Cenozoic Stratigraphy of the East Java Forearc

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INTRODUCTION

The study area is located in the offshore SE Java and is situated at the southeast edge of the Eurasian plate, known as Sundaland (Figure. 1 and Figure 2). Sundaland is the continental core of SE Asia and was constructed by amalgamation of continental blocks during the Mesozoic (Hamilton, 1979; Metcalfe, 1996; Hall & Morley, 2004).The East Java Forearc is a relatively unexplored area and the basement has long been considered to be Cretaceous arc and ophiolitic-accretionary complexes (Hamilton, 1979; Wakita, 2000). But now there is increasing evidence for continental crust beneath the East Java Sea (Manur & Barraclough, 1994; Emmett et al., 2009; Granath et al., 2011), and the southern part of East Java (Smyth, 2005; Smyth et al., 2007, 2008).

This article presents the findings of an MSc study (Nugraha, 2010) and a geological history presented in an IPA paper (Nugraha & Hall, 2012). New seismic lines south of Java have imaged a deep stratified sequence which is restricted to East Java and is absent beneath the West Java forearc. Main datasets were provided by TGS, comprising three long-offset 2D-seismic datasets (SJR-9, SJR-10, and SJI-10). These data consist of thirty-seven 2D marine seismic lines across the Java forearc with a total of 8266 km survey length. Previously published seismic data (Kopp et al., 2006) were limited to shallow imaging 4-streamer seismic sections.

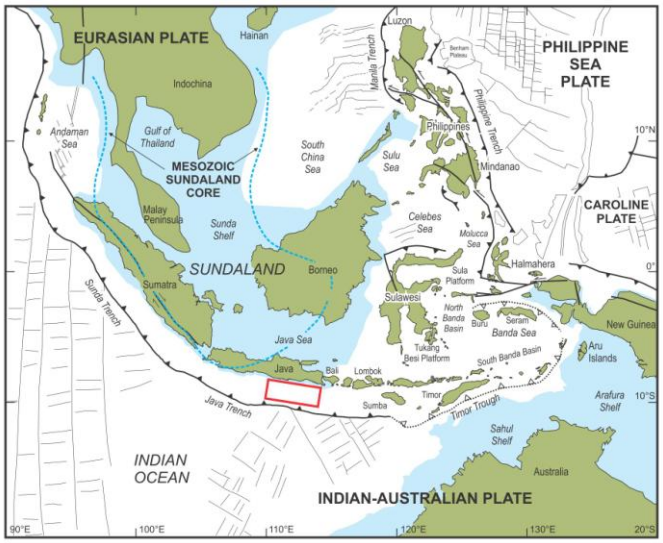


Figure 1. *Location of the study area (red box).*

All three TGS seismic datasets image down to 9 seconds two-way-time (TWT) and show very deep units in the forearc basin not seen in previously published seismic data in the area (Figure 3 and Figure 4). Three well datasets were available, including: Cilacap-1, Borelis-1, and Alveolina-1. The Borelis-1 and Alveolina-1 wells were drilled by Djawa Shell N.V. (Bolliger & de Ruiter, 1975) in the early 1970s and are located in the shallow part of the offshore Central Java forearc (Figure 2). These wells encountered mid-late Cenozoic rocks and have about 2 km total depth (Figure 5). The biostratigraphic top information (Shell interpretations) from these wells form the main reference for our mid and late Tertiary age-controlled stratigraphic interpretation.

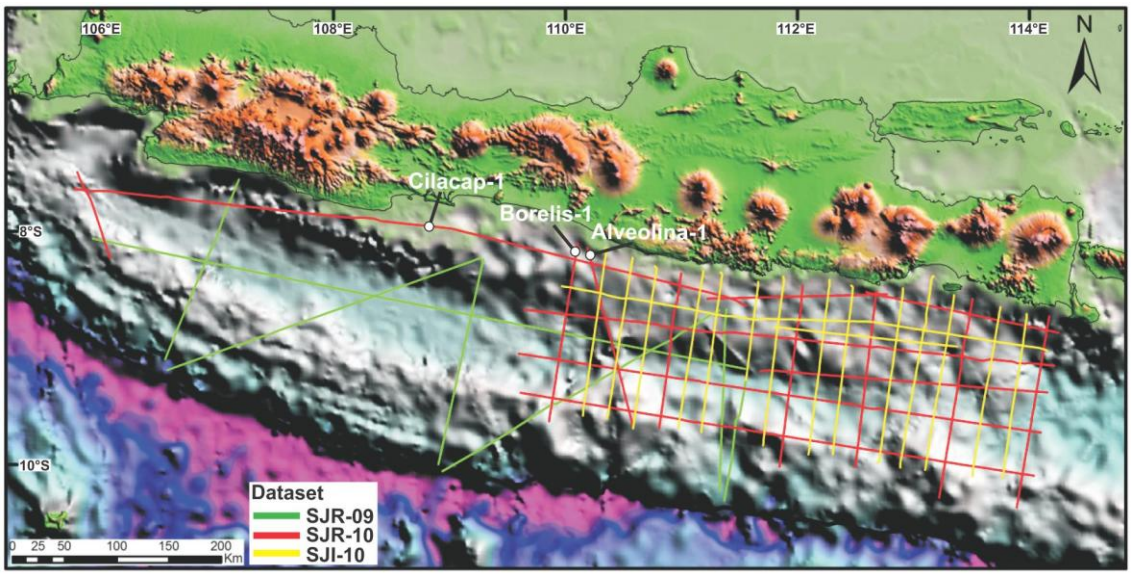


Figure 2. *Seismic grid used in this study and location of wells.*

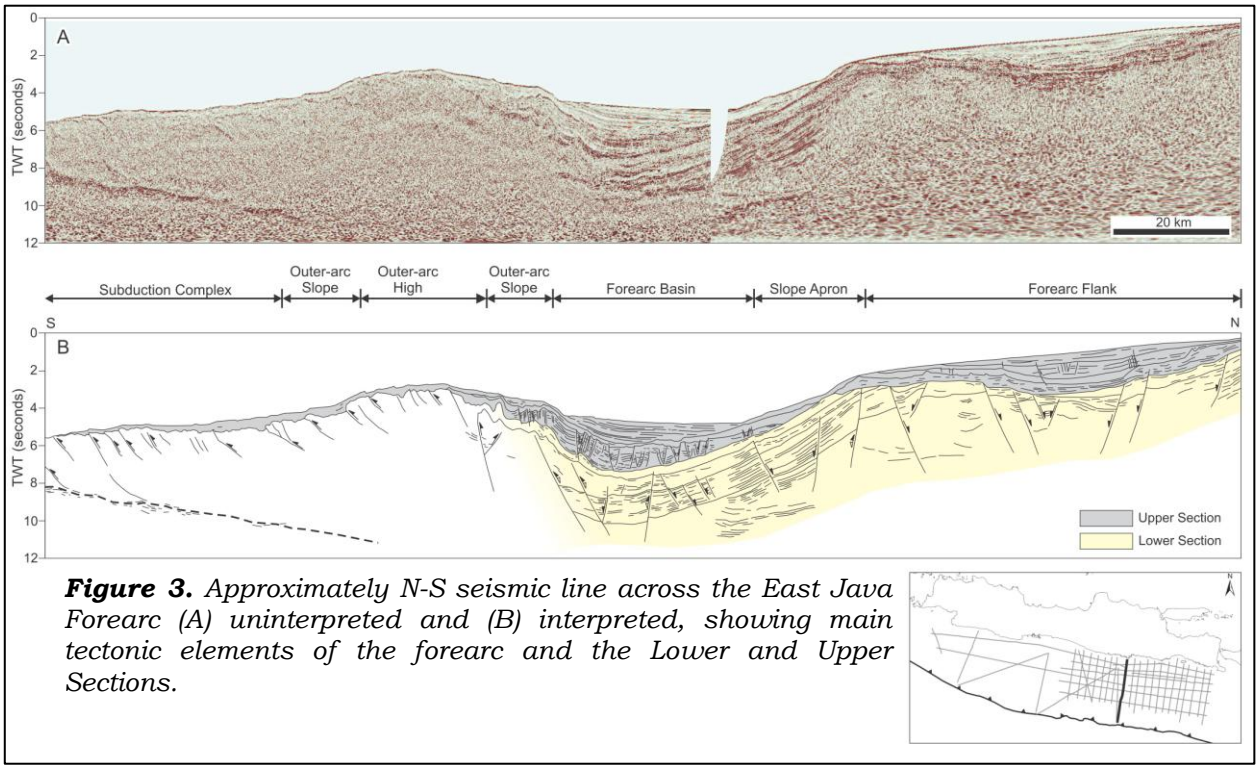


Figure 3. *Approximately N-S seismic line across the East Java Forearc (A) uninterpreted and (B) interpreted, showing main tectonic elements of the forearc and the Lower and Upper Sections.*

