UNIVERSIDADE Ð COIMBRA

Juvêncio de Deus Correia do Rosário

TIMOR LESTE: REGIONAL GEOLOGY AND GEOPHYSIC APPRAISAL OF THE SOUTHERN REGION ONSHORE AND OF THE ADJACENT OFFSHORE SHALLOW AND DEEP-WATER REGIONS

Master of Sciences Thesis in Petroleum Geosciences
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Juvêncio de D. C. do Rosário
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MASTER IN GEOSCIENCES

Specialization in Petroleum Resources

Scientific advisor

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DESCRIPTIVE ABSTRACT

The Southern region of the Timor-Leste micro-continent is characterized by an accretionary wedge resulting from the collision structuring caused by the northwestern motion of the Australian Plate launching towards the Far-East Archipelago. This appraisal study thesis briefly reviews this plate tectonics scenario and is focused on the G & G investigations of data from wells drilled in southern Timor-Leste merged with interpreted data of recent seismic data gathered in the offshore areas.

The regional litho-stratigraphy correlation between several wells of Banli-1, Cova-1, Jahal-1 and Baleia-1 was correlated in the southern onshore, Timor Trough, Sahul Syncline, Laminaria High until Flamingo High indicating in the Jurassic and Triassic the rock units of shales as a source rock or seal, the sandstone units as a reservoir rock and claystones as seal. This play units were ranging from Triassic to Lower Cretaceous in age.

Several horizons boundaries were interpreted from seismic amplitudes these are Seabed, Miocene, Cretaceous carbonates, Jurassic break-up unconformity, Triassic carbonates and the Permian carbonates. Seismic interpretation also identified several regional structuring bound by listric normal faults, thrust fault imbricates, folds, horst and graben, plus chaotic blocks.

Seismic interpretation of the regional lines un-covered multiple attractive, Mesozoic and Paleozoic, prospects in the offshore deep-water region these, if drilled successfully, may impact very favorably on the economy of Timor-Leste. In the offshore area, this thesis also addresses the outlook for future activities in the Greater Sunrise Gas Region and in the Timor Gap oil province particularly the prominent Bayu-Undan and satellite features.

By contrast with the deeper offshore, the regions of southern Timor-Leste onshore and adjacent shallower waters still need substantial additional studies in order to enhance its seismic and drilling risk exploration.

Keywords: Regional G & G Appraisal, Seismic and Well Interpretations, Petroleum Geology, Future Outlook, East-Timor.

RESUMO DESCRITIVO

A região meridional do micro-continente de Timor-Leste configura uma cunha de acreção resultante da colisão causada pelo movimento para noroeste da Placa Australiana e consequente projecção para os Arquipélagos do Extremo Oriente.

Partindo de uma revisão sumária deste cenário de tectónica de placas o presente estudo de avaliação assenta numa investigação G & G que se baseia em dados obtidos a partir de sondagens realizadas no sul de Timor-Leste e na interpretação de dados sísmicos recentes obtidos no offshore.

A correlação litostratigráfica regional entre os diversos poços Banli-1, Cova-1, Jahal-1 e Baleia-1 e os territórios onshore da Fossa de Timor Trough, do Sinclinal de Sahul Syncline, do Alto de Laminaria até ao Alto de Flamingo permitem considerar os shales do Jurássico e do Triássico como rocha geradora ou selo, sendo as unidades areníticas reservatório e as unidades argilíticas selo. Estas unidades abarcam desde o Triássico ao Cretácico.

Foram interpretados alguns horizontes a partir das amplitudes sísmicas: são fundo marinho, carbonatos do Cretácico-Miocénico, descontinuidade do *breakup* Jurássico, carbonatos do Triássico e carbonatos do Pérmico. A interpretação sísmica também permitiu identificar várias estruturas regionais limitadas por falhas lístricas normais, falhas de cavalgamento imbricadas, dobras, *horsts* e *grabens* e ainda blocos caóticos.

A interpretação sísmica de linhas regionais revelou prospectos de águas profundas interessantes e variados do Paleozoico e Mesozoico e que, se forem perfurados com sucesso, poderão ter um impacto positivo na economia de Timor Leste.

Nas áreas de offshore, nesta tese também se apresenta uma perspectiva sobre futuras actividades na Greater Sunrise Gas Region e na província petrolífera de Timor Gap, nomeadamente no Bayu-Undan e em estruturas próximas.

Ao contrário do offshore profundo, as regiões onshore do sul de Timor e de regiões adjacentes de águas rasas ainda carecem de estudos adicionais que permitam uma avaliação mais precisa dos riscos de exploração sísmica e de perfuração.

Palavras-chave: Avaliação Regional G & G, Interpretações Sísmicas e de Sondagens, Geologia do Petróleo, Perspectivas futuras, Timor-Leste.

RESUMO BADAK

Rejiaun Kosta-sul husi mikro kontinente Timor-Leste karakteriza husi acreasaun nebe rejulta husi strutura kolijaun nebe kauja husi mosaun nebe lansa entre NW Plaka Australia ho Far east archipelago. Estudo apresiasaun ida nee halo revisaun scenario akontesimento plaka tektonika nebe foka liu ba investigasaun *G & G* ba dadus posus no mos dadus resente seismika nebe rekolha iha parte tasi laran husi kosta sul Timor- Leste.

Korelasaun litostratigrafia rejional entre posus Banli-1, Cova-1, Jahal-1 no Baleia-1 hirak nee halo iha parte sul rai maran nian, area *Timor Trough, Sahul Syncline, Laminaria High too ba iha area Flamingo hig* nian nebe indika katak unidade fatuk shales ho idade Jurasiku no Triasiku nudar fatuk inan ka gerador iha tempo hanesan sai mos nudar *Seal,* no unidade fatuk arenito nudar Reservatorio no fatuk arjila nebe sai hanesan *Seal* mos.

Interpretasaun husi amplitudo seismika interpreta horizontes hirak hanesan *Seabed, Miocene, Cretaceous carbonates, Jurassic break-up unconformity, Triassic Carbonates* no *Permian Carbonates.* Interpretasaun Seismika ida nee mos identifika strutura rejional nebe ejiste mak hanesan*, normal listric fault, thrust fault imbricates, folds, horst* no *graben*, e bloku *chaotic.*

Interpretasaun husi lina seismika rejional kobre prospektividade atrativo husi Mesozoic no Paleozoic iha rejiaun *offshore deep-water*, tan ne'e perfurasaun nebe suseso bele fo impaktu ekonomika nebe favoravel ba Timor-Leste. Iha parte *offshore* nian, tese ida nee aprejenta mos perspektiva sobre aktividade ba futuro iha *Greater sunrise* no mos iha provinsia petrolifera iha Timor Gap, partikularmente Kampo Bayu – Undan no estrutura proxima hirak seluk.

Iha sorin ketak husi *deeper offshore*, parte rai maran husi sul Timor-Leste to iha area *shallow water* nian sei presija tan estudos ba oin hodi nunee bele permite hodi minimiza riskos wainhira halao esplorasaun seismika no mos perfurasaun.

Liafuan save: Avaliasaun Rejional *G & G*, Interpretasaun Seismika no Posus, Geolojia Petroleo, Prospektividade ba oin.

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CHAPTER I

INTRODUCTION

Geographically Timor-Leste (East Timor) lies between the Australian continent to the south side with maritime boundaries and the Indonesian archipelago to the west, north and east sides with land and sea borders. The astronomical location of the Timor Island is at 8º S – 10º S and 124º E – 128º E. Most of the island of Timor has a tropical climate with relatively small rainfall due to its geographical position closer to the equator.

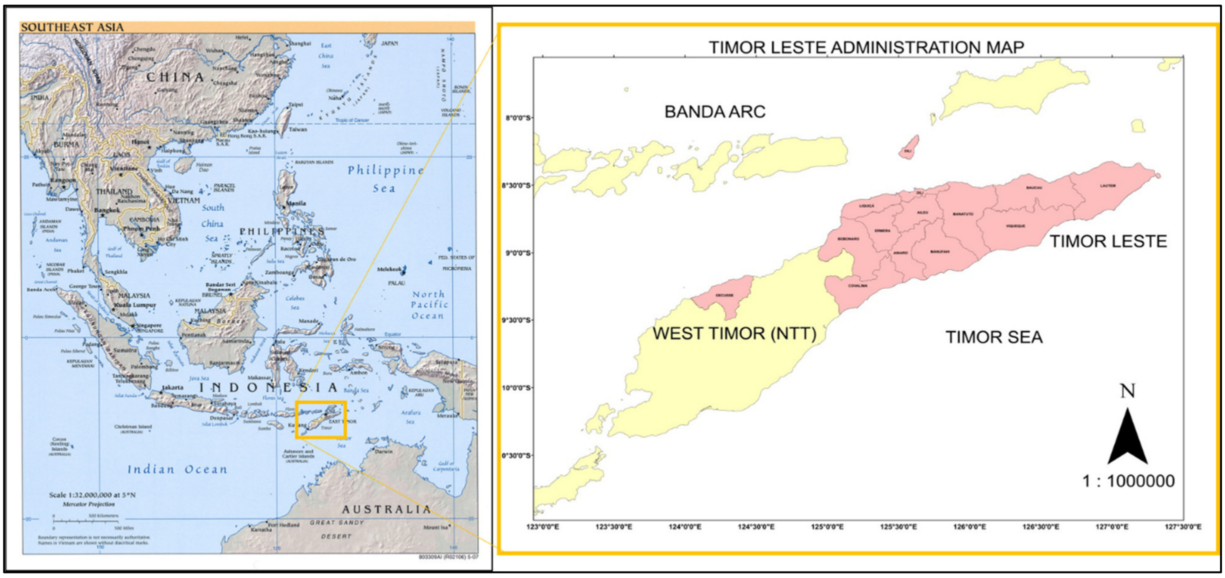


Figure 1. Southeast Asia Archipelago and the Timor-Leste administration map

In colonial times Timor Island was divided between The Netherlands and Portugal. After colonial times, presently boundaries are politically divided between Indonesia to the west, and the independent country of Timor-Leste (East Timor) to the east part of the Timor Island (figure 1). The two halves of the island are referred to in this study as East and West Timor, these names carry no political significance. East Timor corresponds to the mainland portion of Timor-Leste, whilst West Timor comprises part of the Indonesian province of Nusa Tenggara Timur; additionally, the Oe'cusse enclave of Timor-Leste is situated inside province of Nusa Tenggara Timur plus two small islands of Atauro and Jaco and the main eastern region of Timor Island. Altogether it forms the only independent Portuguese speaking country in the large Southeast Asia Far East Archipelago (figure 1).

Timor Island present location is due to the tectonic evolution initiated in 300 million age after the rifting process of Gondwana Megasequence during Permian until middle of Jurassic. This event was followed by several evolution such as the continental breakup at 155 million age during Drifting event of Australian Margin Megasequence in the Late Jurassic until early late Miocene. These events were followed by the Collision event between Australian and Banda Arc Continents in the Neogene time at 15 until 3 million age with recent uplifted of Timor Island (figure 2). These tectonics evolution involved and formed several units of Allochthonous, Autochthonous and Paraautochthonous units in Timor-Leste. Where, the Autochthonous unit of Gondwana Megasequence considered as potential unit for hydrocarbon source.

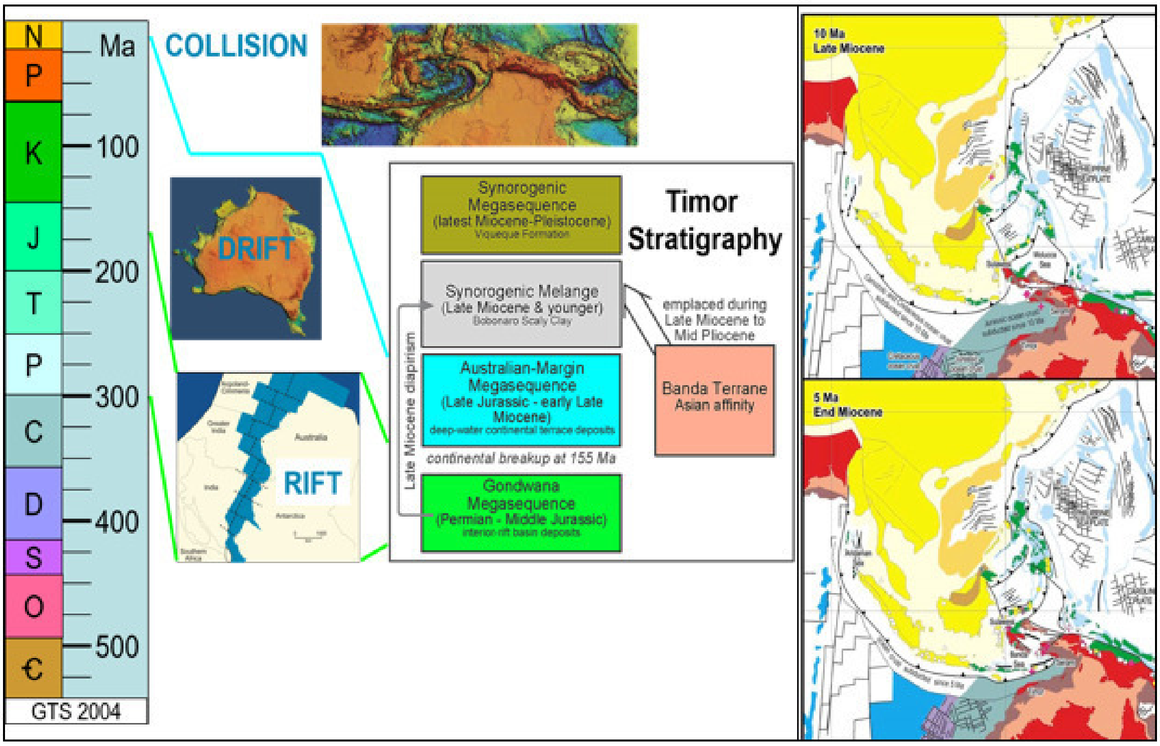


Figure 2. Evolutionary stages of the tectonic history of Timor Island (modified from Haig 2009 and Hall 2002).

Although Timor-Leste is situated close to the equator with hotter temperatures, while the difference in elevations guarantees a system of varied climates. In the lowlands of the coastal lowlands, during drought, the air is dry, typical of a tropical desert climate, cooling at night considerably. Regionally, classification for the climate in Timor are tropical to zero altitude, and variable temperatures in the mountains from 400 meters up. Certain meteorological phenomena cannot fail to exert any influence on climate change, such as monsoon, rain, and humidity (Artur de Sá, 1952).

I.1 Regional Geophysics Data Analyses

I.1.1 Regional Bathymetry map of the Far-East Archipelago

From the bathymetric map (figure 3) of the Far East Archipelago (Roberto Fainstein, 2000) indicated that the depth of Timor shelf is located around 200 – 3000 meters and consider as shallow to deep-waters regions.

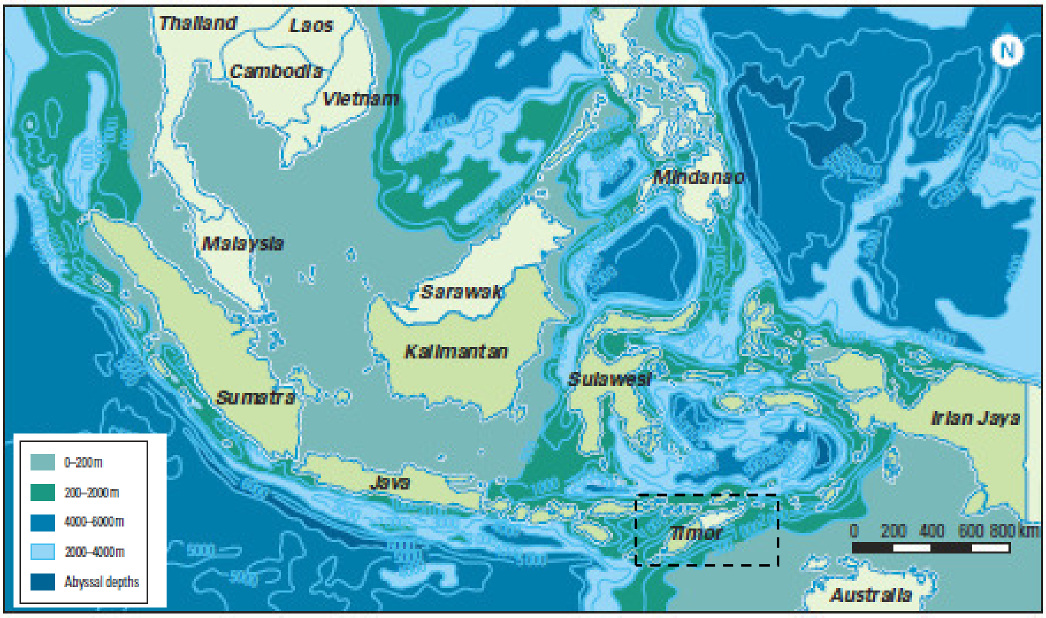


Figure 3. Regional bathymetric map of the far-east archipelago. Shaded areas indicate depths of shelf, slope deep and ultra – deep basins (Roberto Fainstein, 2000)

I.1.2 Gravity Maps

From the free air anomaly (figure 4) and the residual anomaly distribution (figure 5 and 6), Timor-Leste area is located mostly in the middle of spots anomalies distribution. From this character of anomalies distribution indicated that there are most of structure existence in Timor-Leste area due to the complexity of geological conditions in Timor area. Contrast geological features between Timor island and Timor sea looks very different from regional map of free air anomaly and residual bouguer anomalies distribution.

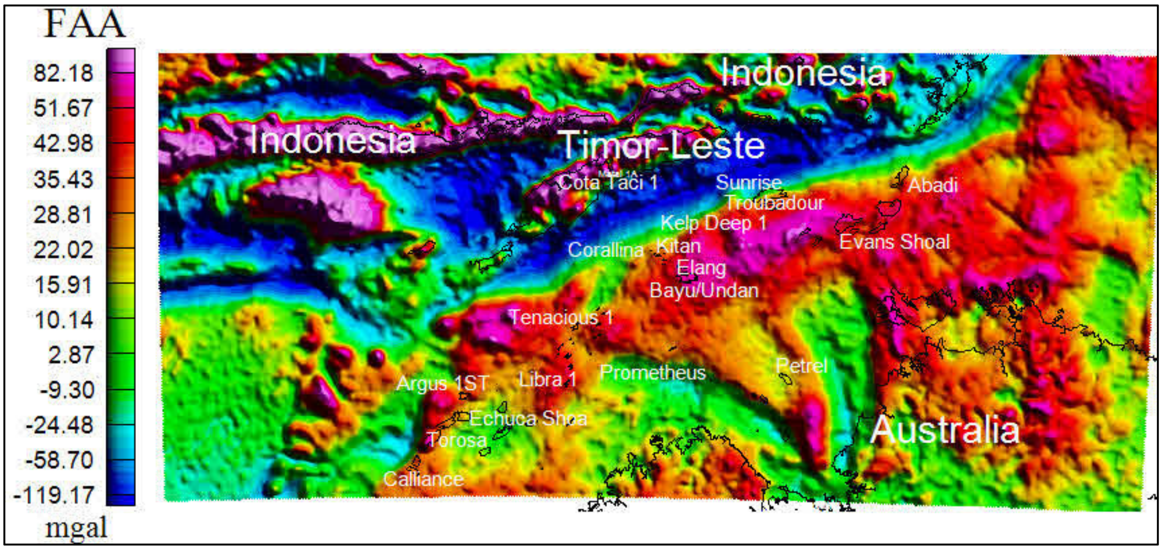


Figure 4. Regional Free Air Anomaly of Timor and Surrounding area with productive oil and gas fields (modified from BGI Datasets)

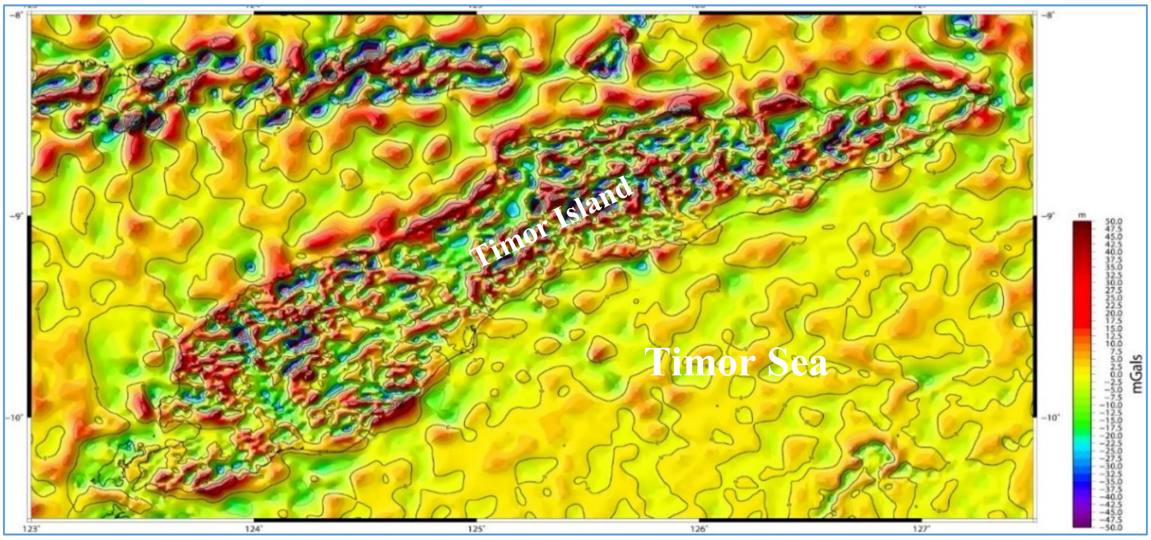


Figure 5. Regional Bouguer residual anomaly Datasets of Timor Island and surrounding area. (modified from Banda Arc Geophysics 2018 datasets)

The residual bouguer anomaly distribution of the Bonaparte basin is around – 400 until 400 μm/s^2 (figure 6). These anomalies distribution is based on geological conditions which is shown the different structure and stratigraphically in the region. The high anomalies are considered as an anticline and the lower anomalies as a syncline, grabens or basins. Mostly of the potential field, well exploration and the production located are shown in the high anomalies that considered as an anticline (Inset A on figure 6).

