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Shallow geology of the CO2CRC Otway Site: Evidence for previously undetected neotectonic features?

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Abstract

Australia's CO2CRC Otway Site hosts a carbon capture and storage (CCS) demonstration facility that has, to date, injected over 80,000 tonnes of CO_2 into two separate geological reservoirs. The reservoir geology is well understood and the site has been the subject of several seismic investigations, though relatively little is known about the near-surface geology and how potential leaks from the injection wells would migrate, particularly within the Port Campbell Limestone. No shallow core has been taken from relevant petroleum wells or water bores, and although there is extensive exposure in the prominent sea cliffs, these are mostly inaccessible. In order to further define the structure and geology of the Port Campbell Limestone at the Otway site, a high-resolution, shallow focused, 3D seismic survey has recently been conducted. The assessment of the near-surface geology described in this paper was used to assist with planning the survey. Using available data, the Port Campbell Limestone is assessed as a series of laterally continuous intercalated limestone, marl, and marly limestones. Interpretation of three previously acquired 3D seismic surveys using a minimum similarity attribute demonstrates evidence for a shallow, steeply east-dipping fault striking approximately NNW-SSE directly below the Otway site. This is observed from approximately 100 m to 380 m depth below surface, where it appears to die out. In the shallow section, the fault is undetectable primarily due to low seismic resolution, and so it is unknown how shallow it propagates. Extrapolation of the fault to the surface projects to between the wells Naylor-1 and CRC-1. A recently acquired high-resolution 3D seismic survey over the study area will allow for this fault to be further delineated.

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Keywords: Seismic attributes; similarity; carbon dioxide; neotectonics; near-surface faulting; shallow fault expression; 3D sesimic; CO2; geological storage; geosequestration; leakage

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1. Introduction

The CO2CRC Otway site hosts a carbon dioxide geological storage project that is located within Australia's onshore Victorian Otway Basin, approximately 19 km northeast of the town of Port Campbell. The Otway Project has, to date, injected over 80,000 tonnes of CO_2 into two separate geological reservoirs. The Otway Project constitutes several demonstration stages with the overarching vision being the development, execution and operation of safe CO_2 storage projects while undertaking applied research in the field of CO_2 storage [1]. The well CRC-1 was drilled during stage 1 of the Otway Project, and focused on gas injection into a structural trap within a depleted gas field to demonstrate safe CO_2 storage on a field scale. Stage 2 of the Project involved the drilling of CRC-2, with subsequent gas injection into a tilted saline formation improving understanding of migration and trapping mechanisms within saline formations [1].

The geology of these reservoirs is well understood; good seismic coverage is provided by numerous seismic surveys, and high quality core and well logs are available from petroleum and CO_2 wells. Conversely, relatively little is known about the near surface geology, including the prominent Port Campbell Limestone (Figure 1a). No core has been taken in the Port Campbell Limestone within the study area, and although well exposed nearby in the prominent sea cliffs, the majority of these are inaccessible and at some distance from the site. Shallow faulting is observed in the Port Campbell Limestone at the sea cliffs and it was suspected that shallow faulting may be present at the Otway site. Faults can serve as fluid conduits and, as potential leakage from injection wells is a risk for geological storage, understanding faults in the subsurface is important in order to minimize that risk. In order to further define structure and the geology of the Port Campbell Limestone at the Otway site, a high resolution, shallow focused, seismic survey was recently conducted [2]. The assessment of the near-surface geology described in this paper was undertaken to assist with planning the survey.

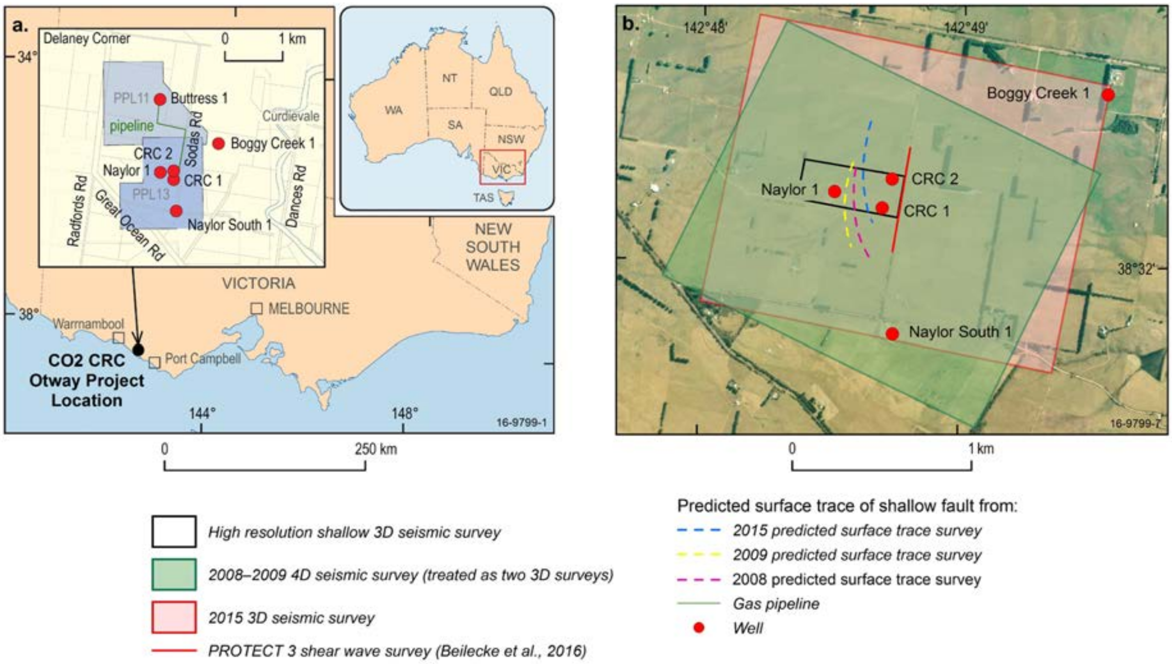

Figure 1: (a) Location map of the CO2CRC Otway Site. (b)Aerial imagery of the Otway Site, illustrating the location of the 3D seismic surveys and wells analysed in this study. Fault traces from interpreted seismic surveys are projected to the surface.

