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Tectonostratigraphy of the Southern Part of Papua and Arafura Sea, Eastern Indonesia

Tektonostratigrafi Papua Bagian Selatan dan Laut Arafura, Indonesia Bagian Timur

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Abstract

Sedimentary history and stratigraphy of the Papua and Arafura Sea areas, eastern Indonesia, are gained from surface geological mapping combined with published data from oil companies. Development of some sedimentary units demonstrates that the tectonism have influenced sedimentation of such units comprising a succession of Phanerozoic rocks developing in a stable continental margin. The succession underlain by Cambrian-Silurian-Devonian metamorphic rocks consists of Tuaba, Kariem, Awitagoh, and Kemum Formation, and Modio Dolomite (Pre-Rift Phase). These rocks having been intruded by Late Permian-Middle Triassic granitoids and Carboniferous granite, are unconformably overlain by Late Carboniferous to Cretaceous siliciclastic-rich units comprising Aifam Group and Tipuma Formation (syn-Rift Phase) and Kembelangan Group (Mesozoic Passive Margin Post-Rift). The Aifam Group is separated by a regionally continuous boundary on its top contact from the Triassic-Early Jurassic Tipuma Formation, which filled the block-faulted rift valley subbasins of continentally deposited red beds in the breakup stage. Regionally, developed erosion surfaces of the breakup unconformity have separated these red beds from generally transgressive post-breakup deposits of the Jurassic to Cretaceous marine-sediments of the Kembelangan Group. Beach to shallow marine-glauconitic sandstone and shale of the group pass upward into shelf mudstone. Relative sea level fall related to the tectonic stability of the area led to the development of Eocene to Late Miocene platform carbonates of the New Guinea Limestone Supergroup which occurred in the entire island of Papua and the southern of Arafura that overlie these non-carbonate units (Tertiary passive margin). It is separated from the siliciclastic-rich packages by the Tertiary - Pre-Tertiary boundary. The sea level fluctuation within the group was also recorded during the formation of thin, discontinuous sandstone beds/lenses of Sirga Formation and Adi Member of the Oligocene age (Convergence phase). Turbidite sediments of the Miocene Klasafet Formation was deposited in a deep marine environment at the same time as the eruption of magmatic arc (Compressional phase). The mainland area was exposed above sea level at Late Miocene to Pleistocene (Melanesian Orogeny) and terrigenous detritus deposition began to fill in the basin as molasses type deposits with a marine influence in part (Buru and Steenkool Formations).

Keywords: Phanerozoic, tectonostratigraphy, continent, phase, Papua

Sari

Data hasil pemetaan geologi permukaan berupa himpunan unit sedimen yang tertata rapi dan hasil pemboran perusahaan migas dapat memperjelas sejarah sedimentasi dan stratigrafi daerah Arafura dan Papua. Perkembangan beberapa satuan sedimen menunjukkan bahwa tektonisme telah mempengaruhi proses sedimentasinya. Satuan-satuan tadi merupakan suatu runtunan batuan-batuan Fanerozoikum yang diendapkan pada tepian benua stabil. Runtunan batuan sedimen tersebut beralaskan batuan malihan berumur Kambrium - Silur - Devon, dan terdiri atas Formasi Tuaba, Kariem, Awitagoh, dan Kemum serta Dolomit Modio (Fase prapemekaran). Batuan-batuan ini diintrusi oleh granitoid Permian Akhir - Trias Tengah dan granit Karbon, kemudian ditindih secara tidak selaras oleh unit kaya akan silisiklastika berumur Karbon

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Akhir- Kapur, yaitu KelompokAifam dan Formasi Tipuma (Fase saat pemekaran) serta Kelompok Kembelangan (Fase tepian pasifMesozoikum). Kontak antara KelompokAifam dan Formasi Tipuma Trias- JuraAwal dipisahkan oleh batas bentang regional. Formasi ini terdiri alas lapisan merah yang mengisi subcekungan lembah pemekaran sesar bongkah sebagai endapan benua tahap pemisahan. Erosi permukaan berkembang secara luas membentuk ketidak selarasan, memisahkan lapisan merah tersebut dari endapan trangresif pasca pemisahan pad a umumnya dari endapan !aut Kelompok Kembelangan Jura- Kapur. Kelompok ini terdiri atas batupasir dan serpih glaukonitan yang diendapkan pada lingkungan pantai -!aut dangkal, dan menerus ke atas menjadi batulumpur paparan. Penurunan relatifpermukaan air !aut yang berkaitan dengan stabilitas tektonik daerah tersebut menyebabkan perkembangan paparan karbona!berumur Eosen - Miosen Akhir dari Supergroup Batugamping Nugini yang terbentuk di seluruh Pulau Papua dan di *selatan Arajura, menutupi unit bukan karbona! (Fase tepian pasifTersier}. Unit ini terpisah dari paket kaya silisiklastika oleh pembatas Tersier- Pra-Tersier. Fluktuasi permukaan !aut dalam supergroup ini terekam selama pembentukan lapisanl lensa batupasir tipis tidak menerus dari F ormasi Sirga danAnggota Adi berumur Oligosen (Fase konvergen}. Batuan sedimen turbidit Formasi Klasafet b erumur Miosen diendapkan pada lingkungan !aut da lam bersamaan dengan erupsi magma busur (Fase kompresional). Daerah daratan utama muncul di atas permukaan !aut pada MiosenAkhir sampai Plistosen (Orogen Melanesia) dan endapan detritus terigenos mulai terendapkan dalam cekungan sebagai sedimen tipe molase dan di lingkungan !aut secara setempat (Formasi Buru dan Formasi Steenkool}.*

Kata kund: *Fanerozoikum, tektonostratigra.fi, benua,fase, Papua*

INTRODUCTION

The southern Papua and Arafura Sea is a continental shelf area situated on the northern part of the Australian Craton (Figure 1). To the north, it is bordered by the Tertiary collision zone between the Australian craton and the northern Papua island arc, while to the south it adjoins the stable Australian craton. The bathymetry ofthe Arafura Shelf exhibits depths of between 50 and 80 m (160 and 260 ft), but deeper parts down to more than 600 m (1,970 ft) occur at the edges. Papua (formerly Irian Jaya) located in the eastern Indonesia has the most complete stratigraphic succession and contains the oldest rock (Cambrian) in Indonesia. Eastern Indonesia is one ofthe most active tectonic regions in the world. Three major crustal plates converge in this area (the Pacific, Eurasia and Australian plates) (Figure 1) have caused a complex pattern of subduction zones, volcanic arcs, mountain ranges and sedimentary basins (Simanjuntak and Barber, 1996).

The landscape of eastern Indonesia is a reflection of this active tectonics. Volcanoes, raised terraces, fault escarpments, and deep valleys characterize it. Eastern Indonesia consists of a core of drowned oceanic crust (Banda Sea) that is surrounded by continent (Australia). The islands of eastern Indonesia are an active belt at the boundary ofthe Banda Sea, Pacific, and Australia. Most of the non-volcanic islands in eastern Indonesia containing fragments of continental crust have stratigraphically much correlative with the Australian NW shelf (Pigram and Panggabean, 1984). The resemblance to the Australian margin forms the basis for the generally accepted idea that many islands of eastern Indonesia are the detached and displaced fragments ofthat margin. Papua contains an extensive Paleozoic basement that consists of clastic sediments and dolomite with occasional gabbroic intrusions (Dow *et al.,* 1988).

Small islands like Seram and Buru contain extensive units of metamorphosed continental basement rocks (Tjokrosapoetro and Budhitrisna, 1982). The overlying Mesozoic and Tertiary sedimentary sequences have stratigraphic features resembling that of the Australian continental margin (Pigram and Panggabean, 1984). The feature characteristic for the geology of the "Australian" fragments in eastern Indonesia are: a metamorphic basement, an Early Mesozoic period of rifting with graben development, followed by a deepening of marine environment, and a late Mesozoic and Early Tertiary period of open, deep marine sedimentation. In the Neogene, the fragments collided with the island arcs around the Banda Sea region.

The geological interpretation on the region discussed is mainly based on the fieldwork data, combined with compilation from available well data, previous work results and published papers. The discussion encompasses the Arafura Sea Basin area, Central Range, Lengguru, Onin - Kumawa,