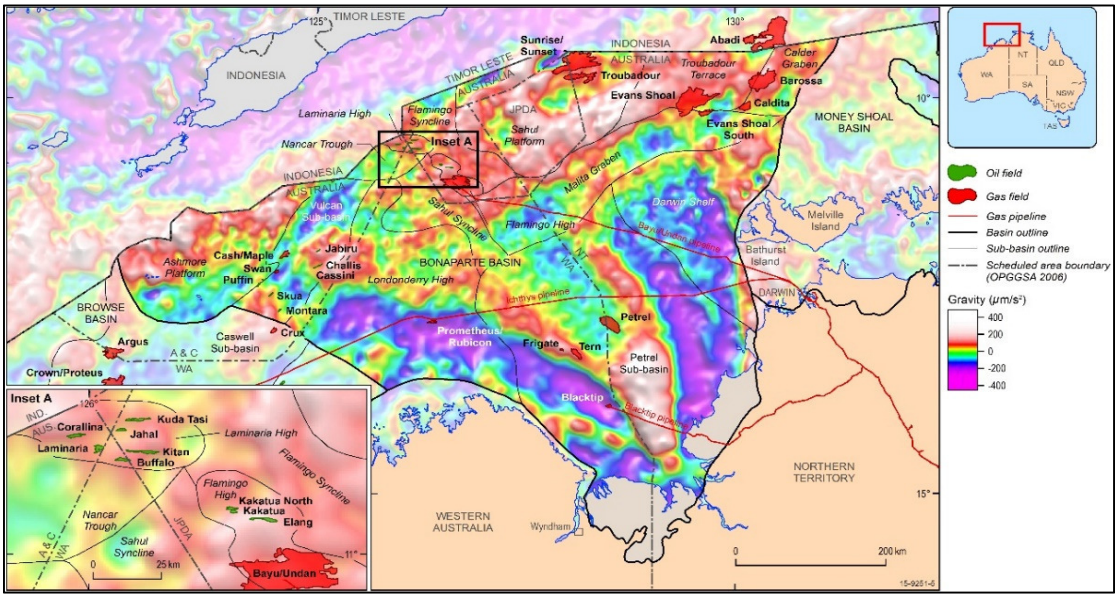


Figure 6. Residual Bouguer satellite gravity data of the Bonaparte Basin data from the DNSC08GRA satellite altimetry derived gravity dataset (Andersen et al, 2010).

I.2 Objectives

The area of the Timor Sea that lies between the Banda Arc microcontinent assemblages with the Australian Continent is geologically accumulated very thick sediments that were laid down since the Permian. These features of sediments accumulation are considered potential and suitable for the generation, migration and trapping of hydrocarbons in the southern part of Timor-Leste.

The results of the previous studies that conducted on the southern Timor Sea confirms the potential for large accumulated gas and petroleum reserves. Due to these various studies on the potential oil and gas content that identified in the Timor Sea, becomes a motivation for the author to conduct further studies to identify the existence of hydrocarbon basins that may potential to be developed for Timor-Leste economically development in the future.

The objectives of this study are to focus on the regional stratigraphy and regional petroleum geology in the southern coastal area, shallow and deep-water regions of Timor-Leste as prospective areas with potential economic development of hydrocarbons.

I.3 Study Limitations

Limitations in this study includes several factors that have a direct impact on the results of this investigation. These impairs the interpretation mainly due to the lack of available data and detailed information to support the analyses and interpretation process.

The data was collecting from Authority National of Petroleum and Mineral – Timor-Leste (ANPM) with permission to utilize for study purposes due to the investigation and interpretation process necessities. These available data include;

- Four (4) regional seismic lines with limited quality resolution available on the offshore area;
- Well Data Reports with low quality and only distributed in the western part of offshore Timor, the important Well of Cova-1 and Well Mola-1;
- Shallow depth penetration of Well Mola-1 limited by drilling capacity.
- Includes additional information from Geoscience Australia reports, International Gravimetric Bureau (BGI) France and from data reports issued by Professor Roberto Fainstein.

I.4 Area of Investigations

The studied region covers the offshore area to the south of Timor-Leste which is the exclusive Area of the Timor-Leste that borders to the Bonaparte basin in the south, and the mainland of southern Timor to the north (figure 7).

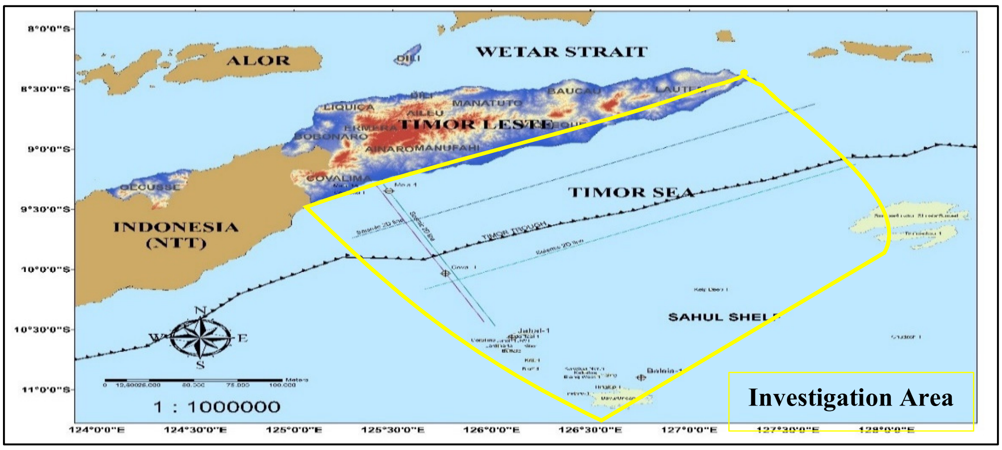


Figure 7. Area of Investigation covering TLEA (Timor-Leste Exclusive Area) to the Sahul shelf

CHAPTER II

MORPHOLOGY & REGIONAL SETTING OF TIMOR-LESTE

II.1 MORPHOLOGY AREA OF STUDY

The morphology of investigation area was divided into 3 areas based on study area coverage, such as Timor-Leste, Timor Trough and Sahul Shelf.

II.1.1 Morphology area of Timor-Leste

The topography relief of Timor-Leste was formally divided into several divisions based on its topographic relief characteristics which formed in the region. The following features or characteristics in the region are described herein below;

a. Mountain Ridge

The morphological division of this region is characterized by a line of large and small mountains that connect to each other in a fairly long span. These mountainous clusters are found on the northern and central area of Timor. The *Guguleu* mountain that range with an altitude of 1160 meters which leads to the northeast where the highest peak is encountered *Fatu-Masin* Mountain with a height of 1417 meters. The highest peak of the eastern part is *Hili-Manu* with an altitude of 1379 meters, from where the slope leads to the sea on the northern part of the *Laclo* River (*Manatuto*). The only remarkable gap in the range is formed by the valley of the *Comoro* River (Figure 8).

The other mountain ridge was forming in the central area of *Ramelau* mountain range with the highest peak on the top of *Tatamailau* Mountain with an elevation of 2920 meters which is the highest in the entire Timor Island. From this point ridges run to the north and south, the rounded ridge to the north running through to *Ermera*, while to the south, the ridge runs out to *Cabalaki* Mountain, which has an elevation of 2472 meters.

b. Fatus type

The characteristic features of this Area are defined by an isolated hill that described from the steep sided limestone massifs that form high peaks in western and eastern part of Timor-Leste (Benincasa, 2015). These features areas that included as a part of the Fatus in Timor are *Matebian* Mountain at *Baucau* Municipality (2315 meters), *Mundo Perdido*

Mountain at *Viqueque* Municipality (1790 meters), *Fohorem* Mountain of *Suai* Municipality, *Lolotoi* Mountain of *Bobonaro* Municipality, and *Paitchau* Mountain of *Lospalos* Municipality with an average elevation of 975 meters (Benincasa, 2015)(figure 8).

c. Plateau type

The plateau type of topography consists of low, flat or gently sloping limestones, in places displaying typical karst topography worked by the abundant underground rivers, sink holes and other remarkable uplands features. This topography is developed in the *Baucau* Plateau on the north coast, in the area between *Viqueque* and the *Luca* River, and in the *Lautem*. The average elevation of these plateaus is about 500 meters (figure 8).

d. The Coastal area

The characteristics of this feature are a zone of low rolling hills on the inner border and a typical flood plain area towards the coast; the streams coming out of the mountains have spread over a wide area, depositing their loads and finally sinking into the gravels, or losing themselves in coastal swamps. The width of this Area various from 3 to 12 kilometres with an average width of approximately 6 kilometres. The topography of the greater portion of the Area is typically that of a constructional line terrace, with some evidence of uplift (figure 8).

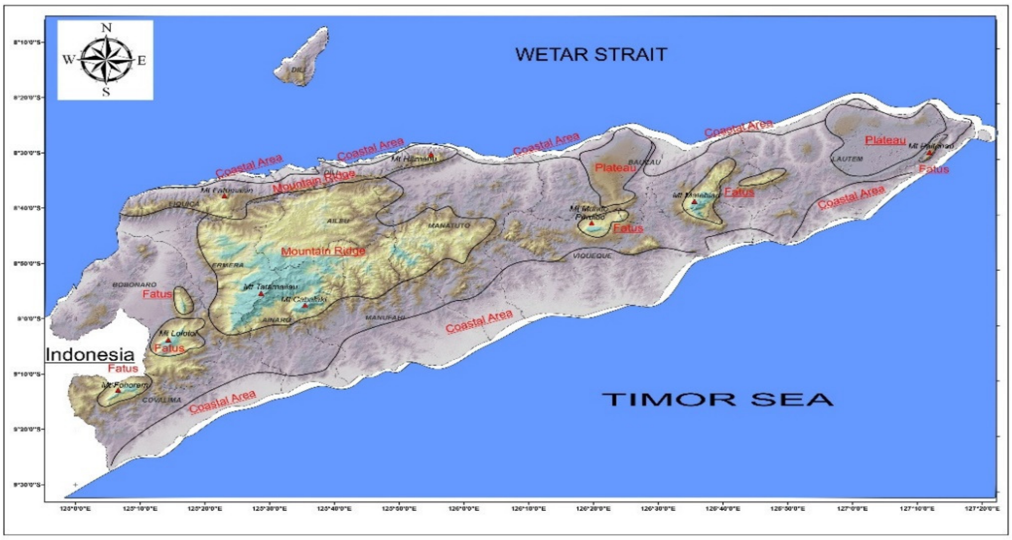


Figure 8. Morphological divisions of onshore Timor-Leste

The topographic conditions upon which the divisions were determined by the following factors such as: morphology structuring, bed-rock conditions such as hardness and resistance to erosion, and by climatic conditions (*Wittouck, 1937*).

II.1.2 Morphology area of Timor trough

The Timor Trough is a fairly long and deep basin as a part of the Sunda Fore-deep, which separates the outermost part of Sunda Arc from the Australian Platform. The area of the Timor Trough has approximately range about 800 km wide with an average deepest depth of 3000 meters (Figure 9). The Timor Trough boundaries in the SW adjoin with Indian Ocean and in the east part adjoin with the Sermata and Aru basins (van Andel & Veevers, 1967).

The north-western slope of the Timor Trough is highly irregular, with numerous steep hills, pinnacles, steps, and scarps. Although the regional gradient averages approximately 3°, local slopes are often 10° or steeper. In the West part, the steps and terraces are generally narrow, and a single slope exists; east of this part the region north of the basin axis is complex and contains several subsidiaries, sometimes flat-floored troughs. These troughs widen eastward and are separated by ranges of hills. Sounding coverage is in adequate to delineate the complex topography of this area, but its structural trend, parallel to the trend of the Timor-Leti-Sermata island chain is clear (van Andel & Veevers, 1967).

II.1.3 Morphology area of Sahul Shelf

The Sahul shelf is a shallow platform in the southern part of Timor Trough that forms the seaward extension of the Australian continent with average wide of 750 kilometres and has a maximum depth of 250 meters (figure 9). The shelf has a flat bowl shape of maximum averaged depth 150 meters which depression of Bonaparte with hills and banks that’s generally smooth, gentle and slopes (van Andel & Veevers, 1967).

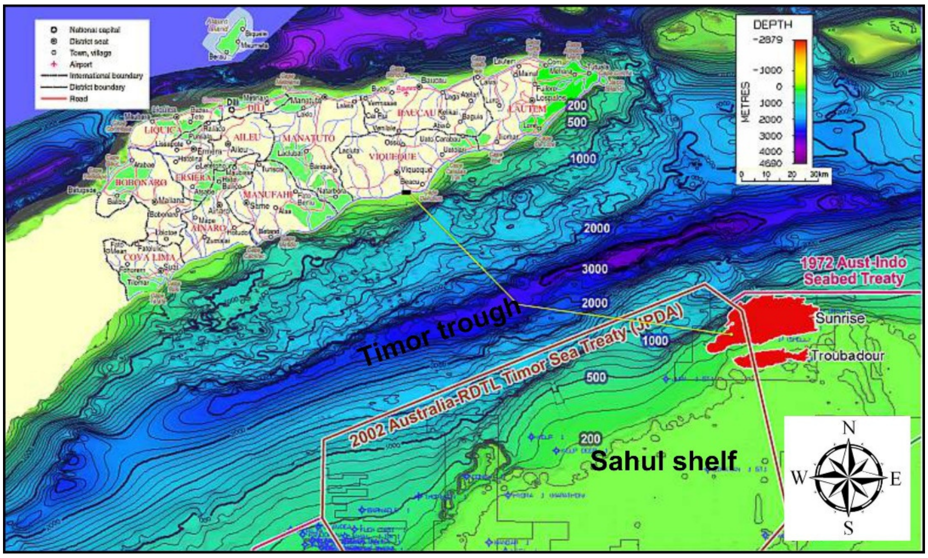


Figure 9. Bathymetry map of the Timor Sea

II.2 REGIONAL SETTING OF TIMOR-LESTE AND SURROUNDING AREA

Tectonically, the Timor Island was formed by the collision event between the Australian continental plate and Euro-Asian plate during the Middle Miocene time (*Harris et al., 2000 in Kenyon, 1974; Hamilton, 1979; Bowin et al., 1980; Abbott e Chamalaun, 1981*). Australian continental crust extends at least to the north coast of Timor (*e.g.Chamalaun et al., 1976*), and the current limit of the Australian Plate likely coincides with the steep gravity low and significant topographic low (N3 km deep Wetar Strait) that lies north of the northern Timor coast (*Audley-Charles, 2004*) (figure 10). *Charlton (2001*) cited that the island of Timor was formed due to the collision between the Australian northwest continental margin and South Asian plate during the Neogene time. The collision result deformed all of sedimentary rocks which were deposited in the Australian continental shelf were uplifted and or obducted to form the Timor island (*Keep e Haig, 2009; Fainstein, 2000)*.

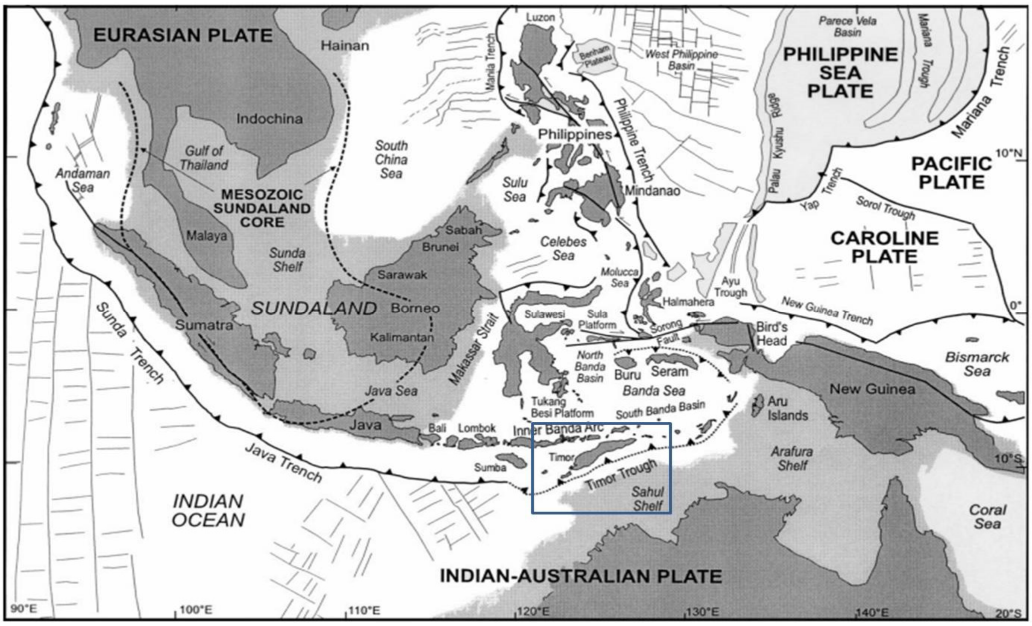


Figure 10. Timor-Leste (microcontinent) situated in the complex context of the Outer of Banda Arc (modified from Hall & Wilson, 2000).

There are three tectonic evolutionary geological models that developed in accordance to these remarkable tectonic events, these models were proposed by *Audley-Charles (1968), Fitch & Hamilton (1974) and Chamalaun & Grady (1978).* These tectonic models are displayed herein below (figure 11):

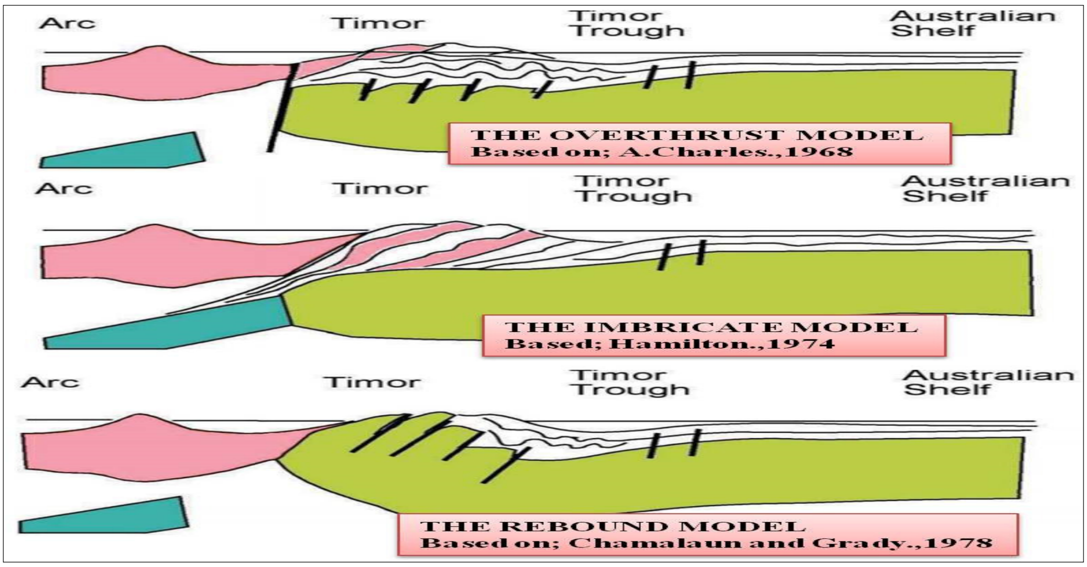


Figure 11. Several proposed tectonics models of Timor Leste (modified from Reed et al. 1996)

The Over-thrust model by *Audley Charles* in 1968, recommend that large scale deformation and erosion of Australian Continental margin sediments occurred during collision, followed by emplacement of thrust sheet from the Asian side of the plate boundary on to the developing boundary (figure 11).

The imbricate model based on *Fitch and Hamilton (1974)* and *Hamilton* (*1978*) interpreted Timor as a large accretionary prism, comprising imbricate blocks of Australian margin and Banda Arc material amidst of a *Bobonaro* Scaly Clay, which they interpreted as tectonic melange (Figure 11).

Chamalaun and Grady (*1978*) proposed the Rebound Model of Timor tectonics after incorporation the field observation with additional gravity and seismic data. The Rebound model interprets Timor as entirely autochthonous, with uplift occurring as the result of isostatic rebound following detachment of the down – going slab. The model assumes that all transfer of exotic material across the plate boundary occurred as olistostromes carried by gravity sliding, resulting in the deposition of the Bobonaro Scaly Clay (sense *Audley – Charles 1968*). The modern consensus is now that the Bobonaro Scaly Clay was placed via shale diapirism (*Barber et al. 1986; Harris et al.1998*), and it is clear that some thrusting of exotic terranes over the plate boundary has occurred, as these have been mapped throughout East Timor (*Audley – Charles 2004; Fainstein, 2000; Fainstein 2003; Keep et al. 2009*). However, the abundance of late-stage high-angle faults does point to components of this model being active during late stage orogeny (*Fainstein, 2000; Fainstein 2003; Keep et al. 2009*).

Those tectonic models of Timor island indicated that continental crust from the Australian plate collision with the Asian plate could have been affected by the sedimentary rocks from Australian continental crust obducted over to form the Timor island with very the complex structures, seen on the island and its offshore continuation.

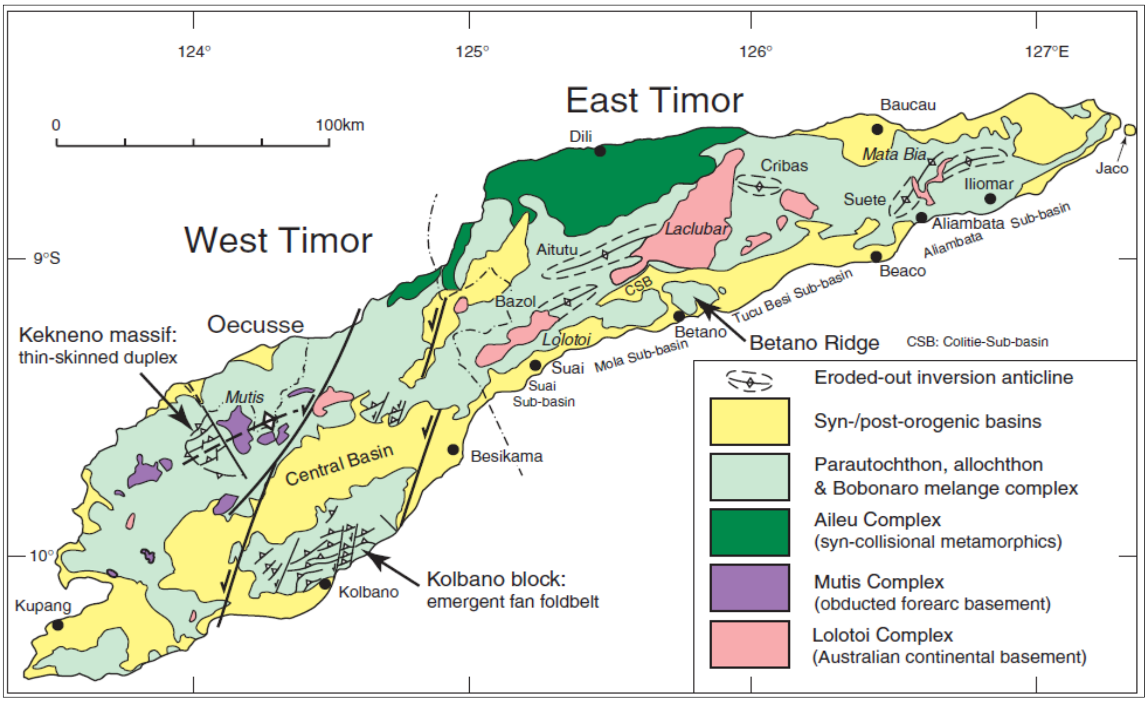


Figure 12. Simplify the tectonics sketch map of Timor Island (Charlton, 2002)**.**

CHAPTER III

EXPLORATION AND PRODUCTION HISTORY OF TIMOR

III.1 Petroleum Resources

The foremost oil and Gas fields of Timor Leste are situated in offshore which undertaken by goverment of Timor-Leste and Australia through joint Petroleum exploration of the Timor Sea by the two countries it formally known as Joint Petroleum Development area – JPDA (*no longer exists and under revision since the established of new maritime boundary between Australia and Timor-Leste on 6th march 2018*) and Timor Leste Exclusive Area - TLEA that's provides the framework for the exploration and development of Petroleum. These blocks are located in the area of Timor Gap which rich in petroleum resources and is therefore of great economic significance to both states. This area lies three main oil and gas resources such as Laminaria and Corallina fields, Bayu-Undan field and the giant gas field of Greater Sunrise (figure 13).

