Constraints on the Tectonic Setting of the Andaman Ophiolites, Bay of Bengal, India, from SHRIMP U-Pb Zircon Geochronology of Plagiogranite
Author(s): D. Srinivasa Sarma, S. H. Jafri, Ian R. Fletcher, Neal J. McNaughton
Source: *The Journal of Geology*, Vol. 118, No. 6 (November 2010), pp. 691-697
Published by: The University of Chicago Press
Stable URL: http://www.jstor.org/stable/10.1086/656354
Accessed: 24/01/2011 02:24

GEOLOGICAL NOTE

Constraints on the Tectonic Setting of the Andaman Ophiolites, Bay of Bengal, India, from SHRIMP U-Pb Zircon Geochronology of Plagiogranite

D. Srinivasa Sarma, S. H. Jafri,[1] *Ian R. Fletcher,*[2] *and Neal J. McNaughton*[3]

National Geophysical Research Institute, Council of Scientific and Industrial Research, Uppal Road, Hyderabad-500007, India
(e-mail: dssarma@ngri.res.in)

ABSTRACT

The Andaman ophiolites are well exposed in the Andaman group of islands, which is part of the Sunda-Burmese double-chain arc system in the Bay of Bengal, India. Plagiogranites occurring on the eastern margin of the southern part of South Andaman Island appear as interstitial vermicular and micrographic intergrowths of quartz and plagioclase. They are tonalitic to trondhjemitic in composition, and their Rb, Yb, Ta, and Y abundances are characteristic of a volcanic-arc affinity. Sensitive high-resolution ion microprobe U-Pb dating of zircons from a plagiogranite within the Andaman ophiolite has yielded a weighted mean $^{206}Pb/^{238}U$ age of 93.6 ± 1.3 Ma, interpreted as the age of its crystallization. The subduction-related plagiogranite has intruded a gabbro unit of the Andaman ophiolites as well as extrusives of the East Coast Volcanics at this time. Since the Andaman ophiolitic rocks predate the plagiogranite, they cannot have been generated in the currently active Late Miocene Andaman-Java subduction zone and were most likely obducted onto the leading edge of the Eurasian continent at an earlier phase of subduction activity during early Cretaceous time.

Online enhancement: appendix.

Introduction

The Andaman-Nicobar ophiolites in the Bay of Bengal, India, form a part of the Sunda-Burmese double-chain arc system, which extends from the Indo-Burmese ranges in the north to the Indonesian Islands in the south (fig. 1). The Andaman-Nicobar Islands are composed of an outer sedimentary arc, represented by the Andaman-Nicobar and Nias islands, and an inner magmatic arc that is represented by Barren Island (an active volcano) and the dormant Narcondam Island (fig. 2*A*). Several of the Andaman-Nicobar Islands, particularly of the Andaman group, are characterized by the occurrence of an ophiolitic suite of rocks (Karunakaran et al. 1968; Vohra et al. 1989; Pal et al. 2003). These ophiolites are generally interpreted as representing the eastern suture of the Indian plate (Gansser 1980; Mitchell 1981; Acharyya 1986). Two models have been proposed for the mode of occurrence of these ophiolites. In one interpretation, it is suggested that the subduction has continued along the western margin of the island arc since the late Mesozoic and the ophiolites in the Andaman-Nicobar Islands represent upthrust oceanic crust that was accreted during this prolonged period of subduction (Curray et al. 1979; Mukhopadhyay and Dasgupta 1988; Pal et al. 2003; Curray 2005). However, the flat-lying mode of occurrence of these ophiolites and their close spatial relationship with a zone of negative gravity anomalies is a feature atypical of ophiolites

Manuscript received November 20, 2009; accepted July 6, 2010.

[1] E-mail: syed1401@rediffmail.com.
[2] Department of Applied Geology, Curtin University of Technology, Bentley 6845, Western Australia, Australia.
[3] John de Laeter Centre, Curtin University of Technology, Bentley 6845, Western Australia, Australia.

