

# Lithostratigraphy and structural setting of the Banda Terrane and Gondwana Sequence on the Northeast of Oecusse Enclave, Timor-Leste

## Litostratigrafia e contexto estrutural do Terreno de Banda e da Sequência Gondwana no Noroeste do Enclave de Oecusse, Timor-Leste

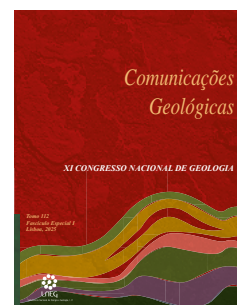
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**Abstract:** The limited geological information of the Oecusse enclave, coupled with its geotectonic complexity, makes it difficult to comprehend its geological context. To better understand the lithostratigraphy and tectonics of the northeastern sector of this territory, a new geological map was created, utilizing the interpretation of remote sensing data and field observations. The studied area consists mainly of the Banda terranes of Asian affinity, which partially correspond to metamorphic rocks, with a Jurassic protolith and mostly Eocene metamorphic age, at the base of the Lolotoe Complex, to deposits with basin facies from the Cretaceous (Paleo Group), associated with shallow water limestones from the Eocene (Dartollu Limestones) and to an Eocene-Pliocene volcanic series (Manamas Group). These units constitute of the thrust pile of a duplex of horse thrusts of Australian affinity (Gondwana Sequence), dominated by shallow-water Triassic silts, clays and carbonates. The roof thrusts have a NW-SE orientation and are linked by left lateral tear faults NE-SW oriented.

**Keywords:** lithostratigraphy, structural setting, Banda Terrane, Gondwana sequence, Oecusse enclave.

**Resumo:** A escassa informação geológica do enclave de Oecusse, e a sua complexidade geotectónica, dificultam a boa compreensão do seu contexto geológico. Para melhor entender a litostratigrafia e a tectónica do sector nordeste deste território, elaborou-se nova cartografia geológica, recorrendo à interpretação de dados de deteção remota e às observações de campo. A área estudada é constituída principalmente por terrenos de Banda de afinidade asiática. Correspondem parcialmente a rochas metamórficas, com protólito jurássico e com metamorfismo de idade eocénica, na base do Complexo de Lolotoe, a depósitos com fácies de bacia do Cretácico (Grupo Paleo), associados a calcários de águas rasas do Eocénico (Calcários de Dartollu) e a uma série vulcânica do Eocénico-Pliocénico (Grupo Manamas). Estas unidades constituem os cavalgamentos-teto de um duplex de escamas de cavalgamento, de afinidade Australiana (Sequência Gondwana), dominadas por siltes, argilas e carbonatos de águas rasas do Triássico. Os cavalgamentos-teto possuem direção NW-SE e estão conectados por falhas de desligamento esquerdo (tear faults), de orientação NE-SW.

**Palavras-chave:** litostratigrafia, contexto estrutural, Terreno de Banda, Sequência Gondwana, enclave de Oecusse.

### 1. Introduction

The Island of Timor is part of the Outer Non-Volcanic Banda Arc that is formed by the collision zone between the Volcanic Banda Arc and the Australian Continental Crust (e.g. Audley-Charles, 2004; Carter *et al.*, 1976; Barber *et al.*, 1977; Tate *et al.*, 2015) (Figura 1). This collision is forming the complex structural and stratigraphical setting of Timor Island, which includes the northeast part of the Oecusse enclave of Timor-Leste (Figura 2). In this region, the Asian affinity Banda Terrane is in structural contact with the northernmost edge of the Australian continental margin, a condition which is not very well depicted on the previous geological map of the area (Suwitodirdjo and Tjokrosapoetro, 1996) (Figura 3). Therefore, the main purpose of this work is to map units that belong to the two different tectonic plates and to develop a working stratigraphic and structural model for the northeast of the Oecusse enclave, Timor-Leste.

