

The Hidden Sunda-Forearc Complex Evidence Underneath the Raitahu Mud Volcano, Southeastern Coast of Timor

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Abstract: The Raitahu mud volcano being one of the active mud volcanoes is located in the southeastern coast of Timor Island. This mud volcano contains scattered unsorted Permian to Neogene fragments including sedimentary, metamorphic, metavolcanics and volcanics materials as xenoliths. These provide insight of underneath geological units. In this study, we described in detail the geologic architecture and xenoliths include discussed the supposed forming-processes. We concluded that the mud volcano was formed originally in subduction channel as tectonic mélanges during Sunda forearc emplaced over the East Gondwana and the Australian passive margin. Subsequently, intruded into Sunda and synorogenic deposit as diapiric processes. Finally, extruded to the ground surface with xenoliths captured in those complexes, and assume that most of syn-collisional mélanges widely cropping out Timor Island (e.g., Bobonaro mélange) could be formed through these tectonic and diapiric processes. This natural phenomenon potentially as Geoheritage site for geoeducation, scientific research and tourist attractions.

Keywords: Raitahu, mud volcano, Sunda-forearc, syn-collisional mélange, geoheritage

1. Introduction

The inclusion of variety of scattered unsorted native and exotic fragments within the mud volcano can be provide insight of geological units lies beneath the Raitahu dormant shield mud volcano. The main aim of this study is a reassessment of the limited data record to appraising the underground lithostratigraphic units beneath a mud volcano from previous to

recent workers and focused on the Sunda forearc complex. The conspicuous Sunda-forearc complex derived the geological units is demonstrated by unsorted fragments of low-grade metamorphic rocks; metavolcanics includes its covers sequences of fore-reef carbonates, volcanoclastics and forearc deep-water siliceous sediments. The East Gondwana

Triassic fragments are most common with lesser Permian fragments incorporated with K-Neogene pelagic deep-water sediments and basal synorogenic deposits. This tentative outcome could be contributing for scientific geoscience research purposes in polygenetic mélanges processes for the Bobonaro melange occurrence throughout in Timor Island, geophysics studies for its origin. The vertical and horizontal extents include its implications for hydrocarbon resources explorations, geohazards studies include potentially for geotourism attractions.

Timor was formed as one of the young orogenic-belts as an outer island arc, which is characterized by a complex geology from Latest Carboniferous to recent geological units with multiple deformation structures that are encompassed mud volcanoes manifestations. The topography of Timor expressed by roughly mountainous terrain mainly in central part. The topography gradually changes to hilly terrains towards the coastal alluvium plain which extensively in the southern coast and scarcely in the north portion. These complex geologic and geomorphologic features were formed prior to

the arc-continent collision between Australian passive margins and the Banda arc [1, 2, 3].

A mud volcano is one of the vital geological phenomena that provide an essential source of information about subsurface sediments and deep structures being often associated with the hydrocarbon resources deposits in sedimentary basins, tectonic subduction zones and orogenic belts in arc-continental collisions. Commonly, the substances emitted by the occurrence of the mud volcano elsewhere in worldwide. These are closely related to gas and liquid, and these are solid phases after explosion. The gases are mostly consisted of methane with minor amounts of N, Ar, CO₂, C₂H₆, and higher hydrocarbon gases. But some of the mud volcanos are dominated by CO₂ gas, which is probably associated with the sediment-hosted geothermal system.

Furthermore, there are more than 76% expel thermogenic gases, 4% expel microbial hydrocarbon gases, and the rest expel mixed gases [4], [5]. In the liquid phase, there is much of water in mud volcano, and the fluids are originated from the marine sedimentary pore

