PROSPECTIVITIES OF BUTON AREA, SOUTHEAST SULAWESI: NEW INSIGHTS FROM REVISITING INTEGRATED GEOLOGICAL-GEOPHYSICAL-GEOCHEMICAL DATA

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ABSTRACT

The Buton area has long been known to have large asphalt deposits and has been in production for a long time. The asphalt deposit is an oil field that has been uplifted resulting in its cap rock to be eroded and the oil that it contained to be degraded into the asphalt. There are also many oil and gas seeps identified in the Buton area, proving the presence of active petroleum system(s). Hydrocarbons have been formed, migrated, and trapped in the Buton area; therefore, oil and gas fields could be found in Buton.

Previous exploration wells failed due to the complicated geology and structural problems, caused by poor seismic data and challenging subsurface imaging. Those wells also often did not reach their objectives or were off structure.

Buton has a long tectonic and stratigraphic history since it was once part of the northern edge of Gondwana. This includes rifting, drifting, collision to SE Sulawesi, and post-collision episodes. Each episode formed its own petroleum system elements and/or processes that could be important for the development of accumulations.

Using a play-based exploration method, this study has resulted in new insights into the petroleum prospectivities of Buton. New reprocessed gravity data show several low areas where petroleum generation may have occurred and basin modelling was carried out in these prospective kitchens. Based on geochemical data from the Mesozoic to the Miocene sections, several source beds are present, comprising various organo-facies sources from terrestrial, transitional and marine origins. The tectonic and stratigraphic histories formed several play types: paleo structure-carbonate build-up plays associated with passive margins, Australian fold-thrust belt play associated with the collision, and strike-slip fault play associated with post-collisional deformation. Tens of structural leads with multiple reservoir targets have been identified, mapped and volumetrically quantified.

The study concludes that Buton remains of strong interest for exploration and that the new insights and mapped leads provided by this study are worth considering for further exploration activities in the Buton area.

INTRODUCTION

Eastern Indonesia as a whole is considered frontier in terms of exploration, uncomparable with the exploration maturity of the Western Indonesian basins. Petroleum discoveries and production remain limited However, Indonesia needs sufficient petroleum supplies for its energy needs, fulfilled in large part by oil imports, which endanger over long term the national energy security. There is need for Indonesia toincrease its domestic production and exploration of Eastern Indonesia could form part of the solution.

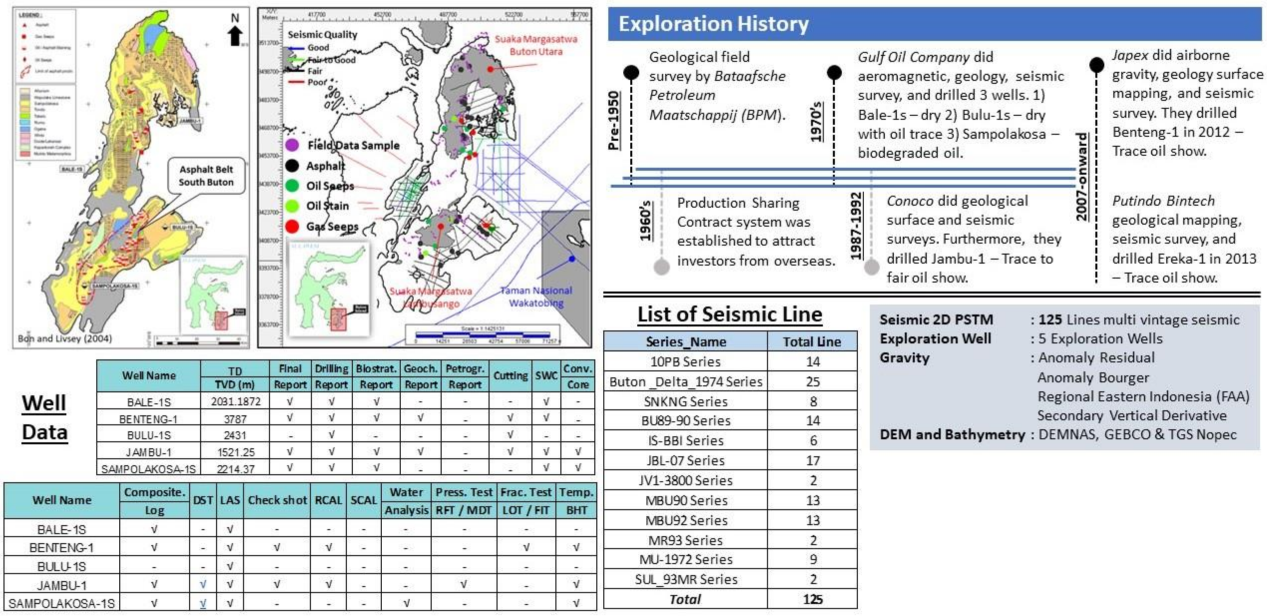
In this regard, the Ministry of Energy and Mineral Resources considered it necessary to convene a Study Team for the Acceleration of Exploration Activities in Eastern Indonesia, the Frontier Region, and the Deep Sea Region. This team was formed by the Decree of the Minister of Energy and Mineral Resources of the Republic of Indonesia No. 171.K/HK.02/MEM.M/2021 dated 13 September 2021. The team's study covers five areas, including Seram, Buton, Aru, Timor, and Warim.

This paper summarizes the results of the Buton Study Team carried out in 2022. The objective of the Buton Study Team was to study the available exploration data from Buton according to standard exploration study methods to determine its petroleum potential, including proposing new Buton exploration concepts.

DATA AND METHODS

The exploration of Buton for asphalt and petroleum has provided geologic, geophysical, geochemical and exploration well data.

Geologic field data was obtained from early geologists in the Dutch colonial time, the national geologists of the Geological Survey of Indonesia, and geologists from several oil companies that had been exploring Buton. Seismic and gravity data were obtained from oil companies exploring Buton from the 1970s to 2010. Around 125 multi-vintage 2D seismic lines cover Buton, primarily onshore data with poor to good quality image. There has been no 3D seismic data ever surveyed in Buton. Six wells have been drilled onshore Buton, including Sampolakosa-1S, Bulu-1S, Bale-1S (Gulf Company in the 1970s), Jambu-1 (Conoco, 1991), Benteng-1 (Japex, 2010) and Ereke-1 (Putindo, 2012 - no data available). No offshore Buton exploration well has ever been drilled. The distribution of seismic lines and exploration wells can be seen in Figure 1. The team used the integrality of those data to revisit the prospectivity of Buton.



Well Data

Well Name	TD TVD (m)	Final Report	Drilling Report	Biostrat. Report	Geoch. Report	Petrogr. Report	Cutting	SWC	Conv. Core
BALE-1S	2031.1872	√	√	√	-	-	-	√	-
BENTENG-1	3787	√	√	√	√	-	√	√	-
BULU-1S	2431	-	√	-	-	-	√	-	-
JAMBU-1	1521.25	√	√	√	√	-	√	√	√
SAMPOLAKOSA-1S	2214.37	√	√	√	-	-	-	√	√

Well Name	Composite. Log	DST	LAS	Check shot	RCAL	SCAL	Water Analysis	Press. Test RFT / MDT	Frac. Test LOT / FIT	Temp. BHT
BALE-1S	√	-	√	-	-	-	-	-	-	-
BENTENG-1	√	-	√	√	√	-	-	-	√	√
BULU-1S	-	-	√	-	-	-	-	-	-	-
JAMBU-1	√	√	√	√	√	-	-	√	-	√
SAMPOLAKOSA-1S	√	√	√	-	-	-	√	-	-	√

List of Seismic Line

Series_Name	Total Line
10PB Series	14
Buton _Delta_1974 Series	25
SNKNG Series	8
BU89-90 Series	14
IS-BBI Series	6
JBL-07 Series	17
JV1-3800 Series	2
MBU90 Series	13
MBU92 Series	13
MR93 Series	2
MU-1972 Series	9
SUL_93MR Series	2
Total	125

Figure 1 – Available geological, geophysical, and related data in the Buton area. Maps show the location of asphalt fields, distribution of hydrocarbon seeps, seismic data coverage, and qualities. Five exploration wells data used for the study show their specific data. The timeline for the exploration history of the Buton area is also shown.

The assessment was based on play-based exploration (PBE) methodology. PBE is an integrated exploration method based on a firm understanding of the basin, petroleum system, play and prospect. The focus of the PBE ranged from regional basin focus to prospect focus.

RESULTS AND DISCUSSIONS

Exploration History

Buton has been known for a long time for its asphalt deposits, the result ofa degraded oil accumulation. Early geological investigations focused on the mining potential of those asphalt deposits. Dutch East Indies Geological Survey initially investigated the area in the early 1920s. It was followed by the mining of the asphalt deposits in 1925 and continued into 1941 by the Boeton Maatschappij (Buton Company), but the Japanese occupation ended it. Because of the progressive understanding that asphalt deposits were in fact degraded oil accumulations and that oil seeps were present in the Buton island, petroleum exploration started in the 1930's by a Dutch Company called Bataafsche Petroleum Maatschappij (BPM). No oil field was discovered at that time. The summaries of geological investigations during this Dutch occupation can be read in Van Bemmelen (1949).

A summary of modern petroleum exploration in the Buton area (since the 1970s) can be found in Davidson (1991), with an updated version available in Satyana et al. (2013). The timeline of the exploration history in Buton can be seen in Figure 1. Indonesia Gulf Oil Company explored Buton from 1970 to 1977. They acquired aeromagnetic, surface geological, land and marine seismic data. Eventually, they drilled three wells: Bale-lS (1976 - dry), Bulu-lS (1976 – oil shows), and Sampolakosa-1S (1976), which discovered a 43 meter column of biodegraded oil (10° API) in the Tobelo carbonates. After ten years of no exploration, Conoco and its partners explored Buton from 1987 to 1992. They conducted a surface geological survey and land and marine seismic survey and, in 1992, drilled one well, Jambu-1 (oil shows, no flow when tested). After a fifteen years activity gap, Buton was explored again from 2007 to 2013 by Japex and its partners. They acquired data on airborne gravity and surface geologic and land seismic data and drilled one well, Benteng-1 (2012) which has oil shows in Miocene Tondo fractured limestone. Contemporaneously with Japex, Buton was also explored by PT Putindo Bintech (2008-2013) which acquired the data from surface geology, geochemistry and marine seismic and drilled Ereke-1 (2012-2013), resulting in oil shows in Miocene Tondo beds.

No exploration have been carried out in Buton between 2013 and 2020 until Pertamina acquired some offshore seismic data as part of the "KKP-JM" (Komitmen Kerja Pasti-Jambi Merang) in 2020 and at the end of 2022 This was a firm commitment related to extending the contract area of Jambi Merang in South Sumatra hat could be carried out in open areas anywhere in Indonesia. There has been no further data acqusition since.

Regional Setting

The Buton Island and the islands to the southeast of Buton (Tukang Besi islands) referred in this paper as Buton-Tukang Besi or Buton area, have been known as a microcontinent that rifted and separated from a bigger continent somewhere to the east, southeast, or south, drifted to its present position (Sulawesi), and collided with it. Hamilton (1979) considered firstly that Buton-Tukang Besi is a microcontinent derived from the Bird's Head of Papua and collided with Muna in SE Sulawesi after drifting through major strike-slip faults. Later tectonic reconstruction emplaced the Buton-Tukang Besi microcontinent derived from the northern part of Gondwana or present northwest Australia (Milsom et al., 1999; Hall, 2012). Hall (2012) emplaced Buton-Tukang Besi as a member of Sula Spur, which collided with Sulawesi in Miocene time by the opening of the Banda Embayment. Together with Buton-Tukang Besi at the Sula Spur are the Southeast Sulawesi and Banggai-Sula microcontinents which collided with Sulawesi sequentially during the Miocene. Figure 2 shows the Buton area's tectonic reconstruction and stratigraphy based on its tectonic histories.

