.01	1455	47
04DTB18	10/05/2019 (6) 01:14:45.00	04DTB18 - 21	343	13	144	7	3.189793	0.123827	0.107400	0.007748	0.070608	1758	58	1755	127	-0.17	1755	127
04DTB18	14/07/2020 (3) 01:32:46.00	04DTB18 - 2.122	315	3	155	2	4.353505	0.143929	0.085700	0.003514	0.279390	1333	39	1331	78	-0.18	1333	39
04DTB18	14/07/2020 (3) 03:21:38.00	04DTB18 - 2.183	244	7	174	5	2.968240	0.209142	0.114300	0.004386	0.236090	1872	108	1858	68	-0.19	1858	68
04DTB18	14/07/2020 (3) 02:30:54.00	04DTB18 - 2.155	298	2	121	1	4.344049	0.145380	0.085800	0.003316	0.145540	1336	39	1333	74	-0.21	1336	39
04DTB18	10/05/2019 (6) 00:34:56.00	04DTB18 - 4	125	2	62	2	3.889537	0.144356	0.092200	0.006544	0.216540	1475	47	1471	130	-0.29	1475	47
04DTB18	13/07/2020 (2) 23:36:00.00	04DTB18 - 2.59	262	7	129	5	3.180662	0.105091	0.107500	0.004250	0.326340	1762	49	1757	71	-0.32	1757	71
0401818	13/07/2020 (2) 23:27:00:00	04D1B18 - 2.53	235	5	243	,	3.912363	0.133351	0.091800	0.003636	0.154280	146/	43	1462	/4	-0.33	146/	43
04D1B18	14/07/2020 (3) 01:20:43.00	04DTB18 - 2.117	203	2	73	1	5.385030	0.183097	0.075900	0.003718	0.222090	1098	33	1092	96	-0.60	1098	33
04DTB18	14/07/2020 (3) 00:23:56.00	04DTB18 - 2.85	131	1	74	1	3.852080	0.269942	0.092600	0.004552	0.458720	1488	88	1479	91	-0.60	1488	88
04DTB18	14/07/2020 (3) 01:13:18.00	04DTB18 - 2.112	590	6	167	3	3.862495	0.123498	0.092400	0.003248	0.151690	1484	41	1475	66	-0.64	1484	41
04DTB18	14/07/2020 (3) 01:07:22.00	04DTB18 - 2.108	285	4	80	2	5.750431	0.194371	0.073500	0.003270	0.312770	1034	31	1027	88	-0.65	1034	31
04DTB18	13/07/2020 (2) 23:47:51.00	04DTB18 - 2.67	63	1	120	1	1.968892	0.140168	0.177200	0.007644	0.208820	2648	146	2626	71	-0.82	2626	71
04DTB18	13/07/2020 (2) 22:34:35.00	04DTB18 - 2.27	687	8	301	2	4.366812	0.142636	0.085100	0.003002	0.311470	1329	38	1317	68	-0.94	1329	38
0401818	13/07/2020 (2) 23:38:55:00	0401818 - 2.61	125	3	46	1	3.926188	0.1355559	0.091100	0.004422	0.241/60	1463	44	1448	91	-1.03	1463	44 54
0401818	14/07/2020 (3) 01:31:19:00	040TB18 - 2 90	239	ŝ	298	6	5.073567	0.168398	0.078000	0.003760	0.256520	1160	34	1145	94	-1.07	1160	34
04DTB18	13/07/2020 (2) 22:21:14.00	04DTB18 - 2.18	92	1	283	5	4.859086	0.175097	0.079700	0.004794	0.177690	1206	38	1189	115	-1.49	1206	38
04DTB18	10/05/2019 (6) 01:10:59.00	04DTB18 - 19	215	3	98	2	4.098361	0.147474	0.088200	0.006464	0.189440	1408	44	1386	135	-1.55	1408	44
04DTB18	14/07/2020 (3) 01:53:33.00	04DTB18 - 2.136	274	3	195	2	3.086420	0.223670	0.108900	0.004078	0.266970	1809	107	1780	68	-1.62	1780	68
04DTB18	10/05/2019 (6) 02:59:15.00	04DTB18 - 61	175	10	77	5	5.324814	0.217075	0.075900	0.006518	0.270900	1109	40	1092	164	-1.64	1109	40
0401818	14/07/2020 (3) 02:29:28:00	0401818 - 2.154	201	5	206	6	3.262643	0.235570	0.103900	0.004278	0.109280	1/24	103	1694	/5	-1.74	1694	15
0401818	14/07/2020 (3) 00:13:32 00	04D1B18 - 35 04DTB18 - 2 78	174	7	204	10	3.403676	0.203190	0.100400	0.003798	0.249150	1661	98	1631	109	-1.76	1631	78
04DTB18	14/07/2020 (3) 00:34:17.00	04DTB18 - 2.92	482	20	183	10	5.691520	0.185096	0.073400	0.003068	0.058423	1043	30	1024	83	-1.89	1043	30
04DTB18	10/05/2019 (6) 01:20:20.00	04DTB18 - 24	348	19	177	7	3.533569	0.144339	0.097500	0.007550	0.260210	1607	56	1576	139	-1.94	1576	139
04DTB18	10/05/2019 (6) 00:36:50.00	04DTB18 - 5	260	6	268	9	3.969829	0.132979	0.089800	0.005896	0.153990	1448	42	1420	121	-1.96	1448	42
04DTB18	10/05/2019 (6) 02:04:16.00	04DTB18 - 37	314	16	110	2	3.988831	0.168877	0.089300	0.008386	0.087058	1442	53	1410	171	-2.30	1442	53
04DTB18	14/07/2020 (3) 00:49:21.00	04DTB18 - 2.99	43	1	57	2	3.084516	0.223432	0.108200	0.005864	0.261900	1810	107	1769	97	-2.36	1769	97
0401818	10/05/2019 (6) 00:38:42.00	0401818 - 6	382	21	161	6	4.9/5124	0.235638	0.078200	0.009164	0.154/20	1181	49	1151	21/	-2.57	1181	49
0401818	10/05/2019 (6) 01:16:35 00	04DTB18 - 22	219	9	114	5	4 768717	0.168144	0.079900	0.006698	0.083228	1200	38	1194	158	-2.00	1227	38
04DTB18	14/07/2020 (3) 01:56:28.00	04DTB18 - 2.138	171	4	79	2	4.692633	0.159915	0.080600	0.004112	0.286450	1245	37	1211	98	-2.85	1245	37
04DTB18	14/07/2020 (3) 00:47:54.00	04DTB18 - 2.98	118	1	119	1	4.952947	0.182467	0.078200	0.004664	0.230880	1186	39	1151	115	-2.99	1186	39
04DTB18	10/05/2019 (6) 02:21:05.27	04DTB18 - 46	311	5	181	5	4.476276	0.231789	0.082700	0.011154	0.218340	1300	58	1261	244	-3.08	1300	58
04DTB18	10/05/2019 (6) 01:27:51.00	04DTB18 - 28	107	6	157	11	2.959455	0.112615	0.111300	0.007226	0.260050	1877	60	1820	114	-3.12	1820	114
0401818	12/07/3030 (3) 33:34:15:00	04D1B18 - 17 04DTP18 - 2 20	207	11	201	9	3.568879	0.147799	0.095700	0.007414	0.291980	1592	55	1541	140	-3.34	1541	140
0401818	13/07/2020 (2) 22:31:35:00	04DTB18 - 2 25	164	1	98	4	4 235493	0.149292	0.085100	0.004102	0.251330	1366	42	1317	92	3.76	1366	42
04DTB18	10/05/2019 (6) 01:05:17.67	04DTB18 - 16	258	6	156	4	3.352330	0.143466	0.099600	0.006092	-0.081039	1683	61	1616	111	-4.15	1616	111
04DTB18	10/05/2019 (6) 00:44:23.00	04DTB18 - 9	220	12	154	10	4.184100	0.151958	0.085300	0.006006	0.304560	1382	44	1322	131	-4.54	1382	44
04DTB18	13/07/2020 (2) 23:44:51.00	04DTB18 - 2.65	154	4	155	4	4.580852	0.165062	0.080800	0.004416	0.441330	1273	40	1216	105	-4.70	1273	40
04DTB18	13/07/2020 (2) 23:34:29.00	04DTB18 - 2.58	284	5	245	5	4.612546	0.151823	0.080400	0.003208	0.353780	1265	37	1206	78	-4.90	1265	37
04DTB18	13/07/2020 (2) 23:41:56.00	04DTB18 - 2.63	135	4	59	2	4.995005	0.177245	0.076900	0.004338	0.173840	1176	37	1118	110	-5.25	1176	37
0401818	14/07/2020 (3) 03:20:09:00	04D1B18 - 2.182 04DTB18 - 2.121	112	1	1/2	1	3.746722	0.271465	0.091100	0.004322	0.300620	1525	92	1448	89	-5.33	1448	89
04DTB18	14/07/2020 (3) 00:35:49 00	04DTB18 - 2.93	201	10	101	5	3.868472	0.126754	0.088800	0.003776	0.392360	1487	47	1399	87	-5.57	1482	42
04DTB18	13/07/2020 (2) 23:33:00.00	04DTB18 - 2.57	169	5	78	2	5.482456	0.196815	0.073200	0.003964	0.344070	1080	35	1019	107	-6.03	1080	35
04DTB18	14/07/2020 (3) 02:38:18.00	04DTB18 - 2.160	265	6	88	2	5.299417	0.173390	0.074300	0.003286	0.342390	1114	33	1049	88	-6.26	1114	33
04DTB18	10/05/2019 (6) 01:03:29.00	04DTB18 - 15	184	12	174	15	3.259452	0.123621	0.099900	0.007898	0.364360	1725	56	1621	141	-6.38	1621	141
040TB18	10/05/2019 (6) 02:02:14.00	04D1B18 - 36	146	8	82	6	3.856537	0.193139	0.088600	0.010972	0.490050	1486	64	1395	221	-6.57	1486	64
0401818	14/07/2020 (3) 00:46-19 00	0401818 - 13 040TR18 - 2 97	116	2	85	2	4.32/131 4.761905	0.189525	0.082300	0.008946	0.118500	1340	51	1252	200	-7.07	1340	51
04DTB18	14/07/2020 (3) 00:20:56 00	04DTB18 - 2.83	233	8	78	3	4.712535	0.158654	0.078300	0.003466	0.250920	1241	30	1140	91	.7 54	1241	37
04DTB18	10/05/2019 (6) 01:01:34.00	04DTB18 - 14	63	3	59	3	3.125000	0.126953	0.102200	0.008144	0.083242	1790	61	1664	141	-7.58	1664	141
04DTB18	10/05/2019 (6) 00:46:12.99	04DTB18 - 10	177	3	86	3	2.940312	0.110679	0.105900	0.008138	0.213850	1887	60	1746	134	-8.06	1746	134
04DTB18	10/05/2019 (6) 00:29:18.00	04DTB18 - 1	432	15	203	8	3.787879	0.181933	0.088600	0.009772	0.211740	1510	62	1395	199	-8.29	1395	199
04DTB18	10/05/2019 (6) 01:29:47.00	04DTB18 - 29	101	4	43	2	3.806624	0.183361	0.088200	0.009464	0.007329	1504	62	1386	194	-8.48	1386	194
04DTB18	10/05/2019 (6) 02:26:52.00	04DTB18 - 48	898	63	162	9	4.782401	0.207718	0.076900	0.007038	0.158070	1224	47	1118	173	-9.51	1224	47
0401818	10/05/2019 (6) 01:12:48 00	0401818 - 2.46 040TB18 - 20	127	27	52	27	5.561/35	0.210220	0.0/1300	0.004926	0.282440	1066	36	965	136	-10.44	1055	50 37
04DTB18	10/05/2019 (6) 01:26:02.00	04DTB18 - 27	415	15	421	13	5.181347	0.216382	0.071900	0.008038	-0.069527	1138	42	982	201	-12.80	1138	42
04DTB18	10/05/2019 (6) 01:31:38.00	04DTB18 - 30	268	10	228	7	5.055612	0.190569	0.072600	0.006352	0.249250	1163	39	1002	169	-16.13	1163	39
04DTB18	10/05/2019 (6) 01:18:29.00	04DTB18 - 23	96	4	58	3	5.327651	0.208735	0.070900	0.006618	0.356060	1109	39	954	181	-16.29	1109	39
04DTB18	10/05/2019 (6) 03:01:09.00	04DTB18 - 62	300	28	394	26	3.516174	0.143268	0.088200	0.008064	0.303390	1614	56	1386	167	-16.41	1386	167
040TB18	10/05/2019 (6) 00:57:39.93	04D1B18 - 12	114	3	116	4	5.076142	0.253549	0.066300	0.008326	U.300960	1159	51	815	243	-42.23	1159	51

			22911 conc		122Th conc				sotopic Ratios			Appari	ent Ages - Calcu	lated in Isoplot R (I	Ma)	Discord	Perferred ag	e 1500
Sample ID	Analysis date-time	Spot ID <sup>1</sup>	2380 conc.	±2ø INT	232111 CORC.	±2σ INT	238U/206Pb	±2σ PROP	207Pb/205Pb	±2σ PROP	rho	238U/206Pb	±2σ PROP	207Pb/206Pb	±2σ PROP	(7/6-6/8)/7/6 *100	Ma cute	off
0307819	2020-07-30 17:38:25:000	030T8190 - 89 - 1 d	22 ppm	2	24 ppm	1	6 689858	0.270765	0.083013	0.006666	0.256375	898	34	1269	157	29.21	Ma	20
03DTB19	2020-07-30 17:45:11.000	003DTB19g - 14 - 1.d	235	20	117	8	5.924952	0.377252	0.081451	0.005155	0.004661	1005	59	1232	124	18.36	1005	59
03DTB19	2020-07-30 16:37:58.000	003DTB19q - 86 - 1.d	68	1	844	11	7.997036	0.303971	0.067944	0.006388	0.222079	760	27	866	195	12.28	760	27
03DTB19	2020-07-30 16:34:33.000	003DTB19q - 76 - 1.d	103	3	59	2	7.956399	0.263150	0.067552	0.005367	0.206280	763	24	854	165	10.62	763	24
0307819	2020-07-30 17-41-48 000	D03DTB190 - 17 - 1 d	117	3	69	2	5 117896	0.162498	0.079613	0.004455	0.219539	1151	34	1187	139	3.03	1151	34
03DTB19	2020-07-30 17:40:08.000	003DTB19q - 8 - 1.d	13	ō	1916	34	7.931832	0.452856	0.054000	0.011563	0.130006	765	41	741	382	-3.29	765	41
03DTB19	2020-07-30 16:36:19.000	003DTB19q - 86b - 1.d	65	1	1200	27	7.763663	0.284781	0.053708	0.005838	0.266352	781	27	731	194	-6.85	781	27
03DTB18	09/05/2019 (5) 22:58:05.00	03DTB18 - 64	386	16	252	8	3.783579	0.168722	0.168000	0.020360	-0.704310	1512	58	2537	191	40.41	2537	191
0307818	09/05/2019 (5) 20:58:17:00	03DTB18 - 19	28	2	34	2	5 379236	0.356436	0.088000	0.024040	0.355610	1018	63	1382	413	20.47	1018	63
03DTB18	09/05/2019 (5) 22:40:42.00	03DTB18 - 62	57	3	50	3	5.889282	0.343229	0.083000	0.014660	0.001177	1011	52	1268	312	20.27	1011	52
03DTB18	09/05/2019 (5) 23:11:17.00	03DTB18 - 71	67	3	32	2	5.260389	0.321047	0.089000	0.015780	0.096044	1122	59	1403	307	20.04	1122	59
03DTB18	09/05/2019 (5) 23:20:43.00	03DTB18 - 76	43	3	48	4	5.714286	0.440816	0.084000	0.016680	0.254250	1040	69	1292	345	19.54	1040	69
03DTB18	10/05/2019 (6) 00:12:01.00	03DTB18 - 95	80	3	42	2	4.911591	0.269510	0.087000	0.012740	0.226560	1195	57	1360	259	12.16	1195	57
03DTB18	09/05/2019 (5) 20:18:29.36	03DTB18 - 2	88	1	42	1	5.230126	0.290511	0.083000	0.012660	0.197130	1128	55	1268	273	11.05	1128	55
03DTB18	09/05/2019 (5) 23:07:31.00	03DTB18 - 69	64	3	49	2	4.446421	0.251048	0.089000	0.014780	0.321180	1308	64	1403	290	6.79	1308	64
03D1818	09/05/2019 (5) 21:32:37.00	0201818 - 33	65	3	122	3	4.405286	0.264/05	0.089000	0.011/80	0.215410	1319	68	1403	236	6.00	1319	68
03DTB18	09/05/2019 (5) 20:39:07.01	03DTB18 - 13	36	2	29	2	5.390836	0.380991	0.078000	0.018560	0.219300	1097	67	1146	413	4.28	1097	67
03DTB18	09/05/2019 (5) 21:49:41.00	03DTB18 - 39	212	8	70	3	4.374453	0.169773	0.088200	0.006764	-0.052460	1327	45	1386	141	4.24	1327	45
03DTB18	09/05/2019 (5) 22:05:02.00	03DTB18 - 43	167	7	117	5	3.325574	0.128444	0.108000	0.009960	0.340660	1695	56	1765	160	3.98	1765	160
03D1818 03DTR18	09/05/2019 (5) 20:16:35:00	03D1B18 - 1 03D1B18 - 57	102	5	91	6	5 112474	0.166886	0.107900	0.011058	0.508560	1696	52	1/63	1//	3.81	1/63	52
03DTB18	10/05/2019 (6) 00:02:40.00	03DTB18 - 90	125	6	35	2	2.958580	0.131823	0.118500	0.009970	0.259300	1877	70	1933	144	2.89	1933	144
03DTB18	09/05/2019 (5) 21:17:19.66	03DTB18 - 28	311	41	208	30	2.111932	0.076137	0.169200	0.010084	0.214720	2499	72	2549	97	1.97	2549	97
03DTB18	09/05/2019 (5) 22:25:40.00	03DTB18 - 54	350	7	174	6	5.414185	0.222606	0.076600	0.005932	0.362030	1093	40	1110	148	1.56	1093	40
03DTB18	09/05/2019 (5) 22:42:57:00	03DTB18 - 68	329	12	124	5	3.162555	0.175450	0.108500	0.007072	0.387580	1771	51	1701	146	0.23	1775	115
03DTB18	09/05/2019 (5) 21:11:39.43	03DTB18 - 25	41	2	23	2	3.194888	0.176178	0.107000	0.014140	0.173050	1756	81	1748	225	-0.43	1748	225
03DTB18	09/05/2019 (5) 21:07:52.00	03DTB18 - 23	121	5	94	4	4.757374	0.228580	0.081000	0.010220	0.196240	1230	52	1221	230	-0.73	1230	52
03DTB18	10/05/2019 (6) 00:00:45.00	03DTB18 - 89	365	9	192	3	5.359057	0.201955	0.076000	0.006820	0.130270	1103	37	1094	171	-0.80	1103	37
03DTB18	09/05/2019 (5) 21:47:46.00	03DTB18 - 38	165	16	75	8	4.847310	0.228526	0.080100	0.009102	0.373230	1209	50	1199	210	-0.88	1209	50
03DTB18	09/05/2019 (5) 22:18:09.00	03DTB18 - 50	131	3	98	4	4.559964	0.211800	0.082800	0.008556	0.412740	1278	52	1264	190	-1.16	1278	52
03DTB18	09/05/2019 (5) 23:18:47.19	03DTB18 - 75	58	2	35	1	1.600000	0.072960	0.236000	0.016720	0.393750	3130	109	3093	109	-1.21	3093	109
03D1818 03DTR18	09/05/2019 (5) 23:30:05:00	03DTB18 - 81 03DTB18 - 9	150	39	120	8	2 162162	0.083915	0.075400	0.005108	0.348250	2451	32	10/8	131	-1.83	2391	32
03DTB18	09/05/2019 (5) 23:49:09.00	03DTB18 - 87	498	14	105	4	2.086376	0.063057	0.160400	0.007008	0.102030	2524	62	2459	73	-2.65	2459	73
03DTB18	09/05/2019 (5) 22:21:55.00	03DTB18 - 52	102	4	67	4	4.201681	0.218205	0.086100	0.010322	0.390440	1376	61	1340	216	-2.74	1376	61
03DTB18	09/05/2019 (5) 22:12:33.00	03DTB18 - 47	281	9	158	5	3.935458	0.140550	0.089800	0.007196	0.273110	1460	45	1420	147	-2.76	1460	45
03D1818 03DTR18	10/05/2019 (6) 00:19:33.00	03D1B18 - 99 03DTB18 - 5	184	10	72	1	3.880481	0.160429	0.090600	0.009112	0.342370	14/8	53	143/	181	-2.83	14/8	53
03DTB18	09/05/2019 (5) 21:40:11.50	03DTB18 - 34	49	3	28	2	1.897533	0.081158	0.175000	0.014500	0.150930	2729	92	2605	133	-4.74	2605	133
03DTB18	09/05/2019 (5) 23:43:24.00	03DTB18 - 85	131	6	54	3	3.907776	0.171307	0.088800	0.008976	0.557140	1469	55	1399	183	-4.99	1469	55
03DTB18	09/05/2019 (5) 22:33:12:00	03DTB18 - 58	296	12	122	5	3.087373	0.113220	0.105100	0.006302	0.223380	1809	56	1715	107	-5.45	1715	107
03D1818 03DTR18	09/05/2019 (5) 22:27:35:00	03DTB18 - 55 03DTB18 - 27	91	3	140	5	4 125413	0.131/68	0.101600	0.009432	0.157360	1/44	60	1853	164	-5.51	1653	164
03DTB18	09/05/2019 (5) 22:23:50.00	03DTB18 - 53	206	5	201	6	5.017561	0.206090	0.076600	0.007132	0.290590	1172	42	1110	176	-5.56	1172	42
03DTB18	09/05/2019 (5) 22:06:52.00	03DTB18 - 44	215	8	124	5	4.987531	0.204228	0.076800	0.007436	0.289950	1178	42	1115	183	-5.64	1178	42
03DTB18	09/05/2019 (5) 23:26:19:00	03DTB18 - 79 02DTB18 - 29	114	4	92	3	4.020909	0.190359	0.086500	0.009530	0.179620	1432	58	1349	200	-6.18	1432	58
03DTB18	09/05/2019 (5) 21:44:01.00	03DTB18 - 36	238	6	135	3	3.016591	0.112201	0.106300	0.007726	0.270070	1846	58	1736	128	-6.31	1736	128
03DTB18	09/05/2019 (5) 20:33:33.00	03DTB18 - 10	194	9	200	12	5.068424	0.227244	0.075900	0.008318	0.061512	1161	46	1092	206	-6.35	1161	46
03DTB18	10/05/2019 (6) 00:13:56.00	03DTB18 - 96	366	11	346	11	4.476276	0.157651	0.080900	0.006718	0.260720	1300	40	1218	156	-6.71	1300	40
03D1818	09/05/2019 (5) 21:42:11:00	0301818 - 35	75	4	32	2	5.944773	0.201829	0.087000	0.012/40	0.303770	1457	64	1360	259	-7.10	145/	64
03DTB18	09/05/2019 (5) 20:52:33.00	03DTB18 - 16	64	3	74	3	5.288207	0.290334	0.074000	0.011480	0.036788	1117	54	1041	285	-7.25	1117	54
03DTB18	09/05/2019 (5) 21:22:55.00	03DTB18 - 31	109	4	165	5	3.408316	0.149483	0.095500	0.010010	0.251750	1659	62	1537	186	-7.90	1537	185
03DTB18	09/05/2019 (5) 23:15:02.00	03DTB18 - 73	50	5	93	11	4.844961	0.319899	0.077000	0.016540	0.201420	1210	69	1120	379	-8.00	1210	69
03D1818 03DTR18	10/05/2019 (6) 00:27:18:00	03DTB18 - 100 03DTB18 - 14	155	3	129	1	4.739336	0.216078	0.077600	0.008952	0.243340	1234	49	1136	215	-8.65	1234	49
03DTB18	09/05/2019 (5) 23:00:01.00	03DTB18 - 65	93	4	35	2	1.949318	0.080785	0.159800	0.011796	0.390420	2669	88	2453	120	-8.83	2453	120
03DTB18	09/05/2019 (5) 23:39:36.00	03DTB18 - 83	403	19	343	16	3.958828	0.135597	0.085800	0.005916	0.102530	1452	43	1333	129	-8.93	1452	43
03DTB18	09/05/2019 (5) 22:20:04.00	03DTB18 - 51	257	5	188	4	3.958828	0.145000	0.085700	0.006814	0.139950	1452	46	1331	147	-9.12	1452	46
03DTB18	09/05/2019 (5) 21:09:43.00	03DTB18 - 24	527	17	500	9	4.604052	0.157793	0.078500	0.005270	0.286590	1267	38	1159	107	-9.35	1267	38
03DTB18	09/05/2019 (5) 23:03:46.00	03DTB18 - 67	208	8	1	0	5.420054	0.231784	0.072400	0.007048	0.072746	1092	41	996	187	-9.56	1092	41
03DTB18	09/05/2019 (5) 22:10:38.00	03DTB18 - 46	109	3	67	3	5.824112	0.303044	0.070100	0.010802	0.150830	1022	47	930	289	-9.84	1022	47
03D1818 03DTR18	09/05/2019 (5) 21:45:56:00	03DTB18 - 37 03DTB18 - 8	163	15	126	5	3.835827	0.153227	0.087000	0.007940	0.31/4/0	1493	51	1360	16/	-9.84	1493	41
03DTB18	09/05/2019 (5) 21:05:58.00	03DTB18 - 22	230	14	114	7	4.198153	0.161511	0.082300	0.006546	-0.009508	1377	46	1252	149	-10.03	1377	46
03DTB18	09/05/2019 (5) 22:01:14.53	03DTB18 - 41	21	1	25	1	3.039514	0.208609	0.102000	0.019040	0.187330	1834	103	1660	312	-10.45	1660	312
03DTB18 03DTB19	09/05/2019 (5) 22:08:47.00 10/05/2019 (6) 00:04:21:00	USD1B18 - 45 030TB18 - 91	74	3	31	2	4.291845	0.209251	0.081000	0.012620	0.150610	1350	57	1221	279	-10.58	1350	57
03DTB18	10/05/2019 (6) 00:06:24.01	03DTB18 - 92	46	1	52	2	4.710316	0.293890	0.077000	0.013540	0.111870	1241	~o 67	1120	255	-10.81	1241	67
03DTB18	09/05/2019 (5) 21:30:39.00	03DTB18 - 32	236	20	73	6	4.159734	0.169712	0.082300	0.006946	0.452800	1389	49	1252	158	-10.94	1389	49
U3DTB18	us/us/2019 (5) 23:31:59.00	USU1B18 - 82 020TB18 - 20	178	7	198	11	3.930818	0.168234	0.085100	0.008002	0.1221/0	1461	54	1317	173	-10.95	1461	54
03DTB18	09/05/2019 (5) 22:29:26.00	03DTB18 - 56	258	10	126	5	5.027652	0.189024	0.074300	0.007086	0.253230	1169	39	1042	140	-11.50	1169	39
03DTB18	09/05/2019 (5) 23:58:47.00	03DTB18 - 88	307	13	1	0	5.546312	0.212439	0.071000	0.006320	0.300350	1069	36	957	173	-11.72	1059	36
03DTB18	09/05/2019 (5) 21:21:00.00	03DTB18 - 30	272	10	105	4	5.636979	0.230309	0.070400	0.007108	0.359440	1053	38	939	195	-12.11	1053	38
03D1818	09/05/2019 (5) 23:22:34:00 09/05/2019 (5) 22:35:07:09	030/B18 - // 030TB18 - 59	341 102	15	115	3	4.972650	0.188471	0.074400	0.009374	0.153110	1181	40	1051	165	-12.35	1181	40
03DTB18	10/05/2019 (6) 00:17:42.00	03DTB18 - 98	191	10	116	7	5.617978	0.260599	0.070300	0.007506	0.364170	1056	43	936	205	-12.80	1056	43
03DTB18	10/05/2019 (6) 00:15:47.00	03DTB18 - 97	247	12	138	7	4.960317	0.200086	0.074300	0.006886	0.172370	1184	42	1049	177	-12.89	1184	42
03DTB18	Uty/U5/2019 (5) 20:56:25.00	USDTB18 - 18 020TB18 - 42	297	19	49	3	3.371544	0.123131	0.092800	0.006556	0.354120	1674	52	1483	129	-12.91	1483	129
03DTB18	10/05/2019 (5) 22:05:06:00	03DTB18 - 94	260	14	81	6	3.906250	0.135108	0.075800	0.006474	-0.125200	1240	44	1089	1/6	-13.85	1469	44
03DTB18	09/05/2019 (5) 23:24:29.00	03DTB18 - 78	208	12	139	10	5.012531	0.215828	0.073400	0.007368	0.229390	1173	44	1024	192	-14.50	1173	44
03DTB18	09/05/2019 (5) 22:38:52.00	03DTB18 - 61	230	13	68	4	5.277045	0.214145	0.071400	0.006428	0.183080	1119	40	968	174	-15.57	1119	40
03DTB18	09/05/2019 (5) 23:41:29.00	03DTB18 - 84 02DTB18 - 7	165	6	307	11	4.766444	0.213468	0.074800	0.007396	0.209850	1228	48	1052	188	-15.59	1228	48
03D7818 03DTB18	09/05/2019 (5) 20:27:53.00	03DTB18 - 66	217	9	58 145	6	3.846154	0.20/5/2	0.083600	0.007134	0.120850	1131 1490	40 49	977 1282	191 159	-15.83 -16.17	1131 1490	40
03DTB18	09/05/2019 (5) 23:47:14.00	03DTB18 - 86	112	5	57	3	4.500450	0.215584	0.076600	0.009932	0.163610	1294	54	1110	240	-16.53	1294	54
03DTB18	09/05/2019 (5) 22:16:18.00	03DTB18 - 49	230	13	142	8	5.327651	0.220088	0.070800	0.006716	0.129270	1109	41	951	184	-16.64	1109	41
03DTB18 03DTB18	09/05/2019 (5) 20:22:17:00 09/05/2019 (5) 22:36:57:00	USD1B18 - 4 030TB18 - 60	141	15	43	6	3.961965	0.160865	0.081600	0.008932	0.194440	1451	51	1235	202	-17.46	1451	51
03DTB18	09/05/2019 (5) 20:37:19.00	03DTB18 - 12	90	5	120	8	4.606172	0.219424	0.075200	0.011104	0.165750	1267	52	1073	272	-18.03	1267	52
03DTB18	09/05/2019 (5) 20:20:22.00	03DTB18 - 3	114	5	64	3	4.967710	0.222745	0.071800	0.007936	0.089709	1182	47	979	211	-20.72	1182	47
03DTB18	09/05/2019 (5) 22:14:23.00	03DTB18 - 48	645	28	40	2	5.344735	0.181167	0.069400	0.004988	0.392700	1106	33	910	142	-21.54	1106	33
03D1818 03D1818	09/05/2019 (5) 21:59:11.84 09/05/2019 (5) 20:42:55:09	0301818 - 40 0301818 - 15	134	9	122	8	7.692308 5.470460	0.414201	0.057200	0.005744	0.225810	788	38	617	288	-27.70	788	38
03DTB18	09/05/2019 (5) 20:54:30.00	03DTB18 - 17	115	5	36	2	5.279831	0.250555	0.056000	0.009120	0.092248	1118	47	805	267	-38.89	1118	47
03DTB18	10/05/2019 (6) 00:08:16.00	03DTB18 - 93	58	1	25	2	5.068424	0.317155	0.066000	0.014320	0.267820	1161	63	805	400	-44.20	1161	63
03DTB18	09/05/2019 (5) 23:09:23.84	03DTB18 - 70	70	11	39	2	5.678592	0.368318	0.062000	0.014240	0.217400	1046	59	673	428	-55.36	1046	59