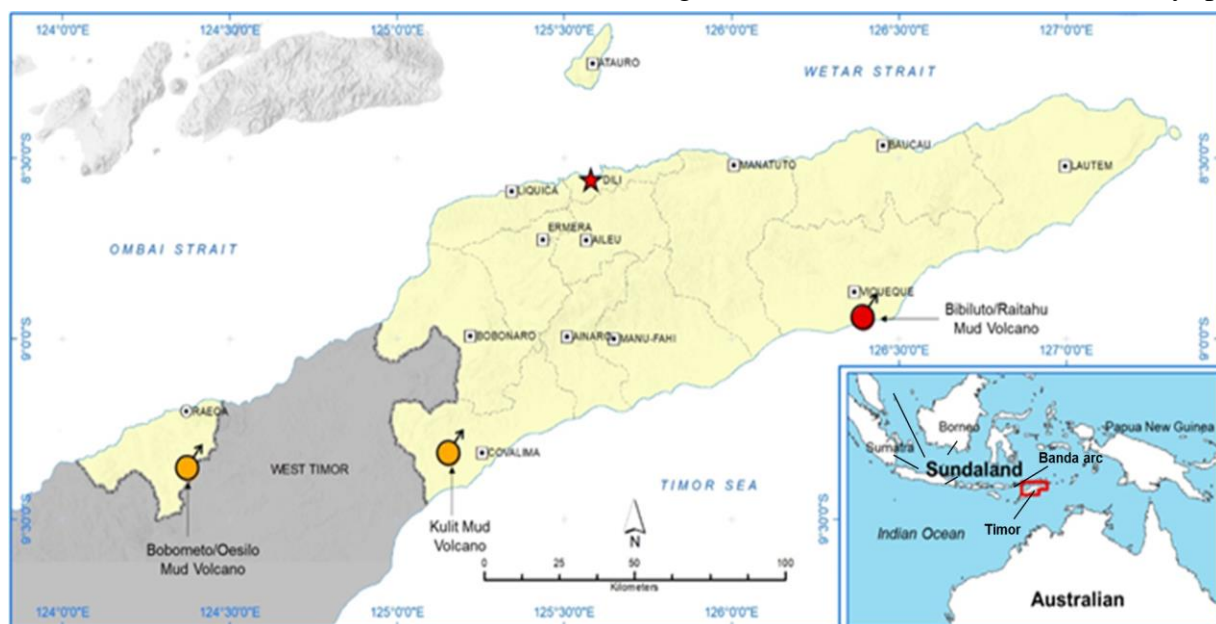


Fig. 1 Location map of mud volcanoes. The study area symbolized in red circle arrow.

fluids. The water may have experienced important diagenesis and/or have been influenced by clay dehydration, water–rock interaction, halide dissolution, and may mix with groundwater, surface runoff, and meteoric water near the land surface [5]. However, the solid matters is mostly derived from the geologic materials around the fluid reservoirs or the sidewalls of migration pathways, mostly clay minerals, such as smectite, illite, kaolinite, chlorite, quartz, and calcites [5] including others rock units around it which mostly by sedimentary rocks and lesser volcanics and metamorphic rocks.

The east Timor as a young orogenic belt consists of several manifestations of mud volcanoes (**Figure 1**) that found elsewhere at Bobometo, Oesilo area, Raitahu, Viqueque area, and Kulit, Suai area. This study is only focused on the Bibiluto mud volcano (Raitahu mud volcano in this study) and commonly local people are called “*Raisút*”.

This mud volcano was first reported by [6, 7, 8] and was represented that third eruption and were took place after first grand explosive eruption of Timor in 1638 and another violent explosive eruption has occurred at Floen-Bano, West Timor in December 1856. Due to the large earthquake nearly Dili (the center of government in Portuguese Timor), a tsunami potentially occurred at the northern adjacent islands and an eruption of the Bibiluto/Raitahu mud volcano was excited. Later, this mud volcano was described by Schneeberger (unpublished report, 1959; in [9]) as presented as flat and shield-like cone and breaks through a cover of Pleistocene to Recent Suai Formation [9].

Previously, [10] described the Raitahu mud volcano as dormant mud volcano contains small craters which NE-SW orientations. The Raitahu Mud volcano rock fragments are comprised of sandstone, limestone, sandy limestone, marl,

chert, mudstone, thinly laminated, micaceous shale, siltstone and red shale, including iron nodules within the red and black shales. With the XRD clay mineral analyses, this mud volcano is dominated by quartz, kaolinite, illite, albite, and a trace mineral being montmorillonite. Recently, [11] has done a review study, and [10] distinguished the rock fragments into formal lithostratigraphic units at Permian-Cretaceous. They are of Atahoc, Cribas, Aituto, Wailuli, Waibua/Nakfunu and Borolalo formation. These recent studies did not incorporate the fragments, which are derived from the Sunda-forearc complex.

As well, some comprehensive clay mineral analysis in West Timor by [12] showed that the smectite-rich mixed with slight illite indicating the source of overpressured clays being derived from stratal intact from the Lower to Middle Jurassic Gondwana succession and the Lower Cretaceous Australian passive margin. While the illite, kaolinite and chlorite rich clays occur mainly from Permian to Triassic Gondwana sequence.

The recent reactivation of the Raitahu mud volcano eruption occurred around 2:00 am on 3rd May 2021 and was accompanied by a massive gas explosion.

2. Methodology

This research study was conducted in several steps as follows: (1) Desk study: it comprised by the literature review, remote-sensed analysis of historical time-lapse optical satellite imagery and digital terrain model. (2) Fieldwork campaign: field observation and describing mud-breccia fragments, taking photographs, and capturing the real-time drone aerial imagery. (3) Analysis of rock fragments and biostratigraphy analysis for fossiliferous fragments and incorporated fragments to adjusting into formal

lithostratigraphic units based similar age and facies associations. (4) Generating supposed lithostratigraphic succession include Sundaland forearc complex derived units beneath the mud volcano and its hypothetical forming-process modeling.

3. Results

3.1. Local Geology background

The Raitahu Mud Volcano is one of ancient mud volcanoes, where is located in the extensively alluvium plain closely to the southeastern coast of Timor-Leste, inside the Viqueque synorogenic Basin (see in **Figure 1**) and nearly 5 km west of Beaco village and 2 km southward of Raitahu village. There are no residential buildings and public facilities, and are present around the main mud emission area, but the site can be representing a natural attraction for geotourism or for research purposes mainly of geophysical investigations related to implications for potential of hydrocarbon resources and geohazards. The surface local geologic architecture in Raitahu and adjacent areas is mainly comprising of widely synorogenic deposits and synorogenic *mélanges* corresponding to muds, which are erupted in this area as active diapiric *mélange* (see **Figure 2**). The synorogenic deposits are characterized by

broadly flat-lying Quaternary to recent with unconsolidated materials of alluvium- and fluvium-deposits around the mud volcano, while the syn-orogenic *mélange* is represented by mud-breccia or scaly-fabric muds dominated with angular-to-subangular shapes ranging from the Permian to the Neogene fragments and from cobbles to lesser large boulders in sized. The mud-breccia deposits should be remembered that these same variegated lithological units are the main character of the Bobonaro *mélange* across the island.