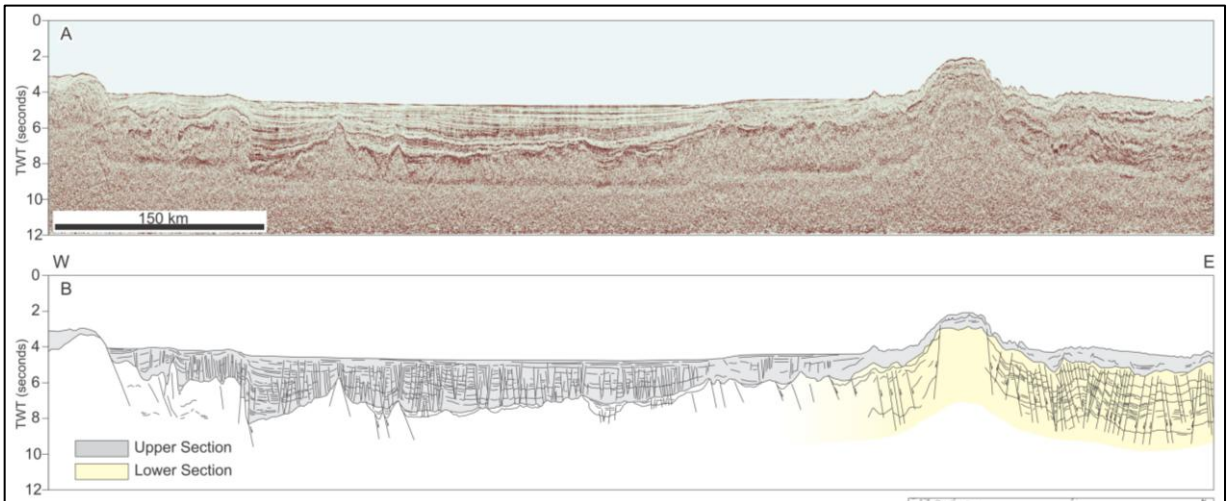
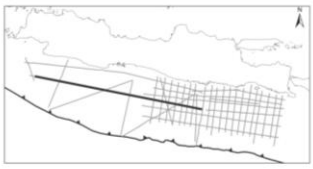


Figure 4. *Approximately E-W seismic line along the Java Forearc (A) uninterpreted and (B) interpreted, showing the contrast in structure and stratigraphy of the forearc south of West and Central Java compared to that south of East Java. The Lower Section is thick south of East Java and dies out close to a cross-arc high at the position of the Progo-Muria lineament of Smyth et al. (2005).*



REGIONAL STRATIGRAPHY

Subduction and significant arc volcanism ceased beneath Java from about 90 Ma to 45 Ma (Hall et al., 2009, Hall, 2009, 2011). Subduction resumed when Australia began to move northwards in the Middle Eocene (Hall, 2009). The oldest Cenozoic sediments reported onshore East Java are Middle Eocene (Lelono, 2000, Smyth et al., 2008) and were deposited unconformably on basement rocks. The Early Cenozoic sandstones above the oldest sediments increase in volcanic material up-section recording initiation of the Southern Mountain Arc (Smyth, 2005). There is an intra-Oligocene unconformity across East Java and the East Java Sea that was mainly caused by sea level change (Matthews & Bransden, 1995; Smyth, 2005).

Explosive volcanic activity was extensive throughout the Late Oligocene to Early Miocene as indicated by thick sequences of volcanic and epiclastic rocks (Smyth, 2005; Smyth et al., 2008). The oldest dated sediments exposed in the Southern Mountains Arc are Oligocene reworked bioclastic tuffaceous mudstones (Smyth et al., 2008). Upper Oligocene volcaniclastic rocks have been reported in the Shell Alveolina-1 well, offshore Central Java. In the Borelis-1 well, the oldest dated rocks are Early Miocene. These two wells terminated in undated basalt (Bolliger & de Ruiter, 1975) confirming the presence of Southern Mountain Arc volcanism in offshore South Java.

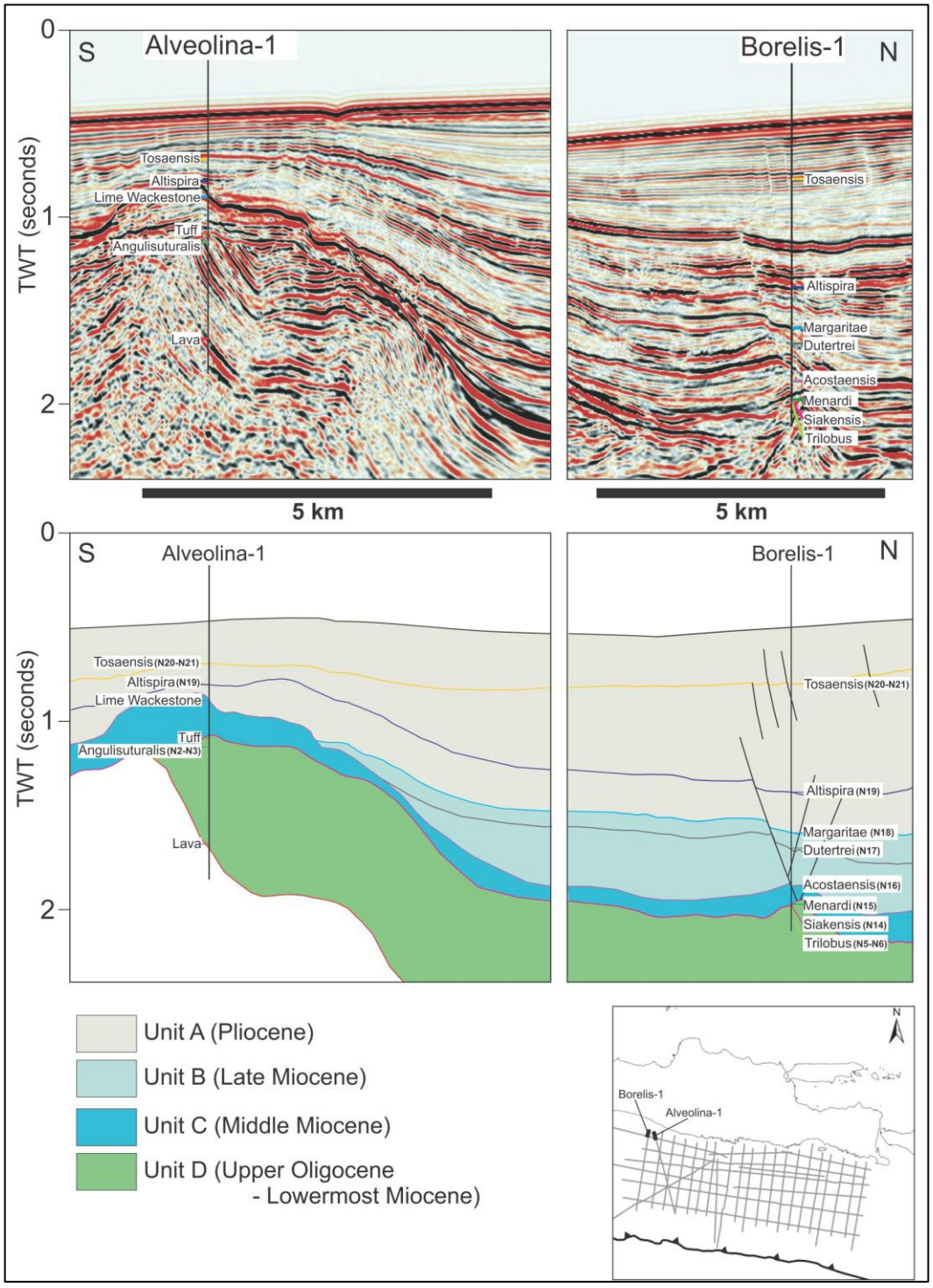


Figure 5. *Parts of seismic lines that intersect wells Alveolina-1 and Borelis-1 showing seismic units identified in this study and ages of horizons from Bolliger & de Ruiter (1975).*

The Early Cenozoic arc volcanism was terminated by the short-lived Early Miocene Semilir super-eruption event (Smyth 2005, Smyth et al., 2008, 2011). The whole southeast region of Sundaland was uplifted during this period (Sribudiyani et al., 2005). To the north, a sequence boundary is placed at the top of the Prupuh Limestone because basin inversion is interpreted to have been initiated on a regional scale near to the end of its deposition in the Middle Miocene (Matthews & Bransden, 1995).

During the Middle Miocene to Late Miocene, volcanic activity was much reduced. Older volcanic material was reworked and carbonate platforms were developed extensively during this period (Bolliger & de Ruiter, 1975; Smyth, 2005). The carbonates range in age from late Early Miocene to Middle Miocene (Lokier, 2000; Smyth, 2005). Several tuff beds are observed in turbidite sequences in the Southern Mountains and range in age from 12 to 10 Ma (Smyth, 2005). This represents the resumption of volcanic activity at the position of the present Sunda Arc (Smyth et al., 2005). Lunt et al. (2009) suggested that an unconformity recorded a Late Miocene tectonic event which created a new series of basins that were filled by erosion of structural highs in Central Java. There are no Pliocene or Quaternary deposits in the Southern Mountains zone due to uplift and erosion.

The Shell exploration wells record a major tectonic event in the Late Pliocene which caused uplift of Java and the deposition of widespread Pliocene and Quaternary sediments in the offshore area (Bolliger & de Ruiter, 1975).