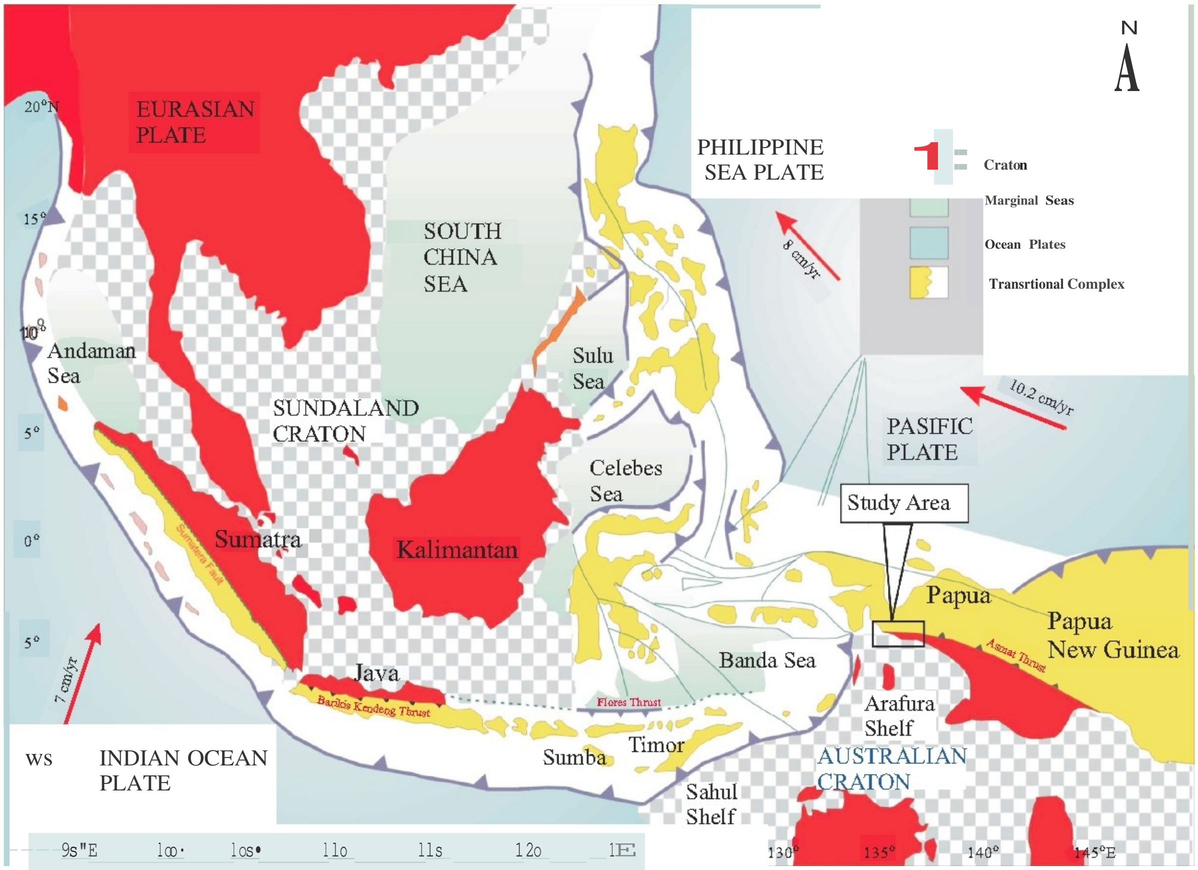

Figure 1. Tectonic framework oflndonesia (Simandjuntak and Barber, 1996). Papua (formerly Irian Jaya) lies on the Australian continental margin

Bird's Head, Salawati-Bintuni Basins, Misool, Kai-Tanimbar Islands, Papua New Guinea, and NW Shelf and North of Australia. The understanding of the geological regional setting ofthe area is important when suggesting the models of tectonic and basin evolution and to large extent the hydrocarbon prospect. This article outlines and verifies general geology including tectonic evolution, tectonostratigraphy, paleogeography, and sedimentation ofPapua and Arafura Sea areas.

GEOLOGY

Regional geologic setting ofPapua andArafura Sea is shown on Figure 2, while its tectonic setting relationship to the eastern Indonesia is displayed on Figure 3. The stratigraphy of Australian Continental Crust (southern Papua and Arafura Sea areas) embraces a large section of Phanerozoic rock record (Figures 4 and 5), showing that the platform has been a stable continental margin up to present time.

Regionally, the basement is made up of Early Paleozoic, Pre-Cambrian sediments and gabbro metamorphosed to various degrees. The basement in the southern region of Papua and Arafura Sea area is suggested to be Pre-Cambrian rock (Kariem and Awitagoh), Cambrian to Devonian (Tuaba and Modio Dolomite/K.ora /K.emum Formations). This basement is unconformably overlain by the Permian Aiduna Formation of the Aifam Group.

Tectonostratigraphically, all the basement rocks have been proposed to be the pre-rift stage. Five major tectonostratigraphy phases during the Pre-Cambrian to present age have been recognized to consist of "pre-rift'', "syn-rift", "passive-margin" (post break-up), "convergence", and "compression"

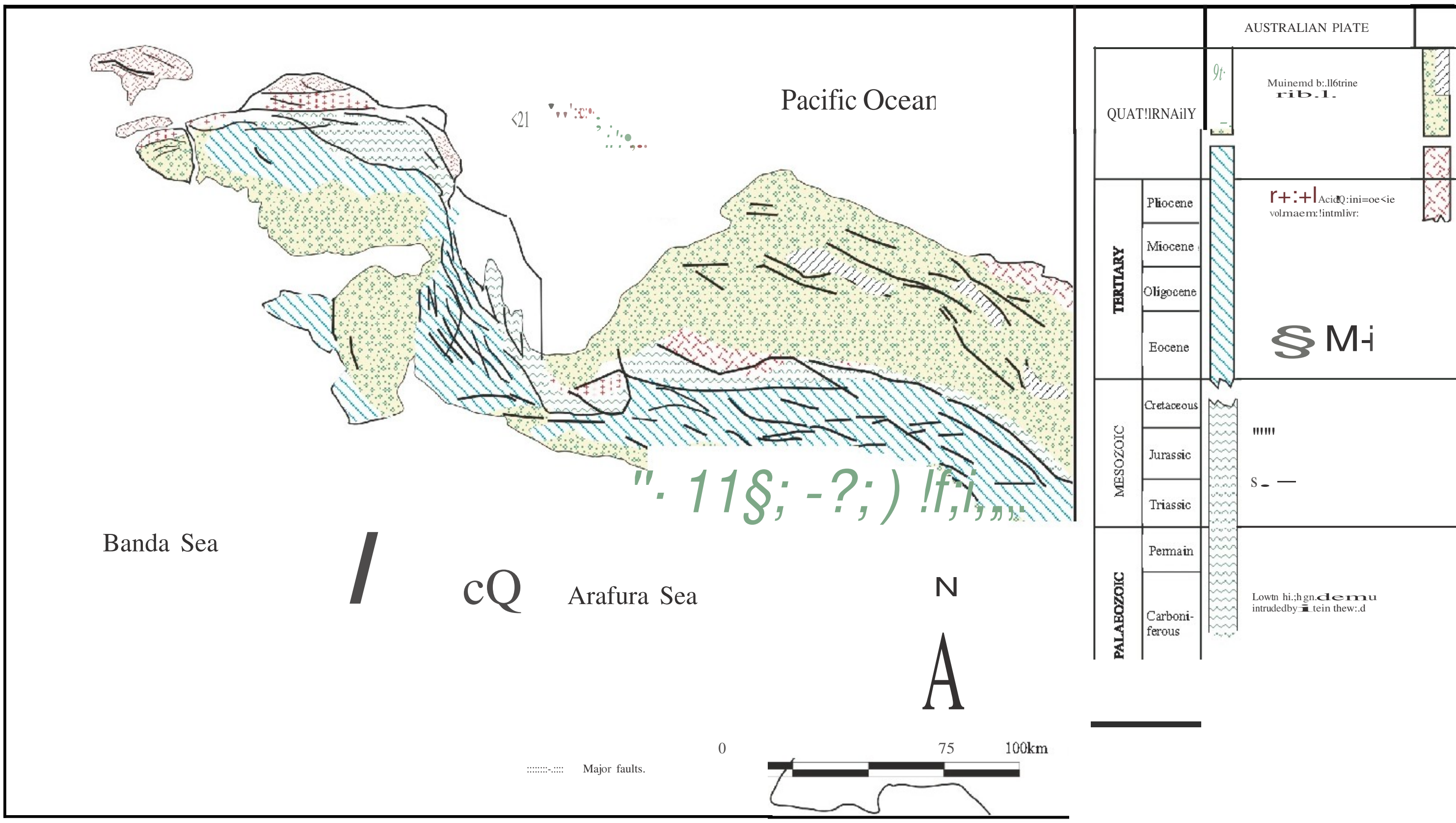

Figure 2. Regional geologic setting of Papua (modified from Dow *et al.,* 1986), the southern region discussed in this article is part of the Australian Contine