# Appendix D5.3: Lu/Hf Results

Sample ID	Analysis date-time	Spot ID	Discord (7/6-6/8)/7/6 *100 Ma cut	ge 1500 off error 2 o	Lu-Hf Isotopic 176H(/177Hf ±2o INT % 0.282785 0.283250	Ratios from Iolite (2% External ±) 17	6Lu/17716m ±2o INT 0.03360 Bouvier et al 0.03840 Griffin et al.,	17676/177Hi ±2a ., 2008 EPSL-273 2002, Lithos-237	INT HE LU DI	sHf Ca 120 ecay	Iculations TDM(Ga) 0.02 Scherer o	TDMCrustal at al., 2001, Science	i HfCHUR(t) His 1e-293	DM(t)	Notes	
207218 207218 207218 407219	10/05/2019 (6) 07:51:08:00 09/05/2019 (5) 23:09:23:84 10/05/2019 (6) 00:08:16:00 10/05/2019 (6) 00:57:39:93	05DTR18 - 114 03DTR18 - 70 03DTR18 - 93 04DTR18 - 12	-61.78 1089 -55.36 1046 -44.20 1161 -47.23 1159	46 59 63	4.21% 0.28234 0.00034 5.65% 0.28231 0.00034 5.42% 0.28232 0.00034 4.27% 0.28232 0.00034	0.00545 0.00545 0.00545	0.00070 0.00 0.00108 0.00 0.00018 0.00 0.00156 0.00	003 0.02710 004 0.03466 000 0.05452 002 0.05034	0.00130 0.2823256 0.00011 0.2822908 0.00040 0.2823130 0.00040 0.2823130	7.86 5.66 9.03 7.43	0.00 1.54 1.26	128 1. 133 1. 129 1.	40 0.282104 51 0.282131 38 0.282058 49 0.282059	0.282463 0.282495 0.282411 0.282412	discordant, not plotted discordant, not plotted discordant, not plotted	
107918 507918 307918	09/05/2019 (5) 20:54:30.00 10/05/2019 (6) 06:29:56:00 09/05/2019 (5) 20:42:55:00	03DTR18 - 17 05DTR18 - 79 03DTR18 - 15	-38.89 1118 -29.12 1301 -28.38 1082	47 52 28	4.17% 0.28234 0.00005 4.00% 0.28226 0.00005 3.48% 0.28227 0.00034	0.00545 0.00545 0.00545	0.00072 0.00 0.00204 0.00 0.00082 0.00	000 0.02864 004 0.08000 002 0.02979	0.0029 0.2823198 0.00220 0.2822099 0.00066 0.2822514	8.31 8.52 5.08	1.86 1.75 1.40	129 1. 144 1. 138 1.	40 0.282085 52 0.281970 58 0.282108	0.282642 0.282308 0.282468	discordant, not plotted discordant, not plotted discordant, not plotted	
207218 207218 507218 507218	09/05/2019 (5) 21:59:11:84 09/05/2019 (5) 22:14:23:00 10/05/2019 (6) 04:13:18:00 09/05/2019 (5) 20:20:22:00	03DTR18 - 40 03DTR18 - 48 05DTR18 - 25 03DTR18 - 3	-27.30 788 -21.54 1106 -21.49 1024 -20.72 1182	28 22 28 47	4.82% 0.28229 0.00034 3.02% 0.28228 0.00034 3.74% 0.28222 0.00034 3.94% 0.28225 0.00034	0.00565 0.00565 0.00564 0.00565	0.00069 0.00 0.00069 0.00 0.00067 0.00 0.00165 0.00	000 0.01981 005 0.08000 000 0.02526 001 0.06325	0.00027 0.2823748 0.00320 0.2822616 0.00014 0.2822091 0.00017 0.2822181	2.88 5.97 2.28 6.14	1.33 1.44 1.37 1.37	122 1. 137 1. 144 1. 143 1.	49 0.282294 54 0.282093 71 0.282145 59 0.282045	0.282683 0.282451 0.282510 0.282395	discondant, not plotted discondant, not plotted discondant, not plotted discondant, not plotted	
507818 507818 H1	10/05/2019 (6) 06:16:44.00 10/05/2019 (6) 03:27:51.00 03/12/2018 (2) 19:54:40.00	05DTB18 - 72 05DTB18 - 8 8H1 - 130	-19.88 1133 -18.94 1137 -18.63 1065	37 55 55	3.30% 0.28225 0.00034 4.87% 0.28205 0.00010 5.15% 0.282285 0.00038	0.00545 0.00544 0.00545	0.00104 0.00 0.00053 0.00 0.0007328 0.0000	005 0.04100 006 0.02040 053 0.03592	0.00180 0.2822248 0.00250 0.2820406 0.0002 0.2822703	5.27 -1.16 5.65	1.47 3.40 1.33	1.42 1. 1.67 2. 1.36 1.	60 0.282076 02 0.282073 54 0.282111	0.282431 0.282428 0.282480	discordant, not plotted discordant, not plotted discordant, not plotted	
207918 207918 507918	09/05/2019 (5) 22:36:57:00 10/05/2019 (5) 22:36:57:00 10/05/2019 (6) 07:22:47:00 09/05/2019 (5) 20:22:17:00	03DTR18 - 12 03DTR18 - 60 05DTR18 - 103 03DTR18 - 4	-18.04 1267 -17.95 1454 -17.30 1437 -17.46 1451	52 55 218 51	4.54% 0.24222 0.00005     3.76% 0.24200 0.00034     15.18% 0.242194 0.00007     3.52% 0.24211 0.00005	0.00564 0.00564 0.00564	0.00062 0.00 0.00118 0.00 0.00073 0.00	005 0.10050 001 0.03567 003 0.04390 007 0.02740	0.00230 0.2822539 0.00237 0.2819810 0.02130 0.2819050 0.02300 0.2820880	3.85 0.78 7.58	1.79 1.33 1.33 1.58	1.38 1. 1.75 1. 1.75 2. 1.60 1.	45 0.281991 94 0.281872 13 0.281883 70 0.281874	0.282196 0.282208 0.282208	discontant, not plotted discontant, not plotted discontant, not plotted discontant, not plotted	
SOTR18 307818 SOTR18	10/05/2019 (6) 08:27:08:00 09/05/2019 (5) 22:16:18:00 10/05/2019 (6) 04:51:11:00	05DTB18 - 129 03DTB18 - 49 05DTB18 - 42	-17.23 1379 -16.64 1109 -16.63 1229	56 41 42	4.08% 0.28216 0.00007 3.66% 0.28203 0.00005 3.40% 0.28226 0.00005	0.00564 0.00565 0.00565	0.00097 0.00 0.00101 0.00 0.00316 0.00	001 0.03712 004 0.02870 010 0.11870	0.00029 0.2821387 0.00190 0.2820068 0.00290 0.2821837	7.75 -2.99 5.98	1.58 1.75 1.86	1.60 1. 1.72 2. 1.49 1.	63 0.281920 11 0.282091 63 0.282015	0.282251 0.282649 0.282360	discordant, not plotted discordant, not plotted discordant, not plotted	
307918 507918 407918 407918	09/05/2019 (5) 23:47:14.00 10/05/2019 (6) 04:45:27:00 10/05/2019 (6) 03:01:09:00 10/05/2019 (6) 01:18:29:00	03DTR18 - 86 05DTR18 - 29 04DTR18 - 62 04DTR18 - 23	-16.53 1294 -16.47 1310 -16.41 1286 -16.29 1109	54 53 167 29	4.16% 0.28210 0.00005 4.04% 0.28223 0.00005 12.04% 0.28202 0.00004 3.47% 0.28232 0.00003	0.00564 0.00564 0.00564 0.00565	0.00079 0.00 0.00144 0.00 0.00134 0.00 0.00085 0.00	002 0.02343 001 0.05634 001 0.04957 007 0.02930	0.00062 0.2820838 0.00053 0.2821895 0.00027 0.2819839 0.00270 0.2823062	3.88 8.01 2.42 7.62	1.79 1.75 1.33 1.12	147 L 147 L 175 L 131 L	82 0.281974 57 0.281964 98 0.281916 43 0.282091	0.282313 0.282301 0.282245 0.282449	discondant, not plotted discondant, not plotted discondant, not plotted discondant, not plotted	
507818 307818 407818	10/05/2019 (6) 06:28:01:00 09/05/2019 (5) 23:01:55:00 10/05/2019 (6) 01:31:38:00	05DTB18 - 78 03DTB18 - 66 04DTB18 - 30	-16.24 1105 -16.17 1490 -16.13 1163	49 49 29	4.43% 0.28227 0.00007 3.28% 0.28198 0.00005 3.32% 0.28299 0.00008	0.00545 0.00564 0.00564	0.00100 0.00 0.00052 0.00 0.00106 0.00	000 0.03701 000 0.01408 003 0.04140	0.00020 0.2822522 0.00038 0.2819674 0.00150 0.2820627	5.62 4.18 0.21	2.35 1.75 2.94	1.38 1. 1.77 1. 1.65 1.	56 0.282094 95 0.281850 95 0.282057	0.282451 0.282169 0.282409	discordant, not plotted discordant, not plotted discordant, not plotted	
201218 201218 201218	09(05/2019 (5) 20:27:53:00 10(05/2019 (6) 01:26:02:00 09(05/2019 (5) 22:41:29:00 09(05/2019 (5) 22:38:52:00	04DTR18 - 7 04DTR18 - 27 03DTR18 - 84 03DTR18 - 61	-15.82 1128 -15.82 1128 -15.59 1228 -15.57 1119	40 42 48 40	2.52% 0.28219 0.00054 2.69% 0.28219 0.00054 2.92% 0.28211 0.00055 2.59% 0.28232 0.00054	0.00544 0.00544 0.00544	0.00066 0.00 0.00207 0.00 0.00042 0.00	001 0.02431 001 0.02431 001 0.09400 000 0.02264	0.00120 0.2822075 0.00171 0.2821760 0.00120 0.2820631 0.00037 0.2823212	3.65 1.67 8.37	1.51 1.47 1.86 1.54	1.49 L 1.49 L 1.66 L 1.28 L	42 0.282077 71 0.282073 91 0.282016 39 0.282085	0.282428 0.282428 0.282362 0.282441	discontant, not plotted discontant, not plotted discontant, not plotted discontant, not plotted	
507818 507818 307818	10/05/2019 (6) 07:43:34.00 10/05/2019 (6) 08:21:28:00 09/05/2019 (5) 23:24:29:00	05DTR18 - 111 05DTR18 - 126 03DTR18 - 78	-15.46 1091 -15.15 1192 -14.50 1173	25 28 44	3.23% 0.28234 0.00005 3.16% 0.28226 0.00005 3.78% 0.28229 0.00005	0.00545 0.00545 0.00545	0.00624 0.00 0.00059 0.00 0.00133 0.00	024 0.28290 000 0.02117 006 0.09347	0.00930 0.2822067 0.00020 0.2822458 0.00060 0.2822636	3.69 7.34 7.54	1.54 2.24 1.61	128 1 150 1 137 1	67 0.282103 52 0.282039 49 0.282051	0.282462 0.282388 0.282402	discordant, not plotted discordant, not plotted discordant, not plotted	
507918 816705 816705 507918	10/05/2019 (5) 08:17:42:00 10/05/2019 (5) 00:10:11:00 09/05/2019 (5) 22:03:06:00 10/05/2019 (5) 06:14:49:00	03DTR18 - 124 03DTR18 - 94 03DTR18 - 42 05DTR18 - 71	-54.82 1229 -54.37 5469 -13.83 1240 -13.26 1547	46 44 67	2.65% 0.28225 0.00011 3.02% 0.28206 0.00034 3.58% 0.28222 0.00034 5.80% 0.28215 0.00034	0.00564 0.00564 0.00564	0.00086 0.00 0.00121 0.00 0.00067 0.00	004 0.09120 003 0.00618 005 0.01342 001 0.02421	0.00120 0.2821876 0.00023 0.2820381 0.00028 0.2821948 0.00007 0.2821315	6.22 6.60 2.29	1.61 1.37 1.30 1.23	147 11 147 11 146 11 155 11	55 0.281952 80 0.281863 60 0.282009 81 0.282067	0.282253 0.282353 0.282420	discontant, not plotted discontant, not plotted discontant, not plotted discontant, not plotted	
207918 207918 407918	09/05/2019 (5) 20:56:25:00 10/05/2019 (6) 00:15:47:00 10/05/2019 (6) 01:12:48:00	03DTR18 - 18 03DTR18 - 97 04DTR18 - 20	-12.91 1483 -12.89 1184 -12.86 1076	129 42 27	8.70% 0.28196 0.00004 3.55% 0.28216 0.00004 3.44% 0.28235 0.00004	0.00564 0.00565	0.00049 0.00 0.00072 0.00 0.00155 0.00	001 0.01744 001 0.07849 001 0.05668	0.00027 0.2819452 0.00034 0.2821478 0.00055 0.2823195	3.26 3.69 7.35	1.44 1.51 1.47	1.80 2/ 1.52 1/ 1.29 1/	00 0.281854 74 0.282044 43 0.282112	0.282174 0.282394 0.282472	discordant, not plotted discordant, not plotted discordant, not plotted	
207218 207218 507218 207218	10/05/2019 (6) 00:17:42:00 09/05/2019 (5) 22:35:07:00 10/05/2019 (6) 04:37:42:00 09/05/2019 (6) 04:37:42:00	03DTR18 - 98 03DTR18 - 59 05DTR18 - 38 03DTR18 - 77	-12.80 1056 -12.77 1449 -12.59 1481 -12.35 1181	43 56 70 40	4.10% 0.28227 0.00003 3.84% 0.28213 0.00005 4.72% 0.28217 0.00008 3.25% 0.28231 0.00004	0.00545 0.00544 0.00544 0.00545	0.00095 0.00 0.00098 0.00 0.00062 0.00 0.00262 0.00	006 0.02559 001 0.00767 002 0.02002 001 0.03180	0.00055 0.2822551 0.00018 0.2821032 0.00078 0.2821506 0.00230 0.2822477	4.62 8.07 10.47 7.17	1.12 1.58 2.87 1.47	1.38 1. 1.58 1. 1.51 1. 1.40 1.	59 0.282125 67 0.281876 54 0.281855 52 0.282046	0.282487 0.282199 0.282176 0.282396	discondant, not plotted discondant, not plotted discondant, not plotted discondant, not plotted	
SOT218 307218 SOT218	10/05/2019 (6) 03:20:19.00 09/05/2019 (5) 21:21:00.00 10/05/2019 (6) 03:41:07.00	05DTR18 - 4 03DTR18 - 30 05DTR18 - 12	-12.30 1122 -12.11 1053 -11.76 1151	46 38 52	4.07% 0.28236 0.00034 3.64% 0.28227 0.00034 4.48% 0.28236 0.00034	0.00545 0.00545 0.00545	0.00069 0.00 0.00063 0.00 0.00096 0.00	004 0.02460 003 0.04940 001 0.03610	0.00120 0.2823403 0.00055 0.2822525 0.00040 0.2823402	9.12 4.46 9.77	1.54 1.51 1.37	126 1 138 1 126 1	25 0.282083 59 0.282127 33 0.282065	0.282439 0.282490 0.282418	discordant, not plotted discordant, not plotted discordant, not plotted	
H1 307918 507918	03/12/2018 (2) 16:41:58:00 09/05/2019 (5) 22:29:26:00 10/05/2019 (6) 06:20:30:00	BH1 - 64 03DTR18 - 56 05DTR18 - 74	-11.65 1093 -11.51 1169 -11.44 1355	36 29 180	3.31%         0.282339         0.000029           3.32%         0.28233         0.00005           3.32%         0.28233         0.00005           13.25%         0.28202         0.00005	0.00545 0.00545 0.00544	0.0005772 0.000 0.00160 0.00 0.00082 0.00	001 0.03099 000 0.01614 002 0.03017	0.00022 0.2823271 0.00062 0.2822917 0.00078 0.2820010	8.30 8.46 2.36	1.02 1.65 1.65	128 1- 133 1- 172 1-	40 0.282093 43 0.282053 96 0.282935	0.282460 0.282460 0.282268	discordant, not plotted discordant, not plotted discordant, not plotted	
819705 819705 819705	09/05/2019 (5) 21:02:07:00 09/05/2019 (5) 22:31:59:00 09/05/2019 (5) 21:30:39:00	03DTB18 - 20 03DTB18 - 82 03DTB18 - 32	-11.36 1642 -10.95 1461 -10.94 1289	140 54 49	8.51% 0.28154 0.00004 3.69% 0.28173 0.00004 3.54% 0.28220 0.00004	0.00563 0.00563 0.00564	0.00083 0.00 0.00003 0.00 0.00157 0.00	001 0.03242 000 0.05170 004 0.03726	0.00078 0.2815122 0.00230 0.2817252 0.00076 0.2821659	-8.53 -5.06 8.76	1.47 1.30 1.44	2.39 21 2.09 21 1.50 11	88 0.281753 52 0.281868 58 0.281914	0.282057 0.282190 0.282243	discordant, not plotted discordant, not plotted discordant, not plotted	
816705 816705 816705	10/05/2019 (6) 00:04:31:00 09/05/2019 (5) 22:08:47:00 09/05/2019 (5) 22:01:14:53	03DTR18 - 91 03DTR18 - 45 03DTR18 - 41	-00.73 0021 -00.58 1250 -10.45 1660	45 57 312	4.54% 0.28229 0.00004 4.21% 0.28227 0.00004 18.77% 0.28130 0.00004	0.00545 0.00545	0.00070 0.00 0.00086 0.00 0.00040 0.00	001 0.01311 000 0.03561 001 0.02862	0.00006 0.2823796 0.00046 0.2822512 0.00038 0.2812914	8.25 11.09 -15.96	1.44 1.47 1.47	121 1. 138 1. 268 3.	33 0.282147 40 0.281938 36 0.281741	0.282513 0.282272 0.282044	discontant, not plotted discontant, not plotted discontant, not plotted	
H1 507818 507818 507818	03/12/2018 (2) 17-27-38.00 10/05/2019 (6) 07-28-22.00 09/05/2019 (5) 21-05-58.00 10/05/2019 (6) 07-12-21.00	8H1 - 81 05DTR18 - 105 03DTR18 - 22 05DTR18 - 98	-00.01 1091 -00.14 1433 -00.03 1277 -00.01 1090	41 51 46 28	3.45% 0.282172 0.000031 3.57% 0.28229 0.00012 3.25% 0.28196 0.00003 3.46% 0.28223 0.00005	0.00564 0.00565 0.00564 0.00564	0.000793 0.000 0.00109 0.00 0.00095 0.00 0.00143 0.00	021 0.0377 004 0.04170 000 0.03736 009 0.05380	0.0011 0.2821542 0.00190 0.2822605 0.00042 0.2819302 0.00340 0.2822026	4.40 13.29 0.32 3.52	1.09 1.09 1.16 1.16	152 1 152 1 182 2 182 1	73 0.282030 32 0.281886 11 0.281921 68 0.282103	0.282288 0.282211 0.282252 0.282462	discondant, not plotted discondant, not plotted discondant, not plotted discondant, not plotted	
819701 819701 819702	09/05/2019 (5) 20:29:48:00 09/05/2019 (5) 21:45:56:00 09/05/2019 (5) 22:10:38:00	03DTR18 - 8 03DTR18 - 37 03DTR18 - 46	-10.00 1310 -9.84 1493 -9.84 1022	41 51 47	3.11%         0.28226         0.00004           3.44%         0.28188         0.00004           4.59%         0.28231         0.00004	0.00545 0.00544 0.00545	0.00218 0.00 0.00062 0.00 0.00086 0.00	002 0.09084 000 0.02530 001 0.03102	0.00087 0.2822090 0.00110 0.2818584 0.00012 0.2822955	8.70 0.39 5.28	1.30 1.40 1.54	1.44 1. 1.92 2. 1.32 1.	52 0.281964 19 0.281847 52 0.282146	0.282301 0.282166 0.282512	discondant, not plotted	
H1 H1 SOT818 SOT818	03/12/2018 (2) 14:47:52:00 03/12/2018 (2) 13:52:08:00 10/05/2019 (6) 07:38:47:00 10/05/2019 (6) 07:18:02:00	8H1 - 2H 8H1 - 2 0SDTR18 - 109 0SDTR18 - 101	-9.82 1063 -9.81 1319 -9.64 1170 -9.59 1152	35 65 34 36	3.41% 0.282296 0.000023 4.90% 0.282259 0.000035 2.89% 0.28225 0.00008 3.09% 0.28227 0.00008	0.00545 0.00545 0.00545	0.0009236 0.000 0.001886 0.000 0.00199 0.00 0.00306 0.00	008 0.05052 031 0.1032 003 0.07970 004 0.13322	0.00025 0.2822775 0.002 0.2822120 0.00150 0.2823080 0.00079 0.2821995	5.96 9.25 9.07 4.81	0.81 1.23 1.79 1.30	1.35 1. 1.44 1. 1.82 1. 1.30 1.	53 0.282112 51 0.282948 39 0.282052 65 0.282064	0.282482 0.282295 0.282404 0.282404		
307918 507918 407918	09/05/2019 (5) 23:03:46:00 10/05/2019 (6) 03:31:36:00 10/05/2019 (6) 02:26:52:00	03DTR18 - 67 05DTR18 - 10 04DTR18 - 48	-9.56 1092 -9.51 1131 -9.51 1224	41 43 47	3.78% 0.28222 0.00034 3.84% 0.28232 0.00034 3.80% 0.28214 0.00034	0.00564 0.00565 0.00564	0.00002 0.00 0.00060 0.00 0.00140 0.00	000 0.01899 004 0.02230 000 0.05149	0.00020 0.2822156 0.00160 0.2823072 0.00037 0.2821077	4.02 8.14 3.16	1.40 1.30 1.26	1.43 1. 1.30 1. 1.58 1.	65 0.282102 42 0.282078 81 0.282018	0.282461 0.282433 0.282364		
507918 507918 816705 816705	10/05/2019 (6) 06:07:05:00 10/05/2019 (6) 07:07:45:00 09/05/2019 (5) 21:09:43:00 09/05/2019 (5) 20:26:02:00	05D1818 - 70 05D1818 - 95 03D1818 - 24 03D1818 - 6	-9.45 1909 -9.36 1430 -9.35 1267 -9.35 982	46 38 31	7.5% 0.28154 0.0008 3.20% 0.28214 0.00011 3.02% 0.28225 0.00005 3.16% 0.28238 0.00034	0.00544 0.00545 0.00545	0.0006 0.00 0.00542 0.00 0.00412 0.00	001 0.01959 002 0.03134 009 0.20960 014 0.15930	0.00041 0.2815060 0.00300 0.2821169 0.00300 0.2821174 0.00480 0.2822989	-2.70 8.16 4.48 4.51	2.21 1.58 1.37	1.53 1. 1.61 1. 1.35 1.	71 0.281582 65 0.281888 76 0.281991 53 0.282172	0.282213 0.282233 0.282541		
307918 507918 507918	09/05/2019 (5) 22:20:04:00 10/05/2019 (6) 06:05:10:00 10/05/2019 (6) 06:01:19:00	03DTR18 - 51 05DTR18 - 69 05DTR18 - 67	-9.12 5452 -9.11 1305 -9.05 1382	45 38 215	3.18% 0.28193 0.00005 2.92% 0.28227 0.00005 15.59% 0.28293 0.00009	0.00564 0.00565 0.00564	0.00097 0.00 0.00270 0.00 0.00066 0.00	000 0.05410 006 0.10160 001 0.02386	0.00600 0.2819024 0.00250 0.2822035 0.00042 0.2819117	1.02 8.39 -0.24	1.65 1.72 3.29	1.86 2. 1.45 1. 1.84 2.	12 0.281874 54 0.281967 15 0.281918	0.282197 0.282305 0.282249		
207218 H1 207218	09/05/2019 (5) 23:39:36:00 03/12/2018 (2) 20:19:21:00 09/05/2019 (5) 23:00:01:00 03/12/2018 (2) 20:56:44:00	03DTR18 - 83 8H1 - 142 03DTR18 - 65 8H1 - 155	-8.93 1452 -8.87 1186 -8.83 2453 -8.69 1175	43 32 120 33	2.98% 0.28217 0.00005 2.66% 0.282226 0.000042 4.91% 0.28124 0.00003 2.84% 0.281835 0.000028	0.00564 0.00562 0.00562	0.00227 0.00 0.002093 0.00 0.00038 0.00 0.00286 0.000	001 0.00126 006 0.1095 000 0.04247 014 0.1268	0.00011 0.2821078 0.004 0.2821792 0.00055 0.2812251 0.0016 0.2817716	8.30 5.15 -0.21 -9.54	1.58 1.47 1.09 0.98	1.58 1. 1.49 1. 2.76 2. 2.09 2.	66 0.281874 67 0.282034 97 0.281231 60 0.282041	0.282197 0.282393 0.281454 0.282400		
307918 307918 407918	09/05/2019 (5) 20:41:04:00 10/05/2019 (6) 00:27:18:00 10/05/2019 (6) 01:29:47:00	03DTR18 - 14 03DTR18 - 100 04DTR18 - 29	-8.66 1140 -8.65 1234 -8.48 1286	51 49 194	4.51% 0.28225 0.00034 3.98% 0.28206 0.00033 14.00% 0.28210 0.00035	0.00545 0.00544 0.00544	0.00085 0.00 0.00110 0.00 0.00090 0.00	000 0.03111 011 0.03957 003 0.03322	0.00015 0.2822277 0.00092 0.2820344 0.00096 0.2820805	5.53 0.79 5.85	1.40 1.19 1.65	1.41 1: 1.68 1: 1.61 1:	59 0.282072 97 0.282012 76 0.282916	0.282426 0.282357 0.282245		
407918 407918 H1 307918	10/05/2019 (5) 00:29:18:00 10/05/2019 (5) 00:46:12:99 03/12/2018 (2) 18:40:13:00 09/05/2019 (5) 23:15:02:00	04D1818 - 1 04D1818 - 10 8H1 - 106 03D1818 - 73	-8.29 1295 -8.06 1746 -8.05 1213 -8.00 1210	134 36 69	7.6% 0.28210 0.00054 7.6% 0.28170 0.00055 3.0% 0.282097 0.00033 5.6% 0.28298 0.00055	0.00564 0.00564 0.00564	0.00100 0.00 0.0010867 0.0000 0.00039 0.00	002 0.06/14 006 0.03450 064 0.05032 004 0.02138	0.00180 0.2816659 0.0006 0.2820721 0.00060 0.2819711	-0.71 1.99 -2.00	1.65 1.05 1.82	1.66 1. 2.18 2. 1.63 1. 1.76 2.	45 0.281685 90 0.282015 13 0.282028	0.281980 0.282372 0.282375		
H1 307918 507918	03/12/2018 (2) 20:09:08:00 09:05/2019 (5) 21:22:55:00 10:05/2019 (6) 07:11:31:00	8H1-137 03DTR18-31 05DTR18-97	-7.90 1081 -7.90 1537 -7.87 1767	46 186 136	4.28% 0.282356 0.000028 12.11% 0.28190 0.00004 7.69% 0.28168 0.00005	0.00545 0.00544 0.00543	0.0009599 0.0000 0.00101 0.00 0.00066 0.00	038 0.04975 003 0.02413 006 0.02320	0.00021 0.2823364 0.00091 0.2818676 0.00210 0.2816580	8.36 1.71 -0.53	0.98 1.47 1.86	1.27 1. 1.91 2. 2.83 2.	38 0.282101 14 0.281820 46 0.281673	0.282469 0.282134 0.281965		
H1 H1 S0T818	03/12/2019 (6) 06:37:26:00 03/12/2018 (2) 19:07:04:00 03/12/2018 (2) 15:14:33:00 10/05/2019 (6) 03:46:47:00	05D1818 - 84 8H1 - 119 8H1 - 37 05DTR18 - 15	-7.81 1295 -7.75 1098 -7.68 1125 -7.65 1298	33 49 56	4.25% 0.28225 0.00007 4.31% 0.282455 0.000036 4.31% 0.282011 0.000034 4.29% 0.28211 0.00005	0.00545 0.00544 0.00544	0.00085 0.000 0.000691 0.000 0.00080 0.00	000 0.022227 025 0.0934 023 0.0273 001 0.02879	0.0013 0.2822105 0.0013 0.2824198 0.0016 0.2819962 0.00034 0.2820913	10.65 11.68 -2.48 4.25	1.26 1.19 1.82	1.43 1. 1.15 1. 1.73 2. 1.60 1.	65 0.281910 18 0.282090 12 0.282066 80 0.281971	0.282457 0.282457 0.282430 0.282310		
H1 407918 H1	03/12/2018 (2) 17:29:37:00 10/05/2019 (6) 01:01:34:00 03/12/2018 (2) 16:16:57:00	841-82 04DTR18-14 841-57 0507048-73	-7.61 2081 -7.58 2664 -7.53 1145	30 141 29	2.77% 0.282376 0.000024 8.52% 0.28170 0.00034 3.41% 0.282087 0.00034 4.30% 0.282087 0.00034	0.00545 0.00543 0.00544	0.0013452 0.0000 0.00097 0.00 0.001026 0.000	028 0.07392 004 0.02390 025 0.0559	0.00061 0.2823486 0.00160 0.2816683 0.0018 0.2820649	8.79 -2.50 0.18	0.84 1.26 1.19	125 1. 218 2: 164 1:	36 0.282101 51 0.281739 96 0.282060	0.282469 0.282041 0.282422		
SOT818 SOT818 SOT818 H1	10/05/2019 (6) 06:18:38:00 10/05/2019 (6) 04:05:48:00 09/05/2019 (5) 20:52:33:00 03/12/2018 (2) 19:56:45:00	05D1818 - 74 05D1818 - 21 03D1818 - 16 8H1 - 131	-7.50 1080 -7.40 1475 -7.25 1117 -7.20 1465	45 56 54 41	4.26% 0.28217 0.00054 4.80% 0.28217 0.00054 2.79% 0.28207 0.00053	0.00545 0.00545 0.00545	0.00102 0.00 0.00116 0.00 0.0008995 0.0000	001 0.03480 005 0.03480 001 0.04447 093 0.04305	0.00200 0.2821445 0.00229 0.2822436 0.00044 0.2820071	10.12 5.57 5.41	151 193 130 105	1.40 1. 1.52 1. 1.40 1. 1.71 1.	44 0.282109 56 0.281859 57 0.282086 88 0.281855	0.282180 0.282443 0.282188		
207218 HL 207218	09/05/2019 (5) 23:28:14:00 03/12/2018 (2) 16:06:40:00 09/05/2019 (5) 21:42:11:00	03DTR18 - 80 8H1 - 52 03DTR18 - 35	-7.18 1083 -7.14 1206 -7.10 1457 7.00 1457	44 34 64	4.04% 0.28225 0.00004 2.85% 0.28212 0.00003 4.38% 0.28299 0.00004	0.00545 0.00544 0.00544	0.00107 0.00 0.0011709 0.0000 0.00059 0.00	001 0.02349 025 0.05949 001 0.04545	0.00015 0.2822232 0.00064 0.2820934 0.00067 0.2819688	4.09 2.57 3.48	1.33 1.05 1.44	1.42 1. 1.60 1. 1.76 1.	64 0.282108 85 0.282021 97 0.281871	0.282468 0.282378 0.282194		
H1 SOT@18 H1	03/12/2018 (2) 18:42:20:00 10/05/2019 (6) 07:15:16:00 03/12/2018 (2) 19:27:40:00	8H1 - 107 05DTR18 - 99 8H1 - 122	-6.93 1129 -6.87 2021 -6.83 2088	36 41 34	3.15%         0.282412         0.000031           3.98%         0.282322         0.00005           3.09%         0.282322         0.00003	0.00545 0.00545	0.001652 0.000 0.00054 0.00 0.00054 0.000	073 0.0829 001 0.02050 048 0.03177	0.0027 0.2823765 0.00063 0.2823085 0.00043 0.2823090	11.09 5.97 7.55	1.09 2.07 1.05	121 1. 219 1. 130 1.	25 0.282064 48 0.282140 44 0.282096	0.282427 0.282505 0.282464		
H1 207218 407218	03/12/2018 (2) 18:27:36:00 10/05/2019 (6) 00:12:56:00 10/05/2019 (6) 02:02:14:00 03/12/2019 (6) 02:02:14:00	8H1 - 105 03DTB18 - 95 04DTB18 - 35 8H1 - 141	-6.77 1221 -6.71 1300 -6.57 1486 -6.45 1220	28 40 64	3.08% 0.282112 0.000032 3.09% 0.28216 0.00005 4.28% 0.28202 0.00006 3.39% 0.382125 0.00003	0.00564 0.00564 0.00564	0.00084 0.000 0.00208 0.00 0.00100 0.00	011 0.04222 001 0.03436 001 0.03521 021 0.03567	0.00079 0.2820927 0.00029 0.2821080 0.00033 0.2819930 0.00038 0.2821587	2.89 4.88 5.01 8.63	1.12 1.79 2.10 1.05	1.60 1. 1.59 1. 1.73 1. 1.50 1.	85 0.282011 76 0.281970 89 0.281852 60 0.281915	0.282367 0.282309 0.282172 0.282257		
