TECTONO-STRATIGRAPHIC FRAMEWORK OF EASTERN INDONESIA AND ITS IMPLICATION TO PETROLEUM SYSTEMS

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Abstract

During Paleozoic-Mesozoic times, the Eastern Indonesia region is considered to be a part of the northern margin of the Australian continent which has now become an active collisional margin. Stratigraphic sections, of Eastern Indonesia at least from Cambrian to Paleogene, show similarities which document two tensional tectonics episodes; an Early Paleozoic infra-rift and a Late Paleozoic to Paleogene rift. Since Miocene times, sedimentary rocks indicate a series of subduction and collision products. The succession of pre-Tertiary sediments in Eastern Indonesia mostly developed unconformbly, overlying the highly metamorphic rocks of Devonian to Permian which are considered as the basement. In the Outer Banda Arc to the Sula-Buton region, pre-Tertiary sedimentary rocks were characterized by a series of carbonate rocks, which developed up to Tertiary times. In contrast, the Papua (Irian Jaya) region was marked by the dominance of siliciclastic rocks during the Paleozoic to Mesozoic and carbonate rocks and shale in Tertiary.

Pre-Tertiary and Tertiary sedimentary rocks in some basins of Eastern Indonesia are proven as hydrocarbon producers. Although pre-Tertiary source rocks are widespread in Eastern Indonesia, the significant example were primarily restricted to three time periods; Permian, Late Triassic and Early-Middle Jurassic. The Reservoir rocks mainly belong to the Mesozoic and Tertiary ages, where sandstone and carbonate rocks developed in the Mesozoic and in the Tertiary were dominated by Miocene limestone and sandstones, and Pliocene sandstones. Traps are mainly controlled by thrust faults, normal faults and carbonate buildup, while the syn-orogeny and passive margin shales provide seal rocks.

Keywords: Hydrocarbon producer, Pre-tertiary, Stratigraphic sections, Tertiary

Introduction

Eastern Indonesia lies within a complex tectonic zone formed as a result of Neogene collision and interaction of the Australian - Eurasian continental plates and the Pacific oceanic plate (Figure 1). This region is characterized by an allocthonous micro-continent with Tertiary and Mesozoic sediment overlying Paleozoic basement, which then juxtaposed against Cretaceous and Tertiary terranes to form collision complexes.

With increasing oil and gas price, exploration activities in Eastern Indonesia nowadays has been conducted in onshore area from Papua, Seram, Timor to Sulawesi Islands as well as offshore area including Arafuru and outer Banda arc. The significant hydrocarbon discovery in the Jurassic-Permian Play System, for instance, the Tangguh, Oseil and Abadi gas fields showed that this region has good potential for hydrocarbon producer. These discoveries are found dominantly in Tertiary producing basins which have been explored since the early 19th century. Jurassic and older systems, however, were also found in the producing Seram Basin and Bintuni Basins, whereas the southeastern edge of Palung Aru Basin is barren. In the outer Banda arc, petroleum is mostly trapped within the

Jurassic siliciclastic reservoir with source rocks interpreted form their own layer zone as well as Paleozoic strata. This paper provides a surface geological study in Tanimbar Islands to support discussion in the occurrences of petroleum system in the outer Banda Arc.

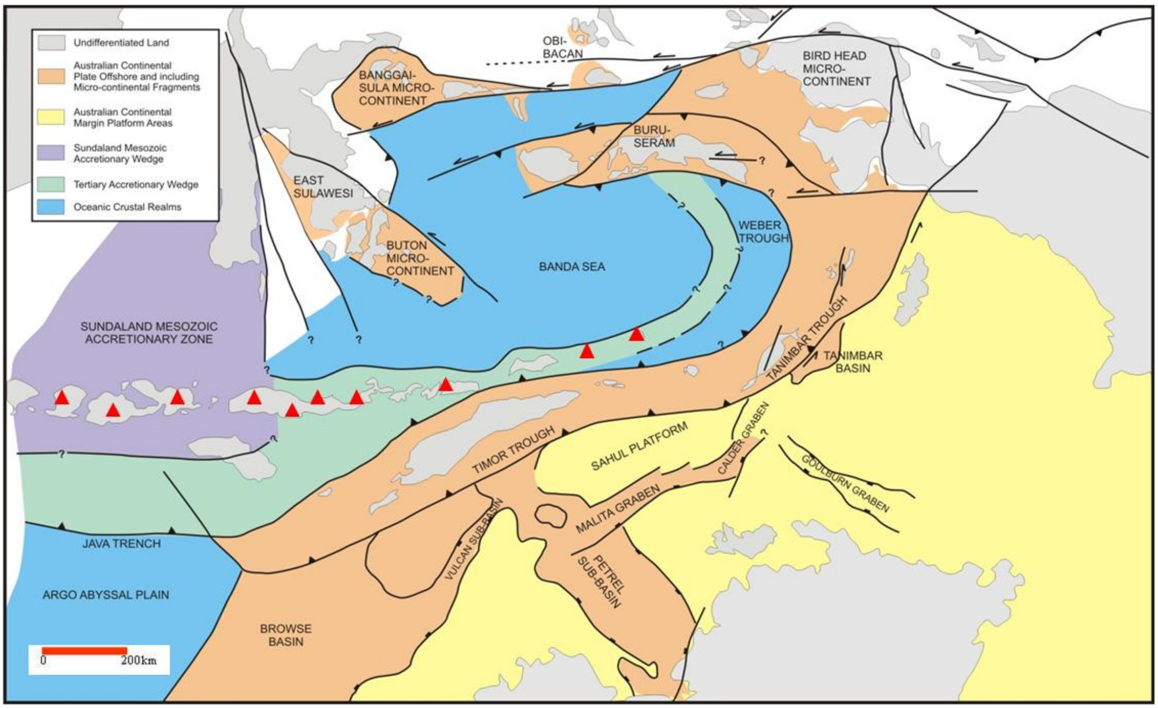

Figure 1. Present eastern Indonesia and the regional tectonic element of the northern Australia continental margin. [1,4,25 with modification]

Research Methods and Importance of the Research

This paper is based on study both published literatures and unpublished data encompassing recently some joint study results with oil companies in Eastern Indonesia and also the field work carried out in the surrounding Tanimbar Islands. The main target of the field work is to investigate the characteristics of reservoir rock and source rock that developed in this area which then extrapolate to the interpretation of the sub-surface beneath the concession area of JOGMEC - INPEX Corporation and Outer Banda Arc region in general.