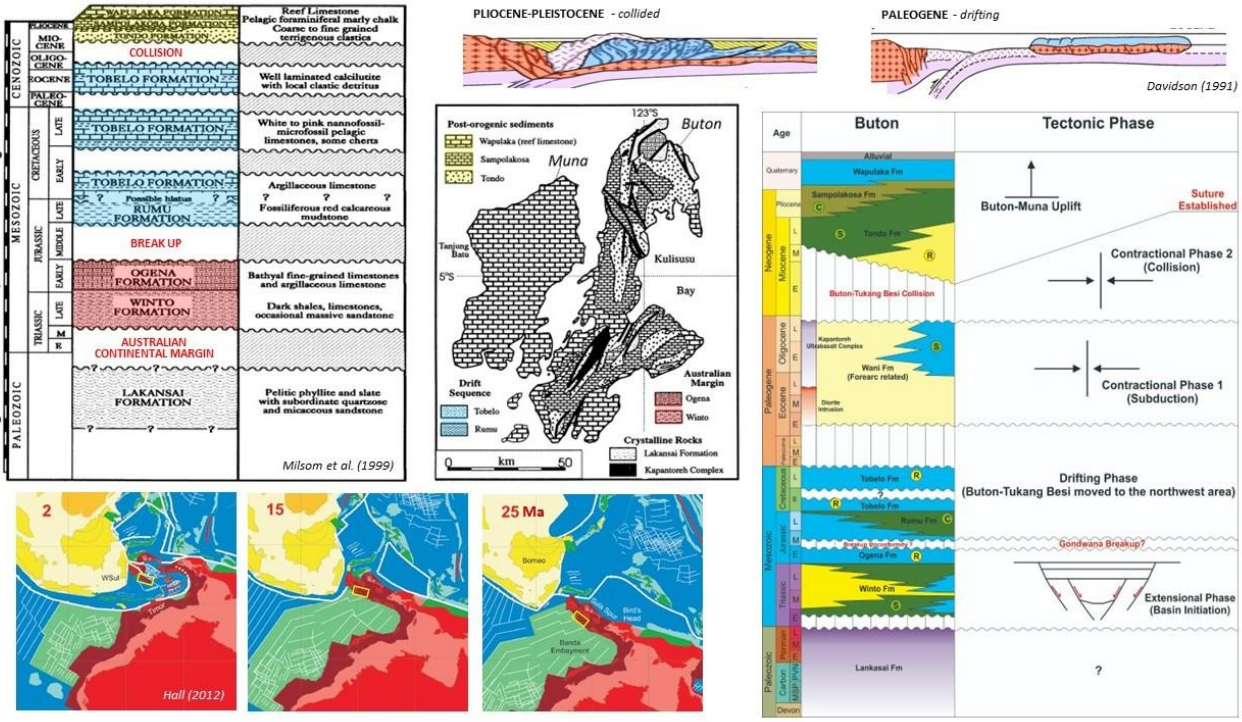


Figure 2 – Tectonic reconstruction of drifting and collision of Sula Spur to Sulawesi; the yellow box is for the Buton area. Buton's simplified surface geological map and stratigraphy are classified based on tectonic histories. Tectonics, stratigraphy, and elements of the petroleum system are shown on the stratigraphy on the right.

Based on tectonic reconstructions supporting that Buton was ever part of northern Gondwana, rifted from it, drifted to its present position, and collided there, the stratigraphy of Buton has been grouped to these events. Milsom et al. (1999) grouped the stratigraphy of Buton into Paleozoic Crystalline Rocks of Lakansai Formation, Late Triassic-Early Jurassic Australian Margin of Winto and Ogena Formations, Late Jurassic – mid-Oligocene Drift Sequence of Rumu and Tobelo Formations, and mid-Miocene – Pleistocene Post-Orogenic sediments of Tondo, Sampolakosa, Wapulaka Formations. Sediments older than the mid-Miocene are essentially pre-collision sediments, whereas sediments deposited after the mid-Miocene are post-collision. The Mid-Miocene collision obducted the pre-Tertiary Kapantoreh ophiolite, exposed in southern Buton. Before the collision, an oceanic crust was positioned between the Sulawesi and Buton microcontinents.

The stratigraphy of the Muna Island to the west of Buton and the Tukang Besi Islands to the east-southeast of Buton is not known because their surface geology only consists of Quaternary carbonate (Pleistocene Wapulaka) (Satyana and Purwaningsih, 2011). Based on gravity data analysis (Milsom et al., 1999), Muna and Tukang Besi are part of the same microcontinent with 30 km and 20 km crust thickness respectively.

Stratigraphy and Structure

Stratigraphy and structure of Buton have been discussed by Davidson (1991), Milsom et al. (1999) and Satyana et al. (2013). The following is a summary from those publications. Figure 2 shows the tectonostratigraphy of the Buton area. Figure 3 shows the structural trends of the Buton area based on gravity data.

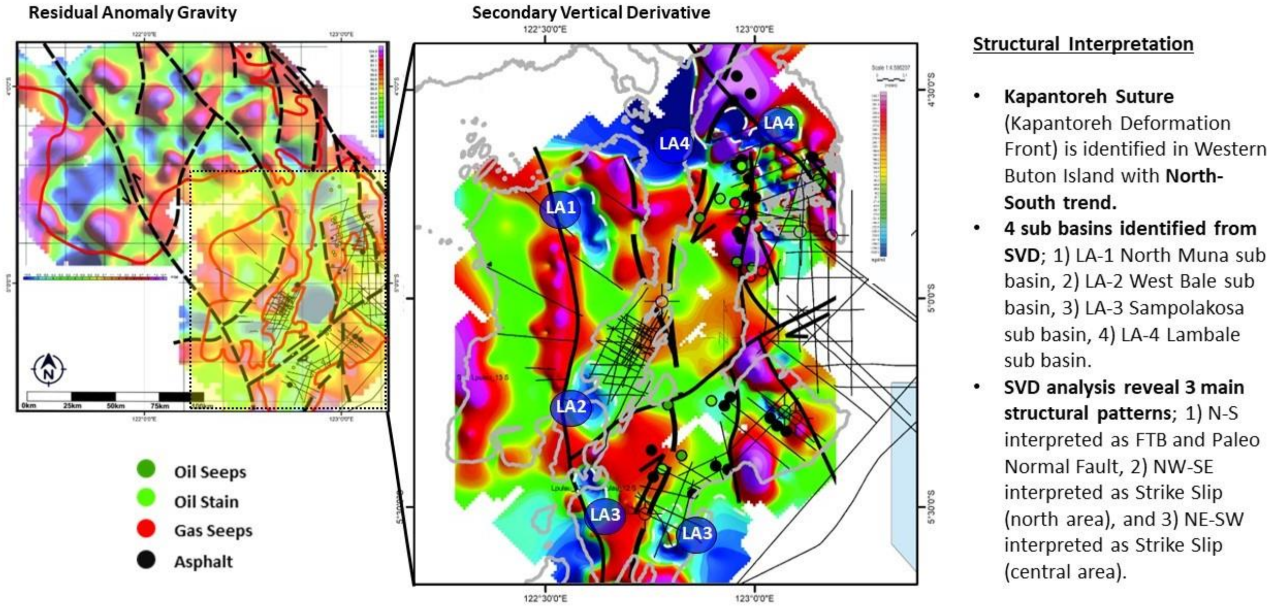


Figure 3 – Residual anomaly gravity and secondary vertical derivative of gravity modeling show the structural trends from various deformation origins in the Buton area and the presence of low areas (LA series). The distribution of hydrocarbon seeps is shown, primarily located close to low areas.

Permian to Early Triassic pelitic phyllites and slates of the Lakansai Formation form the oldest rock unit in Buton. It is part of the continental Gondwana before rifting, forming a microcontinent. Rifting at the continental margin of Gondwana (northern Australia) took place in Late Triassic to Early Jurassic, depositing sediments of Winto and the overlying Early Jurassic Ogena Formation consisting dominantly of limestone, although it appears to have been deposited in deeper water. Clastic sediments, principally shales, are typical in the Winto exposed at southern Buton. Both formations contain abundant organic material, which is generally considered to be the source of hydrocarbons in the area. A fully open marine environment with passive margin sedimentation commenced in the Middle to Late Jurassic with pelagic carbonates as dominant lithologies. It begins with the deep-marine siliceous and calcareous mudstones of the Upper Jurassic Rumu Formation. It continues with the Tobelo Formation, which consists of pelagic limestones with nodules and stringers of red chert. The Tobelo sediments were deposited up into the lower Oligocene. The Rumu and the Tobelo were deposited very slowly, and their lithologies are consistent with deposition during the drift of an isolated continental fragment (syn-drifting sequence). This event is also marked by the overall decrease in clastic sedimentation derived from the continental area.

In the mid-Miocene, the collision of Buton with Southeast Sulawesi took place. The collision led to a shortening of about 60% and the development of thin-skinned thrusts and folds in southern Buton (Milsom et al., 1999). Northern Buton was not affected until the late middle Miocene, when maximum regional compression led to an uplift and the establishment of an unconformity representing a hiatus. In the Late Miocene, the subduction zone became choked. This event was followed by the accretion of Buton to Southeast Sulawesi. The oceanic crust between Muna and Buton was obducted and sheared, forming an ophiolitic Kapantoreh zone. The strait can be interpreted as a successor basin produced by slight compression relaxation following the collision. After the collision, syn-orogenic/collision clastics were deposited as molassic sediments. The sediments immediately above the unconformity forming the coarse clastic upper Miocene–Pliocene Tondo Formation, composed mainly of carbonate detritus, but ultramafic and mafic fragments became dominant later, indicating uplift of the ophiolites above sea level. Tondo Formation deposition was brought to an end by the subsidence of Buton to bathyal depths at approximately 5 My and the deposition of the Sampolakosa chalks and marls. Subsequent uplift was accompanied by the development of reefal carbonates of the Wapulaka Formation.

Sub-Basins of Buton Based on Gravity Analysis

The newly processed second vertical derivative (SVD) gravity data used for this study is shown in Figure 3. The SVD gravity result shows the subsurface's low and high areas. When the SVD gravity result was overlaid with locations of hydrocarbon seeps, it was clear that the hydrocarbon seeps occur over high areas, in the vincity of lows. This could imply that the high areas are traps where hydrocarbons are potentially accumulated, and that the low areas are the generative source pods. The gravity data also shows the presence of north-south trends of highs and lows, in agreement with structural patterns seen from surface geology.

Four potential generative source pods were identified over the Buton and Muna Islands: 1) LA-1 (North Muna sub-basin), 2) LA-2 (West Bale sub-basin), 3) LA-3 (Sampolakosa sub-basin), and 4) LA-4 (Lambale sub-basin). Thermal modeling was performed to confirm their level of maturity and their generative potential for petroleum.