The Raitahu mud volcano displaying oval-shaped, shield-like with flat-lying of the caldera floor and devoid of vegetation (**Figure 3**). The constituent fragments are derived from the Permian to the Neogene units. The mud volcano was practically dormant in the dry season. There are numerous dried small craters and mud pots at the floor of the caldera and forming mud-chips while some craters still wet with very slowly oozing gray mud including occasional gas bubbles. The obvious concentric collapse rims are observed at the NE-edge of the caldera-floor (**Figures 2** and **3a**). The highest elevation at this area is about 32 m in the NE-edge. It gradually decreases to 15 m in the SW area close to the western bank of the Cuha river. Based on the high-resolution of the digital terrain model and the optical satellite imagery, undoubtedly the

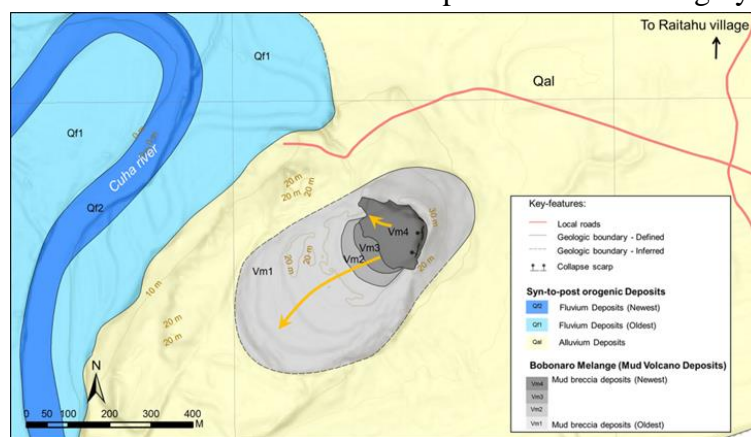


Fig. 2 Simplified Local Geologic map of Raitahu mud volcano. Orange arrow shows the flow directions of mud breccia.

volcanic mud deposits in the ascending order from the oldest to the newest deposits exhibit into four successions; Vm1 - Vm4. The volcanic mud flows of Vm1-Vm3 are in SW directions, while the latest flow Vm4 is characterized by the mud-breccia being flooded at the center of the flat-lying caldera, and muds in Vm1 - Vm4 show outflows mainly to the northwestern part (**Figure 2 and 3**).

3.2. An appraising of supposed lithostratigraphic unit beneath mud volcano

The presence of the diverse fragments from various terranes, which was derived could be supported for estimating the lithostratigraphic succession. Based on the tectonostratigraphic divisions, the fragments are dominated by the Permo-Triassic East Gondwana sequence incorporated with lesser amounts of the Sunda forearc complex, the Australian Passive margin

and the oldest units of syn-orogenic deposits. The East Gondwana sequence is characterized by various sized fragments from large boulders to cobbles of turbiditic brownish grey-micaceous sandstones with planar- and cross-laminations and cone-in-cone structures, thin-bedded light-to-dark-gray mudstones. Some of these sandstone fragments are abundant in phyto-detritus (woody fragments) that belong to Babulo formation. We seldom are seen the Aitutua gray to white limestone (mainly wackestone) fragments with chert nodules, Maubisse reddish limestone fragments with crinoidal-stems and amygdaloidal basalt fragments including some iron nodules typically of the Cribas Formation.

The Sunda forearc complex is represented by Lolotoi low-grade pelitic metamorphic schist fragments, dark-grey quartz-schist fragments