To address the goal of the paper, literatures from various publications and unpublished data were collected, examined, analyzed and put in the interpretation and synthesis. By re-studying various stratigraphy data of eastern Indonesia which is supported by the primary data in the Tanimbar Islands, some exploration wells report as well as seismic lines in the Arafura Sea – Outer Banda Arc and with reference to the results of previous studies primarily related to tectonics, the concept of tectono-stratigraphy of Eastern Indonesia can be summarized in this paper.

The result of this study is very important in providing an understanding of the tectonic and stratigraphic sections in the region of Eastern Indonesia. Integration of surface and subsurface data from multiple locations provides a more complete picture of the recent conditions of the region. This understanding is crucial in supporting the success of Indonesian exploration of oil and gas which are now being focused in Eastern Indonesia region.

Major Tectonic Events in Eastern Indonesia

The initiation of Indonesia Region may have started as early as Cretaceous when several continental blocks separated from Gondwana to form the southern part of Asia mainland including Tarim, North China, South China and Indochina-East Malaya continental blocks [1, 2]. Metcalfe postulated several detachment processes of Gondwanaland to the Mainland Southeast Asia as the slivering process [2]. The significant event during this process was the emplacement of Eastern Indonesia to its recent position that started in the Permo-Triassic when the rifting of Gondwanaland initiated and led to forming of Ceno Tethys Ocean in the Middle to Late Jurassic.

By the Early Eocene (50 Ma) the northern margin of the Australian continent and New Guinea first collided with the Sepik Island arc causing emplacement of Sepik and Papuan ophiolites. After this event the New Guinea margin remained a passive margin for most of the Paleogene.

Major reorganization of plate boundaries in the Eastern Indonesia region took place about 25 million years ago. The New Guinea passive margin collided with the East Philippines–Halmahera–South Caroline Arc system (Pacific plate). A fragment of continental crust from the northern Australian margin, in the Bird's Head region, also began to collide with the SE Asian margin in Sulawesi via the Sorong fault. The first of these to arrive and collide was probably the SE Sulawesi fragment and later the Buton-Tukang Besi, Banggai-Sula and the latest is Obi-Bacan. About 5 Ma was the northward collision of the NW Australian passive margin with the Sunda Trench and Banda Forearc [3].

Stratigraphic Record

Stratigraphy of most of Eastern Indonesia comprises of Paleozoic to Tertiary sediments. Figure 2 shows the generalized stratigraphy of some sites in this region including East Sulawesi, Buton-Tukang-Besi, Banggai-Sula, Seram, Buru, Timor, Tanimbar, Bird’s Head, Bird’s Neck, Central Range Papua, and the northwest shelf of Australia. The following sections briefly describe the stratigraphic record in Eastern Indonesia by time.

Paleozoic

The oldest stratigraphic succession of Eastern Indonesia is recognizable at Central Range of Papua. In this area are outcropped the Neoproterozoic – Cambrian metabasalt-metavolcanic of Awigatoh Formation which has equal age with sandstone and mudstone of Wessel Group, the oldest sedimentary rock in NW Australia [4,5]. Awigatoh Formation is overlain disconformably by Cambrian fine grained turbidites of the Kariem Formation. In Misool, Salawati, Bintuni, Lengguru and Obi areas, the oldest rocks are the Silurian-Devonian in age of Kemum, Ligu and Sibela Formations composed of weakly metamorphosed turbiditic sandstone. This rock succession may be equivalent to Kariem Formation in the Central Range [5], where the dolomitic Midio Formation was also deposited contemporaneously. These two successions are overlain unconformably to disconformably by Carboniferous-Permian shallow water to fluvio-deltaic Aifam – Aiduna Formations [6, 7, 8 and 9]. In Timor and Tanimbar area, Paleozoic sedimentation began during Permian with a primarily shallow marine depositional environment. Muibisse and Selu Limestones, and shallow marine – turbiditic sandstone of Athahoc-Caribass Formation are lithologic succession deposited during Paleozoic. In some parts, limestone in this area are interbeded with basaltic lava [10, 11,12] that indicate deeper marine depositional environments.