8167018 207018 207018	10/05/2019 (6) 01:02:29.00 09/05/2019 (5) 20:32:32.00 09/05/2019 (5) 21:44:01.00	04DTR18 - 15 03DTR18 - 10 03DTR18 - 36	4.38 1621 4.35 1161 4.31 1736	141 45 128	8.70% 0.28199 0.00005 3.94% 0.28200 0.00003 7.40% 0.28192 0.00005	0.00564 0.00564 0.00564	0.00079 0.00 0.00204 0.00 0.00076 0.00	002 0.02856 003 0.07940 004 0.02119	0.00097 0.2819648 0.00170 0.2819555 0.00047 0.2818949	7.06 -3.65 7.19	1.93 1.12 1.79	1.77 1. 1.81 2. 1.86 1.	87 0.281766 19 0.282058 95 0.281692	0.282072 0.282411 0.281987		
207218 507218 207218 507218	09/05/2019 (5) 21:19:10:00 10/05/2019 (6) 08:32:44:00 09/05/2019 (5) 23:26:19:00 10/05/2019 (5) 23:26:19:00	03DTR18 - 29 05DTR18 - 132 03DTR18 - 79 05DTR18 - 128	-6.30 1701 -6.19 1707 -6.18 5432 -6.02 5446	123 117 58 44	7.21% 0.28173 0.00034 6.88% 0.28179 0.00035 4.07% 0.28206 0.00035 3.05% 0.28215 0.00012	0.00564 0.00564 0.00564	0.00127 0.00 0.00078 0.00 0.00063 0.00 0.00063 0.00	002 0.03900 002 0.02887 000 0.04670 001 0.03118	0.00460 0.2816841 0.00059 0.2817657 0.00220 0.2820470 0.00015 0.2821267	-1.09 1.93 5.69 8.84	1.47 2.77 1.72	2.16 2. 2.45 2. 1.66 11 1.72 11	45 0.281715 26 0.281711 81 0.281887 62 0.281827	0.282013 0.282009 0.282212 0.282212		
507818 307818 H1	10/05/2019 (6) 06:48:42:00 03/05/2019 (5) 22:06:52:00 03/12/2018 (2) 18:00:53:00	05DTB18 - 89 03DTB18 - 44 8H1 - 92	-5.90 1660 -5.64 1178 -5.60 1093	142 42 32	8.54% 0.28200 0.00007 3.61% 0.28206 0.00005 3.89% 0.2823 0.000034	0.00564 0.00564 0.00565	0.00104 0.00 0.00089 0.00 0.000455 0.000	001 0.03759 001 0.02510 016 0.02388	0.00036 0.2819704 0.00150 0.2820362 0.0007 0.2822906	8.14 -0.40 7.01	2.66 1.82 1.19	1.46 1. 1.68 2. 1.33 1.	83 0.281741 00 0.282048 48 0.282093	0.282044 0.282398 0.282460		
307918 307918 307918	09/05/2019 (5) 22:23:50.00 09/05/2019 (5) 21:15:24.00 09/05/2019 (5) 22:27:35.00 03/12/2018 (2) 16:23:09.00	03DTB18 - 53 03DTB18 - 27 03DTB18 - 55 8H1 - 60	-5.56 1172 -5.52 1299 -5.51 1653 -5.47 1464	42 61 164 45	3.42% 0.28227 0.00005 4.38% 0.28215 0.00003 9.90% 0.28157 0.00004 3.09% 0.281578 0.000027	0.00565 0.00564 0.00563 0.00564	0.00133 0.00 0.00146 0.00 0.00045 0.00 0.0008014 0.0000	002 0.01216 005 0.02154 001 0.04120 031 0.04049	0.00040 0.2822436 0.00015 0.2821145 0.00150 0.2815508 0.00024 0.2819558	6.81 7.35 -6.91 3.58	158 119 137 0.95	1.39 1: 1.57 1: 2.33 2: 1.78 1:	54 0.282052 68 0.281907 78 0.281746 99 0.281855	0.282403 0.282236 0.282049 0.282188		
107218 H1 507218	09/05/2019 (5) 22:33:12:00 03/12/2018 (2) 18:25:35:00 10/05/2019 (5) 03:29:40:00	03DTB18 - 58 8H1 - 108 05DTB18 - 9	-5.45 1715 -5.42 1111 -5.24 1468	107 40 57	6.25% 0.28175 0.00004 3.56% 0.282029 0.000029 3.90% 0.28202 0.00004	0.00564 0.00564 0.00564	0.00021 0.00 0.0008271 0.0000 0.00075 0.00	000 0.03740 073 0.04329 011 0.02780	0.00430 0.2817390 0.00029 0.2820217 0.00420 0.2819992	1.18 -2.12 4.81	1.40 1.02 1.40	2.07 2. 1.70 2. 1.72 1.	22 0.281706 08 0.282081 89 0.281864	0.282003 0.282647 0.282185		
507818 507818 H1 507818	10/05/2019 (6) 08:41:12:00 10/05/2019 (6) 07:02:04:00 03/12/2018 (2) 20:00:56:00 10/05/2019 (6) 08:02:40:00	05D1818 - 85 05D1818 - 92 8H1 - 133 05D1818 - 116	-5.17 1289 -5.14 2647 -5.07 1475 -5.07 1928	45 91 39 104	2.44% 0.28293 0.0003 2.66% 0.28212 0.0003 5.40% 0.282149 0.00011	0.00542 0.00544 0.00544	0.00059 0.00 0.0016 0.00 0.00053 0.00	004 0.0209 000 0.02099 004 0.0788 000 0.01983	0.00210 0.2822701 0.00008 0.2808973 0.0026 0.2820674 0.00010 0.2814706	-7.40 7.78 -3.50	2.45 1.05 2.98	1.45 1. 2.00 3. 1.63 1. 1.35 2.	60 0.281977 58 0.281105 73 0.281848 78 0.281569	0.281308 0.281308 0.282180 0.281845		
507818 307818 H1 507818	10/05/2019 (6) 07:26:32:00 09/05/2019 (5) 22:43:24:00 03/12/2018 (2) 20:07:03:00 10/05/2019 (6) 02:35:55:00	05DTR18 - 105 03DTR18 - 85 8H1 - 136 05DTR18 - 7	-5.00 1442 -4.90 1469 -4.93 1131 -4.90 2926	51 55 25	3.55% 0.28212 0.00005 3.77% 0.28201 0.00005 3.12% 0.282353 0.000031 5.32% 0.28114 0.00007	0.00564 0.00564 0.00565	0.00104 0.00 0.00069 0.00 0.001122 0.000 0.00039 0.00	000 0.04046 001 0.07947 008 0.04991 001 0.01387	0.00031 0.2821027 0.00015 0.2819860 0.00073 0.2823291 0.00042 0.2811232	7.89 4.36 9.23 4.79	1.47 1.61 1.09 2.49	1.52 1. 1.74 1. 1.27 1. 2.69 2.	67 0.281880 92 0.281863 37 0.282069 94 0.282069	0.282205 0.282185 0.282432 0.281173		
SOT918 207918 H1	10/05/2019 (5) 03:18:19.00 09/05/2019 (5) 21:40:11.50 03/12/2018 (2) 16:02:35.00	05DTR18 - 3 03DTR18 - 34 8H1 - 50	-4.78 1879 -4.74 2605 -4.62 1108	154 122 30	8.19% 0.28163 0.00009 5.09% 0.28124 0.00005 2.74% 0.28234 0.000028	0.00543 0.00542 0.00545	0.00047 0.00 0.00127 0.00 0.000639 0.000	001 0.01701 001 0.02748 042 0.0367	0.00040 0.2816112 0.00052 0.2811768 0.0026 0.2823207	0.37 1.59 8.42	3.29 1.61 0.98	2.25 2. 2.83 2. 1.29 1.	49 0.281601 98 0.281132 40 0.282083	0.281881 0.281339 0.282449		
H1 407818 507818 507818	03/12/2018 (2) 18:58:53:00 10/05/2019 (5) 00:44:23:00 10/05/2019 (6) 07:45:29:00 10/05/2019 (6) 07:45:29:00	BH1 - 115 04DTB18 - 9 05DTB18 - 112 05DTB18 - 122	-4.54 1353 -4.54 1282 -4.52 1694 -4.48 1725	55 44 130	4.05% 0.281994 0.000029 3.17% 0.28215 0.00004 7.65% 0.28185 0.00004 6.49% 0.28169 0.00008	0.00564 0.00564 0.00564	0.001315 0.000 0.00232 0.00 0.00045 0.00 0.00045 0.00	044 0.0694 001 0.09229 000 0.01479 000 0.04446	0.0023 0.2819604 0.00061 0.2820853 0.00006 0.2818397 0.00025 0.2816334	1.20 5.92 4.27	1.02 1.23 2.21 2.94	179 2/ 162 1/ 174 2/ 138 2/	05 0.281925 75 0.281918 10 0.281719 47 0.281657	0.282270 0.282249 0.282018 0.281958		
507818 H1 H1	10/05/2019 (6) 06:35:31.00 03/12/2018 (2) 16:48:06:00 03/12/2018 (2) 19:31:50:00	05DTB18 - 82 8H1 - 67 8H1 - 124	-4.43 1101 -4.38 1443 -4.35 1338	28 53 41	3.44%         0.28236         0.00009           3.65%         0.282139         0.000025           3.05%         0.282251         0.000029	0.00545 0.00544 0.00545	0.00045 0.00 0.000909 0.000 0.0013287 0.000	001 0.01667 023 0.0445 023 0.07034	0.00062 0.2823537 0.0021 0.2821142 0.00059 0.2822174	9.12 8.71 9.99	3.01 0.88 1.02	124 1. 157 1. 143 1.	33 0.282096 65 0.281869 48 0.281936	0.282455 0.282204 0.282281		
407918 507918 507918	10/05/2019 (6) 06:24:15:00 10/05/2019 (6) 01:05:17:67 10/05/2019 (6) 07:37:54:00 10/05/2019 (6) 08:19:37:00	05D1818 - 76 06D1818 - 16 05D1818 - 108 05D1818 - 125	-4.11 1554 -4.15 3516 -3.96 1115 -3.88 1150	144 111 41 56	6.8% 0.28170 0.0008 6.8% 0.28166 0.00034 3.6% 0.28197 0.00035 4.91% 0.28203 0.00034	0.00563 0.00564 0.00564	0.00055 0.00 0.00134 0.00 0.00111 0.00	004 0.02750 004 0.02770 002 0.05570 002 0.04250	0.00130 0.2816291 0.00130 0.2816291 0.00130 0.2819438 0.00100 0.2820100	-4.98 -5.08 -1.96	1.26 3.19 2.73	2.16 2.1 2.23 2.1 2.41 2.1 2.20 2.1	52 0.281771 63 0.281769 25 0.282087 08 0.282065	0.282076 0.282444 0.282449		
H1 H1 307818	03/12/2018 (2) 14:12:36:00 03/12/2018 (2) 15:08:23:00 09/05/2019 (5) 20:24:07:00	8041 - 12 8041 - 34 03DTR18 - 5	-3.85 1168 -3.83 1282 -3.82 1268	42 36 55	3.58% 0.282543 0.000034 2.84% 0.282278 0.000037 4.32% 0.28227 0.00005	0.00545 0.00545	0.000608 0.0000 0.0011 0.000 0.00139 0.00	095 0.03373 021 0.0632 000 0.05239	0.00052 0.2820296 0.0018 0.2822514 0.0026 0.2822326	-0.54 9.92 8.58	1.19 1.30 1.89	1.69 2/ 1.38 1/ 1.41 1/	02 0.282045 44 0.281972 50 0.281991	0.282405 0.282322 0.282332		
SOTR18 SOTR18 SOTR18	10/05/2019 (6) 08:12:06:00 10/05/2019 (6) 08:12:06:00 10/05/2019 (6) 08:38:25:00 10/05/2019 (6) 01:07:14:00	05DTR18 - 121 05DTR18 - 135 06DTR18 - 17	-3.37 1332 -3.35 1412 -3.34 1541	60 45 140	4.51% 0.28228 0.00008 3.16% 0.28210 0.00007 9.08% 0.28291 0.00004	0.00545 0.00544 0.00544	0.00109 0.00 0.00094 0.00 0.00175 0.00	000 0.04239 002 0.03551 002 0.06544	0.00020 0.2822507 0.00078 0.2820740 0.00059 0.2818590	10.68 6.21 1.49	1.00 1.05 2.42 1.26	147 1. 126 1. 193 2.	41 0.281950 76 0.281899 16 0.281817	0.282285 0.282226 0.282131		
SOT818 H1 H1 SOT818	10/05/2019 (6) 07:41:43.00 03/12/2018 (2) 20:27:34.00 03/12/2018 (2) 17:04:35.00 10/05/2019 (6) 06:46:48.00	050TB18 - 110 BH1 - 146 BH1 - 75 050TB18 - 88	-3.32 5698 -3.19 1137 -3.16 5675 -3.12 1208	121 29 87 60	7.14% 0.28202 0.00006 3.47% 0.28202 0.00003 5.21% 0.28291 0.000026 4.92% 0.28221 0.00008	0.00564 0.00564 0.00564	0.00111 0.00 0.000795 0.000 0.00094 0.000 0.00069 0.00	006 0.03970 024 0.0403 033 0.0466 003 0.02477	0.00220 0.2819823 0.0015 0.2820030 0.0014 0.2818802 0.00091 0.2821934	9.41 -2.19 5.72 5.82	2.31 1.05 0.91 1.58	1.44 1. 1.73 2. 1.88 2. 1.68 1.	77 0.281717 10 0.282065 02 0.281719 63 0.282029	0.282016 0.282428 0.282033 0.282376		
407918 H1 407918	10/05/2019 (6) 01:27:51:00 03/12/2018 (2) 20:02:57:00 10/05/2019 (6) 02:21:05:27	04DTR18 - 28 8H1 - 134 04DTR18 - 46	-3.12 1820 -3.08 1133 -3.08 1300	134 34 58	6.28% 0.28183 0.0003 2.98% 0.281957 0.00025 4.48% 0.28244 0.00028	0.00564 0.00564 0.00566	0.00036 0.000 0.001608 0.000 0.00054 0.00	000 0.01251 059 0.0891 004 0.01600	0.00021 0.2818214 0.0025 0.2819227 0.00140 0.2824268	6.48 -5.13 16.19	1.16 0.91 9.80	196 2) 185 2 113 1)	06 0.281639 29 0.282067 03 0.281970	0.281925 0.282431 0.282309		
H1 307818 507818 407818	04/12/2018 (2) 15:33:25:00 10/05/2019 (6) 00:19:33:00 10/05/2019 (6) 04:01:57:00 10/05/2019 (6) 01:16:35:00	03DTR18 - 99 05DTR18 - 19 06DTR18 - 22	-2.83 1297 -2.83 1478 -2.83 1616 -2.82 1227	53 187 28	2.30% 0.28299 0.000031 3.55% 0.28208 0.00005 11.56% 0.28200 0.00007 3.11% 0.28219 0.00003	0.00564 0.00564 0.00564	0.00104 0.00 0.00108 0.00 0.00040 0.00	002 0.03860 005 0.03880 001 0.01372	0.00270 0.2820490 0.00180 0.2819621 0.00299 0.2821807	6.81 6.94 5.83	1.09 1.75 2.42 1.16	1.76 1/ 1.66 1/ 1.77 1/ 1.48 1/	05 0.281952 77 0.281857 88 0.281769 64 0.282016	0.282178 0.282076 0.282362		
H1 817818 818705	03/12/2018 (2) 17:10:45:00 09/05/2019 (5) 22:12:33:00 09/05/2019 (5) 22:21:55:00 03/12/2019 (5) 22:21:55:00	8H1 - 78 03DTR18 - 47 03DTR18 - 52 8H1 - 20	-2.77 1402 -2.76 1460 -2.74 1276 -2.72 1185	47 45 61 32	2.25% 0.282168 0.000044 3.10% 0.28216 0.00004 4.47% 0.28218 0.00005 3.12% 0.28218 0.00005	0.00564 0.00564 0.00564	0.000891 0.000 0.00204 0.00 0.00039 0.00 0.000937 0.000	016 0.0452 007 0.03106 001 0.03574 021 0.05305	0.0012 0.2821444 0.00050 0.2821058 0.00036 0.2821728 0.00041 0.2821971	8.85 8.41 8.90 5.42	1.54 1.54 1.79	1.52 1. 1.58 1. 1.48 1. 1.47 1.	61 0.281895 66 0.281869 56 0.281922 65 0.282923	0.282234 0.282191 0.282253 0.282253		
H1 507818 407818	03/12/2018 (2) 54:31:07:00 10/05/2019 (6) 07:30:17:00 10/05/2019 (6) 02:11:44:96	8H1 - 21 05DTR18 - 107 04DTR18 - 41	-2.70 1218 -2.69 1855 -2.65 1200	36 177 61	2.96% 0.281938 0.000029 9.55% 0.28154 0.00009 5.08% 0.28227 0.00039	0.00544 0.00543 0.00546	0.001061 0.000 0.00104 0.00 0.00152 0.00	022 0.06325 002 0.04088 015 0.05400	0.00089 0.2819136 0.00044 0.2814993 0.00410 0.2822356	-3.52 -4.15 7.16	1.02 2.07 13.65	1.85 2. 1.58 2. 1.41 1.	25 0.282013 76 0.281616 53 0.282034	0.282369 0.281899 0.282382		
207218 407218 507218 207218	09/05/2019 (5) 23:49:09.00 10/05/2019 (6) 00:38:42:00 10/05/2019 (6) 07:20:52:00 09/05/2019 (6) 07:20:52:00	03DTR18 - 87 04DTR18 - 6 05DTR18 - 102 03DTR18 - 9	-2.65 2459 -2.57 1181 -2.54 1236 -2.48 2291	73 49 58	2.96% 0.28120 0.00034 4.15% 0.28225 0.00036 4.35% 0.28217 0.00034 4.43% 0.28217 0.00034	0.00545 0.00545 0.00544	0.00050 0.00 0.00100 0.00 0.00082 0.00 0.00053 0.00	001 0.02885 008 0.03700 006 0.03170 001 0.01961	0.00070 0.2811777 0.00440 0.2822257 0.00250 0.2821452 0.00550 0.2811826	-1.75 6.38 7.02	1.33 1.96 1.72 1.47	2.82 3/ 1.42 1/ 1.47 1/ 2.82 3/	08 0.281227 57 0.282046 65 0.282947 11 0.281271	0.281449 0.282396 0.282282 0.281500		
507818 H1 407818	10/05/2019 (6) 07:09:35:00 03/12/2018 (2) 19:52:39:00 10/05/2019 (6) 02:04:16:00	05DTB18 - 95 BH1 - 129 OIDTB18 - 37	-2.41 3438 -2.32 3423 -2.30 3442	131 42 53	5.38% 0.28119 0.00005 2.94% 0.282124 0.000025 3.66% 0.28205 0.00004	0.00562 0.00564 0.00564	0.00039 0.00 0.001467 0.000 0.00077 0.00	001 0.01424 028 0.07634 003 0.02848	0.00018 0.2811681 0.00095 0.2820846 0.00096 0.2820271	-2.58 7.20 5.22	3.85 0.88 1.54	156 3. 161 1. 169 1.	11 0.281241 73 0.281882 85 0.281880	0.281465 0.282219 0.282204		
H1 H1 507918	03/12/2018 (2) 14:42:41:00 03/12/2018 (2) 14:42:41:00 03/12/2018 (2) 14:14:36:00 10/05/2019 (6) 08:04:35:00	8041-128 8041-22 8041-13 05DTR18-117	-2.29 1178 -2.29 1379 -2.29 1347 -2.11 1026	41 53 32	2.95% 0.282228 0.00031 3.90% 0.281955 0.00035 3.14% 0.28230 0.00055	0.00564 0.00564 0.00565	0.001038 0.00 0.0004228 0.000 0.00062 0.00	001 0.0552 003 0.02295 007 0.02490	0.00055 0.2822040 0.00051 0.2819240 0.00270 0.2822890	10.45 -0.22 5.15	1.09 1.23 3.85	1.46 1. 1.44 1. 1.83 2. 2.44 1.	49 0.281909 14 0.281930 53 0.282144	0.282250 0.282274 0.282509		
H1 H1 407918	03/12/2018 (2) 16:08:45:00 03/12/2018 (2) 20:48:32:00 10/05/2019 (6) 00:36:50:00	8H1 - 53 8H1 - 151 04DTR18 - 5	-2.04 1582 -2.03 1881 -1.96 1448	93 86 42	5.86% 0.281822 0.000028 4.57% 0.281853 0.000026 2.91% 0.28210 0.00005	0.00564 0.00564 0.00564	0.0006421 0.0000 0.000632 0.000 0.00240 0.00	059 0.03346 029 0.0295 002 0.09122	0.00065 0.2818028 0.0014 0.2816304 0.00045 0.2820382	0.84 1.59 5.75	0.98 0.91 1.61	1.99 2. 2.22 2. 1.68 1.	26 0.281779 45 0.281586 82 0.281876	0.282101 0.281880 0.282200		
401918 507818 H1 507818	10/05/2019 (6) 01:20:20:00 10/05/2019 (6) 06:31:46:00 03/12/2018 (2) 14:06:26:00 10/05/2019 (6) 08:10:11:00	06D1818 - 24 05DTR18 - 80 8H1 - 9 05DTR18 - 120	-1.94 1576 -1.93 1286 -1.88 2085 -1.85 1221	48 29 55	8.8/% 0.28299 0.00094 3.7% 0.28208 0.00011 3.5% 0.282305 0.000029 4.49% 0.28219 0.00009	0.00544 0.00545 0.00545	0.00087 0.00 0.00087 0.00 0.00004129 0.00000 0.00038 0.00	005 0.0550 001 0.03112 069 0.001668 ( 000 0.01282	0.00011 0.2820588 0.00013 0.2820588 0.000013 0.2823042 0.00009 0.2821833	5.48 2.82 7.30 5.77	1.47 1.85 1.02 1.26	1.79 1. 1.65 1. 1.30 1. 2.33 1.	45 0.282098 64 0.282020	0.282319 0.282466 0.282367		
H1 SOTR18 307818	03/12/2018 (2) 16:46:06:00 10/05/2019 (6) 03:39:13:00 09/05/2019 (5) 23:30:05:00	8H1-66 05DTR18-11 03DTR18-81	-1.84 1332 -1.84 1144 -1.83 1098	41 40 32	3.05% 0.282039 0.000032 3.46% 0.28223 0.00007 2.94% 0.28229 0.00034	0.00564 0.00565 0.00565	0.000666 0.000 0.00106 0.00 0.00131 0.00	019 0.0343 002 0.03963 006 0.03896	0.0013 0.2820222 0.00084 0.2822112 0.00017 0.2822659	2.92 5.03 5.95	1.12 2.31 1.40	149 11 144 11 137 11	93 0.281940 63 0.282069 53 0.282098	0.282285 0.282423 0.282457		
H2 H2 H2	03/12/2018 (2) 18:09:05:00 03/12/2018 (2) 14:49:57:00 03/12/2018 (2) 14:04:25:00 03/12/2018 (2) 20:44:25:00	801-96 801-25 801-8 801-10	-1.32 2412 -1.79 1415 -1.77 1461 -1.77 1724	42 41 99	2.92% 0.282298 0.00033 2.92% 0.282298 0.00034 2.82% 0.282038 0.00037 5.72% 0.281795 0.00033	0.00564 0.00564 0.00564	0.00126 0.00 0.0008396 0.000 0.001034 0.000	012 0.067 048 0.04391 022 0.0508	0.00012 0.2811776 0.0009 0.2821643 0.00053 0.2820148 0.00087 0.2817612	-2.19 9.86 5.59 2.63	1.16 1.19 1.30 1.05	2.83 8. 1.50 1. 1.70 1. 2.05 2.	11 0.281229 55 0.281886 86 0.281857 26 0.281687	0.282824 0.282224 0.282191 0.281996		
H2 H2	10/05/2019 (6) 01:46:47:00 03/12/2018 (2) 15:58:29:00 03/12/2018 (2) 20:23:28:00 03/12/2018 (2) 20:23:28:00 03/12/2018 (2) 10:35:57:00	04DTB18 - 35 041 - 48 041 - 144 041 - 136	-1.76 938 -1.74 1143 -1.71 1721 -1.64 7720	27 44 95 60	2.90% 0.28235 0.00010 3.81% 0.282216 0.000037 5.55% 0.281349 0.000029 2.19% 0.281349 0.000029	0.00545 0.00544 0.00544	0.00172 0.00 0.000726 0.000 0.0005115 0.0000 0.001147 0.000	001 0.06018 012 0.03785 053 0.02497 029 0.0553	0.00022 0.2823166 0.00099 0.2822004 0.00043 0.2817323 0.0011 0.2809862	4.16 4.93 1.52	1.47 1.30 1.02 1.02	1.30 1. 1.45 1. 2.08 2. 3.09 3.	52 0.282199 65 0.282061 33 0.281689 29 0.281004	0.282573 0.282424 0.281999 0.281999		
407918 407918 407918	10/05/2019 (6) 02:59:15:00 10/05/2019 (6) 01:10:59:00 03/12/2018 (2) 18:19:17:00	04DTR18 - 61 04DTR18 - 19 8H1 - 101	-1.64 1109 -1.55 1408 -1.47 2667	40 44 70	3.61% 0.28242 0.00004 3.12% 0.28216 0.00006 2.64% 0.281089 0.000026	0.00545 0.00564 0.00562	0.00080 0.00 0.00228 0.00 0.0006431 0.0000	003 0.03174 013 0.08120 028 0.03125	0.00086 0.2823983 0.00450 0.2821024 0.0012 0.2810562	10.90 7.11 -0.55	1.47 2.03 0.91	1.18 1. 1.59 1. 2.58 3.	22 0.282091 70 0.281902 21 0.281072	0.282648		
HL HL	uny12/2018 (2) 16:50:11:00 03/12/2018 (2) 18:04:59:00 03/12/2018 (2) 18:11:06:00 03/12/2018 (2) 18:11:06:00 03/12/2018 (2) 18:17:17:0*	8941 - 68 8941 - 94 8941 - 97 8941 - 100	-1.44 2863 -1.44 1129 -1.43 1687 -1.42 129	#2 27 80 25	2.00% 0.28287 0.00033 3.31% 0.282349 0.000035 4.75% 0.281793 0.000033 2.87% 0.281281 0.000033	0.00542 0.00545 0.00564 0.00543	0.000622 0.000 0.001221 0.000 0.001221 0.000	0.02982 031 0.0294 057 0.0621 029 0.0927	0.0017 0.2808366 0.0017 0.2823358 0.0035 0.2817540 0.0018 0.2813690	-4.77 9.42 1.52 -22.63	1.05 1.26 1.16 0.98	s.27 31 1.26 1. 2.06 2. 2.58 5	0.280942     35     0.282070     0.281711     45     0.282008	0.281145 0.282434 0.282024 0.282024	outlier plotting off extent shown on Eie 3.4	y man
507818 H1 507818	10/05/2019 (5) 04:09:32:99 03/12/2018 (2) 16:29:22:00 10/05/2019 (6) 08:30:54:00	05DTR18 - 23 8H1 - 63 05DTR18 - 131	-1.31 2490 -1.27 1057 -1.26 1831	100 31 187	4.02% 0.28127 0.00013 2.95% 0.282323 0.000035 10.19% 0.28148 0.00008	0.00563	0.00055 0.00 0.00059 0.000 0.00052 0.00	002 0.02056 096 0.03251 000 0.01927	0.00077 0.2812439 0.0003 0.2823112 0.0012 0.2814608	1.33 6.91 -6.06	4.55 1.23 5.25	2.73 2: 1.30 1. 1.18 2:	90 0.281207 46 0.282116 87 0.281632	0.281425 0.282487 0.281917		-*
507918 307918 H1	10/05/2019 (6) 04:20:50.00 09/05/2019 (5) 23:18:47.19 03/12/2018 (2) 56:25:15:05	05DTR18 - 29 03DTR18 - 75 8H1 - 61	-1.22 1457 -1.21 3093 -1.18 12 <sup>53</sup>	64 109 41	4.38% 0.28205 0.00009 3.54% 0.28282 0.00005 3.40% 0.282824 0.00005	0.00564 0.00562 0.00565	0.00076 0.00 0.00086 0.00 0.001172 0.000	001 0.02800 001 0.06330 057 0.0589	0.2826802 0.00064 0.2820260 0.00140 0.2807701 0.0033 0.2822974	12.29 5.52 -1.56 9.76	3.15 1.79 1.40	1.69 11 3.36 21 1.32 1	0.282333 84 0.281870 55 0.280814 29 0.282023	0.282735 0.282193 0.280971 0.282390	too old to be shown on Fig. 2	
H1 307818 H1	03/12/2018 (2) 22:11:31:00 09/05/2019 (5) 22:18:09:00 03/12/2018 (2) 18:44:21:00 03/12/2018 (2) 18:44:21:00	8H1 - 181 03DTR18 - 50 8H1 - 108 8H1 - 01	-1.16 1044 -1.16 1278 -0.97 1727	40 52 84	3.85% 0.282324 0.000027 4.94% 0.28227 0.00004 4.85% 0.28237 0.000048 4.55% 0.28193 0.000038	0.00565 0.00565 0.00564	0.001018 0.000 0.00151 0.00 0.0006602 0.0000	075 0.0525 016 0.04090 079 0.03264	0.0044 0.2822040 0.00190 0.2822326 0.0006 0.2818814 0.0008 0.2818814	6.37 8.81 6.97	0.95 1.30 1.33	131 1 141 1 188 1 130	48 0.282124 49 0.281984 98 0.281685 44 0.34	0.282496 0.282325 0.281994		
107918 507918 107918	, 147 414 [2] 17:58:48:00 09(05/2019 [5] 21:47:46:00 10(05/2019 [5] 06:49:17:00 09(05/2019 [5] 21:06:07:00	03DTR18 - 38 05DTR18 - 38 05DTR18 - 41 03DTR18 - 21	-0.95 1088 -0.88 1209 -0.83 1206 -0.82 2511	50 55 123		0.00564 0.00564 0.00562	0.0008 0.00 0.00103 0.00 0.00029 0.00	004 0.02357 007 0.03820 001 0.0108	0.0006 0.2822130 0.00250 0.2822130 0.00250 0.2821256 0.00033 0.2811222	6.56 3.39 -2.53	1.68 2.00 1.26	143 11 156 1 2,89 3	U.282096 58 0.282028 78 0.282030 17 0.281193	0.282464 0.282375 0.282378 0.281410		
307918 507918 307918 H1	10/05/2019 (6) 00:00:45:00 10/05/2019 (6) 04:02:54:00 09/05/2019 (5) 21:07:52:00 03/12/2018 (2) 10:08:01 (**	03DTB18 - 89 05DTB18 - 20 03DTB18 - 23 8H1 - 137	-0.80 1103 -0.77 1081 -0.73 12280 -0.73 12280	27 27 52 92	3.35% 0.28232 0.00004 3.39% 0.28234 0.00003 4.0% 0.28218 0.00004 4.9% 0.28218 0.00004	0.00545 0.00545 0.00564 0.00564	0.00080 0.00 0.00178 0.00 0.00072 0.00 0.001202 0.00	001 0.00891 008 0.06750 000 0.02715 012 0.0595	0.0009 0.2822004 0.00360 0.2822008 0.0005 0.2822664 0.0012 0.3816173	7.28 6.81 5.28 0.87	1.40 1.19 1.40 1.19	1.31 1. 1.32 1. 1.50 1. 2.25 5	45 0.282095 46 0.282109 67 0.282015 49 0.741588	0.282453 0.282469 0.282360 0.282360		
H1 507818 507818	03/12/2018 [2] 17:12:46:00 10/05/2019 [5] 03:10:35:00 10/05/2019 [5] 04:18:55:00	8H1 - 79 05DTB18 - 2 05DTB18 - 28	4.72 1210 4.69 1405 4.66 1159	41 50 35	2.42% 0.282021 0.000038 3.58% 0.28209 0.00003 3.04% 0.28225 0.00005	0.00544 0.00545	0.0004466 0.0000 0.00072 0.00 0.00083 0.00	063 0.02269 001 0.02613 000 0.02931	0.00047 0.2820108 0.00054 0.2820729 0.00009 0.2822338	-0.27 6.08 6.17	1.33 0.95 1.72	171 2/ 162 1/ 141 1/	04 0.282018 76 0.282903 57 0.282060	0.282375 0.282230 0.282412		
507818 H1 H1	10(05/2019 (6) 06:35:52:00 03/12/2018 (2) 14:26:59:00 03/12/2018 (2) 16:52:18:00 03/12/2018 (2) 19:00:54: <sup>00</sup>	05DTB18 - 37 BH1 - 19 BH1 - 69 BH1 - 116	-0.45 1272 -0.45 1841 -0.41 2830 -0.53 2614	46 106 78 89	4.5475 0.28220 0.00005 5.725 0.281278 0.000032 2.745 0.281058 0.000023 3.425 0.281056 0.000023	0.00563 0.00562 0.00562	0.00221 0.00 0.001283 0.000 0.000568 0.000 0.000503 0.000	0.08670 022 0.0694 058 0.0275 011 0.02676	0.00330 0.2821491 0.0013 0.2813332 0.0032 0.2810372 0.0008 0.2810510	5.71 -9.88 2.60 -2.20	2.03 1.12 0.81 1.12	1.53 1. 2.64 3. 3.01 3. 2.99 3	us 0.282988 15 0.281611 13 0.280964 26 0.281113	0.282329 0.281910 0.281170 0.281240		
SOTE18 SOTE18 SOTE18 SOTE18	10/05/2019 (6) 08:06:26:00 10/05/2019 (6) 04:24:35:00 09/05/2019 (5) 21:11:39:43 10/05/2019 (5) 21:11:39:43	05DTR18 - 118 05DTR18 - 21 03DTR18 - 25 05DTR18 - 27	-0.50 1813 -0.45 1099 -0.43 1748 -0.39 12 <sup>54</sup>	125 34 225 53	6.90% 0.28156 0.00034 3.12% 0.28231 0.00036 12.88% 0.28172 0.00033 4.42% 0.28239 0.09995	0.00543 0.00545 0.00543 0.00543	0.00035 0.00 0.00179 0.00 0.00059 0.00 0.00048 0.00	001 0.01273 004 0.06930 001 0.02155 001 0.01744	0.00025 0.2815508 0.00120 0.2822679 0.00043 0.2817005 0.00051 0.2821742	-3.27 6.06 0.56 5.07	1.86 2.26 1.19 1.65	1.33 2/ 1.37 1/ 2.13 2/ 1.49 1/	68 0.281643 53 0.282097 38 0.281685 67 0.282031	0.281930 0.282456 0.281979 0.282379		