Available 3D seismic surveys (OBPP_2008, OBPP_2009, and OBPP_2015), petroleum well and waterbore data, and existing field reports and literature on the region were analysed in order to further define the shallow geology of the CO2CRC Otway site. A previously undetected shallow neotectonic feature was detected within the Port Campbell Limestone, which is assessed as a series of laterally continuous intercalated limestone, marl, and marly limestones. The data available to this study was insufficient to identify the type or amount of offset over the neotectonic feature, though extrapolations of possible surface intersections that may be present were used to inform siting of a recently conducted shallow 3D seismic survey. The feature is interpreted as a fault, rather than a fracture, due to both its similarity in seismic section to previously observed faults, and the presence of shallow faults in surrounding region.

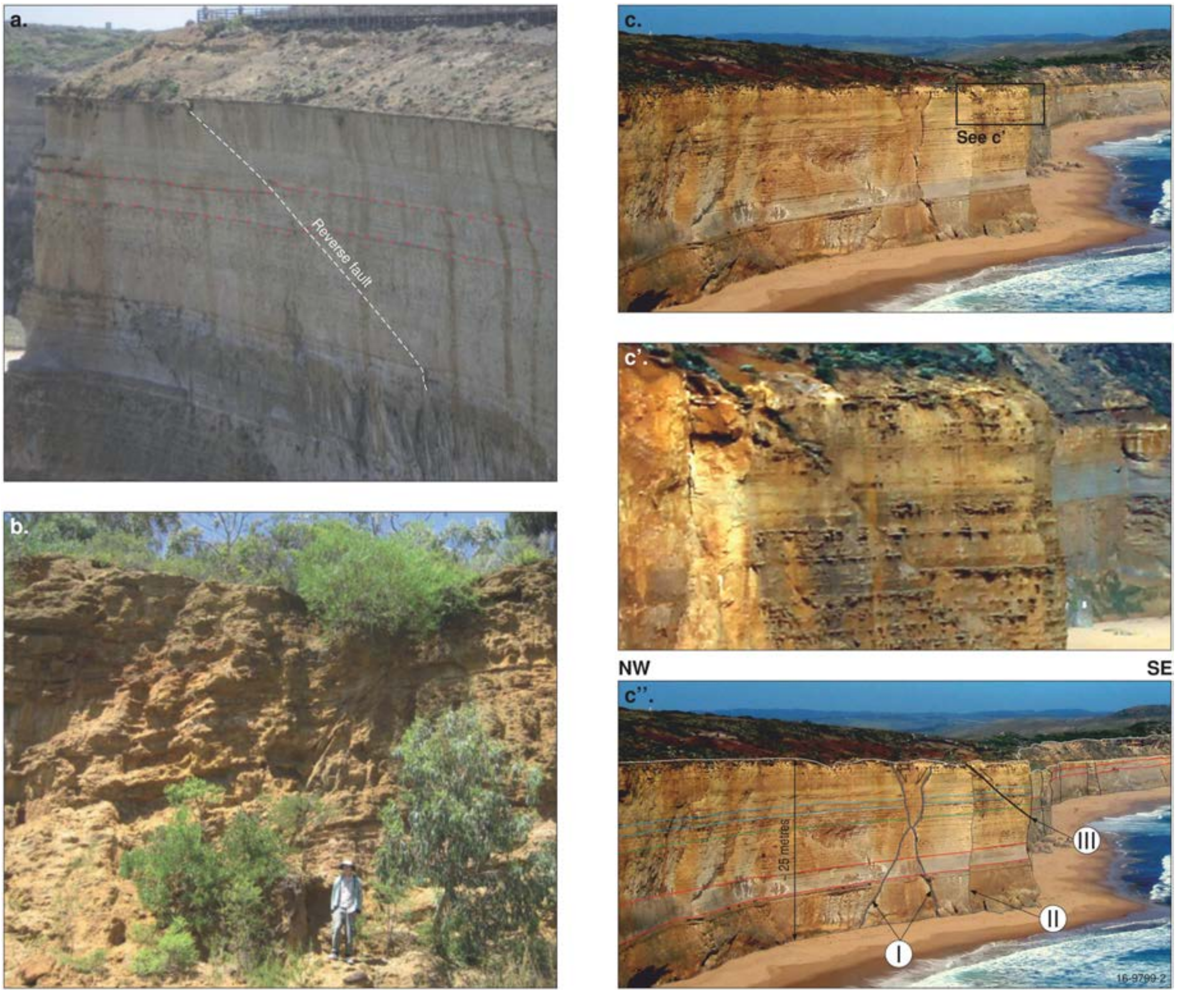

Figure 2: Faults from the area surrounding the Otway Site with surface expressions. (A) Small-scale, low-angle reverse fault dipping ~E-SE in the cliffs near the Twelve Apostles, Port Campbell [4]. (B) High angle reverse fault dipping ~N in a small quarry near Princetown [4]. (C) Faulted cliff at the Twelve Apostles, near Port Campbell. C' is a close up of a low-angle reverse fault, and C" an annotated interpretation of the three types of faulting present: I = conjugate normal faulting, II=strike-slip faulting, III= reverse faulting [35].