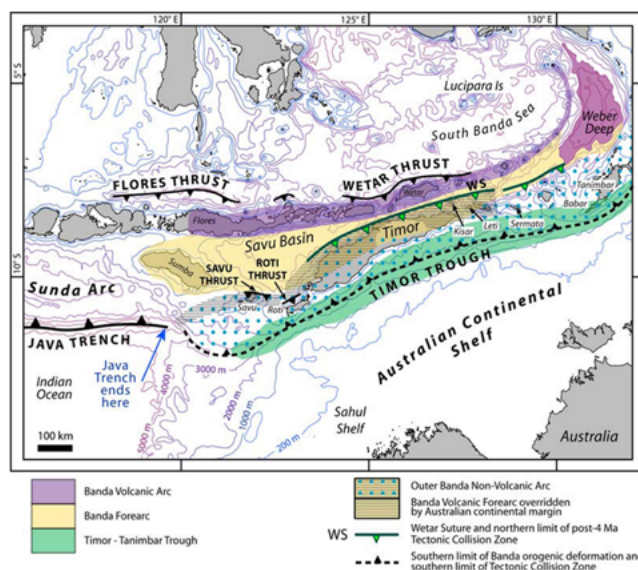


Figure 1. Geotectonic setting of the Banda Arc system (Audley-Charles, 2011).

Figura 1. Enquadramento geotectónico do sistema do Arco de Banda (Audley-Charles, 2011).

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## 2. Regional tectonics and geological setting

Timor island is located north of Australian Continent and is one of the southeasternmost Sunda islands. In the tectonic context, it is positioned at the collisional margin between the oceanic Banda volcanic arc and the Australian continental margin (e.g. Carter *et al.*, 1976; Hamilton, 1979; Nugroho *et al.*, 2009; Audley-Charles, 2011; Seton *et al.*, 2012; Tate *et al.*, 2015) (Figura 1). The island is composed of four main tectonostratigraphic sequences: (1) The Gondwana Sequence (upper Carboniferous-Jurassic) comprises of units deposited on Australian continental crust; (2) the Australian Passive Margin/Kolbano Sequence (Jurassic-Pliocene), deposited after continental breakup; (3) the Banda Terrane, comprising the forearc units of the Banda volcanic arc and having Asian affinity Jurassic tPliocene units; (4) Synorogenic Sequence (upper Miocene-Present), consisting of deposits formed since the start of collision of the Australian continental margin with the Banda forearc (Figura 2).

Based on the previous geological mapping by Suwitodirdjo and Tjokrosapoetro (1996) (Figura 3), the northeast of the Oecusse enclave mainly consists of: (1) the Bobonaro Scaly Clay, a mélange deposit formed during the collision (Tmb); (2) the Triassic Aituto Formation, a part of the Gondwana sequence (TRa); (3) the pre-Permian Ultrabasic rock (Ub); (4) the Miocene Manamas Group (Tmn). Permian Maubisse Formation; (5) Eocene Diorite; (6) Miocene Manamas Group.

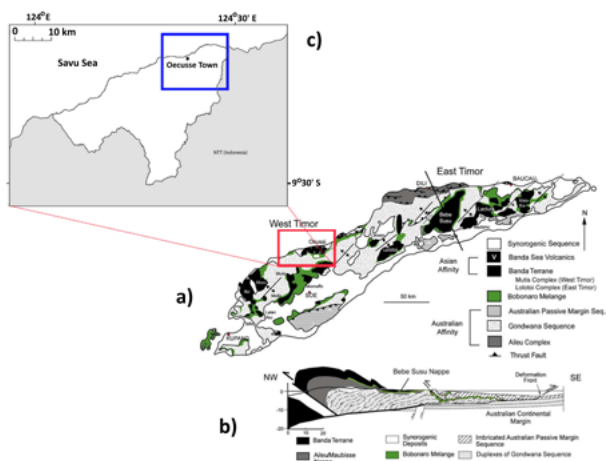


Figure 2. a) Generalized geological map of Timor Island (Harris, 2006). The area within the red rectangle corresponds to the Oecusse enclave; b) NW-SE trending geological cross section of Timor Island (Harris, 2006); c) Location map of the study area in the Oecusse Enclave (blue square).

Figura 2. a) Mapa geológico geral da Ilha de Timor (Harris, 2006). A área dentro do retângulo vermelho corresponde ao Enclave de Oecusse; b) Perfil geológico da Ilha de Timor, segundo a direção NW-SE (Harris, 2006); c) Mapa de localização da área de estudo no Enclave de Oecusse (quadrado azul).