New Seismic Interpretation and Mapping

Multi-vintage seismic lines are distributed on Buton Island, offshore Buton, Buton Strait and Muna Island (Figure 1). The interpretation of the Buton Island area and offshore Buton consists of 10 horizons, from Permian until Recent. Meanwhile, the interpretation of the Buton Strait and Muna Island consists of 9 horizons, from the Cretaceous until Recent. Horizon interpretation of the seismic lines is based on biostratigraphic analysis of exploration wells and internal seismic characters.

The structural interpretation found three main structural styles in Buton. Imbricated fold-thrust belts and listric normal-faulted structures dominate the onshore area of north Buton. The area of north offshore Buton is dominated by listric normal faulted-structures forming half-graben geometry, imbricated fold-thrust belt and strike-slip structures. The duplex fold-thrust belt system is the main structural style of the southern area of Buton Island. Meanwhile, fold-thrust belt imbricated and planar typical faulted structures dominate the Buton strait and Muna Island areas.

Listric normal faults in the Buton's offshore and onshore areas are part of the sub-thrust system. The imbrication of the fold-thrust belt system in that area has gradually changed from a thick-skinned system in the western part of Buton to a thin-skinned one in the eastern part of Buton. It shows that the eastern part is the distal part of the fold-thrust belt system formed in the Neogene period. The fold-thrust belt structure in the Buton area has the N-S and NEN-SWS patterns, where the direction is perpendicular to the direction of the tectonic collision in the Neogene period. The listric normal fault structure in the northern part of Buton is parallel to the N-S Lambele Sub-Basin direction.

Depth structural mapping was conducted based on specific areas. In the Buton Strait area, the structures are dominated by a fault-thrust belt system and depth structural mapping was conducted on the Early Miocene, Middle Miocene, and Late Miocene horizons. In North Buton, depth structural mapping was conducted on the Permian, Early Jurassic, and Cretaceous horizons. The structures are listric normal faulted where half-grabens are formed or thrust fold belts, especially for the Cretaceous horizon. Depth structural mapping was also conducted for Early Miocene and Middle Miocene in North Buton. The structures of these horizons are controlled by a fault-thrust belt system that is imbricated in some places.

The southern area of Buton Island is more complicated in structural styles, with the dominance of duplex fold-thrust belt system Repetition of shallow horizons is common, making the main target structurally deepen and the structures are also compartmentalized, leading to previous wells failing to reach the target. Newly acquired seismic data with specialized structural complicated fields and processing parameters are needed. Existing seismic lines de not allow further seismic interpretation.

Seismic Attribute Analysis

Seismic attribute analysis aims to differentiate geological event by highlighting a certain component from seismic data, such as amplitude and frequency. Seismic attributes help in supporting evidence for the geological concept and show any anomaly event that differs from its surrounding.

In this study, two types of seismic attributes were used. The first used attribute is the envelope attributes, also known as instantaneous amplitude, which represents the amplitude of an oscillatory function. This attribute is proportional to the acoustic impedance contrast and, therefore, can be used as an effective discriminator for bright spots, unconformities, and major lithology or depositional environment changes. The second used attribute is pseudo-relief, an attribute enhancing the seismic reflector and which aims at simplifying the structural interpretation.

Figure 4 shows features of carbonate build-ups from seismic attributes. One can observe on envelope attribute such as a large body representing the high value of envelope attribute that looks like a reefal carbonate. Furthermore, the layer above this feature represents a low value of the envelope attribute, which suggests that lithology changes took place. Unconformity can also be interpreted as the low and high values here having different direction patterns. One can also see a high amplitude in an anticline structure which suggest a bright spot or possible hydrocarbon accumulation. The pseudo-relief attribute can also capture the evidence of reefal build-ups, such as a saddle feature between mounded features resembling the reefal build-up occurrence. We can expect that in the anticline feature, possible hydrocarbon accumulation may exist in the Buton area. The reefal carbonate build-ups also developed in older formations on top of paleo high structures and in younger formations.

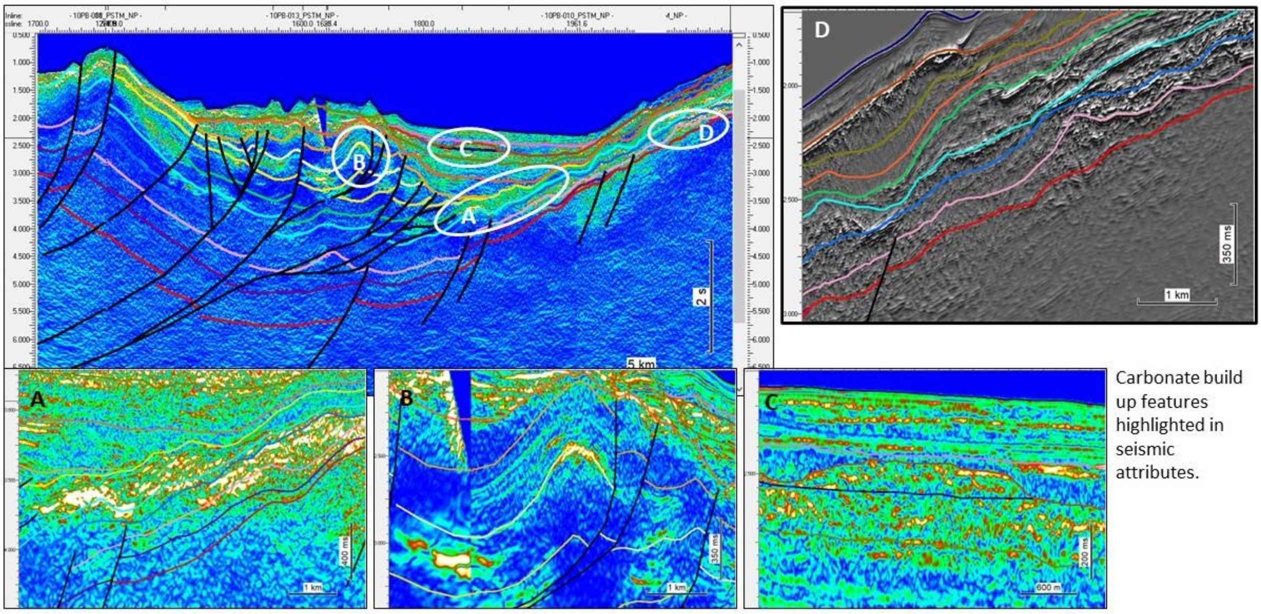


Figure 4 – Seismic attributes of instantaneous amplitude (A-C) and pseudo-relief (D) helps the identification of seismic features related to some structural or stratigraphic features like build-ups.

Dry Well Analysis

Six exploration wells were drilled on Buton Island from the first in 1976 to the last in 2012. Five well data were available for this study. The last well drilled (Ereke-1) is not yet available in the Migas Data Repository (MDR). A summary of the results of the wells and post-mortem interpretations can be seen in Figure 5.

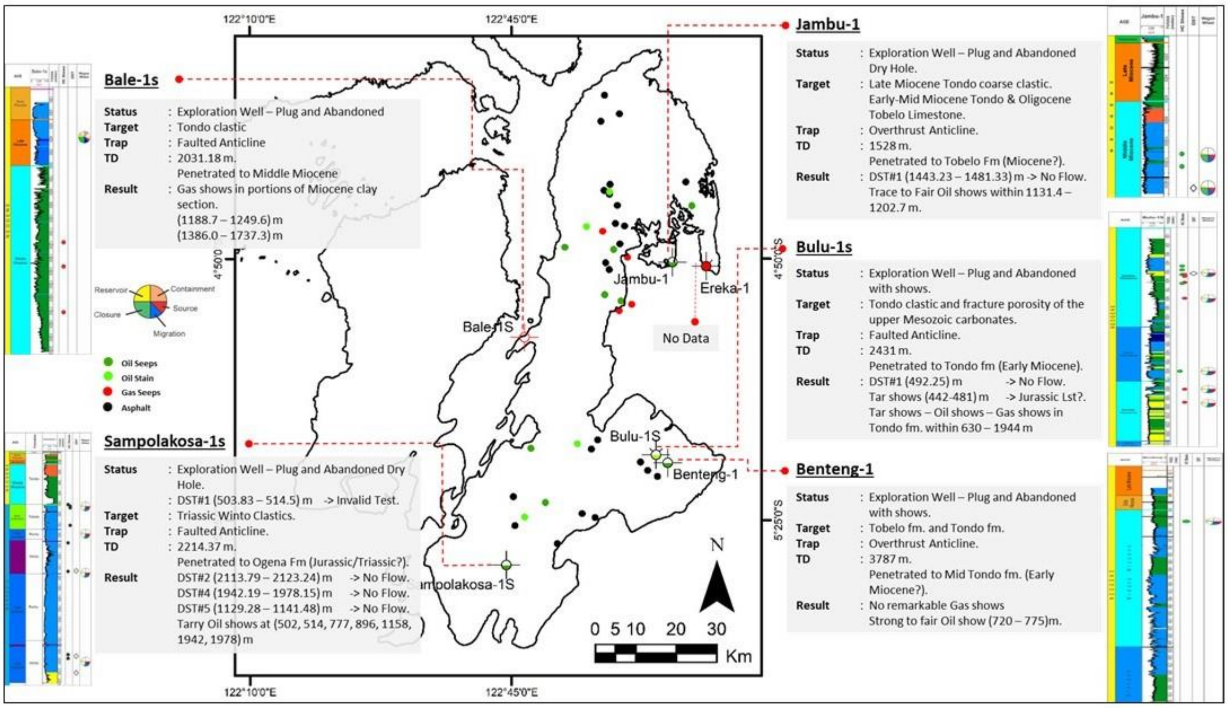


Figure 5 - There were six exploration wells drilled in the Buton area, including Sampolakosa-1S, Bulu-1S, Bale-1S (by Gulf Company in the 1970s), Jambu-1 (by Conoco, 1991), Benteng-1 (Japex, 2010) and Ereke-1 (Putindo, 2012 -no data available). The summaries of well information are shown, and the interpretations of problems related to well failure (problems with closure, reservoir, containment, source, migration).

Bale-1S was drilled by Gulf Oil in 1976. The drilling program was based on regional geologic surveys, including conventional air photos in 1974, an airborne magnetometer survey in 1975, and geological mapping in 1975. No seismic line had been run through this well, nor the Bale Peninsula. The closest seismic lines were the offshore seismic in Buton straits, acquired in 1970 and 1974. The target was Tondo clastic, the trap was faulted anticline, and the TD of the well was 2031 m at the middle Miocene Tondo. Gas shows were encountered in the Miocene clay section. Problems with reservoir and containment are considered reasons for the dry hole.

Bulu-1S was drilled by Gulf Oil in 1976 with Tondo and the uppermost Mesozoic carbonate as the targets. This prospect was a four-way dip closure that was mapped on surface indications. Part of the Tondo clastic was also exposed in this area, but at the depth of the target was faulted anticline. Bulu-1S was drilled up to 2431 m reaching early Miocene Tondo. The targeted reservoir of Tondo had porosities of 12%. Tar, oil, and gas shows were encountered during the drilling. One shallow DST was conducted on the middle Miocene Tondo with no flow. Problems with closure, reservoir, and containment are considered reasons for the dry hole.

Sampolakosa-1S was drilled by Gulf Oil in 1976 to test the hydrocarbon-bearing potential of the clastic reservoirs of the Tondo Formation and the possible fracture porosity of the Mesozoic carbonates. The prospect was a faulted anticline. Sampolakosa-1S was drilled up to 2214 m in fractured quartzitic sandstone interpreted as Upper Triassic – Winto formation. The well penetrated up block of thrusted Winto, below this was a Miocene formation. Tar/asphaltic materials were encountered. Three DSTs were conducted but with no flow. Poor image of closure and poor reservoirs and containment are considered as the reasons for dry Sampolakosa-1S well.