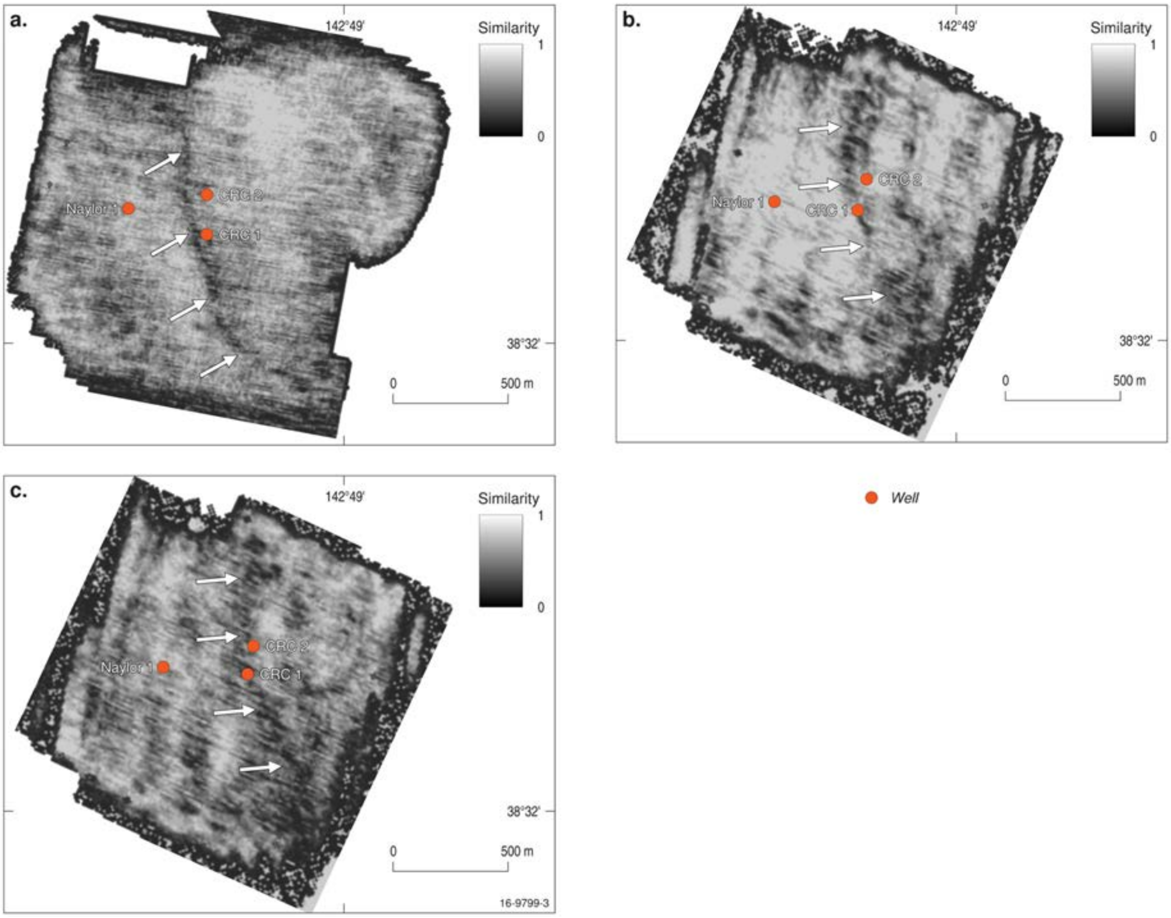

Figure 3: Minimum similarity timeslices through three seismic volumes at ~300 ms TWT (~270 m). The locations of the three wells within the study area are marked. Arrows point out the low values of similarity that indicate a discontinuity, and may represent faulting. (a) 2015 survey, (b) 2008 survey, (c) 2009 survey.

1.1. Geological setting

The CO2CRC Otway site is located on the south coast of Australia, in the Port Campbell Embayment of the onshore Victorian Otway Basin (Figure 1b). The Otway Basin is a large NW-SE trending basin formed along Australia's southern continental margin during rifting of Australia from Antarctica, which began during the Middle Jurassic in the Bight Basin and spread east to the Otway and Gippsland basins by the Late Jurassic [3-5] Encompassing both onshore and offshore parts of South Australia, Victoria, and extending into Tasmanian waters, the Otway Basin contains sediments and volcanic rocks of late Jurassic to recent age [5].Initial N-S extension during the Jurassic produced a series of large E-W to NW-SE trending half grabens that were expanded through progressive extension through the Early Cretaceous [5]. Widespread compression and inversion was experienced during the middle Cretaceous. Inversion was focused in the eastern parts of the basin, where up to 3 km of exhumation alongside extensive deformation in the Otway Ranges is observed [5-9]. A series of major late-Cretaceous depocentres were initiated as renewed extension and subsidence shifted south during the Turonian. Various authors have argued for continued N-S extension (e.g. [10]), though a switch to oblique NE-SW extension has also been proposed [11]. A second major phase of inversion, associated with the reverse faulting and folding, took place during the Miocene [3] and is generally considered to be ongoing at present [3,5]. Distinct phases of deformation can be related to changes in the intraplate stress regime due to fluctuations in plate boundary segment motion (e.g. [12]). Compression features can be identified throughout the basin, including in the expression of shallow faults in sea cliffs (Figure 2), and as offset strandlines [13]. Geomechanical investigations undertaken as part of the Otway Project identify a maximum horizontal stress azimuth of 142°N [14], and indicate a normal faulting regime [14]. However, uncertainty in the magnitude of the horizontal stresses allows for interpretation of strike-slip [14] and reverse faulting stress regimes [15].

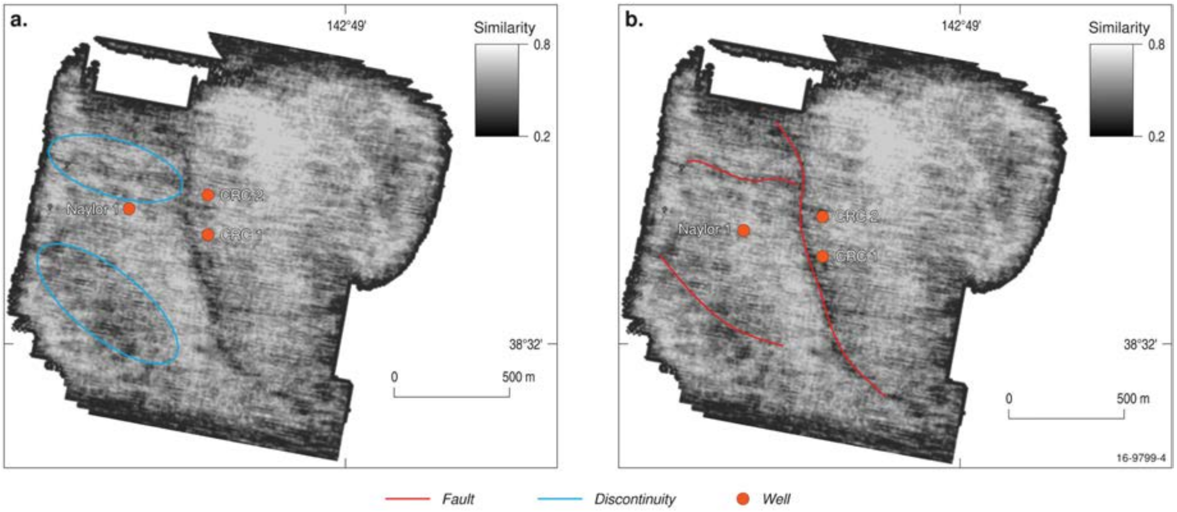

Figure 4: Smaller discontinuities identified via the minimum similarity attribute as applied to the 2015 3D survey. (a) Discontinuous zones representing possible faults, and; (b) possible faults indicated in red.