STRATIGRAPHIC UNITS

We identify six seismic stratigraphy units, labelled A to F, on the basis of their age, seismic character and deformation style in combination with onshore published studies (Figure 6). We describe these units from the shallowest to deepest, i.e. from F to A. The ages of Units D to A are reasonably constrained by the exploration wells drilled south of Central Java. The ages of Units E and F are unknown. We consider two possible interpretations for the lower section. Unit E shows a half graben character in places suggesting that rifting and extension may be plausibly correlated with Southern Mountains volcanics and volcaniclastic deposits on land in East Java (Smyth et al., 2005, 2008). Unit F could represent a deeper part of this arc sequence. To the north of the Southern Mountains lies the thick sequence of the Kendeng Basin. Thus one possibility is that the thick sequence of Units E and F is equivalent to the Middle Eocene to Oligocene deposits of the Kendeng Basin. An alternative is that Unit F is a pre-Eocene sequence that was rifted when arc activity resumed in the Middle Eocene.

Pre-Neogene: Unit F

Unit F is the deepest seismic unit recognizable and it is observed only in the deepest part of the forearc basin (Figure 7). It shows a relatively uniform ~3 s TWT thickness. The lower part shows moderate to weak reflectors, while the middle part is characterized by bright and parallel reflectors with discontinuous lower amplitude reflectors. The upper part is characterized by chaotic, discontinuous weak amplitude reflectors which are brighter and relatively parallel near the forearc basin edges. This unit is cut by a series of planar extensional faults with small displacements forming graben and half graben structures. The faults are more intense in E-W sections along the forearc basin than in N-S sections. A few faults have been reactivated close to the subduction complex and structural highs to the north. There are also a few internal thrust faults within this unit which record later deformation. In places this unit seems to be truncated by younger units.

Unit F is best imaged beneath the forearc basin where the Neogene cover is thin and the structure is relatively simple, and cannot be mapped at depths below about 6 sec TWT beneath the forearc flank closer to the Southern Mountains. Although it not seen Unit F could thicken towards the arc, where its internal character would be expected to become more complex and seismically opaque closer, since it would be dominated by volcanic rocks rather than the volcaniclastics and carbonates deposited farther from the active arc. This unit would then form a load-induced depocentre south of the arc comparable to the Kendeng Basin succession and would thicken towards the arc, although the distribution and thickness of the sequence would influenced by several other factors such as the character of the underlying crust, the width of the forearc and the dip of the subducting slab. The Kendeng Basin formed during the Middle Eocene through to Early Miocene (de Genevraye & Samuel, 1972; Untung & Sato, 1978; Smyth et al., 2005, 2008) and consists of terrestrial and shallow marine rocks in a thick succession that thickens toward the Southern Mountains volcanic arc.

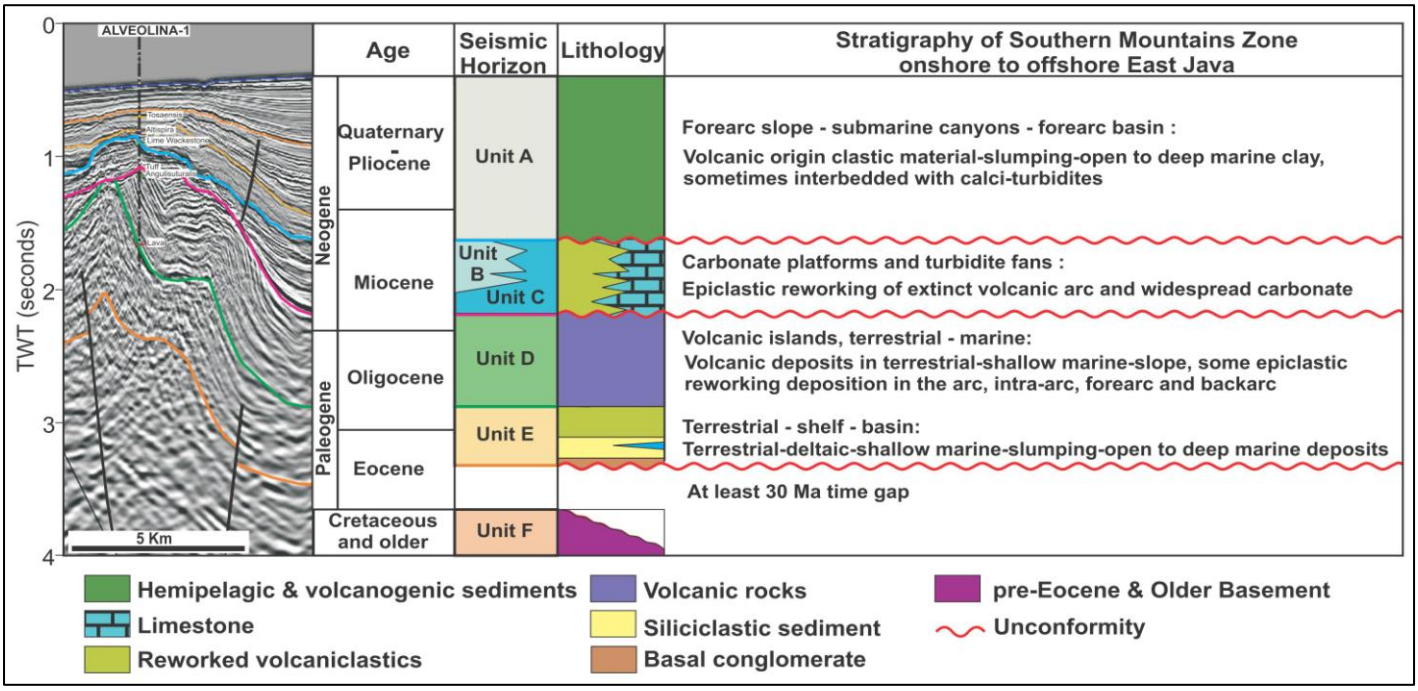


Figure 6. *Proposed relations between seismic units of offshore East Java (Alveolina area) and the stratigraphy of the Southern Mountains Zone on land in East Java (from Smyth et al. 2005, 2008).*

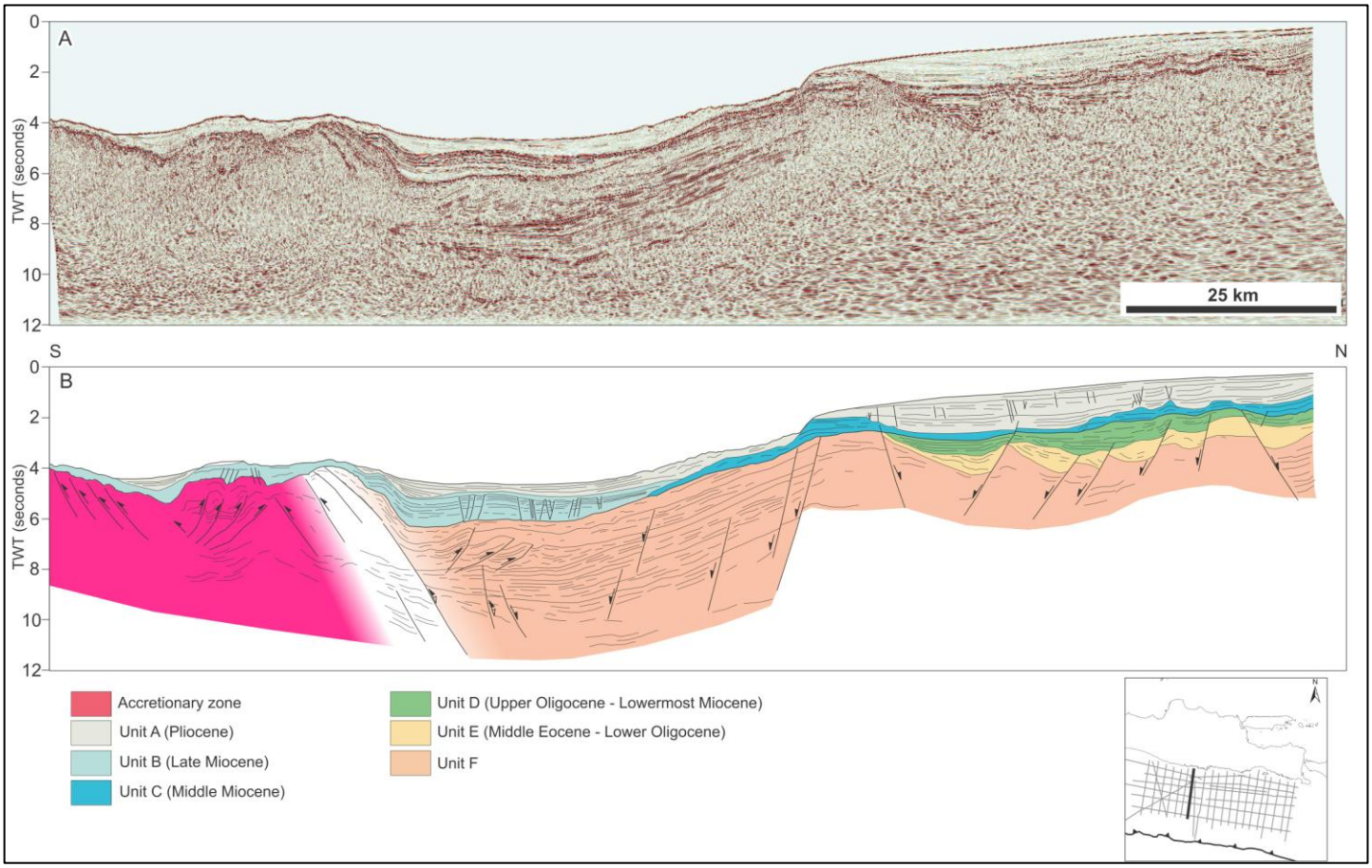


Figure 7. *Approximately N-S seismic line across the East Java Forearc (A) uninterpreted and (B) interpreted showing seismic units and principal structural features. The deeper reflectors of Unit F are mappable mainly below the forearc basin. Note the continuity and broadly constant thickness of seismic reflectors in Unit F which is cut mainly by extensional faults, except close to the accretionary zone where there are some thrust faults.*

Untung & Sato (1978) suggested that the deeper parts of the basin contain ~6 km of section. Waltham et al. (2008) used gravity data to suggest an approximate thickness of up to 10 km and proposed that the Kendeng Basin formed by volcanic arc loading of a broken plate, with a contribution from crustal extension and/or deep crustal loading. In this interpretation the half graben of Unit E would represent extension at a relatively late stage in the development of the Southern Mountains arc.