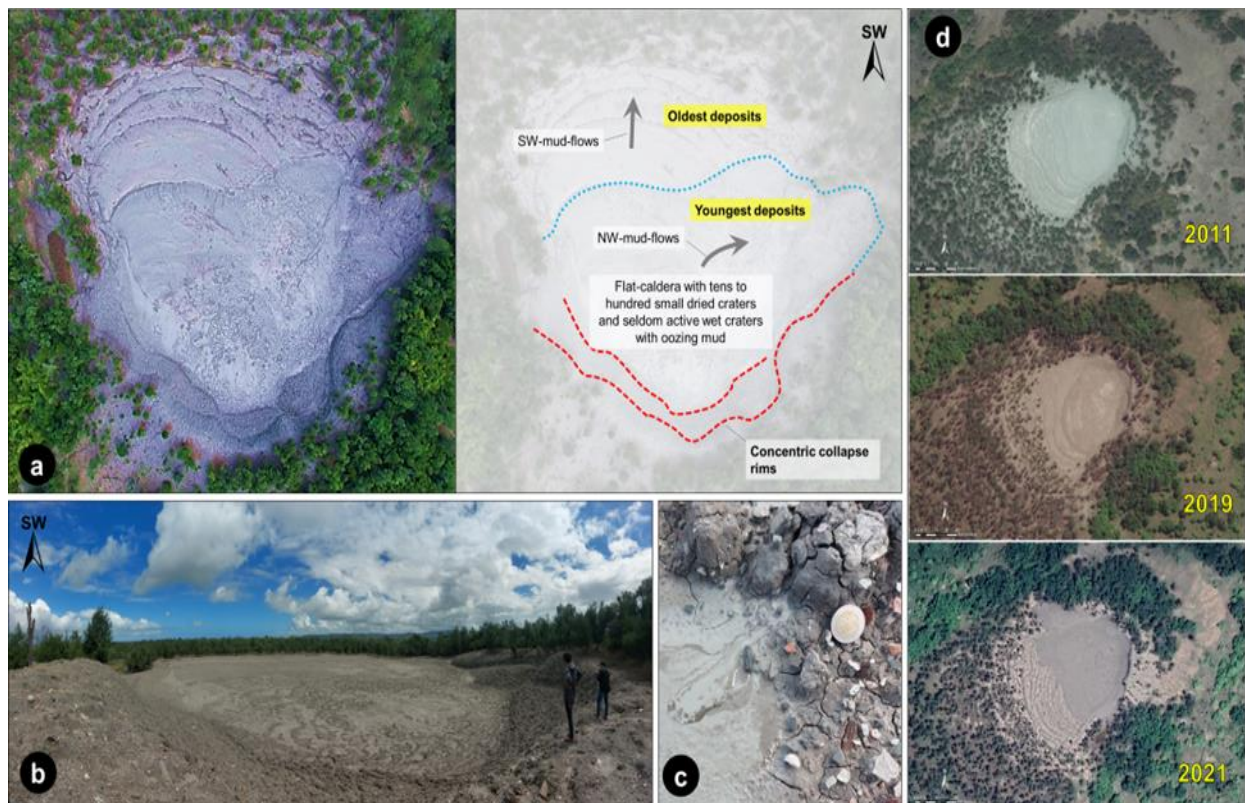


Fig. 3 (a) Bird-eye photoshoot of real-time drone aerial imagery and interpreted marks and labels (b) Panoramic view of the whole Raitahu mud volcano, (c) Close-up view of active small crater with oozing grey muds (d) Sporadic historical satellite imagery of Raitahu Mud volcano from 2011-2021.

Table 1. Representative proportions (in %) of blocks within Raitahu Mud volcano

P-T East Gondwana affinity					Sunda Forearc Complex (Metamorphic + Volcanic + sedimentary cover)						Australian Passive Margin affinity	Synorogenic Deposits
<i>Ss</i>	<i>Cl</i>	<i>V_{ol}</i>	<i>Ls</i>	<i>Fe_s</i>	<i>Sc_h</i>	<i>M_m</i>	<i>Sed</i>	<i>Vc</i>	<i>Sa</i>	<i>Ch</i>	<i>Dlm</i>	<i>Bpc</i>
68%	1%	1%	1%	3%	7%	4%	1%	4%	3%	1%	1%	3%

Note: Ss-Sandstone; Ls-Limestone; Cl-Calcilutite; Vol-Volcanic; Fe s-Iron stone; Sch-Schist; Ch-Cherts; Sa-Siliceous argillite; Dlm-Deep-water limestone and mudstone; Bpc-Basal pelagic carbonate; Sed-Sedimentary cover; Vc-Volcanic conglomerates (agglomerates)

and green metavolcanics fragments, with its volcanics and sedimentary associations such as Eocene Same Limestone [13] (heretofore Dartolu Limestone by [9, 14, 1]) and possibly equivalent with the Eocene Wungkal-Gamping Formation [15] at Bayat, Java Indonesia; Barique volcanoclastic or agglomerates with pebbly to cobble fragments of basaltic-and andesitic-dominated in volcanic sandy-matrix [9, 14] and

some disrupted bedded fragments of deep ocean siliceous sediments of the Noni Formation [16, 17]. It has lithological similarity to huge blocks of thin bedded siliceous argillites within a mélangé zone near the Viqueque area [18]. The Noni formation is a lower part of the Palelo Group, which were unconformable overlaying the Lolotoi Complex in East Timor and Mutis complex in West Timor.