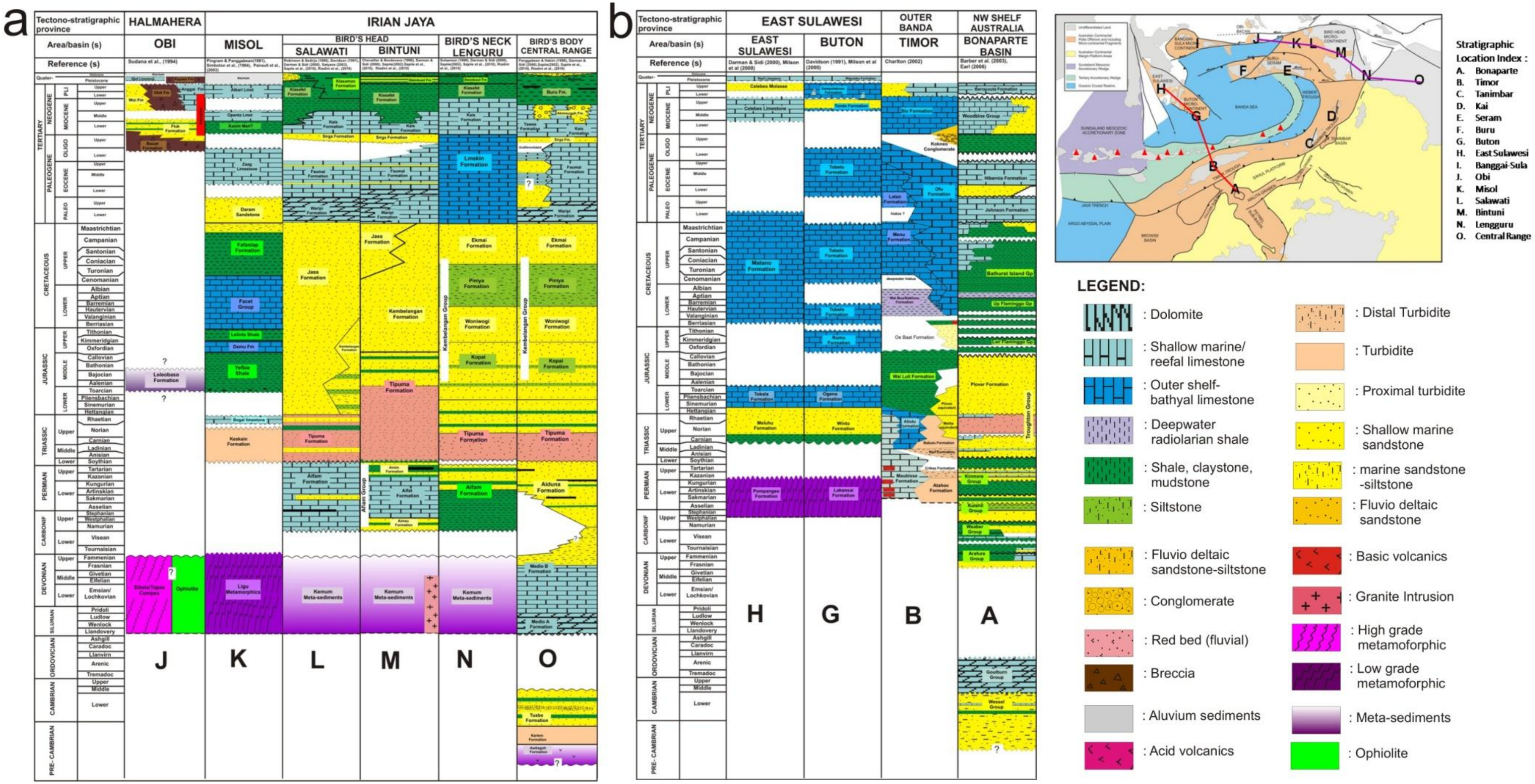

Figure 2. (a) Stratigraphic correlation of Obi-Misool and Papua showing succession of siliciclastics rocks during Paleozoic to Mesozoic Times and carbonate rocks and shale in Tertiary time; (b) Stratigraphic correlation across SE Sulawesi-Buton-Timor showing Pre-Tertiary-Tertiary sedimentary rocks were characterized by series of carbonate rocks, which change into siliciclastics in NW Australia. Lithological logs are adopted from several previous studies since 1981 to 2010. Please refer to references of [17], [15], [7], [6], [18], [8], [19], [16], [5], [11], [12], [20], [4], [21], [9], [22]

Paleozoic rocks consisting of high to low grade metamorphics are also developed in Seram, Buru, Buton, East Sulawesi and Banggai-Sula, which are referred as Kobipoto, Taunusa and Tehoru Formations [13].

Mesozoic

Overlying the Paleozoic sediments in Papua are Mesozoic terrestrial red sandstone of Tipuma and shallow marine sand and mudstone of Kembelangan and Jass Formations. In Misool Island, the weakly metamorphosed Paleozoic basement is directly overlain unconformably by thick marine clastics of Keskain Formation and then continued by shallow marine Bogal Limestone. Unconformably overlying these limestones are the marine shale and limestone of Yefbie, Demu, Lelinta, Facet and Fafanlap Formations.

In the Timor and Tanimbar area, Mesozoic sediments are marked by deposition of turbiditic sandstone of Niof-Babulu-Maru Formations, which interfingers with the shallow to deep marine limestones of Wotar-Aitutu Formations. Charlton suspected that deltaic-shallow marine sandstones of Malita and Plover interfingers with Babulu or is conformable with Maru Formation [11, 12]. In the Jurassic age, claystone and shale of Wai Luli Formation are recognized, where in Timor this formation is overlain by the siltstone and sandstone of Oe Baat Formation, while in Tanimbar unconformably overlain by marine sandstone of Ungar Formation. The Oe Baat Formation in Timor as well as Ungar Formation in Tanimbar area are overlain unconformably by the radiolarian Nakfunu and Arumit subsequently. Deeper marine limestone of Menu-Latan and Ofu Formations covered those both areas in the Late Cretaceous times.

In the Seram, Buru, Buton and East Sulawesi, Mesozoic sedimentation commenced by deposition of turbidities of the Kanikeh-Dalan-Winto Formations and continued by deeper marine limestones of Saman-saman-Ogena-Tokala Formations. In Seram area the deeper marine limestones interfinger with shallow marine Manusela Limestone, which is unconformably overlain by the shales and claystone beds of the Kola Shale. In Banggai-Sula Mesozoic sedimentations are initiated by shallow marine limestone of Nofanni Formation and unconformably continued by Fluvio-shallow marine sandstone of Bobong-Kabau Formation which interfiner with shallow marine limestone of Buya Formation. In the late Mesozoic (Cretaceous times), deeper marine limestone of Sawai-Kuma-Tobelo-Matano and Tanamu took place in Seram, Buru, Buton, East Sulawesi and Banggai-Sula.

Tertiary

Tertiary sedimentation within Papua area was started by deposition of dolomitic to shallow marine limestone of Waripi Formation. In the late Eocene to early Oligocene, deposition of transgressive carbonates of the Faumai Formation took place. Overlying the Faumai carbonates are the late Oligocene siliciclastics of the Sirga Formation. Thick carbonates of the Miocene Kais Formation were deposited following the Sirga siliciclastics. Contemporaneously with the Kais carbonate deposition, was the deposition of the Miocene lagoonal Klasafet Formation. The Pliocene Klasaman-Steinkool and Buru siliciclastics are the youngest Tertiary stratigraphic sequences in the Papua. Molassic deposits of the Sele conglomerates were deposited in the Pleistocene as erosional by-products of the deformed zone along the Sorong fault.

In Misool area, deltaic carbonaceous shales and sandstones of Daram Formation deposited comformably on Late Mesozoic Fafanlap Formation. After deposition of Daram sandstone, Tertiary sediments generally comprise of carbonate rocks. The shallow marine limestones of the Zaag Formation, conformably overlying the Daram, and are unconformably overlain by the marls of Kasim Formation [14]. The Openta Formation covers the Kasim Formation unconformably. The younger Plio- Pleistocene age limestone is the Atkari Formation.