An alternative is that Unit F is older than Middle Eocene. Deighton et al. (2011) suggested that this unit could be Mesozoic based on its position and similarity of seismic character with Mesozoic and/or Palaeozoic sections from the Australian NW Shelf. If the rifting that affects Unit E is Middle Eocene then Unit F is older. Smyth et al. (2005, 2007, 2008) suggested that parts of East Java may be underlain by a Gondwana fragment derived from western Australia, while a thick cover sequence of (possibly?) pre-Cenozoic age, identified offshore East Java (Emmett et al., 2009; Granath et al., 2010), is suggested to have a West Australian origin. In the part of the forearc where Unit F is well imaged it has a relatively constant thickness with sub-parallel reflectors and can be traced for several hundred kilometres along the length of the forearc. Internal deformation is largely restricted to extensional faulting that pre-dates deposition of the forearc basin sequence of Miocene and younger age. These features are consistent with a terrestrial to open marine sedimentary sequence deposited on continental crust when the East Java–West Sulawesi fragment formed part of the Australian margin (Hall et al., 2009).

This suggestion is supported by the existence of deep NW-SE lineaments discussed above. Hall (2011) suggested that some NW-SE deep structural lineaments, traced across Borneo and into Sulawesi (e.g. Satyana et al. 1999; Fraser et al. 2003; Gartrell et al. 2005; Puspita et al. 2005; Simons et al. 2007) represent basement structures inherited from Australian blocks. Deep and old structures can be traced offshore across the NW Shelf and Western Australia (e.g. Cadman et al. 1993; Goncharov 2004). We suggest that the deep NW-SE structural lineaments in the East Java Forearc have a Gondwana origin and, based on the limited evidence available, we prefer to interpret Unit F as a Mesozoic or older section above Australian continental basement.

Pre-Neogene: Units E and D

Unit E is mainly observed in the arc-flank and is characterized by parallel discontinuous reflectors (Figure 8). Wedge geometry is observed with thickening towards faults and is interpreted to indicate sedimentary layers deposited in a syn-rift event. A series of planar extensional faulted graben and half graben are observed within this unit along faults with larger displacements than in Unit F. Several of these faults have been reactivated at the structural highs. Unit E is interpreted to have been deposited unconformably above Unit F. In places close to the slope break in the forearc flank, Unit F seems to be truncated by Unit E.

Unit E is tentatively interpreted as alluvial to delta plain deposits, with higher and lower amplitudes indicating intervals of sand and shale. It is suggested that this sequence was deposited during rifting in the Middle Eocene. Contemporaneous clastic sediments in the East Java Sea Basin (Matthews & Bransden, 1995) and Java were deposited above a regional angular unconformity in a terrestrial to marine environment. In the Southern Mountains the Middle Eocene Nanggulan Formation includes coals, conglomerates, silts and quartz-rich sands (Lelono, 2000; Smyth, 2005; Smyth et al., 2005, 2008).

Unit D was deposited conformably above Unit E .In contrast with the unit below, Unit D shows generally continuous and well bedded strong reflectors with wedge geometry, but does not clearly thicken towards faults. The seismic reflectors become brighter and more continuous basinward which suggests a facies change. Unit C was probably deposited at the end of the syn-rift stage. This unit appears to be thinner and truncated by the base of Unit C near to structural highs, and is interpreted to be associated with inversion and erosion. Unit D contains *Globigerina angulisuturalis* and *Globigerinoides trilobus* fossils from wells and has been dated as Late Oligocene (N2-N3) and Middle Early Miocene (N5-N6) above basalts, volcanic agglomerates, tuffs and clays (Bolliger & de Ruiter, 1975). Contemporaneous volcanic deposits crop out in the Southern Mountains Zone and Kendeng Zone (Smyth 2005; Smyth et al., 2005, 2008).

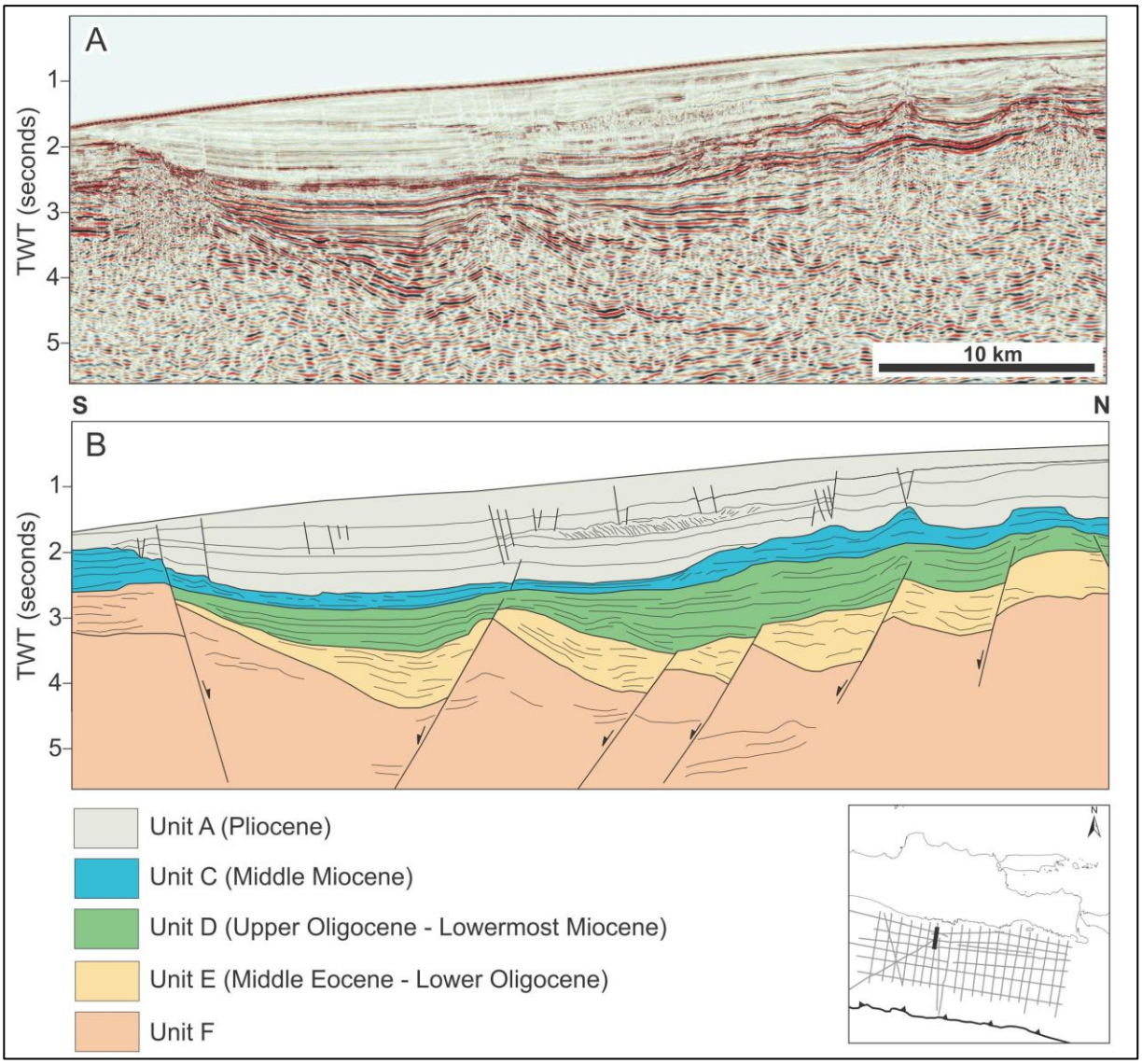


Figure 8. *Approximately N-S seismic line across the forearc flank (A) uninterpreted and (B) interpreted. Units D and E are clearly observed below the Unit C carbonate platform and build-ups.*

Middle Miocene Unit C

Unit C shows strong, parallel and fairly continuous reflectors which become variable in amplitude away from carbonate buildups. The bright reflectors are interpreted as limestone and the varying amplitude is interpreted as an alternation of shelf carbonates and mudstone. The carbonate buildups tend to be developed on top of structural or topographic highs (Figure 9). Pinnacle reefs are observed at the later stage of several carbonate buildup developments. The unconformity between Units D and C is interpreted to be of Early to Middle Miocene age. Based on well data and seismic character Unit C is interpreted to comprise Middle Miocene carbonates equivalent to the onshore Middle Miocene to Lower Pliocene Wonosari Formation (Lokier, 1999). The Borelis-1 well penetrated the lower part of this unit, dated as Late Middle Miocene based on *Globorotalia siakensis*, and the Alveolina-1 well records carbonate wackestone above (Bolliger & de Ruiter, 1975). Unit C is characterized by widespread carbonate development above the unconformity, particularly on structurally high areas associated with localized contractional truncation by the unconformity. Progradational cycles are observed within the lower part of the carbonates above the unconformity showing that they were initially deposited in lowstands during a period of quiet tectonism and much reduced volcanism (Figure 10a), and are followed by cycles from progradational to retrogradational and/or aggradational upward (Figure 9). The carbonate platform is widespread in the western part of the study area and decreases to the east.

