Mud Volcano in Southeast Maluku: Evidence for Neotectonics in East Indonesia

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Abstract

Mud volcanoes are observed in S.E. Maluku, east Indonesia, in Babar, Tanimbar and in the Kai islands. They are active, show bubbles of flammable gases, mud flows and rock fragments, and except in the Kai Islands, are associated with melange complexes. They have also been reported to be present on Timor Island. The formation of active mud volcanoes in S.E. Maluku is closely related to the geology and tectonics of this region, and is due to subsurface overpressures forming liquefied shale that is extruded along thrust faults and fractured zones. The association of melange complexes and Quaternary fractured limestone terraces with mud volcanoes is closely related to the Quaternary and neotectonic activities in this region. Mud volcanism in this region is probably one of the main processes leading to the formation of chaotic deposits in the Quaternary in SE Maluku.

Introduction

The purpose of this paper is to report and document the existence of mud volcanoes in Babar, Tanimbar and the Kei Islands, SE Maluku and their tectonic significance in Eastern Indonesia during the Quaternary Period. Mud volcanoes are also reported to be present on Timor Island. With the exception of the Kei Island, these islands are situated in the outer arc of an accretion and collision zone, where mélange complexes are found.

The tectonic environments and formation mechanisms of mud volcanoes and shale diapirs have been described by several authors. They occur in accretionary complexes (Barber et al., 1986; Westbrook and Smith, 1983; Williams et al., 1984; and Tongkul, 1989) and in passive continental margins (Hedberg, 1980) and are often related to thrust faults (Barber et al., 1986; Ridd, 1970; Tongkul, 1989 and Williams et al. 1984).

Description of Mud Volcanoes

Babar Island

Mud volcanoes are observed in Babar Island, a small island located between Timor and Tanimbar. The geology of the western part of the Babar Island have been described by Fahrizal (1993), who recognized three lithological units. The oldest unit, which forms Melange Complex with several mud volcanoes, is overlain unconformably by Quaternary limestones and alluvial and beach deposits (Figure 1).

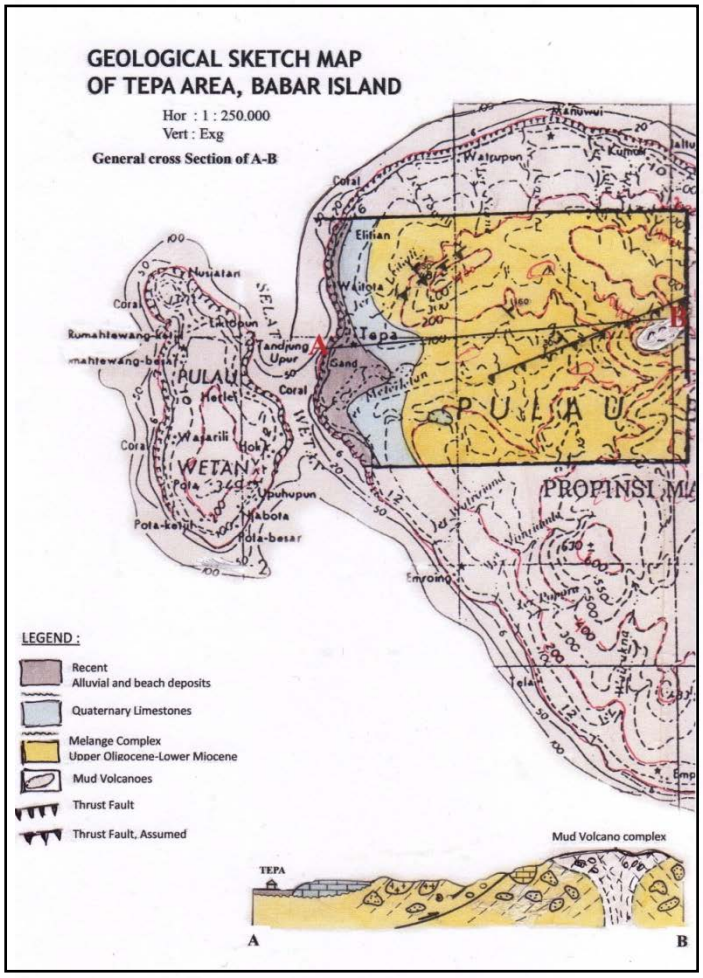


Figure 1. Geological map of Tepa area, western part of the Babar Island (Fachrizal, 1993)