Figure 13. The regional location of all the presently known Petroleum Resources Offshore Block (Northern Territory Geological Survey, 2001)

Additionally, in the onshore part of Timor-Leste, there are many occurrences of Oil and Gas seeps along the middle and southern part of Timor-Leste. That is a remarkable proof that the potential of petroleum resources of Timor-Leste is not restricted only to the offshore but it also occurred in the onshore which needs however further geology and geophysics assessment studies.

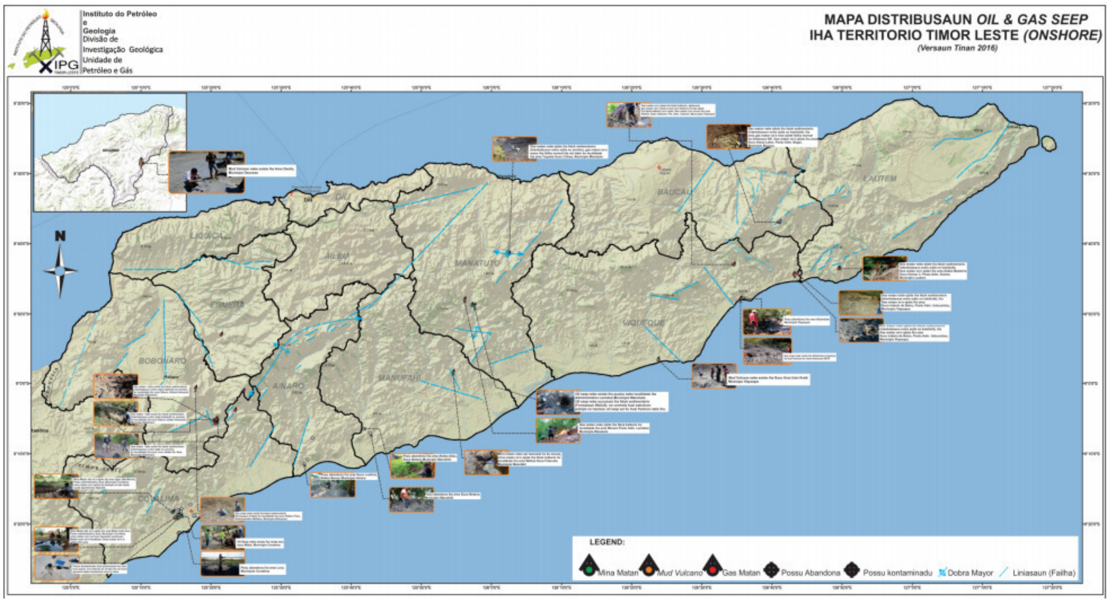


Figure 14. Oil and Gas seep occurrences in the onshore part of Timor (IPG, 2016).

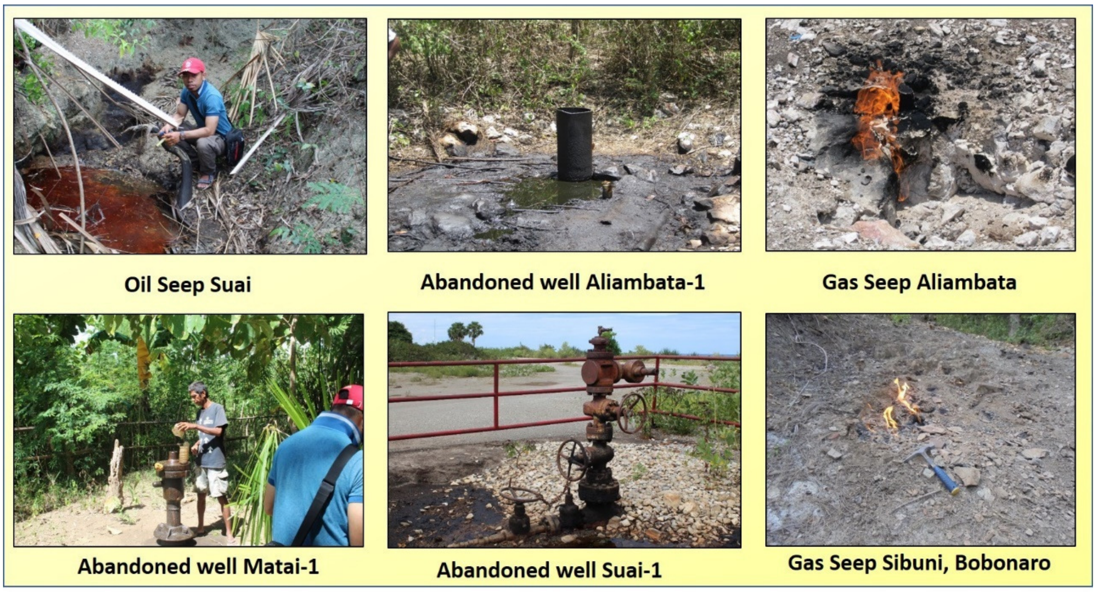


Figure 15. Several images of Oil & Gas seeps occurrences (with corresponding abandoned wells) in the onshore southern region of Timor Leste; these oil seeps are still used for kerosene lamps by local communities. Furthermore, in the Suai River there are Triassic outcrops although the seeps are encountered in recent sandstones.

III.2 Exploration and Production History

- The first geological survey was conducted in 1936 by Allied Mining Corporation (Wittouck in Charlton 2002b).
- First well Drilled at *Aliambata* in 1910 with 140 meters depth (Charlton 2002b).
- In 1914, wells were drilled in *Pualaca*, *Ranoco* and *Matai* with 170 meters depth (Charlton 2002b).
- Further reconnaissance studies by Escher and Grunau for Companhia do Petroleo / Shell with regional Gravity acquired during 1947-1948 (Vening-Meinesz in Charlton 2002b).
- Gageonnet and Lemoine (1958) reported on fieldwork carried out on behalf of L'Institut Français du Pétrole in 1955 (Charlton 2002b).
- Timor Oil in 1956 initial exploration with third well at *Aliambata* (Aliambata -1) up to 1270 metres depth in 1957 and followed by more than 20 wells near Aliambata area, Suai area and Betano (Charlton 2002b).

- In 1968 International Oil commenced oil exploration in West Timor with an offshore seismic survey along the south coast (Charlton 2002b).
- In 1970 the Australian and Indonesian Governments begun the negotiations boundary between the coast of Timor – Australia with ignoring Portuguese Timor objection that the seabed should be demarcated halfway. The treaties "Establishing Certain Seabed Boundaries" between Australian and Indonesian Government that based on the continental shelf principle in 18 May 1971. The absence of Portuguese in the negotiations made these countries could not complete the boundaries between Portuguese Timor and Australia and created the "Timor Gap" zone in that moment.
- In 1970 and 1972 further offshore survey on behalf of Timor Oil and International Oil focused on several areas including offshore Aliambata, Beaco and Suai, south of Timor Leste and areas of West Timor and around south Savu Island further west (Charlton 2002b).
- In 1971 the Arco drilled the Flamingo-1 well in the area of the Timor Sea that resulted the discovery of the gas in that time.
- In 1974 Adobe Oil and Gas of Texas was awarded and exploration block covering the eastern tip of Timor and offshore areas, and Oceanic of Denver, through a Portuguese subsidiary, was granted an offshore contract area beyond the 200 meters shelf limit; no significant geological results have come from these licenses (Charlton 2002b).
- In same year of 1974, Woodside – Burmah Oil NL joined Timor Oil and International Oil subsidiary BOCAL assuming operatorship in both joint ventures, with further seismic survey acquiring and followed by first well drilling in the region named Mola-1 in offshore in 1975 located east part of Suai (Charlton 2002b).
- In the period of 1974 – 1975 the Woodside was discovered the Troubadour and Sunrise gas field recently known as the Greater Sunrise. The fields were discovered and hold gross (100%) contingent resources of 5.13 Tcf of gas and 225.9 million barrels of condensate (net Woodside share 33% of 1.7 Tcf of dry gas and 75.6 million barrels of condensate, Timor-Leste share 30% of 1.54 Tcf of dry gas and 67.8 Mb of Condensate, Shell with 27% and Osaka gas 10%) (Lao Hamutuk, 2008).
- In 1990, Pertamina and Amoseas entered into a Production Sharing Contract (PSC) initiated a further phase of exploration to covering most of West Timor, together with

an offshore area to the south of the Island. This PSC realized extensive field Geological program, together with the gathering of magnetic, gravity, vibroseis and marine seismic reflection (Sawyer et al; Sani et al, in Charlton 2002b).

- In 1993 – 1994, these surveys followed by drilling of the Banli -1 in the Kolbano area of southern West Timor (Charlton 2002b).
- In 1994, Reed et al (1996) reported the results of a reconnaissance field investigation in East Timor carried out on behalf of Mobil Oil Indonesia Inc (Charlton 2002b).
- After the implementation of the Timor Gap zone between Indonesia and Australia in 1991, the new exploration begun in 1994 by BHHP that operated the Elang oil as the first oil discovery in the eastern Timor Sea with 25 MMBO estimation reserves (Roberto Fainstein 1998).
- Followed by the Woodside Petroleum in 1994 discovered the large size of oil accumulations of Laminaria with 200 MMBO reserves and Corallina 80 MMBO reserves, and also drilled the Kakatua oil well by BHHP with 10 MMBO reserves (Roberto Fainstein 1998).
- In the April of 1995, the Shell Development Pty. Ltd conducted 2D seismic survey with 30 lines covering 900,7 kilometers square in the ZOC-A 91-02 block in the Timor sea (ANPM web datasets).
- In the same year of 1995 the Philips Petroleum was drilled the Bayu-1 well that discovered 90 MMSCFD and 5250 b/d of condensates in March and in August also drilled the Undan well with the 26 MMCFD of gas and 1.773 barrels of condensates as a large gas / condensate reservoir. These discoveries were followed by successful completion of the Undan-2 and Undan-3 wells by BHHP during December 1995 and completion of the Bayu-2 well by Philips in February 1996. The Bayu-Undan gas and condensate field in the Timor Sea is estimated to hold over 400 million barrels of hydrocarbon liquids and 3.4 trillion cubic feet of gas (Roberto Fainstein 1998).
- Based on giant discoveries of Laminaria, Corallina, Elang and Bayu-Undan at ZOC-A area during the periods, in 1995 the speculative surveys of the first Geco-Prakla was carried out in April in the eastern of Timor Sea that covered an area more than 1.2 million acres on the outer shelf of Bonaparte Basin. And the Second Geco-Prakla survey was conducted in the end of 1995 in the Western part of the Timor Sea with 1.6

million acres of coverage area. The result interpretation of these surveys is definitely suggestive that the newly proven pre-Tertiary oil and gas Provinces are in the part of Indonesia Timor Sea that was divided in to SABO (1.13 million acres) and RABE (1.6 million acres) blocks for the competitive biddings (Roberto Fainstein, 1998).

- In 1996 the BHHP discovered several oil fields from Buller-1, Jahal-1, and Buffalo-1 (25 million barrels) wells on test from Elang / Laminaria Formations.
- In the end of 1996 during November - December the second survey was conducted by the Geco-Prakla in the Arafura Sea that located in the eastern part of the Timor Sea. This survey was covered more than 3 million acres on the outer shelf and slope of western Arafura sea. From this survey interpretation results the Pertamina-Indonesia delineated this area to the 2 blocks for licensing, such as the Leti block (1.062 million acres) and the Masela block (1.32 million acres).
- The Masela block was contain the giant gas field of Abadi that was discovered by the INPEX in 2000 by the Abadi-1 exploration well, which was drilled between October and December 2000. Four more wells drilled between May 2007 and June 2008 confirmed the presence of significant gas reserves. The field was estimated to contain 10 Tcf (trillion cubic feet) of natural gas reserves (Roberto Fainstein, 1998).
- In January 1997 the Shell Development Australia, UXC acquired 2D seismic survey with 122 lines in length of 5500 kilometers that covered 3 blocks in the ZOCA region (ANPM web datasets).
- In 1997 the Mobil was drilled the Kelp Deep-1 and discovered the gas reserves on the test of Hyland Bay Formation. Otherwise, the Shell also discovered the gas reserves from Sunset-1 well, and the BHHP was discovered the oil fields from the Kakatua-North and Krill-1 in same year.
- The oil production from Laminaria / Corallina fields began in late 1999. During its production history, Laminaria-Corallina generated about $6.8 billion in sales, of which about $2.2 billion was paid 100 % to the Australian government and Timor-Leste did not get its correspondent share (Lao Hamutuk, 2008).
- In September 1998, the BHP Petroleum made 2D seismic survey in the block of ZOC-A 91-01 with that covered 1455 kilometers square. There is lack of information about how many lines that acquired during the survey (ANPM web datasets).

- In December 1999, the Oil production from Buffalo commenced. In 2001, Nexen Petroleum Australia Pty Ltd became the operator of the field and embarked on a development drilling program using the jack-up drilling rig, the 'Ocean Bounty'. During the period of production, there are 4 producing wells on the Buffalo field. Production rates from the field are expected to peak at between 40,000 and 50,000 barrels/day over a three years field life. The Initial reserves at Buffalo field are estimated at 25 million barrels (Department of Primary Industries and Energy, Fainstein1998).
- In 2001, the Woodside drilled the Kuda Tasi-1 well and discovered the oil discovery from the test on the Elang / Laminaria Formations.
- In April 2004 until April 2005, the multi-clients 2D seismic survey was conducted in the Timor-Leste offshore area that operated by Global Geo Services – ASA. This survey was initial by the contract awarded from Government of Timor- Leste to the multi-client seismic contract to a partnership of GGS and the Chinese Geophysical Contractor – BGP which is resulted 6747,9 kilometers square of coverage area (ANPM web datasets).
- In February 2006 the second phase of Bayu-Undan's development, the gas phase, began production and cost \$1.5bn. It has a production capacity of 3.24 million tonnes a year, and ConocoPhillips has entered agreements with the two companies to supply three million tonnes of Bayu-Undan LNG a year over 17 years. The Splits Taxation Revenues for Timor-Leste (90%) and Australia (10%) based on Law no. 3/2003 of 1 July on the taxation of Bayu-Undan contractors.
- In March 2008 the Italian Oil company ENI discovered the Kitan oil field that estimated to be 30-40 million barrels of oil reserves and can be produced up to 20000 bopd. The discovery was made by exploration well Kitan-1, which was drilled by Songa Venus semi-submersible rig to a total depth of 3,568m (www.offshore-technology.com).
- The ENI Timor-Leste. Spa. Also acquired the 2D seismic survey that called Bicuda survey in Timor-Leste offshore area during July to August 2008 with 121 lines (ANPM web datasets).
- The ENI commenced producing in the Kitan oil field in October 2011 and reached its peak of production about six months later. Kitan began paying FTP (royalties) to the

Timor-Leste with 90% based to the Timor Sea Treaty: In September 2012, Kitan paid its first "profit oil" taxes, having paid off its capital investment in less than one year of operation.

- In 2013 the CGG multi-clients conducted 2D seismic survey in the area of Timor-Leste offshore during period of January 2013 – January 2014. There is no clear information about how many lines have been conducted during the survey due to the exploration confidentiality requirements (ANPM web datasets).
- Since today, there have been a lot of survey exploration that conducted in Timor-Leste, 3 seismic 2D survey and 3 Wells in the Timor-Leste Exclusive Area, 58 Wells and 12 seismic 2D survey in the JPDA area since 1971 until recent 2D seismic survey in 2014 in TLEA area that operated by CGG. Most of these surveys (figure 16) are confident and not required for scientific study purposes.

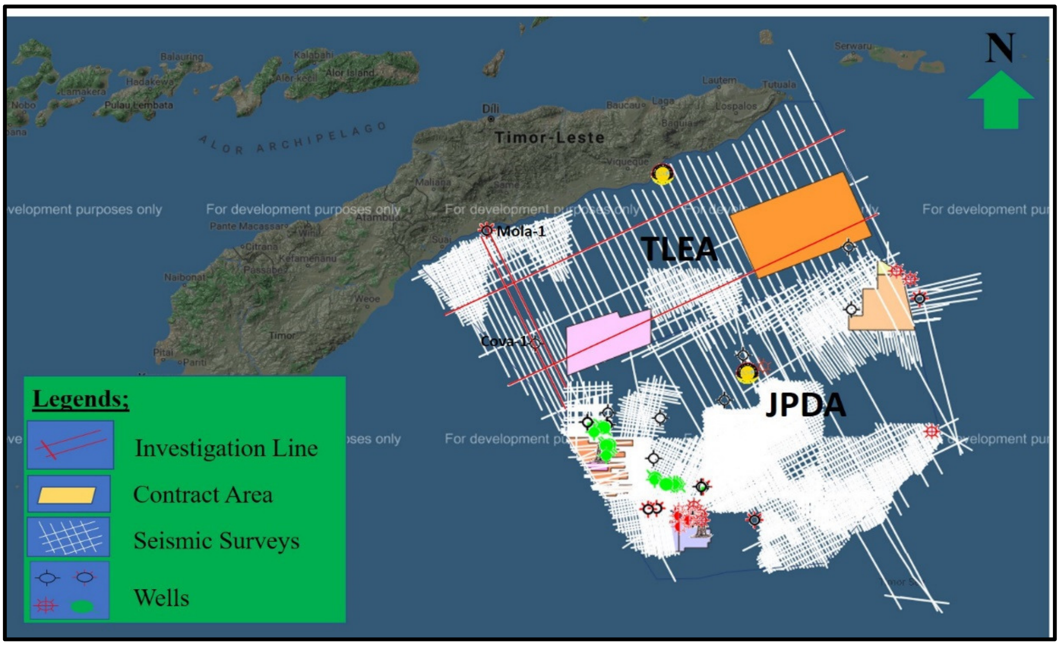


Figure 16. Recent 2D seismic surveys (dip and strike regional lines) carried out in the Offshore TLEA and JPDA areas plus awarded blocks based on ANPM Website Datasets, 2018; these now re-configured.

III.3 Regional Stratigraphy of Timor Island and Timor Sea

Based on (ENI, 2012) Timor regional stratigraphy divided into 2 areas such as Timor Island Lithostratigraphy and Timor Sea Lithostratigraphy. Next, we present a detailed description of the both regional stratigraphy.

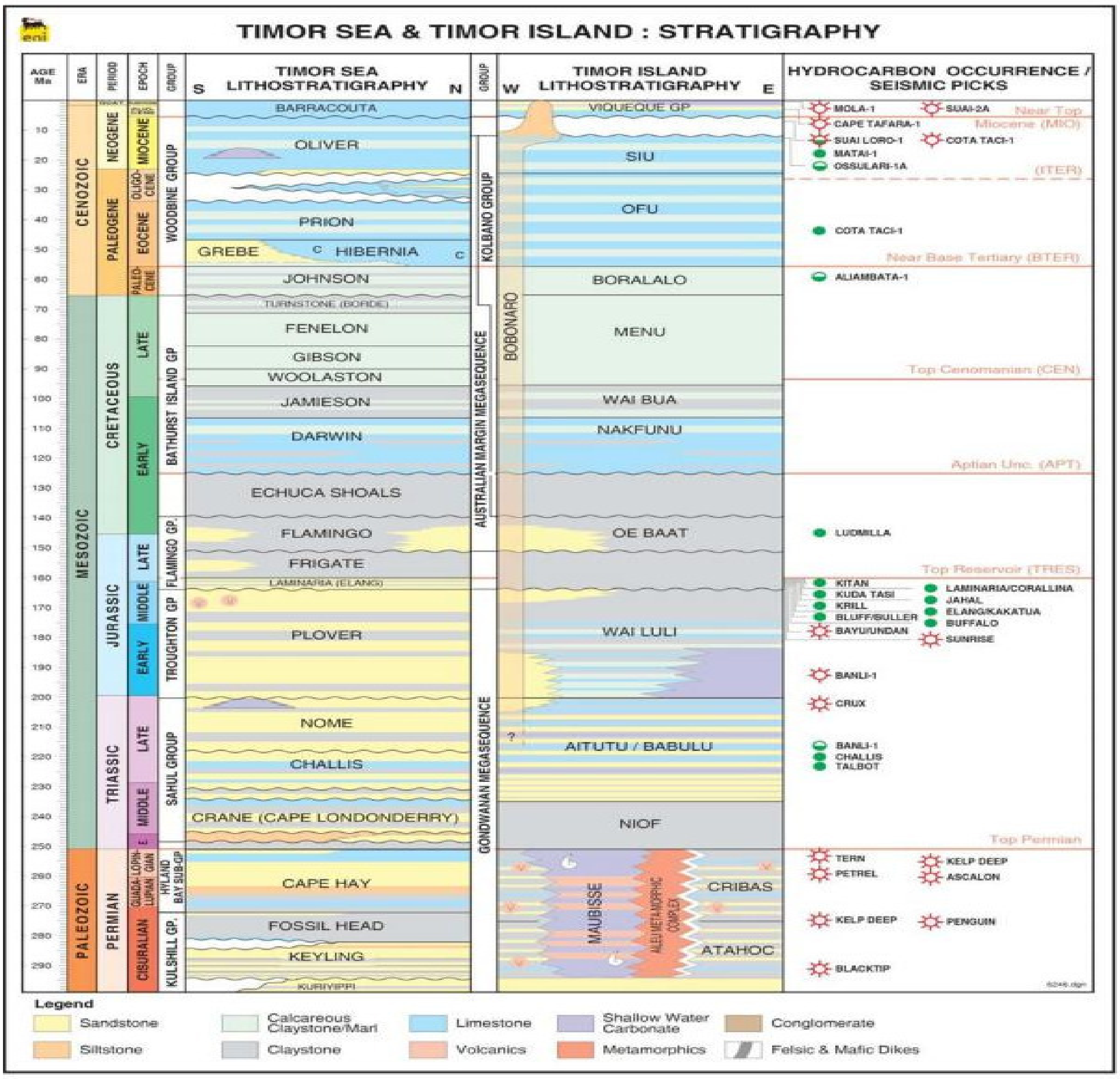


Figure 17. Stratigraphic correlation of Timor sea and Timor Island displaying the occurrences of oil and gas relative to the stratigraphic column (ENI, 2012)

Permian – On the part of Timor Island, The Permian was divided into the lower Atahoc Formation which consisting of quartz sandstone, black shale, calcilutites, amygdaloidal basalt predominating in upper part and calcareous nodules deposited as shallow marine depositional environment with thickness about 600m.