The Otway Project is located in the Naylor Field, a previously producing gas field that is now depleted [16]. The Naylor Field bound by several large extensional faults, to the west by the N-S striking Naylor Fault, and to the east and south by the Naylor East and Naylor South structures, respectively. The Naylor Fault marks the boundary of the up-dip direction of the Cretaceous Waarre Formation reservoir, and does not feature a large enough throw to disturb the overlying Belfast Mudstone seal.

The topmost formations overlying the Waarre-Belfast reservoir-seal pairing are the Oligocene to Miocene sediments of the Nirranda and Heytsebury groups, deposited in increasingly shallow marine conditions [17]. These are, in order of decreasing age, the Narrawaturk Marl, Clifton Formation, Gellibrand Marl, and the Port Campbell Limestone [16,17].

2. Data availability and analysis

The Naylor Field reservoir, the Waarre Formation, lies at a depth of between 1980 and 2180 m TVDSS [18]. Exploration was originally undertaken by Santos Ltd. Under a limited budget; following the acquisition of 3D seismic, a single wildcat exploration well was drilled based on direct hydrocarbon seismic indicators observed in the Curdie Vale 3D survey. This well, the gas well Naylor-1, was completed with limited well logging, no conventional or side-wall core, and no additional testing or sampling [18]. Following the transition of the Naylor Field from Santos to the CO2CRC, much of this lack of well data was remedied through the acquisition of more seismic data (including a 4D survey, composed of OBPP_2008 and OBPP_2009, run from 2008-2009), and the drilling of the wells CRC-1 and CRC-2. Both wells featured extensive wireline logs, well testing, and preserved core.

However, all exploration post-petroleum was keenly targeted at understanding the depleted gas reservoir, seal, and potential flow pathways for any CO_2 injected at reservoir level. Subsequently, while there is an excellent

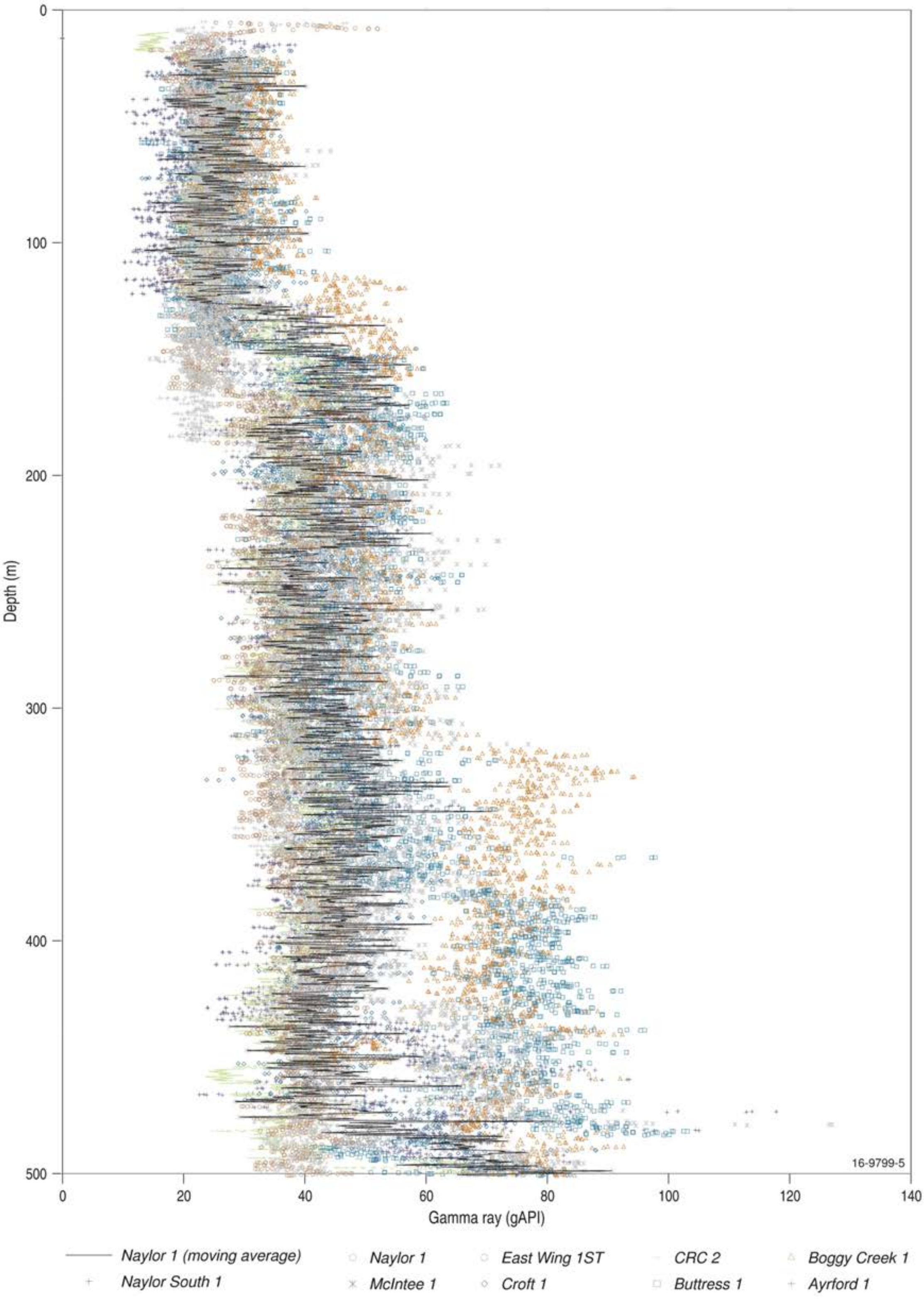

Figure 5: Gamma ray logs from wells within the study area where they were run to the surface, shown from surface to 500 m depth.

understanding of the reservoir geology, relatively little is known about the shallow geology and very little data has been acquired to remedy this.