[The Journal of Geology, 2010, volume 118, p. 691–697] 0022-1376/2010/11806-0007$15.00. DOI: 10.1086/656354

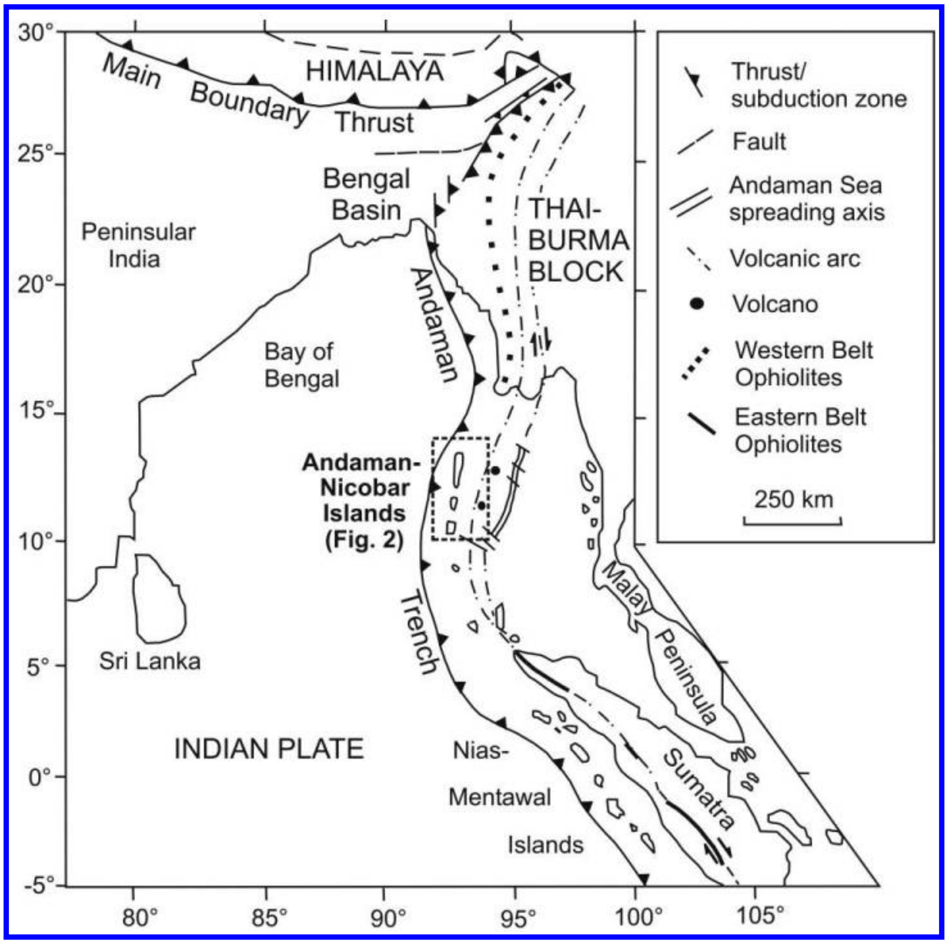

Figure 1. Tectonic setting of the Andaman Island Arc, showing the location of Andaman-Nicobar Islands (after Acharyya 2007).

in sutures or accretion complexes. This has led to the alternative suggestion that the Andaman ophiolites ranging in age between Late Mesozoic and Early Eocene were emplaced tectonically at the leading edge of the Eurasian continent during the Middle Eocene to Late Oligocene event, before the currently active Andaman-Java subduction, which was probably initiated during the Late Miocene (Acharyya et al. 1990; Sengupta et al. 1990; Acharyya 2007). No radiometric age data have been reported for these ophiolites; however, based on paleontological data from the oceanic sediments closely associated with the ophiolites, Upper Cretaceous (Karunakaran et al. 1968; Haldar 1984; Vohra et al. 1989) or Late Cretaceous to Early Eocene ages (Roy et al. 1988; Acharyya et al. 1989) have been inferred for these ophiolites.

The Andaman ophiolites are relatively well exposed in the southern part of South Andaman Island (fig. 2*A*), where they include minor volumes of plagiogranites (Haldar 1984; Vohra et al. 1989; Jafri et al. 1995; Pal et al. 2003). In this article we report the first direct radiometric age constraints on the Andaman ophiolite, from zircon U-Pb geochronology of the plagiogranite, with a view to understanding the tectonic setting of the Andaman-Nicobar ophiolite suite of rocks.

Field Relationships, Petrology, and Geochemistry

The Andaman ophiolites (fig. 2*B*) are regarded as the accreted and uplifted oceanic basement rocks that are thrust over the Paleogene flysch deposited in the Andaman fore-arc basin (Roy 1986; Pal et al. 2003). Ophiolite-detritus conglomerate, sandstone, siltstone, and shale of Lower-Middle-Eocene age named the "Mithakhari Group" (Karunakaran et al. 1968) overlies the ophiolites. Its stratigraphic contact with the ophiolites is in general tectonically disturbed. The Naga Hill Ophiolites of the Indo-