The Maubisse Formation formed of reddish bedded biocalcarenite and reef limestones. The limestone unit is commonly massive but contain interdigitate shales, calcilutites and cherts. This formation deposited in a shallow marine environment with a thickness up to 500 m (S.Bachri and R.I.Situmorang.,1994).

The Aileu Formation of Audley-Charles (1968) is essentially a flysch which becomes more siliceous northwards until near the north coast of Timor, where metaquartzites, micaschists, marbles, metabasics and amphibolites outcrop (Berry and Grady,1980). There is a clear metamorphic zonation from low green-schists in the southwest to upper amphibolite on the north coast. The metamorphic maximum may have occurred in the Jurassic, affecting Paleozoic sediments deposited in a graben. The arc-continent collision in the Late Miocene/Pliocene ended the metamorphic phase by uplifting the Aileu Formation (Berry and Grady,1981).

The later Permian of Cribas Formation which consists of shales, siltstones with quartz-arenites, micaceous quartz sandstones, calcilutites dominating upward and nodules. Permian *foraminifera* and *polycypods* have been reported previously with shallow marine depositional environment with thickness around 500m (S.Bachri and R.I.Situmorang.,1994).

On the offshore part of the Timor sea, The Permian age formations consist of the Kulshill group and Hyland sub – group which began from the middle to the end of Permian. The Formations of the Kulshill group that existed in Timor sea consists of Kurriyapi Fm, Keyling Fm and Fossil Head Fm, while the formation of the Hyland sub – group is the Cape Hay Fm (ENI, 2012).

The Kurriyapi Fm is part of the Kulshill group that was late Carboniferous (Stephanian) age to early Cisuralian (Permian) with a basalt rock unit consisting of sandstone and minor siltstone. This formation has a thickness between 30-90 meters which represents the fluvial depositional environment at the bottom with a sequence of upward-finning siliciclastic which overlays the sequence of glacial siliciclastic from the glacial floodplain depositional environment at the top (Mory, A. J., 1991).

The Keyling Formation consists of a predominantly siliciclastic sequence with minor amounts of coal and limestone at the top of the Kulshill Group. Palynological evidence suggests that the unit is equivalent, in part, to the Fossil Head Formation. The Keyling Formation contains microfloras of the *Grunulatisporites confluens* Oppel-zone and Stage 3a that indicate an Asselian to Sakmarian age. The presence of minor amounts of limestone throughout this unit (especially in Barnett I), and coaly horizons, suggests the Keyling Formation was deposited in fluvial to deltaic environments (Mory, A. J., 1991).

The Fossil Head Formation conformably overlies the Keyling Formation. Palynological evidence suggests that the Fossil Head Formation is equivalent, in part, to the upper part of the Keyling Formation. The lower part of the Fossil Head Formation was probably deposited as prodeltaic muds, as the lower part of the unit is coeval with the deltaic Keyling Formation.

The Hyland Bay Formation contains a *prolific* Stage 5 *microflora* (Kungurian to Kazanian - late Early to Late Permian). The depositional environment of the Hyland Bay Formation commenced in an open-marine environment (Pearce Member) and was followed by deltaic progradation (Cape Hay Member), due to uplift along the Halls Creek Orogen.

The Cape Hay Member (‘Hay Member’ of Bhatia et al., 1984) is the interval of sandstone, mudstone, and siltstone which lies between the two limestone members of the Hyland Bay Formation. Based on well intersections, it varies in thickness from 200 to 450 m (Mory, A. J., 1991).

Triassic – The rocks units of the Triassic in the Timor Island, composed of the Niof Formation, Aitutu Formation, Babulu Member and Broken Formation of Bobonaro. The Niof Formation based on Haig 2011 consists of mainly shale with color banding in some sections. The Niof Formation contains *Amonoids*, *Bivalves* and *Palynomorphs* that shows the range age of the Formation is early to middle Triassic (Haig, 2011).

The Aitutu Formation consists of radiolarian, rich of calcilutites, and dominated with interbedded shales, these shallow marine environment units present a thickness up to hundreds of metres. The range ages of the Aitutu Fm is middle to late Triassic that indicated by fossils contains such as *Conodonts, Palynomorphs, Radiolaries, Forams* and *Bivalves (Halobia)* (Haig, 2011).

The Babulu Member is stratigraphically interfingering with Aitutu Formations and consists of Middle Triassic of well bedded sandstones and shales, and contains of *Palynomorphs, Bivalves (Halobia)* and *forams* (Haig, 2011). The depositional environment is deep marine.

Due to the lithostratigraphy of the ENI 2012 consider that the Bobonaro Formation is an intrusion as a diapir from the Triassic Formation units to the Upper of Pliocene. Besides of the lithostratigraphic of the ENI 2012, but also there have been several interpretations about genesis of this formation, i.e.: which is as 1) Olistotrom units (Audley Charles, 1968), 2) a tectonic mélange unit (Hamilton, 1979), and 3) a result of shale diapir intrusion unit (Barber et al, 1986). The actual age of this formation is still debated among geological researchers, where for there are some geological description on the formation. Besides that, the Presence of the Triassic formation on the Timor sea are parts of Sahul Group. The group reaches a maximum thickness of approximately 2200 m in this area are Crane (Cape Londonderry), Challis Formation and Nome Formation (Mory, A. J., 1991).

The Crane Formation (Cape Londonderry) consists of sandstone and lesser amounts of siltstone and shale. the presence of *Triplexisporites playfordii* Zone in Tern 3, confirms its stratigraphic position to be Smithian to Ladinian (Early to Middle Triassic) in age. The predominance of coarse- grained siliciclastic lithologies throughout the Cape Londonderry Formation indicates a fluvial braided-stream environment. Finer grained rock types and thin coals are probably over-bank deposits (Mory, A. J., 1991).

The Challis Formation consists of interbedded shale, sandstone, and carbonate. The Challis Formation contains palynomorphs of the *Samaropollenites* speciosus Zone that indicate a Ladinian to Carnian (Middle to Late Triassic) age. A shallow, marginal-marine environment is envisaged for most of this formation, based on the common presence of shale, sandstone, and fossdiferous oolitic carbonate (Mory, A. J., 1991).

The Nome Formation is the uppermost unit of the Sahul Group; it consists of interbedded sandstone, siltstone, and shale, with minor amounts of coal. The Nome Formation lies conformably between the underlying Challis Formation and overlying Malita Formation; the upper contact is probably diachronous. The Nome Formation contains palynomorphs of the upper *Samaropollenites speciosus*, *Minutosaccus crenulatus*, and *Shublikodinium wigginsii* Zones. Although these zones indicate a Ladinian to Norian (Middle to Late Triassic) age. The stratigraphic position of this largely coarse siliciclastic formation between a marine unit (below) and a non-marine red-bed sequence (above), and the presence of minor amounts of coal, suggest either a delta plain to delta front, or a barrier complex environment (Mory, A. J., 1991).

Jurassic - The Jurassic Formation in the Timor Island consist of Wailuli Formation and Oe'baat beds. The Wailuli Formation ranges from Late Triassic to Middle Jurassic in age, and contains of *amonoids, nannofossils, palynomorphs* and *forams*. The Wailuli Formation consists of blue grey-marls and calcilutites overlain by calcareous shales (Haig, 2011). The formation containing belemnites, increase upwards that represents turbidities in relatively deep marine environment with the thickness up to 600 – 800 meters (S. Bachri and R.I.

Situmorang.,1994). The Oe’baat beds consist of various colored mudstone and sandstone. The Oe’baat beds containing *bivalves, belemnites, ammonites* and *nannofossils* that indicates the ranges age of the formation is late Oxfordian to Tithonian (Late Jurassic) (Haig, 2011).

On the Timor sea, there are Malita Formation, the Plover Formation, Laminaria (Elang) Formation, Frigate Formation and Flamingo Shale.

The Malita Formation is characterized by multicolored siliciclastic rock types (red beds), especially siltstone and mudstone. Fine to coarse-grained sandstone is also common throughout the unit, which contains rare occurrences of glauconite and shell fragments. In most of the Petrel Sub- basin the Malita Formation lies conformably between the Cape Londonderry Formation (below) and the Plover Formation (above). On the Sahul Platform, western Ashmore Platform, and basin margins, the Malita Formation has been removed by Late Jurassic erosion (Mory, A. J., 1991).

The Plover Formation consists largely of sandstone, but significant siltstone and claystone interbeds occur throughout the unit. The Plover Formation is a predominantly coarse-grained siliciclastic unit that contains minor marine indications and thin coals, indicating deposition under fluvial to coastal conditions and it’s probably deltaic in origin. The Plover Formation ranges in thickness from 104 to 672 m, but the erosion during the Oxfordian - Kirnmeridgian (‘breakup unconformity’) has removed much of the unit, especially on the central part of the Londonderry High, and the present thickness is probably much less than the original thickness of the unit (Mory, A. J., 1991).

The Laminaria Formation consists of sandstones with the ranges age of middle Jurassic to late Jurassic. This formation equivalent to the Elang Formation that composed of Quartzose, very fine- to fine-grained, moderately well-sorted sandstones with interbedded siltstone and claystone with the maximum thickness of 150 meters (Whittam et al, 1996).

The Frigate Formation is the oldest unit of Flamingo Group (Brown, 1992). The Frigate Formation consists largely of grey to green-grey shale and siltstone, with thin beds of fine-grained sandstone and sandy limestone, and based on Helby (1974) determined this Formation as an Oxfordian to Tithonian (Late Jurassic) ages. The Frigate Shale disconformable overlies the Plover Formation of the Troughton Group. The unit has a maximum thickness of 250 m in Petrel 1 and thins towards the Londonderry High and Sahul Platform. The presence of shelly

material and glauconitic lithologies in this fine-grained unit indicates deposition in a low energy marine-shelf environment (Mory, A. J., 1991).
The uppermost unit in the Flamingo Group is the Flamingo Shale which is also called as a Flamingo Formation. The Flamingo Shale is best developed in the grabens, with the minor developments of the lower parts of the unit on the margins of the grabens. The age of the unit is Berriasian to Berremian and relatively deposition of this unit took place in the deep marine conditions (R.K. Sawyer, Kartono Sani, 1993).
Cretaceous – In the part of Timor Island, the cretaceous formation The Waibua Formation, with around 500m in thickness, ranges from Late Jurassic to the Late Cretaceous, consists of radiolarian shales, bedded cherts, radiolarite, calcarenite and calcirudite; deposited in a marine environment (S. Bachri and R.I. Situmorang, 1994). In the Timor Sea, the Flamingo Group was overlain by the Bathrust Group that separated by the hiatus or erosional unconformity. This part of the Hiatus or Erosional unconformity on the regional stratigraphy of the ENI 2012 consider as part of the Echuca Shoals Formation that consists of the Predominantly an extensive claystone; organic-rich, oil-prone marine shale with the range ages of Valanginian to Aptian (Pattillo, J., Nicholls, P.J., 1990).
The lowermost unit in the Bathrust Group is Darwin Formation that ranges from late Barremian to Aptian (R.K. Sawyer, Kartono Sani, 1993). This Formation consists of basal glauconitic claystone and greensand, overlain by radiolarian claystone to calcareous sandstone. The glauconite content of the basal sandstone in outcrop is masked by feminizations. Near Darwin, the basal sandstone of the formation is estimated to contain up to 90% glauconite grains (Mory, A. J., 1991).
Overlies with the Darwin Formation is the Jamieson Formation with the monotonous succession of silty claystone's, with occasional thin limestone or dolomite stringers and ranges from Aptian to Cenomanian age (Pattillo, J., Nicholls, P.J., 1990).
The rock units in the Late of Cretaceous that ranges from Cenomanian to Turonian composed of Pelagic marl, hemipelagic marl and limestone which is considered part of the Woolaston Formation (Pattillo, J., Nicholls, P.J., 1990).
Overlies with the Woolaston Formation is The Gibson Formation which is consists of deep-water limestone; pelagic marl, hemipelagic marl and limestone and the Fenelon Formation that consists of calcareous claystone, marl and some medium grained sandstone of Late Cretaceous.

While the Upper unit of the Bathrust group is the Turnstone Formation of the Late Cretaceous (Campanian to Maastrichtian) that consists of the Calcareous claystone's and calcilutites.

Paleocene - The Borolalo Formation is made of thickly bedded or massive limestone, with chert intercalations and calcareous shale, containing foraminifera ref. This formation deposited in a deep sea environment with more than 200m of thickness (S.Bachri and R.I.Situmorang, 1994).

While, in the part of the Timor sea existed the units of the Johnson Formation that consists of Limestone and minor sands of the Paleocene ages (Pattillo, J., Nicholls, P.J., 1990).

Eocene to Late Miocene – in the Timor Island in this range of ages commenced with the Ofu Formation which was overlies with the Borolalo Formation in the early eocene to early miosene in age (ENI, 2012). Bachri 2015, stated that the deposition process of Ofu Formation began after the occurrence of erosional activity that occurred at the end of paleocene. This formation consists of massive limestones with the appearance of conchoidal to sub-Conchoidal fractures. Mostly outcrops of this Formation there are generally thin laminates, calcite veins, stylolite's, stocky, and fractured. This formation is deposited on the deep-sea environment with a turbidite mechanism.

Overlies with the Ofu Formation was the Siu Formation with ranges of Early Miocene to middle Miocene in ages and generally the formation consists of Sandstones and Limestones based on ENI 2012 lithostratigraphy. Charlton 2002 considered this Formation equivalent to the Aliambata formation in the eastern part of Timor where in the Bachri 1994, described that the Aliambata Formation was also forming in the early of Miocene that consists of poorly bedded limestone and contains abundant foraminifera with is more than 100 meters thick**.**

Due to the tectonic events in the late of Miocene during collision between Australian Continental with the Outer of Banda Arc, caused the mayor hiatus or erosion in that time. This process resulted the distribution of the Viqueque Formation. This Formation with the thickness around 800 meters and mostly consists of marly conglomerates, thinly bedded claystones with intercalations of chalky limestones, tuffs, silts and sandstones; This formation that contains foraminifera, deposited in a litoral to epineritic environment (S.Bachri and R.I.Situmorang, 1994).

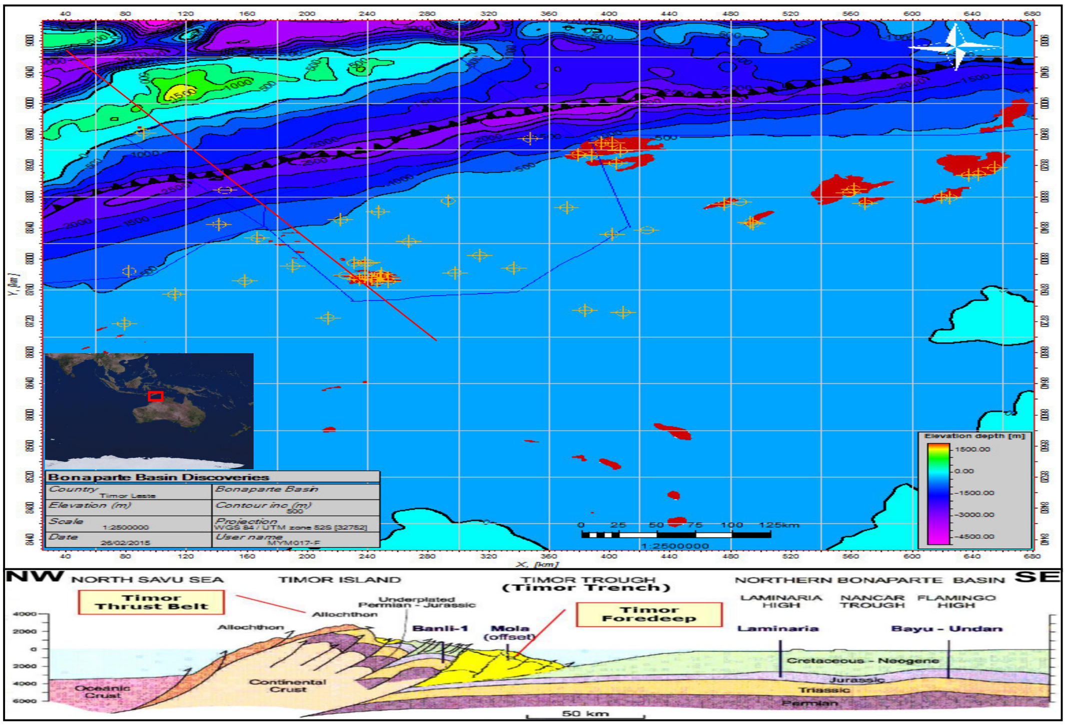


Figure 18. Regional stratigraphy cross section of Timor onshore and offshore.

III.4 Petroleum Geology

Based on the stratigraphy, the Para- Autochthon unit's distribution in Timor-Leste both in onshore and offshore shallow and deep-water part are considered capable of acting as rock elements in the petroleum system on the Timor area (figure 19).

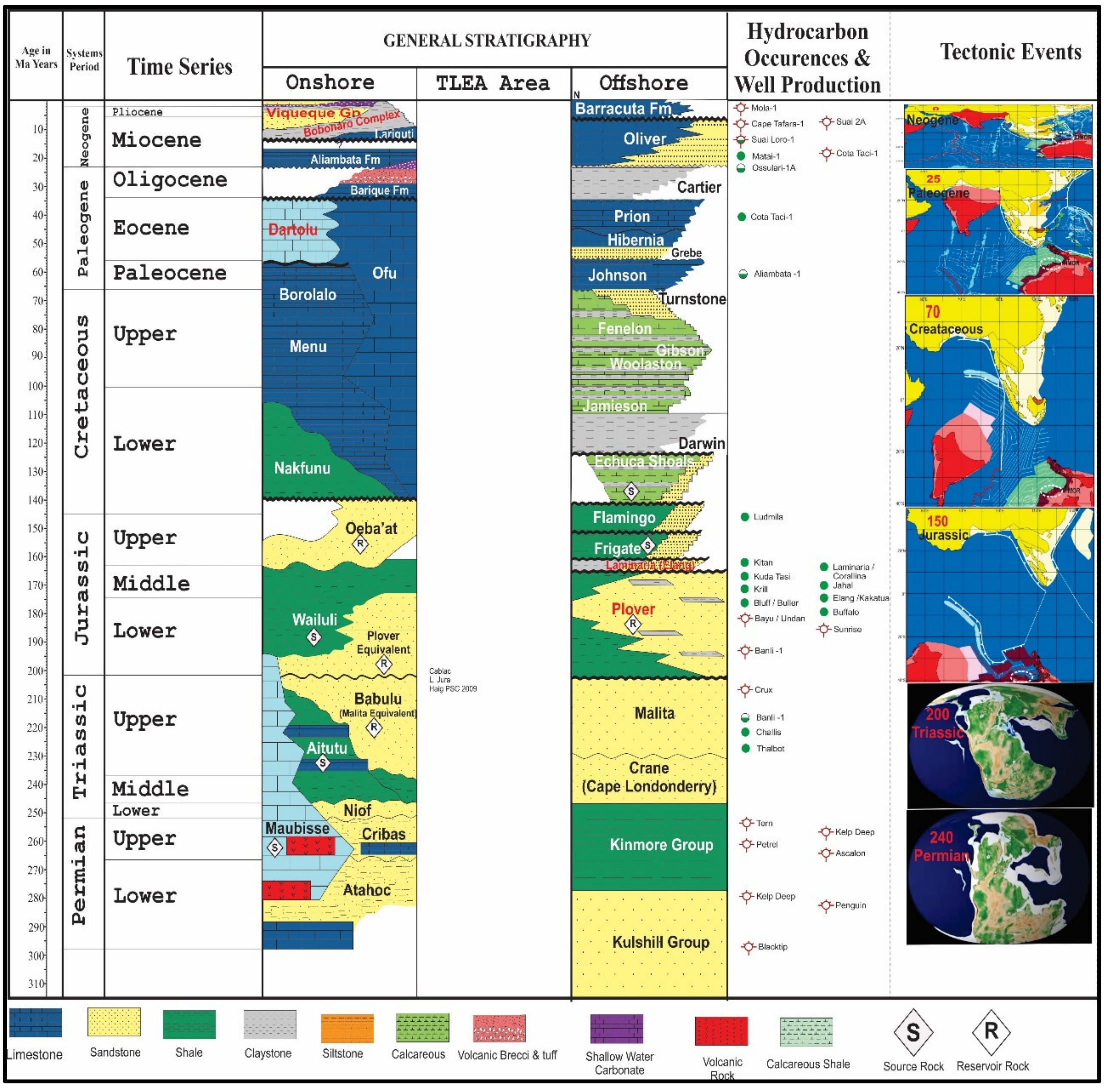


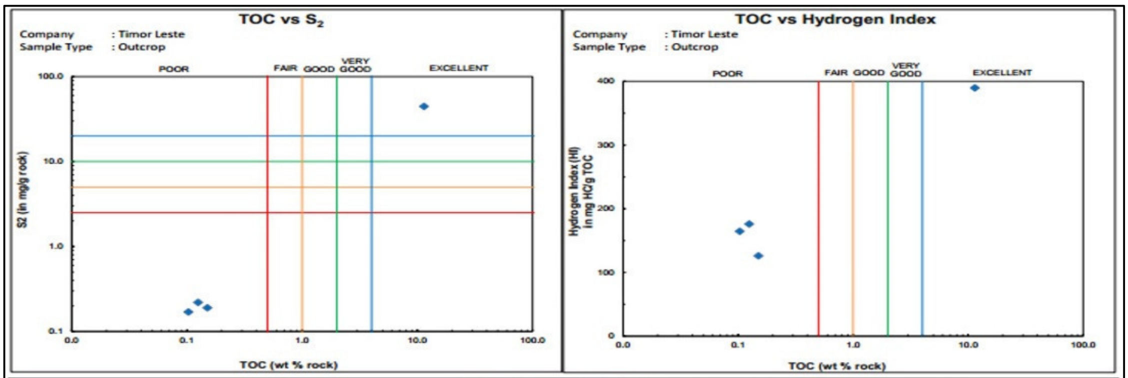
Figure 19. Regional Petroleum geology and stratigraphy markers of Timor and Northern Bonaparte Basins

III.4.1 Source Rock

The Rock units that are considered have suitable physical properties as a source rock is a unit's rock of Upper Permian to Lower Jurassic (Figure 19). These rocks unit deposited in marine environment that mixed with the carbonate and clastic sequences and also proved by Geochemical analysis of Total Organic Content (TOC) for these units.