In Timor, Tanimbar, Seram, Buru, Buton, East Sulawesi and Banggai-Sula area, the Early Tertiary sediment are a continuation of Late Cretaceous deposition. Since Miocene times, shallow marine limestone and sandstones were deposited in Buru, East Sulawesi and Banggai - Sula (Wakatin-Hotong-Celebes and Pancoran Formations). During Pliocene-Pleistocene, the sediment dominantly consists of molassic deposits continued with shallow marine sandstone, siltstone and limestones due to uplifting of the region.

Stratigraphic record in Kai was started in Tertiary correspond to deposition of deeper marine limestone of Elat Formation. This sequence unconformably overlain by shallow marine limestone of Wakatin, Wedular and Weryah Formations [5]

In Obi area, after a long depositional hiatus in the Mesozoic, Late Oligocene Bacan breccias were the first sediment in the Tertiary period. These breccias inter finger with interbeded sandstone and claystone of Flux Formation. Unconformably overlying these sediments are the interfingered Woi, Obit and Anggai Formations which comprises of sandstone, breccias and limestone. During the Miocene, the existing Formation was intruded by diorite and gabro [15].

Tectono-Stratigraphic Framework

Most study of the pre-Tertiary tectonic and stratigraphic sections of Eastern Indonesia [4,6,7,8,9,11,12,14,15,16,17,18,19,20,21,22 and 23] reveals similarities in the region (Please refer to figure 2 for stratigraphic succession). It is well documented that two periods of tensional tectonics, an Early Paleozoic infra rift episode and a Late Paleozoic to Paleogene rift episode, dominated the deposition of pre-Tertiary sediments in Eastern Indonesia. These events are similar with basin evolution which is happen in Arafura Basin, Australia (Figure 3). However, since Neogene times, sedimentary rocks in Eastern Indonesia indicate a series of subduction and collision product. The following describes the tectonic events in Eastern Indonesia with the rocks stratigraphy that resulted during the events.

First (1st) Infra-rift Stage: *Early Paleozoic*

The oldest tectonic events in the Eastern Indonesia may be related to the period of upper crustal extension in Neoproterozoic era. The product was a northeast-southwest trending half graben across much of the basin. Deposition in the North and NW Australia margin commenced during this tectonic event with sediments associated to the rifting process. In NW Australian Shelf the infra-rift episode is represented by the shallow marine Wesel and Goulburn Group.

The effects of Early Paleozoic tensional tectonics of the Australian Craton on the stratigraphic record in Eastern Indonesia are the most speculative. The little evidence for attendance to this Early Paleozoic infra-rift basins are paralic and marine sediment (the Awigatoh, Kariem and Tuaba Formations) preserved in exposures along stream beds in the Central Ranges of Papua and dated as Early Paleozoic [5]

First (1st) Pre Break up – Break up Stage: *Silurian-Devonian*

Subsidence along the margins due to rifting phase allowed shallow seas to inundate the North-Northwestern edge of the Australian Craton. During this stage, the Upper Devonian non-marine to shallow marine Arafura-Weber Group unconformably overlies the

Goulburn Group. Over the shelf area in Central Range Papua, the Modio Dolomite was deposited, while in the deeper area (Bird Head, Misool), the turbiditic facies of Kemum were deposited.

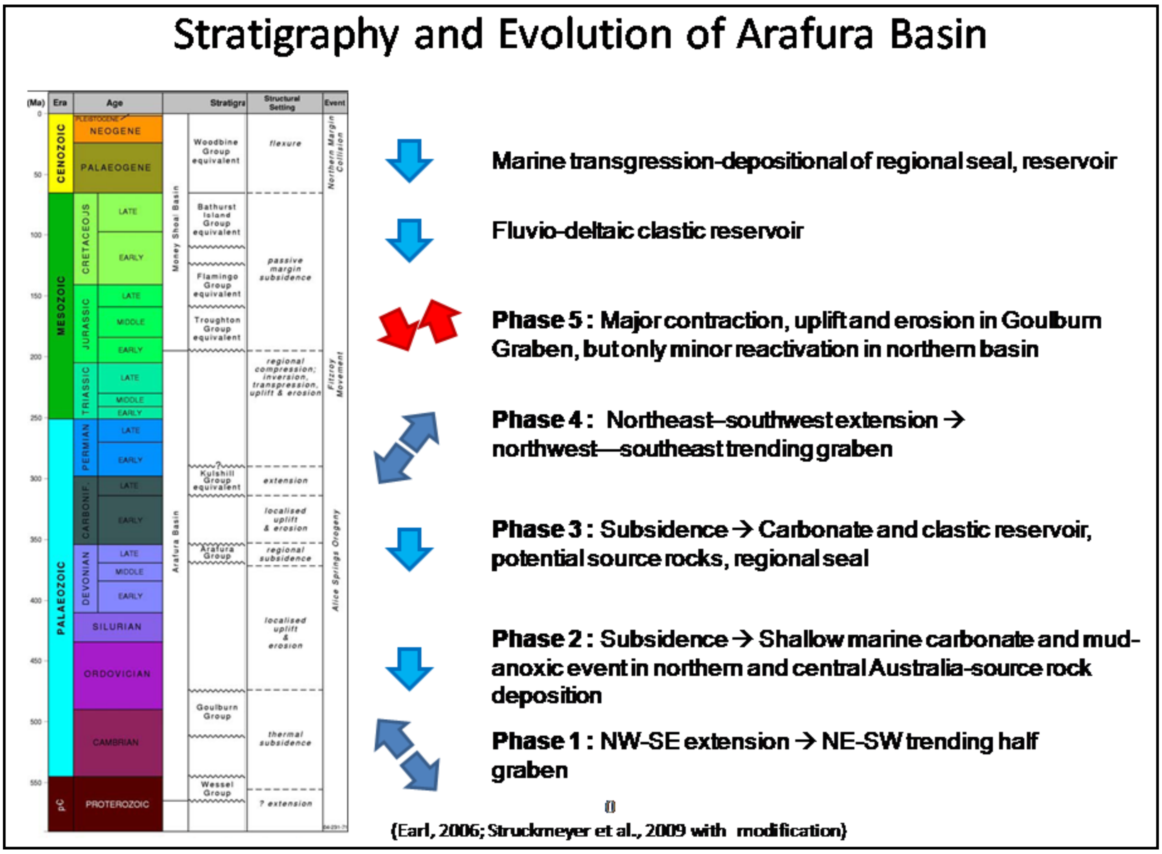

Figure 3. Stratigraphy and evolution of Arafura Basin, showing two major extensional phases during Paleozoic – Early Mesozoic ([22] and [26] with modification)