The Melange Complex consists of:

- matrix: black shale, unsheared except in fault or fracture zones, containing nannofossils of Late Oligocene to Early Miocene age as indicated by *Coccolithus miopelagicus* and *Dictyococcites abisectus.*
- fragments: consisting of blocks of various sizes from 50 cm^3 up to hill size. The blocks consist of basalt (with pillow structure), diabase, quartz sandstones and turbiditic sandstones. Ammonite and belemnite of Mesozoic age, limestones with Pelmatozoan fossils and red clay interbedded with chert are also common.

The mud volcanoes on Babar are found in the central part of the island and are very active, with bubbles of flammable gases and mud flows with rock fragments (Photos 1-4). The mud contains nannofossils of *Coccolithus miopelagicus* and

Cyclocargolithus floridanus of Late Oligocene to Middle Miocene age. The mud composition is dominated by kaolinite, with very rare illite and chlorite. The rock fragments are similar to those found in the mélange complex, but smaller in size (0.5 – 10 cm in diameter). Ammonite and belemnite occurring in the mud are mostly broken and are mixed with other rock fragments. The mud volcanoes are associated with the mélange complex, thrust faults and fractures which trend N50E to N80E. Other fractures are directed toward N130E (Figure 2).

Tanimbar Islands

Mud volcanoes on the island occur in Kabawa complex and they have been studied by Charlton (1992), Ernawan (1993) and Harun (1984). The mud volcanoes are still active and they release mud flows, gases and rock fragments. The mud contains microfossils, which according to Charlton (1992) indicating assemblages of Early to Middle Jurassic based on palynological examination. Ernawan (1993), however, interpreted that the mud is Early Miocene in age based on nannofossils of *Sphenolithus abies, Sphenolithus meriformis, Cyclococolithus leptoporus and Cyclococolithus floridanus.* The difference in interpreted age is probably due to the existence of different clay layers in the stratigraphic succession in the subsurface.

The mud composition is dominantly kaolinite, with very rare illite and chlorite. The rock fragments are of various sizes (1.0–4.0 m in diameter) and they consist of black shales, claystones, serpentinite, red clay, limestones and sandstones. The black shale and claystone fragments are Early–Middle Jurassic in age (Charlton, 1991). The mud volcanoes are associated with the mélange complex, thrust faults and fractures. The fractures trend N52E and N23E.

Kei Islands

In the Kei Islands, mud volcanoes are found in Taroa, Liek, Ut and Wahru Islands. These islands are also known as the Kei Kecil Islands. The mud volcanoes were mapped by Achdan and Turkandi (1981) and have been studied by Ernawan (1993). They are still active, releasing bubbles of flammable gases, mud flow and rock fragments (Photos 5-8). The mud contains nannofossils of *Ceratolithus acutus* that indicates Early Pliocene age (NN12). The mud is dominantly illite, with very rare kaolinite and chlorite. The rock fragments consist of claystone, marl, limestone and turbiditic sandstones of the Late Eocene to Middle Miocene age based on foraminifera analyses. All mud volcanoes in the islands occur in the Quaternary limestones and they are associated with fractures that trend N65E and N40E in the Wahru Island; and N170E in the Ut Island.