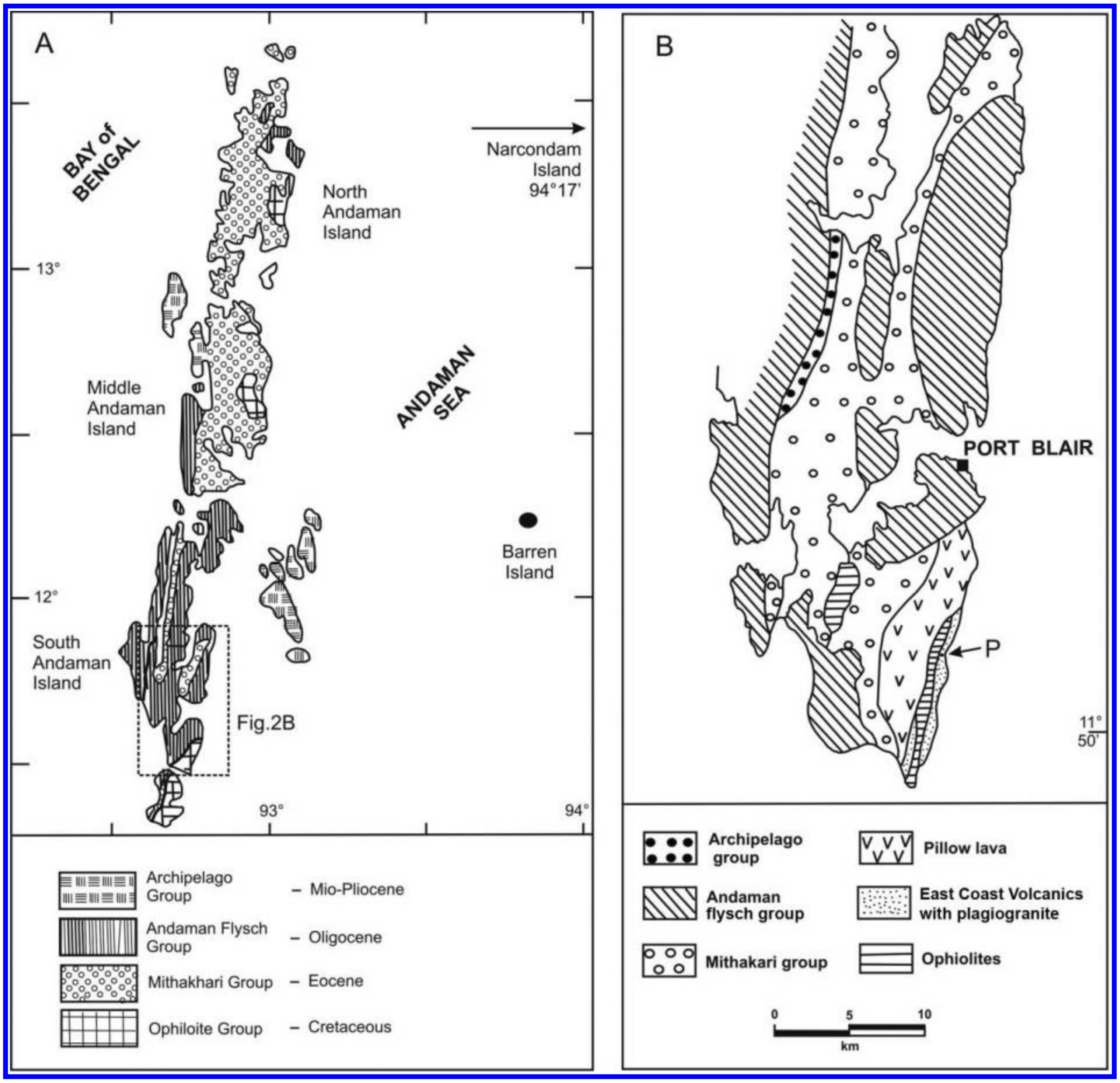

Figure 2. *A*, Geological map of Andaman group of islands, showing the distribution of ophiolites and sedimentary units, and the locations of Barren and Narcondam islands (after Pal et al. 2003). *B*, Geological map of part of South Andaman Island, showing the disposition of different tectonic slices (after Ray et al. 1988; Pal et al. 2003). *P* denotes the plagiogranite sample location.