2.1. 3D Seismic surveys

Three 3D seismic surveys were analysed in this study; OBPP_2008, OBPP_2009, and OBPP_2015. However, while these provide detailed information on the underlying reservoir, acquisition and processing has been carried out in such a way as to preclude most interpretation of features shallower than approximately 400 m TVD below the seismic reference datum (SRD, 30 m above mean sea level) [17]. Additionally, the types of feature being targeted for shallow injection are necessarily small-scale. Seismic amplitude resolution is typically taken to be $\lambda/4$ [19, 20]. In practice this means that faults with throws of less than 10-15 m are generally below seismic amplitude resolution [19, 21, 22]. The data analysed in this study has similar resolution issues. Techniques for improving the detection of sub-seismic amplitude resolution faults and fractures from both 2D and 3D seismic data, however, are available. The primary method is the calculation and analysis of seismic attributes [23,24]. Faults and fractures have been successfully mapped in 3D seismic datasets using several attributes, most notably curvature and similarity attributes. This is due to established correlations between curvature and fractures [25-28], coupled with the demonstrated ability of similarity attributes to highlight discontinuous zones likely to represent fracturing [27-32].

While various attributes were applied to the data, the primary investigation was undertaken using the minimum similarity attribute in dGB Earth Science's OpendTect© software. This algorithm was calculated for the seismic surveys and displayed as non-dip-steered time-slices in the shallow section of the available 3D seismic surveys in order to identify zones of discontinuity within the survey. One time-slice every 4 ms was analysed for features likely to represent discontinuous zones. As only one potential fault identifying attribute was available, a strict criterion was set for the interpretation of discontinuity features that may represent faults:

- The feature must be clearly distinguished as discontinuous;
- The feature must be relatively linear; and,
- The feature must be identifiable on numerous timeslices and form a coherent fault plane when fault picks are made on the 'same' area (i.e., the western most edge of the discontinuous zone).

Under these conditions, several features that may represent shallow faults were identified within the analysed surveys (Figure 3). The most prominent of these, striking ~NNW-SSE, is common to each of the surveys and is observed from ~180 ms TWT down to ~420 ms TWT. Vertical seismic profile (VSP) data from the wells CRC-1 and Naylor-1 (Figure 1b) indicate that these times correspond to depths of ~155 m TVDSRD and ~380 m TVDSRD respectively. Additionally, there are a series of other, smaller features that may represent faults (Figure 4). However, these are not common to each of the surveys, and where they are observed in multiple surveys, do not occur in the same locations and orientations. Hence, we assume they do not definitively define a geological feature.

2.2. Petroleum wells and waterbores

As a popular exploration target and producing petroleum province, the Otway Basin hosts a number of petroleum wells. Ten of these were identified in the vicinity of the Otway Site, in addition to the two CO2CRC wells, CRC-1 and CRC-2. However, as discussed above, the majority of the logs, tests, and core that has been taken from each of these wells targeted reservoir level, particularly the known hydrocarbon reservoirs of the Waarre Formation. The only wireline logs taken in the petroleum wells in the near surface are gamma ray logs (Figure 5). These provide an indication of lithology based on radioactive character, and demonstrate a relatively consistent lithology for the shallow section. Two main trends are observed on the gamma ray logs, a low trend from surface to between 120 m and 180 m depth, and a higher trend from below that depth to greater than 300 m. These values (approximately 30 gAPI and 50 gAPI respectively) are interpreted to represent a sandstone-limestone lithology in the upper section, and a limestone-shale lithology in the lower section. Correlation between these and the known formations indicates that the lithology is as expected. Gamma ray logs unfortunately do not provide anything other than an indication of lithology based on natural formation radioactivity [33], and so cannot be solely used to identify faults or other subsurface features.

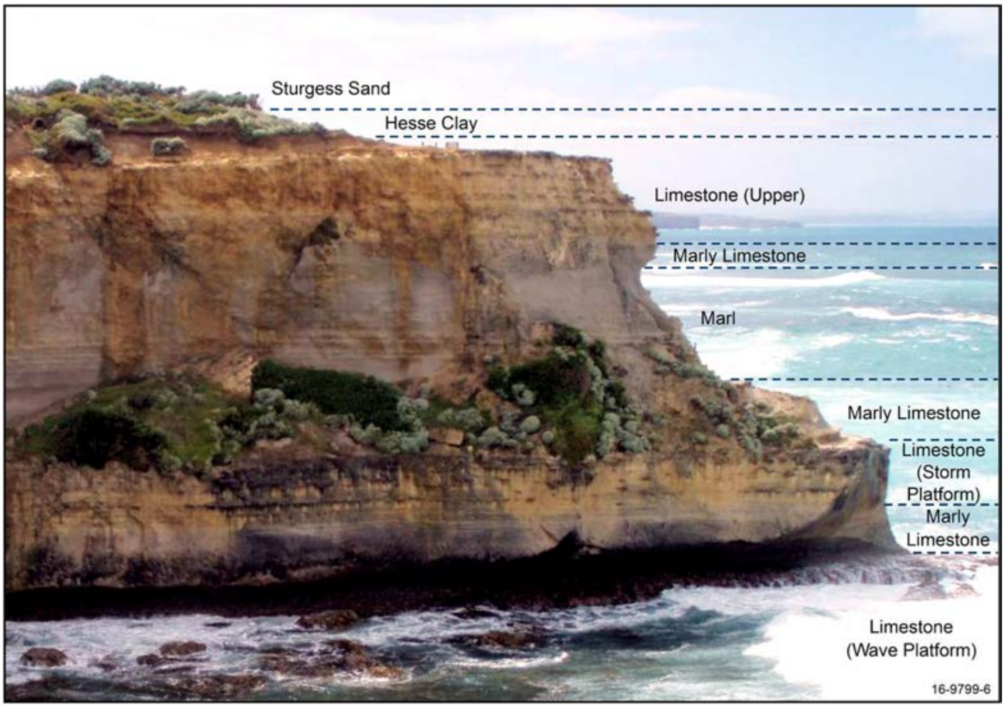

Figure 6: Cliff face from Sturgess Point, Port Campbell, demonstrating preferential weathering by lithology [35]

Each well features a description of the lithology as encountered while drilling. Descriptions of the shallow section, alongside 24 water bores proximal to the site that feature basic lithological descriptions, were used to further characterise the shallow formations. Cuttings from these boreholes indicate that the Port Campbell Limestone is a locally consistent white to brown/yellow white calcarenite with abundant fossil fragments, described as a competent, moderately hard limestone with fair intergranular porosity. This is intercalated with marl to marly limestone that is friable, dispersive, and occasionally described as soft and sticky. Shallow expressions of the Port Campbell Limestone along the coastline show distinct layering of these alternating lithologies, with weathering partially controlled by lithology (Figure 6). The Port Campbell Limestone is overlain in part by Aeolian dune sands formed following the last glacial maximum (Upper Pleistocene to mid-Holocene), and by the Hesse Clay, a unit of residual clays developed through weathering of the Port Campbell Limestone from the Pleistocene to recent [34, 35].