Other Island: Timor Island

The presence of mud volcanoes on Timor Island has been reported by several authors including Rosidi et. al. (1981), Tjokrosaputro (1978) and Barber et al. (1986). Barber et al. (1986) documented mud volcanoes and shale diapirs in the Semau and Kambing Islands region of West Timor and they observed that the mud volcanoes are still active; releasing gases, matrix and rock fragments. The matrix consists of scaly clay with scaly fabrics, scaly surfaces and shining on any freshly broken fragment. The rock fragments are composed

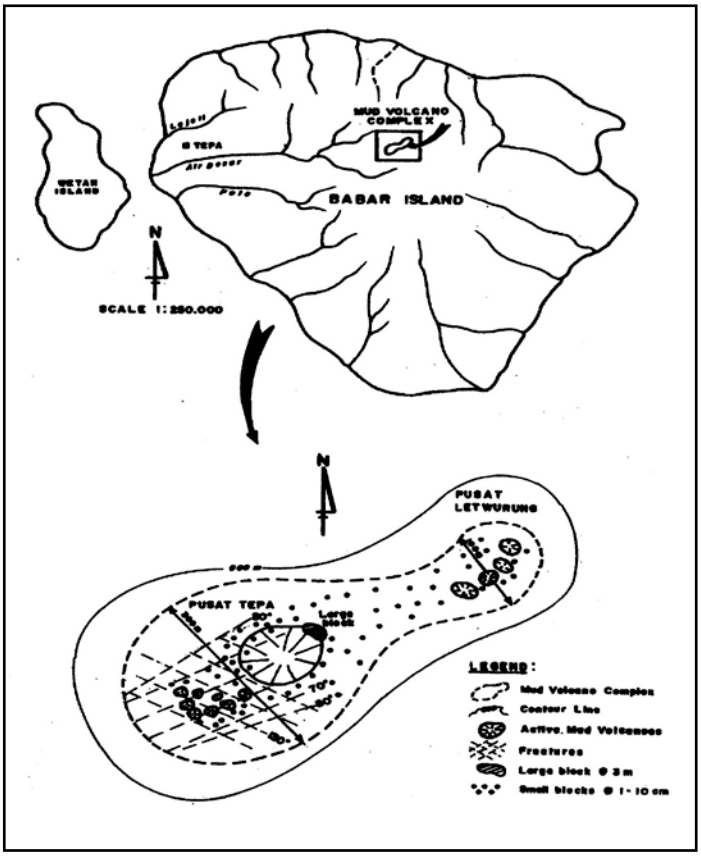


Figure 2. Sketch map of Mud Volcano Complex, central Babar Island.

of Late Permian sandstones and Late Triassic turbiditic sandstones. The mud volcanoes associated with the mélange complex and thrust faults and are called "*diapiric mélange*" by Barber et al. (1986).

Tectonic Significance of Mud Volcanoes in East Indonesia

Mud volcanism is basically formed by the extrusion of overpressured shale or clay. Overpressured shales arise from different levels in the stratigraphic succession of SE Maluku. The age of the mud in the volcanoes of Timor, Babar, Tanimbar and Kei Islands varies from late Jurassic to early Pliocene, indicating that the overpressured shale or clay originated from different horizons at different depths.

Overpressured shales with low density, deep in the structural succession and overlain by denser material, constitute a metastable condition. The association of mud volcanoes with fractures and thrust fault in this region suggests that the seal that confines the buoyant, plastic, overpressured shale units may have been breached (Barber et al.,1986; Tongkul, 1989). During tectonic activity, shale becomes liquefied and extrudes through the fault zones to the surface (Charlton, 1991). The presence of blocks of shale and compacted rocks of different ages in the in mud volcanoes demonstrates that the rock fragments were picked up and ejected along with the mud on the fault zones. This phenomenon suggests that liquefied shale has been extruded through different layers in the stratigraphic succession.