Sample ID	Analysis date-sime	Spot ID	Discord         Preferred age 1500           (7)6-6/8)/7)6 *100         Ma cstaff           Ma         2 σ	Lu-Hf isotopic Rat 176Ht/177Hf 120 INT (2% error % 0.282785 0.28250	atios from iolite 25 External ±) 176Lu/177Wfm ±20 INT 176 0.02360 Bouvier et al., 2008 E 0.02840 Griffin et al., 2002, Lin	Yb/177HI ±2e INT Hfi skil PSL-273 Lu decay hss-237	eHf Calculations ±2a TDM(Ga) TD 0.02 Scherer et al., 200	MCrustal HfOKUR(t) HfDM(t) 1, Science-293	Notes
8H1	03/12/2018 (2) 18:21:23:00	8+1 - 102	0.36 1158 28	2.26N 0.282012 0.000033	0.00564 0.0005473 0.0000053	0.02855 0.00017 0.2820001 -1	82 1.16 1.73	2.10 0.292051 0.29	3412
0507818	10/05/2019 (6) 04:30:11:00	0507818 - 34	0.36 1413 52	2.70N 0.28189 0.00004	0.00564 0.00071 0.00002	0.02487 0.00075 0.2818712 -0	96 1.37 1.90	2.22 0.291899 0.29	2226
0407818	10/05/2019 (6) 00:34:56:00	0407818 - 4	0.29 1475 47	3.21N 0.28213 0.00006	0.00564 0.00120 0.00002	0.04529 0.00099 0.2820927 8	29 2.03 1.60	1.67 0.291859 0.29	2180
8H1	02/12/2018 (2) 21:32:08:00	8H1 - 167	-0.22 1295 41	2.12% 0.242287 0.00009	0.00565 0.0021413 0.000092	0.1106 0.001 0.2822347 13	15 1.72 1.26	124 0.281964 0.35	2213
0407818	10/05/2019 (6) 01:14:45:00	0407818 - 21	-0.17 1755 127	7.25% 0.26181 0.0003	0.0554 0.0092 0.0001	0.03455 0.00082 0.2817825 3	66 1.19 2.02	2.19 0.281680 0.35	2973
0507818	10/05/2019 (6) 06:44:57:00	0507818 - 87	-0.09 1492 66	6.42% 0.26207 0.0005	0.0554 0.0012 0.0001	0.04811 0.00077 0.2820319 6	53 2.21 1.25	1.80 0.281868 0.35	2167
891 891	03/12/2018 (2) 12581500 03/12/2018 (2) 1750:30.00 03/12/2018 (2) 17:31:44.00	881-5 881-87 881-83	-006 1790 94 -006 1197 39 -003 2290 58	2.2% 0.281898 0.000024 2.2% 0.282137 0.000027 1.7% 0.280737 0.00003	0.00564 0.006189 0.000018 0.00564 0.006349 0.000029 0.00561 0.00145 0.00017	0.044 0.0014 0.911860 5 0.03041 0.00023 0.2921227 3 0.0622 0.0067 0.290463 -0	41 0.95 1.56 49 1.05 3.53	2.04 0.241246 0.35 1.79 0.282027 0.35 2.69 0.280659 0.25	2007 2284 0821 too aid to be shown on Fig. 2
8H1 8H1 6577819	03/12/2018 (2) 14:56:06:00 03/12/2018 (2) 14:56:06:00 03/12/2018 (2) 12:50:02:00 10:05/2018 (2) 12:50:02:00	8H1-28 8H1-1 0507018-00	0.01 1555 81 0.02 1242 40 0.04 1242 40	5.21% 0.28183 0.00021 3.25% 0.28215 0.00026 3.25% 0.28215 0.00026	0.00564 0.00112 0.00012 0.00564 0.00107 0.00012 0.00564 0.001077 0.000012	0.0518 0.0071 0.2817968 0 0.0505 0.001 0.2821968 6 0.05058 0.0005 0.2821968 6	01 0.74 2.00 80 0.95 1.47 78 2.00 2.97	229 0.281997 0.28 161 0.281998 0.23 229 0.281998 0.23	2021 2251 5440
0407818	10/05/2019 (6) 01:39:09:75	0407818 - 31	0.17 2595 91	2.49% 0.28123 0.0004	0.00562 0.00097 0.00001	0.02567 0.00027 0.2811800 1	46 1.33 2.82	2.98 0.281129 0.28	1247
8H1	03/12/2018 (2) 18:56:48:00	8H1 - 114	0.17 1431 38	2.62% 0.28268 0.00034	0.00566 0.002263 0.000036	0.1161 0.0024 0.2825188 26	34 8.40 0.84	0.49 0.281876 0.28	2213 outlier plotting off extent shown on Fig. 2 density map
0307818	09/05/2019 (5) 23:05:42:00	0307818 - 68	0.23 1775 115	6.49% 0.28183 0.00034	0.00564 0.00186 0.00000	0.00067 0.00002 0.2818683 7	13 1.51 1.90	1.98 0.281667 0.28	2958
8H1	03/12/2018 (2) 22-23-51.00	8H1 - 187	0.23 1365 38	2.75% 0.28223 0.00024	0.00564 0.0015396 0.000094	0.08441 0.00084 0.2821877 9	55 0.84 1.47	1.52 0.281918 0.29	2261
8H1	03/12/2018 (2) 18-13-12.00	8H1 - 98	0.28 1013 31	2.05% 0.282224 0.00003	0.00565 0.001195 0.00001	0.05667 0.00072 0.2822012 5	57 1.05 1.32	1.51 0.282166 0.29	2518
8H1	03/12/2018 (2) 16-12-51.00	8H1 - 55	0.36 1656 95	5.72% 0.28282 0.000025	0.00564 0.0006386 0.000001	0.02289 0.00026 0.2817900 2	10 0.88 2.01	2.26 0.281731 0.29	2006
0407818	10/05/2019 (6) 00:33:05:00	0407818 - 3	0.40 1290 54	4.19% 0.28220 0.0008	0.00564 0.00092 0.00001	0.02607 0.00037 0.2821727 6 0.05431 0.00073 0.2822796 6 0.02805 0.00094 0.2818651 -0	72 2.94 1.49	1.62 0.281888 0.29	2223
0507818	10/05/2019 (6) 08:00:46:00	0507818 - 115	0.47 1107 29	2.52% 0.28221 0.0009	0.00565 0.00132 0.00001		64 1.27 1.94	1.50 0.282092 0.29	2650
8H1	03/12/2018 (2) 18:23:24:00	8H1 - 103	0.47 1443 45	2.0% 0.281886 0.00052	0.00564 0.000765 0.000016		12 1.12 1.91	2.21 0.281868 0.29	2203
891	03/12/2018 (2) 16:04:40:00	8H1 - 51	0.48 2405 77	3.18% 0.281213 0.000032	0.00562 0.000728 0.000021	0.0276 0.00084 0.2811796 -2	27 1.12 2.82	2.11 0.281242 0.28	5889
891	03/12/2018 (2) 17:56:47:00	8H1 - 90	0.48 1052 51	4.82% 0.282271 0.000029	0.00565 0.001074 0.00007	0.0524 0.0042 0.2822897 4	62 1.02 1.39	1.60 0.282119 0.28	2690
891	03/12/2018 (2) 22:50:58:00	8H1 - 195	0.50 1831 138	7.52% 0.281502 0.000031	0.00563 0.0002534 0.000012	0.012582 0.00056 0.2814929 -4	44 1.09 2.40	2.79 0.281618 0.28	2917
8H1	03/12/2018 (2) 21:48:53.00	8H1 - 170	0.70 1097 24	2.12% 0.282285 0.000033	0.00565 0.001184 0.000027	0.0591 0.002 0.2823605 9 0.07600 0.00260 0.2820805 6 0.05281 0.00029 0.2822127 6	57 1.16 1.23	1.32 0.282090 0.35	3457
6407818	10/05/2019 (6) 02:06:45.00	0407818 - 65	0.77 1480 63	4.26% 0.28230 0.00008	0.00564 0.00598 0.00006		54 2.70 1.67	1.79 0.281856 0.35	2177
8H1	03/12/2018 (2) 14:18:50:00	8H1 - 15	0.78 1057 29	2.70% 0.282331 0.000028	0.00565 0.0009183 0.0000041		56 0.98 1.20	1.45 0.282115 0.35	3487
891	03/12/2018 (2) 16:58:28:00	8H1 - 72	0.85 1111 29	2.47% 0.282129 0.000029	0.00564 0.0008923 0.0000069	0.04697 0.00023 0.2821203 1	36         1.02         1.57           54         1.12         1.62           74         0.77         1.28	1.85 0.282082 0.28	2647
891	03/12/2018 (2) 20:29:47:00	8H1 - 547	0.91 1113 24	2.06% 0.282145 0.000022	0.00564 0.003401 0.000046	0.1367 0.0015 0.2820957 0		1.91 0.282080 0.28	2646
891	03/12/2018 (2) 15:52:22:00	8H1 - 45	0.91 1221 23	2.67% 0.282312 0.000022	0.00565 0.00227 0.0001	0.1216 0.0041 0.2822574 8		1.47 0.282011 0.28	2266
8H1	03/12/2018 (2) 21:57:05:00	8H1-174	0.92 1125 24	2.02% 0.282238 0.000027	0.00564 0.001051 0.000013	0.0512 0.0011 0.2822155 5	20 0.95 1.43	1.62 0.282066 0.28	3429
0507818	10/05/2019 (6) 04:15:09:00	0507818-26	0.93 1895 194	10.24% 0.28185 0.00006	0.00564 0.00023 0.00000	0.01130 0.00006 0.2818433 8	96 2.17 1.93	1.96 0.281591 0.28	1870
8H1	03/12/2018 (2) 21:34:10:00	8H1-168	0.94 1066 29	2.65% 0.282253 0.000026	0.00565 0.0005221 0.0000018	0.02594 0.00016 0.2822425 4	68 0.91 1.29	1.61 0.282110 0.28	3480
8H1	03/12/2018 (2) 17:08:40:00	8H1 - 77	0.95 1400 55	2.91% 0.29215 0.00009	0.00564 0.00095 0.000042	0.0694 0.0019 0.2821247 8	22 1.05 1.55	1.65 0.281890 0.28	2228
0407818	10/05/2019 (6) 02:06:06:00	0407818 - 28	1.09 1222 41	2.36% 0.29229 0.00004	0.00564 0.00099 0.00001	0.02780 0.00059 0.2821672 5	24 1.44 1.50	1.68 0.292019 0.28	2366
0507818	10/05/2019 (6) 06:33:41:00	0507818 - 81	1.07 1077 43	4.00% 0.29236 0.00005	0.00565 0.00083 0.00000	0.02252 0.00036 0.2823441 8	25 1.61 1.25	1.37 0.292111 0.28	3472
8H1	02/12/2018 (2) 22:44:48:00	8H1 - 192	1.15 1302 43	2.21% 0.242265 0.00004	0.00564 0.001833 0.000045	0.084 0.0024 0.2822189 5	70 1.60 1.57	1.72 0.281959 0.39	2007
8H1	03/12/2018 (2) 22:03:19:00	8H1 - 177	1.19 1199 27	2.11% 0.242259 0.000056	0.00565 0.001333 0.000059	0.0658 0.0037 0.2822289 7	22 1.30 1.41	1.55 0.282025 0.39	2003
0507818	10/05/2019 (6) 03:50:32:00	050TR18 - 17	1.21 1154 28	2.42% 0.24225 0.00005	0.00565 0.00049 0.00001	0.01884 0.00035 0.2822288 8	93 1.68 1.26	1.35 0.282088 0.39	2005
8H1 0207818 8H1	04/12/2018 (2) 2015/02.00 09/05/2019 (5) 22:42:37:00 03/12/2018 (2) 15:06:22:00	8H1 - 125 0207818 - 63 8H1 - 23	1.31 1056 45 1.31 1265 41 1.31 1059 27	2.0% 0.292294 0.000041 2.29% 0.29222 0.00004 2.48% 0.292245 0.000031	0.00565 0.001125 0.000026	0.0600 0.00360 0.2822678 9 0.061 0.0034 0.2822678 9	24 109 153 21 126 126 26 109 129	1.58 0.281860 0.39 1.43 0.282005 0.39 1.43 0.282115 0.39	2549 2649
891 891	10/06/2019 (6)04/26/26/26/00 03/12/2018 (2) 22:07:26:00 03/12/2018 (2) 17:00:28:00	0521418 - 32 8H1 - 179 8H1 - 73	1.41 2953 55 1.42 1655 117	1.94% 0.282978 0.00007 7.08% 0.280978 0.000027 7.08% 0.282037 0.000029	0.00562 0.0003653 0.000038 0.00564 0.001584 0.000044	0.0079 0.00015 0.2809580 0 0.0779 0.0028 0.2819874 9	20 2.59 1.22 23 0.95 3.11 06 1.37 1.74	1.40 0.26066 0.35 2.30 0.26069 0.35 1.79 0.281732 0.35	540 1153 2048
8H1 8H1 8H1	04/12/2018 (2) 22:55:05:00 03/12/2018 (2) 20:42:23:00 03/12/2018 (2) 17:32:45:00	2011 - 227 2011 - 542 2013 - 545	1.69 1813 101 1.53 1103 43 1.55 1448 45	2.89% 0.282027 0.000029 2.12% 0.282041 0.000021	0.00564 0.000564 0.0000047 0.00564 0.000728 0.000016 0.00564 0.000728 0.000016	0.021026 0.000056 0.2820142 -2 0.02621 0.000066 0.2820142 -2 0.02621 0.00004 0.2820208 5	00 0.95 1.99 07 1.02 1.71 51 1.09 1.69 10 1.00	2.11 0.241629 0.35 2.10 0.282087 0.35 1.86 0.281865 0.35	2460 2652 2200
8H1 8H1 8H1	03/12/2018 (2) 15:31:24:00 03/12/2018 (2) 15:31:24:00 03/12/2018 (2) 14:24:58:00 02/12/2018 (2) 18:15:12:00	2H1-40 2H1-12 2H1-28	1.65 1857 97 1.71 1083 25 1.72 1449 49	5.24% 0.281608 0.00025 3.19% 0.28234 0.00025 3.29% 0.28234	0.00563 0.0006783 0.000068 0.00565 0.00084 0.0000064 0.00564 0.001278 0.0000064	0.02587 0.00067 0.2815811 -0 0.04575 0.00022 0.2822229 7 0.0650 0.00025 0.2822822 11	40 1.20 2.28 50 1.23 2.28 50 0.88 1.28 48 1.12 1.46	2.57 0.281601 0.28 1.41 0.292099 0.23 1.42 0.291654 0.20	1898 3667 7160
0507818	10/05/2019 (6) 02:42:01.00	0507818 - 13	1.74 2585 116	4.50% 0.28128 0.00004	0.00563 0.00052 0.00001	0.01725 0.00031 0.2812576 4 0.04762 0.00048 0.2820405 -2 0.09411 0.00091 0.2817431 5	00 123 2.71	2.81 0.281545 0.28	1254
8H1	02/12/2018 (2) 15:12:28:00	8×1 - 36	1.82 1074 51	4.71% 0.282058 0.000025	0.00564 0.000864 0.000015		29 0.88 1.68	2.06 0.282505 0.38	3676
8H1	03/12/2018 (2) 22:52:58:00	8×1 - 296	1.88 1689 118	7.01% 0.2818 0.000029	0.00564 0.001799 0.000002		18 1.37 2.08	2.32 0.281710 0.35	3022
0207818	08/05/2019 (5) 21:17:19:66	0307818 - 28	1.97 2549 97	3.82% 0.28124 0.00004	0.00563 0.00102 0.00011	0.05400 0.00180 0.2811943 0	92 1.30 2.80	2.98 0.281169 0.28	1201
0507818	10/05/2019 (6) 06:26:11:00	0507818 - 77	1.97 1293 55	4.28% 0.28226 0.00007	0.00565 0.00180 0.00004	0.05940 0.00110 0.2822171 8	60 2.59 1.42	1.51 0.281975 0.28	2214
8H1	03/12/2018 (2) 17:54:41:00	8H1 - 89	2.06 1795 88	4.88% 0.281648 0.000037	0.00563 0.0003798 0.00004	0.0199 0.0004 0.2816251 -0	21 1.30 2.21	2.50 0.281641 0.28	2944
8H1	03/12/2018 (2) 14:54:05:00	8H1 - 27	2.11 1342 28	2.81% 0.281821 0.000033	0.00564 0.00563 0.00012	0.0867 0.0057 0.2817897 -5	10 1.16 2.03	2.45 0.281834 0.35	2278
0507818	10/05/2019 (6) 04:28:21:00	050TR18 - 33	2.54 2117 89	2.85% 0.28073 0.00005	0.00561 0.00061 0.00001	0.02208 0.00032 0.2906883 -3	91 1.79 3.47	3.72 0.280798 0.35	2953 too old to be shown on Fig. 2
8H1	03/12/2018 (2) 17:48:29:00	8H1 - 86	2.22 1290 47	3.64% 0.282331 0.000027	0.00565 0.002466 0.000019	0.1412 0.0017 0.2822710 10	78 0.95 1.25	1.39 0.281967 0.35	2216
891	03/12/2018 (2) 15:56:27:00	8H1 - 47	2.34 1859 127	6.82% 0.281379 0.00004	0.00563 0.00062 0.0000043	0.02861 0.00011 0.2813571 -4	62 1.40 2.59	3.08 0.281600 0.28	1297
891	03/12/2018 (2) 18:02:53:00	8H1 - 93	2.34 1217 29	3.21% 0.281948 0.000021	0.00564 0.0007909 0.0000018	0.03905 0.00025 0.2819298 -2	97 0.74 1.92	2.21 0.282014 0.28	2269
891	03/12/2018 (2) 15:29:19:00	8H1 - 39	2.34 1108 24	3.06% 0.282383 0.000027	0.00565 0.001386 0.000049	0.0657 0.0029 0.2823541 9	59 0.95 1.24	1.33 0.282084 0.28	2649
0407818	10/05/2019 (6) 02:09:50:05	0407818 - 40	2.25 2576 143	5.57% 0.28145 0.00023	0.00563 0.00039 0.00010	0.01790 0.0060 0.2914306 9	95 8.05 2.48	2.42 0.281151 0.29	1261
8H1	03/12/2018 (2) 15:54:22:00	8H1 - 46	2.31 1748 106	6.04% 0.281412 0.00003	0.00563 0.001086 0.000041	0.0513 0.0017 0.2913760 -40	49 1.05 2.58	3.11 0.281672 0.29	1978
8H1	03/12/2018 (2) 16:18:58:00	8H1 - 58	2.34 1107 34	2.05% 0.282098 0.000063	0.00564 0.000582 0.000011	0.02156 0.00087 0.2920859 0	06 2.21 1.61	1.94 0.282084 0.29	2650
891	03/12/2018 (2) 14:51:58:00	8H1 - 26	2.37 1225 24	2.66% 0.282026 0.000027	0.00564 0.0008101 0.000033	0.04601 0.00024 0.3820065 1	05 0.96 1.72	2.00 0.281977 0.25	2227
891	03/12/2018 (2) 14:20:54:00	8H1 - 26	2.39 1251 28	2.84% 0.282096 0.000021	0.00564 0.005055 0.000036	0.0589 0.0016 0.3820681 4	97 0.74 1.63	1.81 0.281928 0.25	2271
891	03/12/2018 (2) 21:27:57:00	8H1 - 265	2.40 1005 22	3.26% 0.282345 0.00003	0.00565 0.0006534 0.000067	0.0327 0.00085 0.3823625 7	45 1.05 1.24	1.39 0.282142 0.25	2516
891	03/12/2018 (2) 14:00:19:00	8H1-6	2.41 1212 35	2.926 0.282207 0.00024	0.00565 0.002319 0.00029	0.1283 0.0023 0.2822540 8	41 0.84 1.28	1.48 0.282017 0.28	2272
891	03/12/2018 (2) 20:58:50:00	8H1-156	2.48 1118 46	4.096 0.282114 0.00024	0.00564 0.001268 0.00003	0.066 0.0012 0.2820873 0	26 1.19 1.62	1.92 0.282077 0.28	2642
891	03/12/2018 (2) 22:57:05:00	8H1-298	2.49 1368 51	3.726 0.282195 0.00026	0.00564 0.001211 0.000013	0.06135 0.00012 0.2821637 8	26 0.91 1.50	1.59 0.281917 0.28	2259
0407818	11/12/2019 (6) 02-23:02:00	0407818 - 47	2.58 1283 29	2.07% 0.28202 0.00009	0.00564 0.0097 0.00004	0.1248 0.00310 0.2819915 0	27 115 174	2.03 0.281981 0.35	2671
8H1	03/12/2018 (2) 19:11:11:00	8×1 - 121	2.67 1169 25	2.02% 0.282237 0.000041	0.00565 0.002314 0.000042	0.1248 0.0035 0.2822860 8	56 144 134	1.64 0.282066 0.25	2605
8H1	03/12/2018 (2) 18:46-26:00	8×1 - 209	2.34 1092 25	2.22% 0.282258 0.000029	0.00565 0.002304 0.000012	0.06669 0.00055 0.2822313 4	88 102 141	1.62 0.282096 0.25	2661
8H1 6307818 6407818 841	uny 12/2018 (2) 19:48-31.00 10/05/2019 (4) 00:02:40.00 10/05/2019 (4) 01:41:14.27 02:722208 (4) 01:41:14.27	895 - 127 0307818 - 90 0407818 - 32 991 - 100	2.89 1150 24 2.89 1933 144 3.05 1155 27	2.16% 0.2822 0.00009 7.66% 0.28124 0.0008 2.17% 0.28226 0.00008 6.5%	0.00552 0.00254 0.00000 0.00555 0.00256 0.00000 0.00555 0.00254 0.00000	0.0816 0.0013 0.2821721 4 0.02243 0.00021 0.282271 -12 0.10270 0.00380 0.2822037 5 0.0006 0.2822037 5	06 147 2.76 00 119 146	1./1 0.292057 0.25 3.32 0.291566 0.29 1.64 0.292062 0.29	2841 2841 2615 2624
8H1 8H1 0607949	03/12/2018 (2) 22:25:36:00 03/12/2018 (2) 20:25:36:00 03/12/2018 (2) 18:52:36:00 10/05/2018 (2) 18:52:36:00	841 - 168 841 - 145 841 - 112 04070+0 - 67	4.09 1229 55 3.11 1642 429 3.19 1124 29 3.10 1124 29	w.s.w. U.28251 0.00009     26.126 0.282309 0.000053     2.45% 0.282275 0.000026     2.45% 0.282275 0.000026	0.00554 0.00025 0.00021 0.00555 0.00156 0.00021 0.00555 0.00156 0.00031	0.0676 0.0013 0.2822041 7 0.0676 0.0013 0.2820803 12 0.0575 0.001 0.2822603 6 0.02560 0.0005 0.2822603 6	14/ 142 07 186 161 28 081 129 10 365 17	1.59 0.281740 0.25 1.59 0.281740 0.25 1.55 0.282072 0.25 1.29 0.261744	2057 2427 2275
040-413 8H1 8H1 8H1	03/12/2018 (2) 21:52:58:00 03/12/2018 (2) 21:52:58:00 03/12/2018 (2) 54:10:31:00 03/12/2018 (2) 54:10:31:00	9841-172 2841-11 2841-11	4.22 1345 47 3.32 1860 88 3.33 1073 40 3.34 1073 40	4.74% 0.281486 0.00011 4.74% 0.281486 0.000204 2.69% 0.282224 0.00025 5.54% 0.282224 0.00025	0.00563 0.00082 0.000364 0.00565 0.001147 0.00083 0.00563 0.001147 0.00083	0.0656 0.0010 0.282263 11 0.066 0.0014 0.282403 -5 0.066 0.0014 0.2824038 6	24 0.84 2.47 91 1.23 1.32 28 6.65 5.55	2.87 0.281941 0.25 2.87 0.281599 0.25 1.47 0.282205 0.25 2.51 0.261740	1895 3475 1998