Burma Range, farther north, are unconformably overlain by ophiolite-derived Mid-Eocene sediments (Acharyya 1986), which are very similar in facies to the Mithakhari Group. The Mithakhari Group also includes the tectonically juxtaposed olistostromal Lipa Formation (Acharyya et al. 1989). The Late Eocene–Oligocene Andaman Flysch Group is made up of greywacke sandstones and turbidites, whereas the Miocene-Pliocene Archipelago Group consists of tuff, sandstones, siltstone, limestone, claystone, and carbonate turbidites (Pal et al. 2003; Bandopadhyay 2005). All members of the ophiolite suite are well exposed, except for sheeted dikes, and the suite is composed mainly of ultramafic (harzburgite, pyroxenite, and dunite) and mafic plutonic rocks (gabbro, olivine gabbro, and troctolite), pillow basalt, plagiogranite, basic dike swarms, and radiolarian cherts. The ophiolitic rocks are closely associated with pillow lava as well as a distinctive suite of volcanic rocks that range in composition from basalt to andesite to dacite, which have been termed the East Coast Volcanics (Ray 1985; Ray et al. 1988). The East Coast Volcanics exposed at the eastern margin of the southern part of South Andaman Island are mostly agglomeritic in nature and at places plagiogranite shows intrusive relationship with the East Coast Volcanics.

Plagiogranite is well exposed in an intertidal zone on the east coast of South Andaman Island and occurs as small outcrops (typically 5-10 m) in contact with gabbro and the East Coast Volcanics. Xenoliths of gabbro have been observed in this plagiogranite and, in a few places, the plagiogranite shows an intrusive relationship with gabbro (Haldar 1984; Jafri et al. 1995). The sample dated for this article (AN-60) is a massive, medium-grained plagiogranite, collected (92°44′30″N, 11°34′05″E) ca. 10 km south of Port Blair on the eastern coast of South Andaman Island (fig. 2*B*). It is weakly foliated and consists predominantly of plagioclase and quartz with minor amounts of hornblende, some of which has been altered to chlorite. Magnetite, ilmenite, and titanite are accessory minerals. Samples of the plagiogranite have fairly uniform SiO_2 contents (64.2–66.7 wt%) and are trondhjemite to tonalite in composition, with low Rb (4 ppm) content and low Rb/Sr (<0.015) ratios, similar to an oceanic plagiogranite composition. Various elemental relationships such as Rb : (Y + Nb), Rb : (Yb + Ta), Ta : Yb, and Nb : Y show similarities between the Andaman plagiogranite and typical volcanic arc granites (see Jafri et al. 1995 for details on the mineralogy and geochemistry of Andaman plagiogranite).

The Andaman plagiogranite is characterized by the occurrence of micrographic-vermicular and graphic intergrowths of quartz and plagioclase feldspar (Jafri et al. 1995), providing evidence for the simultaneous late stage growth of quartz and feldspar in an extremely differentiated liquid derived from an initially low-K magma, as suggested by Coleman and Donato (1979). Based on field studies, petrological studies, and elemental abundance, the plagiogranite is interpreted to have been generated by low-pressure crystal fractionation of a basaltic magma derived from partial melting of the mantle in a suprasubduction zone tectonic setting, and it postdates ophiolite formation in a mid-ocean ridge setting (Jafri et al. 1995). The Andaman ophiolites showing mid-ocean ridge basaltlike characteristics and the gabbro-plagiogranite showing arclike characteristics resemble the back-arc-basin setting for the complex as inferred by Ray et al. (1988).

Zircon Geochronology

Approximately 100 zircon grains and grain fragments were recovered from a ca. 5-kg portion of plagiogranite AN-60 by standard crushing, grinding, magnetic, and heavy liquid techniques. The grains comprise a homogeneous population of euhedral, colorless (or very pale brown) prismatic grains with square cross sections, mostly ca. 300 μm long. Examination of the grains in transmitted light and cathodoluminescence images revealed fine concentric zones interpreted as evidence of a magmatic origin. Multistage growth structures, such as cores surrounded by optically distinct rims, were not observed (fig. 3).

The zircon grains were cast in a 25-mm resin mount with chips of the BR266 zircon standard (559 Ma, 903 ppm U; Stern 2001) for ion probe (SHRIMP) analysis. The SHRIMP analyses followed established procedures (e.g., Smith et al. 1998) and were carried out in three analytical sessions. Data tables that include details of the sessions may be found in the appendix, available online or from the *Journal of Geology* office. The data were reduced using SQUID 2.5 (Ludwig 2009) and define a single U-Pb age population (fig. 4) with a combined $^{206}Pb/^{238}U$ age of 93.6 ± 1.3 Ma (95% confidence limits; $n = 25$), interpreted as the crystallization age.