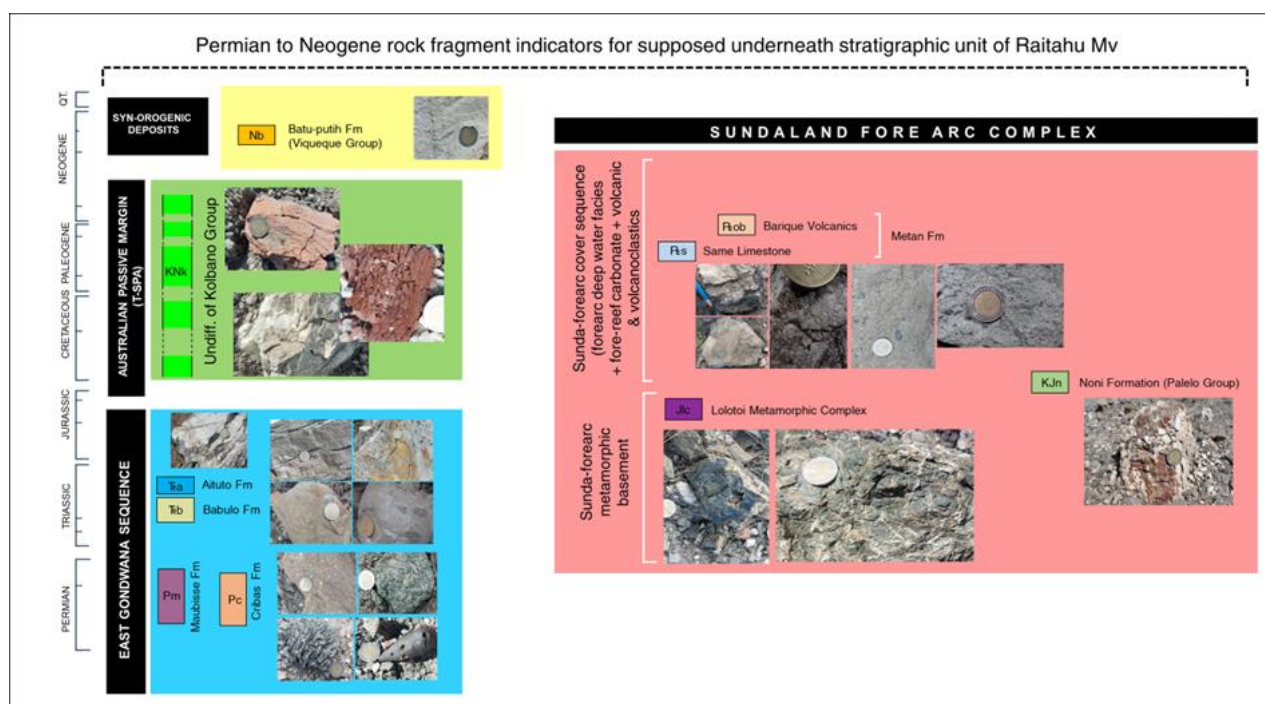


Fig. 4 Supposed Lithostratigraphic units underneath the Mud volcano, include tectonostratigraphic units: East Gondwana, Australian Passive Margin, and Sunda forearc complex and synorogenic deposits.

The Australian Passive Margin (T-SPA) is represented by the occasionally fragments of reddish pelagite limestone, pale yellowish / creamy to white radiolarian limestone and some reddish mudstones of the K-Neogene undifferentiated Kolbano group. Lastly, there are the fragments of the basal synorogenic sediments within the mud volcano that is represented by rarely white-massive marl fragments with abundant of foraminifera, which is probably derived from Batu-putih formation being one of the oldest units in synorogenic deposits as unconformable on the Bobonaro melange across the southern coast of Timor Island.

Based on the representative blocks that are calculated as shown in **Table 1**, we disclosed that the most common blocks within the mud volcano are derived from 1) the Eastern Gondwana affinity units corresponding to Triassic-dominated units with lesser Permian units for about 75%; 2) lesser fragments of forearc of the Sundaland comprising the Lolotoi Metamorphic complex, the Eocene Limestone, the Barique volcanoclastic or agglomerates (gathered in Metan Fm, following [19, 20]) and the Palelo Group deep water siliceous sediments) with 21% including very rare of the Australian passive margin deep water pelagite limestone and mudstone of the undifferentiated Kolbano group with 1 % and basal pelagic carbonate of the Batu putih formation with 3%.

4. Discussion

The appearance fragments of the Sunda forearc complex are observed in the entire of the mud volcano, and it provides lines of supported evidence for overthrust of the Sunda-forearc complex over the East Gondwana and the Australian passive margin rather than the Australian basement [21]. Furthermore, the Sunda-derived blocks probably appear as extends southward below sea level and buried

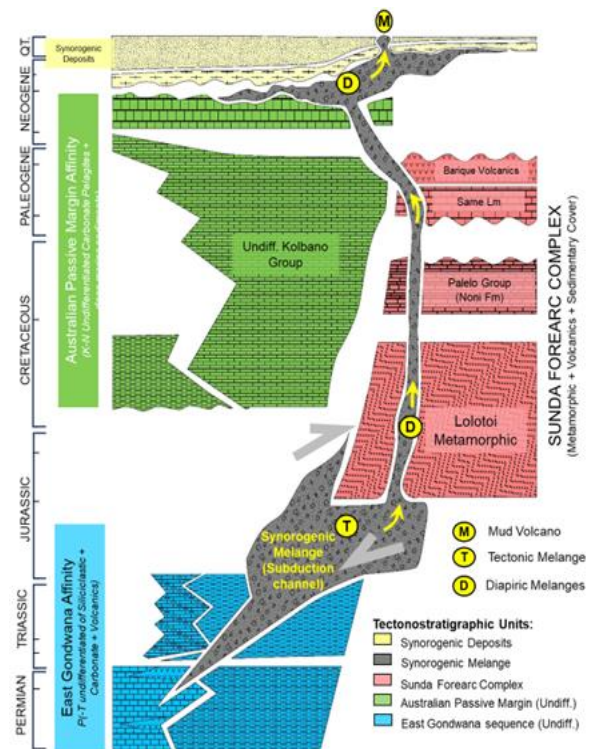


Fig. 5 Schematic tectonostratigraphic divisions include Sunda-derived units beneath the mud volcano, modified from [19, 20] based on fragments within Raitahu mud volcano.

underneath the Viqueque synorogenic basins similarly to the exploration wells penetrations [14, 21, 20, 22, 19] in the Suai synorogenic basin.