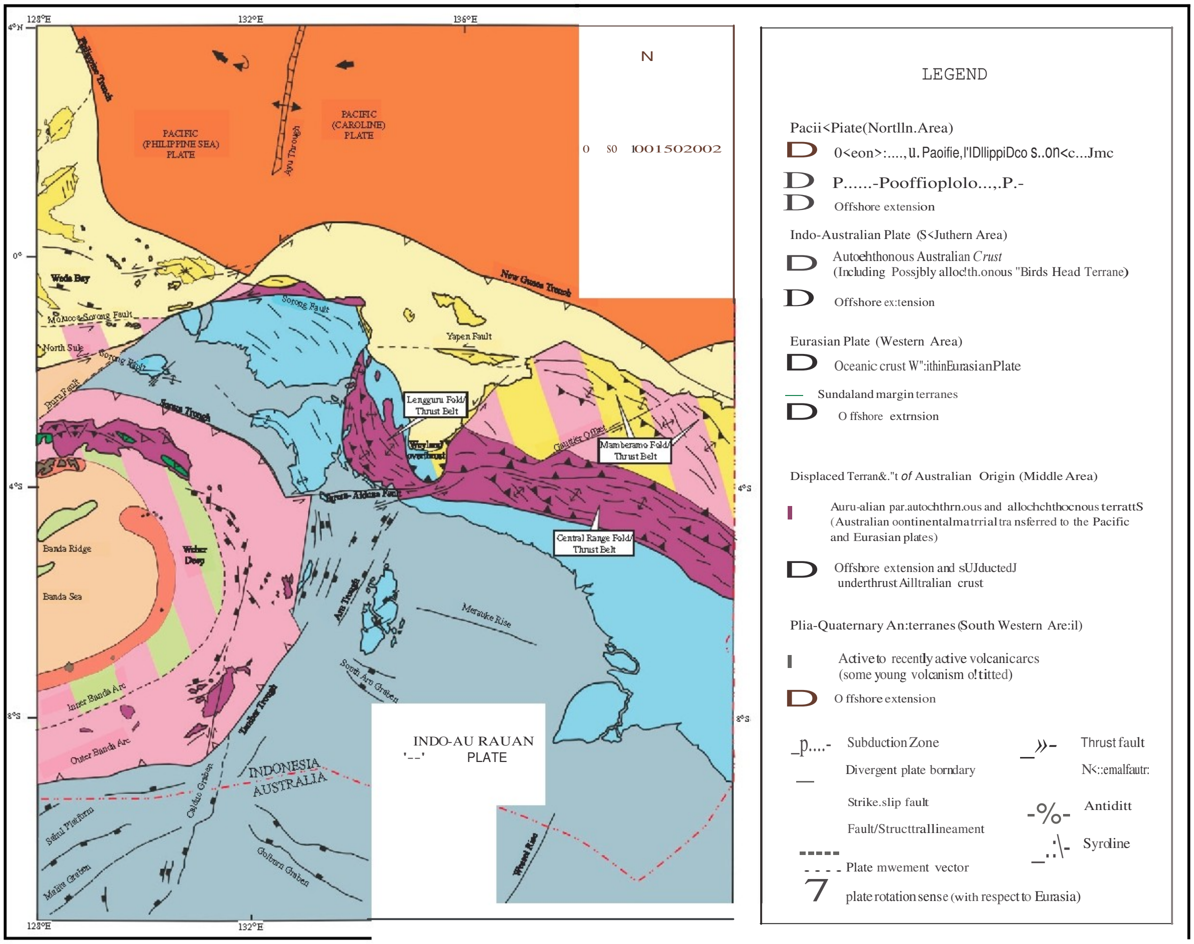

Figure 3. Regional tectonic map of eastern Indonesia (data source from KNOC, 1999; Dow *et al.,* 1986; Hamilton, 1979; Simandjuntak and Barber, 1996).

phases (Figure 4). The pre-rift phase expresses the tectonic condition during Proterozoic time (Cambrian to Early Paleozoic) showing a pre-breakup, breakup, and post-breakup stages where are all stages become the oldest basement of the northern margin of Australia and the region.

The Permian-Early Jurassic breakup appeared to be the initial geological feature of the Papua and Arafura. In this phase, Australia and India (Gondwanaland) have generated rift or graben system of Triassic-Jurassic times. The graben systems are thought to lie under the Arafura Platform and were eventually filled in with shale and sandstone of a fluvio-deltaic, estuarine to a shallow marine, and near-shore to outer shelf environments.

During Late Jurassic to Early Tertiary, a passive margin phase took place and eventual total inundation by the Tethyan Sea was followed by deposition of shale, sandstone, and partly carbonates rocks

The deposition of platform and pelagic carbonates was interrupted by several tectonic events during Tertiary time. An initial NE-SW compression event of Eocene time (42 m.y) might have been the initial and reactivation of the Aru Trough (Am-Calder-Malta Graben) and possibly several NW-SE trending arches crossing the Arafura Platform. By inference, it is possible that some early and limited structures ofthe Arafura were introduced at this time.

Formation ofthe Central Range and transitional zone ofPapua or Papuan Fold Belt (Dow, 1977) was initiated during the collision of Australian Continent and Pacific Oceanic plates at 24 m.y (Late Oligocene). Continuation of an oblique plate collision has initiated the development of several major lateral

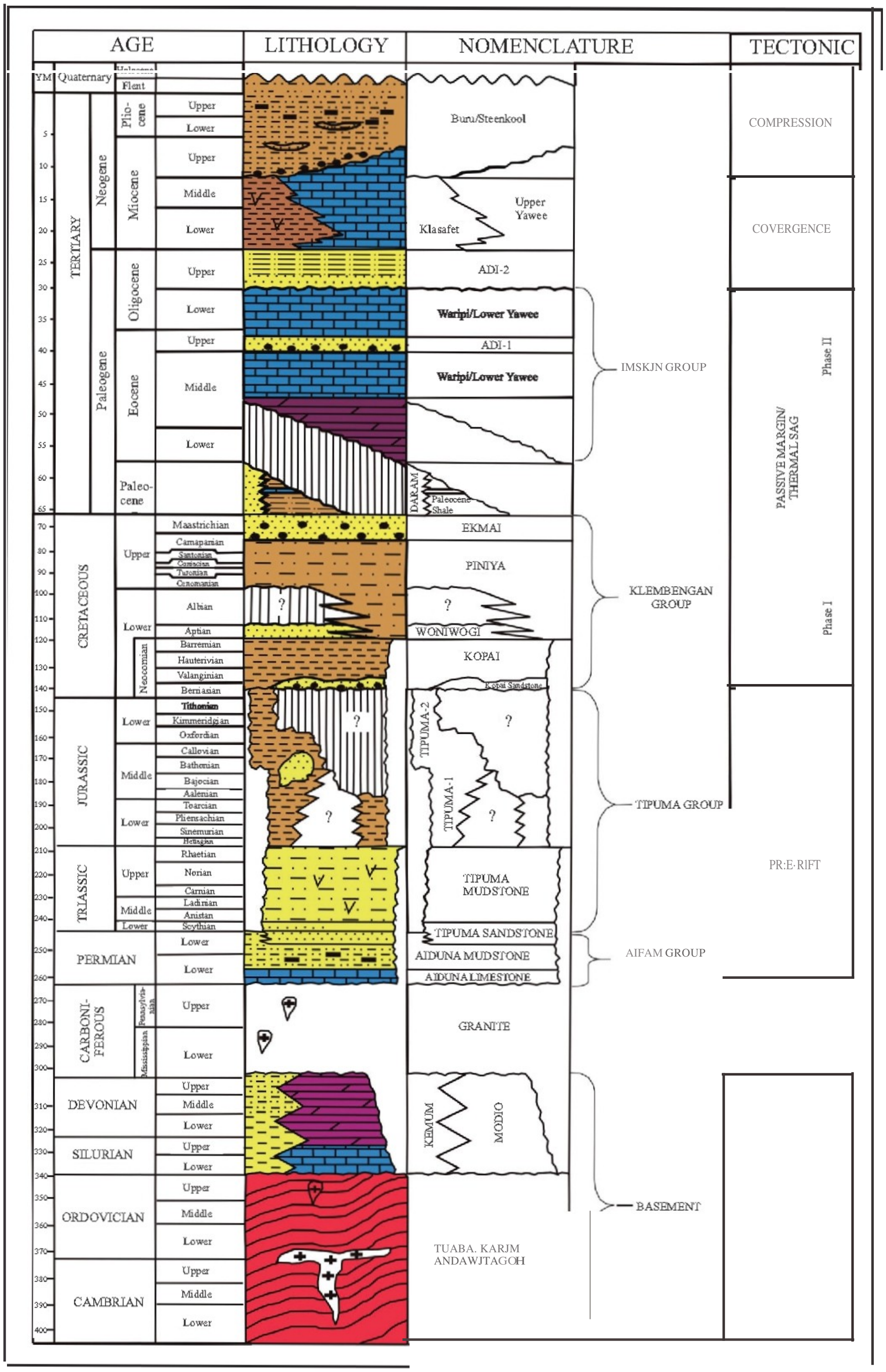

Figure 4. Tectonostratigraphy phase diagram of southern Papua and Arafura Sea area (data is derived from many sources *i.e.* Pieters *et al.,* 1983; Dow *et al.,* 1986 etc).