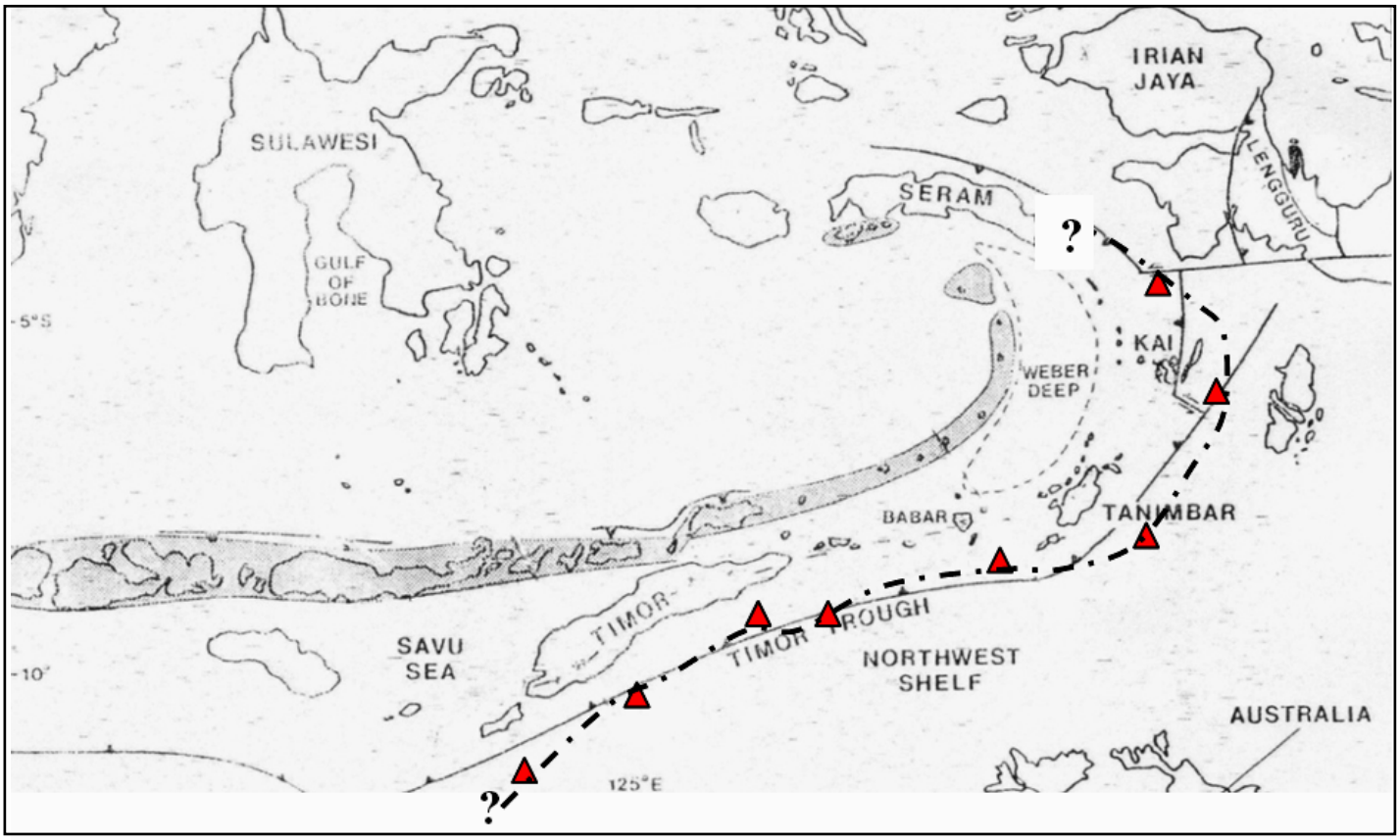


Figure 3. *Distribution and orientation of mud volcanoes in SE Maluku coincide with tectonic line of the region (red triangles: Mud volcanoes are plotted on the tectonic map of Charlton, 1991).*

According to Tongkul (1989) the process above may be abrupt and catastrophic, because in order to support the blocks, the mud must either be fluid moving at high velocity or must have a high viscosity. The extrusion of mud like toothpaste with striated and slickensided surfaces, indicates that the mud has indeed a high viscosity.

The mud volcanoes in S.E. Maluku are situated in an active accretionary zone belonging to modern subduction zones. They occur along thrust fault and fractures zones of NE-SW orientation that coincide with tectonic trends of this region (Figure 3). The thrust faults and fractures in this region are associated with active seismic activities (Nishimura and Suparka, 1986), which commonly contribute to the development of mud volcanism.