The constituent fragments are characterized by the mixed-block-in-clay structure [12]. In all facies, the most common blocks are derived from the Triassic sandstone of the Eastern Gondwana sequence with < 1 m in diameter, and additionally they are incorporated with mixture of the lesser Permian fragments, the Sunda forearc complex, the Australian Passive margin and the basal synorogenic deposits.

Regarding to the fragments observed within the Raitahu mud volcano, they indicated that the bulk of the melange source is derived mostly from underthrust stacking of the East Gondwana succession with highly over pressured pre-collision mudstones, which are weakened

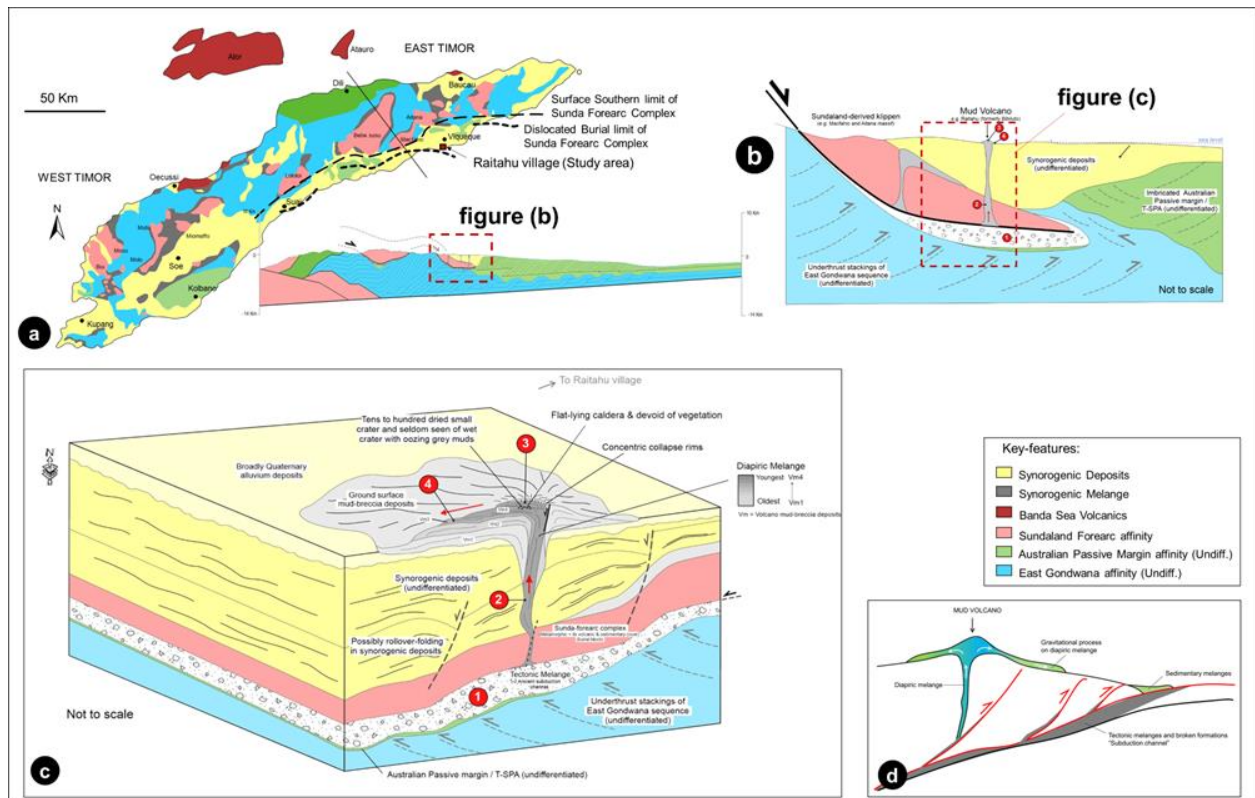


Fig. 6 (a) Sketch tectonostratigraphic map of Timor, modified from [22, 20] and simplified central Timor sections modified from [25, 20], based local geology architecture in red box for fig. b ; (b) Close-up interpreted section related to formation process of Raitahu Mv (c) Schematic 3D box model for Raitahu Mv with numbered by (1) ancient subduction channel (tectonic mélange); (2) diapiric mud intruded the Sunda-forearc and synorogenic deposits; (3) mud eruption and concentric collapse (4) sedimentary process (mud-breccia deposits after diapiric) (d) Collisional polygenetic mélanges model guidance suggested by [24]

commonly by elastic clay-rich layers within the décollement or below sequence as the Sunda forearc being designated as tectonic melange zone (Subduction channel), which equivalent to the Sonnebait Disruption Zone (SDZ) in west Timor [15]. The diapiric mélange is a significant component in recent accretionary-collision belts. It suggests that diapiric processes should be considered as a main genetic factor even in ancient mélange [23].