Middle Paleozoic Variscan Orogeny: *Early-Middle Carboniferous*

Penecontemporaneous to closing of the ancient Paleo-Tethys Sea, to the north of the Indian and Australian Cratons, resulted in uplift and widespread erosion of the stratigraphic section or non-deposition throughout northwestern Australia-Papua. The absence of deposition was recorded by the unconformity between Lower Carboniferous Weaber Group and Upper Carboniferous Kulshil Group. In Central Range Papua, the orogenic event is proven by the disconformable relationship between the Silur–Devon Medio Formation and Late Carboniferous Aiduna Formation, while the Bird Head and Lengguru area is recorded as unconformable between Silur–Devon Kemum metasediments and Late Carboniferous Aifam Formation.

Second (2nd) Infra-rift Stage: *Late Carboniferous-Triassic*

The Late Carboniferous –Permian rifting episode initiated and established the West Australian Super Basin System forming a NE-trending fault system. This overprints the older NW-SE trending Paleozoic basin trends. Basinal areas formed during an extensional phase undergoing gradual subsidence and infill by terrestrial to marine sediment. The infra-rift stage occurs at slightly different times in several places. NW Australia, Papua, Timor, Tanimbar and Banggai-Sula are the first representations of this stage, and then followed by Seram, Buru, Buton, East Sulawesi and Banggai Sula in Triassic – Jurassic Time.

In Bird Head of Papua and Lengguru, the infra-rift stage was represented by deposition of the highly carbonaceous clastic Aifam Group unconformably on the Siluro-Devonian Kemum Formation. In the same period, in the southern flank of the Central Range region is shown by the deposition of shallow marine to paralic sediments of Aiduna Formation. In NW Australia, the Arafura Group is overlain unconformably by Kulshill Formation and followed by Kinmore Formation that consists of non-marine to marginal marine sediments. In Misool Island the weakly metamorphosed basement is directly overlain by thick marine clastics of Keskain beds and followed by fragmental limestone of Bogal Formation. In Timor and Tanimbar area, the stratigraphic records of infra-rift stage began by deposition of Muibisse or Selu and shallow marine – turbiditic sandstone of Athahoc-Caribass Formation. The presence of basaltic lava in some part, however, indicates the onset of rifting during the Permian.

In Seram, Buru, Buton, and East Sulawesi area began experiencing an infra-rift stage during Early Triassic. The oldest recorded non-metamorphosed sedimentary rocks on these areas are those of the Early Triass Kanikeh-Dalan-Winto Formations that sit either unconformably on the igneous or metamorphic units.

Second (2nd) Pre Break up – Break up Stage: *Triassic - Paleogene*

The beginning of the breakup stage in Papua is estimated between the Aiduna and Tipuma Formations, at the end of the Permian and beginning of early Triassic time. During the break up stage, terrestrial to locally marine red beds with minor acid volcanics (Tipuma Formation) were deposited in Triassic and Early Jurassic times. Subsequently, the start of the passive margin sequence is marked by a marine transgression which is interpreted as middle Jurassic in age. The Kembelangan Group was deposited in Papua during this phase, while Yefbie, Demu, Lelinta, Facet and Fafanlap Formation were deposited in Misool area.

A platform carbonate regime began in the Late Cretaceous and by the Eocene an extensive carbonate platform was established (Waripi, Faumai, Kais). Carbonate sedimentation ceased by the Middle Miocene and fine clastics were deposited (Klasefet, Buru Formation).

In the Timor and Tanimbar area, rifting began with deposition of turbidite of Niof-Babulu-Maru Formation which interfinger with shallow to deep marine limestone of Wotar - Aitutu Formation. Sedimentation continued with deposition of Wai Luli claystone and shale followed by siltstone and sandstone of Oe Baat Formation in Timor, while in Tanimbar unconformably overlain by sandstone of Ungar Formation. The Ungar sandstone is interfinger with Arumit Radiolarian. In Timor area, the Nakfunu Formation is found unconformably over the Oe Baat Formation.

Sedimentation of the Late Cretaceous is represented by deposition of deeper marine limestone of Menu-Latan and Ofu Formations which indicate the beginning of a passive margin sequence. In Kai area sedimentation began with deposition of deeper marine limestone of Elat Formation.

In Banggai-Sula, the basement complex became block faulted initially during the Late Triassic times and is overlain unconformably by early Jurassic, continental to shallow marine Kabauw and red beds bearing Bobong Formations. A major transgressive cycle associated with graben subsidence caused the deposition of the restricted shallow marine Buya Formation. Later, Tanamu Formation was deposited as a passive margin sequence

Sedimentation in Seram, Buru and Buton areas in East Sulawesi during the late Jurassic was marked by a shift from intra rift to continental breakup. In Seram area, the evidence of this episode was represented in the presence of Kola Shale, which is unconformable over the Manusela Formation. The Kola Shale is overlain unconformably by limestones of the Nief Beds. The Nief Beds in Seram and also Kuma-Weken, Rumu-Tobelo and Matano Formation in Buru, Buton and East Sulawesi represent the onset of a marginal sag basin following the end of the main breakup phase.

Neogene Orogeny

Since Early Neogene times gradual uplift and shallowing of sediment occurred in most parts of Eastern Indonesia. This compression and initiation of left lateral translation of the micro continent from northern margin of Australia was the consequence of the interaction of the Pacific and Australian plate.

In the Late Miocene the fragment of continental crust (Buton-Tukang Besi, Banggai-Sula) arrived and collided with Sulawesi, while Bird's Head collided with Papua (New Guinea) and translated northward along a strike-slip fault at the Aru Basin Edge. This event marked with thrusting and rapid orogenic uplift, a gravity slide / slump unit, which is deposited and sits unconformably on the sediments of the passive margin sequence.