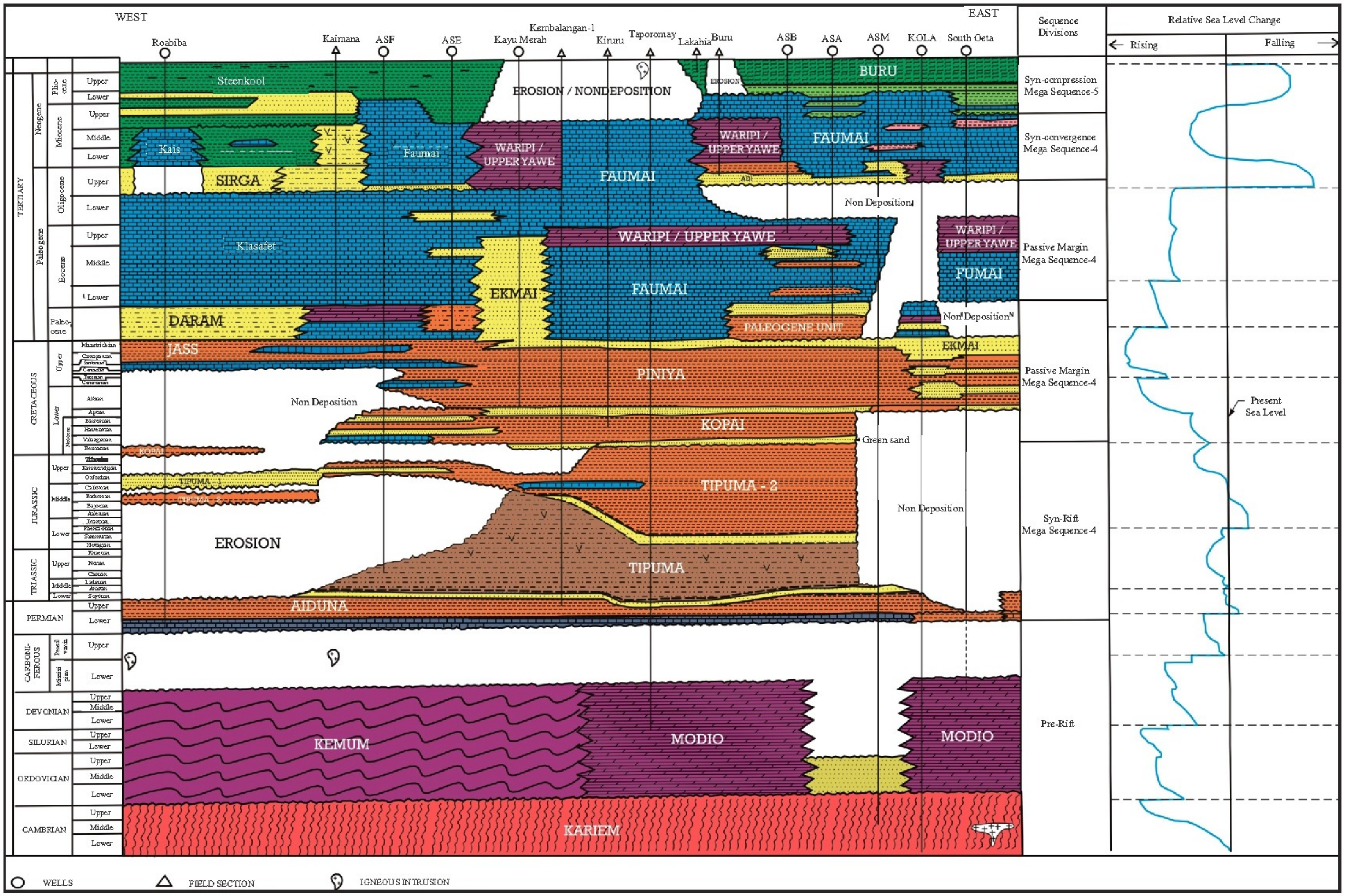

Figure 5. Time space stratigraphic diagram from Roabiba to South Oeta wells (data is derived from wells and KNOC, 1999).

strike-slip faults (i.e. Sarong, Tarera and Aiduna faults, Dow *et al.,* 1988). In the collision stage, the oceanic plate was depressed the continental margin, drowning the New Guinea Limestone platform and some reefs, and depositing deep-water shale.

Growth of the fold belt during the Melanesian Orogeny has instrumented the erosion and deposition of molasse deposits in the foreland basin. Inversion of Aru graben of the Triassic-Late Jurassic rifting (Peck and Saulhol, 1986) had occurred during the collision of the Banda Sea and Australia continental margin in Plio-Pleistocene times (3-5 m.y).

Lithostratigraphy

Most exploration wells in Papua are located in its western part, Salawati, and Bintuni Basins. There are scattered wells in the eastern part of southern Papua and theArafura Sea (Figure 6). Wells in these areas are commonly penetrated the Pre-Tertiary rocks, with some may reach pre-Cambrian basement. Surface exposures of Pre-Cambrian to Tertiary stratigraphy have been studied in several places in Central Range of Papua, i.e. Enarotali, Waghete, Timika, and Wamena sheet areas including well data from oil companies.

The lithostratigraphic unit of the area studied is presented on Figures 7 and 8. While, the geological cross section (Cambrian to Tertiary) is presented as a time-space stratigraphic diagram shown in Figure 5. Regionally, the basement is made up ofEarly Paleozoic, Pre-Cambrian sediments and gabbro metamorphosed to various degrees. The basement in the southern region of Papua and Arafura Sea areas is suggested to be pre-Cambrian rock (Kariem and Awitagoh) and Cambrian to Devonian (Tuaba and Modio Dolomite Kora/K.emum Formations). This basement is unconformably overlain by the

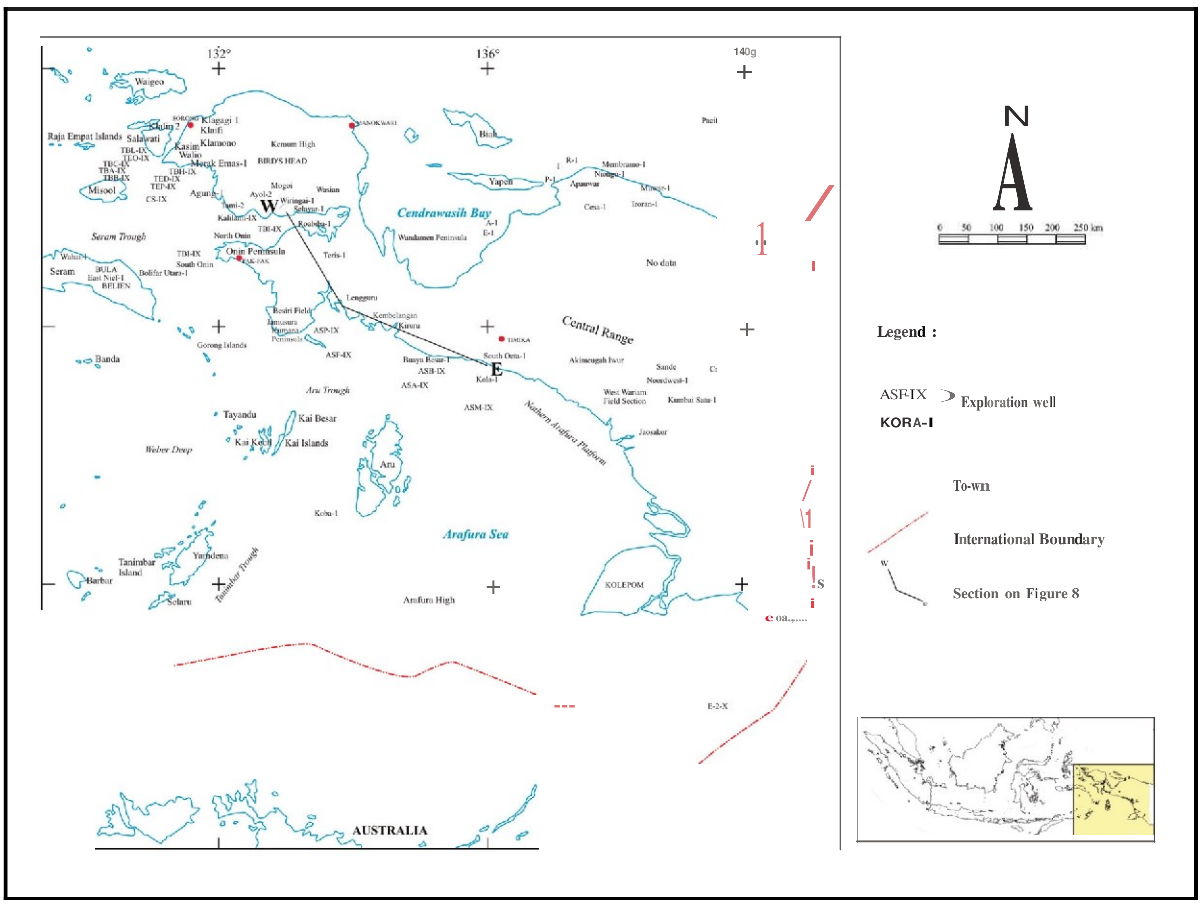

Figure 6. Distribution of wells in Papua (KNOC,l999).

UNITS	TI11CKNESS	LITIWLOGY	DESCRIPTION	ENVIRONMENT
A1luiflum			Alluvium	
	! 200 m		Mudstone, bluish grey, soft, calc, rich in carbonaceous material and contain foraminifera	Open marine, paralic to nonmarine
Upper Yawe Limestone	300 m		Limestone	Marine, open shelf
Imskin Lengguru & Yaweefms	800m		wen bedded, thm beds, pelagic limestone with small forarns (Planktomc forarns) Wel1 bedded-mass, calc, hiocalc, m1cr, hiom1c, calcird, calcit, ooht, calc, sandy calc, Bryozoa, coral, algae, minor molusc fragment, abundant forarn marme	Deep marine and shallow shelf
Ad1Fm	1000m		Quartz sandstone sandy sh, marl and coral	Shallow to paralhc
Fawe Fm	100m		Limestone, well bedded, hght grey, b10clastic packstone, W1th glaucomte, gastropods, brvalves and foramimfera	Shallow Shelf
WaripiFm	500 m		Well bedded, sandy oolit, calcnit, biocalcnite, calc, quartz sandstone, slst, calc, mudstone, contain shallow shelf foram	Shallow Shelf
EkmalFm	500 m		Th1ck bedded, wstrd, mostly quartz sandstone with mmor glauc., htlric sst., shale, and slst, occ, carb, shl	Inner shallow shelf
Pm1yaFm	900m		Thinly+massive, partly calc, dark+JIJey to black, locally glauc, mdst, thinely bedded, fg., glauc, qtz, sst and slst. Ammonite moceramus, sp.	Shallow Shelf
WonowogiFm	250m		Well bedded-mass, glauc, py, ortoqzt, minor sht, and calc, mdst belemnite present	Near shore inner shelf
KapaiFm	300m		Black mudstone.Amonite, belemnite, pelecypod & JIJastropod. Gren gluconite, sandstone, coarse JIJain+very coarse JIJained, belemnite.	Shallow Shelf
TipumaFm	500 m		Well bedded maroon, locally, J!Jeen mdst, and maroon, J!Jeen grywh. lithic sst, & cgl.X.bdd abundant.	FluVlatile environt
AidunaFm	! 200m		Wei1 bedded, feldphaticlm1cac, hthic sst, mtrbdd wfblck, carbn, shl and slst, minor higly fossiliferous, gxy-black biocalcnite, polymict, cgl, and coal Brachiopod fauna and flora present, x-bdd, bioturb, worm tube, cut & fill, skip mask & load coas.	Delt a-shallow manne
Modic Fm	1000m		Dolodtone, dolom1tic1st, shale, sbt and mmor calc, Qzt.sst. Conodont faune present.	Marine environt
KariemFm	2500 m		Interbedded sandstone, claystone, and siltstone with volcanic beds;carbonaceous and pyritic, slighly metamorphosed	Marine environt

Figure 7. Summary of the lithostratigraphy of the eastern part of southern Papua and Arafura Sea areas (data is derived from many sources i.e. Pieters *eta!.,* 1983; Dow *eta!.,* 1986 etc).