Upper Miocene Unit B

Unit B is characterized by bright, continuous, alternating reflectors, which are weaker in the middle part (Figure 11). The upper part of Unit B is observed to onlap onto the lower part of the carbonate buildup Unit C (Figure 7). Unit B shows a relatively constant 0.6-0.8 s TWT thickness suggesting deposition on the margin slope or outer platform.

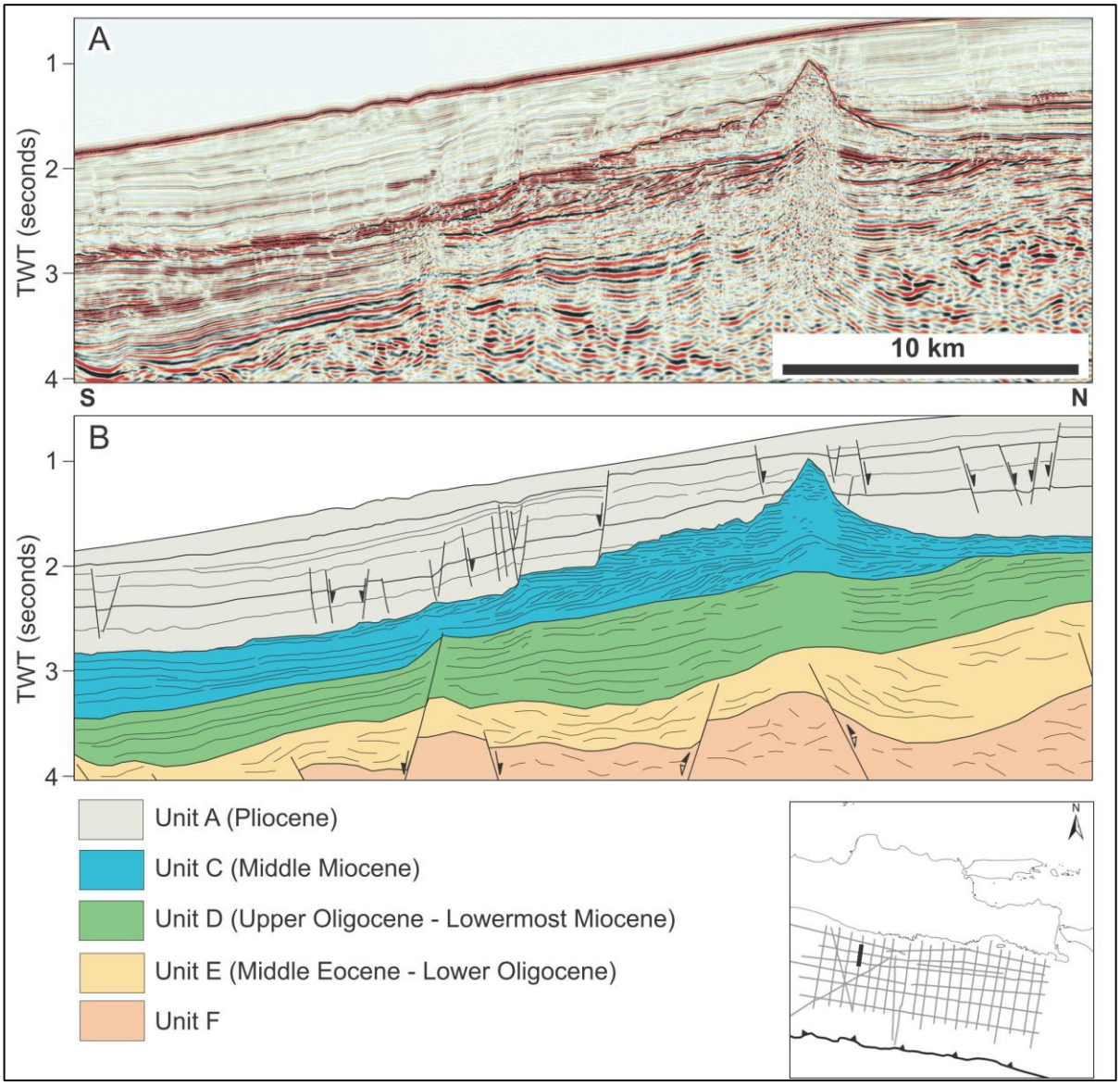


Figure 9. *Seismic section crossing carbonate build-up of Unit C in the forearc flank (A) uninterpreted and (B) interpreted. The internal structure of Unit C shows cycles of progradation, retrogradation and aggradation.*

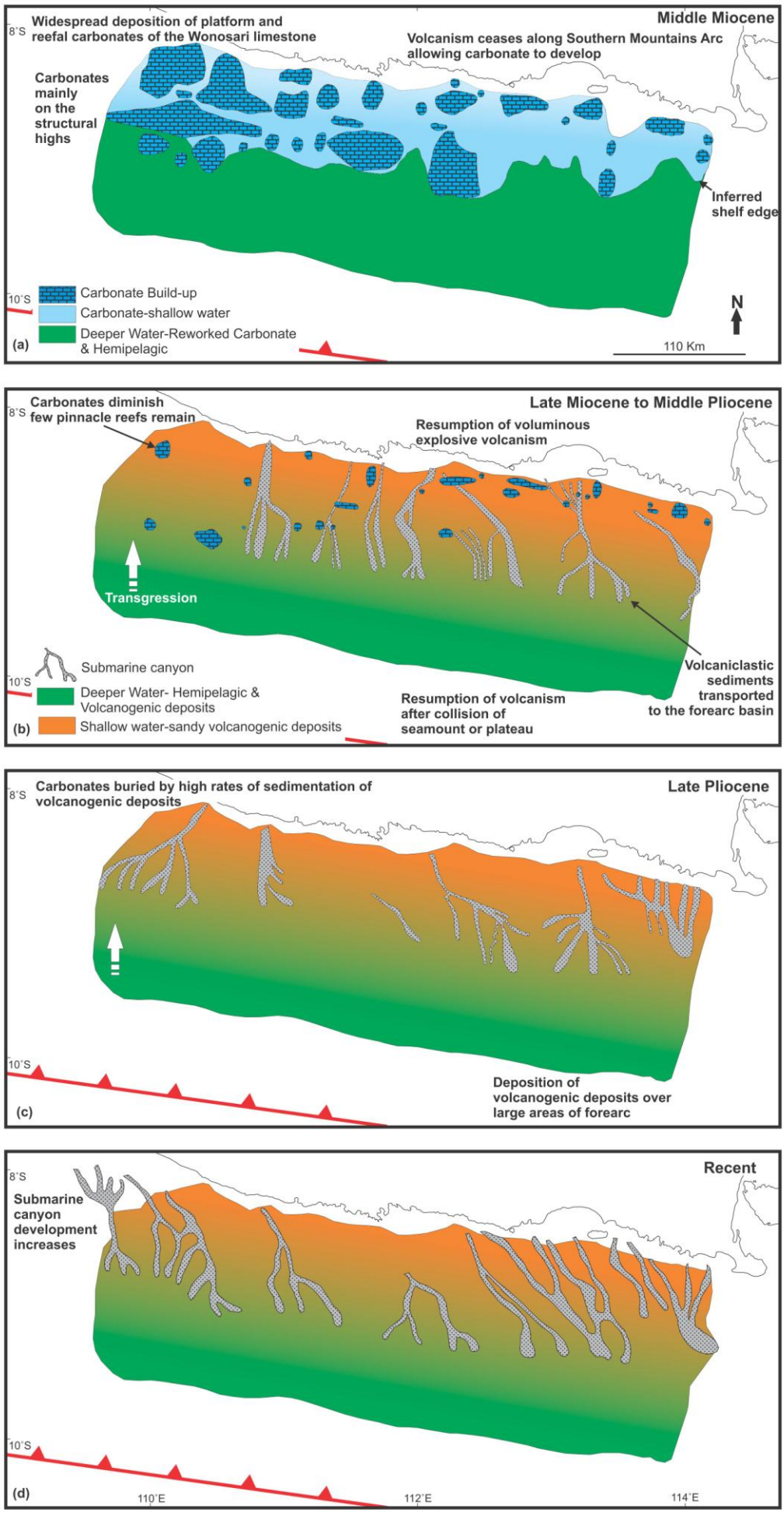


Figure 10.
Palaeogeographic maps for the East Java forearc based on this study for (a) Middle Miocene, (b) Late Miocene to Middle Pliocene, (c) Late Pliocene, and (d) Recent. The entire forearc has subsided significantly since the Late Miocene.