From the previous geochemical analysist for hydrocarbon potential in Timor-Leste has been described that the rock units from Permian to Jurassic age as a best class of source rock. This is proven by Bachtiar on 2013, described from the surface and well sampling resulted that, the total organic content (TOC) ranges for black shale of Atahoc Formation (0.5 – 1 %), shale of Cribas Formation (0.15 – 1.45%), shale of Niof Formation (0.26 – 0.35%), Shale of Babulu (0.7 -1.15%) and shale of Wailuli (0.5 – 1.33%).

Intituto do Petróleo e Geologia in 2017 also made analysist to the quality of the source rock by surfaces sampling on samples from pyrolysis and TOC data and resulted how mixed type of II/III (figure 20). All triterpenes biomarkers generally exhibit characteristic of marine algal as organic matter with marine depositional environment, and also sterane composition has indicated sample to be originated from mixed diatom or algal organic matter that were deposited in marine depositional environment. Based on lithological description of MT 23 LG that was used to analysed for TOC (11.44%), these characteristics were expected as a part of the Triassic Formation of Aitutu.



TOC and Pyrolysis Analysis Data
Perusahaan/Instansi : PSG

No.	Sample ID	Sample type	Litology Description	TOC (%)	S1 (mg/g)	S2 (mg/g)	S3 (mg/g)	PY (mg/g)	Tmax (°C)	PI	PC	HI	OI
1	MT 11 LG	Outcrop	Limestone, light grey, massive, Calcareous	0.12	0.05	0.22	0.12	0.27	432	0.19	0.02	176	96
2	MT 17 LG	Outcrop	Limestone, light grey, massive, Calcareous	0.10	0.04	0.17	0.11	0.21	440	0.19	0.02	165	106
3	MT 23 LG	Outcrop	Shale, dark grey, massive, non-Calc	11.44	0.52	44.60	2.08	45.12	416	0.01	3.74	390	18
4	MT 63 VM	Outcrop	Sandstone with carbon streak, light grey, massive	0.15	0.04	0.19	0.04	0.23	441	0.17	0.02	126	27

Remarks :
TOC : *Total Organic Carbon*
OC : *Outcrop /Singkapan*
PY : Total Kandungan Hidrokarbon = (S1 + S2)
PI : *Production Index* = (S1/ S1 + S2)
PC : *Pyrolysable Carbon*
Tmax : Temperature maksimal (°C) saat puncak S2 paling tinggi
HI : *Hydrogen Index* = (S_2/TOC) x 100
OI : *Oxygen Index* = (S_3/TOC) x 100

Figure 20. TOC and Pyrolysis analysis Data for Source Rock Potential (IPG, 2017)

Otherwise, Peters et al (1999) and Ware and Ichram, (1997) in Charlton 2002b, also made geochemical analysis for the oil seeps samples from Aliambata and Pualaca area. From the analysis resulted the oil seeps from Aliambata has low sulphur (0.08%) and 25^{o} API gravity with lack of the oleanane indicates an absence of flowering plants which is interpreted as

Jurassic or older source, and another sample from Pualaca seeps was interpreted by biomarkers as source from an Upper Triassic – Middle Jurassic sequence.

Jurassic shales of Wailuli Formation in Timor are the lateral equivalent of middle Jurassic shales in the Plover Formation (Figure 19). Audley-Charles (1968) interpreted the Wailuli Formation deposited in very shallow marine environments at least locally anaerobic, and possibly in a series of closed stagnant basins.

III.4.2 Reservoir Rock

The potential reservoir rocks which is suitable as a reservoir are the sandstones units from Triassic Babulu, Jurassic Wailuli, and upper Jurassic of Oe'baat Formation (figure 19). This formation has been proved by in the exploration of the Banli-1 in the West Timor, where the principal reservoir target was sandstones of the Upper Jurassic of Oe'Baat Formation, with a secondary target in turbiditic sandstones in Triassic Babulu Formation (Sani on Charlton 2002b).

Bachri in 2013 cited that, the sandstones units of Viqueque Formation that ranges from Pliocene to Pleistocene in age with shallow-deep marine that composed of marl with interbedded limestones and sandstone have average porosity of 15% and considered as a good potential of reservoir rocks in mainland area. However, the limestone intervals in the pre – orogenic sequence also expected to maintain good primary reservoirs and also the limestone units of Batu-Putih Formation with basal interval of the post-orogenic sequence extremely has a high porosity and should prove to be an excellent reservoir (Crostella and Powel,1975).

The Malita equivalent consist of Upper Triassic shallow marine siliciclastic that found in the well Banli-1 perhaps similar to the Nome or Chalis Formations of Londonderry High and Ashmore Platform (Mory,1988 in Charlton 2002b) rather than with the non-marine fluvial reds of Malita Formation. However, on the Australian margin, the fluvial Malita formation is a potential reservoir target, and the middle – upper Triassic marginal marine strata form the main reservoirs in the Challos and Talbot fields of the Vulcan Sub-basin (Wormald, 1988; Bourne and Faehrmann, 1991 in Charlton 2002b). Reservoir quality is described as excellent, with effective porosities in the main reservoir sand averaging 29%, and horizontal permeability ranging between 500 – 7000 millidarcy (Charlton, 2002b).

In the Northern Bonaparte basin, the Plover Formation consist of fluvio-deltaic sandstones with variable proportions of shale and minor coal, ranging in age from lower to Middle Jurassic. The Plover Formation forms part of the Reservoir sequence in the Jabiru field of the Vulcan Sub-basin and the Laminaria and Corallina fields immediately south of Timor (Charlton 2002b).

In the Jabiru, Lower Jurassic beach, Barrier Island and tidal channel sands of the Plover Formation average 21% porosity and have permeability's in the range 600-10000 md (Mac-Daniel 1988 in Charlton 2002b). And in the Laminaria and Corallina fields the Plover Formation contains excellent reservoir quality sandstones, with porosities about 17% and permeability's up to 2500 md (Smith in Charlton 2002b).

III.4.3 Seal Rock

On the Onshore part, the Shales units of the Middle Jurassic of Wailuli Formation was considered as the primary sealing horizon for the main potential reservoir sequences of the sandstone unit of Malita and Plover equivalents (Charlton, 2002b). The Stratigraphic thickness of the formations in the Banli-1 well exploration it's only about 100 meters thick compare to the measured stratigraphic thickness based on Audley-Charles 1968 that indicate up to 1000 meters thick. The differences thickness that reducing in the Banli-1 well shows that may be result of significant thinning, that also form the primary decollement horizon that separating shallow-level structural complexity from a deeper, less intensely deformed structural domain (Charlton, 2002b). These shales that encountered with a substantial thickness in the well Banli-1 can be a prospective sealing despite of the fairly intense structural thinning of the Wailuli Formation.

In the Offshore part, from Cova-1 well exploration indicate the carbonates and the shales units of the upper Jurassic from the Frigate Formation and the Flamingo group can be a good prospective sealing for the Reservoir of Malita and Plover Formations (Charlton, 2002b).

III.4.4 Trap

From the geological and geophysical that have been carried out from the previous exploration have been indicated the presence of some main traps, such as the stratigraphic and anticline structure traps. These traps forming from different units of Sandstone and Limestone of the Atahoc, Cribas, Aitutu, Wailuli and Viqueque (Bachtiar, 2013).

CHAPTER IV

METHODOLOGY OF STUDY

For this technical study purpose, there were several methods that were applied so as to obtain maximum exhaustion of the available data study results during the entire research process. This Investigation methodology included:

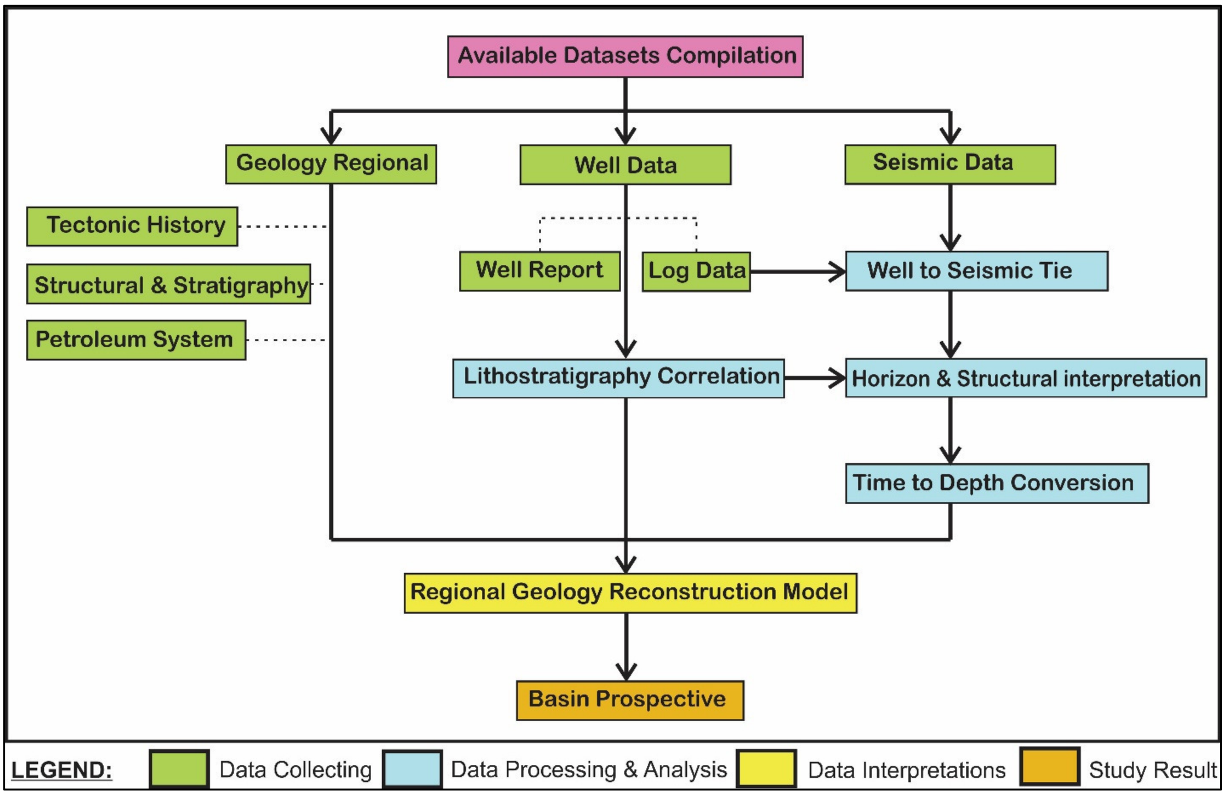


Figure 21. Flowchart for Method of Investigation utilized in this thesis work

IV.1 Reference study of Timor-Leste

The activities undertaken involved collecting many of the previous studies related to the Geological research in Timor-Leste. During the collection process, the author utilized every detail of information that has been obtained from previous research studies concerning Timor-Leste in order to merge these into a unified information effort to be used during the whole of the research process, particular emphasis on the interpretation of new data.

Therefore, information utilized in this reference study consist of, geological information about Timor-Leste tectonic history, its geological structure and stratigraphy, and moreover information leading to hydrocarbon prospectively and the related petroleum system in the area of Timor.

IV.2 Data Support

The geological investigation for the exploitation of natural resources in Timor-Leste that foremost includes hydrocarbon resources prospecting was hence supported by all the available data in hand to support this study. The author utilized the support of the various datasets from previous regional exploration and field geological (onshore part) information in Timor-Leste and tied these to the drilled wells data information, as per the table below that refer to the two wells that were tied to seismic regional data.

No	Type of Data	ID	Location
1	Well data (Las)	Mola-1 Cova-1	TLEA
2	Well Report (Pdf)	Baleia-1 Banli-1 Jahal-1	TL Offshore (Bayu) Onshore (Indonesia) TL Offshore (Laminaria)
3	Seismic (SGY)	4 Line	TLEA

To support the analyzing and interpretation process, there are also need related field geological survey and secondary data from many previous geological investigations of in the onshore part southern Timor-Leste, that are useful as a geological information about structure, stratigraphy, hydrocarbon prospecting and many others that related to use for this case study.

IV.3 Discussion of Procedures

Well data and seismic regional profiles were loaded into workstation utilizing a Petrel 2017 Schlumberger License. Horizons that were interpreted and mapped included the sea-floor, Miocene, Cretaceous, Jurassic Break-up Unconformity, top Triassic and Top Permian. The purpose of these mapping was to reveal the prospects on the Jurassic, Triassic and Permian.

Analogues were searched from previous work established nearby in the Timor Sea such as the Jurassic oil reservoirs in the Bayu-Undan and the gas-condensate reservoirs in the Sunrise - Troubadour areas.

Interpretation workflow included the investigation of dominant frequencies and bandwidth, analyses of amplitudes, seismic attributes, sections flattening, TWT picking of reflectors, and time structural mapping.

The mapping, tied to the wells on the shallower strata, revealed a series of horst graben patterns in the deep-water of the Timor Sea, these could be upgraded from leads to prospects once more data becomes available from new surveys. Be it as it may, several attractive fault blocks were mapped in which reservoirs targets the Cretaceous carbonates and Jurassic sands. Triassic carbonates and Permian carbonates, all pointing out for the possibility of a significant future discovery.

The interpretation mapping for lead/prospect evaluation was restricted to the deep-water areas in the unaffected side of the subduction zone. In the accretionary wedge the predicament concerning the interpretation was the broken-up nature of reflections due to the intense compressive efforts that continue into present geologic time. Therefore, in the accretionary wedge interpretation was more focused into understanding development of the fault imbricates, these reverse faults also defining block boundaries.

IV.4 Investigation Results

The perspective result from this study will be based on the geological evidence from geophysical and geological interpretation such as;

a. The stratigraphic correlation of the investigation area;

   The stratigraphic correlation is a preliminary result which will be indispensable before a seismic horizon analysis, which previously carried out a well seismic tie process between well data and seismic data. The purpose of the well tie process is to be able to occupy the same depth position between the seismic data and the data well so as to facilitate the process of stratigraphic horizon interpretation which ultimately results in a proper stratigraphic correlation.

b. Geological structure;

   After the process of regional structure analysis results, the interpretation will support geological information which is to lead us to determine the several structure that develops and controls the hydrocarbon play in the study regions.

c. Hydrocarbon play;

Process to determine the Hydrocarbon play in the regions are based on the stratigraphic correlation and regional structure analysis and interpretation results of well and seismic data, based on subsurface geological models or maps. In determining Hydrocarbon play, the play components must consist of several components of petroleum system, such as;

- Source Rock; is the rocks units or formations that are considered as a source rock based on interpretation results must relevant to several physical parameters such as, must have a proper level of maturity to produce Hydrocarbon that based on age and temperature, and rich in organic material content. Rocks that are feasible as source rock are rocks that form in the depositional environment of deep seas, lakes and marine deltas.
- Migration Path; is the process when Hydrocarbon moves from Source rock to the Reservoir through a path that results from geological structural processes such as faults and fractures. The structure generated around for Hydrocarbon migration is often called the migration path.
- Reservoir Rock; Reservoir rock must have a large degree of porosity and permeability and become a container that can accommodate Hydrocarbon fluid during the displacement. Usually rocks that have physical characteristics are deposited in the shallow marine environment, the deposit fan and turbidite environments.
- Trap Rock; Trap is a structure that allows Hydrocarbon to be trapped, usually in the form of structural traps and stratigraphy.
- Cap Rock; is rock units with the impermeable characteristics which is cannot be passed by fluid or Hydrocarbon. These rocks become a solid shield that cannot pass Hydrocarbon elsewhere and will continue to be stored properly in a trap.

d. Basin Prospect Evaluation;

After defined several Hydrocarbon Play that existed in investigations area based on the regional stratigraphy and structure interpretation from regional wells correlation and seismic interpretation. The information of the existed Hydrocarbon Play in the regions, will be leads to determine the existence of a basin that has a preliminary prospect that deserves to be used as an exploration area in the future.

CHAPTER V

GEOPHYSICAL INTERPRETATION

V.1 Geophysical Data Analysis and Interpretation

Geophysical interpretation has been divided into two segments, one pertaining to deep-water of the subducted plate of the accretionary wedge and another pertain to the compressive structuring of the obducted plate both offshore and onshore. The information is mostly from seismic interpretation analyses so as to obtain geological models that accurately represent the substratum of this rather complex region. The main purpose in interpreting all geophysical data (seismic, gravity and magnetics) is to merge these with as much geological information as possible during the analysis process, for an output of realistic structural geologic models and seismic stratigraphic layers.

Herein below are described the steps that were considered in the process of Geophysical data analysis and interpretation:

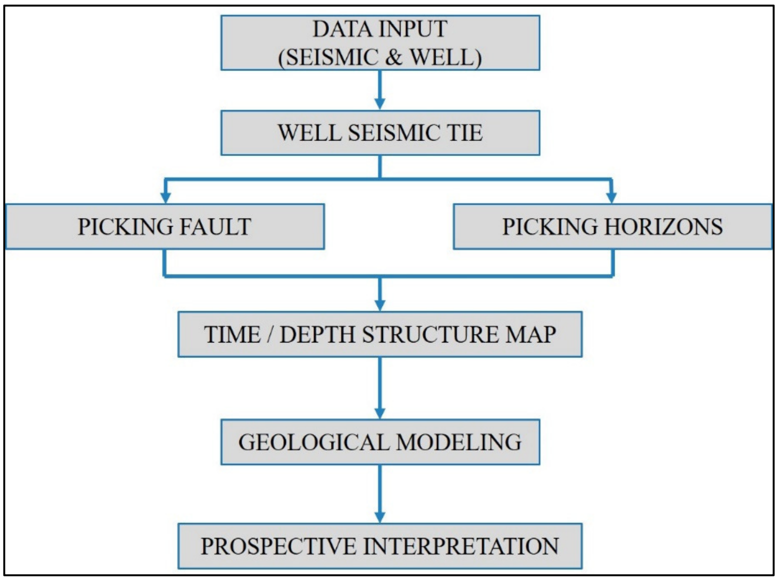
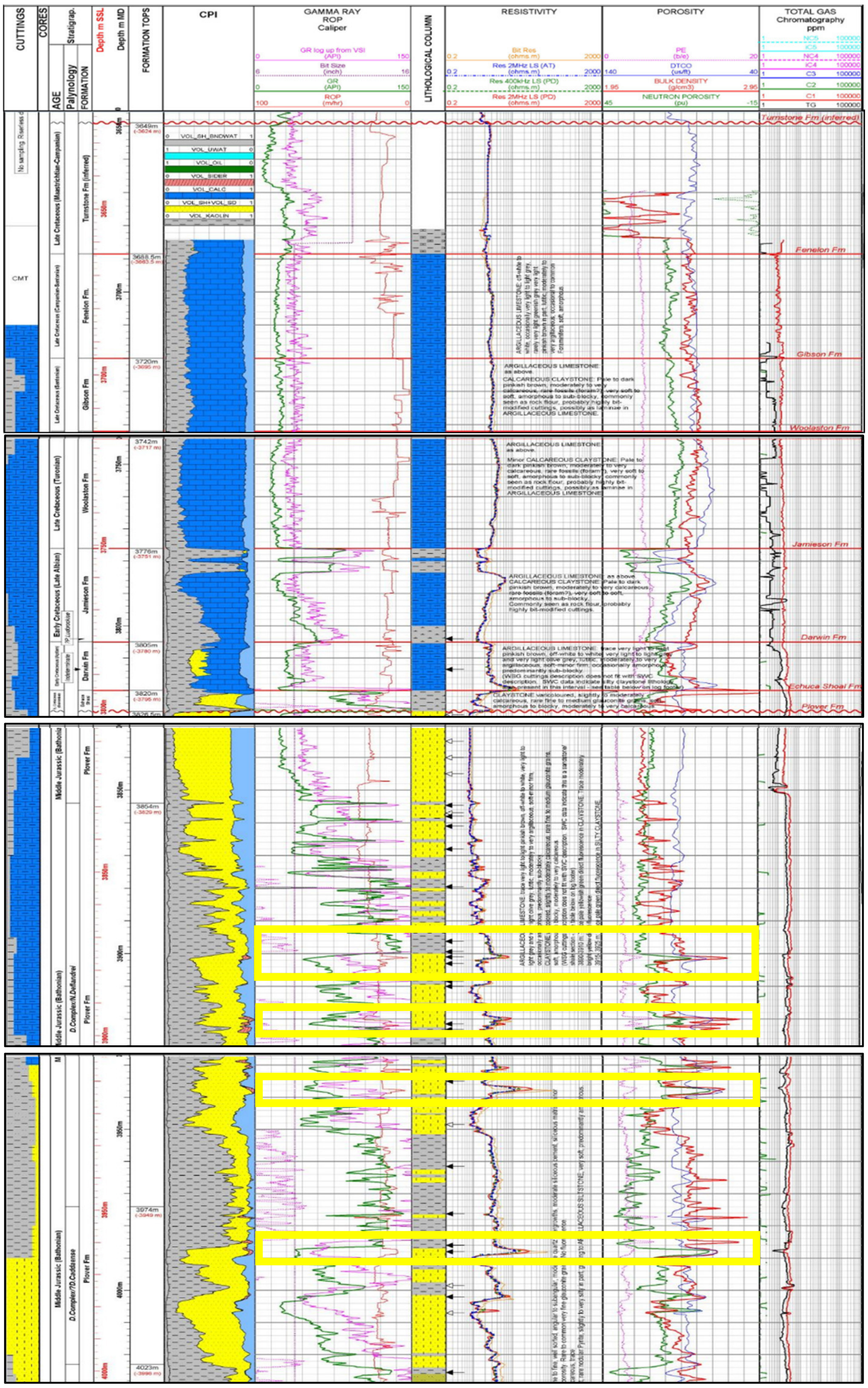


Figure 22. Flowchart of Geophysical data analysis and interpretation process

V.1.1 Well Cova-1 Composite Log Analysis

From the composite log interpretation of the Cova-1 well (figure 23) shows the zone of top Cretaceous Turnstone until the Jurassic Plover. From the log deflection of Gamma Ray indicated the reservoir units of Plover sandstones is higher than the limestones units of the early cretaceous until late cretaceous units. The sandstones unit is a main target for reservoir unit in Cova-1 well and the limestones with carbonates units above the sandstone units of plover Formation as the Seal rock (see figure 23).