The melange-types occurred in the Raitahu area is corresponding with the polygenetic mélange processes being initially by tectonic (subduction channel) and subsequently by diapiric and lastly eruptive processes. During the

eruption, they produce successively mud-breccia flows and deposits at adjacent areas by the gravitational sedimentary processes [24] see in **Figure 6c**.

In Timor, [26] reported that the strike-slip faults also contributed to the mud diapir forming-process. The faults were originally by breaking through the overthrust stack having breached the seal that confines the buoyant, plastic and overpressure shales units, and the muds were developed, liquefied and extruded into the fault zone and rosen through the covering succession towards the surface as a mud diapir.

Besides the mud volcano is a unique geological feature and active geomorphic process, which is forming new landform and

revealing the insights for regional geological setting, and as active diapiric melange extruding materials or rocks beneath the surface. This mud volcano is considered a high geoheritage value and has a national and higher significance. It is essential to provide geoinformation, geo-education and management of site utilization, realizing geotourism programs, valuing local cultures and proposed to promote massively this geological site.

5. Concluding remarks

The major tectonic structures in this study area are thrust faults, extensional faults, strike-slip faults and diapirs. All these tectonic structures have provided escape pathways for overpressured materials and fluids and/or have favored upward fluid movement along the sedimentary column and eventually the buildup of mud volcanoes. Regarding to tectonostratigraphic units, there are several routes where are derived from the East Gondwana, the Australian Passive margin, the Sundaland Forearc Complex and the Basal Synorogenic deposits. We have done the litho- and bio-stratigraphic analyses and generated the supposed lithostratigraphic units and its hypothetical forming-process modeling being a tentative result that it required to more detailed paleontological and radiolarian analyses. The clay mineral analysis is needed to know the depths of clay-dominated source including geophysical survey for exactly structure of the mud volcano and the sub-surface extent of the buried Sunda forearc complex underneath the Viqueque synorogenic basin. We recommend to local people to living away and agricultural activities from this natural phenomenon including several settlements construction as national roadways and highways and other projects.

This tentative outcome could be contributing for geoscience research purposes in polygenetic mélanges processes within the arc-continental collisions, geophysics studies for its origin, vertical and horizontal extents including its implications for hydrocarbon resources explorations, and geohazards studies, and considered as a geoheritage site in which potentially for geoeducation, scientific researches and tourist attractions.

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Credit authorship statements

Nazário Boavida (writing - original draft, conceptualization, software, formal analysis, methodology, investigation, data curation and visualization, review and editing), Kiichiro Kawamura (writing – review and editing), Cornélio Cardoso (fieldwork, investigation, review), Osvaldo Sarmiento (investigation, review), António Lira (writing – review and editing), Afonso da Silva Soares (fieldwork, review), Jaime Martinho Guterres (fieldwork, review), Moises Mendonça (fieldwork), Franculino Esteves (fieldwork).

Declaration of Competing Interest

This research established by self-funding and no potential conflict of interest was reported by the authors.