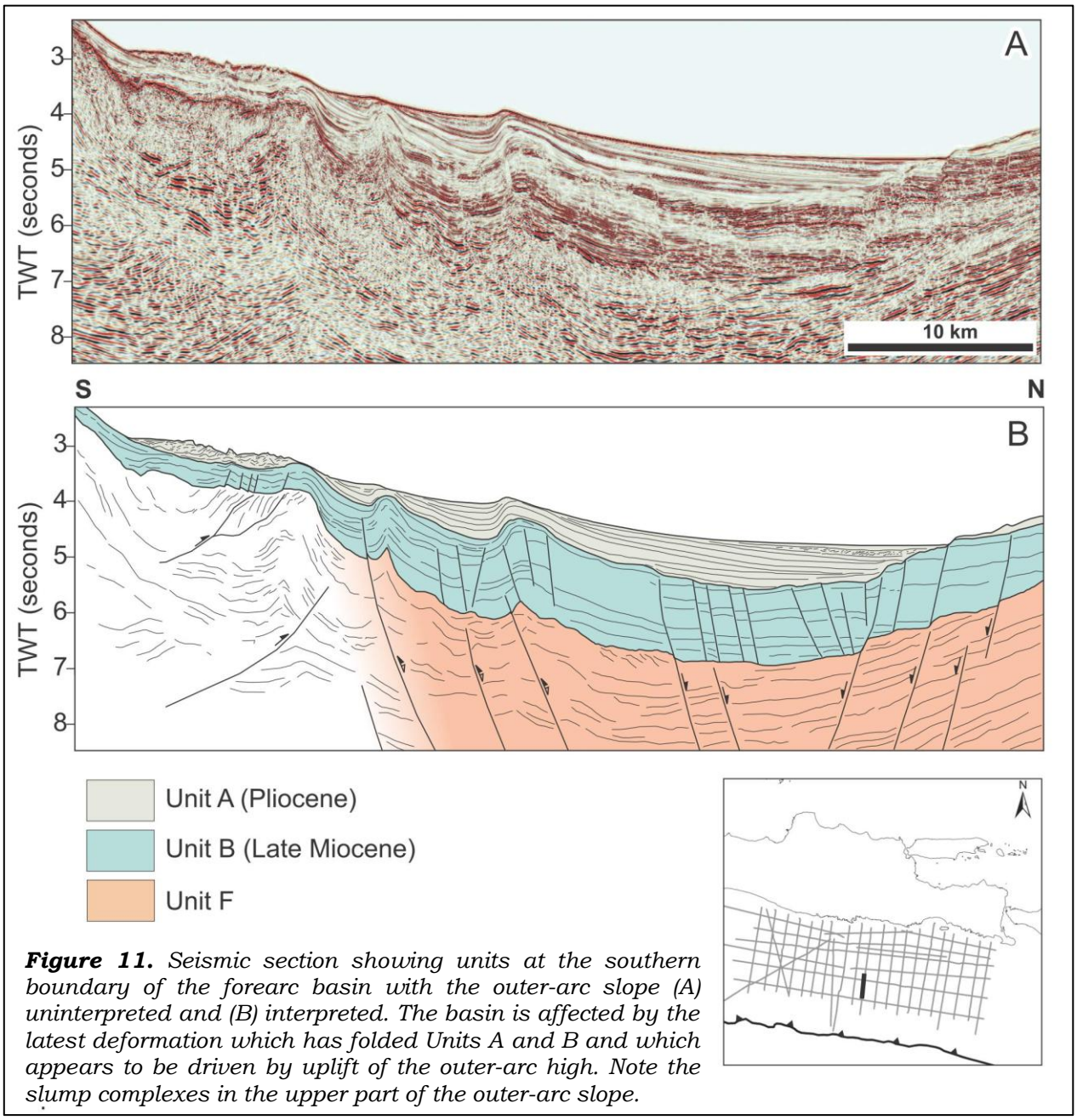


Figure 11. *Seismic section showing units at the southern boundary of the forearc basin with the outer-arc slope (A) uninterpreted and (B) interpreted. The basin is affected by the latest deformation which has folded Units A and B and which appears to be driven by uplift of the outer-arc high. Note the slump complexes in the upper part of the outer-arc slope.*

The lower part is interpreted as carbonate mudrock, while the upper part could be mudrock or tuff. To the east, close to Lombok Basin, Unit B thins towards the forearc basin depocentre (Figure 12) where it is interpreted to have been deposited above a paleo-high, suggested by a high positive gravity anomaly across the eastern part of the East Java forearc (Seubert & Sulistianingsih, 2008). This unit has been uplifted and eroded in the outer arc ridge and forearc flank (Fig 11). A slump or mass transport complex is observed and is interpreted to be the result of reactivation of an older structure.

Unit B was deposited conformably above Unit C in a transgressive setting. Deepening at this time is associated with a diminished area of carbonate deposition characterised by isolated pinnacle reefs (Figure 10b). The Borelis-1 well penetrated clay at the top of this unit dated as Late Miocene (N18) based on the presence of *Globorotalia margaritae* (Bolliger & de Ruiter, 1975). Deformation characterized by uplift that folded and eroded the upper part of the sequence occurred during deposition of Unit B. This abrupt deformation is interpreted to be related to the arrival of a seamount or buoyant plateau (similar to but not the Roo Rise) at about 8 Ma. Lunt et al. (2009) noted several basins filled with reworked material caused by this deformation in Central Java.

Pliocene Unit A

Unit A shows moderate to weakly continuous reflectors interrupted by bright continuous reflectors in places (Figure 11). It is interpreted to consist of rapidly deposited pelagic/hemipelagic and volcanogenic deposits (Figure 10c). Unit A was deposited unconformably above Unit B across the whole East Java Forearc. This unit contains *Globoquadrina altispira* and *Globorotalia tosaensis* dated as Early Pliocene (N19) and Middle-Late Pliocene (N20-N21) in the wells.

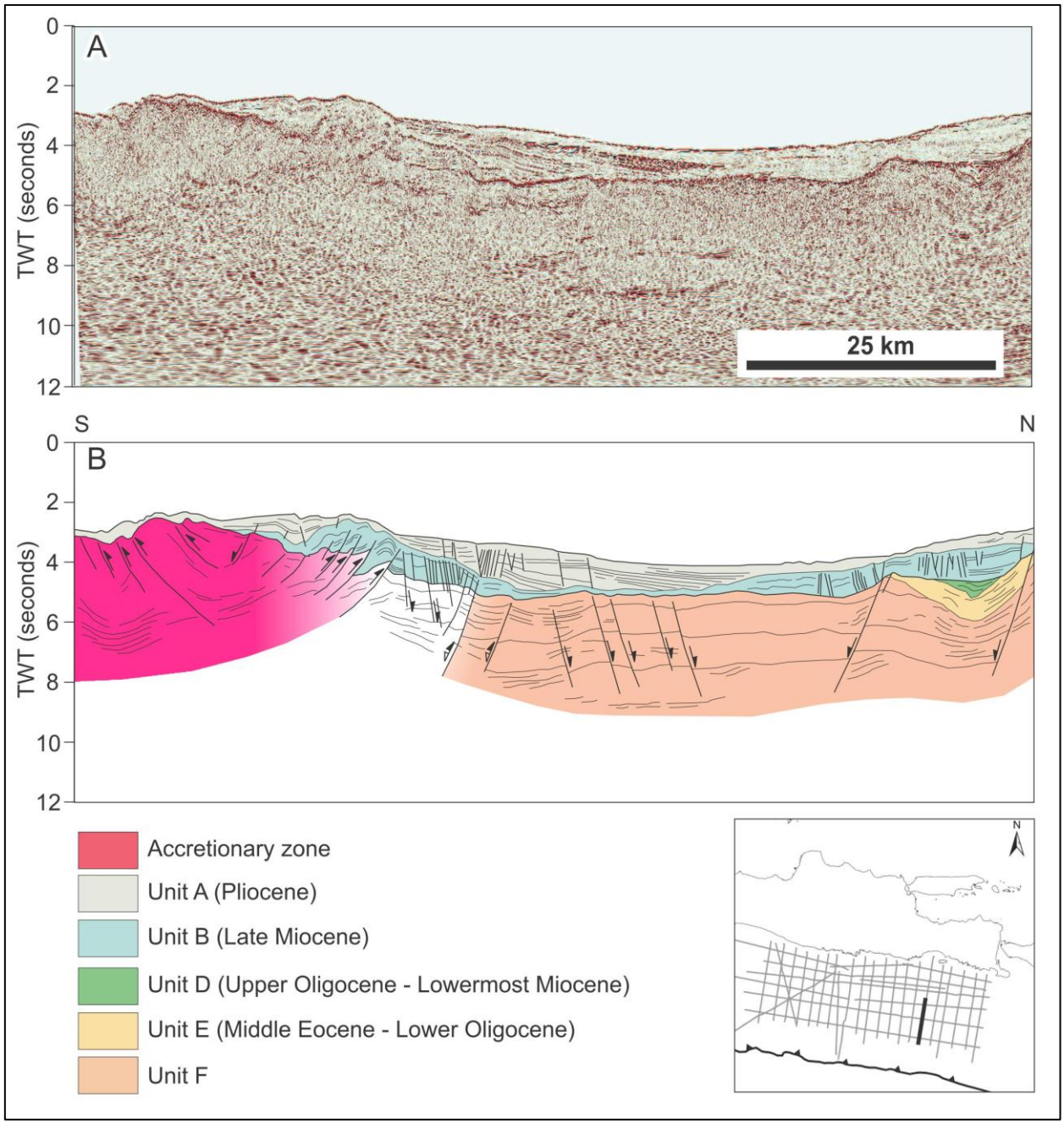


Figure 12. *Seismic section showing units at the southern boundary of the forearc basin with the outer-arc slope east of Figure 9 (A) uninterpreted and (B) interpreted. The forearc basin in this area here is largely filled with Pliocene sediments of Unit A. Note that Unit B is thinner towards the forearc basin depocentre.*