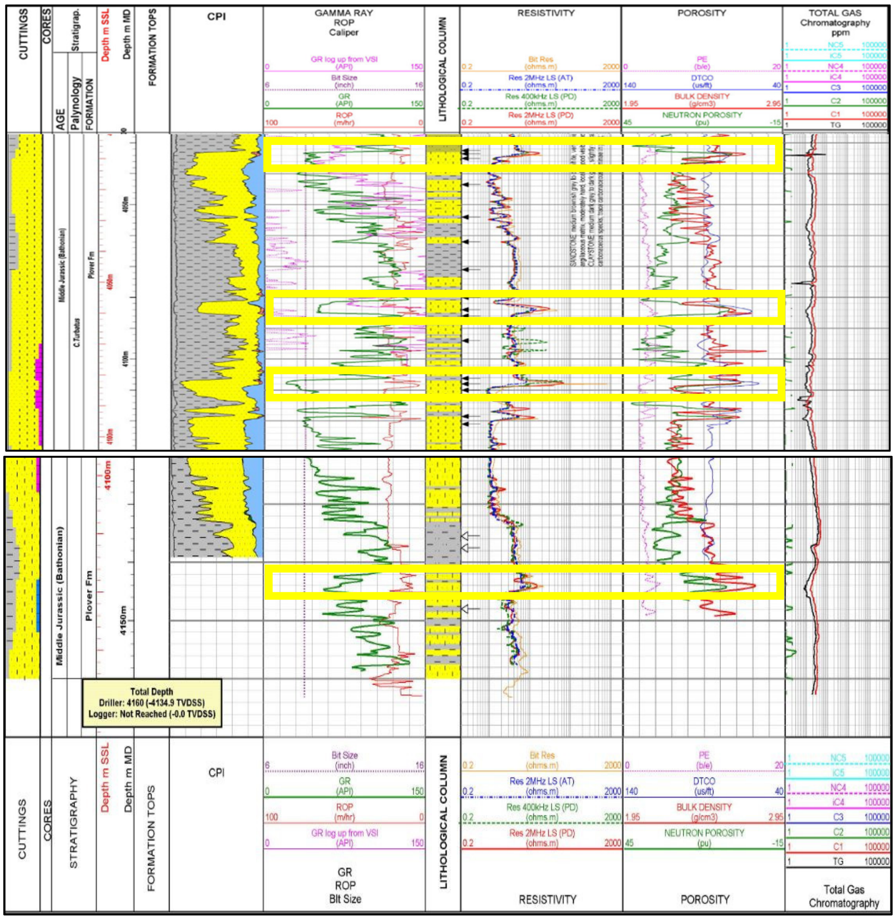


Figure 23. Well Cova-1 log interpretation of top Cretaceous Turnstones – Plovers Formations zone of Jurassic with several zone of Hydrocarbon indications.

Herein below are several discovery wells of fields oil and gas producing with well interpretation result that located in the offshore Timor-Leste, such as Elang-1 well, Sunrise-2 well and Bayu-1 well. These interpretation results are on the well log analysis interpretation that resulted the lithology units and hydrocarbon indication in the reservoir zones.

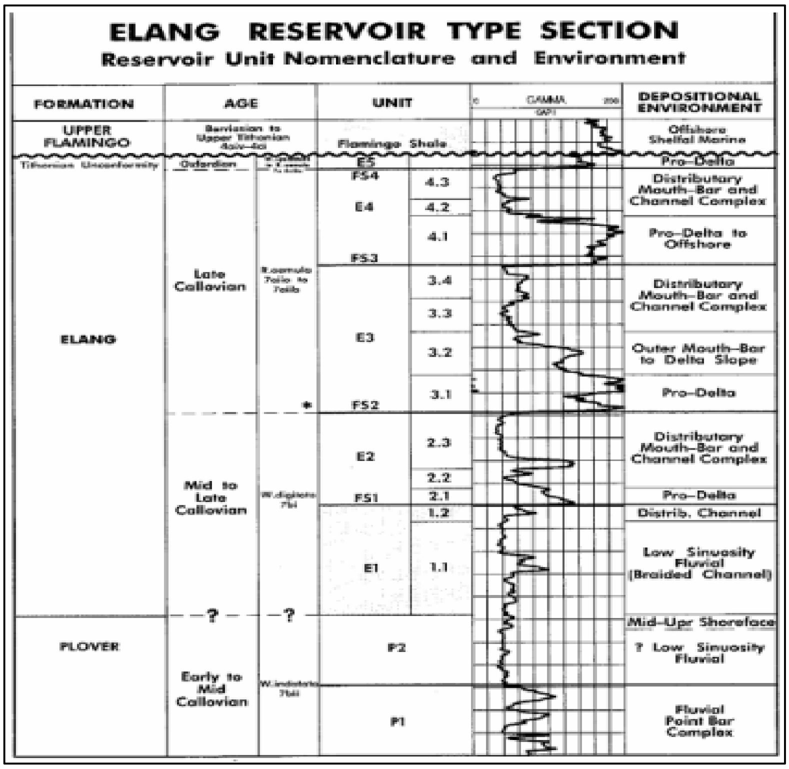


Figure 24. Reservoir Summary for Elang-1 discovery well

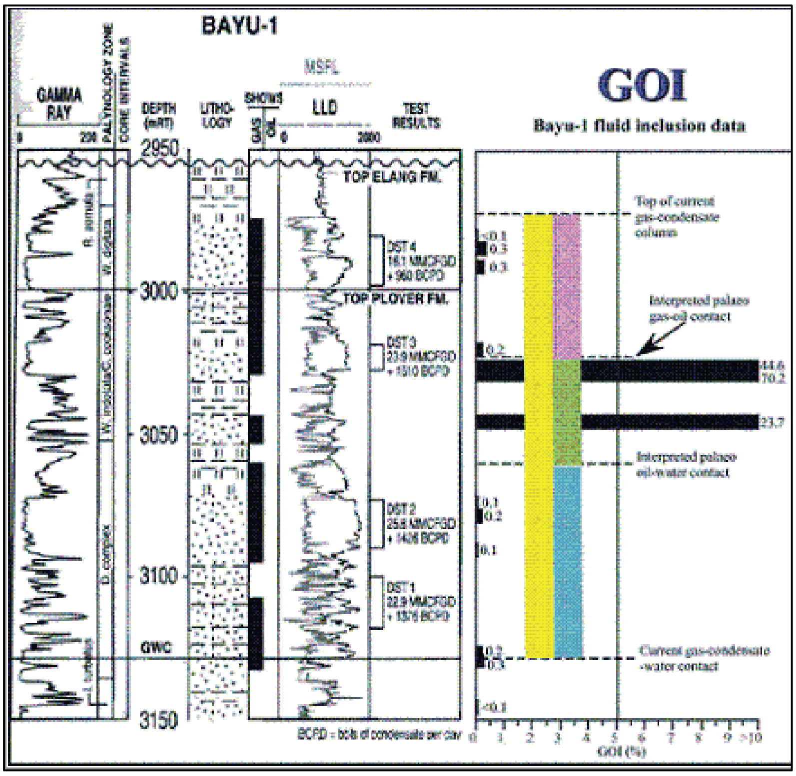


Figure 25. Reservoir Summary of Bayu-1 with hydrocarbon oil and gas interpretation

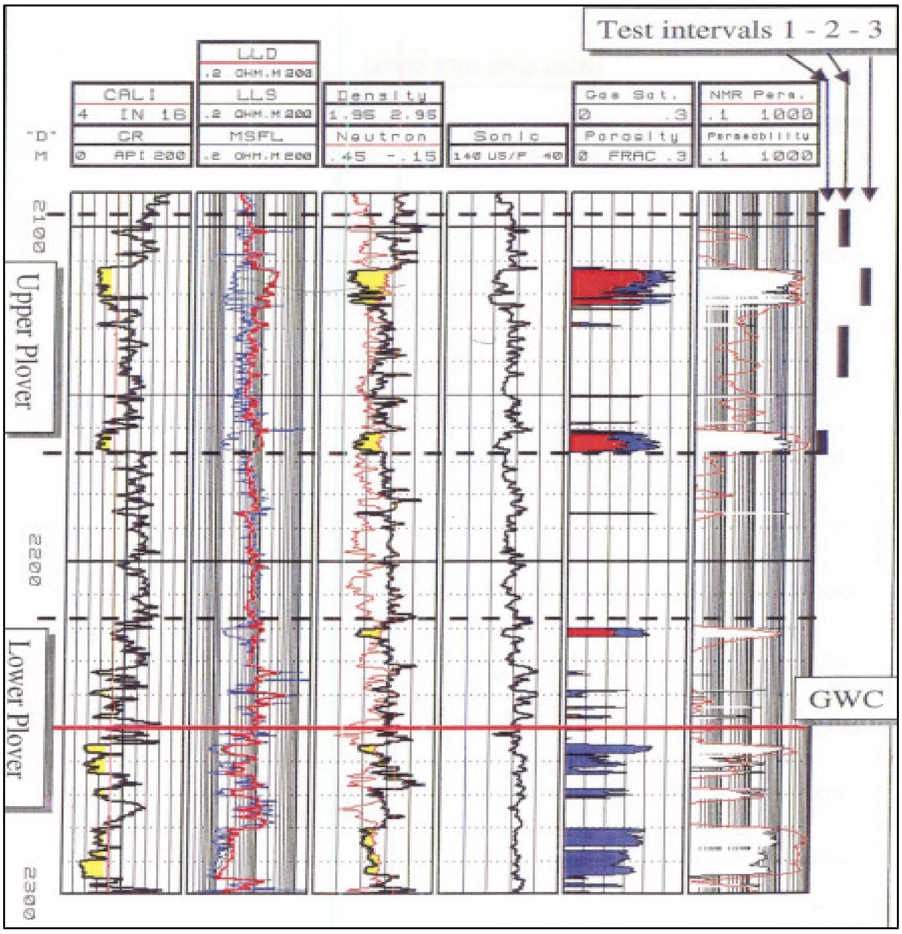


Figure 26. Reservoir Summary of Sunset-1 with hydrocarbon gas interpretation.

V.1.2 The Lithostratigraphic Correlation

This interpretation process begun with the correlation between available wells such as Banli-1, Cova-1, Jahal-1 and Baleia-1 in the investigation area based on lithostratigraphic information. The purpose of correlation is to compile geological history, interpreted geological conditions, and reconstruct subsurface geological models and find out the lateral and vertical distribution of stratigraphic units in the study area.

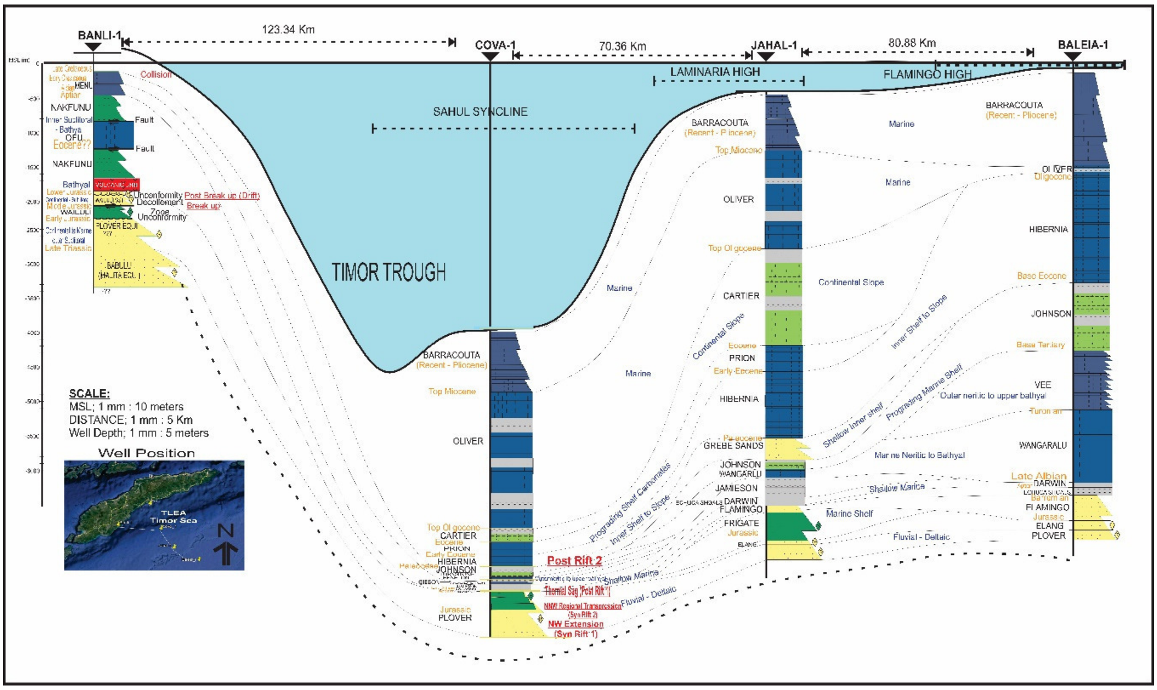


Figure 27. Lithostratigraphic regional correlation in the study area based on the similarity of stratigraphic units and age.

The regional lithostratigraphic correlation was covered from onshore part of Timor Island to the south passed Timor Trough through the Sahul Syncline, Laminaria High and the Flamingo High. Most of the well penetration depth is only reached into the Plover Formation of the Jurassic, while the Banli-1 well penetrated until the equivalents units of Malita in the Triassic age. The reason of these depth penetrations are the sandstone units in the Jurassic age in the shallow to deep-water regions and the sandstone units in the Triassic age in the onshore part are proved from its lithology units can accumulated the hydrocarbon as the reservoir units. The sandstone unit in the shallow offshore and deep-water regions are formed on the Fluvial – Deltaic environmental system, while the sandstones units in the onshore part are formed in the continental to marine outer sublittoral of Triassic units and continental to sublittoral system of lower Jurassic.

Apart from the reservoir units, the shales units of the Jurassic age of Wailuli Formation in the onshore part and the shale units of the Plover and Frigate Formation are potential as the source rock in offshore shallow and deep-water regions. These shales units are formed in the Marine shelf environments system.

This petroleum system in this lithostratigraphic correlation results considered as the Mesozoic play for hydrocarbon in the onshore, offshore shallow and deep-water regions.

V.1.3 Well to Seismic tie

The objective in establishing the well to seismic tie is to align the difference in the respective domains between well data in depth domain to seismic data in time domain, in order to ultimately position the seismic horizons in true depth.

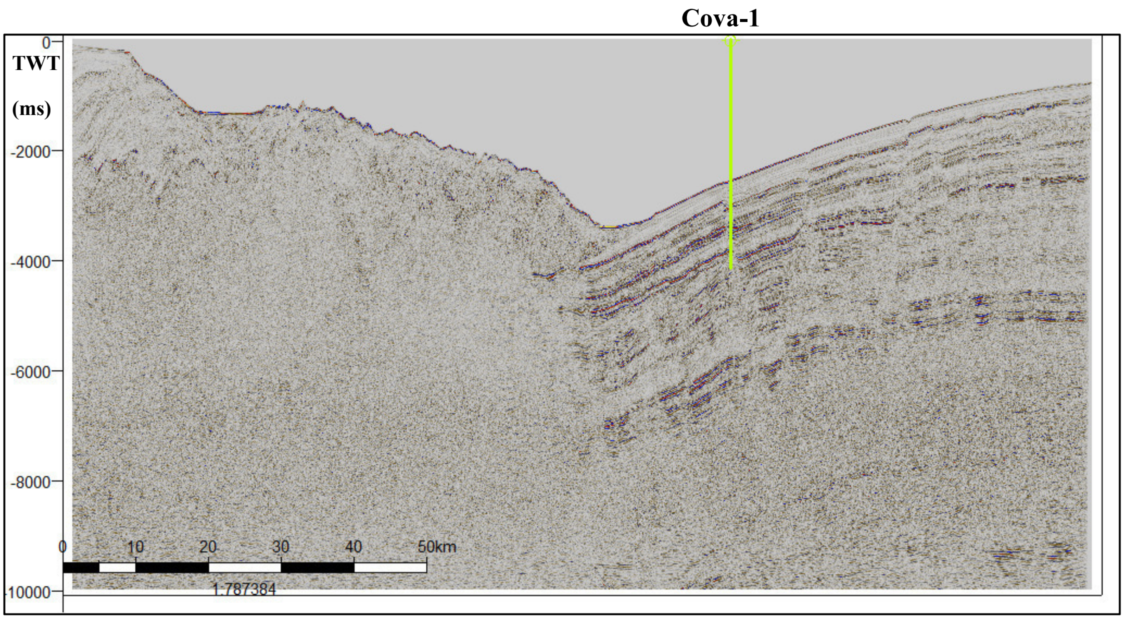


Figure 28. The Seismic dip line (J1) that cross the Well Cova-1 which use to made the well seismic tie.

This well tie process is an important process that needs to be done in order to determined and interpreted the true position of horizon boundary.

In this study, the well tie process was carried out simply by doing a comparison graph of time to depth according to information from seismic data and well data. The purpose of this graph is related to the equation of $V = Z / \Delta T$, where the velocity of the rock is inversely proportional to the travel time of the seismic wave.

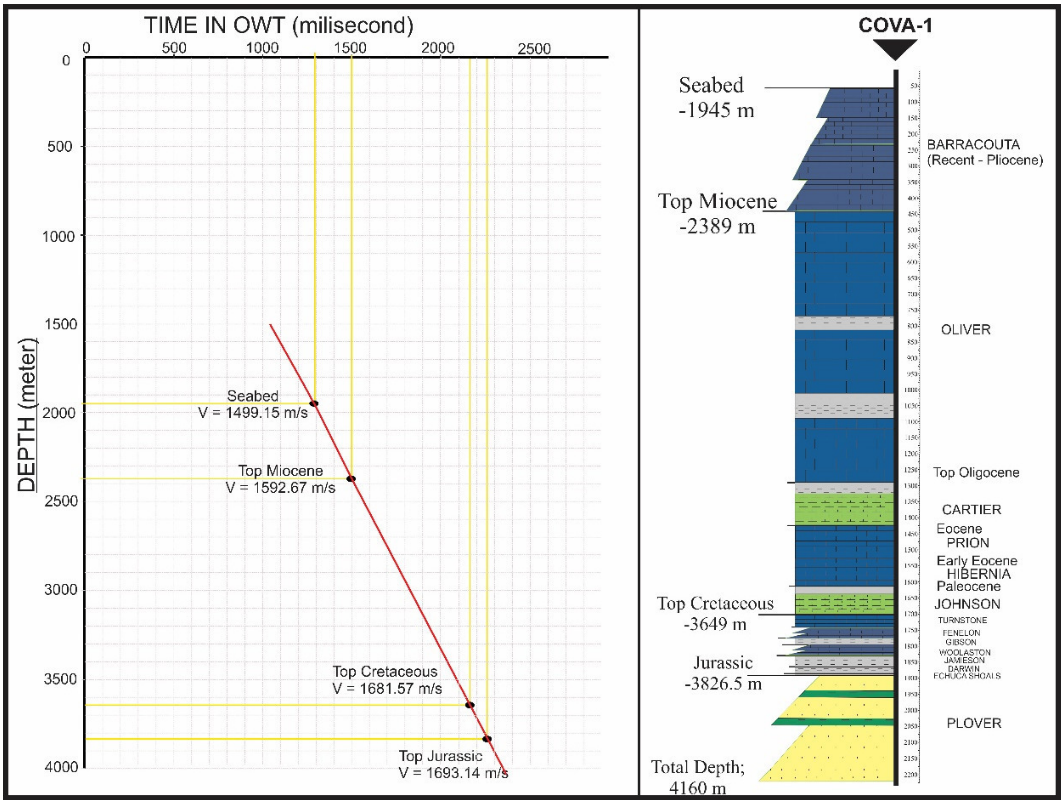


Figure 29. Graphic of Time vs Depth to calculate the pertinent velocities of the stratigraphic units in terms of the stratigraphic Horizons interpretation in the seismic sections tied with the well interpretation (Cova-1 well).

Based on the results of the velocities calculation from depth and travel times, shows the difference between horizons that related to the composition of lithology units due to physical characteristics in every sequence. The velocity of seabed horizons about 1499.15 m/s is represented the velocity of seawater, sequence of Miocene with 1592.67 m/s consist of limestone with clay and calcareous, sequence of Cretaceous with 1934.18 m/s consist of interbedded limestone with claystone and the Jurassic sequence with 1964.52 that mostly consists of sandstone and intercalated with shales (figure 29).

V.1.4 Analysis and Interpretation of Seismic Lines

The interpretation of the seismic data enables for a realistic construction of the structuring of the accretionary wedge and its petroleum geology prospectivity. The interpretation of seismic horizons and faults were made both by hand interpretation and with software (Petrel). The existence and identification of horizon markers and faults pillars are made directly in the seismic cross section by using the difference indication of the physical properties of each layer of rock against the compressional wave velocity that traverse these layers.

Fault and horizon are interpreted on seismic cross-section on each path. It is necessary to make the best possible model of horizon and fault geometry in 2D and 3D form.

Parameters that need to be taken into consideration during interpretation are the frequency value of the wave, the amplitude of the wave, the value of the velocity wave, the reflector change, as well as certain indications or characteristics that may indicate the presence or alteration of the characteristics of each layer of the rock. Each interpreted geologic marker, be it in the Tertiary, Mesozoic or in the Paleozoic is characterized by particular seismic amplitudes and also from well to seismic tie process.

a. Fault interpretation

Faults are fracture zones in the rock layers that have been shifted either in a straight line or in a rotation, resulting in displacement between the opposing sections caused by tectonic events. Accuracy in interpreting seismic data, especially in understanding the changes in the geometry and orientation of a fault plane will determine the tectonic pattern of the area.

The rock shifts occur along a surface called the fault plane. Fault occurs due to unbalanced pressure on a layer of rock. As explained in the theory of elasticity, the rock will deform, which, if passed the threshold of elasticity strength of rock that will result a fault. In a simple sense, the faults are made up of two non-vertical sections called hanging wall and footwall. From the definition, the hanging-wall is a fault section that is above the fault plane, while footwall is part under the fault plane.

In principle, the structural interpretation of faults in seismic data generally describes or embraces meaningful geologic structures.

