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**REVISIT GEOLOGY AND GEOCHEMISTRY OF BUTON ASPHALT DEPOSITS, SE
SULAWESI: IMPLICATIONS FOR PETROLEUM EXPLORATION OF BUTON AREA**

Awang Harun Satyana*

Cepi Irawan*

Wendy Kurniawan*

ABSTRACT

Asphalt deposits of Buton Island, SE Sulawesi, have been known since 1920's and it is the only natural asphalt deposits mined in Indonesia. The deposits contain 15 to 35 % asphalt/bitumen making reserves of 100 to 132 million tones of asphalt. The deposits occurred mainly as impregnated materials within carbonates of Pliocene Sampolakosa and/or sandstones of Miocene Tondo formations. The traps are uplifted and intensively thrust anticlines formed by collision of Buton-Tukang Besi micro-continent with Muna block.

All geochemical data indicate that the asphalt deposits are biodegraded crude oils derived from marine, type II kerogen. Good to excellent correlations based on biomarkers were obtained between asphalt deposits and the Triassic calcareous shales and bituminous limestones of Winto Formation. Severe deformation due to collision eroded cap rocks of the traps, causing meteoric water flushing and biodegradation of oils, leading to asphalt deposits.

Occurrences of large asphalt deposits and numerous oil seeps show that petroleum system of Buton area is working. However, exploration efforts in this area are so far disappointing. The main risks include complicated structures and absence of cap rocks. Poor quality seismic data hinder detailed imaging of structures.

The paper presents some ideas of exploring Buton area based on revisited geology and geochemistry of the asphalt deposits and recent exploration results.

INTRODUCTION

Asphalt, also known as bitumen, is a sticky, black

and highly viscous liquid or semi-solid that is present in most crude petroleum and in some natural deposits, it is a substance classed as a pitch.

Natural asphalt deposits and asphaltic rocks are reported their occurrences in areas of petroleum where the reservoirs of petroleum are uplifted and exposed to the surface. One of these areas where its asphalt deposits have been mined since 1920s is the asphalt deposits of the Buton Island.

The presence of asphalt deposits in Buton Island shows that oils have been generated, migrated and trapped but later the cap rocks of the traps were eroded due to intensive deformation. The oil accumulations were biodegraded to become asphalts. Exploring oils in this area therefore, should be focused on preserved traps with their intact seals/caps.

The paper revisits the geology and geochemistry of the asphalt deposits in Buton Island, implying their information for the advantages of petroleum exploration, based on updated analyses and recent exploration activities.

METHODS

Published and unpublished works on Buton for petroleum and asphalt mining were studied for background of the paper and existing knowledge of this area. New geochemical analysis on asphalts and oil seeps form backbone for revisited petroleum system. Data from recent exploration activities in this area, including geological and seismic survey and exploration drilling, update the knowledge on petroleum prospectivity and its challenges. All of these data were analyzed and synthesized to update the knowledge on petroleum geology of Buton area.

* SKK Migas

RESULTS

History of Asphalt Mining and Petroleum Exploration in Buton Island

Initial geological investigations of Buton were conducted in the first half of 1920's by the Dutch East Indies Geological Survey. This resulted in geological descriptions and reserve estimates for asphalt fields.

Early exploitation/mining of asphalt deposits occurred from 1925 to 1941 by the Boeton Maatschappij producing initially 670 tons of rock asphalt in 1925, peaked in 1930 (12,900 tons of rock asphalts), and 8000 tons in 1941 (van Bemmelen, 1949). All asphalts were used for road construction in Indonesia.

After the Independence of Indonesia, the mining operation of Buton asphalt was carried out by "Perusahaan Aspal Negara (PAN). Until the late 1960's, PAN produced asphalt around 10,000 tons of rock asphalt annually (Sigit et al., 1969). The mining of the asphalt deposits in 1980's and 1990's were conducted by PT Sarana Karya. Nowadays, several private companies are mining asphalt deposits in Buton with limited annual production. PT BAI (Buton Asphalt Indonesia) produces 5000 - 10,000 tons of asphalt annually.

The total asphaltic deposits are estimated to be 660 million tones of asphaltic rocks with bitumen content ranges from 15 – 35 %, averagely 20 %, resulting in 132 million tones of asphalt/bitumen.

Despite its world-class deposits, mining asphaltic rocks in the Buton Island has subdued since 1970's due to costly operation, technical difficulties related to asphalt extraction, grading and purification to match requirement for road construction, and could not compete with asphalt derived from petroleum refinery.

The presence of significant asphalt deposits and oil seeps in Buton Island triggered petroleum exploration in this area. Bataafsche Petroleum Maatschappij (BPM) in 1930's started exploring Buton for oil but no record was reported.

In modern time (June 1969), Pertamina and the Southeast Asia Oil and Gas Company signed a Production Sharing Contract for the Offshore South Sulawesi Area. The block encompassed approximately 100,000 square kilometers and included Buton area. Indonesia Gulf Oil Company acquired operatorship in May 1970. After

acquisition of aeromagnetic data, surface geological data, and marine as well as land seismic data, Gulf drilled three wells: Bale-1S (1976 - dry), Bulu-1S (1976 – oil shows), and Sampolakosa-1S (1976 – discovered 43 meter column of biodegraded oil (10° API) in Tobelo carbonates. Gulf relinquished the area totally in June 1977.

After ten years with no petroleum exploration, on December 1, 1987 the Buton Block was awarded to Conoco as operator with partners of Shell and Enterprise. Conoco and its partners conducted geological survey, land and marine seismic survey and in 1992 drilled one well Jambu-1 (oil shows, no flow on testing). The Buton Block was returned to the Government of Indonesia in 1992.

Buton area was not explored more since then. But after fifteen years with no petroleum exploration, in January 2007 the Buton Block was awarded to Japex with partners of Premier and Kufpec (later Citic). Japex acquired data of airborne-gravity, geologic and land seismic surveys. In April to June 2012, Benteng-1 well was drilled and plugged and abandoned as dry well with oil show in Miocene Tondo fractured limestone. The main target of Late Cretaceous Tobelo carbonate was not yet penetrated due to complicated structure. Japex and its partner proposed to return the working area totally in February 2013.

To the north of the Buton Block, the Buton-I Block was awarded to PT Putindo Bintech in November 2008. Putindo Bintech acquired the data of geology, geochemistry and marine seismic. In November 2012, Putindo Buton I spudded its well called Ereke-1 targeting the Miocene Tondo sandstones/carbonates and Cretaceous Tobelo carbonates. Until 11 March 2013, the well was being drilled in Tondo Formation.

Geology of the Buton Island

Buton is considered to be a rifted fragment of the Australia-New Guinea continent based on stratigraphic similarity (Figure 1). Stratigraphy of Buton can be grouped into sequences of tectonostratigraphic setting, successively from old to young as: part of Australia (pre-rifting sequence), its detachment from Australia (syn-rifting sequence), its drifting to the present location (syn-drifting sequence), and during and after the collision with SE Sulawesi (syn-orogenic/collision and post-orogen/collision sequences) (Davidson, 1991; Milsom et al., 1999; Satyana, 2011; Satyana and Purwaningsih, 2011) (Figures 2, 3).

The pre-rift sediments occurred before the Middle Triassic when Buton was a part of the Australia-New Guinea continent. The Buton pre-rift Triassic stratigraphy consists of continental-derived clastic sediments deposited unconformably on Permian(?) metasedimentary rocks. Final separation from Australia occurred in the Late Triassic or Early Jurassic, preceded by a transition from pre-rift to syn-rift sedimentation in the Middle-Late Triassic. Late Triassic rocks (Winto Formation) rest on pelitic phyllites and slates (Lakansai Formation) which are exposed over an area of only about 40 km² northeast of the island (Figures 2, 3). Both the Winto and the overlying Early Jurassic Ogena Formation consist dominantly of limestone, but the Ogena appears to have been deposited in deeper water. Clastic sediments, principally shales, are common in the Winto of southern Buton. Both formations contain abundant organic material, which is generally considered to be the hydrocarbon source.