## 3. Methodology

This research project encompasses a comprehensive methodology involving both fieldwork and remote sensing data interpretation. Field truthing, which entails verifying and validating findings on the ground, is a crucial component of this endeavor. Additionally, the study involves the interpretation of various types of remotely sensed data, including digitally processed imagery from satellites such as Landsat 8, as well as data derived from ASTER DEM (Digital Elevation Model). Aerial photographs, capturing high-resolution images from above, also play a significant role in our analysis. By integrating these diverse sources of information, we aim to gain a thorough understanding of the research area's geological characteristics.

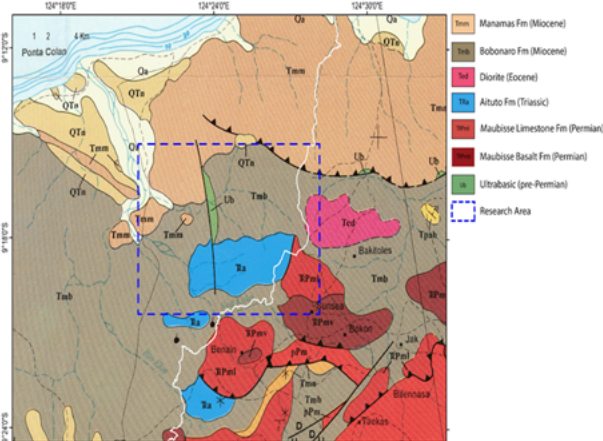


Figure 3. The regional geological map of the research area by Suwitodirdjo and Tjokrosapoetro (1996).

Figura 3. Mapa Geológico regional da área de estudo, da autoria de Suwitodirdjo e Tjokrosapoetro (1996).

## 4. Results and discussion

The study that has been carried out shows that the geological setting of the research area (Figs. 4 and 5) is much more complex than previously thought, as depicted in our recent geological map (Figura 6). In the previous geological map (Suwitodirdjo and Tjokrosapoetro, 1996; Figura 3), the authors only recognized 6 (six) units as described in point 2. However, through our work (Figs. 4-6) several tectonostratigraphic units/formations can be individualized, such as:



Figure 4. Outcrop viewing of the Gondwana Sequence. a) Grupo Babula (observação de sul para norte); b) Grupo Aituto (observação de sudeste para noroeste).

Figura 4. Vista de afloramento da Sequência do Gondwana. a) Grupo Babula (observação de sul para norte); b) Grupo Aituto (observação de sudeste para noroeste).

**(1) Gondwana Sequence**

This unit mainly comprises poorly differentiated Permian-Triassic siliciclastic and carbonate rocks of the Bandeira, Babulu and Aitutu Groups (Figs. 4 and 6). Mud-rich units of the Gondwana Sequence form decollements throughout the region and are the source of mud diapirs and mud volcanoes throughout Oecusse. They mainly occur on the base of overthrusts.

**(2) Banda Arc Terrane**

The Banda Arc Terrane of Audley-Charles and Harris (1990) comprises several units ranging in age from Jurassic to Pliocene (Figs. 5 and 6). The description of each unit is as follows:

-*Lolotoe/Mutis Complex* (Lo) (Jurassic): Metamorphic forearc basement units with a Jurassic and younger protolith age that was metamorphosed during the late Eocene and early Oligocene. It comprises of gneiss, amphibolite, micaschist, graphitic phyllite, and greenschist (Figura 5a). This unit is overlain by the Palelo and Barique Group.

-*Palelo Group* (Cretaceous-Paleocene) of Earle (1983): Divided into two formations, the Noni Formation, and the Haulasi Formation. In the research area, only the Haulasi Formation (Hs) is exposed as overlying the Lolotoe/Mutis Complex and is overlain by the Dartollu Limestone (DI). The Haulasi Formation consists of a basal conglomerate, turbidite successions of sandstone, siltstone, and shale.

-*Dartollu Limestone* (DI) (late Paleocene-Middle Eocene) of Audley-Charles (1968): Occurs as dismembered blocks of shallow water late Paleocene to middle Eocene thick-bedded limestone deposited above the Palelo Group. The limestone contains abundant large foraminifera such as nummulites, Discocyclina and Alveolina (Figura 5b).