Implications and Discussion

Ophiolitic plagiogranites are commonly associated with high-level layered or massive gabbros that occur at the top of the cumulate portion of ophiolites that represent sections of oceanic crust created at mid-oceanic ridges (Moores and Vine 1971; Coleman and Donato 1979. However, other studies have suggested that some ophiolites have formed in marginal or back-arc basin ridges (Malpas 1979; Saunders et al. 1979), island arcs (Miyashiro 1973; Gerlach et al. 1981; Alabaster et al. 1982) and suprasubduction zone settings (Alabaster et al. 1982; Pearce et al. 1984), and this is a particular characteristic of Mesozoic Neotethyan ophiolites (e.g., Troodos, Hatay, Antalya, Vourinos, Oman, Sarikaraman), which display a significant proportion of plagiogranites throughout their magmatic pseudostratigraphy (Aldiss 1978; Pearce et al. 1984; Floyd et al. 1998). In the Andaman ophiolite, the high-level intrusives, which are represented by the plagiogranite-diorite-andesite suite of rocks, are closely intermingled with each other and show marginal intrusive relations with cumulates (Pal et al. 2003). The acid differentiates (dacites) of the East Coast Volcanics are similar in composition to those

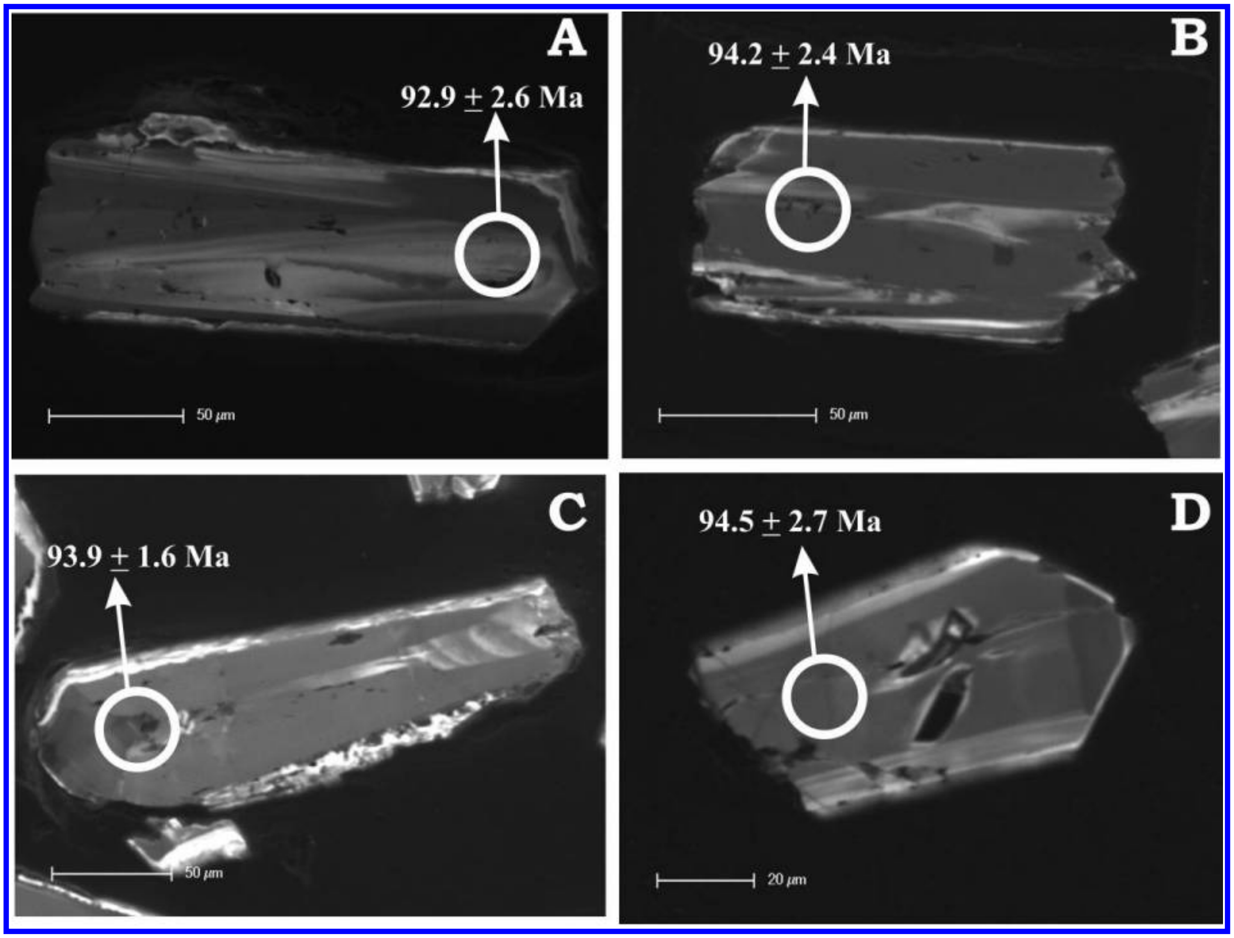

Figure 3. Cathodoluminescence images of zircons from plagiogranite from Andaman Islands; circles outline the SHRIMP pits where the U-Pb analyses were carried out. *A*, Grain 0657-1 (session 3); *B*, grain 0657-2 (session 3); *C*, grain 0657-5 (session 2); and *D*, grain 0657A.12 (session 3).