3. Discussion

As outlined earlier, several 3D seismic surveys were interpreted for possible shallow faulting (Figure 2; Figure 4, Figure 5). Several likely features were identified and one feature is potentially the most interesting. Under the defined interpretation criteria, a common discontinuity that may represent faulting was identified in each of the surveys, where it was observed at a similar location within each survey (Figure 2; Figure 4).

Interpretation of three previously acquired 3D seismic surveys using the minimum similarity attribute demonstrates evidence for a shallow, steeply east dipping fault striking approximately NNW-SSE. This is observed from approximately 160 m to 380 m, where it appears to die out, suggesting that it is disconnected from the underlying faults that intersect the reservoir. A shallow shear wave survey previously carried out at the Otway Site provides further evidence for this shallow fault; however, it is only partially imaged by the relevant survey line (PROTECT 3) [36]. In this survey, a fault is seen at ~350 m below sea level (bsl), where it unfortunately intersects the edge of the survey and cannot be traced higher. Interestingly, the authors note that a topographic low is observed at the surface location corresponding to the extrapolated fault at the north of the site [36]. Furthermore, they identify two further shallow structures, the first of which is enclosed within the survey limits and extends from ~100 m bsl to the surface. The second of which appears to consist of several interlinked fault planes, extending from ~350 m bsl to ~100 m bsl, where it once more intersects the edge of the survey and cannot be traced higher [36].

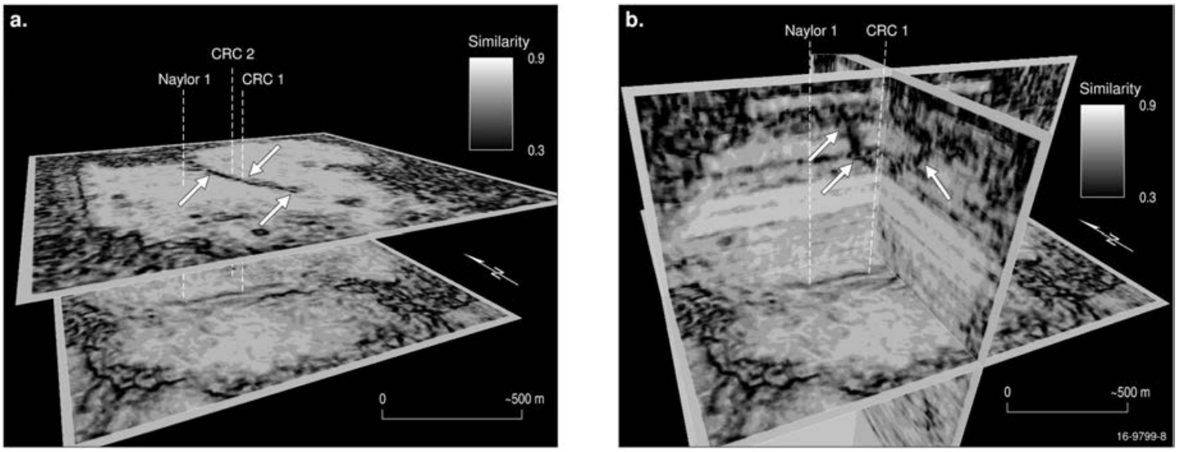

Figure 7: Fault identification on the reprocessed (for shallow section) 2015 3D seismic survey. Fault interpretation is indicated on both timeslices and inlines by white arrows [37]. The indicated fault trace can be identified to ~100 msTWT.

While not imaged to the surface in high resolution on the shear wave survey PROTECT 3, the identified fault can be interpreted on the 3D surveys to approximately 165 m below the ground surface (~120 m bsl). However, the lack of an identifiable feature at depths shallower than this is likely due to the limitations of the data observed in seismic datasets at such shallow levels. The surveys analysed, like the majority of data taken over the study area, have been processed for reservoir depths and so lack resolution in the shallower segments. Fortunately, reprocessing of the data to focus on the shallow sections allows for some improvement to seismic resolution [37]. Reprocessing of the 2015 3D survey, followed by application of the similarity attribute, improves fault zone visibility such that the structure can now be traced to ~100 m below the ground surface (~55 m bsl). (Figure 7).

Extrapolation of the identified discontinuity to the surface places the potential fault surface trace in between the two CRC wells to the east and the Naylor-1 well to the west (Figure 1b). This places it in the approximate centre of the proposed high resolution shallow 3D seismic site.

Minor topographic changes that have been suggested [36] to coincide with surface extrapolation of the fault identified in 3D seismic surveys could be due to variation from other factors such as lithology, erosion, or other landform processes. The Port Campbell Limestone, in the vicinity of the Otway Site, is an essentially flat lying formation with very limited exposure [38]. The main exposure of this formation is seen in the extensive sea cliffs for which the area is renowned (Figure 3, Figure 7). There are several locations where faults can be observed in these cliffs, most notably in the vicinity of the Twelve Apostles, near Port Campbell. Here, a series of faults representing the three major types of faulting [39] are seen in proximity to one another (Figure 3). Compressional inversion is evident with throws of approximately 2 m in the cliff face; however, the entirety of this throw is not preserved in the overlying topography where the overlying sands and clays serve to smooth much of the difference between hanging wall and footwall (Figure 3). Besides the well preserved examples at the Twelve Apostles, there are limited known surface expressions of faults within the Port Campbell Limestone. Small, high angle (~60°) reverse faults are observed in a quarry near Princetown, Victoria, where they are interpreted as inverted normal faults with interpreted present-day throws of 1-2 m [5] (Figure 3). Again, minor topographical changes are observed in the vicinity of the faults [5]. Shallow faulting, and larger faults that have surface exposures, are observed throughout the Otway Basin (e.g. [29, 5]). Furthermore, it is likely that the present-day Otway coastline, particularly in the Port Campbell Embayment, has been sculpted by sets of tectonic joints [35], highlighting the commonality of shallow tectonics in the area. While large numbers of shallow faults are not exposed in the region, it is likely that this is mainly due to the present day landform. Many faults with surface expressions are likely located under the recent sediments of the Sturgess Sand and Hesse Clay.