-*Barique Group* (Eocene-Oligocene): Overlying the Dartollu Limestone is the Barique Group (Figura 5c). This unit consists of volcanic rock with

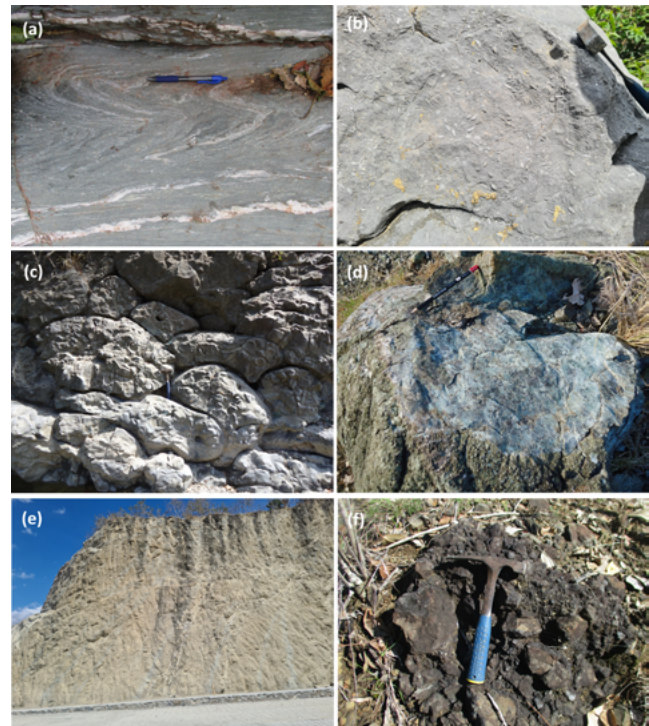


Figure 5. Outcrop viewing of the Banda Arc Terrane. a) Lolotoe Complex; b) Dartollu Limestone; c) Barique Group; d) Ultramafic bodies; e) Kutete Formation; f) Manamas Formation.

Figura 5. Vista de afloramento do Terreno do Arco de Banda. a) Complexo de Lolotoe; b) Calcário de Dartollu; c) Grupo Barique; d) Corpos ultramáficos; e) Formação Kutete; f) Formação Manamas.