A fully open marine environment with passive margin sedimentation commenced in the Middle to Late Jurassic with pelagic carbonates as dominant lithologies. The uppermost Mesozoic on Buton is poorly exposed. It begins with the deep-marine siliceous and calcareous mudstones of the Upper Jurassic Rumu Formation and continues with the Tobelo Formation, which consists of pelagic limestones with nodules and stringers of red chert. The Tobelo was originally classified as entirely Upper Cretaceous, but has now been shown to extend from the end of Rumu deposition up into the upper Eocene or lower Oligocene. Both the Rumu and the Tobelo were evidently laid down 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 Early Miocene, collision between Buton Island and Muna/SE Sulawesi took place. A hiatus at the top of the Tobelo Formation can be attributed to this collision (Figure 3). The collision led to shortening of about 60% and to the development of thin-skinned thrusts and folds in southern Buton. Northern Buton was not affected until the middle Miocene, when maximum regional compression led to uplift and the establishment of an unconformity representing a hiatus. In the Late Miocene, the subduction zone became choked. This event was followed by accretion of Buton to Muna/SE Sulawesi. The oceanic crust between Muna and

Buton was obducted and sheared, forming a range of ophiolitic mountains called Kapantoreh (Figure 2). The Kapantoreh ophiolites based on gravity data (Milsom et al., 1999) are rootless, detached forming thin thrust slices removed from their areas of origin. Exposed ophiolites in Buton therefore, are allochthonous detached klippen, that were transported away from their root zone by thrusting. A terrane suture is most probable along the line of the Buton Strait. The strait can be interpreted as a successor basin produced by slight relaxation of compression following collision. The gravity data suggest that the suture swings west just north of the narrowest part of the strait and cuts across southern Muna.

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 become dominant later, indicating uplift of the ophiolites above sea level. Tondo Formation deposition was brought to an end by subsidence of Buton to bathyal depths at approximately 5 Ma and deposition of the Sampolakosa chinks and marls. Subsequent uplift was accompanied by the development of reefal carbonates of the Wapulaka Formation (Figure 3).

Occurrences and Resources/Reserves of the Asphalt Deposits

Asphalts on Buton Island occur as impregnations of porous beds, coatings on fractures, and / or late stage crosscutting veins or "bitumen dikes". All occurrences are structurally controlled and located adjacent to, or within, reactivated Miocene thrust faults or Pliocene - Pleistocene strike-slip faults (Figure 4).

The asphalt deposits occur throughout the Triassic to Pliocene stratigraphic units but they are mostly abundant in the Pliocene foraminiferal packstones Sampolakosa Formation and sandstones and conglomerates of the underlying Miocene Tondo Formation (Davidson, 1991). Although asphalt occurrences are present in both the north and south of the island, the main concentrations occur in a NNE-SSW trending belt in the south of the island. Here the largest asphalt deposits are confined to the southern end of the island in a 50 kilometer by 10 kilometer belt between Lawele and Sampolawa. These deposits were discovered in the early 1920s and intermittently mined until August of 1987.

Asphalt extraction has continued intermittently from nineteen asphalt accumulations within the asphalt belt with the Kabungka, Lawele and Mana pits identified by Hetzel (1936) as the most significant fields. Hetzel (1936) described the reserves in various localities, with bitumen contents ranging from 4% to 48%. The Lawele pit has the largest reserves with millions of cubic meters of rock containing as high as 30% bitumen. Gribi (1974) estimates approximately 150-180 million barrels in place, while Davidson (1991) quotes a figure of 100 million tones of total asphalt reserves within the asphalt belt, based on an extensive evaluation by PT Sarana Karya and the Alberta Research Council in 1988. This is the equivalent of approximately 500 million barrels of 30°API oil. Recent figure (Direktorat Jenderal Bina Marga, 2009) estimated 660 million tones of asphalt deposits, with 20 % asphalt content within the deposits resulting in total 132 million tones of bitumen which equivalent with asphalt demand for more than 132 years.

Geochemistry of the Asphalt Deposits: Biodegraded Oil Fields

While the source of these asphalts is believed to be the Winto Formation by most workers, the mode of origin is more controversial. Several authors suggest these heavy oils are the products of low maturity source rocks while Davidson (1991) suggests that they are more likely the result of surface and near-surface biodegradation (Figure 5).

The geochemical composition of the asphalt samples provides clear evidence of the origin of these deposits. Thirty-six asphalt, or asphalt impregnated rock samples were analyzed by solvent extraction, fractionation, gas chromatography (GC), gas chromatography-mass spectrometry (GC-MS), and carbon isotope (Davidson, 1991). Biomarker and carbon isotope data are identical and are similar to most of the analyzed Buton oils. All geochemical data indicate the asphalt is biodegraded crude oil derived from a marine, type II kerogen. Good to excellent correlations were obtained between the asphalts and the Triassic Winto Formation calcareous shales and bituminous limestones. Liquid chromatography indicate the Buton asphalts are primarily composed of asphaltenes, NSO compounds and aromatics. Biodegradation has significantly reduced the saturated hydrocarbon content which ranges from 4% to 23%. Sulfur content is generally high and varies from 2.53 to 9.36 weight percent.

Recent analyses and interpretation of the geochemical characteristics of the asphalt confirm Davidson (1991)'s conclusions. Several features confirm that the asphalts are in fact heavily biodegraded oils (Figure 6A). These include:

- presence of demethylated hopanes in several of the samples analyzed. These are either a product of biodegradation or enhanced by biodegradation,
- absence of straight-chain and branched-chain alkanes and concentration of polycyclic alkanes,
- sterane and triterpane alteration patterns which are typical of biodegraded hydrocarbons, and
- absence of biomarkers identified in low maturity source rocks (e.g. *bisnorhopane*)

The overall biomarker composition is also consistent with derivation from a marine source rock with strong carbonate influence but there are several differences between these asphalts and the live/moderately altered oil seeps. These differences are documented below:

- the asphalts generally contain moderate to very abundant *gammacerane*, a feature not observed in the unaltered oils,
- the asphalts are generally isotopically heavier than the unaltered oils, and
- the asphalts exhibit a sterane distribution with a higher proportion of C28 and C29 steranes than the oils.

While these features could be taken to be indicators of source facies variations they may also be related to the effects of biodegradation and it is assumed that this accounts for these differences and that the asphalts are also sourced from the Winto Formation. Supporting evidence for this comes from less severely degraded asphalts, such as those from the Lawele Tar Pit, which retain a full set of only partially altered hopanes, but contain demethylated hopanes and which contain only moderate amounts of *gammacerane*. Some of the partly degraded oil staining also shows properties intermediate between the oil seeps and the asphalts.

It is noticeable that not all the asphalts contain demethylated hopanes, despite the apparent severity

of biodegradation of most of these samples, and that the highest levels of these compounds are observed in subsurface samples (Sampolakosa-1) and the deepest sample from the Lawele Tar Pit. Although this may relate to the extent of biodegradation it is also possible that they are produced/concentrated only by subsurface alteration rather than surface alteration, possibly due to the varying bacteria present in these locations, or that these compounds may have been removed by surface alteration.

Petroleum Implications

Abundant asphalt deposits on Buton are evidence of active or previously-active petroleum system. Oils were generated in some kitchen, migrated and trapped, but later due to active tectonics the traps' seals were breached or eroded, exposing the reservoirs with oil accumulation to meteoric water flushing and/or biodegradation, yielding asphalt deposits. Oil exploration in Buton should be focused on intact traps sealed with cap rocks to preserve oil accumulation from water flushing and biodegradation

Based on five exploration wells drilled on Buton: Bale-IS (1976 - dry), Bulu-IS (1976 – dry with oil shows), Sampolakosa-1s (1976 – discovered 43 meter column of biodegraded oil 10° API in Tobelo carbonates), Jambu-1 (1992 – dry with oil shows in Miocene Tondo), and Benteng-1 (2012, dry with oil shows in Miocene Tondo); exploring Buton is considered a high risk area although minimal 500 MMBOE of asphalts deposits have been discovered and produced. The critical elements for exploration failures include: complicated structure, cannot be imaged by poor seismic data and absence of cap rocks.