0407818 8H1 8H1	10/05/2019 (4) 02:47:38:00 03/12/2019 (4) 02:47:38:00 03/12/2018 (2) 19:09:04:79 03/12/2018 (2) 27:58:41:00	0407818 - 59 8H1 - 120 8H1 - 129	2.23 2679 118 2.41 913 27 2.49 1002	4.29% 0.28129 0.0005 4.02% 0.28129 0.0005 4.02% 0.28285 0.00037 3.15% 0.2828 0.00037	0.00562 0.00019 0.00000 0.00567 0.00101 0.00015 0.00565 0.00101 0.00015	0.02968 0.00022 0.2815523 2 0.061 0.013 0.2828227 22 0.0229 0.0034 0.1023662 44	42 1.99 2.96 12 12.95 0.57 27 1.05 5 ***	2.98 0.28108 0.28 0.36 0.28208 0.29 1.26 0.28208 0.39	1284 1284 2001 - Fig. 2 density map 1961 - 1961
8H1	03/12/2018 (2) 22:17:43:00	8H1 - 184	2.62 1784 85	4.77% 0.281568 0.000036	0.00563 0.007885 0.0000092	0.03925 0.00042 0.2815413 -3	81 1.26 2.26	2.72 0.281649 0.28	2952
8H1	03/12/2018 (2) 22:01:13:00	8H1 - 176	3.70 1128 28	2.46% 0.282285 0.000076	0.00565 0.003442 0.000045	0.1848 0.009 0.2822218 8	90 2.66 1.20	1.39 0.282071 0.28	2425
0307819	09/05/2019 (5) 22:34:34:00	0307818 - 57	3.71 1460 45	4.52% 0.282285 0.000076	0.00564 0.00065 0.000442	0.05114 0.00025 0.2823218 8	85 1.67 5.75	2.07 0.282074 0.39	2417
0207818 0407818	09/05/2019 (1) 22:11:21:00 09/05/2019 (5) 20:16:35:00 10/05/2019 (6) 02:28:46:00	0307818 - 1 0407818 - 49	3.81 1763 177 3.84 1665 136	10.05% 0.28157 0.00004 8.19% 0.28152 0.00004	0.00563 0.00054 0.00001 0.00564 0.00178 0.00007	0.01923 0.00034 0.2915499 -4 0.05540 0.00290 0.2915688 4	45 1.33 2.33 30 1.51 1.92	2.71 0.281675 0.28 2.08 0.281738 0.28	2967
8H1	03/12/2018 (2) 14:08:31:00	8H1 - 20	2.97 1053 21	2.90% 0.282304 0.000029	0.00565 0.00012 0.000036	0.00553 0.00021 0.2823018 6	50 1.02 1.31	148 0.292118 0.29	3689
0207818	09/05/2019 (5) 22:05:02:00	020TR18 - 43	2.98 1765 160	9.09% 0.28156 0.00004	0.00563 0.00069 0.00004	0.04350 0.00560 0.2815389 -4	79 1.33 2.35	2.72 0.291674 0.29	1966
0507819	10:05/2019 (5) 22:05:02:00	050TR18 - 6	4.02 1990 190	9.5% 0.28166 0.00004	0.00554 0.00063 0.00002	0.02344 0.00091 0.2815493 13	34 1.03 1.00	1.72 0.291504 0.29	1973
0507818	10/05/2019 (6) 05:30:58:00	0507818 - 58	4.02 1050 42	3.97% 0.28242 0.00093	0.00565 0.00069 0.00001	0.02562 0.00051 0.2824064 9	85 3.50 1.17	1.24 0.282128 0.39	3492
8H1	03/12/2018 (2) 16:10:46:00	8H1 - 54	4.11 1678 145	8.66% 0.281856 0.00034	0.00564 0.0006243 0.000022	0.02234 0.00053 0.2817902 2	67 1.19 2.00	2.32 0.281717 0.39	3020
0407818	10/05/2019 (6) 02:57:16:00	0407818 - 60	4.15 1193 47	3.91% 0.28212 0.00034	0.00564 0.00065 0.00000	0.02417 0.00041 0.2821004 2	21 1.44 1.59	1.85 0.282038 0.39	2287
0507818	10/05/2019(6)041123.00	050TR18 - 24	4.23 1169 59	5.05N 0.29223 0.00007	0.00565 0.00094 0.00005	0.03460 0.00300 0.2822103 5	58 2.49 1.64	1.61 0.282053 0.35	3404
0307818	09/05/2019(5)214941.00	030TR18 - 29	4.24 1227 45	2.29N 0.29199 0.00005	0.00564 0.00051 0.00000	0.02250 0.00170 0.2819813 1	00 1.65 1.75	2.03 0.281953 0.35	2289
0307818	09/05/2019(5)203907.01	030TR18 - 13	4.28 1097 67	6.11N 0.29226 0.00005	0.00565 0.00115 0.00001	0.04600 0.00067 0.2822282 4	94 1.72 1.40	1.60 0.282099 0.35	3457
0507818	10/05/2019 (6) 07:00:08:00	0507818 - 91	4.35 1669 185	11.22% 0.28182 0.00007	0.00564 0.00064 0.00001	0.02272 0.00012 0.2817979 1	77 2.00 2.97	2.23 0.281768 0.28	2052
8H1	03/12/2018 (2) 16:14:51:00	8H1 - 56	4.63 1600 106	6.56% 0.28178 0.00029	0.00564 0.001168 0.000095	0.0545 0.0043 0.2817844 -0	58 1.02 2.08	2.37 0.281761 0.28	2080
0507818	10/05/2019 (6) 03:22:10:00	0507818 - 5	4.67 1689 117	6.91% 0.28180 0.00008	0.00564 0.00259 0.00003	0.09347 0.00093 0.2818181 3	42 1.44 1.98	2.15 0.281723 0.28	2022
8H1	03/12/2018 (2) 15:00:11:00	8H1 - 30	4.34 1647 95	5.79% 0.28218 0.00012	0.00565 0.00131 0.000055	0.0699 0.0048 0.2821291 14	28 4.55 1.52	1.45 0.281727 0.28	2053
8H1	03/12/2018 (2) 22:21:51:00	8H1 - 186	4.36 2713 88	3.22% 0.281205 0.000027	0.00562 0.000963 0.000026	0.0443 0.0019 0.2811560 4	08 0.95 2.85	2.95 0.281041 0.28	1258
0607818	10/05/2019 (6) 02:15:31:00	04DTR18 - 43	4.81 1708 116	6.77% 0.28168 0.00008	0.00563 0.00545 0.00002	0.05450 0.00130 0.2816562 -2	63 1.51 2.23	2.55 0.281710 0.28	2008
891	03/12/2018 (2) 21:00:56:00	8H1 - 157	4.84 2647 80	2.01% 0.281132 0.000025	0.00562 0.0005368 0.000034	0.02284 0.00025 0.2811048 0	71 0.88 2.92	2.11 0.281085 0.25	1208
891	03/12/2018 (2) 15:10:27:00	8H1 - 25	5.20 1123 28	2.34% 0.282198 0.000025	0.00564 0.001267 0.000089	0.0686 0.0046 0.2821710 3	66 0.88 1.50	1.72 0.282068 0.25	3621
891	03/12/2018 (2) 13:56:14:00	8H1 - 4	5.17 1289 45	3.22% 0.28215 0.000025	0.00564 0.000915 0.000039	0.0481 0.0024 0.2821260 7	90 0.88 1.55	1.66 0.281903 0.25	2242
8H1	03/12/2018 (2) 16/21/08/00	8H1 - 59	5.19 1158 42	2.61% 0.282011 0.000023	0.00564 0.000558 0.00016	0.0255 0.0013 0.2819966 -1	95 0.81 1.72	2.10 0.282052 0.28	2613
0507818	10/05/2019 (6) 05/23/27/00	050TR18 - 54	5.24 2390 82	2.62% 0.28077 0.00004	0.00562 0.00117 0.00000	0.06448 0.00027 0.2806925 2	69 1.44 2.46	3.51 0.280618 0.28	2745 too aid to be shawn an Fig. 2
0407818	10/05/2019 (6) 02/45/47/00	040TR18 - 58	5.50 1126 43	3.80% 0.28220 0.00004	0.00564 0.00076 0.00002	0.02778 0.00067 0.2821828 3	66 1.22 1.48	1.70 0.282081 0.28	2626
0307818	09/05/2019 (5) 23:16:57:00	0307818 - 34	5.75 1007 53	5.22% 0.28228 0.00005	0.00565 0.00168 0.00004	0.01270 0.00150 0.2822482 2	28 158 140	1.63 0.292156 0.29	2523
0307818	09/05/2019 (5) 21:32:37:00	0307818 - 33	6.00 1329 68	5.16% 0.28222 0.00004	0.00564 0.00079 0.00001	0.06710 0.00200 0.2821954 8	41 137 146	1.55 0.291958 0.29	2295
0407818	10/05/2019 (6) 01:09:04:00	0407818 - 18	6.27 1459 61	4.18% 0.28206 0.00004	0.00564 0.00123 0.00010	0.06660 0.00400 0.2820260 5	57 154 169	1.94 0.291969 0.29	2192
8H1	02/12/2018 (2) 21:59:06:00	8×1-175	6.27 1368 43	2.41% 0.24214 0.00025	0.00564 0.001879 0.000029	0.0866 0.0014 0.2821860 5	86 0.88 1.53	1.69 0.281981 0.39	2022
0507818	10/05/2019 (6) 07:03:59:00	0507818-99	6.29 1297 53	4.0% 0.26235 0.0006	0.00564 0.00083 0.00004	0.02120 0.00150 0.2821287 5	90 1.37 2.20	1.69 0.281972 0.39	2011
8H1	02/12/2018 (2) 21:55:00:00	8×1-173	6.44 992 43	4.2% 0.262259 0.0009	0.00565 0.0006602 0.000097	0.02163 0.00066 0.2822104 5	41 1.05 1.30	1.50 0.282158 0.39	2534
0407818 0407818 0307818	10/06/2019 (6) 01/24/04/50 10/06/2019 (6) 02:42:52:00 08/06/2019 (6) 22:07:31:00	0407818-25 0407818-57 0307818-69	6.55 1255 46 6.29 1228 64 6.20 1228 64	6.6/% 0.25222 0.00054 2.42% 0.25234 0.00054 4.36% 0.25222 0.00054	0.0564 0.00145 0.00003 0.0564 0.00145 0.00003 0.0564 0.00097 0.00001	0.02550 0.00058 0.222004 7 0.02750 0.00270 0.2220936 5 0.07472 0.00040 0.2222000 8	44 1.40 1.40 61 1.33 1.60 22 1.30 1.45 10 0.00 1.77	1.64 0.28190 0.39 1.75 0.281925 0.39 1.54 0.281965 0.39	2659 2268 2203
8H1 0407818	03/12/2018 (2) 20:21:27:00 10/05/2019 (6) 01:22:14:00	8H1 - 543 040TR18 - 25	6.93 1920 85 6.95 1928 41 3.95 1928 41	4.68% 0.281921 0.000034 2.52% 0.28230 0.000034	0.00564 0.000926 0.00099 0.00565 0.00224 0.00011	0.0431 0.0046 0.2819947 9 0.08900 0.00390 0.2822460 7	72 1.19 1.96 04 2.63 1.40	158 0.281625 0.28 153 0.281625 0.28 153 0.282048 0.28	2025 2268
8H1	02/12/2018 (2) 17:06:40:00	8H1 - 76	7.07 1088 29	2.55% 0.282235 0.00025	0.00564 0.0006765 0.000094	0.0254 0.0008 0.282211 4	41 0.88 1.42	1.64 0.292096 0.29	2664
0407818	10/05/2019 (6) 01:44:58:00	0407818 - 34	7.07 2018 161	7.99% 0.28152 0.00003	0.00563 0.00066 0.00003	0.0254 0.0006 0.2814927 4	Ω 1.09 2.41	2.67 0.291512 0.29	1778
0507819	10/05/2019 (6) 01:44:58:00	0507918 - 34	7.27 2018 161	2.45% 0.29215 0.00009	0.00564 0.00075 0.00003	0.02534 0.00064 0.2814927 4	0 2.66 1.46	1.60 0.291965 0.20	1220
0407818	10/05/2019 (6) 02:34:28:00	0407818 - 52	7.49 1264 46	3.61% 0.28208 0.00006	0.00564 0.00150 0.00003	0.05813 0.0006 0.2820811 1	70 2.03 1.68	193 0.281993 0.28	2225
8H1	03/12/2018 (2) 18:48:28:00	8H1 - 110	7.52 1034 22	3.20% 0.282226 0.000028	0.00565 0.001302 0.000061	0.0637 0.0025 0.2823009 5	80 0.98 1.32	150 0.282137 0.28	2511
0407818	10:05/2018 (2) 18:48:28:00	0407818 - 55	7.59 1235 44	3.12% 0.28234 0.000028	0.00554 0.00992 0.00002	0.0555 0.00094 0.282309 5	16 1.33 1.21	192 0.292137 0.28	2553
0407818	10/05/2019 (6) 02:42:02:00	040TR18-56	7.83 1084 53	4.91% 0.28218 0.00003	0.00554 0.00066 0.00001	0.02387 0.00060 0.2821706 2	25 109 149	1.76 0.282907 0.28	367
8H1	03/12/2018 (2) 19:02:59:00	8H1-117	7.84 974 26	2.64% 0.282365 0.000025	0.00565 0.001006 0.000013	0.0538 0.0012 0.2823466 6	29 0.88 125	1.43 0.282959 0.28	2547
0507818	10:05/2019 (2):04:42:35:00	050TR18-40	7.85 1028 22	3.09% 0.282385 0.000025	0.00555 0.00011 0.00000	0.00389 0.00050 0.2823466 6	50 199 120	1.21 0.282949 0.29	200
8H1	03/12/2018 (2) 21:29:57:00	8H1 - 166	7.87 1220 41	3.10% 0.28206 0.000028	0.00564 0.0008457 0.000084	0.04254 0.00032 0.2820389 3	25 0.98 1.67	1.90 0.281947 0.29	2294
0407818	10/05/2019 (6) 00:31:07:50	0407818 - 2	7.96 756 20	3.92% 0.28242 0.00004	0.00565 0.00096 0.00010	0.05320 0.00640 0.2824084 3	35 1.51 1.17	1.43 0.282314 0.29	2706
8H1	03/12/2018 (2) 14:22:54:00	8H1 - 17	7.99 985 25	3.52% 0.282321 0.000027	0.00565 0.000477 0.000012	0.0274 0.00088 0.2822222 5	66 0.95 1.28	1.48 0.282362 0.29	2519
8H1	03/12/2018 (2) 17:02:34:00	8H1 - 76	8.08 1037 40	3.82% 0.282302 0.000032	0.00565 0.00172 0.00054	0.0872 0.0076 0.2822684 4	94 1.12 1.37	157 0.282129 0.28	2501
8H1	03/12/2018 (2) 20:46:30:00	8H1 - 150	8.27 1074 44	4.11% 0.282343 0.00003	0.00565 0.0002797 0.0000072	0.01954 0.00051 0.2822353 8	16 1.05 1.26	139 0.282105 0.28	3674
0507818	10/05/2019 (6) 08:28:58:00	050TR18 - 130	8.42 1050 62	5.87% 0.282341 0.00005	0.00565 0.00065 0.00001	0.02550 0.00068 0.2823972 9	52 1.23 2.71	127 0.282129 0.28	3692
8H1	03/12/2018 (2) 14:58:09:00	8H1 - 29	8.67 951 29	4.09% 0.282467 0.00029	0.00565 0.00100 0.000025	0.058 0.0017 0.2824291 8	69 102 114	126 0.292184 0.29	2564
0507818	10/05/2019 (6) 05:29:07:00	050TR18 - 57	8.92 2007 112	5.50% 0.28165 0.00011	0.00563 0.00118 0.00006	0.06050 0.00190 0.2816044 3	72 3.85 2.26	2.40 0.291500 0.29	1764
0507818	10/05/2019 (6) 05:21:38:00	050TR18 - 53	9.10 1122 55	4.88% 0.28227 0.00004	0.00565 0.00055 0.00002	0.02028 0.00082 0.2822592 10	01 1.54 1.23	1.30 0.292077 0.29	3622
8H1	03/12/2018 (2) 17:52:34:00	8H1 - 88	9.56 1896 112	5.88% 0.281467 0.000022	0.00563 0.0004225 0.0000062	0.02017 0.00044 0.2814518 -4	29         1.12         2.46           08         1.44         1.25           20         0.98         1.72	2.84 0.281576 0.28	1869
0507818	10/05/2019 (4) 06:22:25:00	0507818 - 75	9.48 1085 34	2.10% 0.28221 0.00004	0.00565 0.00547 0.00004	0.06180 0.00180 0.2822779 6		1.51 0.282106 0.28	3666
8H1	03/12/2018 (2) 20:50:37:00	8H1 - 152	9.52 1190 57	4.82% 0.282011 0.000028	0.00564 0.00060872 0.00000074	0.02921 0.00028 0.2819973 -1		2.08 0.282081 0.28	2289
8H1	02/12/2018 (2) 16:27:18:00	8H1-62	9.45 1289 27	2.66% 0.282281 0.000027	0.00555 0.00119 0.000077	0.16 0.0042 0.2821092 10	49 0.95 1.45	1.49 0.281903 0.39	2263
0507818	10/05/2019 (6) 05:10:21:00	0507818-47	9.89 1456 60	6.12% 0.28236 0.00004	0.00554 0.00214 0.0009	0.08230 0.00300 0.2821012 8	16 1.33 1.59	1.67 0.281871 0.39	2594
8H1	02/12/2018 (2) 22:42:47:00	8H1-291	92.06 1172 25	2.02% 0.282151 0.000087	0.00554 0.001005 0.00006	0.0494 0.0028 0.2821288 3	06 1.30 1.55	1.80 0.282042 0.39	3602 discordant, not plotted
0407818 8H1	10/05/2019 (6) 08:08:21:00 10/05/2019 (6) 00:40:37:00 03/12/2018 (2) 15:50:16:00	0521818 - 119 0607818 - 7 8H1 - 66	01.72 1160 50 03.81 1004 35 03.96 1052 38	4.27% 0.2620 0.0000 3.68% 0.26228 0.00004 3.64% 0.282376 0.000033	0.00565 0.00200 0.0003 0.00565 0.00251 0.0003	0.07050 0.00560 0.2822463 2 0.0726 0.0058 0.2823461 8	22 1.40 1.55 93 1.44 1.41 03 1.56 1.26	146 0.282059 0.38 1465 0.282158 0.39 138 0.282119 0.39	2011 decordant, not plotted 2015 decordant, not plotted 2010 decordant, not plotted
0507818 0507818	10/05/2019 (4) 05:14:04:59 10/05/2019 (4) 05:14:04:59 10/05/2019 (4) 05:19:43:00	050TR18 - 49 050TR18 - 52	11.24 2689 143 11.24 1329 49 11.23 1329 49	5.22N 0.29125 0.00005 3.74N 0.29228 0.00005	0.00563 0.0001 0.0002 0.00565 0.00535 0.0001	0.03000 0.00120 0.2813046 8 0.20950 0.00120 0.2813046 6 0.20950 0.00120 0.2821448 6	66 186 2.65 61 137 155	2.62 0.281078 0.28 1.66 0.281958 0.28	1277 discordant, not plotted 2296 discordant, not plotted 2483 discordant, not plotted
0507818 8H1	10/05/2019 (6) 05:49:53.00 03/12/2018 (2) 21:03:01:00	0507818 - 65 8H1 - 158	1156 1997 128 1156 1997 128 1175 980 26	6.29% 0.29184 0.00005 2.62% 0.292254 0.000021	0.00564 0.00082 0.00003 0.00565 0.000873 0.00023	0.02990 0.00130 0.2918068 9 0.0456 0.0015 0.2918068 9	99 158 198 56 0.74 140	197 0.281526 0.25 197 0.281526 0.25 167 0.282566 0.25	1794 discordant, not picture 2543 discordant, not pictured 2543 discordant, not pictured
8H1	03/12/2018 (2) 18:54:41.00	8H1 - 113	11.86 1413 46	4.385 0.281935 0.00007	0.00564 0.001836 0.00002	0.0922 0.0017 0.2818860 0	07 0.88 1.89	2.19 0.281888 0.28	2226 discordant, not plotted
0507818	10/05/2019 (4) 03:48:37.00	050TR18 - 16	12.15 1009 44	4.385 0.28225 0.00007	0.00565 0.00055 0.00002	0.02569 0.00094 0.2822897 6	58 2.31 1.26	1.42 0.282154 0.28	2521 discordant, not plotted
0307818	10/05/2019 (4) 03:48:37.00	030TR18 - 95	12.16 1465 C3	4.775 0.28277 0.0007	0.00565 0.00065 0.00002	0.02240 0.000150 0.7422547 6	59 1.27 1.24	1.50 0.282167 0.28	2286 discordant, not plotted
8H1	03/12/2018 (2) 19:04:59:00	8H1 - 118	12.38 1254 35	2.75% 0.282354 0.00035	0.00564 0.00509 0.000014	0.0586 0.008 0.3820792 3	12 123 162	1.86 0.281990 0.35	2242 discordant, not plotted
8H1	03/12/2018 (2) 21:11:13:00	8H1 - 162	12.58 1129 38	3.27% 0.281999 0.000023	0.00564 0.005937 0.000016	0.02944 0.00088 0.3829863 -2	74 0.81 175	2.14 0.282063 0.35	2626 discordant, not plotted
0507818	10/05/2019 (6) 05:25:22:00	050TR18 - 55	12.59 1088 64	6.22% 0.28230 0.00014	0.00564 0.00059 0.00014	0.02141 0.00011 0.3820869 -	62 1.30 164	1.94 0.282106 0.76	2664 discordant, not plotted
0507818	10/05/2019 (6) 03:52:23:00	050TR18 - 18	12.70 1066 61	5.75% 0.28236 0.00005	0.00565 0.00064 0.00002	0.02432 0.00047 0.2823482 8	14 1.58 1.25	1.37 0.282118 0.28	3480 discordant, not plotted
8H1	03/12/2018 (2) 21:46:47:00	BH1 - 169	12.71 1223 66	5.36% 0.282362 0.000047	0.00565 0.00227 0.00024	0.112 0.011 0.2823092 10	82 1.65 1.30	1.34 0.282006 0.28	2558 discordant, not plotted
0507818	10/05/2019 (6) 08:36:30:00	050TR18 - 134	13.22 1160 68	5.88% 0.28204 0.00006	0.00564 0.00068 0.00002	0.02650 0.00000 0.2820222 -5	20 1.65 1.30	2.04 0.282059 0.28	2411 discordant, not plotted
8941	cm 12/2018 (2) 20:52:38:00	885-153	12.53 1250 42	x.em 0.282232 0.000025	0.00564 0.000765 0.000062	0.0998 0.0028 0.2821895 6	70 116 147	1.51 0.281992 0.25	awar weckstant, not pietted
