Paleozoic basin indication at south of Papua, Indonesia

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Abstract. Eastern Indonesia Paleozoic basin to recent is still an under-explored basin. The study about this oldest sediment sequence is needed to be done because, in Australia, this sequence is already producing hydrocarbon in several basins, known as the Larapintine petroleum system. This paper is subjected to present Paleozoic sediment occurrence in the south of the Papua area, from outcrop, several wells penetrated this unit and from seismic data. Furthermore, this paper aims to construct a geological schematic diagram in the south of the Papua area. Identified Paleozoic rocks in the southern Papua area are Pre-Permian sequence, consist of Otomona Formation (Late Proterozoic–Cambrian), Tuaba Formation (Ordovician) and Modio Formation (Silurian–Devonian), and Aiduna Formation (Late Carboniferous–Permian) from the Permian–Triassic sequence. Otomona Formation was deposited at the submarine fan environment while the Tuaba Formation was deposited in a shallow marine shelf setting. Modio Formation was deposited at shallow marine to shelf environment, and Aiduna Formation was accumulated at deltaic setting. Paleozoic basin occurred from Arafura sea to onshore of southern Papua with a thickness of up to 5 seconds. This unit's potential trap is the gentle anticline with geometry up to 8 km long and stratigraphic trap top lap with the unit above it.

Keywords: Paleozoic basin, eastern Indonesia, Papua

1. Introduction

Paleozoic sedimentary basins offshore of the northern Australia region are located at Arafura Basin and Bonaparte Basin. Paleozoic sediment at Arafura Basin consists of Cambrian–Ordovician Goulburn Group, Late Devonian Arafura Group, and Late Carboniferous–Early Permian Kulshill Group [1]. At Bonaparte Basin, Paleozoic sediment is Late Devonian–Early Carboniferous Arafura Group, Early–Late Carboniferous Weaber Group, Late Carboniferous–Early Permian Kulshill Group, and Early Permian–Early Triassic Kimmore Group. Continuation of this Paleozoic sediment to Indonesia, according to Panggabean and Pigram [2] and Davies [3], outcropping at the Timika area, Wagethe area, and west of Nabire area. This Paleozoic sediment in Indonesia is known as Cambrian Otomona Formation, Ordovician Tuaba Formation, Silurian to Devonian Modio Formation, and Late Carboniferous to Permian Aiduna Formation [2-5]. In early 2011, two explorations well (Aru-1 and Mutiara Putih-1) encountered Upper and Lower Paleozoic sediments at Arafura sea [6]. They conclude that there is appears to be about a maximum of 30 km of Paleozoic–
Proterozoic sedimentary section preserved in this area. Not much literature about Indonesian Paleozoic sediment, particularly about its subsurface continuity and its hydrocarbon potential.

This paper aims to present the Paleozoic sediment outcrop analog description from Timika–Tembagapura section, conduct outcrop to well correlation, perform seismic stratigraphic analysis, and construct a geological schematic diagram at the south of Papua.

2. Methods
A geological transect for outcrop analog was performed at Timika–Tembagapura road section (Figure 1). Rock outcrops selected section was divided into their lithological division, including rock type, unit thickness, heading and distribution of units, and lateral and vertical changes.

Well data used for this research are Noordwest-1 [7], Kola-1 [8], ASM-1X [9], Jaosakor-1 [10], Aripoe-1 [11], Merauke-1 [12], E-1X [13], E-2X [14], and E-3X [15] (Figure 1). Well analysis comprises lithologic interpretation using log, cutting, and core report, combine with outcrop characterization analogy to interpret unit boundary and depositional environment interpretation. The lithology unit age used the biostratigraphic report of each well.

The pre-interpretation stage involved seismic data and well log geodetic positioning data before the interpretation stage. The pre-interpretation stage also includes seismic data enhancing quality (use seismic attribute enhance from software) and well to seismic tie. The seismic 2D interpretation was conducted to show subsurface configuration, including horizon and structure picking.