Primary source rocks are the bituminous marine shales and carbonates of the Triassic Winto Formation. Geochemical analysis show these rocks have good to excellent oil generating potential (TOC-total organic carbon ranges from 0.57 % to 15.9 %, averagely 6-7 %; HI-hydrogen index 441-662 mg/g). The sources contain high concentrations of oil-prone, sulfur-rich, Type II kerogen. Secondary amounts of cutinite, resinite, and vitrinite are also present. Mature source rocks will generate a high sulfur, low wax, paraffinic crude oil. Generation of oils from these source rocks started in Late Miocene, contemporaneously with collisional thrusting and imbrication. 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 carbonates of the Winto Formation. Tondo Formation shales and mudstones are a secondary source rock, again with excellent potential (TOC ranges 6-10.8 %). One oil seep called Nunu seep to the east of Buton Strait (west Buton) show moderately degraded oil, containing oleanane indicating Tertiary sources (Tondo). Oil extracted from SWC sample at depth 731 m of Benteng-1 well (Japex Buton, 2012) indicates generation from Tondo marine shales/calcareous shales as shown by presence of high oleanane content, tricyclic terpanes, high 29-norhopane to 30-hopane and ratio of Ts/Tm < 1.0 (Figure 6B) .

Collision-related play types of Buton and related elements and processes of petroleum system is illustrated in Figure 7.

Primary reservoirs are the coarse clastic facies of the Tondo Formation. This facies is comprised of stacked sands and conglomerates as well as carbonates deposited as deltaic, shallow marine to deep marine turbidite fans. Total thickness of individual reservoirs range from 5 meters to over 100 meters. The reservoir potential varies from poor to good. Porosities range from 8% to over 25% and average 19%. Maximum measured vertical and horizontal permeability is 172 mD. All evidence suggest that early migration of hydrocarbons into the reservoirs is critical in inhibiting diagenesis and retaining primary porosity. Additional potential reservoirs include interbedded pinnacle reefs and platform carbonates of the Pliocene Sampolakosa Formation, Pliocene / Pleistocene Wapulaka Formation, and paleokarst development at the top of the Tondo and / or Tobelo limestones. Reservoir quality of the Sampolakosa Formation platform carbonates and Tobelo Formation paleokarst was assessed by Sampolakosa-IS and Bale-IS wells. The Sampolakosa and Tobelo platform carbonates have average porosities of 31% and 23 %, respectively. Japex (2008) based on field outcrops, distinguished Tobelo carbonates into (Upper) Tobelo Formation, Oligocene with karsted and/or fractured limestone (porosity 5 - 38%, permeability 1 – 221mD) and (Lower) Tobelo Formation, Cretaceous with karsted and/or fractured limestone (porosity 17 - 33%, permeability 25 – 480mD). Another possible reservoir is Ogena Formation, Jurassic fractured limestone (porosity 9 – 29%, permeability 13 – 429mD).

Calcareous mudstones and claystones of the Late Miocene Tondo Formation, and marls and

mudstones of the Early Pliocene Sampolakosa Formations are the principal seals. The sealing potential is greatest in north Buton where 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. Comparable thicknesses of stacked Tondo Formation claystones were encountered in the Sampolakosa-IS and Bulu-IS wells. Deformation in south Buton is more intensive than its northern counterpart.

Primary traps in the onshore areas are thrust-related anticlines with four-way dip closure. In the offshore area, primary traps are wrench-related anticlines. Stratigraphic traps, including reefs and clastic fans are also recognized in several offshore areas. The onshore thrust-related anticlines are Late Miocene age and developed as a result of the collision of Buton and Muna / S.E. Sulawesi. Onset of doming coincided with deposition of the Tondo limestones and/ or the basal coarse clastic facies in the Early to Middle Miocene. Many of the structures were further deformed during the forward collision in the Late Pliocene to Pleistocene. Deformation involved reactivation of young faults and recompression of the older structures. In all thrust structures, tectonic deformation increases with depth. Stratigraphic traps include Pliocene / Pleistocene reefal buildups and Pliocene fan deposits. These are confined to the offshore areas between Buton Island, Muna Island and Sulawesi. Additional seismic data is required to assess the potential of these plays.

It seems that complicated structures cause five exploration wells drilled in Buton Island were dry. Bale-1S (Gulf, 1976), Bulu-1S (Gulf, 1976), and Benteng-1 (Japex, 2012) did not reach the targets due to the main targets of Tobelo limestones positioned much deeper than were prognosed by repetitive beds of Tondo Formation deformed as multiple thrust sheets (Figure 8). Jambu-1 (Conoco, 1992) failed to find hydrocarbons due to absence of good topseals (coarse conglomerates overlies possible reservoirs). Sampolakosa-1S (Gulf, 1976) found 43 meter column of biodegraded oil, but it is considered leaks due to intensive faults.

Qualities of seismic data mostly poor to fair because of complicated structure, accordingly difficult to image. Reprocessed the data incorporating advanced seismic attribute analysis did not help much the data improvement. Better parameters for

seismic acquisition are required for better structure imaging.

Petroleum is proven in Buton Island. Based on asphalt volumetric, at least 500 MMBOE of petroleum accumulation exist and mined as asphalt. Liquid oils are still possible to be trapped here, but the exploration efforts require better seismic imaging, not too complicated structures, with Tondo and/or Tobelo sandstones and limestones, and the cap rocks (Figure 8).

CONCLUSIONS

1. Asphalt deposits in Buton geochemically are biodegraded oils sourced by marine calcareous shales of Triassic Winto Formation, mainly trapped in Pliocene Sampolakosa carbonates and Miocene Tondo conglomerates and sandstones. Biodegradation took place due to erosion of cap rocks by intensive deformation.
2. Presence of asphalt deposits shows working petroleum system of Buton. However, five exploration wells (all dry, some with oil shows) drilled in Buton Island from 1970 to 2012 show that locating oil accumulation is not easy. Most failures related to complicated structures could not be imaged by existing seismic lines. Three wells could not reach the main targets due to the targets are deformed too deep beyond as prognosed. Two wells drilled in unsealed structures due to erosion.
3. Exploration should locate simple structures with intact seals. Improvement of seismic data is required to have better seismic imaging.