8941	03/12/2018 (2) 22:19:44:00	885-185	12.58 1253 54	3.65% 0.282395 0.00032	0.00565 0.0007266 0.000062	0.02612 0.00067 0.2821714 8	70 116 149	1.58 0.281926 0.25	2006 discordant, not pietted
8941	03/12/2018 (2) 15:02:16:00	881-31	12.66 1046 29	3.69% 0.282428 0.00034	0.00565 0.0007266 0.000062	0.04209 0.00063 0.2824125 10	28 119 116	1.28 0.282123 0.28	2005 discordant, not pietted
0507818	10/05/2019 (6) 05:40:33:00	050TE18 - 60	54.79 1818 122	6.70% 0.28197 0.00003	0.00564 0.00103 0.00001	0.04028 0.00047 0.281988 10	40 2.31 1.80	1.79 0.281640 0.28	2926 discordant, not plotted
0507818	10/05/2019 (6) 03:44:51:00	050TE18 - 56	1500 1129 42	3.75% 0.28184 0.00005	0.00564 0.00120 0.00002	0.0408 0.00046 0.281925 0	43 1.79 2.00	2.53 0.282079 0.28	A624 discordant, not plotted
8H1	03/12/2019 (6) 03:44:51:00	9H5 - 80	1515 1400	6.285% 0.28184 0.00005	0.00565 0.04122 0.00002	0.0516 0.0004 0.2819125 0	38 1.16 5.44	1.59 0.282079 0.28	2655 discordant, not plotted
0507818	10/05/2019 (4) 05:02:43:00	050TE18 - 44	15.16 1489 58	2.86% 0.28220 0.00004	0.00564 0.00214 0.00004	0.07220 0.00170 0.2821847 10	29 140 154	1.57 0.281850 0.28	2170 discordant, not plotted
0407818	10/05/2019 (4) 02:17:22:47	040TE18 - 44	15.26 1488 47	2.20% 0.28158 0.00004	0.00563 0.00540 0.00007	0.04980 0.00000 0.2815168 -11	26 126 2.37	2.92 0.281853 0.28	2172 discordant, not plotted
0407818	10/05/2019 (4) 02:17:22:47	040TE18 - 45	15.33 1229 36	2.19% 0.28199 0.0VV <sup>C</sup>	0.00564 0.00312 0.00007	0.12550 0.00050 0.2819166 -3	49 129 199	2.24 0.29205 0.76	2260 discordant, not plotted
0907818	09/05/2019 (5) 20:35:24:00	0307818 - 11	16.13 1.847 1.17	6.34% 0.39160 0.00005	0.00563 0.00084 0.00004	0.03640 0.0090 0.385566 1	83 1.72 2.31	2.61 0.281621 0.25	1905 discordant, not plotted
0507818	10/05/2019 (6) 06:02:20:00	0507818 - 68	17.27 2.085 1.80	6.69% 0.29180 0.00004	0.00564 0.00072 0.00001	0.02536 0.00090 0.385706 10	73 1.23 2.03	1.99 0.281659 0.25	1728 discordant, not plotted
0507818	10/05/2019 (6) 05:27:12:00	0507818 - 56	17.42 955 43	6.40% 0.29229 0.00%%	0.00565 0.00054 0.0011	0.02075 0.00064 0.3822764 6	66 2.00 1.24	1.38 0.282189 0.76	2561 discordant, not plotted
0407818	10/05/2019 (4) 02:08:00:00	0407818 - 29	17.71 1043 52	5.04N 0.28228 0.00005	0.00555 0.00545 0.00005	0.05500 0.0050 0.3822536 4 0.073 0.0059 0.3821806 5 0.07730 0.00150 0.3821865 2	25 1.82 1.29	1.60 0.282123 0.28	2006 discordant, not plotted
8H1	03/12/2018 (2) 22:09:32:00	8×5 - 180	17.83 1147 61	5.12N 0.282213 0.000028	0.00564 0.005457 0.000052		22 0.98 1.48	1.67 0.282033 0.28	2002 discordant, not plotted
0507818	10/05/2019 (4) 05:15:57:00	0507818 - 50	17.85 1049 24	3.25N 0.28224 0.00004	0.00564 0.00595 0.00005		47 1.27 1.47	1.72 0.282023 0.28	2002 discordant, not plotted
8H1	03/12/2018 (2) 19:33:51:00	8H1 - 125	17.89 1308 72	5.51N 0.282117 0.00009	0.00564 0.00176 0.00017	0.0861 0.0097 0.3820725 4	20 1.37 1.63	1.83 0.281955 0.25	2202 discordant, not plotted
0507818	10/05/2019 (6) 06:43:02:00	0507818 - 86	18.21 1982 105	5.27% 0.28183 0.00006	0.00564 0.00102 0.00008	0.03990 0.00390 0.3817919 9	27 1.37 1.63	2.00 0.281528 0.25	2797 discordant, not plotted
8H1	03/12/2018 (2) 21:09:08:00	8H1 - 161	18.71 1006 27	2.69% 0.282224 0.000038	0.00565 0.000974 0.000032	0.0529 0.0036 0.3823056 5	56 1.33 1.31	1.50 0.282549 0.25	2526 discordant, not plotted
8H1	03/12/2018 (2) 15:48:08:00	8H1-43	18.73 1050 54	5.11% 0.281973 0.000034	0.00564 0.00056 0.00012	0.02955 0.00052 0.2819619 -5	62 1.19 1.78	2.25 0.282121 0.28	3492 discordant, not plotted
0507818	10/05/2019 (6) 05:42:23:00	0507818-61	19.04 1072 45	4.16% 0.29221 0.00008	0.00565 0.00054 0.00001	0.02124 0.00027 0.2823020 6	64 2.80 1.31	1.47 0.282115 0.28	3476 discordant, not plotted
0407818	10/05/2019 (6) 02:32:28:70	0607818-51	19.13 1276 57	4.47% 0.29229 0.00006	0.00564 0.00112 0.00001	0.02729 0.00070 0.2821631 6	20 2.07 1.50	1.45 0.281885 0.28	2226 discordant, not plotted
8H1	04/12/2018 (2) 21:05:01:00	BH1-159	19.23 1104 51	4.62% 0.28224 0.00011	0.00567 0.00595 0.00023	0.325 0.017 0.2821163 26	45 1.93 0.02	-0.44 0.292086 0.29	anua assordant, not platted
0307818	09/05/2019 (5) 23:20:43:00	0307818-36	19.54 1040 69	6.65% 0.28236 0.00006	0.00565 0.00081 0.00005	0.02804 0.00034 0.2823452 7	46 1.93 1.25	1.39 0.292125 0.29	2699 discordant, not platted
0507818	10/05/2019 (6) 05:46:07:96	0507818-63	19.64 1075 41	3.77% 0.28238 0.00006	0.00565 0.00042 0.00002	0.01587 0.00088 0.2823765 9	28 2.21 1.21	1.30 0.292113 0.29	2674 discordant, not platted
0407818	11/15/2019 (6) 03:04:55:60	0407818 - 64	19.74 1309 56	4.21% 0.28156 0.00004	0.00563 0.00088 0.00007	ud2700 00000 0282850 -15	94 1.54 2.36	2.03 0.281965 0.28	Jacz associant, not platted
0307818	09/05/2019 (5) 23:11:17:00	0307818 - 71	20.04 1122 59	5.30% 0.38222 0.00005	0.00565 0.00052 0.00002	0.04140 00060 0282200 7	94 1.58 1.30	1.42 0.282983 0.28	3439 discordant, not platted
8H1	03/12/2018 (2) 21:25:48:00	8H1 - 164	20.06 1056 56	5.22% 0.282307 0.00082	0.00564 0.00032 0.000015	0.0444 0.00067 0282287 -0	99 1.12 1.61	1.96 0.282117 0.28	3487 discordant, not platted
0407818 0407818 0307818 841	08/06/2019 (4) 22:40:42:00 10/05/2019 (4) 00:42:27:00 09/05/2019 (5) 20:58:17:00 09/05/2019 (5) 20:58:17:00	0401918 - 62 0407818 - 8 0307818 - 19 9wt - 10*	20.27 1001 52 20.25 1225 55 20.47 1099 63 20.49 145	5.1/% 0.29232 0.00004 4.45% 0.29229 0.00011 5.76% 0.29222 0.00004 3.000	0.00554 0.00554 0.00000 0.00554 0.00554 0.00000 0.00554 0.00554 0.00000	0.02545 0.00059 0.2822045 5 0.02736 0.00080 0.3822742 9 0.01917 0.00054 0.3822148 4 0.0256 0.0023 0.3822148 4	22 134 121 22 185 125 26 127 142	1.50 0.282153 0.25 1.42 0.282011 0.25 1.64 0.282097 0.25	unuu unuu daht, hit piitted 2556 dikoordant, net piitted 3656 dikoordant, net piitted 3656 dikoordant, net piitted
0507818 0407818 0507819	10/05/2019 (6) 05:51:48:00 10/05/2019 (6) 05:51:48:00 10/05/2019 (6) 02:12:34:79 10/05/2019 (6) 02:12:34:79	050TE18 - 66 060TE18 - 66 050TE18 - 42 050TE18 - 412	21.54 1093 38 21.10 1495 79 21.10 1495 20	4.99% U.28231/ U.00082 2.40% 0.28230 0.00064 5.26% 0.28188 0.00005 4.99% 0.28187 0.00005	0.00564 0.0002 0.00003 0.00564 0.0002 0.00003 0.00564 0.0002 0.00003	0.05100 0.0010 0.2822748 6 0.02775 0.00090 0.2822748 6 0.02775 0.00090 0.2818462 0	14 154 155 00 186 194 58 186 194	1.94 0.282001 0.28 1.52 0.282002 0.28 2.22 0.281866 0.28 2.40 0.391665 0.39	2460 discordant, not plasted 2165 discordant, not plasted 2165 discordant, not plasted
8H1	03/12/2018 (2) 16:56:23:00	8H1 - 71	21.30 1125 42	2.45% 0.28228 0.00009	0.00565 0.001298 0.000034	0.0721 0.0018 0.2822525 6	27 105 128	1.55 0.282073 0.28	3427 discordant, not plotted
0507818	10/05/2019 (6) 05:48:04:00	050TR18 - 64	21.47 1218 68	5.16% 0.28228 0.00009	0.00565 0.00084 0.00002	0.02081 0.00051 0.2822551 9	44 205 141	1.48 0.281959 0.29	2296 discordant, not plotted
0507819	10/05/2019 (6) 05:48:04:00	050TR18 - 49	21.69 1218 **	2.22% 0.28225 0.00009	0.00565 0.00084 0.00002	0.01042 0.00051 0.2822551 9	15 158 5 <sup>34</sup>	1.92 0.394933 0.39	2264 discordant, not plotted
0407818	10/05/2019 (6) 02:36:17:00	040TR18 - 53	22.67 1062 53	5.07% 0.28242 0.00054	0.00564 0.00105 0.00011	0.02920 0.00320 0.2819942 4 0.02790 0.00690 0.2856041 40 0.05440 0.00170 0.2820640 40	72 1.47 1.74	2.18 0.282127 0.28	2690 discordant, not plotted
0407818	10/05/2019 (6) 02:30:41:00	040TR18 - 50	22.96 1382 53	3.78% 0.28266 0.0005	0.00564 0.00123 0.00001		92 1.82 2.30	2.82 0.281912 0.28	2241 discordant, not plotted
0407818	10/05/2019 (6) 02:30:41:00	040TR18 - 63	22.42 1185 45	3.76% 0.28260 0.0005	0.00564 0.00123 0.00009		76 1.40 1.65	1.92 0.292092 0.76	2292 discordant, not plotted
0507818	10/05/2019 (6) 04:32:06:00	050TB18 - 25	23.69 1150 59	5.16N 0.28239 0.00006	0.00564 0.00046 0.00000	0.01696 0.00014 0.3820161 -1	74 2.34 1.70	2.06 0.282065 0.28	2419 discordant, not plotted
0507818	10/05/2019 (6) 05:08:27:00	050TB18 - 46	22.75 1134 59	5.17N 0.28234 0.00004	0.00565 0.00082 0.00000	0.03029 0.00022 0.3822215	72 1.37 1.28	1.38 0.282075 0.28	2410 discordant, not plotted
0607818	10/05/2019 (6) 01:42:02:00	040TB18 - 32	25.80 1054 55	5.26N 0.28224 0.0004	0.00565 0.00082 0.00000	0.03530 0.00520 0.3822283 3	72 1.40 1.42	1.67 0.282151 0.76	2518 discordant, not plotted
8H1	03/12/2018 (2) 19:29:44.00	8H1 - 123	25.86 1348 47	2.46N 0.281767 0.00004	0.00564 0.000954 0.000025	0.0581 0.0029 0.3857437 4	61 140 208	2.55 0.281880 0.35	2272 discordant, not plotted
0507818	10/05/2019 (4) 05:06:33:00	050TB18 - 45	26.89 1154 29	2.52N 0.28221 0.00008	0.00564 0.00633 0.00008	0.16670 0.00290 0.382180 0	86 2.63 1.61	1.86 0.282095 0.35	2652 discordant, not plotted
0507818	10/05/2019 (4) 05:38:35:00	050TB18 - 59	27.80 1225 45	2.51N 0.28211 0.0007	0.00564 0.00079 0.000%	0.02140 0.00290 0.3820917 7	84 4.20 1.64	1.86 0.282095 0.35	2256 discordant, not plotted
8H1	03/12/2018 (2) 15:27:14:00	8H1-38	27.92 1277 122	9.54% 0.282017 0.00072	0.00564 0.00507 0.00056	0.0555 0.0087 0.2819912 0	57 2.52 1.74	2.04 0.281975 0.28	2225 discordant, not plotted
0507818	10/05/2019 (6) 05:17:52:00	0507818-51	28.98 1042 42	4.00% 0.28227 0.00003	0.00565 0.00047 0.00000	0.01737 0.00017 0.2822557 7	57 1.05 1.24	1.37 0.282134 0.38	2698 discordant, not plotted
8H1	03/12/2018 (2) 22:48:54:00	8H1-294	31.17 1078 74	6.90% 0.28348 0.00075	0.00572 0.00554 0.0004	0.104 0.033 0.2834687 47	71 26.25 4.34	-1.21 0.282133 0.28	2671 discordant, not plotted
0507818	10/05/2019 (6) 07:05:50:00	050TB18 - 94	21.70 844 29	2.42% 0.29236 0.00006	0.00565 0.00129 0.00005	0.05460 0.00280 0.282365 2	76 26.25 -0.34	1.54 0.282259 0.28	2662 discordant, net platted
8H1	03/12/2018 (2) 22:05:26:00	BH1 - 178	22.62 1009 50	4.92% 0.29206 0.000028	0.00564 0.000186 0.000025	0.0102 0.0013 0.2820565 -3	20 0.98 1.64	2.06 0.282147 0.28	2522 discordant, net platted
8H1	03/12/2018 (2) 18:50:33:00	BH1 - 111	23.60 1045 88	8.42% 0.292028 0.00004	0.00564 0.000843 0.000011	0.0418 0.0011 0.2820154 -3	98 1.40 1.72	2.14 0.282124 0.28	2695 discordant, net platted
8H1	UA/12/2018 (2) 13:54:09:00	8x5 - 3	22.97 1089 25	2.22% 0.287 0.005	0.00566 0.00219 0.00035	0.152 0.029 0.2869551 172	28 56.00 -5.86	-10.34 0.282096 0.28	ama ancordant, not platted
0507818	10/05/2019 (4) 04:07:38:00	050TR18 - 22	34.82 2382 107	4.51% 0.28176 0.0005	0.00564 0.00666 0.00005	0.05830 0.0090 0.2856928 14	78 1.82 2.12	1.95 0.281276 0.28	1566 discordant, not platted
8H1	03/12/2018 (2) 14:02:20:00	8x5 - 7	34.86 1078 42	2.32% 0.282366 0.000035	0.00565 0.000667 0.000036	0.0214 0.00035 0.2822545 8	84 1.23 1.24	1.35 0.282205 0.28	1878 discordant, not platted
8H1	08/12/2018 (2) 15:35:30.00	8H1-42	44.00 828 85	10.29% 0.2826 0.00032	0.00564 0.0056 0.0006	0.0685 0.0046 0.2820260 4	1.1% 1.70	2.15 0.292362 0.29	awaw wasawdant, not plotted
8H1	03/12/2018 (2) 14:45:46:99	8H1-23	35.53 850 81	9.51% 0.2852 0.0038	0.00564 0.0056 0.0006	0.155 0.047 0.2851585 183	14 62.00 -2.00	-5.26 0.292368 0.29	3627 discordant, not plotted
0507818	10/05/2019 (6) 07:24:37:00	050TR18-936	36.27 1346 54	4.01% 0.28194 0.00007	0.00564 0.00561 0.00050	0.06810 0.00610 0.2819011 -1	42 62.00 -2.00	2.20 0.292961 0.29	2275 discordant, not plotted
0207818	uwyu5/2019 (5) 23:12:09:75	0307818 - 72	28.70 1018 74	7.22% 0.28213 0.00004	0.00564 0.00058 0.00002	ud2400 0.00110 0.3821199 -1	04 1.33 1.56	1.92 0.282149 0.28	2515 discordant, not plotted
8H1	03/12/2018 (2) 20:11:09:00	8×1 - 128	28.93 1099 87	4.27% 0.282299 0.00024	0.00565 0.001256 0.000017	0.0588 0.0011 0.3822730 6	51 0.84 1.36	1.52 0.282089 0.28	2656 discordant, not plotted
8H1	03/12/2018 (2) 16:54:23:00	8×1 - 70	28.07 2887 269	12.72% 0.281882 0.000031	0.00564 0.000613 0.000055	0.02218 0.00055 0.3818564 23	34 1.09 1.90	1.18 0.280920 0.28	2119 discordant, not plotted
0507818	10/05/2019 (6) 03:08:40:00	0507818 - 1	40.12 2805 96	2.41% 0.28120 0.00004	0.00562 0.00120 0.00007	ud5160 0.00350 0.3811235 5	14 1.47 2.88	2.92 0.280989 0.29	11/e ascordant, not platted
0307818	09/05/2019 (5) 22:58:05:00	0307818 - 64	40.41 2537 191	7.52% 0.28209 0.00004	0.00564 0.00115 0.00001	0.08420 0.00220 0.3820384 36	66 1.23 1.64	1.03 0.281176 0.29	1860 discordant, not platted
8H1	03/12/2018 (2) 20:15:15:00	8H1 - 540	40.48 847 58	6.88% 0.281899 0.000037	0.00564 0.000865 0.000021	0.0842 0.001 0.3818652 -12	90 1.30 1.90	2.55 0.282250 0.28	1860 discordant, not platted
8H1 0507818 8H1 8H1	uny u2/2018 (2) 22:28:00:00 10/05/2019 (6):04:22:40:00 03/12/2018 (2) 16:00:33:00 03/12/2018 (2) 25:00:33:00	8943 - 389 0507818 - 30 8945 - 49 9941 - 99	45.50 1381 61 45.61 1382 90 46.36 829 36 40.02 1001	6.4/% 0.281454 0.000066 7.05% 0.28225 0.00006 3.08% 0.282783 0.00009 3.88% 0.282783 0.00009	0.00555 0.00025 0.000029 0.00555 0.00025 0.000029 0.00555 0.002142 0.000029	0.02580 0.00000 0.2822234 12 0.12580 0.0007 0.282234 12 0.1258 0.0027 0.282766 17	44 2.54 1.27 29 1.72 0.69	x.se 0.281909 0.28 1.26 0.281982 0.29 0.61 0.282262 0.29 1.22 0.292262 0.29	zano unice dalli, not pioteed 2222 discordant, not pioteed 2653 discordant, not pioteed 2666 discordant, not pioteed
8H1 0407818 8H1	03/12/2018 (2) 22:46:53:00 10/05/2019 (6) 00:48:05:51 03/12/2018 (2) 22:46:53:00	8H1 - 293 0407818 - 11 8H1 - 205	48.00 764 55 50.51 821 47 51.42 653 76	7.17% 0.282199 0.000033 5.62% 0.282293 0.000033 6.82% 0.28223 0.00003 6.82% 0.28223 0.00003	0.00564 0.00365 0.000083 0.00564 0.00365 0.000083 0.00564 0.0031 0.00003 0.00565 0.0031 0.00003	0.0848 0.0029 0.28248/9 48 0.01090 0.00087 0.2821692 48 0.01090 0.00087 0.2822882 4	72 116 152 27 112 141 28 193 5 <sup>54</sup>	1.00 0.282303 0.28 1.97 0.282303 0.28 1.79 0.282267 0.28 1.62 0.282267 0.29	2700 discordant, net plasted 2652 discordant, net plasted 2656 discordant, net plasted
8H1 0507818 8H1	03/12/2018 (2) 22:15:38:00 10/05/2018 (2) 07:17:05:69 03/12/2018 (3) 34:57:1	BH1-122 0507818-100 BH1-171	52.67 847 34 55.64 1114 27 60.60 749 74	2.98% 0.29225 0.000038 2.33% 0.29242 0.000138 6.00% 0.3924* 0.00013	0.00565 0.00122 0.00002 0.00565 0.01122 0.00002 0.05555 0.01122 0.00005	0.00768 0.00061 0.2822865 3 0.05130 0.00080 0.2823822 10 0.0542 0.0040 0.2823822 10	12 1.22 1.27 29 1.22 1.27 00 1.47 1.41	1.53 0.282260 0.28 1.53 0.282250 0.28 1.23 0.282268 0.29 1.44 0.382340	2640 discordant, not plotted 2645 discordant, not plotted 2789 discordant, not plotte4
8H1	03/12/2018 (2) 21:07:07:00	8H1 - 160	64.62 469 50	10.62% 0.282% 0.00068	0.00565 0.00232 0.00054	0.1306 0.0094 0.2824196 -2	46 2.38 1.19	1.59 0.282490 0.28	2014 discordant, not plotted
8H1	03/12/2018 (2) 21:12:13:00	8H1 - 163	64.24 597 62	10.52% 0.2826 0.0005	0.00568 0.00128 0.00038	0.078 0.026 0.282967 20	78 17.50 0.25	0.20 0.282499 0.28	2021 discordant, not plotted
8H1	03/12/2018 (2) 16:46:01:00	8H1 - 65	68.83 1012 74	7.27% 0.28298 0.00059	0.00566 0.002204 0.00038	0.1212 0.0099 0.282760 21	66 1.72 0.67	0.47 0.282545 0.28	2019 discordant, not plotted