Petroleum System Implication

Source Rock

The potency for hydrocarbon is mainly controlled by the presence of mature source rocks. Without charging the system from mature source rock to the reservoir in the traps, the petroleum system will not work properly, except there are other charging systems from other basins nearby. Pre-Tertiary source rocks are widespread in Eastern Indonesia but significant source rock accumulation is primarily restricted to three periods, namely, Permian, Late Triassic and Early-Middle Jurassic periods. Proven Tertiary source rocks are identified in restricted areas of Eastern Indonesia but have been shown to be prolific hydrocarbon producers. The source rocks of Paleozoic-Mesozoic are mostly of infra-rift origin, while the Tertiary source rocks are related to syn-orogeny sediments. The cha-racteristic of petroleum system in some field in Eastern Indonesia can be seen in Table 1.

Pre-Permian

The Permo-Cambrian Wesel, Goulburn, Arafura and Kulshill Group are identified as good to very good potential source rocks within the Northwest Shelf Province. These generally comprise carbonaceous shales and coals deposited in marginal marine of fluvio-deltaic environments.

Permian- Jurassic

The Permian-Jurassic source rocks are identified in almost all regions in Eastern Indonesia. The list of potential source rocks can be described as follow: In NW Australia; Plover and Echuacha shoal, In Papua area; Aifam-Aiduna, Tipuma and Kembelengan Group, In Misool area; Yefbie and Lelinta, In Seram area; Kanikeh and Saman-saman, In Timor, potential source rocks are Cribas, Aitutu and Wai luli Formation, In Tanimbar; Maru Formation, In Buru; Dalan and Ghegan Formation, In Buton; Ogena, Winto and Tobelo Formation, In East Sulawesi; Menhulu and Tokala Formation.

Tertiary

Tertiary source rocks are regionally less widespread than the pre-Tertiary units but have been correlated to the producing or tested hydrocarbons such as in the Salawati Basin (Early Pliocene Klasaman), and Banggai-Sula (Early Miocene Salodik). Two tectonic systems control hydrocarbon generation within this period and these are the Mesozoic graben and the late Neogene thrust loading during collision. The petroleum system has been working in the graben system since the Mesozoic, while in the thrust loading system; hydrocarbon generation has taken place since the Pliocene.

Reservoir

The Reservoir rocks belong to the Mesozoic and Tertiary. The Mesozoic reservoirs are sandstone and carbonate rocks, while the Tertiary rock consists of Miocene limestone and sandstones and also Pliocene sandstones. The limestone geometries mainly are platform and buildup. The porosity is mainly secondary type due to dissolution and cracking.

Table 1. Petroleum System Characteristic of Some Fields in Eastern Indonesia

AREA	FIELD	RESERVOIR			SOURCE ROCK			SEAL			TRAP
		AGE	FM.	LITH.	AGE	FM	LITH.	AGE	FM.	LITH.	
BINTUNI	Wiriagar Vorwata Ofaweri Roabiba	Mid.Jurassic	Kembelangan Group	Sandstone	Permian Jurassic	Ainim Yefbie	Carbonaceous shale & coal shale & coal	Late Jurassic	Upper Kembelangan	Claystone and shale	anticline pinchout Pop-up structure anticline
SALAWATI	Klamono Walio Kasim	Miocene Miocene	Kais Klasefet	Limestone Limestone	Early Pliocene	Klasaman	Shale	Miocene Miocene	Kais Klasefet	Intraformational Shale	Thrust anticline
SERAM	Oseil	Early-Mid. Jurassic	Manusela	Limestone	Triassic Jurassic	Kanikeh Manusela	Calc.shale Carbonate	Late Jurassic	Kola	Shale	Thrust anticline
BANGGAI	Tiaka	Jurassic Early Miocene Late Miocene	Bobong Tomori Mtindok	Sandstone Limestone Sandstone	Jurassic Early. Miocene	Buya Salodik	Marine shale Shale & carbonate	Late Miocene	Matindok	Marine shale	Thrust anticline
TIMOR	Abadi	Mid. Jurassic	Plover	Sandstone	Early. Jurassic	Plover eq.	Marine shale	Early Cretaceous	Echuca Shoals	shale	Normal Fault
	Bayu-Undan	Mid.Jurassic	Elang Plover	Sandstone Sandstone	Mid.Jurassic	Elang Plover	Sandstone Sandstone	Early Cretaceous	Echuca Shoals	shale	

Trap and Seal

The traps in Eastern Indonesia are mainly structural traps which include thrust and normal faults, while minorities are stratigraphic traps of carbonate buildup. For the seal rocks, the petroleum system in Eastern Indonesia is mostly provided by the syn-orogeny and passive margin shales. This rocks type is usually deposited in a wide depositional environment and therefore can act as a regional seal rock.

Hydrocarbon Opportunities in Eastern Indonesia: Lesson from Geological Condition of Tanimbar Islands

The Tanimbar is an archipelago of more than 40 islands situated in the southeastern part of the Banda Arc, Eastern Indonesia (Figure 4a). It was formed as part of the collision complex between the Banda Arc subduction zone and the NW continental margin of Australia. The Tanimbar Island also lie immediately north of the recent Abadi commercial gas discovery in INPEX's Abadi gas field.

The stratigraphy of the Tanimbar Islands is comparable to the other Banda forearc island in comprising Australian continental margin sequences added to the forearc and collision complex by accretionary processes. Based on and this research [12], the geology of Tanimbar island in hydrocarbon prospectivity framework can be briefly described as follow: Paleozoic sedimentation within Tanimbar area began during Permian with deposition of shallow marine limestone of Selu. The limestone shows considerable evidence for primary porosity created by dolomitization and mouldic porosity. Mesozoic sedimentation is marked by deposition of fluvial-turbiditic sandstone of Maru Formation which interfingers with the shallow - deep marine limestone of Wotar Formation. Maru Formation in Tanimbar which is dominantly composed of light brown and grey micaceous quartz sandstones with some interbedded claystones-shale may have some potential source rock and reservoir. This formation also forms part of the same Plover fluvio-deltaic system that act as reservoirs the Abadi gas fields. Porosity analyzed from outcrop samples indicated that Maru sandstone have porosity up to 14%. In the Jurassic age shallow inner shelf to middle shelf homogenous dark grey colored claystone and shale (Wai Luli Formation equivalent) took place. The claystone and shale are unconformably overlain by marine sandstone of the Ungar Formation (See figure 4b-d). This Formation mainly consists of quartz sandstone with well rounded and moderately to well sorted grain, and it may have potential reservoir for Early Cretaceous sediment with the porosity up to 18%. The Ungar sandstone interfingers with Arumit Radiolarian which was deposited in Late Cretaceous and continued by deposition of deeper marine limestone (Ofu Formation equivalent).