Reference

- [1] M. G. Audley-Charles, "Tectonic post-collision processes in Timor," *From: Hall, R., Cottam, M. A. & Wilson, M. E. J. (eds) The SE Asian Gateway: History and Tectonics of the Australia-Asia Collision. Geological Society, London, Special Publications, 355,, no. 355, pp. 241-266, 2011.*
- [2] B. Duffy, M. Quigley, R. Harris and U. Ring, "Arc-parallel extrusion of the Timor sector of the Banda arc-continent collision," *Tectonics*, vol. VOL. 32, pp. 641-660, 2013.
- [3] C. E. Standley and R. A. Harris, "Tectonic evolution of forearc nappes of the active Banda arc-continent collision: Origin, age, metamorphic history and structure of the Lolotoi Complex, East Timor," *Tectonophysics*, no. 479, pp. 66-94, 2009.
- [4] G. Etiope, A. Feyzullayev and C. L. Baciú, "Terrestrial Methane Seeps and Mud Volcanoes: A Global Perspective of Gas Origin," *Mar. Pet. Geology*, vol. 26, pp. 333-344, 2009.
- [5] H.-C. Chao, C.-F. You, I.-T. Lin, H.-C. Liu, L.-H. Chung, C.-C. Huang and C.-H. Chung, "Two-End-Member Mixing in the Fluids Emitted From Mud Volcano Lei-Gong-Huo, Eastern Taiwan: Evidence From Sr Isotopes," *Front. Earth Sci.*, vol. 9, 2021.
- [6] M. A. Perrey, "'Sur le Bibiluto: Volcan de L'île de Timor". Nouvelles Annales des Voyages, de la Géographie, de l'Histoire, et de l'Archéologie 6.3.," A. Bertrand, French, 1858.
- [7] G. Adams, "'Timor Island; its supposed volcano and its probable tectonic relations'," *Philippines Journal of Science*, vol. 7A4, pp. 283-289, 1912.
- [8] R. Blong, "The Eruption of Timor in 1638: 350 years of plagiarism, embellishments and misunderstandings," *Volcanica Research Article*, 2019.
- [9] M. G. Audley-charles, "The Geology of Portuguese Timor," 1965.
- [10] H. C. Guterres, F. C. dos Santos, J. M. Perreira and A. Araujo, "Mud volcano in East Timor: constituent materials, the process the geological structure and its interpretation," in *Proceeding of 1st International Congress of Geology of Timor Leste*, CCD, Dili- Timor Leste, 2012.
- [11] J. R. Ruibere Cab and Munasri, "Estimating the underlying stratigraphic sucession of Mud volcanoes - a desk study," in *Proceeding of 5th IPG Internacional Conference*, CCD, Dili - Timor Leste, 2022.
- [12] R. A. Harris, R. K. Sawyer and M. G. Audley-Charles, "Collisional melange development: geologic associations of active melange-forming processes with exhumed melange facies in the western Banda orogen, Indonesia.," *Tectonics*, no. 17, p. 458 – 479., 1998.
- [13] D. W. Haig, Z. K. Mossadegh, J. H. Parker and M. Keep, "Middle Eocene neritic limestone in the type locality of the volcanic Barique Formation, Timor-Leste: Microfacies, age and tectonostratigraphic affinities," *Journal of Asian Earth Sciences: X 1*, 2019.
- [14] M. G. Audley-Charles, "The Geology of Portuguese Timor," *Memoirs of the Geological Society of London*, vol. No 4, 1968.
- [15] D. Rahmawati, D. H. Barianto and W. Rahardjo, "Analisis Mikrofasies Batugamping Formasi Wungkal-Gamping Jalur Padasan, Gunung Gajah, Bayat, Klaten, Jawa Tengah," *Jurnal Teknik Geologi: Ilmu Pengetahuan dan Teknologi*, vol. 5, pp. 1-8, Juni 2022.
- [16] A. H. Harsolumakso, M. Villeneuve, J. J. Cornee, P. De Weber, G. Tronchetti, J.

- Butterlin, G. Glacon and P. Saint-Marc, "Stratigraphie des series paraautochtones du Sud de Timor occidental (Indonesie)," *Comptes Rendus del'Academie des Sciences*, vol. Series 11A (320), pp. 881-888, 1995.
- [17] Munasri and A. H. Harsolumakso, "Late Cretaceous Radiolarians from the Noni Formation, West Timor, Indonesia," *Berita Sedimentologi* , pp. 5-18, 2020.
- [18] Haig, D W; Bandini, A N, "Middle Jurassic Radiolaria from a siliceous argillite block in a structural melange zone near Viqueque, Timor Leste: Paleogeographic implications," *Journal of Asian Earth Sciences* 75, pp. 71-81, 2013.
- [19] M. Bucknill, B. Duffy, J. Noble and A. Berkovitch, "What lies beneath? Prospecting for Hydrocarbons under a metamorphic allochthon, Timor-Leste," in *Australasian Exploration Geoscience Conference AEGC) 2019 Data to Discovery*, Perth, Western Australia, 2019.
- [20] B. Duffy, J. Kalansky, K. Bassett, R. A. Harris, M. Quigley, D. J. van Hinsbergen, L. J. Strachan and Y. Rosenthal, "Mélange versus forearc contributions to sedimentation and uplift, during rapid denudation of a young Banda forearc-continent collisional belt," *Journal of Asian Earth Sciences* 138, pp. 186-210, 2017.
- [21] T. R. Charlton, D. Gandara, D. Freitas and M. Guterres, "Explanatory notes of the Geological map sheet Suai (2406-523) with scale 1:25,000," 2021.
- [22] R. A. Harris, "Rise and fall of the Eastern Great Indonesian arc recorded by the assembly, dispersion and accretion of the Banda Terrane, Timor," *Gondwana Research*, no. 10, p. 207–231, 2006.
- [23] S. -I. Park, H. J. Koh, S. W. Kim and Y. H. Kihm, "The Occurrence and Origin of a Syn-collisional Mélange in Timor," *Econ. Environ. Geol.*, 47(1), pp. 1-15, 2014.
- [24] A. Festa, K. Ogata and G. Pini, "Polygenetic mélanges: a glimpse on tectonic, sedimentary and diapiric recycling in convergent margins," . *Journal of the Geological Society*, vol. 177 (3), pp. 551-561, 2020.
- [25] G. W. Tate, N. McQuarrie, D. J. van Hinsbengen, R. R. Bakker, R. A. Harris and H. Jiang, "Australia going down under: Quantifying continental subduction during arc-continent accretion in Timor-Leste," *Geosphere*, v. 11, no. 6, 2015.
- [26] A. J. Barber, S. Tjokroapoetro and T. R. Charlton, "Mud Volcanoes, Shale Diapirs, Wrech faults, and Melnages in Accretionary Complexes, Eastern Indonesia," *The American Association of Petroleum Geologist Bulletin*, Vols. 70, No 11, 1986.