UNIT	THICKNESS	LITHOLOGY	DESCRIPTION	ENVIRONMENT
Alluvium	?			
Steenkool Fm	2000-4000 m		SaDdltone, mudltone, siltstone, coDglomente, and """calc and lipitc. Dominant S8lldstono on upper part. Dominant mudstone on lower port. Interbedded sandstone, mudltone, limestone, highly bioturbeOOi contain bivalve& and gaatropods, lamination, cros1beda, pllllllktonie foraminifera, corbonaceoua maleriol, shell coquina.	Deltaic to paralic
KlasafetFm	100-300 m		Mudltone and oanclatone. The mudotono, dark grey calc, micaeeowo, catbonaceons and cDDIBin piBIIklnnic foraminifem. The llS!ldstone light grcenioh grey, wry fine grain, mcdente tc well oortA:d and containa a &trong vo1amiclastic COD!pOllOilt, croubeds andlaminstion.	Open+ :ep marine
KaisFm	250-350m		Biocalcilutite, hiocalcarmite and reef limestone	Reef, fore reef, and back red on shelf platform
SirgaFm	50-200m		Quartz arenite, minor mudstone and calcarenite	Beach doposits
FaumaiFm	200-434 m		Biocalcarenite, minor biocalcilutite, shale and dolostone	Shallow water carbonate shelf
Puragi Fm	144-320 m		Dolomitic shale to clayey dolostone, with minor sandy shale and sandy limestone near base, and anhydrite bed near top	Sabkha (&ballow lagoon) oubject to intermittent drying and flooding
JasFm	400 m		Callearecus and non callearcous sandstone, mudltone and oiltstone with minor marl&tone, colsilutitc, sandy calcarenie, and eong!omc:rate	Shallow+marine shc:lf to shoreline
TipumaFm	300-500 m		R.c:ddish brown, light reddish grey, cream and white mudstone, siltstone, minor sandstone, local conglomerate, cross bedding, lamination.	Fluaviatile with arid to semi arid climate
AinimFm	750 m		Black carbonaceous silty shale, quartz sandstone, greywackc:, and siltstone, coal seam up to 1 m thick	Fluvio deltaic
AifatFm	700m		Massive, finely lami!lated black ealeareous mudstone with abudance ll<>l>lll'dioru; minor thin beds of marlstcne and sandy limestono, rare quartz S8lldstono beds	Shallow marine
AimauFm	250-1500 m		Red oligomictic conglomerate, sandstone and interbedded red shale, calcareous well bedded white sandstone and dark shale	Fluviatile to littoral
KemumFm	>1000m		Low+grad.c: metasediment: slate, slaty shale, argi llite and siltstone	Distal and minor proximal turbidite

Figure 8. Summary of the lithostratigraphy of the western part of southern Papua and Arafura Sea area (data is derived from many sources *i.e.* Pieters *et al.,* 1983; Dow *et al.,* 1986 etc).

Permian Aiduna Formation of the Aifam Group (Figure 4).

Apart from the basement, the diagram on Figure 5 shows the rock association divided into five major megasequences. The first is megasequence-1 comprising the base carbonate and clastics of Aiduna and Tipuma Formations, the Tipuma-1, and Tipuma-2 units. The second is megasequence-2 made up of the Kopai, Woniwogi, Piniya, Jass, and the Ekmai Formations, and Paleocene units including the Daram Formation. The third is megasequence-3 comprising the Lower Yawee, Waripi, Faumai, andAdi-1 Formations. The fourth is megasequence-4 consisting ofthe Upper Yawee, Sirga, and Adi-2, Kais, and Klasafet Formations. The fifth is megasequence-5 including the Buru and Steenkool Formations. Each of the megasequences in the area is generally characterized by several geological events, i.e., a broadly unconformity, erosion plane and non-deposition, facies changes, and tectonic events or stages.

Tectonostratigraphy

The tectonic evolution of Papua has involved a complex interaction ofthe Pacific, Indo-Australian, and Eurasian Plates split the stratigraphy into a number of megasequences. These events include periods of rifting of Australian continent during the Paleozoic and Mesozoic, the formation of passive margins following oceanic crust emplacement, and Late Oligocene to Recent major tectonism associated with the interaction of the three major plates of the area.

The tectonostratigraphic divisions shown on Figure 4, are as follows: 1. Pre-Rift phase, 2. Syn-Rift phase, 3. Post-Rift or Passive margin phase, 4. Convergence phase (Collision ofNorthernAustralia against Pacific Plate), and 5. Melanesian Orogeny. The new reconstruction presented in this article is based on the available data (surface and subsurface) in order to provide the general framework for a better understanding of the tectonic and stratigraphic evolution of the area. The model of each phase is based on modification of Peck and Soulhol (1986) and also compiled and simplified from Struckmeyer *etal*. (1990 &1993), Metcalfe (1996), Hall (1996), and Packham (1996).

The tectonostratigraphy phases of the south Papua and its surrounding is discussed below and time space stratigraphic diagram illustrated on Figure 5. Distribution of wells and geographic name mentioned in this article is shown on Figure 6. Summary of lithostratigraphic units of the discussed area based on surface data are summarized on Figures 7 and 8.

Pre-rift phase (Cambrian -Devonian)

During Middle Cambrian to Early Ordovician, broadly transgressive paralic and shallow water sediments were deposited within the infra-rift basin in the southern super-continent of Gondwana (Peck and Soulhol, 1986). In the Papua region, sediments ofthis period, comprising shallow water claystones and carbonates of the Kariem and Tuaba/Otomona Formations, (Visser and Hermes, 1962; Rusmana *et al.,* 1995; and Amirudin, 1998) were deposited in the Central Range and possibly in the South Aru Graben (Peck and Soulhol, 1986).

The period between the Middle Ordovician and the beginning of Silurian was a time of pre-rift in Gondwanaland. Peck and Soulhol (1986) proposed a southward directed marginal "aulacogen" (a tectonic trough, cf. graben or rift that open outward) began to develop west of Eastern Indonesia, causing a "ripple" effect as it continued to cut south through the Cambrian-Ordovician infra-rift basins. South of eastern Indonesia, fault-bounded rift basins or grabens were initiated firstly in the Money Shoal Graben, followed by the Petrel Sub-basin, as the aulacogen wedged further south. The block faulting of the pre-Cambrian hinterland accommodated erosion to provide abundant sand, which was deposited as red beds associated with evaporite accumulations in the Carnavon Basin (Exon and Willcox, 1978).

This tectonic event in eastern Papua resulted in the deposition of Silurian - Devonian Modio Dolomite (Panggabean and Pigram, 1989) over the northern edge of Australian Continent. Meanwhile, the Kemum Formation (Visser and Hermes, 1962) and Kora Formations (Conoco, pers. com.), were respectively deposited to the north in western Papua and central East Papua; alternatively, it was possible that the formations were deposited in an earlier pre-Tethys rift (Peck and Soulhol, 1986). Non deposition and erosion in the Early Devonian were followed by a marine transgression, which persisted into the Early Carboniferous, giving rise to a widespread sequence of shallow marine sandstone and carbonate over the northwestern Australia.

The Variscan or Hercynian Orogeny, marking the closing of the ancient pre-Tethys sea, occurred in a series of pulses during the Carboniferous and Permian periods (Peck and Soulhol, 1986). The collision between the northern margin and the Paleo-Tethys Ocean resulted in metamorphism and broadly erosion of the stratigraphic section or non-deposition. The Kemum Formation in Papua was intruded by Permian-Carboniferous granite (Melaiurna Granite, Pieters *et al.,* 1983, Harahap *et al.,* 1998), predated by volcanic eruptions.

Syn-rift phase (Carboniferous- Jurassic)

A broad transgressive cycle was initiated in the Late Carboniferous period to Early Permian with a shelf depositional environment ranging from estuarine to a shallow marine. During this time, a major intra-cratonic extension and rifting occurred throughout northwest Australian margin resulting in a series of north to northeast thickening rift basin. The northwest shelf of Australia was glaciated during the Paleozoic with maximum glaciation reached the Early Permian (Exon *et al.,* 1991). No glaciation is recognized during this period in Papua.

During Permian, fluvial to a mostly marginal marine sediments of the Aiduna Formation were deposited above a stable basement and may have occupied almost flat-lying (gentle slope), northward dipping, broad depositional surfaces and on the restricted basin in the west, between Kemum High and Arafura High.