of plagiogranite (Jafri et al. 1995), suggesting a genetic link between them, as it is suggested that the felsic volcanic rocks are the extrusive equivalents of plagiogranites (Floyd et al. 1998; Escunder et al. 2006). The East Coast Volcanics are considered as separate thrust slices over the pillow basalts and seem to have an oceanic island arc affinity (Ray 1985). However, the Andaman plagiogranites, which show an intrusive relationship with the host gabbro, lack sheeted dykes, and have a compositional similarity with volcanic-arc granites, are inferred to have formed within a subduction zone setting rather than at a mid-ocean ridge (Jafri et al. 1995).

The SHRIMP results provide for the first time the age of magmatic crystallization of the plagiogranite in the Andaman ophiolites, at 93.6 ± 1.3 Ma. Thus, arc magmatism was initiated much earlier than the Eocene accretion of the Andaman ophiolites proposed by Sengupta et al (1990) and possibly represents extension of an earlier phase of Early–Mid-Cretaceous ophiolite accretion as was postulated by Acharyya (2007). The plagiogranite intruded a gabbro unit of the Andaman ophiolites in late Early Cretaceous times in an inferred subduction zone setting, when the Andaman ophiolites were already in a suprasubduction zone setting, probably as part of the leading edge of the Eurasian continental margin.

The above interpretation is also supported by the occurrence of several Mid-Cretaceous granodioritic to tonalitic plutons and batholiths (94–98 and 90–110 Ma) intruding the thick folded sequence of Mawgyi basaltic-andesite and pillow basalts in the Central Burma Magmatic Arc to the north (Mitchell 1993), and the 74–115-Ma calc-alkaline plutons and batholiths that intrude the Woyla Group ophiolites of western Sumatra in the south (Mitchell

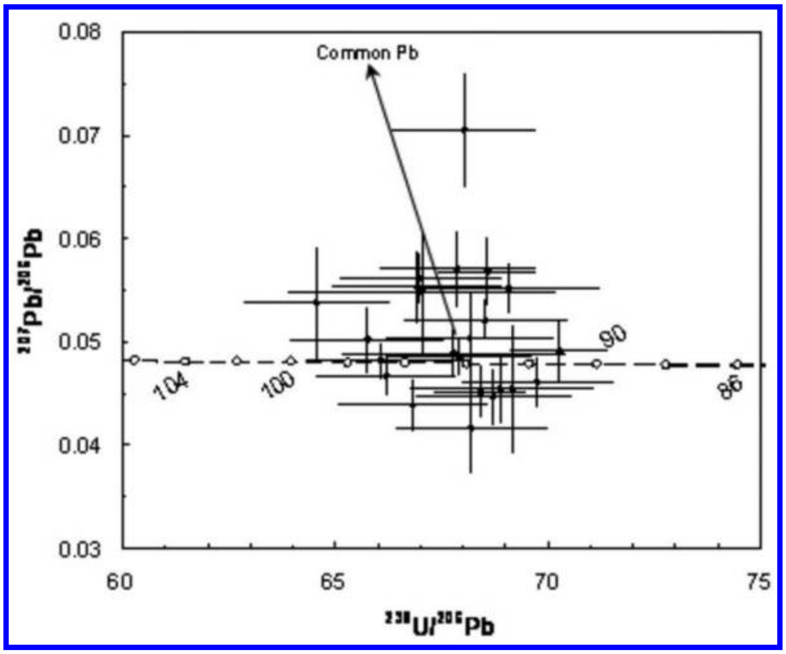

Figure 4. Concordia plot of SHRIMP U-Pb data for zircons from Andaman plagiogranite AM-60, before common Pb correction. Error bars are 1σ. Two analyses with >5% common ^{206}Pb lie above the frame.

1993), which may define likely extensions of the subduction zone into which these ophiolites were initially accreted (Mitchell 1993; Acharyya 2007). Further, the Andaman plagiogranite (93.6 Ma) is similar to the plutons from Myanmar and Sumatra magmatic arcs, and together they suggest the existence of a continuous subduction zone on this scale during the Middle to Late Cretaceous.