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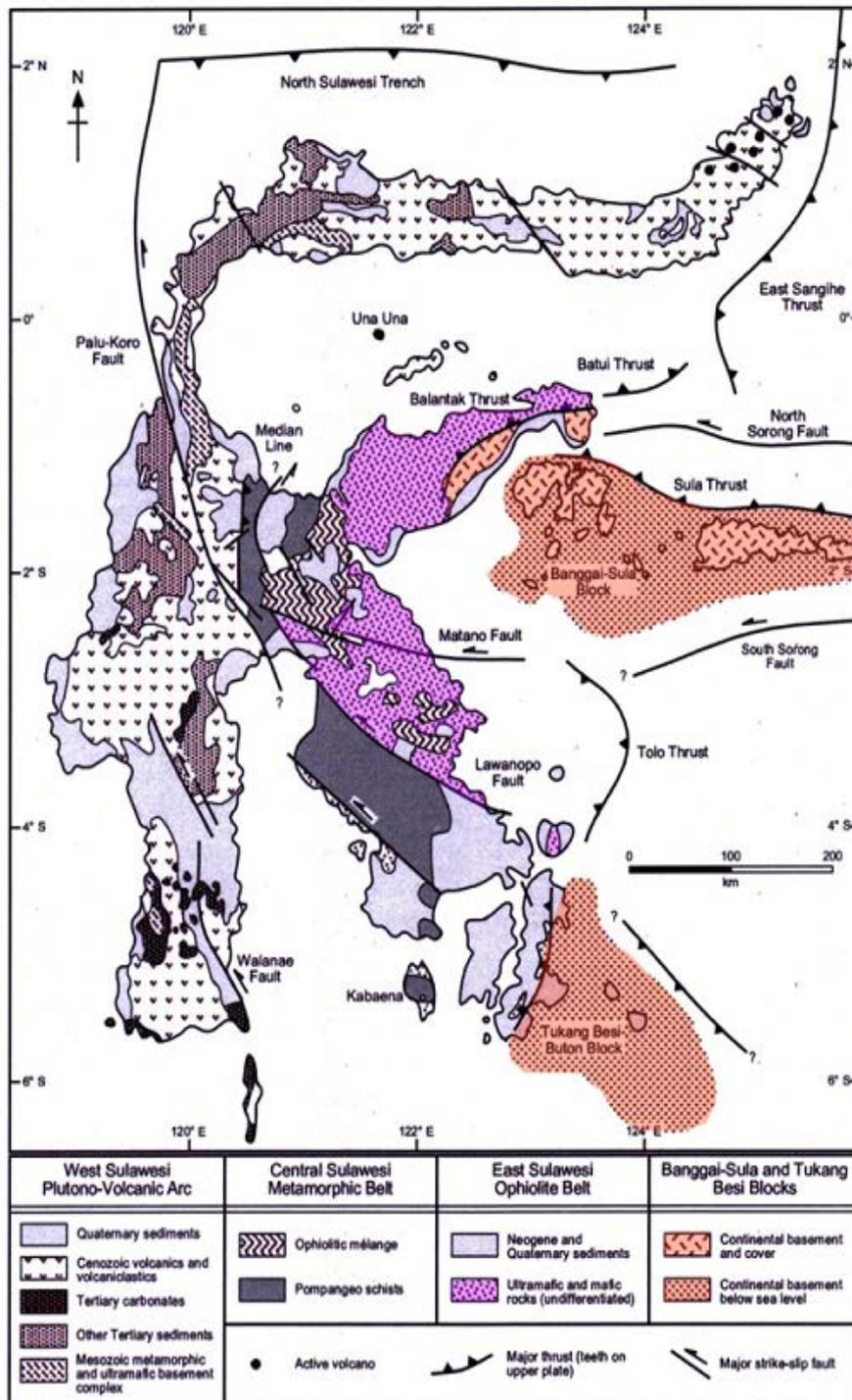


Figure 1 - Regional setting of Sulawesi showing four geologic provinces due to collision of terranes compose Sulawesi and adjacent islands (Moss and Wilson, 1998).

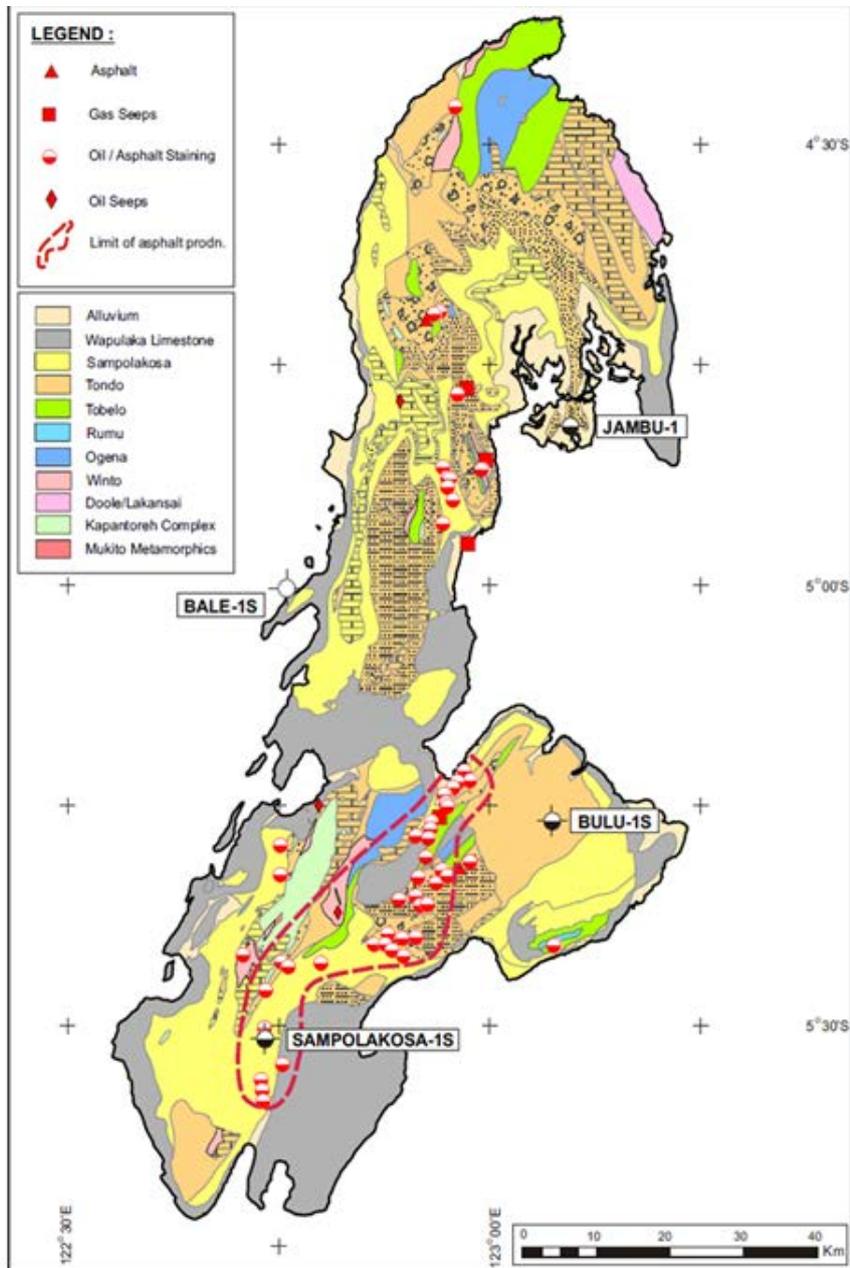


Figure 2a - Geological map of Buton Island showing distribution of exposed rock units, occurrences of petroleum seeps and area of asphalt deposits (Bon and Livsey, 2004).