Based on seismic section interpretation of the research area, it can be identified as much as approximately 25 larger faults defining compartmentalized fault blocks spread throughout the study area (figure 30, 31 and 32). The limitations during in the process of interpretation in research area are due to the insufficient number of available seismic and well data in adequate quantity and quality. Herein below is an example of several fault interpretations from seismic section close to Timor Trough (Figure 30, 31 and 32). Mostly geological structure that interpreted from the seismic lines are normal fault and thrust fault with some reverse and electric fault.

b. Horizon interpretation

Seismic picking horizon interpretation begins with matching display of the horizon marker data from well log and the well tie. In deep-water however there are large areas without well ties, nonetheless data interpretation is possible by amplitude analogies of the diverse seismic markers.

Well seismic tie become the initial reference for interpretation of horizon marker on seismic cross section. The horizon interpretation of the seismic cross section is carried out on seismic portions that having a seismic reflection or a clear reflector plane.

Basically, interpretation of horizon or picking horizon is done to limit the assumption of the formation or layer to be mapped to a map of the structure. In general, picking horizons are based on high and continuous seismic reflections, based on the assumption that each wave front indicates a new medium; it will cause impedance contrast to the seismic data. In the process of picking the horizon there are restrictions based on the medium and age of the layer.

Results of horizon interpretation in the research area (figure 30, 31 and 32), generated several horizon markers that are distributed and representing the age of rocks in the area, which are consist of the following horizons:

- Seabed
- Miocene
- Cretaceous Carbonates
- Jurassic Break-Up Unconformity
- Triassic Carbonates;
- Comparative Permian Carbonates.

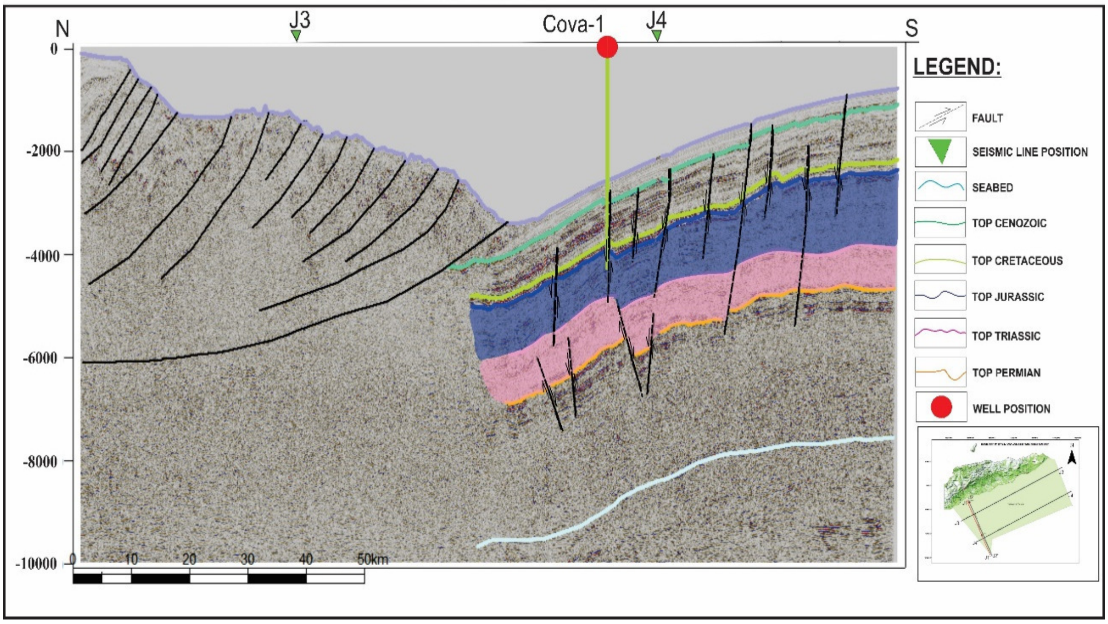


Figure 30. 2D seismic interpretation of dip line J1, consist of Fault and horizon picking of seabed (violet), Miocene (green), Cretaceous (yellow), Jurassic break-up unconformity (blue), Triassic (pink) and Permian (gold). (Time value: ms).

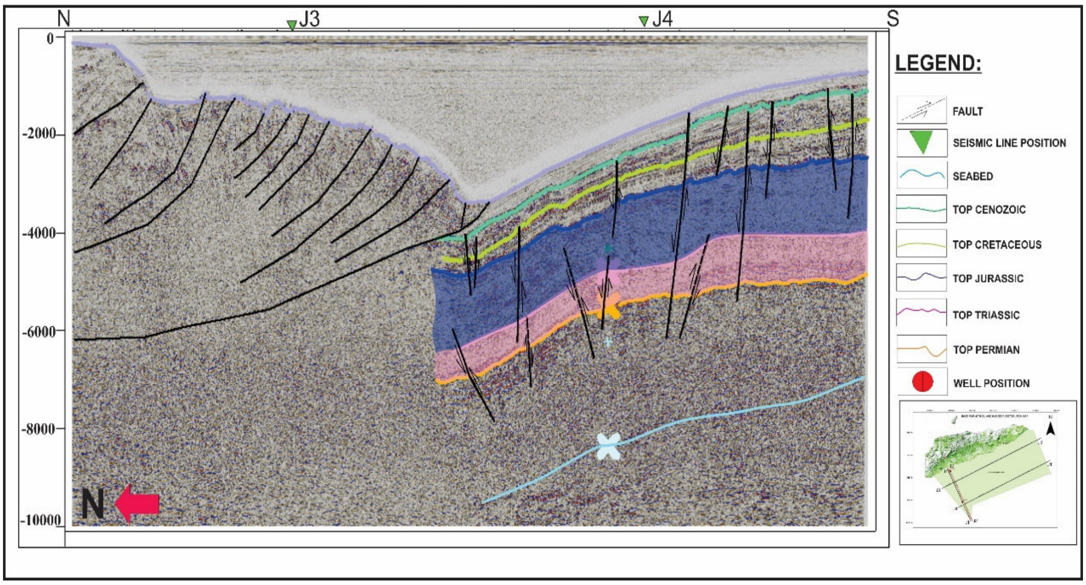


Figure 31. 2D seismic interpretation of dip line J2, consist of Fault and horizon picking of Seabed (violet), Miocene (green), Cretaceous (yellow), Jurassic break-up unconformity (blue), Triassic (pink) and Permian (gold). (Time value: ms).

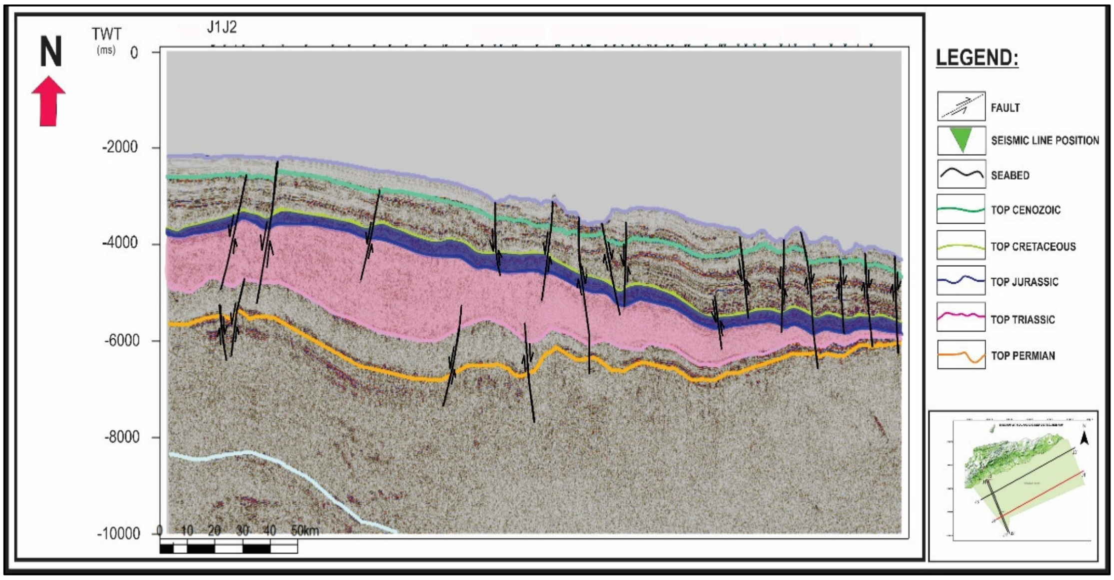


Figure 32. 2D seismic interpretation of strike line J4, consist of Fault and horizon picking of Seabed (violet), Miocene (green), Cretaceous (yellow), Jurassic unconformity (blue), Triassic (pink) and Permian (gold). (Time value: ms).

V.1.5 Time to Depth Conversion

The Time migration is considered adequate for seismic imaging in areas with mild lateral velocity variations. However, even mild variations can cause structural distortions of time-migrated images and render them inadequate for accurate geological interpretation of subsurface structures (Cameron, M. et al., 2008).

Therefore, the objective of depth conversion is to get real subsurface information of subsurface geological conditions that represent in true depth. Otherwise, Interpretation for the presence of stratigraphic and structural in the depth domain section will be very accurate define and identified.

From the result of dip line J1 depth conversion (figure 33), was utilize as a true depth reference in this study for the others seismic sections interpretations in terms of stratigraphy and structural identification in order to accurately defined the locations of viable prospects for petroleum resources.

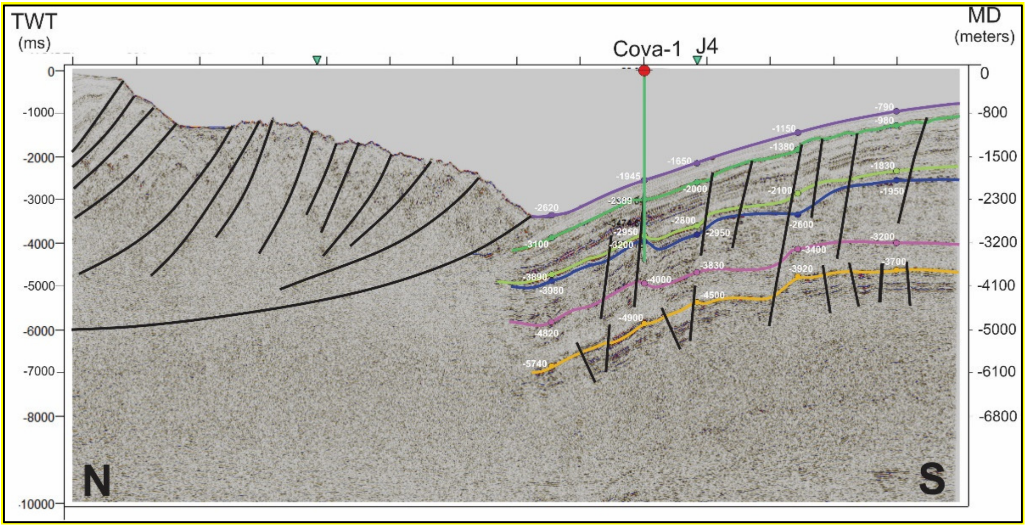


Figure 33. Time to depth Conversion section of dip line J1

V.2 Comparative profiles from vintage deeper water seismic data in the Timor Sea

In the following several profiles from a survey in the deep-water Timor Sea are compared with the data closer to coast from this thesis. These data comprise marine data to the west of Timor-Leste (Timor Sea Data) and to the east of Timor-Leste (Arafura Sea Data).

According to the interpretation of the dip line in the Timor Sea (Roberto Fainstein, 2000) (figures 34, 35, 36, 37 and 38) shows how complex geologic structures evolved in the region are inextricably linked to tectonic activity occurring during the period of rifting to collision in the Timor sea. The types of structures that develop are mostly normal faults that generally lead to NW – SE direction. Stratigraphically, during the periods before collision time in the era of Devonian until Early Jurassic is visible clearly shown.

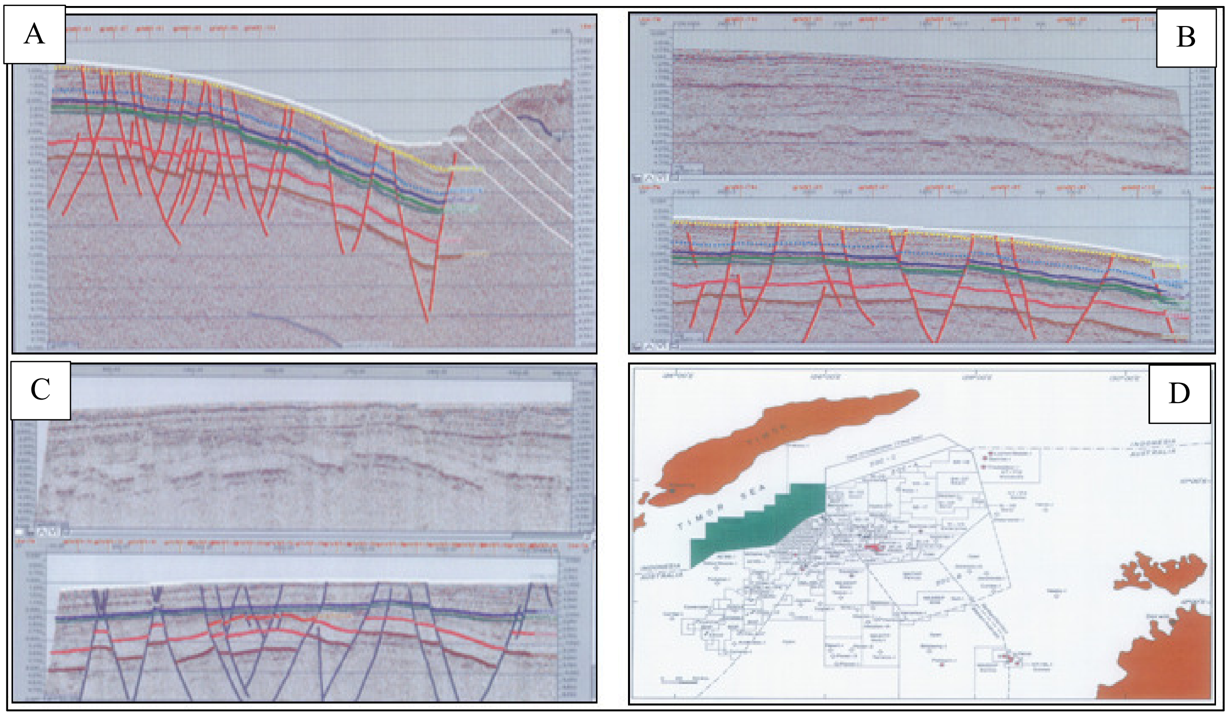


Figure 34. Regional Dip line GPTSI 95-48 and strike Line GPTSI 95-40 and GPTSI 95-29 interpreted results in **Sabo Block (**R. Fainstein 1995)., these compare and are similar to profiles interpreted in Timor-Leste.

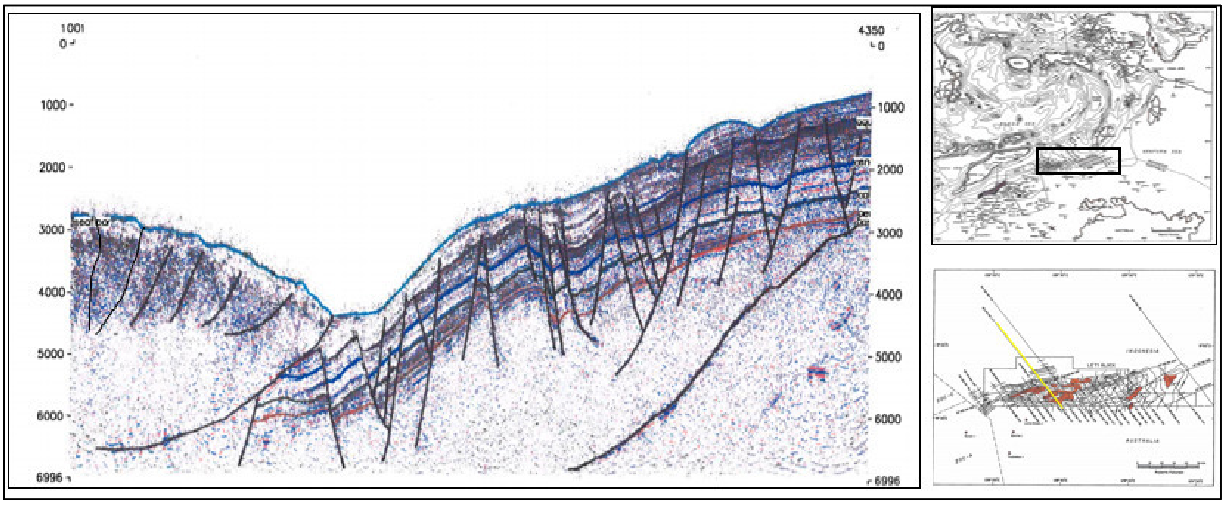


Figure 35. Regional Dip Line GPARI 96-117 interpretation in the **Leti Block**, shows horizons and block faulting Dipping plate maintains integrity in the collision complex of subduction zone, whereas the Timor-Leste microcontinent is highly fractures. (R. Fainstein 1998)

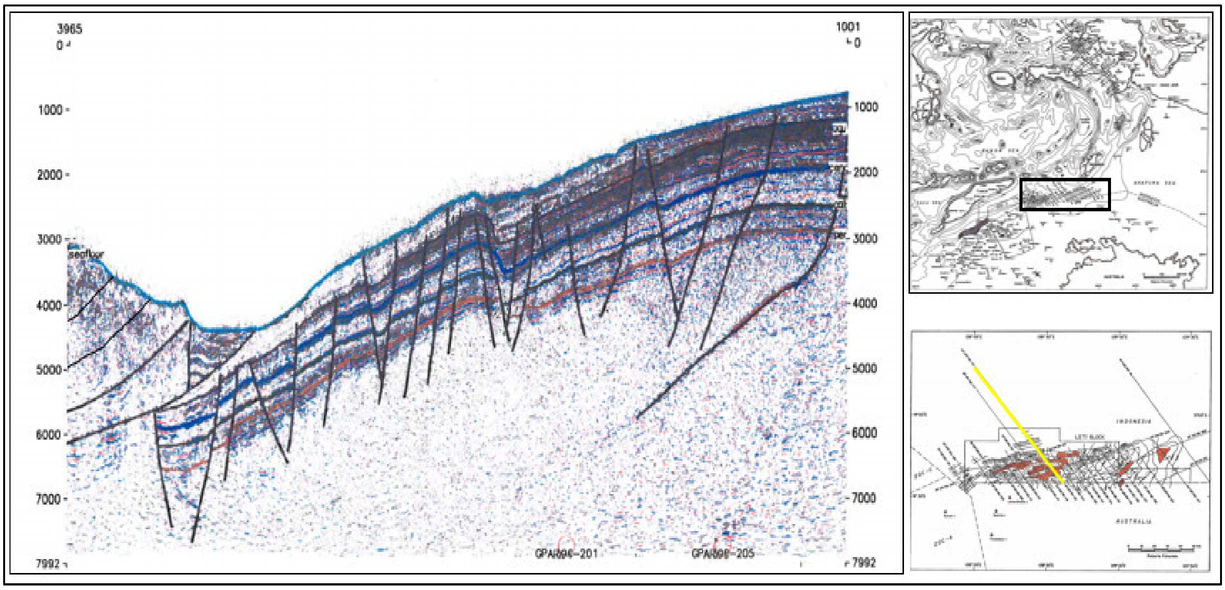


Figure 36. Regional Dip Line GPARI 96-121 interpretation in the Leti Block, shows major regional rollover Structural closures at the outer shelf against the basement fault. (R. Fainstein 1998)

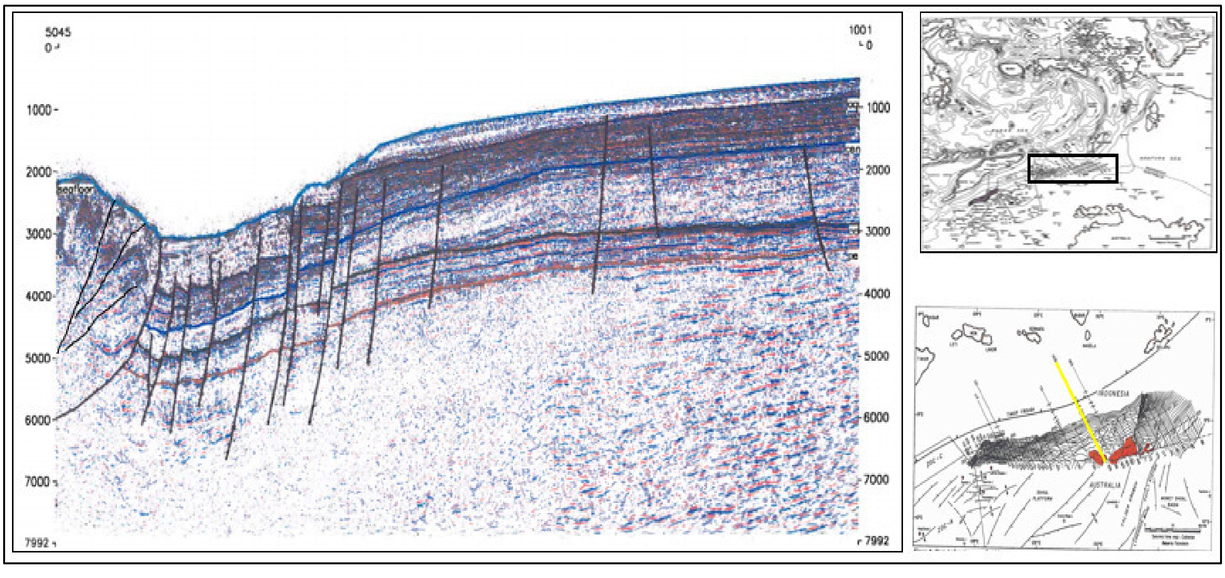


Figure 37. Regional Dip Line GPARI 96-159 interpretation from Masela Block towards Timor Trough, Showing thickening of the Cretaceous beds towards the east and south and rich foreset beds stratigraphy in the Createous (After R. Fainstein 1998).