Appendix	x D5.4	continu	ed.
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Metric	Method	Reference				-
			BH1	03DTB19	04DTB19	05DTB19
Youngest analysis	single analysis	Ludwig and Mundil, 2002	715±22	764±22	739±21	768±31
Youngest single analysis with uncertainty	single analysis	Dickinson and Gehrels, 2009	715±22	764±22	739±21	768±31
Youngest single grain (multiple analysis)	Weighted mean	Spencer et al., 2016	735±11	N/A	759±18	N/A
Youngest analysis cluster 2 or more (1σ overlap)	Weighted mean	Dickinson and Gehrels, 2009	718±18	770±16	757±10	N/A
Youngest cluster 3 or more (1σ overlap)	Weighted mean	Dickinson and Gehrels, 2009	727±11	770±16	757±10	N/A
Youngest three grains	Weighted mean	Zhang et al., 2016	723±14	770±16	749±14	N/A
Youngest cluster 2+ (2σ overlap)	Weighted mean	Coutts et al., 2019	736±17	770±16	<b>760±</b> 16	N/A
Concordia age of youngest cluster	Concordia Age	Dehler et al., 2010	758±8 (1 rej)	770±16	760±16	N/A
Youngest Unmix population (6+ grains needed)	Isoplot unmix function	Dehler et al., 2017	729±13	N/A	746±30	N/A
Youngest graphical peak (PDP, 2 grain minimum)	Probability density plot	Dickinson and Gehrels, 2009	759	769	759	N/A
Maximum Likelihood Age	IsoplotR radial plot minimum finite mixture	Vermeesch, 2020	726±7	771±7	760±5	N/A