Shallow faulting is present within the Port Campbell Embayment, and topographical changes have been suggested as evidence for faults reaching shallow depths and perhaps the surface. The acquisition of high resolution topographic information such as LIDAR, aerial photography, or other sources of information may allow for identification of surface features related to subsurface structures. Topographical changes related to faulting may be able to be identified and correlated with interpreted faults, allowing for more accurate constraints on their morphology and location. Furthermore, detailed topography may allow for identification of dissolution features such as dolines (commonly known as sinkholes) by their influence over surface topography.

While evidence exists for karst and dissolution features within the Port Campbell Limestone, what is generally observed is neither particularly large nor extensive [39]. Small dissolution cavities are relatively common, and there is some evidence to suggest that several larger sea caves are karstic in character and may be partially due to dissolution processes. It is, therefore, unlikely that the discontinuity represented in the seismic surveys is due to dissolution; however, there is evidence for dissolution along regional joints [35], so the possibility remains that this feature could be caused by dissolution processes rather than faulting. Channel deposits can also cause discontinuities in seismic data, though the Port Campbell Limestone is not commonly known as a channel affected lithology. Further, the morphology of the identified discontinuity makes it more likely to be a fault than stacked channels (Figure 7).

Given the data presently available, the throw and offset of the newly identified fault cannot be accurately estimated and it is not clear whether it is a reverse, strike-slip, or normal fault (Figure 4, 7). Acquisition of high resolution, shallow focused, 3D seismic over the study area will allow for the fault to be further delineated, and to assess whether the site is suitable for a planned shallow CO2 controlled release experiment at the identified fault [2].

4. Conclusions

An assessment of the near surface geology of the CO2CRC Otway Site in Victoria's Otway Basin, undertaken to support the planning of a high resolution seismic survey, has resulted in the identification of a shallow feature likely to represent a previously unknown fault within the Port Campbell Limestone.

Available 3D seismic surveys, as well as data from petroleum wells and waterbores, were used inform the assessment, with additional comment sought from experts on the region. The Port Campbell Limestone is assessed to be a laterally continuous lithology, defined by intercalated limestones, marls, and marly limestones. The weathering of these lithologies, in conjunction with regional tectonic jointing, is responsible for the distinct morphology of the coastal cliffs. The Port Campbell Limestone exhibits some Karst and dissolution features, but these are limited in extent and size and are considered to be unlikely to be a major feature of the study area, based on analysis of similar features exposed along the coastline.

Interpretation of the existing 3D seismic survey data using the minimum similarity attribute demonstrates evidence for a shallow, steeply east dipping fault striking approximately NNW-SSE. This is observed from approximately 100 m to 380 m, where it appears to die out. In the shallow section, the fault is undetectable primarily due to the low seismic resolution, and so it is unknown at what depth it dies out. However, there is evidence for shallow faulting within the Port Campbell Embayment, and topographical changes have been suggested as evidence for this fault reaching shallow depths and perhaps the surface. Extrapolation of the fault to the surface projects an intersection approximately between the wells Naylor-1 and CRC-1 and it may provide a useful site for future fault experiments.

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References

[1] Tenthorey, E., T. Dance, Y. Cinar, J. Ennis-King, and J. Strand 2014. Fault modelling and geomechanical integrity associated with the CO2CRC Otway 2C injection experiment. International Journal of Greenhouse Gas Control 30, 72-85.

[2] Feitz, A.J, R. Pevzner, B. Harris, R. Schaa, K. Tertyshnikov, A,H. Bailey, T. Ransley, U. Schacht, T. Fomin, and M. Urosevic 2016. The CO2CRC Otway shallow CO_2 controlled release experiment: Site suitability assessment, Energy Procedia (submitted).

[3] Norvick, M., and M. Smith, 2001. Southeast Australia-Mapping the plate tectonic reconstruction of southern and southeastern Australia and implications for petroleum systems, APPEA Journal, 41(1), 15–36.

[4] Finlayson, D. M., D. W. Johnstone, A. J. Owen, and K. D. WakeDyster, 1996. Deep seismic images and the tectonic framework of early rifting in the Otway Basin, Australian southern margin, Tectonophysics, 264(1–4), 137–152, doi:10.1016/s0040-1951(96)00123-0.

[5] Holford, S. P., R. R. Hillis, I. R. Duddy, P. F. Green, M. S. Stoker, A. K. Tuitt, G. Backé, D. R. Tassone, and J. MacDonald, 2011. Cenozoic postbreakup compressional deformation and exhumation of the southern Australian margin, APPEA Journal, 51, 613–638.

[6] Cooper, G.T. and K.C. Hill, 1997. Cross-section balancing and thermochronological analysis of the Mesozoic development of the eastern Otway Basin. APPEA Journal, 153, 390–414.

[7] Duddy, I.R., 2003. Mesozoic, a time of change in tectonic regime. In: Birch, W.D. (ed) Geology of Victoria, Geological Society of London, Special Publication 23, 239–86.

[8] Green, P.F., P.V. Crowhurst, and I.R . Duddy, 2004. Integration of AFTA and (U-Th)/He thermochronology to enhance the resolution and precision of thermal history reconstruction in the Anglesea-1 well, Otway Basin, SE Australia. In: Boult, P.J., D.R. Johns, and S.C. Lang, (eds)Eastern Australian basins symposium II, Petroleum Exploration Society of Australia, Special Publication, 117–31.

[9] Tassone, D.R., S.P. Holford, and R.R. Hillis, 2010. Quantification of Cretaceous-Cenozoic exhumation in the Otway Basin using sonic velocities and implications for hydrocarbon exploration. ASEG Extended Abstracts, 1–4.

[10] Krassay, A.A., D.L. Cathro, and D.J. Ryan, 2004. A regional tectonostratigraphic framework for the Otway Basin. In: Boult, P.J., D.R. Johns, and S.C. Lang, (eds)Eastern Australian basins symposium II, Petroleum Exploration Society of Australia, Special Publication, 97–106.