Unit A is interpreted to comprise Pliocene volcaniclastics and deep marine clays, sometimes interbedded with calci-turbidites (Bolliger & de Ruiter, 1975). In the forearc basin, Unit A is characterized by a wedge shape, tilted landwards, with a number of local unconformities that record the episodic uplift of the outer arc ridges (Figure 11). These sequences onlap and downlap onto Unit B. Mass transport-slump complexes observed in this unit reflect submarine slope failure associated with uplift of the outer-arc high above the subduction zone. Further north canyons incise Unit A; some are infilled whereas others are active at the present-day (Fig 13). The high rates and widespread sedimentation could be related to resumption of volcanic activity in the modern Java Arc.

CONCLUSIONS

New seismic data allow the East Java forearc to be divided into six major seismic units bounded by three major unconformities. We suggest that the deepest, Unit F, may represent a pre-Cenozoic sequence deposited on continental crust, derived from Western Australia. A major regional unconformity separates this from a Middle Eocene to Lower Miocene sequence (Units E and D) equivalent to the Southern Mountains volcanic arc and Kendeng Basin deposits of East Java. Extensive shallow water carbonates (Unit C) were deposited above a Lower–Middle Miocene unconformity during a tectonically quiet period with much reduced volcanism in the northern part of the present forearc. Major changes in the forearc began in the Late Miocene.

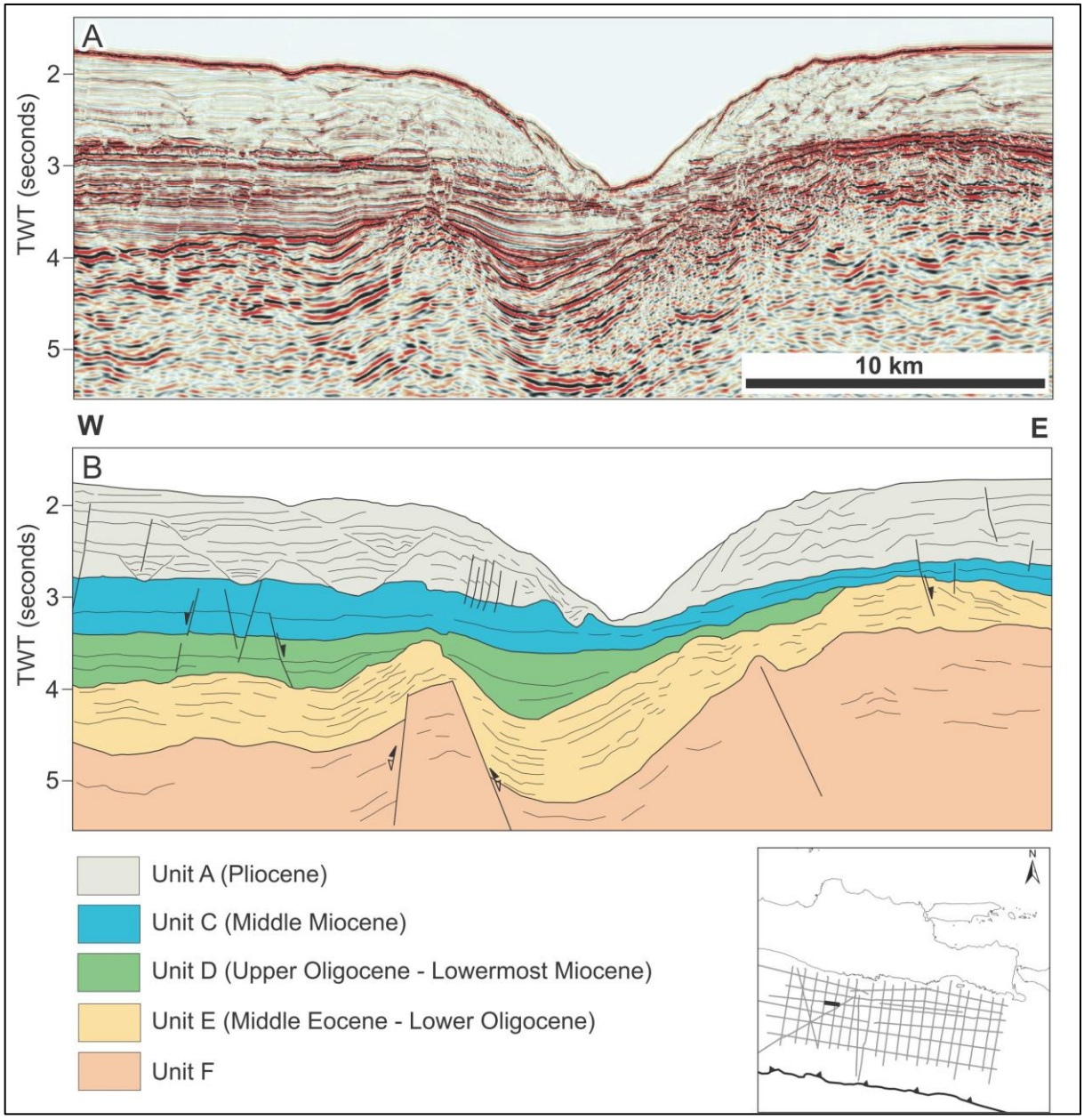


Figure 13. *Cross section across one of the present-day submarine canyons in the outer part of the forearc flank (A) uninterpreted and (B) interpreted. The stepped profile of the canyon margin suggests that repeated cut and fill has taken place. There are several inactive canyons which has been filled and buried by later sediment.*

There was significant subsidence (Unit B) with drowning of the former carbonate platforms. We interpret deformation at the southern side of the forearc to be caused by arrival of a buoyant plateau at the subduction margin producing a regional unconformity that can be mapped across the whole East Java forearc. Afterwards, older rocks were buried by Late Pliocene volcanogenic deposits (Unit A) with high rates of sedimentation.

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REFERENCES

Audley-Charles, M.G., 1983, Reconstruction of eastern Gondwanaland: Nature, v. 306, p. 48-50.

Bolliger, W., and de Ruiter, P.A.C., 1975, Geology of the South Central Java Offshore Area: Indonesian Petroleum Association, Proceedings 4th annual convention, Jakarta, 1975, v. I, p. 67-82.

Cadman, S.J., Pain, L., Vuckovic, V., and le Poidevin, S.R., 1993 Canning Basin, W.A. , Bureau of Resource Sciences, Australian Petroleum Accumulations Report Volume 9.

de Genevraye, P., and Samuel, L., 1972, The geology of Kendeng Zone (East Java): Indonesian Petroleum Association, Proceedings 1st annual convention, Jakarta, 1972, p. 17-30.

Deighton, I., Hancock, T., Hudson, G., Tamannai, M., Conn, P., and Oh, K., 2011, Infill seismic in

the southeast Java Forearc Basin: Implications for Petroleum Prospectivity: Proceedings Indonesian Petroleum Association, 35th Annual Convention, p. IPA11-G-068.

Emmet, P.A., Granath, J.W., and Dinkelman, M.G., 2009, Pre-Tertiary sedimentary "keels" provide insights into tectonic assembly of basement terranes and present-day petroleum systems of the East Java Sea: Proceedings Indonesian Petroleum Association 33rd Annual Convention, p. IPA09-G-046 1-11.

Fraser, T.H., Jackson, B.A., Barber, P.M., Baillie, P., and Myers, K., 2003, The West Sulawesi Fold Belt and other new plays within the North Makassar Straits - a Prospectivity Review, Indonesian Petroleum Association, Proceedings 29th Annual Convention, Volume 1: Jakarta, p. 431-450.

Gartrell, A., Hudson, C., and Evans, B., 2005, The influence on basement faults during extension and oblique inversion of the Makassar Straits rift system: Insights from analog models: AAPG Bulletin, v. 89, p. 495-506.