The seismic line used for this study (Figure 1) is Lines 1501, 1517, 1520, IA90-102, IA90-114, IA90-131, IA90-151, IA90-152, IA90-153 (courtesy of Pusdatin, KESDM), AGATS-015 [16], Lines C-C’, E-E’ and F-F’ of passive seismic tomography (PST) Jaosakor/Asmat area [17]. The seismic analysis comprises dividing seismic stratigraphy based on the strong amplitude classification guide by stratigraphic analog from well and outcrop correlation. This available seismic data consists of multi-vintage 2D lines mostly acquired before the 1990s, which are poor to fair in quality.

**Figure 1.** The location map of the study area, showing the location of the geological transect, wells location, seismic lines, and PST location.
3. Results and discussion

3.1 Stratigraphy

Stratigraphy of the study area is divided as follow:

3.1.1 Proterozoic Basement. During Neoproterozoic, the dominantly clastic sediments of the Wessel Group were deposited. According to Plumb et al. [18], it consists of Buckingham Bay Sandstone (quartz sandstone, quartz greywacke, and skolithos beds), Raiwalla Shale (shale and fine sandstone with minor quartz sandstone), Marchinbar Sandstone and Elcho Island Formation (trilobite bed, dolomitic siltstone, glauconitic sandstone, and siltstone). Kusnama [5] reported outcrop of Proterozoic rocks at the Timika area, Papua. This unit consists of basalt pillow lava, greenschist and, marine sediment limestone, siltstone, and shale. K–Ar dating on slatestone gives 1.250 Ma age for this unit [5]. Furthermore, he stated this unit is age correlated with basalt lava, dolerite, siltstone and shale of Awitagoh Formation, age 820 ± 21 Ma and 847 ± 5 Ma [19], Diabas Nalca aged 1.189 Ma from Waghete [20] and Dolerite from Beoga area aged 1.128 Ma [21]. The thickness of the Nerewip Formation is 600 m [4], while the thickness of Kariem and Awitagoh Formation is more than 2.5 km [22].

3.1.2 Late Proterozoic - Cambrian. Extension in the Neoproterozoic, resulting in Early Paleozoic rift sediment deposition, is called a major basin forming event [1]. Early Paleozoic rocks at southern Papua is the Otomona Formation.

The lower part of Otomona Formation consists of interbedded mudstone with siltstone, well-bedded blackish gray. In some parts, this unit is slightly metamorphosed into slate. The lower part of the Otomona Formation thickness reaches a maximum of 1.200 m [23]. The upper part of the Otomona Formation is dominated by fine to medium grain sandstone with mudstone and siltstone intercalation. This package show well bedding, with the thickness of the sandstone bed reaches a maximum of 50 cm. Slumping sedimentary structures occur in this package. The thickness of the upper part of the Otomona Formation reaches a maximum of 2.900 m [23]. The Otomona Formation is interpreted as a part of the coarsening upward turbidite sequence resulted from submarine fan progradation [4]. One Cambrian zircon fission-track by Parris [4] dated this unit as 675 Ma.

3.1.3 Ordovician. Ordovician sediment at the south of Papua is represented by Tuaba Formation [2-5]. At Timika–Tembagapura section, the lower part of this formation consists of quartz sandstone, medium to coarse grain, cross-bedding structure, and bed thickness of 0.5–1.5 m. At the upper part, this formation consists of fine clastic rocks interbedded of fine-grain sandstone, claystone, and siltstone, reddish, thin well-bedded, with structure sediment found was parallel lamination. The Tuaba Formation is interpreted as a shallow marine shelf deposit [4,5]. The total thickness of the Tuaba Formation is 1000 m [4,24]. Ordovician age from the nautiloids and graptolites [3,4,22].