[11] Schneider, C.L., K.C. Hill, and N. Hoffman, 2004. Compressional growth of the Minerva Anticline, Otway Basin, Southeast Australia—evidence of oblique rifting. The APPEA Journal, 44, 463–80.

[12] Holford, S. P., A. K. Tuitt, R. R. Hillis, P. F. Green, M. S. Stoker, I. R. Duddy,... and D. R. Tassone, 2014. Cenozoic deformation in the Otway Basin, southern Australian margin: implications for the origin and nature of post - breakup compression at rifted margins. Basin Research, 26(1), 10-37.

[13] Wallace, W., J. Dickinson, D. Moore, and M. Sandiford 2007. Late neogene strandlines of southern Victoria: A unique record of eustasy and tectonics in southeast Australia, Australian Journal of Earth Sciences, 52(2), 279{297, doi:10.1080/08120090500139455.

[14] Tenthorey, E. 2014. Gemechanical Investigations. In: Cook, P.J. (Ed.) 2014, Geologically storing carbon: Learning from the Otway experience. CSIRO Publishing, Melbourne. 113-128.

[15] King, R.C., S.P. Holford, R.R. Hillis, A. Tuitt, E. Swierczek, G. Backe, D. Tassone, M. Tingay. 2012. Reassessing the in-situ stress regimes of Australia's petroleum basins. The APPEA Journal 52, 415-426.

[16] Cook, P.J. (Ed.) 2014, Geologically storing carbon: Learning from the Otway experience. CSIRO Publishing, Melbourne.

[17] Ziesch, J., C. M. Aruffo, D. C. Tanner, T. Beilecke, T. Dance, A. Henk,... and C.M. Krawczyk, 2015. Geological structure and kinematics of normal faults in the Otway Basin, Australia, based on quantitative analysis of 3 - D seismic reflection data. Basin Research, 1–20, doi: 10.1111/bre.12146

[18] Dance, T. 2014. Characterising the storage site, in: Cook, P.J. (Ed.) 2014, Geologically storing carbon: Learning from the Otway experience. CSIRO Publishing, Melbourne.

[19] Chopra, S., J. Castagna, and O. Portniaguine, 2006. Seismic resolution and thin-bed reflectivity inversion. CSEG Recorder, 31 (1), 19–25.

[20] Widess, M.B., 1973—How thin is a thin bed? Geophysics, 38 (6), 1,176–80

[21] Childs, C., J.J. Walsh, and J. Watterson, 1990. A method for estimation of the density of fault displacements below the limits of seismic resolution in reservoir formations. In: Buller, A.T., E. Berg, O. Hjelmeland, J. Kleppe, O. Torsæter, and J.O. Aasen, (eds) North Sea Oil and Gas Reservoirs—II. Dordrecht, The Netherlands: Graham & Trotman.

[22] Gauthier, B.D.M. and S.D. Lake, 1993. Probabilistic modelling of faults below the limit of seismic resolution in Pelican Field, North Sea, offshore United Kingdom. The AAPG Bulletin, 77 (5), 761–77.

[23] Bahorich, M. and Farmer, S., 1995—3D seismic discontinuity for faults and stratigraphic features: the coherence cube. The Leading Edge, 14 (10), 1,053–8.

[24] Chopra, S. and K.J. Marfurt, 2005. Seismic attributes: a historical perspective. Geophysics, 70 (5), 3SO–28SO.

[25] Lisle, R.J., 1994. Detection of zones of abnormal strains in structures using Gaussian curvature analysis. AAPG Bulletin, 78 (12), 1,811–9.

[26] Roberts, A., 2001. Curvature attributes and their application to 3 D interpreted horizons. First Break, 19 (2), 85–100.

[27] Backé, G.V.R., A. Khair, H. Farouq, R.C. King, and S.P. Holford, 2011. Fracture mapping and modelling in shale gas target in the Cooper basin, South Australia. The APPEA Journal, 51, 397–410.

[28] Bailey, A.H.E., R.C. King, S.P. Holford, J.M. Sage, G.V.R. Backe, and M. Hand 2015. Defining structural permeability in Australian sedimentary basins. The APPEA Journal, 55, 119 – 148.

[29] Bailey, A.H.E., R.C. King, S.P. Holford, J.M. Sage, G.V.R. Backe, and M. Hand 2014. Remote sensing of subsurface fractures in the Otway Basin, South Australia. Journal of Geophysical Research: Solid Earth, 119(8), 6591-6612.
[30] Cline, M., 2008. Two alternative seismic fault interpretation techniques: part one. Houston Geological Society Bulletin, 50 (8), 45–7.
[31] Crutchley, G.J., C. Berndt, D. Klaeschen, and D.G. Masson, 2011. Insights into active deformation in the Gulf of Cadiz from new 3-D seismic and high-resolution bathymetry data. Geochemistry Geophysics Geosystems, 12 (7), Q07016, 20 pp.
[32] Bailey, A. H. E., R. C. King, S. P. Holford, and M. Hand, 2016. Extending interpretations of natural fractures from the wellbore using 3D attributes: The Carnarvon Basin, Australia. Interpretation, 4(1), SB107-SB129.
[33] Bertozzi, W., D. V. Ellis, and J. S. Wahl, 1981. The physical foundation of formation lithology logging with gamma rays. Geophysics, 46(10), 1439-1455.
[34] Gill, E.D. 1965. Quaternary geology, radiocarbon datings, and the age of australites. Geological Society of America Special Paper 84. pp: 415-432.
[35] DSE, 2011. Review of land stability at Sturgess Point, Port Campbell. Department of Sustainability and Environment. Report # 514/01/11.
[36] Beilecke T.C.H., C.M. Krawczyk, J. Ziesch, and D.C. Tanner 2016. Near-surface fault detection using high-resolution shear-wave reflection seismics at the CO2CRC Otway Project site, Australia, Journal of Geophysical Research Solid Earth, 121, doi:10.1002/2015JB012668.
[37] Pevzner, R. 2015. Personal Communication
[38] Tickell, S.J., J. Edwards and C. Abele, 1992. Port Campbell Embayment 1:100,000 geological map. Report 95, Geological Survey of Victoria.
[39] Anderson, E.M., 1951. The Dynamics of Faulting and Dyke Formation with Applications to Britain. Oliver & Boyd, Edinburgh.
[40] White, S. 2015. Personal communication.