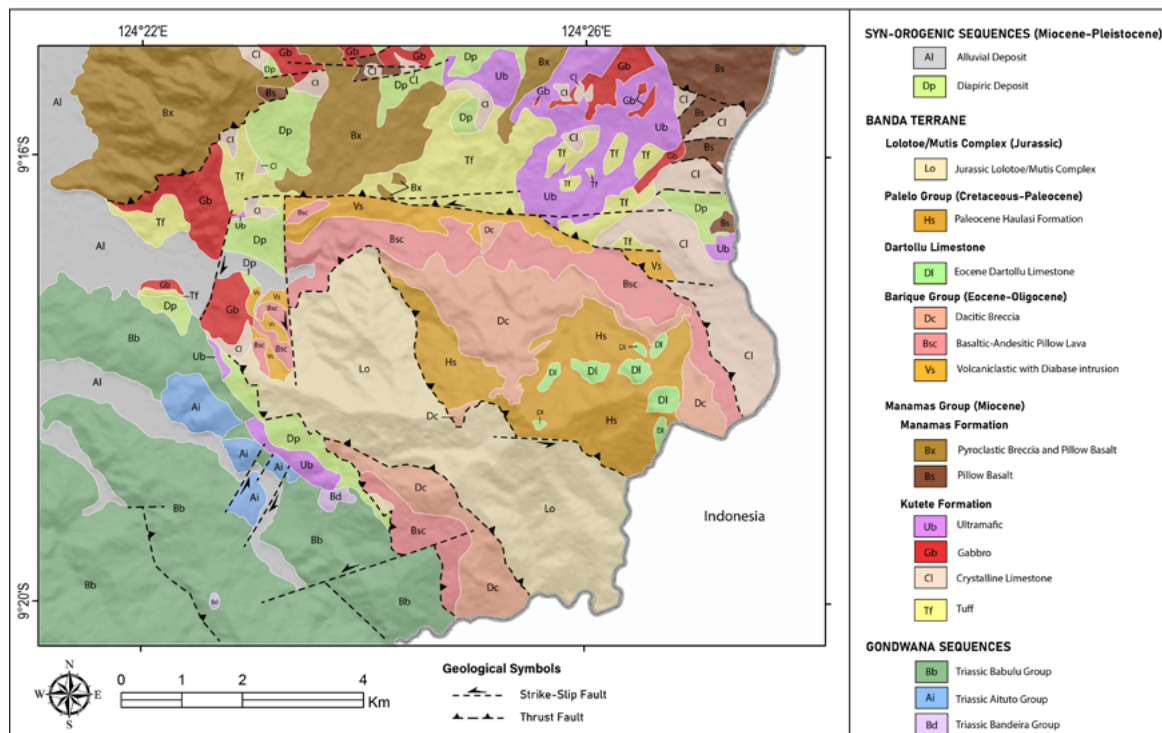


Figure 6. The new Geological Map of the research area produced by the authors.

Figura 6. A nova carta geológica da área de estudo, produzida pelos autores.

dacite and dacitic breccia at the base (Dc), intercalated basaltic-andesitic pillow lava (Bsc) and volcanoclastic successions intruded by diabase (Vs) in the middle, and overlain by thick marl at the top of the group. The Barique Group is structurally overlain by Kutete Formation and Manamas Formation of the Manamas Group.

*-Manamas Group* (late Miocene): Mainly comprises two formations: i) the Kutete Formation, consisting of fragmented material, including crystalline limestones (Cl), ultramafic bodies (Ub), gabbros (Gb), tuff and basaltic breccia (Tf) (Figura 5e); ii) the Manamas Formation, of pyroclastic breccia (Bx), pillow basalt (Bs), and tuff (Figura 5f). The Manamas Formation overlies the Kutete Formation and forms the framework of the Serra de Manamas.

Our interpretation is that the Gondwana Sequence of Oecusse forms a thrust duplex beneath a segmented roof thrust composed by a mélange and dismembered fragments of the Banda Terrane. The roof thrust segments mainly have a NW-SE orientation and are linked by vertical NE-SW trending left lateral tear faults.

The ultramafic bodies consist of dunites and harzburgites, with the upper part mostly metamorphosed to serpentinite (Figura 5d). Regarding their origin, there are 2 hypotheses: i) it might be part of the distal Australian continental basement that formed during Permian rifting of Gondwana (Gondwana affinity); ii) it may be part of the Banda forearc upper mantle included in the Banda Arc accretionary wedge, integrated in the roof thrusts during the collisional process (Banda affinity). Regardless of their affinity, our claim is that these ultrabasic bodies, together with other dismembered fragments (crystalline limestones, gabbros, tuff and basaltic breccia), form the mélange that are part of the accretionary prism (or the subduction channel) associated with the Banda Arc, constituting, as a whole, the tectonostratigraphic Kutete Formation (Manamas Group).

## 5. Conclusion

Based on the interpretation conducted in the northeast of the Oecusse enclave, Timor-Leste, several significant findings have emerged, shedding light on the complex geological setting of the region. Through detailed fieldwork and the integration of various data sources including satellite imagery and aerial photographs, a refined understanding of the tectonic evolution and geological setting of the area has been achieved. The delineation of distinct geological units, such as the Gondwana Sequence, Banda Arc Terrane, and Ultramafic Bodies, highlights the intricate nature of the region's geological history. Notably, the Gondwana Sequence exhibits a thrust duplex beneath the mélange, suggesting complex tectonic interactions. The Banda Arc Terrane comprises several units spanning Jurassic to late Miocene ages, each characterized by distinct lithological compositions and depositional environments. Noteworthy formations include the Lolotoe/Mutis Complex, Paleole Group, Dartollu Limestone, Barique Group, and Manamas Group.

The origin of the ultramafic bodies presents an intriguing aspect of the study, with hypotheses suggesting a possible connection to either the distal Australian continental basement or the Banda forearc upper mantle, incorporated as dismembered fragments in an accretionary wedge or a mega-fault breccia with the fault being the collisional suture, or subduction channel, between the Asian and the Australian plates. In conclusion, this study contributes significantly to the understanding of the geological framework of the northeast Oecusse

enclave, Timor-Leste, providing valuable insights into its tectonic evolution, structural setting, and lithological diversity.

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