Early Tertiary sediment in Tanimbar is continuation of Late Cretaceous deeper marine limestone deposition. This deeper marine limestone was unconformably continued by deposition of Early Miocene shallow marine limestone and marine claystone and sandstone Tangustabun Formation. Subsequently deeper marine limestone of Middle-Late Miocene reefal limestone of Batimafudi Formation (figure 4e-f) was deposited. During Pliocene, the sediment deposition consists of shallow marine limestone (Batilembuti Formation) due to the uplift of the region.

The most likely trap type in the Tanimbar area is inversion anticlines, formed by reactivation in compression of pre-collisional graben structures. Listric normal faults on the eastern (lower-plate) margin of the pre-collisional Calder graben system are interpreted as having been reactivated in compression to form inversion anticlines beneath the complex surficial fold and thrust/mélange belt.

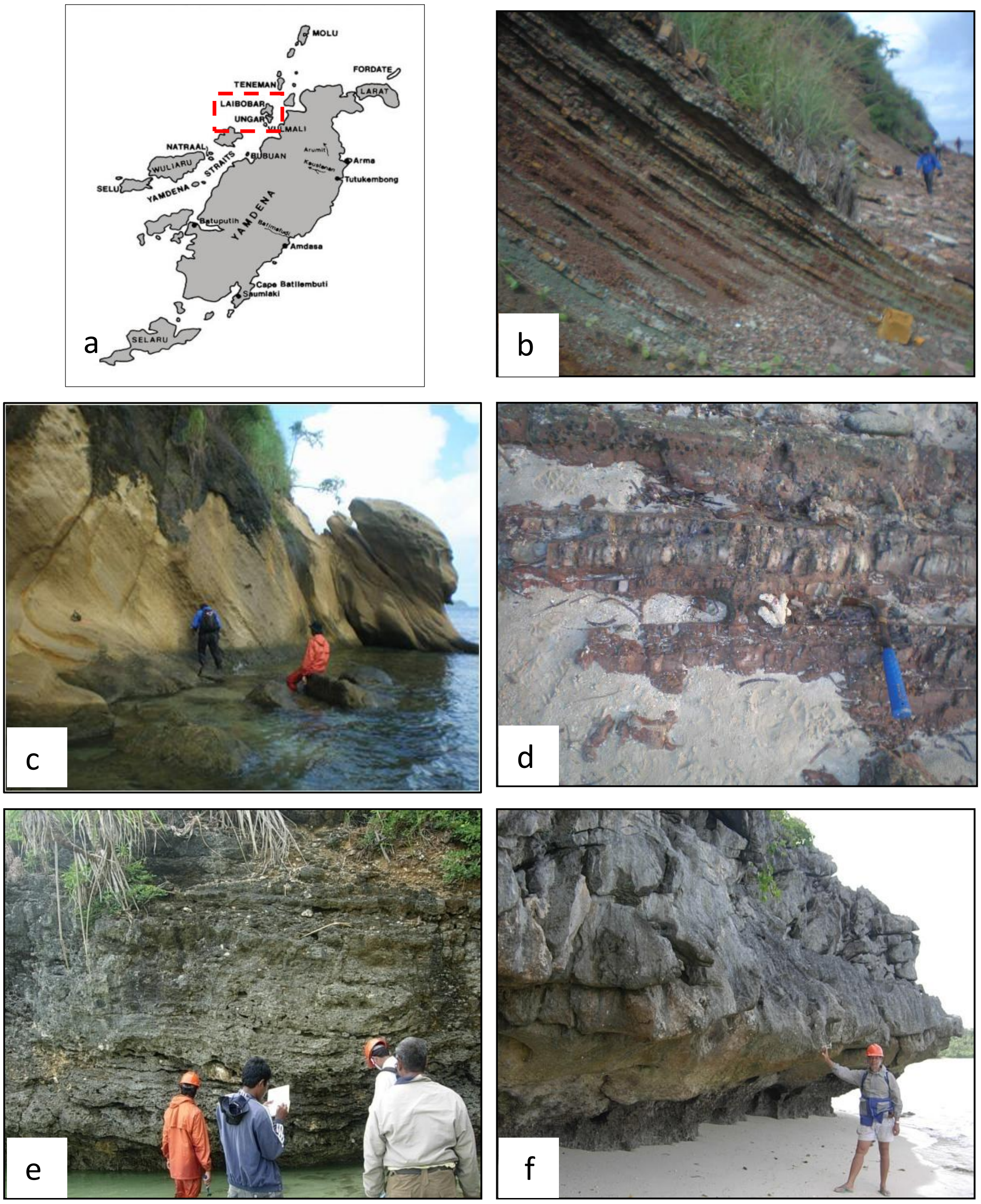

Figure 4. (a) Tanimbar Islands, red dashed box is the location of geological survey (b-c) Sandstone interbeds of Ungar Formation (d) Arumit member in Ungar Island (e-f) Limestone of Batimafudi Formation in Laibobar Island

Conclusions

The present tectonic setting of Eastern Indonesia Region is closely related to the long history of NW Shelf Australian tectonic evolution since the Paleozoic to Tertiary. Tensional tectonic events mostly occurred during Paleozoic to Mesozoic which may be contemporaneous with the slivering process of Gondwanaland to form Southeast Asia Mainland.

In the Neogene period, the tectonic events in Eastern Indonesia were the compression due to subduction – collision of Australian Plates into Eurasian and a number of smaller micro continents which are considered to be of Australian affinity.

Stratigraphy of Eastern Indonesia from Palaeozoic – Mesozoic is mostly dominated by terrestrial to shallow marine deposits that resulted from tensional tectonic event, while the Tertiary to Recent sediments indicate a shallow marine to deeper marine deposition of carbonate with minor siliciclastic sedimentary rocks.

Hydrocarbon potential of Eastern Indonesia mainly developed in the Mesozoic petroleum play for siliciclastic play and in the Neogene limestone for limestone play. Eastern Indonesia has the upside potential for hydrocarbon accumulation, mainly for Paleozoic siliciclastic play or late Tertiary deeper marine play.