# Appendix D5.5: U/Pb-Lu/Hf Standards

Recommended <sup>176</sup>Hf/<sup>177</sup>Hf value for zircon reference materials and weighted mean standard corrected ratio obtained in each analytical session (Mud Tank primary reference material).

Zircon	Recommended	Weightedmean	Weightedmean	Weighted mean for
standard	<sup>1/6</sup> <b>Hf</b> / <sup>1/7</sup> <b>Hf</b>	for session 1	for session 2	session 3
		(3/12/2018)	(09/05/2019)	(17/03/2020)
	$0.282505 \pm$	$0.282507 \pm$	$0.282507 \pm$	$0.282507 \pm 0.00009$
Mud	0.000044	0.000006	0.000004 (MSWD	(MSWD=0.11,
Topk	(Woodhead	(MSWD=0.47,	= 0.89,	n = 20)
Talik	and Hergt,	n = 17)	n = 20)	
	2005)			
	$0.282000 \pm$	$0.282027 \pm$	0.282011 ±	$0.282013 \pm 0.00005$
CI 1	0.00005,	0.000008 (MSWD	0.000005 (MSWD	(MSWD=0.30,
GJ-1	(Morel et al.,	= 0.21,	= 1.00,	n = 19)
	2008)	n = 16)	n = 19)	
	$0.282482 \pm$	$0.282485 \pm$	$0.282473 \pm$	$0.282477 \pm 0.000006$
Distanta	0.000013	0.000009	0.000006 (MSWD	(MSWD=0.55,
riesowce	(Sláma et al.,	(MSWD=0.52,	= 0.77,	n = 9)
	2008)	n = 10)	n = 8)	
	0.282306 ±	0.282300 ±	0.282303 ±	$0.282306 \pm 0.000005$
01500	0.000311	0.000009	0.000006 (MSWD	(MSWD=0.59,
91500	(Woodhead et	(MSWD=0.18,	= 1.03,	n = 19)
	al., 2004)	n = 15)	n = 18)	

Recommended ages for zircon reference materials and weighted mean standard corrected ages obtained in each analytical session.

Zircon	Recommended	1st session	2nd session	3rd session
standard	age (Ma)	(03/12/2018)	(9/05/2019)	(7/03/2020)
GJ-1	608.5 ± 1.5 Ma (Jacks on et al., 2004) 601.5± 0.40 Ma (Horstwood et al., 2016)	$603.6 \pm 0.88$ Ma (MSWD=0.83, n = 20)	608.3± 1.4 Ma (MSWD=5.0, n = 17)	602.2 ± 0.84 Ma (MSWD=1.38, n=19)
Plešovice	337.13 ±0.37 Ma (Sláma et al., 2008)	338.4 ± 0.7 Ma (MSWD=2.0, n = 9)	-	339.5 ± 1.79 Ma (MSWD=4.5, n = 7)
91500	1062.4 ±0.4 Ma (Wiedenbeck et al., 1995)	$1062.0 \pm 2.6$ Ma (MSWD=0.54, n = 20)	$1061.4 \pm 3.9$ Ma (MSWD=0.01, n = 20)	$1062.3 \pm 1.6$ Ma (MSWD=0.89, n = 20)
OGC	3467 ± 3 Ma (Stern et al., 2009)	3465.2 ±2.2 Ma (MSWD=0.54, n = 18)	-	$3465.1 \pm 4.0 \text{ Ma}$ (MSWD=1.69, n = 14)

# Appendix D6.1: Compiled U/Pb Data Sources

		U-Pb Detrital Zircon Data presented in Fig. 5	
Sample Number	Area	Unit	Source
09JK08	Pocatello	Camelback Mountain Fm	Yonkee et al., 2014
20AY11	Pocatello	Geertsen Canyon Fm	Yonkee et al., 2014
66CD10	Pocatello	Geertsen Canyon Fm	Yonkee et al., 2014
05Z08	Pocatello	Camelback Mountain Fm	Yonkee et al., 2014
03Z08	Pocatello	Mutual Fm	Yonkee et al., 2014
04Z08	Pocatello	Mutual Fm	Yonkee et al., 2014
01JK08	Pocatello	Caddy Canyon Fm	Yonkee et al., 2014
65CD10	Pocatello	Browns Hole Fm	Yonkee et al., 2014
59CD10	Pocatello	Mutual Fm	Yonkee et al., 2014
57CD10	Pocatello	Caddy Canyon Fm	Yonkee et al., 2014
Sample E*	Grand Canyon	Sixtymile Fm	Karlstrom et al., 2018
Sample D*	Grand Canyon	Sixtymile Fm	Karlstrom et al., 2018
Sample C*	Grand Canyon	Sixtymile Fm	Karlstrom et al., 2018
Sample B*	Grand Canyon	Sixtymile Fm	Karlstrom et al., 2018
Sample A*	Grand Canyon	Sixtymile Fm	Karlstrom et al., 2018
Tapeats 1*	Grand Canyon	Tapeats Sandstone	Gehrels et al., 2011
Sample F*	Grand Canyon	Tapeats Sandstone	Karlstrom et al., 2018
Sample G*	Grand Canyon	Tapeats Sandstone	Karlstrom et al., 2018
Sample H*	Grand Canyon	Tapeats Sandstone	Karlstrom et al., 2018
06SA10*	New Mexico	Bliss Sandstone	Amato and Mack, 2012
04SASC2*	New Mexico	Bliss Sandstone	Amato and Mack, 2012
04SASC6*	New Mexico	Bliss Sandstone	Amato and Mack, 2012
07SD3c*	New Mexico	Bliss Sandstone	Amato and Mack, 2012
07SD3a*	New Mexico	Bliss Sandstone	Amato and Mack, 2012
09MS1*	New Mexico	Bliss Sandstone	Amato and Mack, 2012
08FM8b*	New Mexico	Bliss Sandstone	Amato and Mack, 2012
08FM9*	New Mexico	Bliss Sandstone	Amato and Mack, 2012
09SL1*	New Mexico	Bliss Sandstone	Amato and Mack, 2012
09SL2*	New Mexico	Bliss Sandstone	Amato and Mack, 2012
10BM216*	New Mexico	Bliss Sandstone	Amato and Mack, 2012
10BM215*	New Mexico	Bliss Sandstone	Amato and Mack, 2012
11LHM03*	New Mexico	Bliss Sandstone	Amato and Mack, 2012
CS12-5*	New Mexico	Van Horn Fm	Spencer et al., 2014
CS12-3*	New Mexico	Van Horn Fm	Spencer et al., 2014
MD09	C. Appalachians	Weverton Fm	Satoski, 2013
MD10	C. Appalachians	Weverton Fm	Satoski, 2013
MD11	C. Appalachians	Weverton Fm	Satoski, 2013
VA12	C. Appalachians	Weverton Fm	Satoski, 2013
VA13	C. Appalachians	Weverton Fm	Satoski, 2013
VA14	C. Appalachians	Weverton Fm	Satoski, 2013
VA15	C. Appalachians	Weverton Fm	Satoski, 2013
VA16	C. Appalachians	Weverton Fm	Satoski, 2013
Rome 1	C. Appalachians	Rome Sandstone	Thomas, 2004
Rome 2	C Annalachians	Rome Sandstone	Thomas 2004

\*Presented max depositional age constraints (shown in Fig. 2) are from Karlstrom et al., 2018 and shown in Karlstrom et al., 2018 supplementary tables

# Appendix D6.2: Compiled Lu/Hf Data Sources

	Lu-Hf Detrital Zircon Data from late T	onian-Cambrian strata presented in Fig.	3 and 4
Sample Number	Group	Unit	Source
08LW6	Tonian-Cryogenian Strata	Little Willow Fm	Spencer et al., 2012
BCF-HF	Tonian-Cryogenian Strata	Middle Big Cottonwood Fm	Spencer et al., 2012
LW17-3	Tonian-Cryogenian Strata	Little Willow Fm	Spencer et al., 2012
Caddy	Tonian-Cryogenian Strata	Caddy Canyon Quartzite	Gehrels and Pecha, 2014
J39-A-9	Ediacaran Strata	Johnnie Fm	Howard et al., 2015
NR30	Ediacaran Strata	Stirling Quartzite	Howard et al., 2015
Mutual	Ediacaran Strata	Mutual Fm	Gehrels and Pecha, 2014
WQ	Ediacaran Strata	Wildhorse Meadows	Wooden et al., 2013
Geertsen	Cambrian Strata	Geertsen Canyon Fm	Gehrels and Pecha, 2014
Wood Canyon	Cambrian Strata	Wood Canyon Fm	Gehrels and Pecha, 2014
85NV_CL_3B	Cambrian Strata	Wood Canyon Fm	Howard et al., 2015
83WMAM_4	Cambrian Strata	Campito Fm	Howard et al., 2015
Zabriskie2	Cambrian Strata	Zabriskie Quartzite	Gehrels and Pecha, 2014
Proveedora	Cambrian Strata	Proveedora	Gehrels and Pecha, 2014
ZAB	Cambrian Strata	Zabriskie Quartzite	Wooden et al., 2013
ZBR	Cambrian Strata	Zabriskie Quartzite	Wooden et al., 2013
WC	Cambrian Strata	Wood Canyon Fm	Wooden et al., 2013
12COPP-03	Pikes Peak	Pikes Peak Syenogranite	Howard et al., 2015
12COPP-02	Pikes Peak	Pikes Peak Monzogranite	Howard et al., 2015
12COPP-05	Pikes Peak	Pikes Peak Quartz syenite	Howard et al., 2015
Yqs-10	Pikes Peak	Lake George quartz syenite	Guitreau et al., 2016
Ypm-9	Pikes Peak	Lake George monzogranite	Guitreau et al., 2016
Ypp-20	Pikes Peak	Pikes Peak granite	Guitreau et al., 2016
11LBM_01	Llano/Wichita	Little Hatchet Mountain Granite	Howard et al., 2015
12TXFM01	Llano/Wichita	Franklin Mountains, Stage 2	Howard et al., 2015
12TXFM02	Llano/Wichita	Franklin Mountains, Stage 4	Howard et al., 2015
12TXFM03	Llano/Wichita	Franklin Mountains, Stage 1	Howard et al., 2015
5/04 LL-1	Llano/Wichita	Escuadra Granite	Howard et al., 2015
GRLL-5	Llano/Wichita	Lone Grove pluton	Howard et al., 2015
GRLL-14	Llano/Wichita	Grape Creek pluton	Howard et al., 2015
CS12-4	Llano/Wichita	compiled in Martin et al., 2020	Mulder et al., 2018
CS12-5	Llano/Wichita	compiled in Martin et al., 2020	Mulder et al., 2019
CS12-1	Llano/Wichita	compiled in Martin et al., 2020	Mulder et al., 2020
CS12-3	Llano/Wichita	compiled in Martin et al., 2020	Mulder et al., 2021
OK-4-WL	Llano/Wichita	compiled in Martin et al., 2020	Thomas et al., 2016
OK-1-VN	Llano/Wichita	compiled in Martin et al., 2020	Thomas et al., 2016
BR-1	Grenville	Blowing Rock Gneiss	Howard et al., 2015
CG	Grenville	Corbin Gneiss	Howard et al., 2015
ТХ	Grenville	Toxaway Gneiss	Howard et al., 2015
WL	Grenville	Wiley Gneiss	Howard et al., 2015
WD	Grenville	Woodland Gneiss	Howard et al., 2015
13-AM-007	Grenville	compiled in Martin et al., 2020	Augland et al., 2016
13-FS-1029	Grenville	compiled in Martin et al., 2020	Augland et al., 2016
13-TC-5016	Grenville	compiled in Martin et al., 2020	Augland et al., 2016
n3422	Grenville	compiled in Martin et al., 2020	Spencer et al., 2015
n3423	Grenville	compiled in Martin et al., 2020	Spencer et al., 2015
n3427	Grenville	compiled in Martin et al., 2020	Spencer et al., 2015
CS11-1	Grenville	compiled in Martin et al., 2020	Spencer et al., 2015
CS11-13	Grenville	compiled in Martin et al., 2020	Spencer et al., 2015
CS11-18	Grenville	compiled in Martin et al., 2020	Spencer et al., 2015
CS11-20	Grenville	compiled in Martin et al., 2020	Spencer et al., 2015
CS11-3	Grenville	compiled in Martin et al., 2020	Spencer et al., 2015
CS11-6	Grenville	compiled in Martin et al., 2020	Spencer et al., 2015
CS11-9	Grenville	compiled in Martin et al., 2020	Spencer et al., 2015
KY-18-CB	Grenville	compiled in Martin et al., 2020	Thomas et al., 2017
KY-19-PR7	Grenville	compiled in Martin et al., 2020	Thomas et al., 2017
KY-21-SG	Grenville	compiled in Martin et al., 2020	Thomas et al., 2017
OH-1-SS	Grenville	compiled in Martin et al., 2020	Thomas et al., 2017
VA-1-GN	Grenville	compiled in Martin et al., 2020	Thomas et al., 2017
WV-1-PR	Grenville	compiled in Martin et al., 2020	Thomas et al., 2017

WV-1-PR Abbreviations: FM - Formation
## **Appendix D6.3: Statistical Comparison Results**

Statistical results generated from DZStats-2D (Sundell and Saylor, 2021)

Sundell, K.E., and Saylor, J.E., 2021, Two-dimensional Quantitative Comparison of Di Geochemistry: Geochemistry Geophysics Geosystems, doi:10.1029/2020GC009559. on of Density Distributions in Detrital Geochronology and DZstats2D Results

Cross-correlation							MDS PLOTS
	Grenville	Pikes Peak	Llano/Wichita	Stentian-Cryogenian	Ediacaran	Cambrian	
Grenville	1	0.426854753	0.274316864	0.770183729	0.474454264	0.462331331	See Fig. 4
Pikes Peak	0.426854753	1	0.062011811	0.187423138	0.078132217	0.19763872	
Llano/Wichita	0.274316864	0.062011811	1	0.380173424	0.653479709	0.800640595	
Stentian-Cryogenian	0.770183729	0.187423138	0.380173424	1	0.56196941	0.472054653	
Ediacaran	0.474454264	0.078132217	0.653479709	0.56196941	1	0.692551412	
Cambrian	0.462331331	0.19763872	0.800640595	0.472054653	0.692551412	1	