Goncharov, A., 2004, Basement and crustal structure of the Bonaparte and Browse basins, Australian northwest margin, in Ellis, G.K., Baillie, P., and Munson, T.J., eds., Proceedings of the Timor Sea Symposium, Volume Special Publication 1: Darwin Northern Territory, Australia, Northern Territory Geological Survey.

Granath, J.W., Christ, J.M., Emmet, P.A., and Dinkelman, M.G., 2011, Pre-Cenozoic sedimentary section and structure as reflected in the JavaSPAN crustal-scale PSDM seismic survey, and its implications regarding the basement terranes in the East Java Sea in Hall, R., Cottam, M.A., and Wilson, M.E.J., eds., The SE Asian Gateway: History and Tectonics of the Australia-Asia collision, Volume 355: Geological Society of London Special Publication, p. 53-74.

Hall, R., 2002, Cenozoic geological and plate tectonic evolution of SE Asia and the SW Pacific: computer-based reconstructions, model and animations: Journal of Asian Earth Sciences, v. 20, p. 353-434.

Hall, R., 2009, The Eurasian SE Asian margin as a modern example of an accretionary orogen, in Cawood, P.A., and Kröner, A., eds., Accretionary Orogens in Space and Time, Volume 318: Geological Society of London Special Publication, p. 351-372.

Hall, R., 2011, Australia-SE Asia collision: plate tectonics and crustal flow, in Hall, R., Cottam, M.A., and Wilson, M.E.J., eds., The SE Asian Gateway: History and Tectonics of the Australia-Asia collision, Volume 355: Geological Society of London Special Publication, p. 75-109.

Hall, R., Clements, B., and Smyth, H.R., 2009, Sundaland: Basement character, structure and plate tectonic development: Proceedings Indonesian Petroleum Association, 33rd Annual Convention.

Hamilton, W., 1979, Tectonics of the Indonesian region, Volume 1078, U.S. Geological Survey Professional Paper, p. 345.

Hamilton, W., 1988, Plate tectonics and island arcs: Geological Society of America Bulletin, v. 100, p. 1503-1527.

Kopp, H., 2011, The Java convergent margin: structure, seismogenesis and subduction processes, in Hall, R., Cottam, M.A., and Wilson, M.E.J., eds., The SE Asian Gateway: History and Tectonics of the Australia-Asia collision, Volume 355: Geological Society of London Special Publication, p. 111-137.

Kopp, H., Flueh, E.R., Petersen, C.J., Weinrebe, W., Wittwer, A., and Scientists, M., 2006, The Java margin revisited: Evidence for subduction erosion off Java: Earth and Planetary Science Letters, v. 242, p. 130-142.

Lelono, E.B., 2000, Palynological study of the Eocene Nanggulan Formation, Central Java, Indonesia [Ph.D. thesis], University of London.

Lokier, S.W., 2000, The development of the Miocene Wonosari Formation, south Central Java: Indonesian Petroleum Association, Proceedings 27th Annual Convention, Jakarta, 2000, v. 1, p. 217-222.

Lunt, P., Burgon, G., and Baky, A., 2009, The Pemali Formation of Central Java and equivalents: Indicators of sedimentation on an active plate margin: Journal of Asian Earth Sciences, v. 34 p. 100-113.

Macpherson, C.G., and Hall, R., 1999, Tectonic controls of Geochemical Evolution in Arc Magmatism of SE Asia, Proceedings 4th PACRIM Congress 1999: Bali, Indonesia, Australian Institute of Mining and Metallurgy, p. 359-368.

Macpherson, C.G., and Hall, R., 2002, Timing and tectonic controls on magmatism and ore generation in an evolving orogen: evidence from Southeast Asia and the western Pacific, in Blundell, D.J., Neubauer, F., and von Quadt, A., eds., The timing and location of major ore deposits in an evolving orogen, Volume 204: Geological Society of London Special Publication, Geological Society of London Special Publication, p. 49-67.

Manur, H., and Barraclough, R., 1994, Structural control on hydrocarbon habitat in the Bawean area, East Java Sea: Indonesian Petroleum Association, Proceedings 23rd annual convention, Jakarta, 1994, v. 1, p. 129-144.

Masson, D.G., Parson, L.M., Milsom, J., Nichols, G.J., Sikumbang, N., Dwiwanto, B., and Kallagher, H., 1990, Subduction of seamounts at the Java Trench; a view with long range side-scan sonar: Tectonophysics, v. 185, p. 51-65.

Matthews, S.J., and Bransden, P.J.E., 1995, Late Cretaceous and Cenozoic tectono-stratigraphic development of the East Java Sea Basin, Indonesia: Marine and Petroleum Geology, v. 12, p. 499-510.

Nugraha, A.M.S., 2011, Tectono-stratigraphic Evolution of the East Java Forearc, Indonesia:

MSc Thesis. London, Royal Holloway University of London.

Nugraha, A.M.S., and Hall, R., 2012, Cenozoic History of the East Java Forearc: Indonesian Petroleum Association, Proceedings 36th Annual Convention.

Puspita, S.D., Hall, R., and Elders, C.F., 2005, Structural styles of the Offshore West Sulawesi Fold Belt, North Makassar Straits, Indonesia: Indonesian Petroleum Association, Proceedings 30th Annual Convention, p. 519-542.

Satyana, A.H., Nugroho, D., and Surantoko, I., 1999, Tectonic controls on the hydrocarbon habitats of the Barito, Kutei, and Tarakan Basins, eastern Kalimantan, Indonesia: major dissimilarities in adjoining basins: Journal of Asian Earth Sciences, v. 17, p. 99-122.

Seubert, B.W., and Sulistianingsih, F., 2008, A proposed new model for the tectonic evolution of South Java, Indonesia, Proceedings Indonesian Petroleum Association 32nd Annual Convention.

Shulgin, A., Kopp, H., Mueller, C., Lueschen, E., Planert, L., Engels, M., Flueh, E.R., Krabbenhoeft, A., and Djajadihardja, Y., 2009, Sunda-Banda arc transition: Incipient continent-island arc collision (northwest Australia): Geophysical Research Letters, v. 36, p. L10304, doi:10.1029/2009GL037533.

Shulgin, A., Kopp, H., Mueller, C., Planert, L., Lueschen, E., Flueh, E.R., and Djajadihardja, Y., 2011, Structural architecture of oceanic plateau subduction offshore Eastern Java and the potential implications for geohazards: Geophysical Journal International, v. 184, p. 12-28.

Simons, W.J.F., Socquet, A., Vigny, C., Ambrosius, B.A.C., Abu, S.H., Promthong, C., Subarya, C., Sarsito, D.A., Matheussen, S., and Morgan, P., 2007, A decade of GPS in Southeast Asia: Resolving Sundaland motion and boundaries: Journal of Geophysical Research, v. 112, p. B06420.

Smyth, H., Hall, R., Hamilton, J., and Kinny, P., 2005, East Java: Cenozoic basins, volcanoes and ancient basement: Indonesian Petroleum Association, Proceedings 30th Annual Convention, p. 251-266.

Smyth, H.R., 2005, Eocene to Miocene basin history and volcanic history in East Java, Indonesia [Ph.D. thesis], University of London.

Smyth, H.R., Hall, R., and Nichols, G.J., 2008, Cenozoic volcanic arc history of East Java, Indonesia: the stratigraphic record of eruptions on an active continental margin, in Draut, A.E., Clift, P.D., and Scholl, D.W., eds., Formation and Applications of the Sedimentary Record in Arc Collision Zones, Volume 436: Geological Society of America Special Paper, p. 199-222.

Smyth, H.R., Hamilton, P.J., Hall, R., and Kinny, P.D., 2007, The deep crust beneath island arcs: inherited zircons reveal a Gondwana continental fragment beneath East Java, Indonesia: Earth and Planetary Science Letters, v. 258, p. 269-282.

Sribudiyani, Muchsin, N., Ryacudu, R., Kunto, T., Astono, P., Prasetya, I., Sapiie, B., Asikin, S., Harsolumakso, A.H., and Yulianto, I., 2003, The collision of the East Java Microplate and its implication for hydrocarbon occurrences in the East Java Basin, Indonesian Petroleum Association, Proceedings 29th Annual Convention: Jakarta, p. 335-346.

Untung, M., and Sato, Y., 1978, Gravity and geological studies in Java, Indonesia: Geological Survey of Indonesia and Geological Survey of Japan, Special Publication, v. 6, p. 207pp.

van der Werff, W., 1996, Variation in the forearc basin development along the Sunda Arc, Indonesia: Journal of Southeast Asian Earth Sciences, v. 14, p. 331-349.

van der Werff, W., Prasetyo, H., Kusnida, D., and van Weering, T.C.E., 1994, Seismic stratigraphy and Cenozoic evolution of the Lombok forarc basin, Eastern Sunda Arc: Marine Geology, v. 117, p. 119-134.

Wagner, D., Koulakov, I., Rabbel, W., Luehr, B.G., Wittwer, A., Kopp, H., Bohm, M., and Asch, G., 2007, Joint inversion of active and passive seismic data in Central Java: Geophysical Journal International, v. 170, p. 923-932.

Wakita, K., 2000, Cretaceous accretionary-collision complexes in central Indonesia: Journal of Asian Earth Sciences, v. 18, p. 739-749.