At the end of the Paleozoic, geologically, the northern margin of the Australian craton was contiguous with Western Australia. Sporadic Permian and Triassic igneous activities were preceded Triassic and Jurassic rifting and extension of the Papua margin. The Triassic fluvial of dominated red color sediments of the syn-rift Tipuma Formation was accumulated on the Aiduna Formation and block-faulted basement rocks.

Exon and Wilcox (1978) reported that a phase of gentle folding, block faulting and erosion on the Exmouth plateau and inner Gulf Basin, offshore Canning Basin, and locally in the northern Carnavon Basin the boundary between the Permian and Triassic is only disconformity. The Permian and Triassic boundary is conformable in Papua (Visser and Hermes, 1962).

The Triassic climate was generally warm and humid, probably monsoon, with a wide extends of land and low sea level that promote aridity. Along northern and northwestern Australian margins, Triassic sediments accumulated in fluvial, paralic, and shallow marine rift environments. The Triassic sediments in the Northwest Shelf consist of a thick sequence of fine-grained sediments and coals. Reef and fine-grained sediments were deposited in the latest Triassic further offshore along the outer margins ofthe Northwest Shelf (Exon *et al.,* 1991).

In Papua, coarse- to fine-grained clastics were deposited in mostly fluvial and eolian environments. The presence of red beds and evaporitic carbonate may indicate deposition in playa or sabkha environments. The Triassic was also a time of significant tectonism and volcanism in Papua and Papua New Guinea (Pieters; 1982; Pigram and Panggabean, 1984; Simbolon *et al.,* 1984) and large part of eastern and central Australia.

On Early Middle Jurassic, in western and northwestern Australia (Boote and Kirk, 1989) and Papua extensional grabens were formed. Continental transform or wrench fault zones generated areas of folding, minimal subsidence, and even uplift and erosion. The Triassic was stripped in some areas (i.e., Bintuni Basin). During the Jurassic, an extensive alluvial system of paralic to deltaic fringe present in the Australian Northwest Shelf region led to deposition of thick, coarse-grained clastics, coal, and carbonates. Jurassic deposition in central Australia comprises fine-grained clastics and coal beds.

The corresponding deposition in Papua New Guinea and Papua comprises shallow marine of fine-grained sediments and coals (Tipuma 1 & 2). These rift sequences were partly block faulted with extensive erosion on the high blocks.

Post-Rift Mesozoic Passive Margin

Following the Jurassic rifting and sea floor spreading along the northern and northwestern margins of Australia, during the Cretaceous period, these regions were characterized by a more quiescent tectonic regime with continuing subsidence along passive margins and drift sedimentation. Australia experienced a major inundation during the Early Cretaceous, with extensive continent areas covered by a shallow-offshore marine. Marine deposition is mostly siliciclastic rocks (Kembelangan Group) that is predominated in Papua. Sediments of the Kembelangan Group are typical passive margin sequence deposited in beach systems down into an outer shelf. These sediments occurred during dominant marine flooding or high-stand of sea level and post rift subsidence.

Intermittent igneous activity continued in the north as the margin subsided throughout the Jurassic and Cretaceous. Sediment supplied from an erosion of the craton to the south (Aru High) and northwest (Kemum High) formed sandstone in proximal locations, and mudstone in the distal areas to the north. During Cretaceous times, the relief created by rifting as filled by sediments and shallow water marine condition was widespread.

Early Cretaceous (Barremian-Aptian) sediments (Kopai Formation) are black mudstone with TOC (total organic contents) up to 2.86 %. Oil shows reported by Visser and Hermes (1962) from the Kopai or Lower Kembelangan Formation in Kembelangan-1 well at 800 m depth. The Kopai Formation is absent in Buaya besar-1, South Oeta-1, Kola-1, andASM-1Xwells (northern Am area). The absence of this unit may be the result of transgression onto a long-standing Arafura High. Since the Late Jurassic-Early Cretaceous, the Gondwana breakup subsidence of Australian continental margin combined with global sea level occurred. The Kopai Formation is also generally absent in Western Papua (Bird's Head), which may be related to separation of northwestern Australia and northeastern mainland India along the northwestern Shelf of Australia in Late Jurassic (Pigram and Panggabean, 1983) or Early Cretaceous (middle Neocomian) (Boote and Kirk, 1989).

The Woniwogi Sandstone conformably overlies the Kopai Formation (Figures 4 and 5). Sandstones are strongly glauconitic, although quartz is more dominant constituent. Deposition taking place in a shore setting was influenced by storms. The provenance was probably derived from the north and south areas. Oil and gas seeps appear to come out from this formation at Kembelangan and Kiruru areas (Robinson *et al.,* 1988).

The Late Cretaceous (95 m.y) or during the deposition ofEkmai Sandstone and Piniya Mudstone, separation of Australia and the Antarctic, with the Australia shifting northward, resulted in volcanism along the northern plate. A comparable igneous activity in Papua consists of granite and tuff present predominantly in the west (Sorong Sheet, Bird's Head; Amri *et al.,* 1990). Sediments of the Piniya Mudstone have been reported from most of the southern region of Papua.

In the latest Cretaceous and Paleocene, rifting occurred in southern New Guinea Island prior to extension tectonics (block faulting) in the Coral Sea between 62 and 56 m.y (Weissel and Watts, 1979). In the Arafura Sea areas, the sediments of this age have been recorded in Bintuni called the Daram Formation (Rusmana *et al.,* 1995) and in ASE-1X and ASA-1X wells called Paleocene unit. While the rest of wells in the Arafura Sea area shows that an erosion contact exists probably suggesting a block faulting.

Tertiary Passive Margin (Deposition ofCarbonate Platform)

The breakup and separation of the Antarctic Plate to the south, resulted in a marked change in the Late Cretaceous, when clastic sedimentation gave way almost everywhere along the western-northwestern Australian margins to carbonate platform deposition. The Cenozoic stratum of the Northwest Shelf consists of a monotonous prograded carbonate sequence (Exon and Wilcox, 1978). Cenozoic platform carbonate in Papua includes the Lower Yawee Limestone (Panggabean and Pigram, 1989). On the 1:250 000 Kaimana Sheet area (Robinson *et al.,* 1988), the Eocene reef has also been developed on the uplifted block. There may have some erosions ofthe crest of these blocks before reef growth. Sandstone of the Adi Member-1 was deposited in Late Eocene. The deep-water pelagic limestone (Imskin Limestone) continued to be deposited in the fore-reef and deeper environments to the northeast of the Eocene reef complex throughout the Eocene.

Various workers (i.e. Dow, 1977; Hamilton, 1979; and Audley-Charles, 1988) agree that plate direction in East Asia changed between 40 and 50 m.y. The Pacific Plate moved north, and at about 42 m.y (Late Eocene) the direction of motion changed, from almost due north to west-northwest. The change in direction was initiated by the collision of India with Asia.

The probable results of this plate collision in Papua (as noted by Lunt and Djaafar, 1991) is the presence of an unconformable or a diastrophic event on the base ofNew Guinea Limestone Super Group. The largest basal unconformity occurs in the western part of the Bird's Head area (Salawati and Bintuni Basins), where the uplifting of the Mesozoic sediments and Late Cretaceous Salawati Granite (Amri *et al.,* 1990) resulted in erosion. In the western end of the Bird's Head, New Guinea Limestone Super Group rests unconformably on Permian sediments.

Convergence phase (Upper Oligocene – Middle Miocene)

In the Oligocene time, the northwest portion of the Australian Plate began to collide with and underthrust the Pacific Plate. In Papua is a time of emergence or non-deposition (Visser and Hermes, 1962) and was also a major tectonic event where the Mesozoic and Lower Tertiary through sediments along the northern margin ofthe craton called Derewo Metamorphic (Harahap *et al.,* 1990; Harahap, 1997) were regionally metamorphosed. Further north within the Pacific Oceanic Plate, the rocks of the Auwewa Volcanic Group (Upper Cretaceous to Lower Oligocene) are intensely deformed (Harahap and Sukanta, 1996).

This event is a manifest in several ways in western Papua (Dolan and Hermany, 1988; Lunt and Djaafar, 1991) including a shift structural dip between the Sirga and Kais Formations. It is suggested a northeast-southwest compressive phase in the Bintuni Basin, forming the NW-SE trending Inanwatin and Puragi-Tarof arches. A compression ripple was transmitted southward across Australia (Boote and Kirk, 1989), uplifting the northwestern margin of the Australian continent and reactivating deep-seated crustal weakness within the buried Mesozoic grabens.

A middle/upper Oligocene drop in sea level on the northwestern margin of the Australian continent allowed erosion and local redeposition of clastic sequences. In Papua, these clastics are known as the Sirga Formation and Adi Member-2. At 31 m.y (Latest Oligocene-Earliest Miocene), the northwest margin of the Australian Plate began to collide with and underthrust Southeast Asia (Dow, 1977).

Melanesian Orogeny (Upper Miocene- Present)

In Miocene, a time of eruption of magmatic arc including the Moon Volcanics, Lembai Diorite, and Utawa Diorite (Atmawinata *et al.,* 1989; Harahap *et al.,* 1990), Australian Plate collide with the westward moving Pacific and Philippines plates, incorporating a Cretaceous-Eocene Island Arc, the Sepic Arc (Dow *et al.,* 1977) into the present day northeast margin of New Guinea. The collision is marked by the development of New Guinea Trench. In Papua, sediments of the Klasafet Formation (Visser and Hermes, 1962) were deposited in a deep marine environment with some turbiditic current influences in the western part (Arguni Bay), while to the east inArafura sea area, deposition of limestone (Upper Yawee Limestone) continued.