ACKNOWLEDGMENTS

S. H. Jafri and D. S. Sarma thank V. P. Dimri, director, National Geophysical Research Institute, Hyderabad, for encouragement and permission to publish these results. S. H. Jafri thanks the Department of Science and Technology (DST), Government of India, New Delhi, for a Grant-in-Aid project to carry out fieldwork. This work was carried out when D. S. Sarma held a Better Opportunities for Young Scientists in Chosen Areas of Science and Technology (BOYSCAST) fellowship provided by the DST. U-Pb analyses were performed on the Western Australia SHRIMP II, operated by a Western Australia university-government consortium with support from the Australian Research Council, Perth, Australia. We thank S. K. Acharyya for his critical review of the manuscript and valuable suggestions, which improved the presentation of these results. Constructive comments and editorial handling by David B. Rowley is gratefully acknowledged.

REFERENCES CITED

Acharyya, S. K. 1986. Tectono-stratigraphic history of Naga Hill ophiolites. Geol. Surv. India Mem. 119:94–103.

———. 2007. Collisional emplacement history of the Naga-Andaman ophiolites and the position of the eastern Indian suture. J. Asian Earth Sci. 29:229–242.

Acharyya, S. K.; Ray, K. K.; and Roy, D. K. 1989. Tectono-stratigraphic and emplacement history of the ophiolite assemblage from the Naga Hills and Andaman Island Arc, India. J. Geol. Soc. India 33:4–18.

Acharyya, S. K.; Ray, K. K.; and Sengupta, S. 1990. Tectonics of ophiolite belt from Naga Hills and Andaman Islands, India. *In* Naha, K.; Ghosh, S. K.; and Mukhopadhyay, D., eds. Structures and tectonics: the Indian scene. Proc. India Acad. Sci. (Earth Planet. Sci.) 99: 187–199.

Alabaster, T.; Pearce, J. A.; and Malpas, J. 1982. The volcanic stratigraphy and petrogenesis of the Oman ophiolite complex. Contrib. Mineral. Petrol. 81:168–183.

Aldiss, D. T. 1978. Granitic rocks of ophiolites. PhD dissertation, Open University, Milton Keynes, United Kingdom.

Bandopadhyay, P. C. 2005. Discovery of abundant pyroclasts in the Namunagarh Grit, South Andaman: evidence for arc volcanism and active subduction during the Paleogene in the Andaman Sea. J. Asian Earth Sci. 25:95–107.

Coleman, R. G.; and Donato, M. M. 1979. Oceanic plagiogranites revisted. *In* Barker, F., ed. Trondhjemites, dacites, and related rocks. Amsterdam, Elsevier, p. 149–168.

Curray, J. R. 2005. Tectonic and history of the Andaman Sea region. J. Asian Earth Sci. 25:187–232.

Curray, J. R.; Moore, D. G.; Lawver, L. A.; Emmel, F. J.; Raitt, R. W.; Henry, M.; and Kieckhefer, R. 1979. Tectonics of the Andaman Sea and Burma. *In* Watkins, J.; Montadert, L.; and Dickerson, P. W., eds. Geological and geophysical investigations of continental margins. Am. Assoc. Petrol. Geol. Mem. 29:189–198.

de Smith, J. B.; Barley, M. E.; Groves, D. I.; Krapez, B.; McNaughton, N. J.; Bickle, M. J.; and Chapman, H. J. 1998. The Scholl Shear Zone, West Pilbara: evidence for a domain boundary structure from integrated tectonostratigraphic analyses, SHRIMP U-Pb dating and isotopic and geochemical data of granitoids. Precambrian Res. 88:143–171.

Escunder, V. J.; Diaz de Neira, A.; Hernaiz Huerta, P. P.; Monthel, J.; Garcia Senz, J.; Joubert, M.; Loper, E.; et al. 2006. Magmatic relationships and ages of Caribbean Island arc tholeiite, boninites and related felsic rocks, Dominican Republic. Lithos 90:161–186.

Floyd, P. A.; Yaliniz, M. K.; and Goncuoglu, M. C. 1998. Geochemistry and petrogenesis of intrusive and extrusive ophiolitic plagiogranites, Central Anatolian Crystalline Complex, Turkey. Lithos 42:225–241.

Gansser, A. 1980. The peri-India suture zone. *In* Aubouin, J.; Debelmas, J.; and Latereille, M., eds. Geology of Alpine Chain born of Tethys. Mem. Bur. Rech. Geol. Min. Fr. 115:140–148.