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References

[1] C.J. Pigram, and H. Panggabean, "Rifting of the northern margin of the Australian continent and the origin of some micro continents in eastern Indonesia," *Tectonophysics*, Vol. 107, No. 3-4, pp. 331–353, 1984.

[2] I. Metcalfe, "Palaeozoic and Mesozoic tectonic evolution and Palaeogeography of East Asian Crustal Fragment," *Gondwana Research*, Vol. 9, No. 1-2, pp. 24-46, 2006.

[3] R. Hall, "Plate tectonic reconstruction of the Indonesia region," In: *Proceedings Indonesian Petroleum Association 24th Annual Convention*, pp. 71-84, 1995.

[4] P. Barber, P. Carter, T. Fraser, P. Bailie, and K. Myers, "Paleozoic and Mesozoic petroleum system in the Timor and Arafura seas, Eastern Indonesia," In: *Proceedings Indonesian Petroleum Association 29th Annual Convention*, pp. 1-16, 2003.

[5] H. Darman, and F.H. Sidi, *An Outline of The Geology of Indonesia*, Indonesian Association of Geologist, Jakarta, Indonesia, 2000.

[6] H. Panggabean, and A.S. Hakim, "Reservoir rock potential of the Paleozoic-Mesozoic sandstone of the southern flank of the central range, Irian Jaya," In: *Proceedings Indonesian Petroleum Association 15th Annual Convention*, pp. 461-481, 1986.

[7] B. Chevaller, and M.L. Bordenave, "Contribution of geochemistry to the exploration in Bintuni basin," In: *Proceedings Indonesian Petroleum Association 15th Annual Convention*, pp. 439-460, 1986.

[8] A. Sulaeman, A. Sjapawi, and S. Sosromihardjo, "Frontier exploration in the Lengguru Foldbelt Irian Jaya, Indonesia," In: *Proceedings Indonesian Petroleum Association 19th Annual Convention*, pp. 85-105, 1990.

[9] A.H. Satyana, "Re-Evaluation of the sedimentology and evolution of the kais carbonate Platform, Salawati basin, eastern Indonesia: Exploration significance," In: *Proceedings Indonesian Petroleum Association 29th Annual Convention*, pp. 1-23, 2003.

[10] T.A. Reed, M.E.M. de Smet, B.H. Harahap, and A. Sjapawi, “Structural and depositionalhistory of east Timor,” In: *Proceedings of the Indonesian Petroleum Assocation 25th Annual Convention*, pp. 297-308, 1996.
[11] T.R. Charlton, “The petroleum potential of west Timor,” In: *Proceedings Indonesian Petroleum Association 28th Annual Convention*, pp. 301-317, 2002.
[12] T.R. Charlton, *Permo-Mesozoic Stratigraphy of The Tanimbar Island, Eastern Indonesia*, Internal report of the INPEX, 2010.
[13] R.A. Garrard, J.B. Supandjono, and Surono,“The geology of the Banggai-Sula micro continent, Eastern Indonesia,” In: *Proceedings of the Indonesian Petroleum Association 17th Annual Convention*, pp. 23-52, 1988.
[14] B. Simbolon, S. Martodojo, and R. Gunawan, “Geology and hydrocarbon prospect of the pre-tertiary system of Misool area,” In: *Proceedings of Indonesian Petroleum Association 13th Annual Convention*, pp. 317-340, 1984.
[15] D. Sudana, A. Yasin, and K. Sutisna, *Geological Map of The Obi Sheet, Maluku*, 1:250,000, Indonesia: Geological Research and Development Centre, 1994.
[16] C.J. Pigram, and H. Panggabean, “Pre-tertiary geology of western Irian Jaya and Misool island: Implication for the tectonic development of eastern Indonesia,” In: *Proceedings Indonesian Petroleum Association 10th Annual Convention*, pp. 385-399 , 1981.
[17] C.G. Robinson, and H. Soedirdja, “Transgressive development of Miocene reefs, Salawati basin, Irian Jaya,” In: *Proceedings of Indonesian Petroleum Association 15th Annual Convention*, pp. 377-403, 1986.
[18] J. Davidson, “Geology and prospectivity of Buton island, S.E. Sulawesi, Indonesia,” In: *Proceedings of the Indonesian Petroleum Association 20th Annual Convention*, pp. 209-233, 1991.
[19] B. Sapiie, “Structural pattern and deformation style in the central range of Irian Jaya (West Papua), Indonesia,” In: *Proceedings Indonesian Petroleum Association 28th Annual Convention*”, pp. 369-376, 2002.
[20] A.A. Pairault, R. Hall, and C.F. Elders, “Tectonic evolution of the Seram trough, Indonesia,” In: *Proceedings of Indonesian Petroleum Association 29th Annual Convention*, pp. 355-370, 2003.
[21] K.L. Earl, *An Audit of Well in the Arafura Basin*, Geoscience Australia, 2006.
[22] P. Riadini, B. Sapiie, A.S.M. Nugraha, F. Nurmaya, R. Regandara, and R.P. Sidik, “Tectonic evolution of the Seram fold-thrust belt and Misool-Onin-Kumawa antcline as implication for the birds head evolution,” In: *Proceedings of Indonesian Petroleum Association 34th Annual Convention*, pp. 1- 21, 2010.
[23] B. Sapiie, A.C. Adyagharini, and P. Teas, “New insight of tectonic evolution of Cendrawasih bay and it’s implication for hidrocarbon prospect, Papua, Indonesia,” In: *Proceedings of Indonesian Petroleum Association 34th Annual Convention*, pp. 1-11, 2010.
[24] Y. Kaneko, S. Murayama, A. Kadarusman, T. Ota, M. Ishikawa, T. Tsujimori, A. Ishikawa, and K. Okamoto, “On-going Orogeny in The Outer-Arc of The Timor-Tanimbar Region, Eastern Indonesia,” *Gondwana Research*, Vol. 11, pp. 218-233, 2007.
[25] K.C. Hill, “Tectonic and regional structure of Seram and the Banda arc,” In: *Proceeding of Indonesian Petroleum Association 33th Annual Convention*, pp. 559-578, 2005.
[26] H.I.M. Struckmeyer, *Petroleum Geology of the Arafura and Money Shoal Basins*, Geoscience Australia, Australia, 2006.