In Late Miocene to Pleistocene (Melanesian Orogeny), a huge compression force was generated due to tectonic convergence between the Pacific Oceanic Plate in the north and the Australian Continental Plate in the south (Dow and Sukamto, 1984). The northern margin of the continental crust reacted mainly by southwards and southeastwards overthrusting (thin skinned tectonics). The resulting pattern of crustal response has been very complex, and has given the island of New Guinea its unique "Bird-like" shape, which is controlled by major transgressive structures that accommodated greatly different crustal responses in the west and east (Dow and Sukamto, 1984).

The south verging Papuan Fold Belt (Dow, 1977; Dow and Sukamto, 1984) is thought to have started developing in the Late Miocene - Early Pliocene. Growths of the fold-belts were accompanied by shedding material of the fold-belts and depositing the material (Steenkool and BuruFormations) off the fold-belts and depositing the material into developing foreland basins to the south. These include the Akimeugah and Iwur Basins in the east, and Salawati and Bintuni Basins in the west (Visser and Hermes, 1962). The formation ofOnin-KumawaAnticlinorium (Tobing and Robinson, 1995) is interpreted by Robinson *et al.* (1988) to be associated with Plio-Pleistocene northeastward directed stress from the Banda Arc (3 - 5 m.y) and the southwestward directed (minor) compression from Lengguru Thrust Fold Belt.

The mainland area was exposed above sea level at this time and the overall south and southerly movement where terrigenous detritus deposition took place (Buru and Steenkool Formations) began to be poured into the basin formed to the south. The Buru and Steenkool Formations were accumulated as molasse type deposits with a marine influence in part. The sediments advanced towards south and west (Bintuni Basin).

DISCUSSION

Many geoscientists have mentioned the tectonic configuration of northern margin of Australia, but very few of them explained the tectonostratigraphy of the region. Some contributions in understanding the regional geology of Eastern Indonesian region were given by Visser and Hermes (1962); Carteret *al.* (1976); Hamilton (1979); Audley-Charles *et al.* (1979); Bowin *et al.* (1980); Pigram and Panggabean (1981 and 1984); Hartono and Tjokrosapoetro (1984); Dow and Sukamto (1984); Peck and Soulhol (1986); Pigram and Davies (1987); Audley-Charles (1988); Bradshaw *et al.* (1988); Daly *et al.* (1987 & 1991); Henage (1993); Struckmeyer *et al.* (1990 & 1993); Metcalfe (1996); Hall (1996) and Packham (1996); Weiland (1999); Kendrick and Hill (2001); Pubellier and Ego (2002); Bailly *et al.* (2009); and Davies (2010).

Despite the fact that the movement of the major plates (Eurasia, Indo-Australia and Pacific) has been documented by many geo-scientists, the Tertiary movement of north Australia has partly been well defined, but there is currently no coherent model for the tectonic development in Eastern Indonesia. Several authors *(e.g.* Hamilton, 1979; Johnson a Jaques, 1980; Dow & Sukamto, 1984; Pigram and Panggabean, 1984; Pigram and Davies, 1987; Daly *et al.,* 1991; Struckmeyer *et al.,* 1990 and 1993; Cloos *et al.,* 2005) emphasized different tectonic processes. Thus, it would certainly give no quantitative description of geological evolution in eastern Indonesia in providing the basis for evaluating the geological knowledge. The northern Australian passive margin may have been complex, with microcontinental fragments north of the main cratonic block (Pigram and Panggabean, 1984).

Major tectonic evolutions of the region during the pre-Cambrian to present age are pre-rift, syn-rift, passive-margin (post break-up), convergence, and compression phases. The model of each phase is based on modification of Peck and Soulhol (1986) and is also compiled and simplified from Struckmeyer *et al.* (1990 and 1993), Metcalfe (1996), Hall (1996), and Packham (1996).

The pre-rift phase in south Papua and Arafura Sea area consists ofPre-Cambrian-Early Paleozoic basement rocks comprising low-grade metamorphosed rocks of the Kariem Formation, the volcanic Nerewip/Awitagoh Formation and siliciclastic Tuaba Formation, Kemum Formation, and Modio Dolomite.

The initial episode of pre-rift phase of infrarift stage during Pre-Cambrian-Ordovician time where east-west or northwest trending infrarift basins or grabens formed due to crustal thinning was accompanied by deposition of fine-grained clastic sediments of the Kariem Formation and extrusion of basic igneous rocks. Similar rocks have also been found in Queensland area, northeast Australia as described by Day *et al.* (1982). Thus, it can be suggested that the southern part of Papua might have land connection during this infrarift stage.

Subsequently, the sediments ofModio Dolomite, typical turbiditic Kemum Formation and its equivalent Kora Formation continued to be deposited in a gradual deepening of marine conditions and then the paleo-Tethys oceanic plate initiated to subduct into the northern Australian Continent. This breakup condition would have progressively be little effects within the infracratonic rifts in the south, such as further to the north the sediments became thicker as the Kemum Formation in the Birds Head block of western Papua.

During the end of post breakup stage (Late Devonian-Carboniferous), it was speculative that the first convergence and subsequent collision between the northern paleo-Tethys ocean and the Australian Continent would result in the intrusion, volcanism and the metamorphism of the Kemum Formation in the Bird's Head, followed by a broadly erosion and non-deposition in Middle Carboniferous time. The Kemum basement suggests an original position for the Bird's Head along the northeastern Australian margin (Pigram and Davies, 1987; Struckmeyer *et al.,* 1993). Meanwhile, the proto-Indian Ocean opened inbetween Greater Indian and West Australian continent having a trend of northeast - southwest (NE-SW). It was then an initial development of the Permian-Triassic rifting in northwest Australia and Papua. According to Peck and Soulhol (1986), towards the end of the post-breakup stage, the paleo-Tethys ocean closed and the deposition rates decreased and more paralic depositional environments prevailed over the northwestern Australian craton.

It was well documented by many previous workers (Powell, 1976; Falvey and Mutter, 1981; Pigram and Panggabean, 1984; Audley-Charles, 1988; Metcalfe, 1996)that initial major rifting phase occurred on the margin of northeast Gondwanaland and north and northwest of Australian continental margin in the Early Permian. This phase is indicated by a number of substantial continental fragments severed from Gondwanaland (Metcalfe, 1996) corresponding to the initiation of seafloor spreading of proto-Indian Ocean between Greater Indian and Australian Continents.

The first stage rifting affected the northern and northwestern Australian margin during Permian-Early Jurassic. This phase led to continental breakup and then extension which developed and was concentrated in the northwest shelf of Australia (Vulcan, Malita and Calder Grabens) extended up to west Papua trend ofNE- SW rifting this rifting-corresponded to the direction of the proto-Indian Ocean opened.

In addition, Henage (1993) proved that the result of reconstruction of the NW ShelfMesozoic rifting in Papua was overriden with the Pliocene age Banda Arc. He concluded that the general strike direction ofMesozoic rifting in Papua was NE-SW. The direction also corresponded to the trend of paleo-slope ofMesozoic paleogeography ofthe northern margin of the Australian Plate as discussed by Struckmeyer *et al.* (1990, 1993). The NE-SW Mesozoic trending rift forming graben or half-graben might obviously be present in Aru area that was parallel with the present direction of Aru Trough, and hence the continuation of the northeast trending rift graben system evidenced to the Lengguru "depocenter" in the Bird's Neck of Papua. However, the Aru graben or half-graben Mesozoic predecessor might have been failed continuation of the NW Shelf Australian rifting system due to various motions of tectonics. Some parts of pre-Cambrian-Paleozoic basement might have been emerged to form horsts or highs in the Aru and Koba areas where the areas became the important source and provenance of clastics for the Kembelangan Group in Papua. Peck and Soulhol (1986) postulated that the Mesozoic rift-drift basins in eastern Indonesia would have developed at right angles to the earlier imprint of pre-rift phase grabens.

During this stage, however, sedimentation in the northern and northwestern Australia continental margin was possibly still controlled by the preceding NW-SE Early Paleozoic structural trends or the primitive infrarifts. On the shelf areas, a broadly transgressive-regressive cycle of the Aiduna and Tipuma Formations was deposited as filling the rift valleys with depositional environments ranging from fluvio-deltaic, estuarine to a shallow marine, and near-shore characteristic. The sources of sediments were originated from the land mass rising in the southeast (north Australia) and north-northeast (central Papua New Guinea) as a continuation ofthe Tasman mobile belt system. In some places, however, the invading warm northern waters of neo-Tethys Seas accommodating some evaporitic carbonate depositions occur along the edge shelf (Peck and Soulhol, 1986). The presence of an unconformity between the underlying Tipuma and Kembelangan units in ASM-1X well and the new age results on the lower section of an Kembelangan rocks in the Yera Anticline area (Harahap, 1996) are evidences of post-breakup stage in the area.

Metcalfe (1996) suggested that a renew rifting has occurred during Late Triassic to Late Jurassic time on the northeast margin of Gondwanaland and the initial rifting of the third continental sliver (Lhasa, West Burma, and Woyla) from Gondwanaland opened the Neo-Tethys.