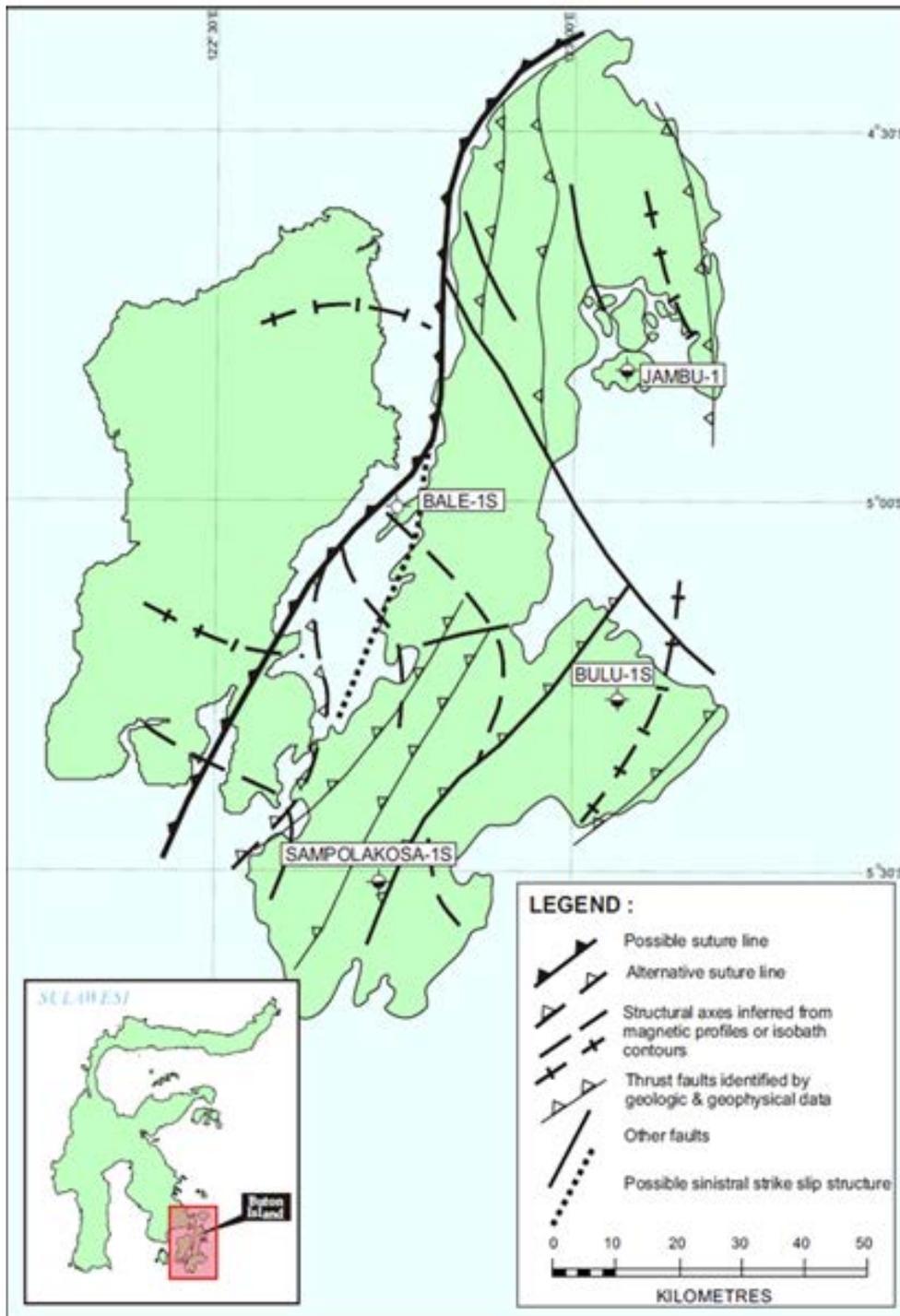


Figure 2b - Structural map of Muna and Buton Islands showing imbricated thrusts as response to collisional tectonics (Bon and Livsey, 2004).

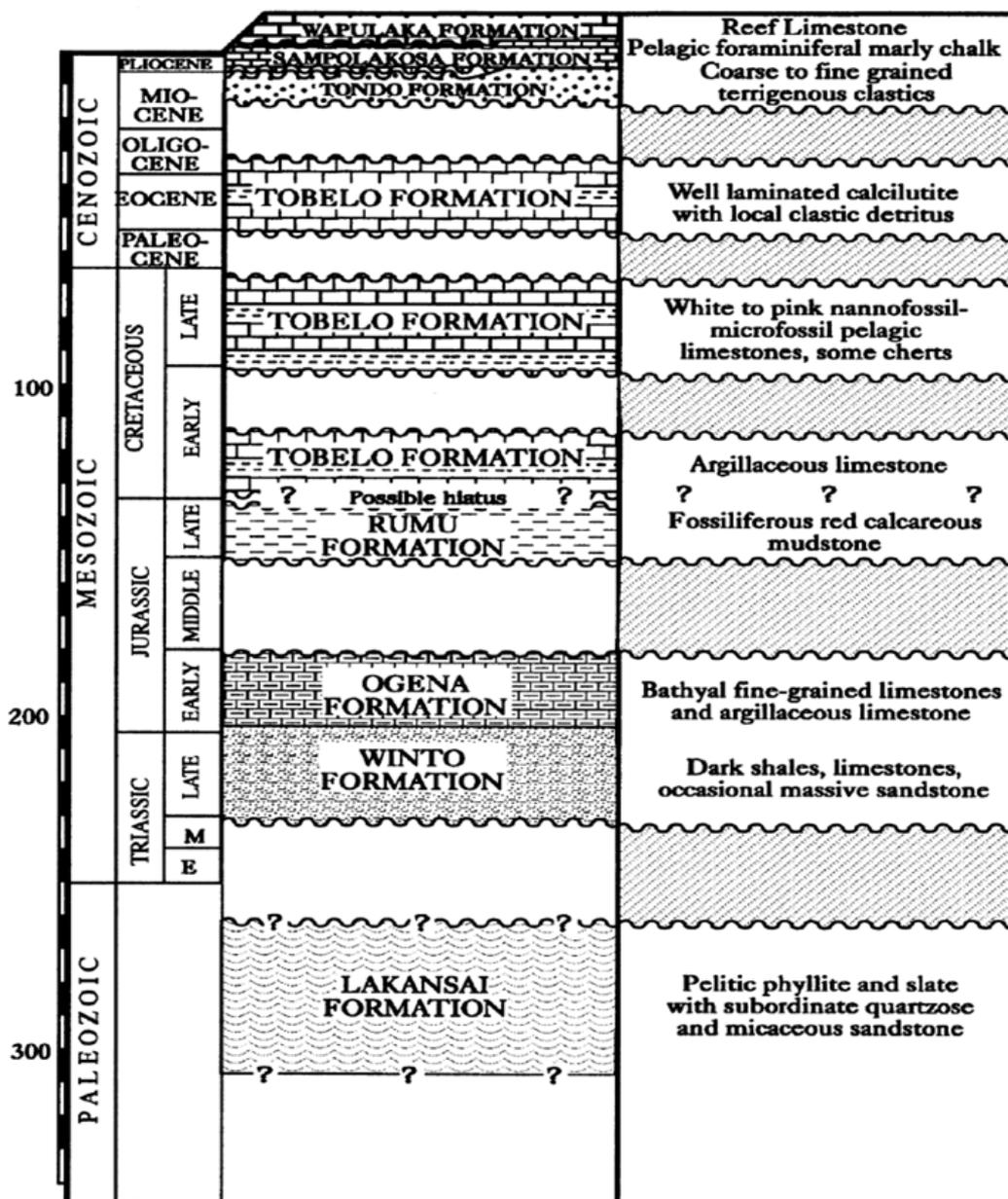


Figure 3 - Stratigraphy of Buton Island. Hiatuses between rock formations showing tectonostratigraphy of the rock sequences as pre-rifting, syn-rifting, syn-drifting and post-collision sequences (Milsom et al., 1999).