Jambu-1 was drilled by Conoco in 1992, drilled to a TD of 1528 m at Tondo. The objectives were Miocene Tondo clastic and carbonates and Paleogene Tobelo limestone. The prospect was overthrusted anticline. Tondo Formation was penetrated. Traces to fair oil shows were encountered, but an open-hole DST proved that the formation was tight. Problems of closure, reservoir quality, and containment became the issue for the dry hole of Jambu-1.

Benteng-1 was drilled by Japex in 2012 with Tobelo carbonates as the target; the prospect was overthrusted anticline. The well was drilled into 3787 m after deepening to reach the target, but the well TD was at mid-Miocene Tondo. Repetitive shallow targets by overthrust caused the Tobelo beyond the target TD even after deepening. The penetrated middle Tondo limestone and sandstone reservoir quality were generally poor but partially good. An oil show was encountered on the Tondo target, and the sample was extracted, resulting in terrestrial sourced oil. The seismic section shows a complicated fault thrust belt system structure, hence poor structural imaging. The well location is far from the potential generative sub-basin interpreted from the gravity anomaly. Problems related to closure, reservoirs, and containment are considered reasons for the dry hole.

Most of the wells drilled in the Buton area appears to have no issue with hydrocarbon charging. Major recognized issues are recognized to be hydrocarbon containment, the quality of the reservoir, and the less integrated data interpretation done in the past. The problem of the dry wells is mainly related to the image of the structure due to poor seismic data cause by the intensive deformation and thick repetitive carbonate beds. New seismic acquisition and processing methodology to better image the structures would ideally be needed. Once the structures can be well-imaged, the probability of success will be high.

Sampolakosa-1S is the well with the most critical data. The well-penetrated Triassic Winto shales with excellent analyzed source potential (8 % TOC). The well also drilled a 43-meter column of biodegraded oil (10° API) in the Tobelo carbonates, but it penetrated the Cretaceous Tobelo carbonates at the flank of the structure. That well along the large asphalt field near surface, prove that an active petroleum system exist in Buton exists.

Petrophysical Analysis

Petrophysical analysis of the Buton area was conducted on 7 wells (Bale-1S, Bulu-1S, Sampolakosa-1S, Jambu-1, Benteng-1, Abuki-1 and Oseil-1). Abuki-1 and Oseil-1 are exploration wells in Southeast Sulawesi near Kendari city and Seram Island, respectively. Those wells were included in the study as they penetrated the key reservoir objectives and can be used asanalogs. The petrophysical analysis is required to obtain parameters to calculate the volumetric of prospects and leads. All the analysis results have been validated with data such as core analysis, DST, mud log, etc.

Petrophysical summary of Pleistocene. The net reservoir of the Pleistocene interval in the Buton area is provided by the analog well of Abuki-1. The average net reservoir result is 284m, with the Vclay, porosity, and permeability of 31.4%, 21.7%, and 877 mD, respectively.

Petrophysical summary of Pliocene. The reservoir presence in the Buton area is interpreted from 3 intervals of 2 wells available: early Pliocene of Benteng-1 well, early Pliocene, and late Pliocene of Abuki-1. An average of 85m net reservoir is calculated from all 3 intervals with the Vclay, porosity, and permeability averages of 39.6%, 15.7%, and 460 mD, respectively.

Petrophysical summary of late Miocene. The interval of the late Miocene is penetrated by 4 wells: Abuki-1, Bale-1, Jambu-1, and Sampolakosa-1S, with an average net reservoir of 177 m. Vclay, porosity, and permeability averages are 28.5%, 23.7%, and 863 mD, respectively.

Petrophysical summary of middle Miocene. The Middle Miocene interval of the Buton area is penetrated by wells Benteng-1, Bale-1S, Bulu-1S, Jambu-1, and Sampolakosa-1S. The average Vclay is 28.3%, the porosity is 16.7%, and the permeability is 346 mD. The net reservoir presence is 224 m thick.

Petrophysical summary of early Miocene. The Early Miocene interval is represented only by Bulu-1S well. The petrophysical analysis resulted in 39m of net reservoir with the Vclay, porosity, and permeability averages of 21.7%, 9.3%, and 6 mD, respectively.

Petrophysical analysis of Miocene carbonates in Buton is referenced to the carbonate build-up of the Senoro gas field or the fractured carbonate platform of the Tiaka oil field. The two fields are located in Banggai Basin, eastern Sulawesi. The average porosities of Senoro carbonate build-up and Tiaka carbonate platform are 27% and 9,4%, respectively. Average permeabilities are variable. The average net-to-gross ratio for Senoro carbonate build-up is 0.85-0.95 and 0.31 for the Tiaka carbonate platform.

Petrophysical summary of Cretaceous. The Cretaceous interval is only represented by Sampolakosa-1S well. The petrophysical analysis resulted in 113m of net reservoir with the Vclay, porosity, and permeability averages of 9.4%, 19.9%, and 466 mD, respectively.

Petrophysical summary of Late Jurassic. The petrophysical summary of the Late Jurassic interval in the Buton area is represented by the Sampolakosa-1S well, which contains 3 different levels of Late Jurassic, caused by repetitive thrusting. The average net reservoir of the Late Jurassic interval is 132m, with the Vclay, porosity, and permeability averages of 17.5%, 9.8%, and 7.4 mD, respectively.

Petrophysical summary of Early Jurassic. No well penetrated the Early Jurassic interval in Buton; the analog reservoir is referenced to Oseil-1 well in Seram Island penetrating Manusela carbonates. The Early Jurassic interval of Oseil-1 is a fractured reservoir that still flows fluid, although the porosity and permeability are very low. The net reservoir is 185m, with the Vclay, porosity, and permeability averages of 6.1%, 7.5%, and 11.4 mD, respectively.

Gross Depositional Environments

Gross depositional environment (GDE) maps were constructed in this study. GDE maps of Mesozoic and Cenozoic sediments were constructed for Permo-Triassic, Late Triassic, Early Jurassic, Cretaceous, middle Miocene, and late Miocene levels (Figure 6).

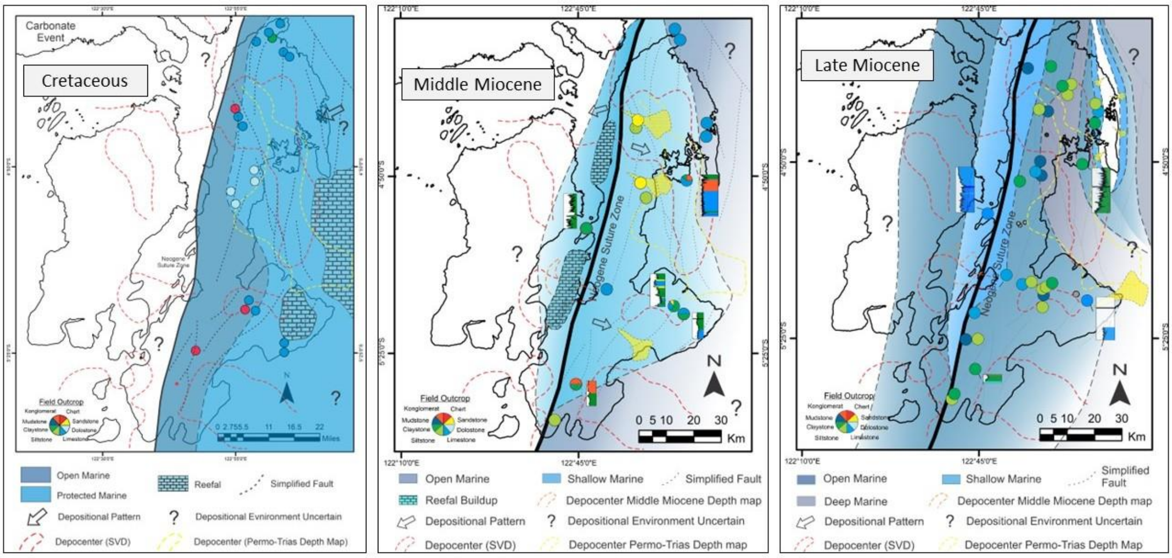


Figure 6 - Gross depositional environments of sediments from Permo-Triassic to Late Miocene in Buton.

Permo-Triassic. The marginal marine developed in the northern area with possible small deltaic trending NE-SW, the evidence of delta feature is shown at seismic sections. The transition into shallow marine is interpreted at the edge of the low area presented in SVD gravity data. The Permo-Triassic carbonate platform sequence is penetrated in Sampolakosa-1S well, and its distribution is interpreted to be relatively widespread.

Late Triassic. The Late Triassic sequence comprises a carbonate platform that is distributed widely. Carbonate build-ups are identified from seismic development in high areas controlled by faults and supported by SVD gravity high areas. Outcrop data shows a different environment in the northern part from the carbonate realm into clastic (siltstone and claystone), which indicates the provenance might be in NE of the area. This Late Triassic carbonate build-up may become a potential exploration objective/play type.

The early Jurassic environment was marked by the development of a carbonate platform in the western part and carbonate build-ups in the eastern part. The outcrop data shows that carbonate developed in an open marine setting. The Early Jurassic carbonate build-ups are the objective for the exploration target.

Cretaceous. During the Cretaceous, the carbonate platform still dominated with build-ups in the eastern part. The carbonate build-ups developed in the high area, which follow the paleo structure with the N-S trend. The outcrop data shows that the environment was getting deeper towards the west.

Middle Miocene. In the mid-Miocene time, the Buton-Tukang Besi microcontinent collided with SE Sulawesi. The depositional setting differed after the collision; fans of sands developed with provenances coming from the west as high areas due to the collision. Siliciclastic deposits are recorded from wells in Buton's northern and southern parts. Due to some erosion and peneplain, the western part submerged when the sea level rose and became the site for carbonate build-ups to develop, trending north-south. Therefore, the exploration objectives for the middle Miocene are siliciclastic Tondo Formation and carbonate build-ups in the western part.

Late Miocene. In the late Miocene, after the continuing collision, the high areas were concentrated in the suture zone forming a shallow marine environment. The carbonate build-ups developed in the suture zone, while deeper water shales, siltstones, and mudstones were deposited in the western and eastern parts. Siliciclastic deposits also developed in the eastern part of North Buton. The provenance came from high areas trending north-south caused by the collision and was surrounded by deep marine shales.

Petroleum System Analysis

The analyses of petroleum systems in Buton and surrounding areas used a combination of surface and subsurface data consisting of surface geology, asphalt field, hydrocarbon seeps, gravity, multi-vintage seismic data and five exploration wells. In summary, the asphalt field and hydrocarbon seeps show that the petroleum systems in Buton are working. The analyses also show that the Buton area has the potential for multiple source rocks, reservoirs, and regional seals. The petroleum system events chart of the time relations of elements and processes of the petroleum system of Buton is shown in Figure 7.