3.1.4 Silurian - Devonian. The lower part of this formation consists of dark gray, thinly bedded dolomite. The thickness of this dolomite facies is 1.530 m [23]. The upper part of Modio Formation is interbedded of micaceous silt and fine sandstone, well-bedded with swallow cross-bedding. This unit is interpreted to be accumulated in shallow marine to shelf setting [4,5]. The thickness of this unit is 1.030 m [23]. Silurian–Devonian age of this unit was from corals [25] and poorly preserved conodonts [4]. Based on graptolite fossil found at this unit, Monograptus convolutes, Kusnama [5] concluded that this unit is Upper Silurian to Devonian in age.

3.1.5 Late Carboniferous - Permian. The lower part of Aiduna Formation consists of interbedded shale with siltstone, papery laminated. This unit also has intercalation of coal deposit with a thickness of 1.5 m. Fine-grain clastic with coal indicated that this unit was deposited at a low energy current possible for sediment suspension and carbon material preservation. The upper part of this unit is dominated by fining and thinning upward stacking coarse grain pattern to conglomerate at the lower part and interbedded of sandstone and shale, then shale dominated at top. Cross bedding occurred at the sandstone part. It is interpreted that Aiduna Formation in this section was deposited in a deltaic setting [5,26].

The thickness of this formation reaches 2.450 m [23]. Stratigraphic contact of Aiduna Formation with the older Modio Formation found at Timika–Tembagapura section is an angular unconformity. Kusnama [5] gave Late
Carboniferous–Permian age for this unit based on the finding of brachiopod fossils such as *Neospirifer* sp., *Stereochia* sp., and *Cancrinella* sp.

### 3.2 Outcrop to well correlation

The stratigraphic column from the Timika–Tembagapura road section (Figure 2) shows that the total thickness of Paleozoic sediment (Otomona, Tuaba, Modio, and Aiduna Formation) is around 10.100 m [23]. Lithological data from Noordwest-1, Jaosakor-1, Aripoe-1, Merauke-1, E-3X, E-2X, and E-1X also show Paleozoic sediment’s presence in southern Papua.

From well correlation (Figure 2), it can be shown that the Mesozoic rock (Woniwogi and Piniya Formation) is still present at Noordwest-1 and Jaosakor-1 but absent at Aripoe-1. It is then interpreted that the Mesozoic rock was pinched out between Jaosakor-1 and Aripoe-1. This Mesozoic pinch out at the south part also presents between Merauke-1 and Aripoe-1. Stratigraphic gap at Aripoe-1 from Devonian to Early Tertiary show that the area around this well at Devonian to Early Tertiary was paleo high/nondeposition area. This event was probably related to Triassic–Middle Jurassic major contraction event [1], which resulted in uplift and erosion at Aripoe-1 surrounding area.

Late Carboniferous–Triassic sediment (Aiduna and Tipuma Formation) was absent at Noordwest-1, Jaosakor-1, Aripoe-1, Merauke-1, E-3X, and E-2X. It is only present at E-1X. This gives the impression that the southern Papua area was dominantly at the nondeposition area during Late Carboniferous–Triassic, except in the south region (E-1X area). This event is probably also related to the Triassic–Middle Jurassic major contraction event [1].
3.3 Seismic stratigraphy

Seismic stratigraphy unit is divided into:
1. Proterozoic basement, top of this sequence is the Basement marker [27].
2. Pre-Permian sequence consist of Otomona, Tuaba, and Modio Formations. The bottom boundary is the Basement marker, and the top boundary is Near Top Carboniferous [27]. These three units can be divide at several studied seismic profiles based on interpreted Top Ordovician, Top Devonian, and Top Permian strong amplitude.
3. Permian–Triassic sequence consists of Aiduna and Tuaba Formations. The bottom boundary is Near Top Carboniferous, and the top boundary is Near Base Jurassic SB [27].

Above it subsequently is Kembelangan Group Sequence, Nugini Limestone Sequence, and Mid Tertiary–Quaternary Sediment Sequence [28].