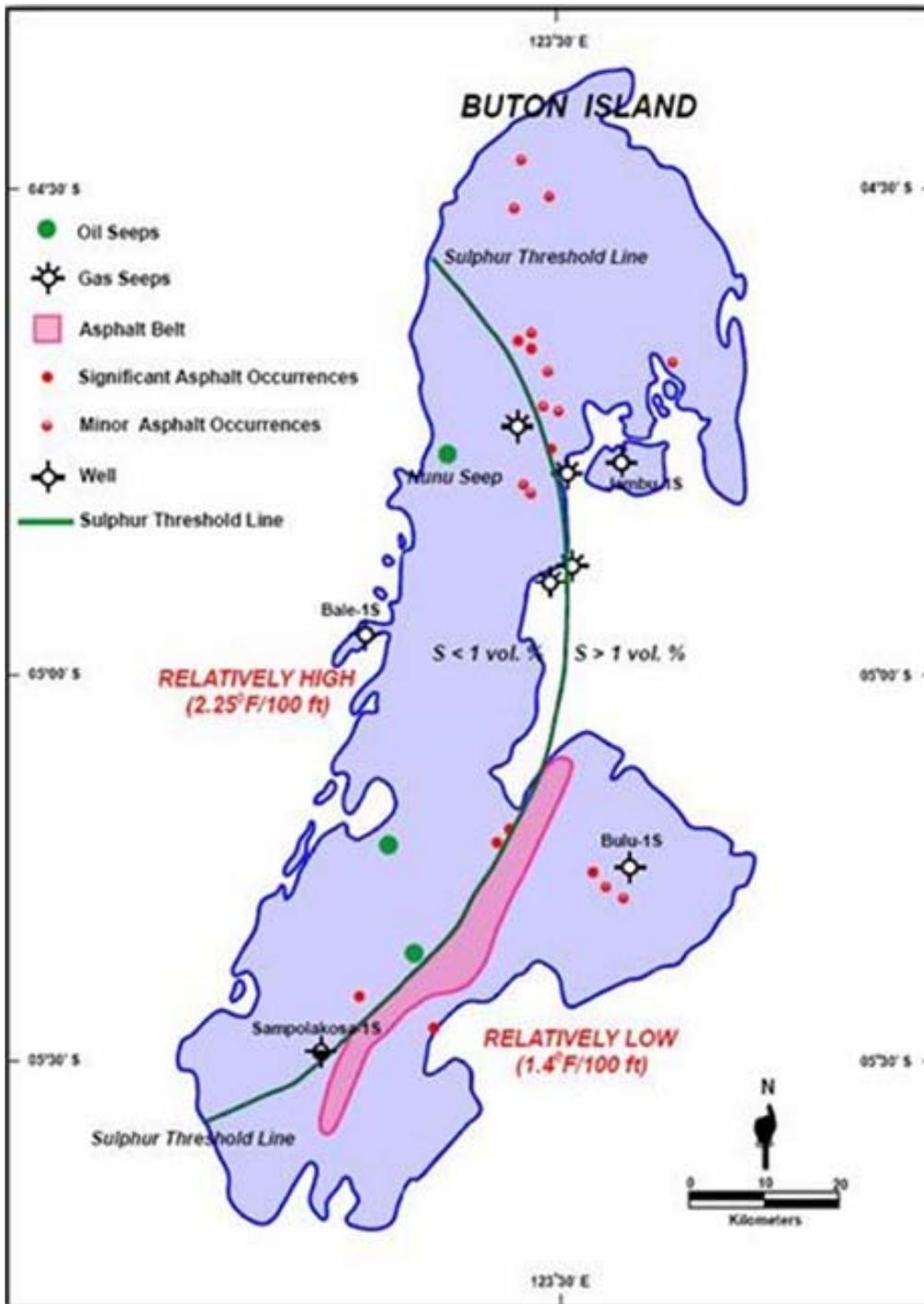


Figure 4a - Asphalt belt of Buton occurring at the southern part of the island.



Figure 4b - Some photographs showing asphaltic rocks at Buton Island as impregnated materials/bitumen of the rocks. The rocks are 15-35 % impregnated by asphalt/bitumen. Lowermost photograph shows mining work of asphalt deposits at Buton Island.

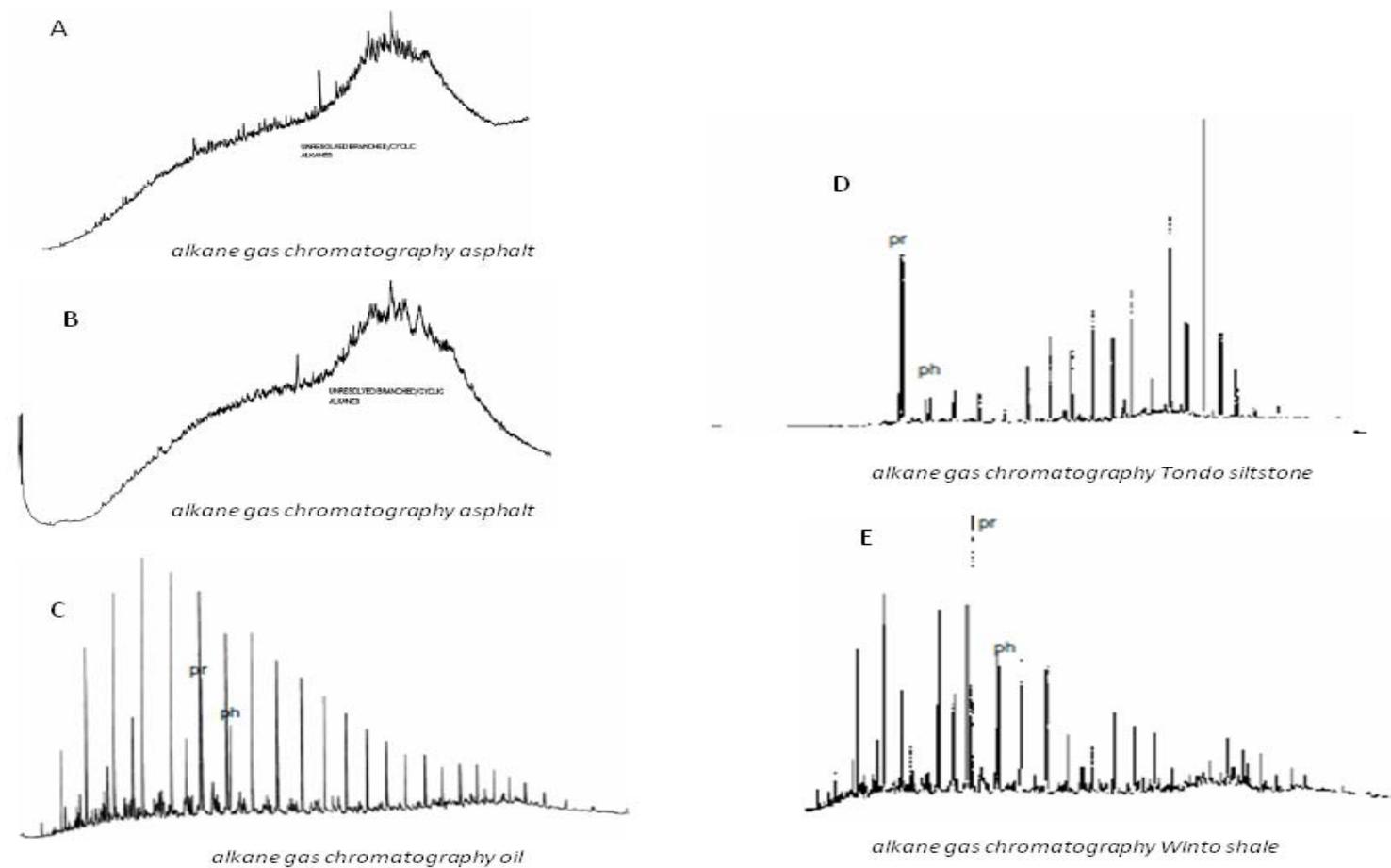


Figure 5 - a - b. Fully biodegraded oil of Buton to become asphalt as shown by degraded peaks of alkane gas chromatography, compared to unbiodegraded oil gas chromatography at 5c. 5d. Alkane gas chromatography of Miocene Tondo siltstone showing terrestrial source facies/high pristane (pr) to phytane (ph) ratio, not correlatable with Buton oil (5c). 5E. Alkane gas chromatography of Triassic shale showing marine source facies /low pristane (pr) to phytane (ph) ratio, correlatable with Buton oil (5c).