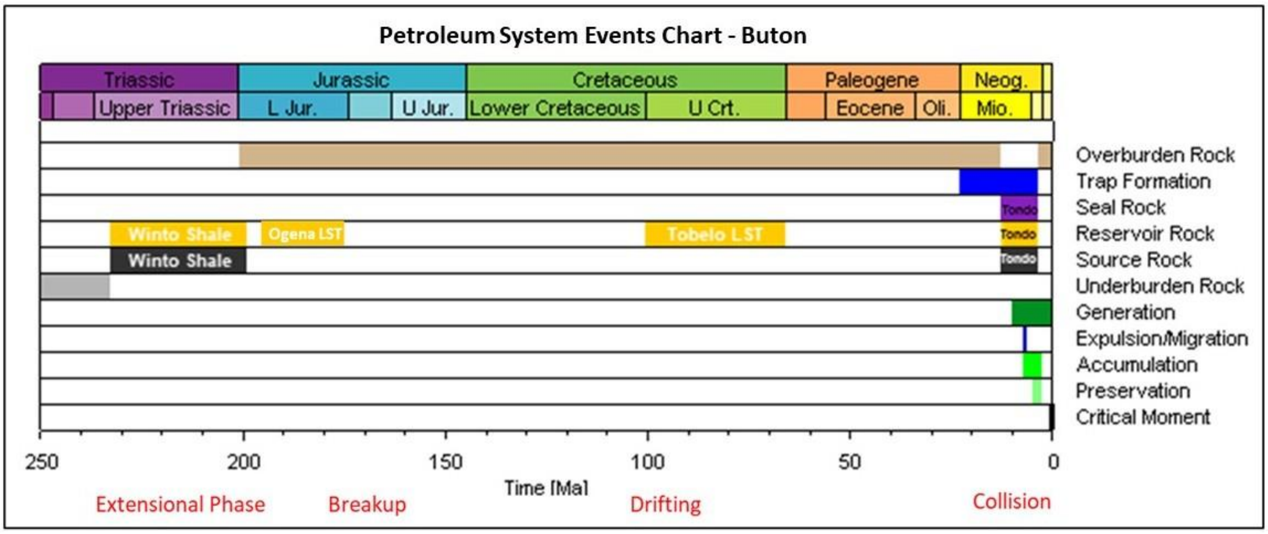


Figure 7 – The petroleum system events chart of Buton showing temporal relations of all elements and processes of the petroleum system, the most factors developed after collision in mid-Miocene time.

Source Rock. The source rock potential in the Buton area is divided into two systems: Mesozoic and Cenozoic source rocks. The Mesozoic source rocks are from Triassic Winto Formation. The following is quoted from Davidson (1991). "Geochemical analysis indicates these rocks have good to excellent oil-generating potential. Total organic carbon (TOC) ranges from less than 1% to over 16%. Most samples of the Winto Formation contain high concentrations of oil-prone, sulfur-rich, Type II amorphous kerogen. In outcrop, Winto source rocks are immature to marginally mature marginally—Spore Coloration Index and Vitrinite Reflectance value average 3.5 and 0.4, respectively. At thermal maturity, these rocks will generate high sulfur, low wax, and paraffinic crude oil. Burial history and maturation modeling suggest that the unthrusted Winto sediments, at depth, entered the oil window (0.5% Ro) in the Late Miocene. The onset of oil generation was coincident with thrusting and imbrication, development of overthrust anticlinal structure, and deposition of Tondo Formation coarse clastic facies. The numerous live oil seeps from the Winto Formation indicate that these rocks are locally still within the oil window. Carbon isotope, pyrolysis-GC, GC, and GC-MS biomarker data for all asphalt samples and most live oils indicate derivation from the calcareous shales and bituminous limestones of the Winto Formation. Delineation wells in the Buton asphalt mines indicate that these sediments have already expelled approximately 18 million tons of bitumen or 87 million barrels of 30° API oil equivalent. Miocene Tondo Formation shales and mudstones are secondary source rock. Assessment of their potential is difficult, primarily due to asphalt contamination and the inclusion of reworked Triassic material. Tondo shales are generally gas-prone with fair to poor potential and contain both terrestrial and algal kerogen and the biomarker Oleanane. TOC ranges from less than 1% to over 10%. Oils from the Nunu seep, northwest Buton, were typed to Tondo sediments."

Reservoir. Buton has multiple potential reservoirs consisting of: 1) Basement-Lower Winto Formation (?Permian-Early Triassic), 2) carbonate facies of Ogena Formation, 3) carbonate facies of Tobelo Formation, and 4) carbonate-sandstone facies of Tondo Formation. The reservoir potential of the Basement-Lower Winto Formation consists of metamorphic and clastic limestone. Fractures control porosity development. This reservoir is located offshore and onshore in the northern part of Buton. It is associated with a relatively N-S trending half-graben system formed in the Triassic extensional system. Carbonate reservoir facies from Ogena Fm. has similarities with the Early Jurassic Manusela carbonate facies of Seram Island. Ogena Fm. is deposited in protected marine to open marine environments. These carbonate facies was part of the NW Australian shelf. Manusela and Ogena carbonates are significantly controlled by inter-connected fracture porosity that developed during the collision phase in Neogene. Buton also has the Cretaceous carbonate facies of the Tobelo Formation, which has potential as a reservoir.

Tobelo Formation consists of dolostone, limestone, and chert deposited in a protected marine to open marine environment. In the Sampolakosa-1 well, the Tobelo carbonate facies have an average porosity of 0.12% and permeability of 82.45 mD with a net reservoir of 193 m. Orogenic sediments of the Tondo Formation also have potential as a reservoir. Reservoir targets of the Tondo Formation are divided into three intervals: Lower Tondo, Middle Tondo, and Upper Tondo. The petrophysical characteristics of the Tondo reservoirs are discussed in the petrophysical analysis section.

Seal. Calcareous mudstones and claystone of the Late Miocene Tondo Formation and marls and mudstones of the Early Pliocene Sampolakosa Formations are the principal seals. The sealing potential is most significant in north Buton, where tips to 120 meters of interbedded mudstones and siltstones are observed. In south Buton, over 50 meters of Sampolakosa Formation mudstones and siltstones with good sealing potential were penetrated by the Bale-IS well (Davidson, 1991). Sampolakosa Formation is a syn-orogenic sediment; this formation in several areas of Buton Island has not been deposited or had been eroded. Sampolakosa Formation, in several places, became an asphalt-bearing formation because during the orogenic process the hydrocarbons re-migrated from underlying reservoirs and were trapped in this formation. Based on this, exploration in the Buton area is focused on areas with complete stratigraphy from the Triassic to the Recent because they have the best chance of success and minimize uncertainty in the seal component (containment).

Trap. Structural traps are the main traps in Buton Island; structural evolution from Mesozoic to Cenozoic is the leading key trap development. Structural traps in deeper targets, mostly Mesozoic reservoirs (Permian? and Early Jurassic carbonate Ogena Formation) located in the north Buton area, are controlled by the extensional phase. The basement high was formed due to half-graben geometry becoming the main trap on the target leads. Besides that, the flexural system of the half-graben also becomes a reasonably good trap system where this system forms a relatively good 4-way dip closure. Both trap systems can be found in the Lambele Sub-Basin area (North Buton) and the north offshore Buton area. Trap formation on the Cretaceous-Miocene target is controlled by the tectonic contraction phase, where the trap system is dominated by faulted anticline. The northern area of Buton (onshore-offshore) and the Buton Strait have a more simple system than the southern area of Buton Island, where an imbrication of the fold-thrust belt system dominates the northern area and the Buton Strait.

In contrast, a duplex fold-thrust belt system dominates the southern area. Based on this, south Buton has more complicated traps than other areas due to the repetition of stratigraphy and compartmentalization, which is the main challenge for hydrocarbon exploration. Offshore Buton has quite different trap features from onshore Buton and Buton Strait. In this area, the trap system is dominated by strike-slip fault trending NW-SE, forming a transpressional geometry resulting in a positive flower structure system.

Petroleum Generation. From basin modeling, it is found that the Upper Triassic source rock of the Buton area (Winto shales) has been able to generate hydrocarbons in the middle Miocene time, or it happened after the collision event. Source rocks of the Upper Triassic reached a critical moment relative in recent times, but the accumulation was well preserved since the latest Miocene because seal and trap had already been established from the very late Oligocene until Mio-Pliocene. Meanwhile, the younger source rock from the Tondo Formation, based on modeling in some areas of Buton, shows that Tondo shale source rock has a good potential and generative capacity for hydrocarbons

Migration. The migration of hydrocarbons in Buton and surrounding areas is strongly controlled by fault systems that developed during the Triassic to Pliocene periods. Hence, we interpret that the hydrocarbon maturity and the timing of hydrocarbon migration occurred in the Neogene period; this coincides with the collision of the Buton microcontinent.

Play Concept/Play Types

At least three play types are identified in the Buton area. Figure 8 shows these play types and seismic section samples identifying them.

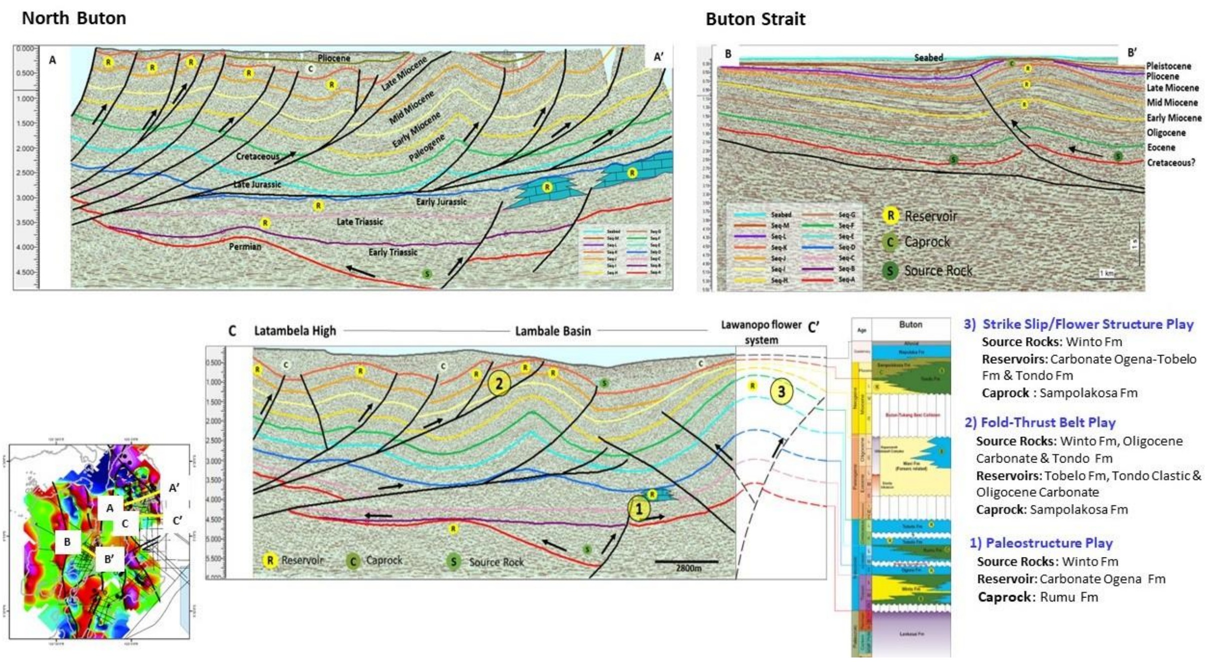


Figure 8 – Petroleum play types developed in the Buton area and samples of seismic sections where the play types exist. Three play types can be recognized in Buton Strait and North Buton, including (1) paleostrucure play, (2) fold-thrust belt play, and (3) strike-slip structure play. The elements of source rocks, reservoirs, and caprocks are indicated for each play.