By the end ofJurassic time, the decreasing rifting was followed by subsidence and thermal sag, and then the feature of north and northwest of Australian continent markedly changed due to the development of seafloor spreading between western and northwestern Australia and greater India. Contemporaneously, the Banda Sea was formed in Cretaceous time (Pigram and Panggabean, 1983; Bowin *et al.,* 1980). According to Pigram and Panggabean (1984), a screen of continental fragments in the western and northern areas detached from Gondwana along the proto-Indian and Pacific Oceans, and they moved to north and northeast (Banda Sea region).

The initial passive margin sediments were deposited onto a very irregular Paleozoic block faulted surface (Peck and Soulhol, 1986). The source of sediments was from south and southeast as proven by paleo-current direction measured within the Mesozoic sandstone of the Woniwogi, Piniya, and Ekmai Formations (Kembelangan Group). However, if the

Kemum Block emerged during this time, there was possibility that the source of sediments might have also been transported from northern and northeast ern areas. Deposition is negligible on several ancient emerged basements, such as Merauke High, Kemum Block, Koba High, Ashmore-Sahul High, and Onin-Kumawa High.

At the end of passive margin phase, the northern Australian continent became more stable and continued to move to the north in approaching the western Indonesian terranes. Subsequently, a widespread platform carbonate (the New Guinea Limestone Super-group) tremendously developed in the northern margin of Australian continent.

In the convergence phase, increasing rates of northward movement of the Australian Plate were succeeded by a change in the movement direction of the Pacific Plate from northwards to westwards since Late Eocene. Similarly, the motion of Australia had also been changed from eastward to northward as rapid ocean-floor spreading began in the southern Indian Ocean, and then the onset of this more rapid spreading episode was coincident with the onset of the continental collision between India and Asia (Daly *etal.,* 1987, 1991). Thechangeofmovement has ultimately caused the oblique collision of the Pacific, Eurasian, and Australian Plates. This event was simultaneously succeeded by the conversion of the northern Australian margin to be a convergent tectonics during Oligocene to Middle Miocene. Cullen and Pigott (1989) suggested that the Oligocene time was marked by a dramatic shift from extensional to convergent tectonics in the region of Papua New Guinea.

Southerly subduction is believed to have taken place beneath the Papua in the Early Oligocene time resulted in gradually uplift of the Central Range of Papua followed by erosion and deposition of clastics onto the foreland basins. The regional unconformity in the Adi Member unit is coincident with a global fall in sea level (Vail *et al.,* 1977). Subduction continued further to the east along the northeastern New Guinea margin (Smith, 1990; Struckmeyer *et al.,* 1993). According to Smith (1990), during this period a continental back-arc extensional event took place causing a extensional reactivation of pre-existing faults.

By Middle Miocene time, ophiolite obduction of the southern edge ofthe Pacific Plate occurred on the Central Range of Papua and continued to the east. The oblique collision between the Caroline Plate and Papua taking place and the continuation movement of the Pacific Plate to the west, caused major effects which propagated an initiation of westwards and left-lateral strike slip fault systems, such as the Sorong and Tarera- Aiduna Faults. The strike-slip faults led to the forming of pull-apart basins of the Waipoga and Mamberamo Basins in northern Papua and probably the Akimeugah in southern part. Dow *et al.* (1985) considered that diapiric shale or chaotic material has intruded along the fault zone systems.

The development of plate motions appears to have resulted in compression deformation within the whole passive margin sequences. The continental crust of the Australian passive margin began to curve-shape and collide the Banda subduction system. Further south it led to the development of the arc-continent collision complex of the Timor region (Charlton *et al.,* 1991; Simandjuntak and Barber, 1996).

Daly *et al.* (1991) suggested that the Banda arc collision occurred at about 10-5 m.y overriding the NW Shelf rift system. Buru Island commenced to move southwestwards by the splay of the Sorong Fault System, while the Seram Island started to move westwards relative to the Bird's Head from 12-4m.y (Hall, 1996). This fault system also caused the reorganization of a number of micro-continental fragments to the west region, such as Banggai, Sula, Buton, and Buru Islands that are recently incorporated onto the Eurasian Plate. According to Hamilton (1979), one ofthe most important events during this time was also the initiation of lateral movement along the Sorong and Koor Faults, causing the possible displacement of the Banggai-Sula microcontinent from western Papua and it eventually collided with Sulawesi in the Middle Miocene. The Tarera-Aiduna wrench fault, also left lateral, developed during the Miocene. Igneous and volcanic activities have eventually taken place in Papua.

During the Neogene (Miocene-Pliocene) times, the tectonic event was very important since the northward collision of the NW Australian passive margin with the Pacific and Eurasian plates generated orogeny, metamorphism (Derewo Metamorphism) and thrusting along the Central Range. At the same time, the carbonate platform sediments were buried by extremely rapid deposition of thick post-orogenic clastic shed (Buru and Steenkool

Formations) from the northern emerging mountain belts (Central Range, Bird's Head and Bird's Neck).

By Pleistocene time, orogeny continued to built-up the highlands (Jayawijaya peak) reflecting continued uplift and the development ofthe southern fold and thrust belts.

CoNCLUSIONS

The sedimentary history and stratigraphy of the areas can be developed since Cambrian to Recent time,whilst tectonic evolution ofPapua andArafura Sea has been started from Pre-Cambrian to Recent time. Five major evolutions have been proposed here, i.e. Pre-Rift, Syn-rift, Post-Rift or Passive margin, Convergent (Collision Thin Skinned Tectonic), and Melanesian Orogeny.

The pre-rift phase has expressed the evolution of northern margin of Australia since Pre-Cambrian to Carboniferous ages representing the evolution of Australian continent when the three main continents (Australia, Antarctica, and India) maintained their integrity into a single super continent called as Gondwanaland. In this pre-rift phase, the Kariem Formation and Tuaba/Otomona Formation were deposited in a broadly trangressive paralic and shallow water within the infra-rift basin. Possibly in the Middle Ordovician and Silurian the block faulting of the Pre-Cambrian hinterland accommodated erosion to provide abundant sand in Arafura Sea areas. While, in Papua mainland the Silurian-Devonian Modio Dolomite, Kemum Formation, and Kora Formation were deposited. Non deposition and erosion in the Early Devonian were followed by marine transgression giving rise to shallow marine sandstone and carbonate. The Kemum Formation was then isoclinally folded, weakly metamorphosed, and uplifted during the Late Devonian or Early Carboniferous.

Symift phase explained the change of the northern Australia during the breakup time (Permian-Early Jurassic) subsequently passive margin phase during the post-break up (Late Jurassic-Early Tertiary). This phase represents the development of seafloor spreading and northward movement of the Australian continent. In the syn-rift phase, a major intra-cratonic extension and rifting occurred in Carboniferous to Permian with a shelf depositional environment. In Triassic time, a dry oxidizing desert climate prevailed and certain amount of acidic volcanic activity took place. In these conditions, the Tipuma Formation was probably deposited in a low-relief near-shore fluvial environment, accumulated on theAiduna Formation and block faulted basement rocks. There may have been some erosions of the Tipuma red bed sequence during the low sea level period in the Early Jurassic. Extensional graben with wrench fault and folding was formed during Jurassic time with deposition of coarse-grained clastics, coals and carbonates in some part of the areas. Sea level rose during Middle Jurassic and a transgressive sequence was deposited over the Tipuma Formation. Following the Jurassic rifting (post-rift), the area was characterized by a more quiescent tectonic regime with extensive continent areas covered by a shallow-offshore marine. Marine deposition is mostly siliclastic rocks (Kembelangan Group), supplied from an erosion ofthe craton (Aru and Kemum Highs). A rise in sea level also took place at this time and the younger part ofKembelangan Group (Pinya Mudstone and Ekmai Sandstone) followed by the youngest part of the Imskin Limestone were rapidly deposited on the subsiding blocks. An intermittent igneous activity continued in places. In Tertiary (breakup stage), carbonate rocks were deposited over platform area replacing the Late Cretaceous clastic sedimentation. During this time, the plate direction changes as an initiation of collision between India and Asia, resulted in a large basal unconformity in Bird's Head. In this area, New Guinea Limestone Super Group rests unconformable upon Permian sediments.

Convergence phase (Oligocene-Middle Miocene) resulted in a gradually uplift ofPapua followed by erosion and deposition of clastics into the foreland (Sirga Formation). Compression phase encompasses the reorganization of a number of continental fragments in eastern Indonesia and the collision between Papua and Pacific Plate generated orogeny and metamorphism. In Oligocene, drop in sea level allowed erosion and local re-deposition of clastic sequences (Sirga Formation andAdi Member-2). In Latest Oligocene-Earliest Miocene, the northwestern margin oftheAustralian Plate began to collide with and underthrust Southeast Asia.

Miocene is a time of eruption of magmatic arc including the Moon Volcanics, Lembai Diorite, and Utawa Diorite. The Australian Plate collide with the westward moving Pacific and Philippines plates, incorporating a Cretaceous-Eocene Island Arc, the Sepic Arc, into the present day northeast margin of New Guinea. Sediment of the Klasafet Formation were deposited in a deep marine environment with some turbiditic current and deposition of limestone (Upper Yawee Limestone).

In the Late Miocene to Pleistocene (Melanesian Orogeny), a huge compression force was generated, resulted in a very complex pattern of crust. Growths of the fold-belts were accompanied by shedding material of the fold-belts depositing the material (Steenkool and Buru Formations) into developing foreland basins to the south. The mainland area was exposed above sea level at this time and the overall south and southerly movement taking place led to the terrigenous detritus deposition (Buru and Steenkool Formations).

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