Gerlach, D. C.; Ave Lallemant, H. G.; and Leeman, W. P. 1981. An island arc origin for the Canyon Mountain ophiolites complex, eastern Oregon, U.S.A. Earth Planet. Sci. Lett. 53:225–265.

Haldar, D. 1984. Some aspects of the Andaman ophiolite complex. Rec. Geol. Surv. India 115:1–11.

Jafri, S. H.; Charan, S. N.; and Govil, P. K. 1995. Plagiogranite from the Andaman ophiolite belt, Bay of Bengal, India. J. Geol. Soc. Lond. 152:681–687.

Karunakaran, C.; Roy, K. K.; and Saha, S. S. 1968. Tertiary sedimentation in the Andaman-Nicobar geosyncline. J. Geol. Soc. India 9:32–39.

Ludwig, K. R. 2009. SQUID 2: a user's manual. Berkeley, CA, Berkeley Geochronology Center, 100 p.

Malpas, J. 1979. Two constrasting trondhjemitic associations from transported ophiolites in western Newfoundland: initial report. *In* Barker, F., ed. Trondhjemites, dacites, and related rocks. Amsterdam, Elsevier, p. 465–487.

Mitchell, A. H. G. 1981. Phanerozoic plate boundaries in mainland of Asia, the Himalaya and Tibet. J. Geol. Soc. Lond. 138:109–122.

———. 1993. Cretaceous-Cenozoic tectonic events in the western Myanmar (Burma) Assam region. J. Geol. Soc. Lond. 150:1089–1102.

Miyashiro, A. 1973. The Troodos ophilitic complex was probably formed in an island arc. Earth Planet. Sci. Lett. 19:128–224.

Moores, E. M., and Vine, F. J. 1971. The Troodos Massif, Cyprus and other ophiolites as oceanic crust: evaluation and implications. Phil. Trans. R. Soc. A 368:443–466.

Mukhopadhyay, M., and Dasgupta, S. 1988. Deep structure and tectonics of the Burmese arc: constraints from earthquake and gravity studies. Tectonphysics 149:299–322.

Pal, T.; Chakraborty, P. P.; Gupta, T. D.; and Singh, C. D. 2003. Geodynamic evolution of the outer-arc-forearc belt in the Andaman Islands, the central part of the Burma-Java subduction complex. Geol. Mag. 140:289–307.

Pearce, J. A.; Harris, N. B. W.; and Tindle, A. G. 1984. Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. J. Petrol. 25: 956–983.

Ray, K. K. 1985. East Coast Volcanics: a new suite in the ophiolite of Andaman Islands. Rec. Geol. Surv. India 116:83–87.

Ray, K. K.; Sengupta, S.; and Van Den Hul, H. J. 1988. Chemical characters of volcanic rocks from Andaman ophiolite, India. J. Geol. Soc. Lond. 145:393–400.

Roy, D. K.; Acharyya, S. K.; Ray, K. K.; Lahiri, T. C.; and Sen, M. K. 1988. Nature of occurrence and depositional environment of the oceanic pelagic sediments associated with the ophiolite assemblage, South Andaman Island. Indian Miner. 42:31–56.

Roy, T. K. 1986. Petroleum prospects of the frontal fold belt and subduction complex associated with the India plate boundary in the northeast. Proc. Southeast Petrol. Explor. Soc. 7:192–212.

Saunders, A. D.; Tarney, J.; Stern, C. R.; and Dalziel, I. W. D. 1979. Geochemistry of Mesozoic marginal basin floor igneous rocks from southern Chile. Geol. Soc. Am. Bull. 90:237–258.

Sengupta, S.; Ray, K. K.; Acharyya, S. K.; and de Smeth, J. B. 1990. Nature of ophiolite occurrences along the eastern margin of the Indian plate and their tectonic significance. Geology 18:439–442.

Stacey, J. S., and Kramers, J. D. 1975. Approximation of terrestrial lead isotope evolution by a two-stage model. Earth Planet. Sci. Lett. 26:207–221.

Stern, R. A. 2001. A new isotopic and trace-element standard for the ion microprobe: preliminary thermal ionization mass spectrometry (TIMS) U-Pb and electron-microprobe data. Current Research 2001-F1, Report 13. Ottawa, Ontario, Geol. Surv. Can., p. 1–11.

Vohra, C. P.; Haldar, D.; and Ghosh Roy, A. K. 1989. The Andaman-Nicobar ophiolite complex and associated mineral resources: current appraisal. *In* Ghose, N. C., ed. Phanerzoic ophiolites of India. Patna, India, Sumna, p. 281–315.