Fold-Thrust Belt Play. This play type was formed in the Cenozoic time following the collision. The reservoirs are Tobelo carbonate, Tondo clastic, and Oligocene carbonate formation. The source rock for this play comes from Winto, Oligocene carbonate, and Tondo formation. Containment is provided by the regional Sampolakosa formation and interbedded shale layers within Cenozoic intervals.

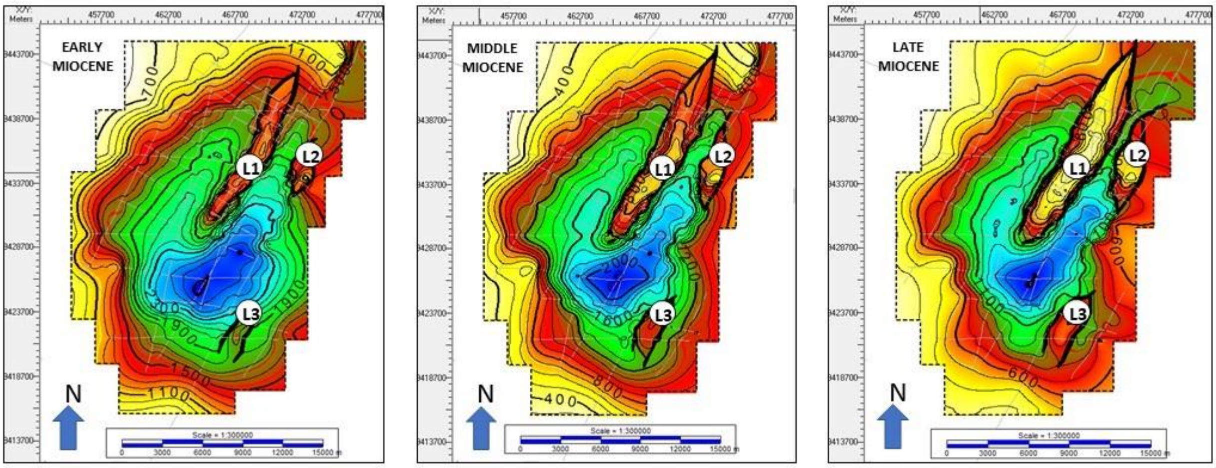
Strike-Slip Play. This play was formed in the Cenozoic time as post-collision deformation. Reservoirs are Ogena-Tobelo carbonate formation and Tondo clastic formation. The source rock for this play is constituted by the Winto shales. The cap rock for this play is also the regional Sampolakosa formation and interbedded shale layers within Cenozoic intervals.

Paleo-Structure or Sub-Thrust Play. This play was formed in the Mesozoic time. The reservoirs are from the Ogena carbonate formation. The source rock of this play comes from Winto shales. The cap rock primarily relies on the Rumu formation of Late Jurassic age.

Structures Identified and Volumetric Calculation

We identified 28 structures during this study that could form structural traps for hydrocarbon accumulations. 3 were mapped in the Buton Strait area, and 25 were mapped in the North Buton area. Due to data limitations, all structures are classified as leads.

In the Buton Strait, the 3 identified structures are from the fold-thrust belt play type, each with multiple reservoir targets. Up to 9 reservoir targets of Miocene age were identified in associastion with those structuters. Reservoirs and seals are the main geological risks in this area. The preliminary volumetric calculation for all 3 structures with a total of 9 reservoir targets is a range of 295 MMBO (P50 oil in place, unrisked) and 1,351 MMBO (P10 oil in place, unrisked). No gas was generated in the Buton Strait based on basin modeling. Figure 9 summarizes the structures mapped in Buton Strait and the volumetric calculation. Figure 10 shows an example of one lead and its summary.



BUTON STRAIT VOLUMETRIC CALCULATION

	Target Name	Oil In Place (MMBO)			Oil Recoverable (MMBO)		
		P10	P50	P90	P10	P50	P90
Early Miocene	EM1	94.79	30.92	7.76	47.40	13.91	3.10
	EM2	35.32	6.84	1.46	17.66	3.08	0.58
	EM3	7.44	1.89	0.46	3.72	0.85	0.18
Middle Miocene	MM1	425.00	82.00	18.00	212.50	36.90	7.20
	MM2	56.12	18.02	4.74	28.06	8.11	1.89
	MM3	33.25	6.54	1.42	16.63	2.94	0.57
Late Miocene	LM1	617.00	122.00	26.00	308.50	54.90	10.40
	LM2	62.35	20.50	5.32	31.17	9.22	2.13
	LM3	20.15	6.59	1.71	10.08	2.97	0.68
TOTAL		1351.42	295.30	66.85	675.71	132.89	26.74

TOTAL P50 OIP FOR:
- L1: 234.92 MMBO
- L2: 45.36 MMBO
- L3: 15.02 MMBO

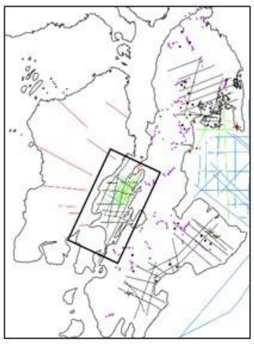


Figure 9 – Three structures are identified in Buton Strait; each has multi targets of early-, middle-, and late Miocene. Volumetric calculations of unrisked oil in place for P10, P50, and P90 are shown. No gas is generated in Buton Strait based on basin modeling.

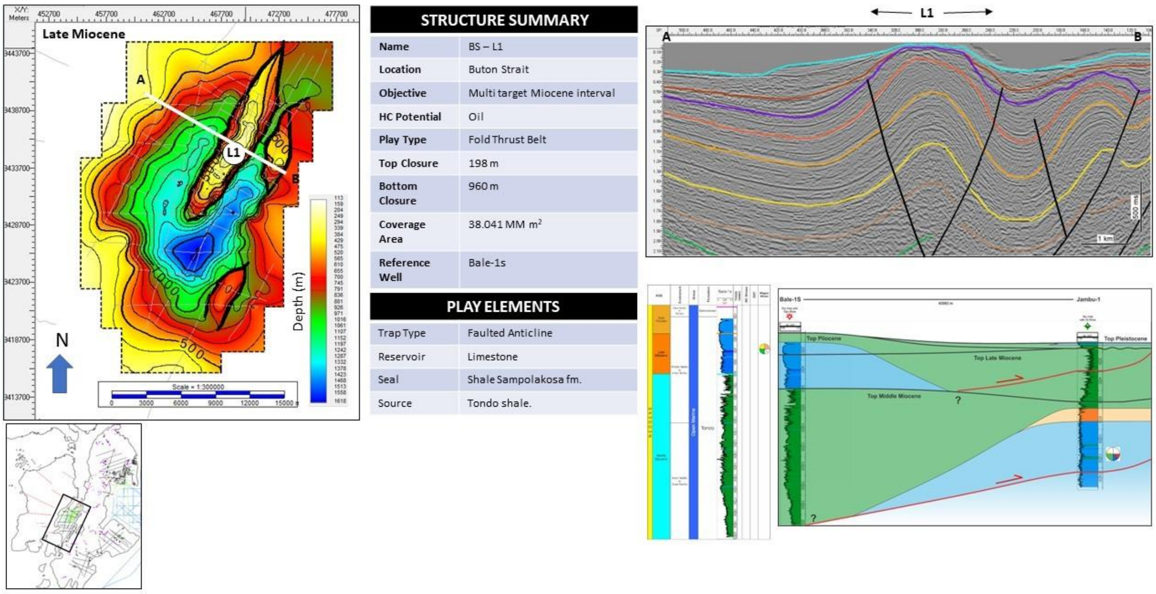


Figure 10 – Summary of Lead 1 and its play elements in Buton Strait having the largest volumetrics. A key seismic line and a section displaying the reference well for this structure are shown.

In North Buton, 25 structures were identified from the Permian to Miocene horizons. Up to 34 targets were identified in association with those 25 structures. The reservoir targets include the Permian, Early Jurassic, Cretaceous, early Miocene and middle Miocene. Structures with Permian and Early Jurassic targets are paleo-structure play type, with the possibility of carbonate build-up developing at the high structure of the Early Jurassic. The Cretaceous structures are related to the fold-thrust belt and strike-slip fault play types. However, seismic data coverage is very limited in the northeastern part of North Buton; therefore, the available structures can not be defined further. The early Miocene and middle Miocene targets are of fold-thrust belt play type. The main risk in these structures is reservoirs and seals. The preliminary volumetric calculation for all 25 structures with a total of 34 targets is 689 MMBO and 3.9 TCFG (P50 oil and gas in place, unrisked) or 2,950 MMBO and 16.5 TCFG (P10 oil and gas in place, unrisked). Figure 11 summarizes the structures mapped in Buton Strait and the volumetric calculation. Figure 12 shows an example of one lead and its summary.

NORTH BUTON VOLUMETRIC CALCULATION

Target Name		Oil in Place (MMBO)			Gas in Place (TCF)			Recoverable Oil (MMBO)			Recoverable Gas (TCF)		
Age	Target	P10	P50	P90	P10	P50	P90	P10	P50	P90	P10	P50	P90
Permian	P1	6.19	2.00	0.48	0.03	0.01	0.003	0.929	0.250	0.048	0.028	0.008	0.002
	P2	1.64	0.59	0.16	0.01	0.00	0.001	0.246	0.073	0.016	0.007	0.002	0.001
	P3	6.19	2.02	0.47	0.03	0.01	0.003	0.929	0.253	0.047	0.028	0.008	0.002
	P4	1.39	0.55	0.18	0.01	0.00	0.001	0.209	0.069	0.018	0.006	0.002	0.001
	P5	10.21	3.24	0.72	0.06	0.02	0.004	1.532	0.406	0.072	0.046	0.013	0.002
	P6	16.75	3.65	0.75	0.09	0.02	0.004	2.512	0.456	0.075	0.075	0.014	0.003
	P7	79.68	25.72	5.87	0.45	0.14	0.033	11.953	3.215	0.587	0.357	0.101	0.020
Early Jurassic	EJ1	245.2	47.8	10.2	1.37	0.27	0.057	36.787	5.979	1.022	1.099	0.187	0.034
	EJ2	14.8	3.3	0.7	0.08	0.02	0.004	2.223	0.407	0.075	0.066	0.013	0.003
	EJ3	10.3	3.9	1.3	0.06	0.02	0.007	1.541	0.483	0.126	0.046	0.015	0.004
Cretaceous	C1	228.8	46.3	9.7	1.28	0.26	0.054	91.512	13.899	1.937	0.769	0.130	0.024
	C2	209.4	41.6	8.8	1.17	0.23	0.049	83.752	12.494	1.762	0.704	0.117	0.022
	C3	60.3	12.2	2.6	0.34	0.07	0.015	24.135	3.670	0.526	0.203	0.034	0.007
	C4	519.0	105.0	22.0	2.91	0.59	0.123	207.600	31.500	4.400	1.744	0.294	0.055
	C5	77.6	25.2	6.6	0.43	0.14	0.037	31.024	7.569	1.316	0.261	0.071	0.017
	C6	59.1	19.3	5.0	0.33	0.11	0.028	23.654	5.775	1.004	0.199	0.054	0.013
Early Miocene	EM1	287.0	56.5	11.9	1.61	0.32	0.067	143.500	25.425	4.760	0.804	0.142	0.027
	EM2	73.9	14.5	3.1	0.41	0.08	0.017	36.950	6.525	1.240	0.207	0.037	0.007
	EM3	45.4	8.9	1.8	0.25	0.05	0.010	22.700	4.005	0.720	0.127	0.022	0.004
	EM4	125.5	49.9	18.6	0.70	0.28	0.104	62.750	22.455	7.440	0.351	0.126	0.042
	EM5	72.3	14.3	3.0	0.40	0.08	0.017	36.150	6.435	1.200	0.202	0.036	0.007
	EM6	9.0	1.7	0.4	0.05	0.01	0.002	4.500	0.765	0.144	0.025	0.004	0.001
	EM7	22.0	7.2	1.9	0.12	0.04	0.010	11.000	3.236	0.740	0.062	0.018	0.004
	EM8	5.4	1.1	0.2	0.03	0.01	0.001	2.700	0.477	0.088	0.015	0.003	0.000
Middle Miocene	MM1	347.0	68.4	14.4	1.94	0.38	0.081	173.515	30.776	5.752	0.972	0.172	0.032
	MM2	35.4	11.8	3.0	0.20	0.07	0.017	17.675	5.288	1.198	0.099	0.030	0.007
	MM3	22.0	4.5	1.0	0.12	0.03	0.005	11.000	2.025	0.384	0.062	0.011	0.002
	MM4	64.6	12.9	2.7	0.36	0.07	0.015	32.300	5.796	1.096	0.181	0.032	0.006
	MM5	187.0	61.7	15.9	1.05	0.35	0.089	93.480	27.747	6.364	0.523	0.155	0.036
	MM6	59.7	19.7	5.2	0.33	0.11	0.029	29.840	8.847	2.068	0.167	0.050	0.012
	MM7	8.2	2.6	0.7	0.05	0.01	0.004	4.105	1.188	0.272	0.023	0.007	0.002
	MM8	5.0	1.0	0.2	0.03	0.01	0.001	2.475	0.450	0.086	0.014	0.003	0.000
	MM9	6.7	1.3	0.3	0.04	0.01	0.002	3.370	0.605	0.112	0.019	0.003	0.001
	MM10	27.4	8.8	2.4	0.15	0.05	0.013	13.711	3.982	0.940	0.077	0.022	0.005
TOTAL		2950	689	162	16.52	3.86	0.908	1222.26	242.52	47.63	9.57	1.94	0.40