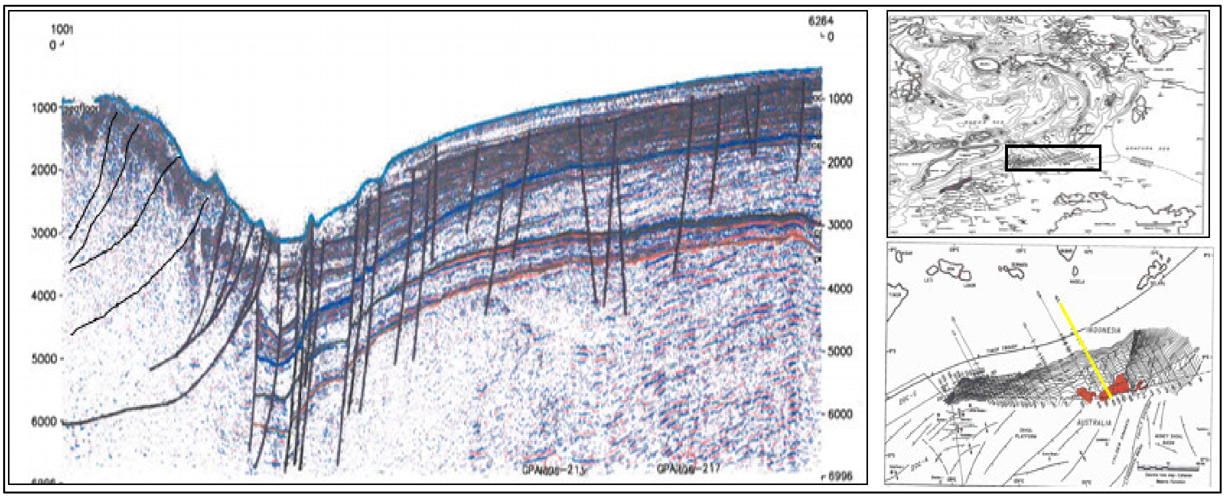


Figure 38. Regional Dip Line GPARI 96-163 interpretation from Masela Block towards Timor Trough, displying Fault blocks at higher angle relative to the western block. (R. Fainstein 1998).

Based on Fainstein 1998, there are few tectonics mass events that related to the regional geological conditions in this area. Commonly, the rifting process eventually occurred during Devonian until mid – Carboniferous which than followed by sedimentation and subsidence process. The tectonics events during tensional of continental separation and sea floor spreading period of mid – Triassic and also in the mid to late Jurassic resulting similar fault trends to the shelf of edge that followed by the Callovian uplift and its erosional unconformities.

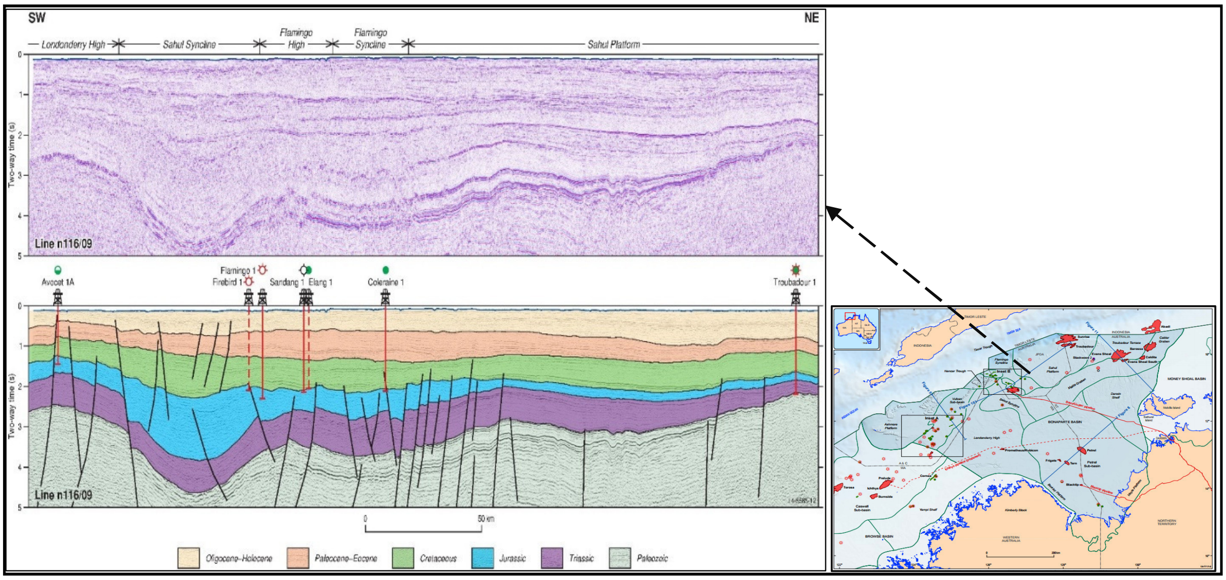


Figure 39. AGSO seismic line no 116/09 Interpretation across the Londonderry High, Sahul Syncline, Flamingo High, Flamingo Syncline and Sahul Platform (modified after Geoscience Australia, 2014).

According to the AGSO seismic line n116/09 that interpreted by Geoscience Australia in 2015 (figure 39) is covering Londonderry high, Sahul Syncline, Flamingo high, Flamingo syncline and Sahul platform, indicates the regional structures that occurred in this area are dominantly with the Normal fault are lies to the Northwest – Southeast direction. The faults structures in the eastern part that covering Flamingo high until Sahul Platform are initial during range of Palaeozoic until early Cretaceous, while the several faults in the western part occurred during the Jurassic until Oligocene – Holocene time.

Stratigraphically, the sedimentation distribution laterally is thick from the east to west. The structures that affect in the western part made the erosional resulted the Sahul Syncline in range of Triassic – early of Jurassic and filled by sediments of the early Jurassic that accumulated and formed thicker sediments in this area during this range.

From the geological stratigraphic cross – section (figure 40) that covering the Malita – Calder Graben, Money Shoal Platform and the Goulburn graben. These grabens are featured in the northern part of the northern Arafura shelf (Fainstein, 2000). Arafura continental shelf is filled by sediments with the range from late Palaeozoic to Mesozoic and Cenozoic that underlain by granitic basement. The Arafura basin contains of Palaeozoic sediments (± 5000 meters) is unconformably overlain by Mesozoic sediments (± 4500 meters) of the Money Shoal basin (Fainstein, 2000). The most complete sequence of Palaeozoic that known as Goulburn graben is lies within the Arafura graben with N – NW trending ± 300 km long by ±85 km wide. Formations that originally in this graben are probably occurred from Late Palaeozoic – late Triassic (Fainstein, 2000).

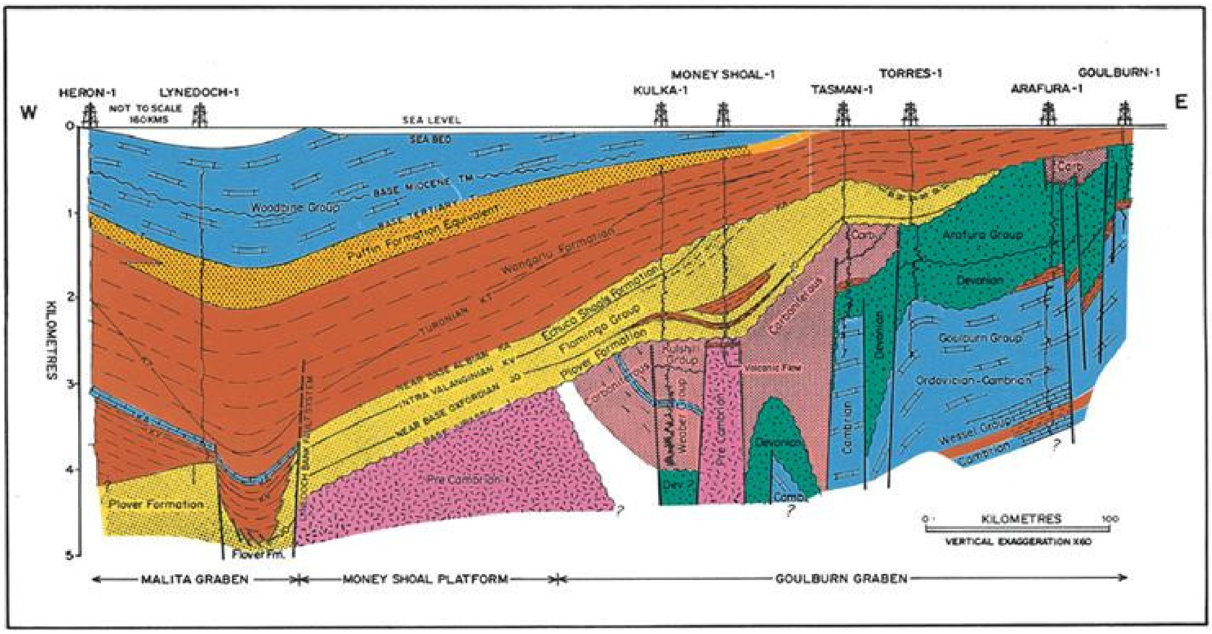


Figure 40. The Stratigraphic cross – section covering the Malita - Calder Graben, Money Shoal Platform and the Goulburn Graben (Roberto Fainstein, 1998).

CHAPTER VI

DISCUSSIONS

The prospectivity analysis and future outlook were made for lithostratigraphic correlation of wells and 2D seismic interpretations resulted several interpretations such as based on regional seismic analysis and lithostratigraphy correlation.

VI.1. Regional Seismic Interpretation

From the regional interpretations of the 2D seismic lines J1, J2 and J4 (figure 30, 31 and 32), identified several horizons based on seismic character reflector that referred for stratigraphic units. These horizons consist of Seabed in the 2594.8 millisecond TWT, Top Miocene in the 3000 millisecond TWT, Top Cretaceous in the 3773.2 millisecond TWT, Jurassic break-up unconformity in the 3895.6 millisecond TWT, Top Triassic in the 4720 millisecond TWT and Top Permian in the 5450 millisecond TWT.

Based on the 2D seismic interpretation Dip lines of J1, J2 and J4 strike lines (figure 30, 31 and 32) defines the existence of regional structure in the area are fold and thrust belt, horst and grabens with several mayor fault and minor fault with the northwest to southeast direction, and the mayor normal electric fault with southeast to northwest direction along the Timor trough area through huge chaotic blocks in the northern part of Timor trough.

The blocks of the horst and graben are formed in the Jurassic period were several folds that represented by presence of anticline were resulted by normal fault in the regions. These blocks and structure formed during extensional period of the rifting phase between Australia continental and Gondwana sequence. While, the collisional events that occurred during collision between Australia continent and Banda micro arc at the Miocene, also formed fold and thrust fault, after several reactivated of normal fault along the regions in the Late Pliocene. The recent Uplift events after collisional events formed mayor chaotic blocks and several micro diapir lenses in the Timor Island itself that considered as a part of chaotic melanges. These chaotic melanges that occurred in the onshore part considered as part of Bobonaro (ENI, 2012) and considered as diapir with characteristics of mixed units from Triassic until Miocene units.

VI.2. Regional Interpretation of Lithostratigraphy Correlation

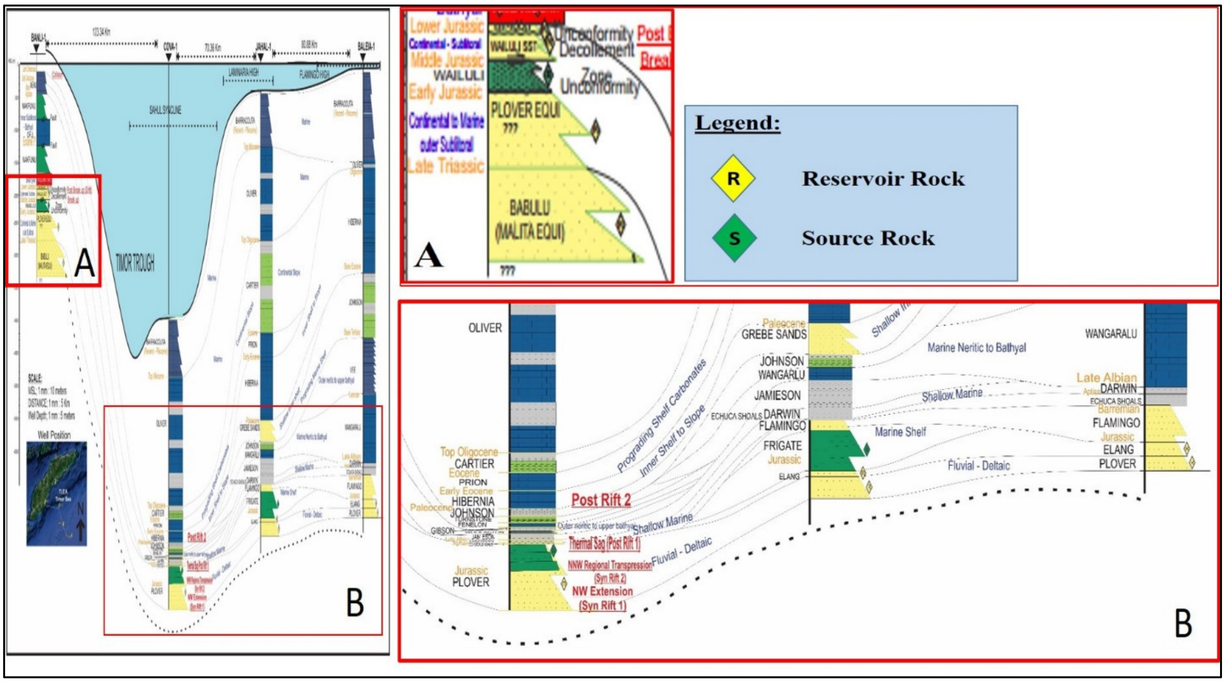


Figure 41. Potential stratigraphy units as hydrocarbon play in the onshore (A) and offshore shallow to deep-water (B) regions based on regional lithostratigraphic correlation (figure 27).

From the lithostratigraphy analysis of well correlation between wells Banli-1, Cova-1, Jahal-1 and the Baleia-1, the sediments that occurred from lower Jurassic – late Triassic on the onshore part of well Banli-1 penetration showed the siliciclastic units of Triassic in the lower part and the shale units of Jurassic that formed during extensional period of break-up events. The shales units of Wailuli showed unconformity with the Triassic siliciclastic units beneath it. These units are formed in the same depositional environment of continental to marine outer sublittoral environment. In the well Banli-1 penetration showed the thickness of the Triassic units around 341 meters of Malita equivalent and 224 meters of equivalent Plover, and the Jurassic units 94.5 meters of Shales and 81.7 meters of sandstone units. The Jurassic units of Wailuli had unconformable contact with the Oebaat Formation with 22.5 meters of sandstone units.

In the offshore region, the interpretation correlation covered Timor Trough, Sahul Syncline, Laminaria high and Flamingo high. These areas have various water depth from 70 – 3000 meters and considered as a shallow to deep-water regions. 3 wells are located in the offshore of southern Timor Trough, with deeper seabed ranges in the Cova-1 well with 1945 meters and the shallow seabed in Banli-1 well with 75 meters. From the seabed ranges, showed that the deeper area is located in the Sahul Syncline area to the north through Timor Trough until 3000 meters deep. The sediments units that occurred in these 3 wells of Jurassic age are formed in the Fluvial Deltaic for Sandstones units and Marine environments for the Shales units. The older units in these wells are Sandstones intercalated with Shales units of Plover Formation, the sandstone units of Elang Formation and Flamingo Formation only showed in the Jahal-1 and Baleia-1 wells, clay units of Echuca Shoals, and the Darwin Radiolarite units. the thickness of these formations is various from these wells, which is Plover Formation with the average thickness of 491.5 meters, Elang Formation with 37.5 meters, Frigate Formation with 233 only showed in the Jahal-1 well, Flamingo Formation 122.5 meters, Echuca Shoals Formation with the 65.5 meters and the Darwin Radiolarites with 36 meters. From the sediments distribution the Plover formation is thicken to the north, while Elang Formation, Flamingo Formation, Echuca Shoals Formation and the Darwin Radiolarites are thickened to the south.

VI.3. Regional Hydrocarbon Plays

The hydrocarbon plays that defined from lithostratigraphic correlation and the regional seismic interpretation defined the Paleozoic to Mesozoic play for hydrocarbon in the onshore, offshore shallow and deep-water regions. In these regions, the sediments units of Australian margins have potentiality as prospect to generate and accumulated hydrocarbon, such as the stratigraphy units from early Triassic - Jurassic which are consists siliciclastic units of shales and sandstones that distributed in onshore and offshore part; these formations are Plover Formation, Elang Formation, Frigate Formation and Flamingo Formation in the offshore shallow until deep-water regions, otherwise in the onshore part are the Triassic Formations of Babulu and the Wailuli Formation;

On the onshore region considered that, the shale units of the Wailuli as the source rock and also as a seal for the reservoir of Triassic sandstone units beneath it. Apart from the Wailuli and Babulu units, there are shale and carbonates units of the Aitutu Formation and Atahoc Formation were also considered as potential for source rock units that can produce the hydrocarbon in the onshore region. The existence of the normal and thrust fault that identified in the seismic interpretation as a migration paths for hydrocarbons in the regions, while the evidence of diapir will developed the possibilities of stratigraphic trap and also the structural trap in the regions. The stratigraphy units that potentially to be prospective as Reservoir units are the sandstone units of equivalent Malita and equivalent Plover from Late Triassic – early Jurassic, and also the sandstone units of Wailuli Jurassic. These plays were considered as part of Paleozoic to Mesozoic play and already proved by several geochemical studies and relevant geological studies in the previous exploration (Charlton, 2002b).

Otherwise, the source rock for the hydrocarbon in the offshore part from the lithostratigraphic correlations are the shales units of Plover and Frigate Formation. These shales units showed in the horizons part of Top Jurassic in the region that deposited in the marine environments and were part of Mesozoic play. Also, from the seismic interpretation showed the Permian Carbonates as the older source rock for hydrocarbon in this area. While, the existence of normal and thrust fault in the regions as a good migration path for hydrocarbon that generates from several source rock in the regions. Most of the trap in the shallow to deep-water regions are formed by structural trap with evidence show in the seismic interpretation with several horst and anticline. The stratigraphy units that potentially as a reservoir rock in these regions are sandstone units of Plover Formation, Elang Formation, and Flamingo Formation. While the Echuca Shoals and Darwin Radiolarite as the seal rock in the regions. These plays considered as part of Permian to Jurassic hydrocarbon plays.

Based on other geological exploration in the offshore region of shallow and deep-water of Timor Sea, in this region have been defined by several petroleum systems that existed in the Bonaparte Basin regions, such as Jurassic play, Permian play and Perm – Carboniferous play (Barrett, Hinde, & Kennard, 2003).

VI.4. Future Outlook

Based on regional lithostratigraphic correlation and regional seismic 2D interpretation, identified additional prospective areas based on mapping interpretation that indicate the Triassic Carbonates and the Permian Carbonates as remarkable possibility of a significant future discovery. This interpretation mapping for lead and prospect evaluation was restricted to the offshore shallow and deep-water regions, while for the southern onshore regions need additional further explorations to defined future prospective areas.

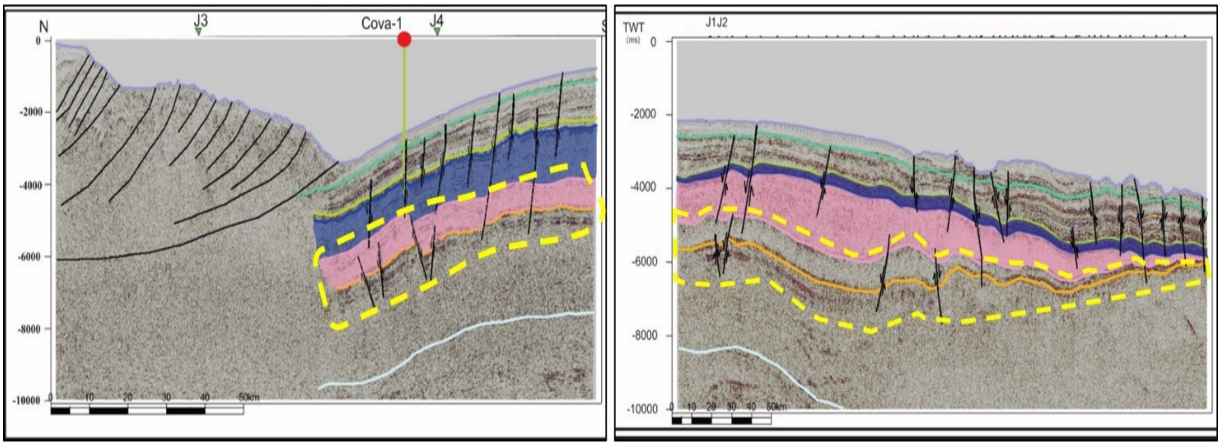


Figure 42. The yellow highlight zone indicated the remarkable possibility of a future significant discovery in the offshore shallow and deep-water regions.

CHAPTER VII

SUMMARY AND CONCLUSSIONS

- This regional study deals with the interpretation and evaluation of the regional seismic data and well data of the southern part of Timor-Leste, in terms to identify subsurface geological structures and stratigraphic patterns prevailing in the area.
- The seismic reflection data (2D) and well data, integrated with the geological data, are interpreted to define the structural configuration of the area, through a set of structural maps for several seismic two-way-time marker horizons with geophysical depth conversion.
- From the appraised interpretation for stratigraphic patterns in the area of study, the horizons that were interpreted included the Seabed, top Miocene, top Cretaceous, top Jurassic – break-up unconformity, top Triassic, and top Permian.
- From the free air anomaly map and the regional gravity of bouguer anomaly map of the offshore shallow to deep-water regions were indicated mostly oil and gas fields are located in the high anomaly distribution. The distribution of free air anomaly presented related topographic characters and relief, while the range anomaly value of residual bouguer anomaly related to the existed structure as a anticline and syncline that formed Sahul Platform, Laminaria High and others structures and also related with the rocks densities units that formed in the regions.
- The Petroleum geology in this study divided into onshore and offshore shallow to deep-water regions due to the different regional stratigraphy units between onshore and offshore regions. In the onshore part, the rocks units of Atahoc and Babulu carbonates with Wailuli shales as the source rock, and the reservoir rock units are Malita and Plover equivalent sandstones, while the shale of Wailuli also as the seal rock in the onshore region. While, in the offshore shallow and deep-water regions, the source rock units consist of Permian carbonates of Kinmore group with Jurassic Shales of Plover and Frigate Formations. The reservoir rocks in the regions are sandstones units of Plover, Elang and Flamingo Formations, while the Darwin Radiolarites units and Echuca Shoals units as the seal rocks in the offshore shallow and deep-water regions.

- Based on geological and geophysical appraisal study in the offshore region of shallow and deep-water of Timor Sea, have been defined several plays in these regions, such as Jurassic play, Permian play and Perm – Carboniferous play.
- Presently, the oil and gas fields in the offshore Timor Sea are produce from Cretaceous Carbonates and from Jurassic Sands reservoirs, however additional prospective targets that are based on study interpretation mapping indicate the Triassic Carbonates and the Permian Carbonates as remarkable possibility of a significant future discovery in the regions. This interpretation mapping for lead and prospect evaluation was restricted to the offshore deep-water regions, while for the southern onshore and offshore shallow regions need additional further explorations to defined future prospective areas.

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