Seismic stratigraphy unit division of passive seismic tomography data of Jaosakor area [17] based on Vp and Vp/Vs range value from outcrop lithological characteristic, is divided into:
1. Proterozoic basement, Vp range value >5.50, Vp/Vs range value >1.740.
2. Pre-Permian sequence:
   − Otomona Formation, Vp range value 5.30–5.50, Vp/Vs range value 1.730–1.740.
   − Tuaba Formation, Vp range value 4.70–5.30, Vp/Vs range value 1.720–1.730.
   − Modio Formation, Vp range value 4.40–4.70, Vp/Vs range value 1.714–1.720.
3. Kembelangan Group Sequence, Vp range value 4.30–4.40, Vp/Vs range value 1.712–1.716.
4. Nugini Limestone Sequence, Vp range value 3.30–4.30, Vp/Vs range value 1.706–1.712.
5. Akimeugah Formation/Mid Tertiary–Quaternary Sediment Sequence, Vp range value 2.10–3.30, Vp/Vs range value 1.660–1.712.

Based on seismic tie with Jaosakor-1 well, the Permian–Triassic sequence (Aiduna and Tuaba Formations) is not present in this area.

3.4 Paleozoic basin

The Pre-Permian sequence, which forms the Paleozoic basin at Arafura sea, Indonesia, is span about 500 km (Figure 3). The thickness of this sediment is more than 1 second. Modio Formation (Pre-Permian sequence) and Aiduna and Tuaba Formations (Permian–Triassic sequence) are present at Kola-1 and ASM-1X well, confirming truncated (on lap) of Permian–Triassic lithological sequence to Pre-Permian sequence as shown at the north and south part of southern Papua (Figure 2 & 3). South part area of this section shows the presence of Permian–Triassic sequence at E1-X well while at E2-X and E3-X well, the Permian–Triassic sequence is not present. This shows the limited spreading area of the Late Devonian rifting, which resulted in the limited deposition distribution of Permian–Triassic sequence.

At the onshore of the southern Papua area, the Pre-Permian sequence still occurred, with the Mesozoic sequence on lap truncated above it (Figure 2). The thickness of the Pre-Permian sequence at this onshore area is estimated at around more than 1 second. Poor quality of scanned onshore seismic profile limits the observation of the possible structure and stratigraphic trap potential in this area.

Arafura-1 and MP-1 well drilled in 2013 also encountered 700 m and 2.500 m of Paleozoic sediment at Arafura sea [6]. They concluded that the Arafura sea Paleozoic basin-fill had undergone deeper burial and more severe uplift and erosion. They also estimated that the Aru structure had experienced approximately 15,000 ft uplift and erosion, and the lower Paleozoic petroleum system was not preserved. Line AGATS-015 seismic profile from [16]
shows the sequence of Paleozoic sediment unconformable below the Mesozoic sequence (Figure 4). The thickness of this unit in this area is around 1 second. The large gentle anticline of Paleozoic sediment spans up to 5 km long.

At the seismic profile Lines IA90-114 and IA90-152 show the presence of thick Paleozoic sediment (up to 5 seconds) with the possible inverse anticline trap (Figure 4). Section Lines IA90-114 and IA90-152 also show unconformable top lap and down lap of Pre-Permian sequence to Kembelangan Group Sequence and Nugini Limestone Sequence, opening the possibility for the stratigraphic trap of Pre-Permian sequence and Kembelangan Group Sequence at this area.

Interpreted PST data of Badan Geologi [17] show the presence of the Pre-Permian sequence below the unconformity with the Mesozoic sequence (Figure 5). The total thickness of the Otomona Formation, Tuaba Formation, and Modio Formation is around 6,000 m. Possible structural highs show in Figure 5 is the gentle anticline similar to the Arafura sea anticline still present in this area, with a geometry of 8 km long. The possible stratigraphic trap between the Pre-Permian sequence with overlying Mesozoic sequence is also present, as shown in Figure 5.