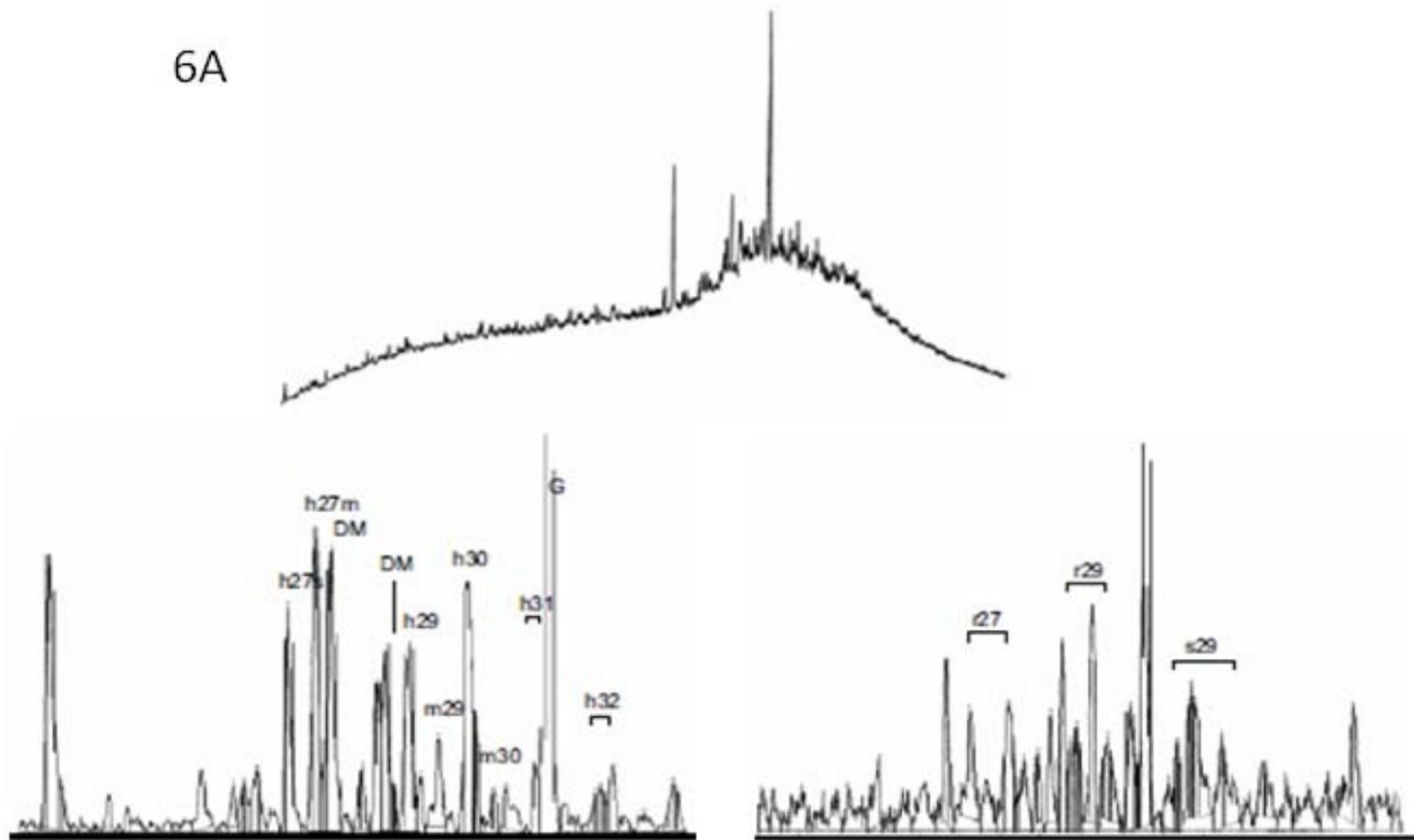


Figure 6a - Severely biodegraded oil from marine source rich in gammacerane and containing demethylated hopanes. Degraded sterane distribution.

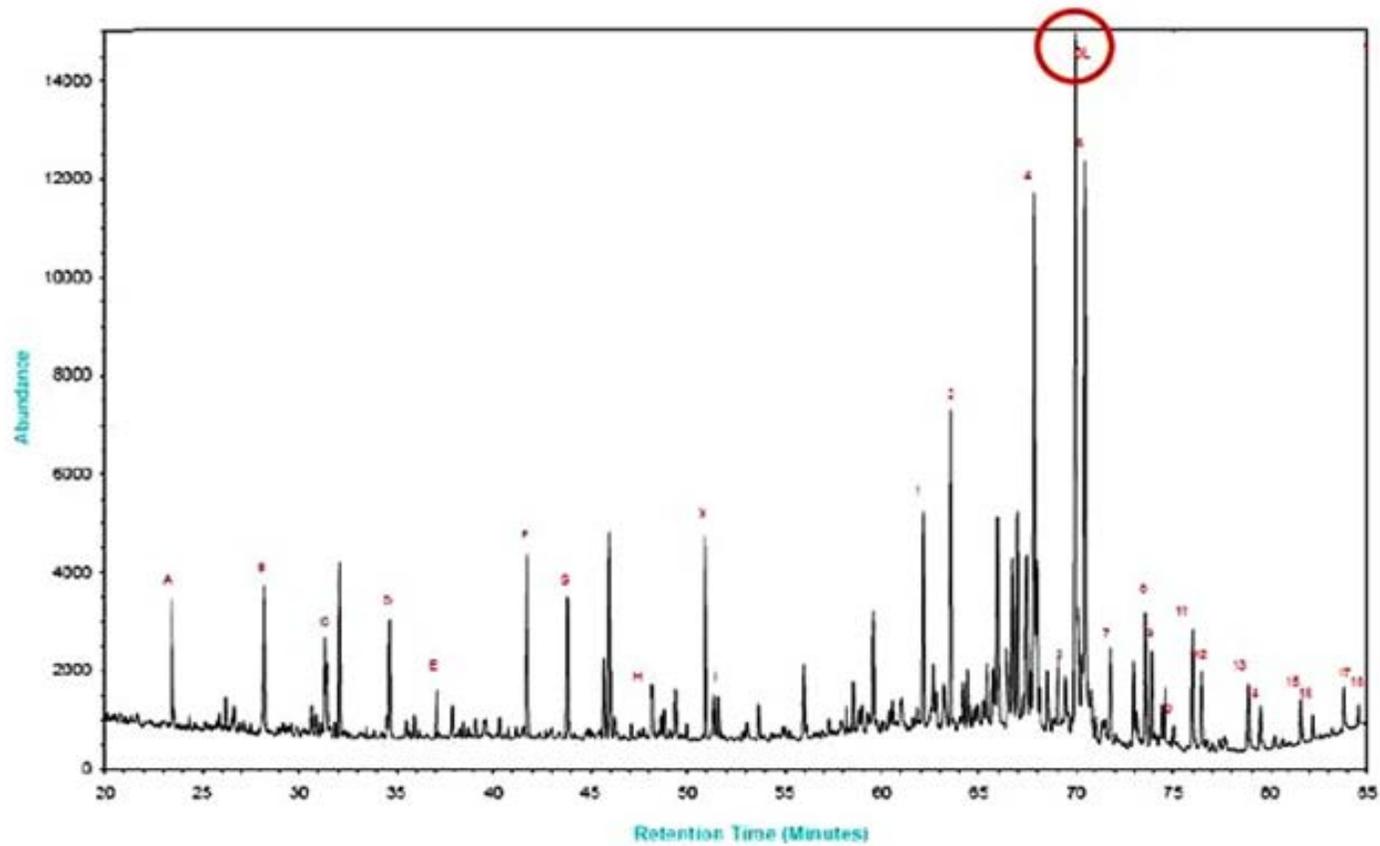


Figure 6b - Triterpane distribution of SWC extracted oil sample from Miocene Tondo limestone of Benteng-1 well, indicating source from Miocene marine shales, rich in olenane (red circled).