All mud volcanoes in this region are still active and are also associated with mélange complexes, except for those in the Kai Islands. The rock fragments extruded are similar to the fragments found in the mélange complexes themselves. Williams et al. (1984) and Barber et al., (1986) believe that mud volcanoes that are associated with mélange complexes are the product of shale diapirism or *diapiric mélange* and that they are abundant in many modern accretionary terrains.

Some authors also believe that there is a genetic link between mud volcanism and many of the chaotic deposits in accretionary complex (Williams et al., 1984; Barber et al., 1986; McManus and Tate, 1986 and Tongkul, 1989): Furthermore, that mud volcanism is probably one of the main processes that contribute to the formation of chaotic deposits, together with tectonic and slumping processes



Photo 1. *Mud volcano eruptions with fresh "mud lava flow" observed at the Mud Volcano Complex in the central part of Babar Island (photo courtesy of Zaim).*

(Tongkul, 1989). The existence of mud volcanoes in SE Maluku supports this proposal.

Quaternary fractured limestone terraces are observed in S.E. Maluku at elevations of about 50 m to 150 m above present sea level in Babar Island (Fahrizal,1993), and from 50 m to 1297 m in Timor as reported by Tjokrosaputro (1978). The Kai Kecil Islands are formed entirely of Quaternary limestone (Ernawan, 1993), and the active mud volcanoes in this region are mostly found in fracture zones within the terraces, thus suggesting that the development of mud volcanoes is probably related to Quaternary and neotectonic activities in this region.



Photo 2. *Left: fresh "mud lava". Right: semi-dry mud that formed "ropy-mud lava". Location: Mud Volcano Complex, central part of the Babar Island (photo courtesy of Zaim).*



Photo 3. *Top: other mud volcano eruptions with fresh "mud lava flow". Bottom left: cone structure that contains gravel-size rock fragments and Ammonite and Belemnite fossils. Bottom right: active bubble gases. Location: Mud Volcano Complex, central part of the Babar Island (photo courtesy of Zaim).*





Photo 4. *Top - Fractures pattern seen in the Mud Volcano Complex. Bottom - Large block (± 1.5m in diameter) of turbiditic calcareous sandstones found in the Mud Volcano complex (photo courtesy of Zaim).*



Photo 5. *Mud volcano found in the Liek Island showing active bubble gases. Location: Kei Kecil Islands (photo courtesy of Zaim).*



Photo 6. *Circular fractures as a trace of (dried-up) mud volcano activities found in the Ut Island. Location: Kei Kecil Islands (photo courtesy of Zaim).*



Photo 7. *Mud volcano complex found in the Wahru Island, Kei Kecil Islands. Local witness stated that the large blocks seen in the photo were erupted in 1981 (photo courtesy of Zaim).*



Photo 8. *A large block (± 4m in diameter) of calcareous sandstones was erupted in 1981. Location: Wahru Island, Kei Kecil Islands (photo courtesy of Zaim).*

Conclusion

The origin of active mud volcanoes in Babar, Tanimbar and Kei Islands as well as Timor Island, S.E. Maluku can be related to the geology and tectonics of this region. The association of mud volcanoes with thrust faults and fractured zones indicates that their development in this region is due to liquefied shale which extruded along such zones. The different type and age of rock fragments ejected by mud indicate that the volcanism passed through a number of stratigraphic sequences.

The association of mud volcanoes with mélange complexes and the fractures in Quaternary limestone terraces indicates that the formation and development of mud volcanoes is related to active tectonic activities of this region and suggests that the mud volcanism is probably one of the main processes to the formation of chaotic deposits in the Quaternary in SE Maluku.

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The data have never been published in any journal, except in an abstract that has been presented as an oral presentation by the first author in the International Symposium on Geology and Environment, Chiang Mai, Thailand on the 31st of January to the 2nd of February 1996.

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