The structure map, which shows the southern Papua area's major structure trend, is presented in Figure 6. It is a compilation map between the subsurface structure map identified in this study, compile with the result of Barber et al. [27], Pertamina and Corelab [29], and Harahap [30], and with the total magnetic intensity map of Badan Geologi [17] and Siagian et al. [31]. Two major structure trends is present, NW-SE and NE-SW trend. The NW-SE graben trend is due to the Early Paleozoic intracratonic rift (known as the Fitzroy Movement), and the NE-SW graben trend is due to Late Mesozoic (Triassic–Middle Jurassic) tensional force [27]. The interpreted boundary of pinch out of the Mesozoic rock into the Paleozoic rock was also drawn in Figure 6. This half-circle area at southern Papua, previously called Arafura basement high, is identified as a large Paleozoic basin [32].

![Figure 3](image_url)

**Figure 3.** North to south seismic and well correlation at Arafura sea. Shows the present of Paleozoic sediment with a minimum thickness of 1 second (brown colour at seismic profile). Note truncated Mesozoic rock (Kembelangan sequence) and Late Carboniferous–Triassic sediment (Tipuma - Aiduna sequence) at the north and south part. The blue line in location map is the seismic lines while the black line is the well correlation.
Figure 4. Top: Line AGATS-015 seismic profile from Badan Geologi [16], show Paleozoic sediment unconformable below the Mesozoic sequence with thickness around 1 second. Bottom: Lines IA90-114 and IA90-152 seismic profile show the present of Paleozoic sediment with thickness up to 5 seconds. The seismic data are courtesy of Pusdatin, KESDM.

The above result and discussion are the aims of this study to promote further exploration of the eastern Indonesia Paleozoic basin. Schematic illustration from the combination of Jaosakor/Asmat PST data, Akimeugah low land fold belt [28], and diagram from Nayoan et al. [33] and Satyana [34] are presented in Figure 7. It shows the possibility of the presence of Paleozoic rift graben play at southern Papua. Paleozoic basin in Indonesia is age correlated with the Larapintine petroleum system of Australia. Larapintine system is sourced by early to mid-Palaeozoic marine facies (shales and carbonates). e.g., Weaber and Turtle discoveries, Bonaparte Basin [32,35]. With this lot of potential covering all over southern Papua, this area deserves further exploration attempt, such as burial history study and kitchen identification, to reveal its hydrocarbon prospective.
Figure 5. Interpretation of Lines E-E’, F-F’ and C-C’ Jaosakor/Asmat area passive seismic tomography data, shows Paleozoic basin configuration above Mesozoic rock [17]. Note gentle anticline of the Paleozoic sediment and truncated position with Mesozoic rock above it as potential hydrocarbon Paleozoic play. See Figure 1 for the location map of PST data.
Figure 6. Structure map of Arafura sea and southern Papua onshore, show two major trends NW-SE and NE-SW trend. Modified from Barber et al. [27], Pertamina and Corelab [29], and Harahap [30], and total magnetic intensity map of Badan Geologi [17] and Siagian et al. [31]. Note the half-circle interpreted trend of pinch out of the Mesozoic rock to Paleozoic sediment.

Figure 7. Play types of Mesozoic and Paleozoic rock at southern Papua. Paleozoic rift graben play is located at the southern area of Papua. Modified from Fakhruddin et al. [28], Nayoan et al. [33], and Satyana [34].

4. Conclusion

Identified Paleozoic rocks of southern Papua area are:
1. The Pre-Permian sequence consists of Oтомона Formation (Late Proterozoic–Cambrian), Tuaba Formation (Ordovician), and Modio Formation (Silurian - Devonian).
2. The Permian–Triassic sequence consists of Aiduna Formation (Late Carbon–Permian) and Tipuma Formation (Late Triassic–Jurassic).

The Paleozoic basin occurred from Arafura sea to onshore of southern Papua with a thickness of up to 5 seconds. This unit’s potential trap is a gentle anticline with geometry up to 8 km long and stratigraphic trap top lap with the unit above it.

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