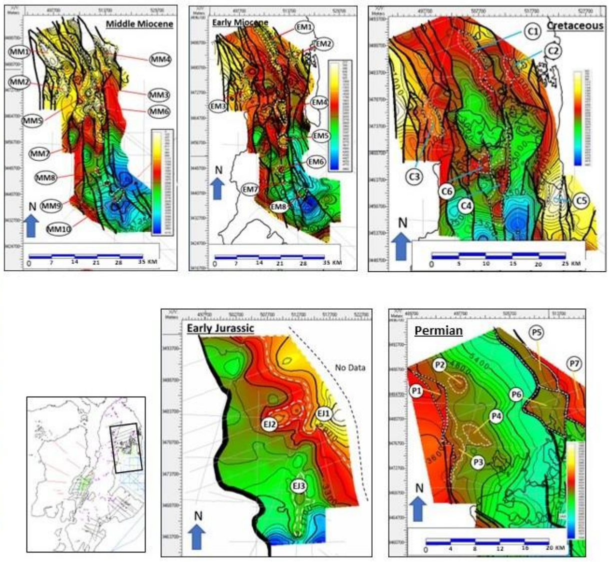


Figure 11 – There are 25 structures identified in North Buton. Most structures have multi targets from the Permian to the middle Miocene. 34 targets have been identified, mapped, and their unrisked oil-in-place and gas-in-place volumetrics have been calculated with three probabilities (P10, P50, P90).

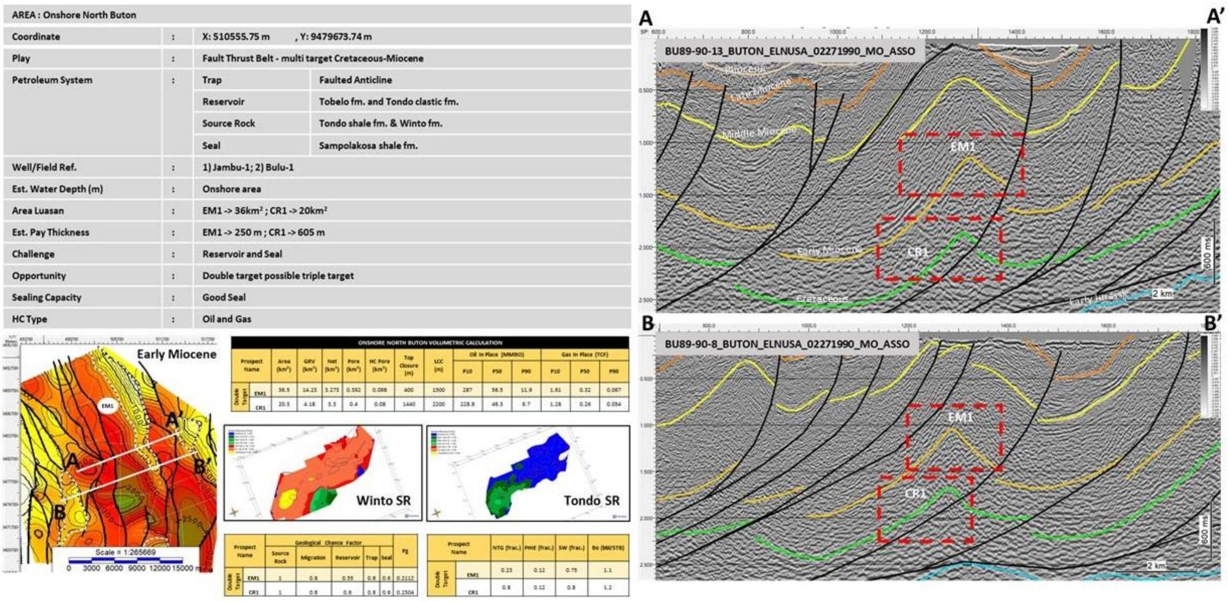


Figure 12 – Summary of a Lead in North Buton related to fold-thrust belt play type. Key seismic lines for this structure are shown. Basin modelling results indicate gas and oil generation from Triassic Winto and Miocene Tondo sources.

Risk Analysis

Following the definition of play types, a risk analysis wascarried out by building a common risk segment (CRS) map in order to estimate the risk associated with the petroleum system elements of source rock, reservoir, and seal. These CRS maps were then combined as composite CRS maps to define the play fairway in the study area.

Seal Common Risk Segment. got the CRS seal map was based on the criteria for seal presence and quality. Seal presence is observed from the geological map, while seal quality is based on its thickness, which can be analyzed from the isopach map. As for seal quality, high risk is defined when the bed thickness is less than 20 m, medium risk is defined when the thickness is up to 40 m, and low risk is defined when the thickness is greater than 40 m. CRS seal for the middle Miocene, early Miocene, and Late Jurassic are shown in Figure 13.

Reservoir Common Risk Segment. The CRS reservoir map was based on the criteria for reservoir presence and quality. The GDE map and porosity values obtained from the well are the data for creating a CRS reservoir. The shallow marine environment is still considered to be a low-risk profile. The risk gets higher toward open marine since carbonate is less likely to develop in open marine and siliciclastic will also be finer and less likely to be a good reservoir. Porosity values obtained from the well also give a rough boundary in defining risk areas. Porosity higher than 10% is considered low risk, while porosity lower than 5% is considered high risk. CRS reservoirs for the middle Miocene, Early Jurassic, and Permo-Triassic are shown in figure 14.

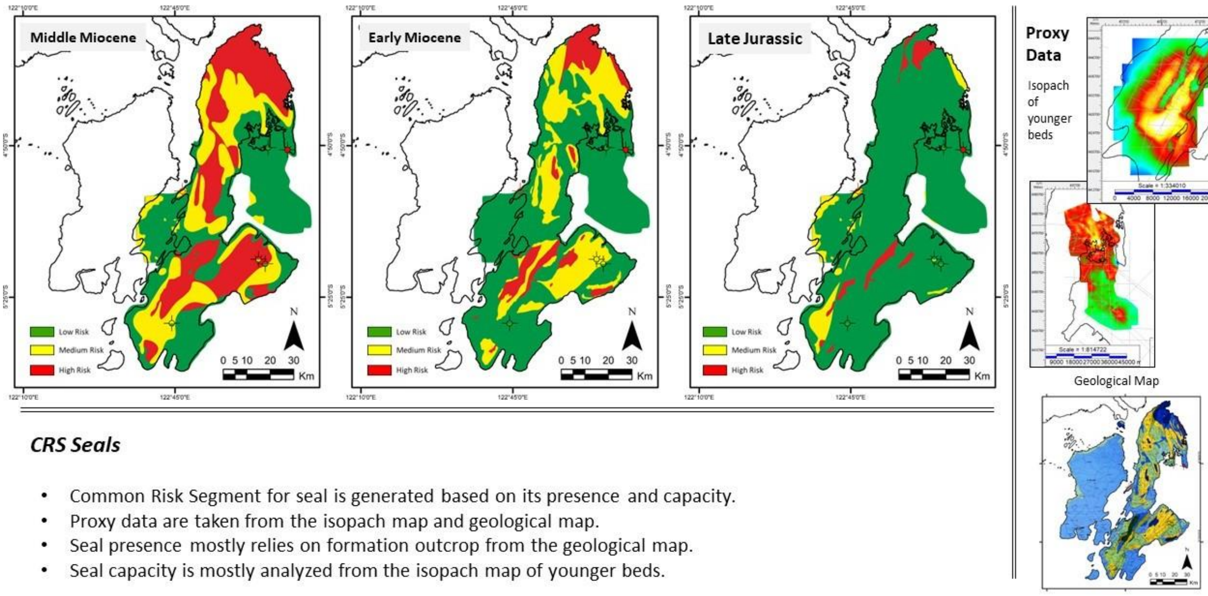


Figure 13 – Risk analysis for Late Jurassic, early Miocene, and middle Miocene seals. Proxy data for the analysis is shown. The older the seal, the better since thicker burial by younger sediments.

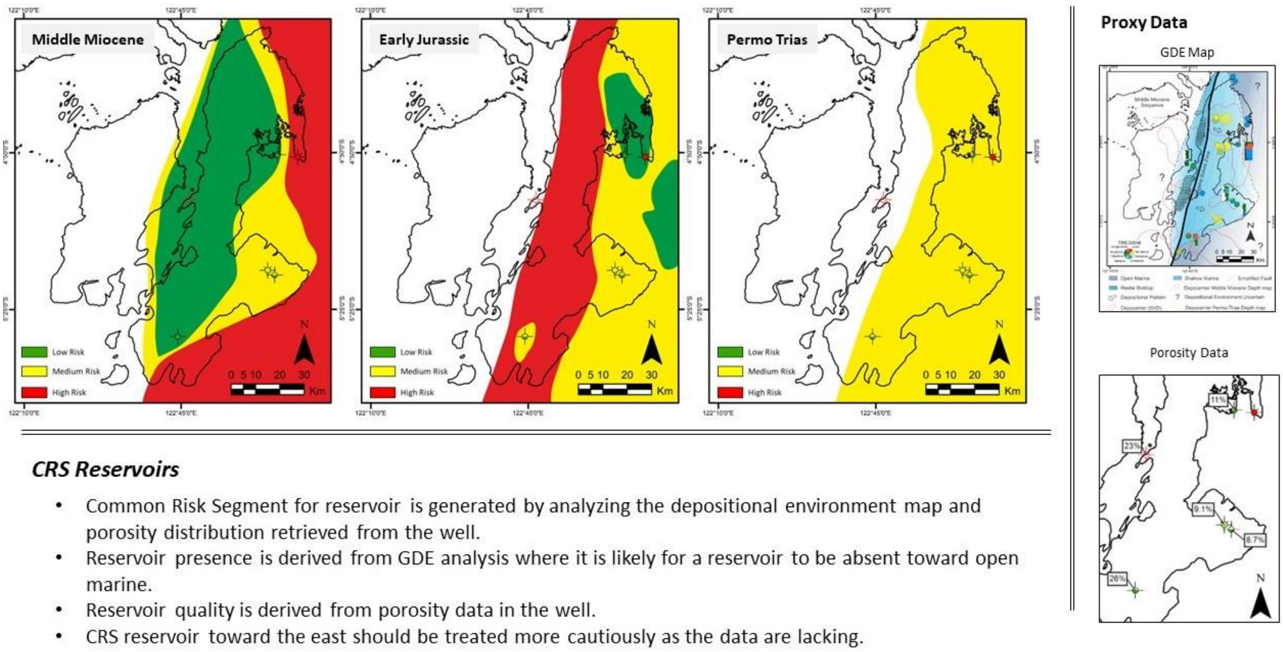


Figure 14 – Risk analysis for Permo-Triassic, Early Jurassic, and middle Miocene seals. Proxy data for the analysis is shown.