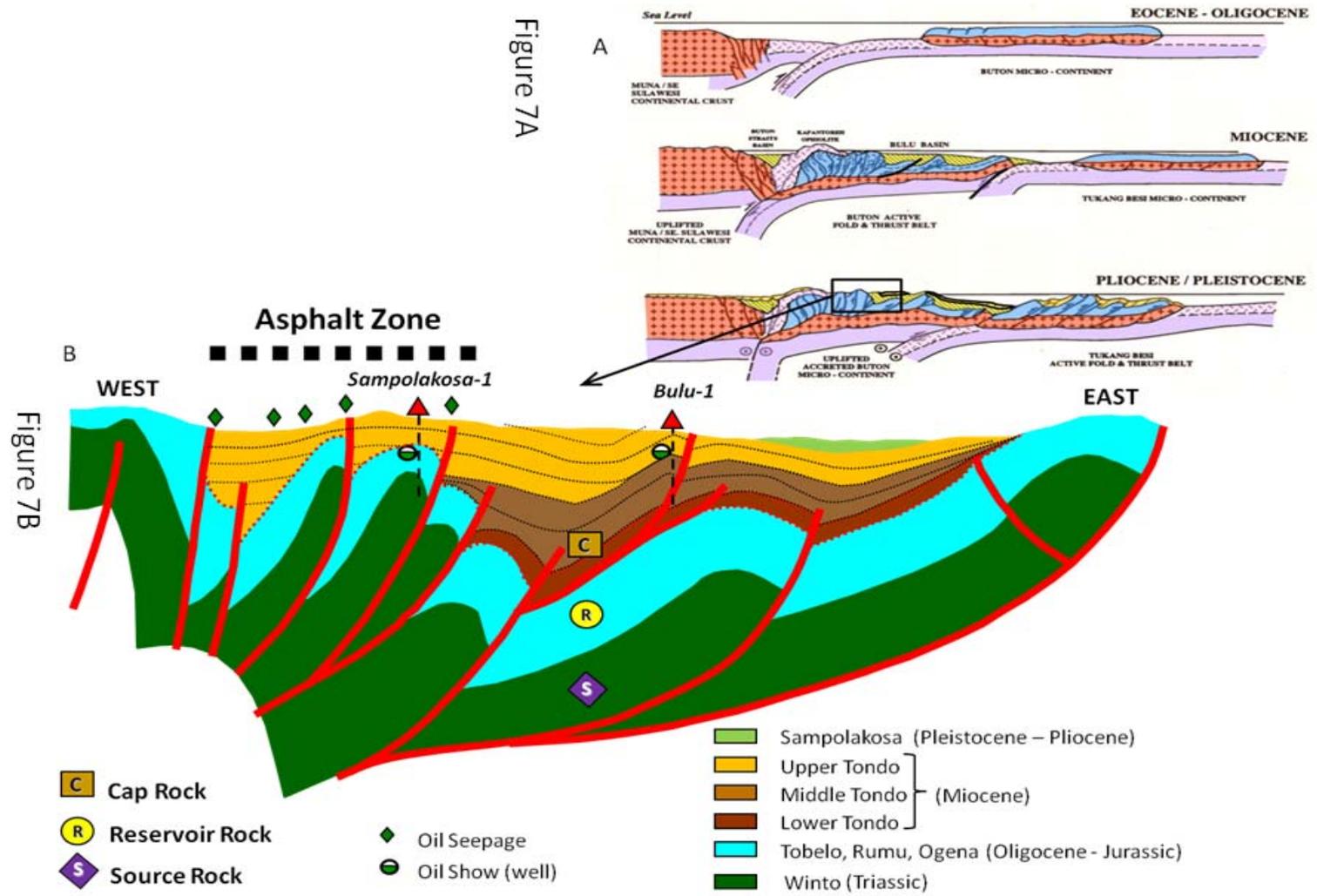


Figure 7 - a. Schematic evolution of collision of Buton-Tukang Besi micro-continent with Muna block (Davidson, 1991). b. Petroleum geology of Buton asphalt deposits. Asphalt deposits are biodegraded oil accumulation due to the absence of cap rocks and exposed reservoirs by intensively deformation. Sampolakosa-1 and Bulu-1 were exploration wells drilled to search for unbiodegraded petroleum.

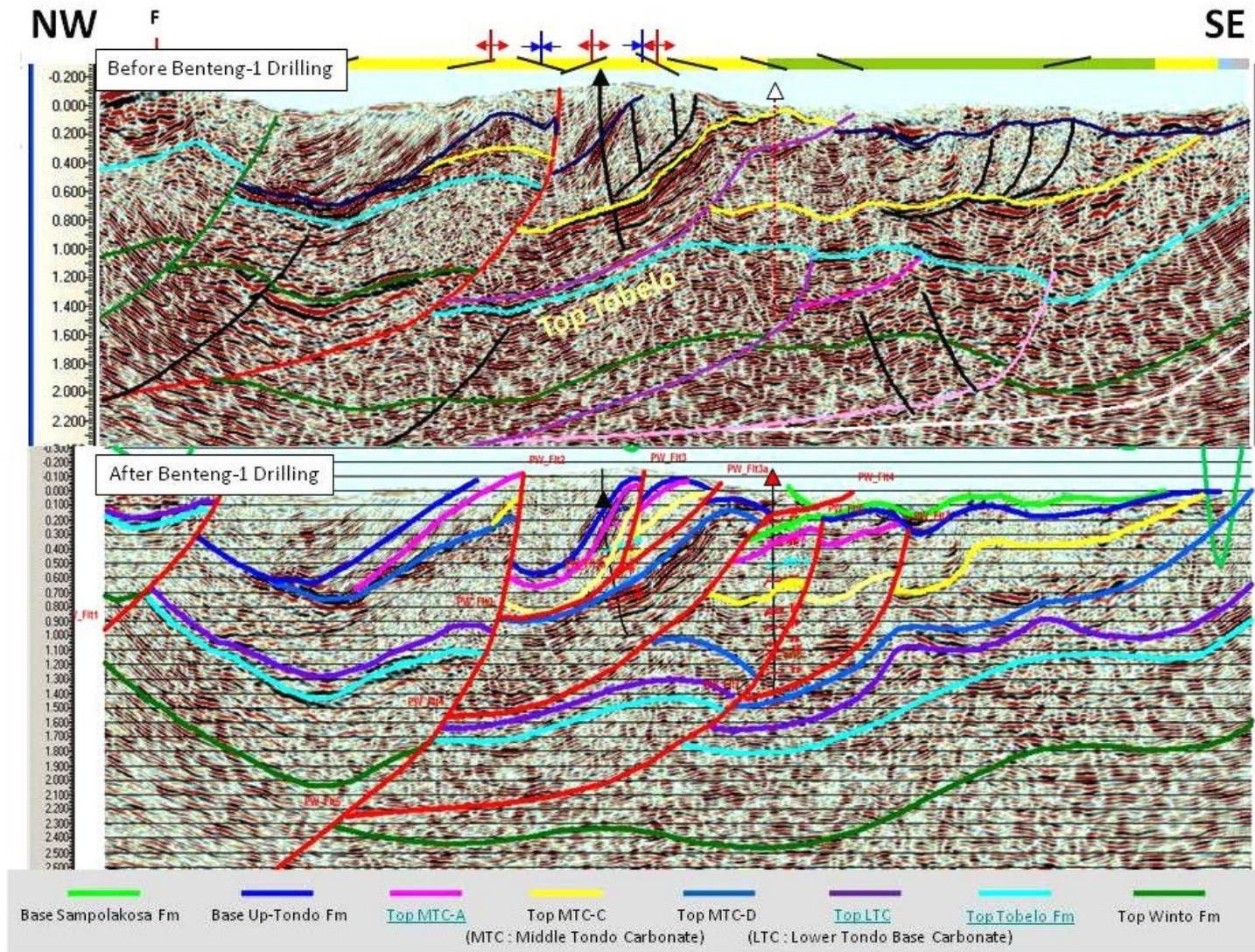


Figure 8 - Seismic sections interpreted before and after drilling Benteng-1 well (Japex, 2012). The deformation is much more complicated than prognosed, making Tobelo objective could not be penetrated due to much deeper than prognosed. Seismic data was acquired in 2008, poor quality due to complicated deformation.