Source Rock Common Risk Segment. The CRS source rock map was developed based on the criteria for source rock presence and quality. Field data, basinal low areas from gravity data, and depth maps are the primary proxy data in interpreting the source rock presence. Transformation ratio, maturity, and hydrocarbon generation maps are the basin modeling results to interpret the source rock quality distribution. CRS source rock for Winto/Triassic, middle Miocene, and Eocene are shown in Figure 15..

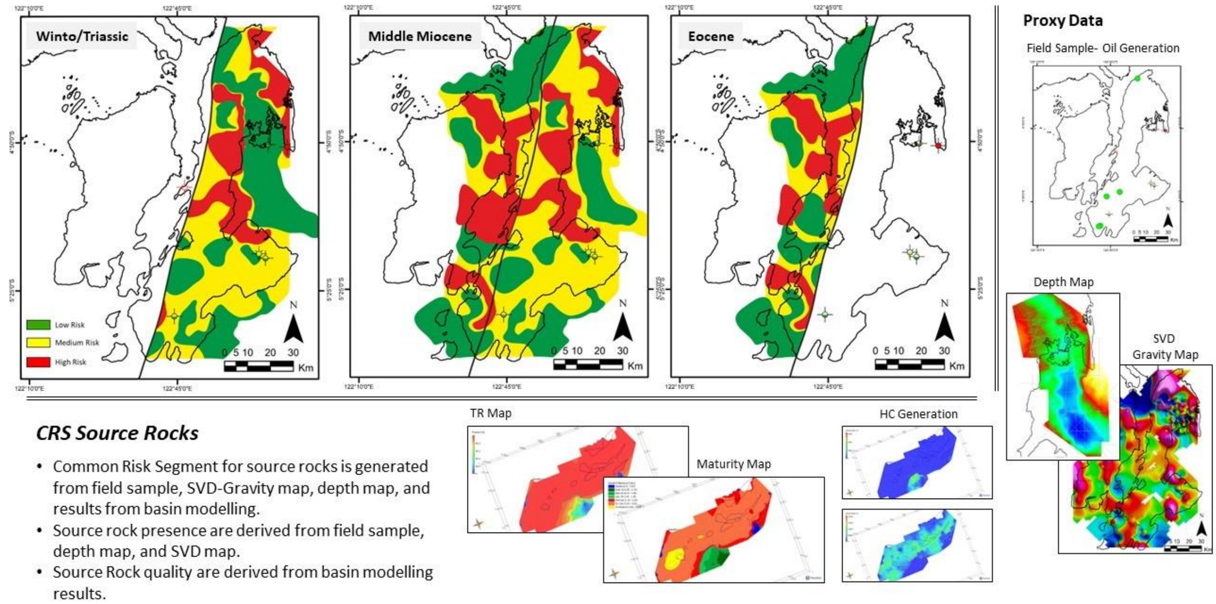


Figure 15 – Risk analysis for source rocks of Triassic (Winto), middle Miocene, and Eocene. Proxy data for the analysis is shown. Results of basin modeling are also shown.

Composite CRS (CCRS)/ Play Fairway. three play fairways generated from CCRS maps were made. Play fairways for Permo-Triassic are mostly medium risk. The seal CRS map highlights the high-risk area where layers younger than Triassic are exposed. Play fairways for Early Jurassic are dominated by high and medium risks. The reservoir CRS map highlights the high-risk area where the data suggest that the area was in an open marine environment causing poor reservoir. The low-risk area is where the area is supported by seismic data, and carbonate build-up features are present. Play fairways for Miocene are dominated by high-risk areas. These are highlighted by the seal CRS map on the onshore where the Miocene formation or Tondo and Sampolakosa formations are exposed.

Meanwhile the areas of medium to high risks to northeastern Buton are still inconclusive since the data are limited. The compilation of those play fairway maps is shown in Figure 16. Figure 17 shows the focus/priority areas of exploring Buton.

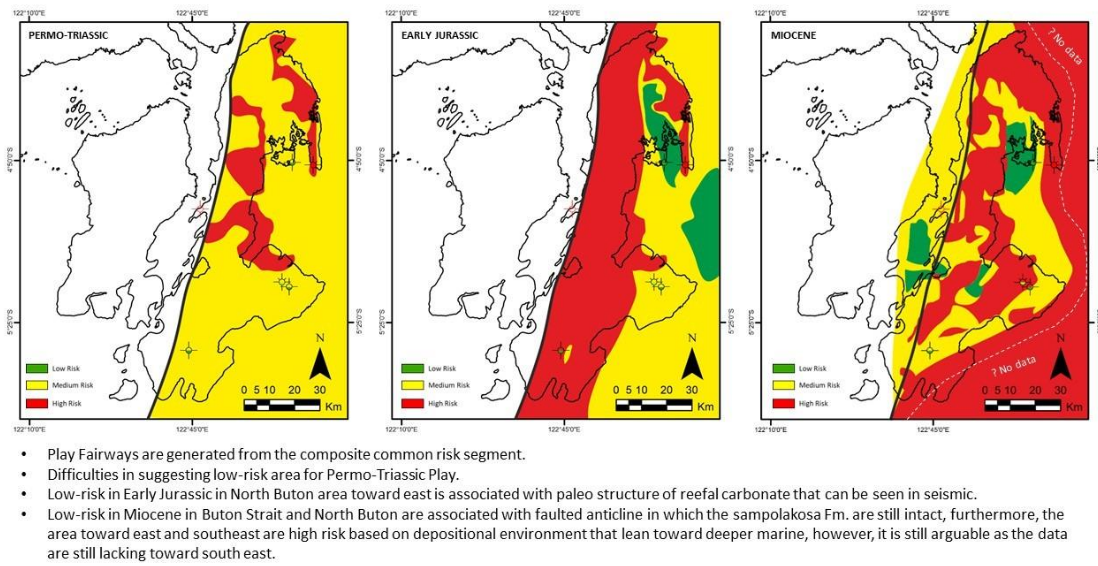


Figure 16 – Composite risk analysis or CCRS-composite common risk segment, combining seals, reservoirs, and seals for Permo-Triassic, Early Jurassic, and Miocene. The maps show the final risks of exploring Buton at specific targets.

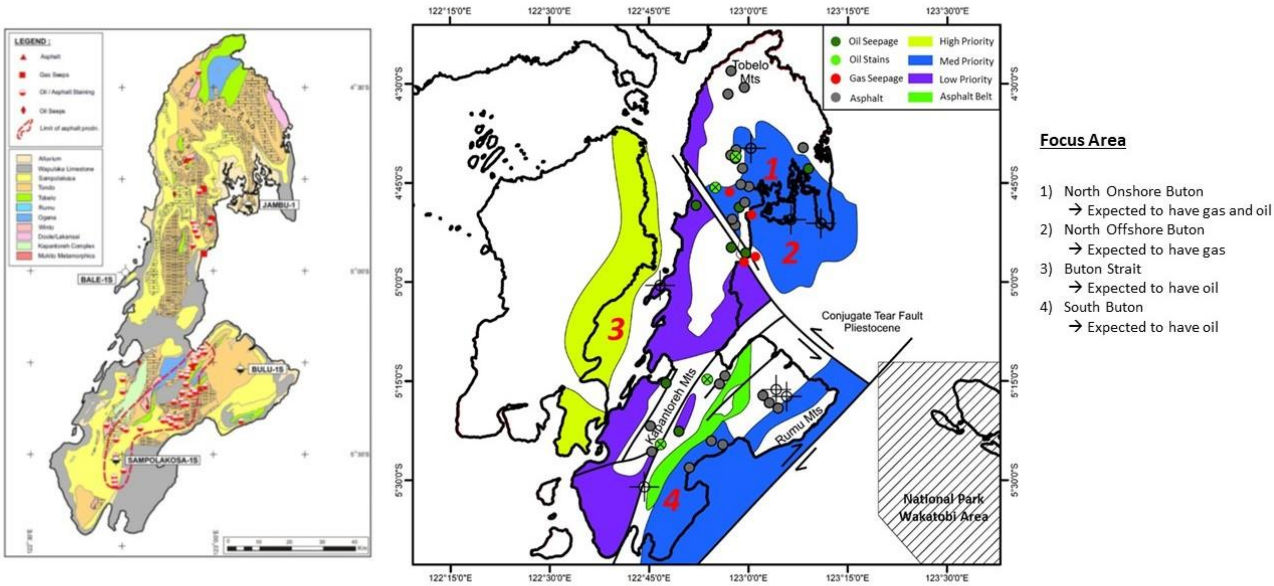


Figure 17 – Focus areas or exploration fairways of exploring Buton. Buton Strait is a high priority for exploration, followed by the NE and SE parts of Buton. Locations of asphalt belt and hydrocarbon seeps are shown.

CONCLUSIONS

1. Buton has a long tectonic and stratigraphic history since it was once part of the northern edge of Gondwana. It rifted, drifted, and collided with SE Sulawesi, undergoing post collision sedimentation until present day. Each event contributed to the elements and processes of the Buton petroleum system.

2. Hydrocarbons have formed and migrated in Buton. Buton has long been known to have large asphalt deposit. This asphalt deposit was in fact an oil field uplifted due to the collisional event so that its cap rock was eroded, and the oil was degraded into the asphalt. In addition, Buton has also many oil and gas seeps. It indicates that there are active petroleum systems in Buton, and therefore oil and gas fields could be discovered in Buton.

3. Past exploration wells mostly failed due to the complexity of structuration involving damaged closure, poor seismic data or imaging or wells unable to reach their targets. Improving seismic data quality would the number one priority for a successful exploration of the Buton area.

4. This study has found several new insights into the petroleum prospectivity of Buton. Gravity data show several low areas where petroleum generation may have occurred, as supported by our basin modeling. Several source beds from various source facies are found from the levels of Mesozoic to Miocene. Tectonic and stratigraphic histories had formed several play types associated with passive margins of Australia, fold-thrust belts related to the collision, and post-collision strike-slip faulting. Tens of structural traps from various stratigraphic levels have been identified and mapped, and their unrisked volumetrics have been computed.

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