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View Biostratigraphy as A Useful Tool for Hydrocarbon Exploration – case from the Pre-Tertiary Sediment in the Bird's Head Region, Papua

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Abstract

Biostratigraphy plays an important role in hydrocarbon exploration as a way to determine sedimentation ages and to give insights into sedimentary environments. However, little is known about the importance of biostratigraphy in hydrocarbon exploration. This paper focuses on the role of biostratigraphy as a useful tool for hydrocarbon exploration to support the search for new hydrocarbon reserves in Indonesia. We presented a case from the Lemigas Stratigraphy Group study on the pre-Tertiary sediment of the Bird's Head in Papua as an example. This study aims to provide a better understanding of the pre-Tertiary sedimentary stratigraphy by providing a zonal division of age and depositional environment of the sediment of the study area.

The biostratigraphy including foraminiferal, nannoplankton and palynological analyses, was performed on surface samples from the Sungai Ainim traverse, in Ayata Village, Meibrat Region, West Papua and subsurface samples (Wells W-1, S-1, A-2, M-1, O-1, W-4, R-1 and V-1). Overall, this study revealed five chronostratigraphic frameworks, including Permian-Triassic, Middle Jurassic, Late Jurassic, Early Cretaceous, and Late Cretaceous.

The depositional environment initially occurred in a non-marine setting during the Permian-Triassic age. The Early Jurassic age is recorded as a hiatus. Subsequently, the Middle Jurassic is deposited in a non-marine environment. The environment then shifted to a marine setting during the Late Jurassic age. The sediment succession disappeared during the Early Cretaceous age due to massive erosion. Finally, the Late Cretaceous environment was deposited in a marine setting.

From the biostratigraphic data, we provide an insight into the role of sedimentary age and depositional environment in the framework of petroleum geology. Our findings show that the shale Ainim Formation in the Permian-Triassic age serves as a primary source rock, while the fluvial sandstone of the Tipuma Formation in the Middle Jurassic is considered the main reservoir. The occurrence of deep marine shale formed a caprock during the Late Jurassic age. Finally, the deep marina shale of the Jass Formation in the Late Cretaceous acted as a caprock element in the petroleum system.

The outcome of this research shows that biostratigraphy plays an important role in the construction of geological models for hydrocarbon exploration. It has become a useful tool to support the search for new reserves, especially in the Eastern part of Indonesia.

Keyword(s): Biostratigraphy, Palaeoenvironments, Permian-Cretaceous, Bird's Head

1 Introduction

The dating of rock units using biostratigraphy is commonly applied in hydrocarbon exploration (Imraz et al. 2013). Biostratigraphy poses as a key method in petroleum exploration as it provides a cost-effective, quick, and simple way to determine sedimentation ages and to give insights into sedimentary environments. Paleoenvironmental studies can be used to constrain sequence stratigraphic interpretations for predicting source, reservoir, and seal rock environments. Thus, it plays a critical role in the building of geological models for hydrocarbon exploration as a tool to accurately locate hydrocarbon reservoirs (Chitty 2021). Further, biostratigraphy data can also be used to reconstruct a paleogeographic map. An introduction to the paleogeography of a certain area is essential to provide information in which direction hydrocarbon exploration should be carried out.

Despite its importance, the role of biostratigraphy is not widely realized in petroleum geology and our current knowledge of its contribution to the success of hydrocarbon exploration and production is limited. This paper will highlight the importance of biostratigraphy as a useful tool for hydrocarbon exploration to support the search for new hydrocarbon reserves in Indonesia.

To date, LEMIGAS has conducted many biostratigraphic studies with a focus on Western Indonesia. Here, we presented a case study from the Eastern part of Indonesia, as this part is less explored for hydrocarbon exploration activities. This study is part of the study on the pre-Tertiary sediment of the Bintuni Basin conducted by the LEMIGAS Stratigraphy Group in 2009 and is the only in-house study that has been done by this group in Papua. This investigation is intended to determine past geographical conditions during the formation of pre-Tertiary age by providing the zonal age and depositional environment of the Bird's Head in Papua.

We presented this study as an example because information on paleogeography and potential hydrocarbons of the pre-Tertiary sediment of the Bird's Head region, Bintuni Basin in Papua is still scarce. A study is needed to better understand its hydrocarbon potential as pre-tertiary deposits have a different petroleum system from tertiary deposits.

The results of this study regarding the sedimentary age and environmental depositional setting have been published by Setyaningsih (2014) and Lelono et al. (2010), respectively. In this paper, we will exclusively present the results of the zonal age and environmental deposition of the study area from the published data. Furthermore, we will emphasize the role of biostratigraphy as a useful tool by providing an insight into what new findings we attained from the available data.

2 Geology and Stratigraphy

The Episodes of tectonic and geology in the Bird's Head area of West Papua were related to the large-scale tectonics that occurred in Eastern Indonesia as well as Australia. This tectonic episode has implications for the complexity of the structural design in part of West Papua (Dow et al. 1988). The Bintuni Basin is bounded by the Sorong Fault Zone in the north, the Lengguru Foldbelt in the south, and the Banda Arc in the west. The existent pre-Tertiary formations in the study area consist of (from older to younger) Kemum Formation, Aisasjur Formation, Aimau Formation, Aifat Formation, Ainim Formation, Tipuma Formation, and Jass Formation (Poetro et al., 1990).

The oldest pre-Tertiary sediment in the studied area, the Kemum Formation, was formed in the marine environment with turbiditic currents during the Silurian-Devonian. The Kemum Formation is inter-fingering with the Aisasjur Formation which was deposited in a shallower marine environment. Both the

Kemum and Aisasjur Formations are overlain by the Late Carbonaceous-Early Permian Aimau Formation. This formation might have been deposited in the shallow marine environment (close to the shoreline). The Aimau Formation is conformably overlain by the Early–Late Permian Aifat Formation, which was deposited in a shallow marine environment. It was subsequently conformably overlain by the Ainim Formation. This formation was shaped during the Late Permian, which is conformably overlain by the Tipuma Formation. The Tipuma Formation is assumed to have been deposited during the Triassic-Early Jurassic age. This formation is unconformably overlain by the youngest pre-Tertiary sediment, the Jass Formation, which was formed during the Middle-Late Cretaceous in the shallow water environment (Poetro et al., 1990).

3 Material and Methods

This study was conducted in an onshore and off-shore area in the southern part of the Bintuni Basin (figure 1). The biostratigraphy, including foraminiferal, nannoplankton and palynological analyses, was performed on surface samples from the Sungai Ainim track, in Ayata Village, Meibrat Region, West Papua, as well as subsurface (well) data provided by oil companies, represented as Well W-1, S-1, A-2, M-1, O-1, W-4, R-1, and V-1.

This presentation will briefly outline the pre-Tertiary sedimentary stratigraphy by providing a zonal division of age and depositional environment during the Permian to Cretaceous age. The zonal division age interpretation was done using palynological analysis as the main proxy. We employed the foraminiferal assemblages to reconstruct the marine depositional environment, whilst for interpretation of the non-marine and transitional environments we used palynomorph assemblages. Marine paleoenvironmental classification and nomenclature refer to the modified results of Tipsword et al. (1966) and Ingle (1980).

4 Results and Discussion

4.1 Biostratigraphy of the Bird's Head region in Papua

This is the first study to access the fossil content of Permian-Cretaceous sediments. However, many of the fossil taxa remain unknown, especially palynomorph taxa, due to the limitations of pre-Tertiary references. Therefore, this is an opportunity for micropaleontologists in Indonesia to challenge this issue and support biostratigraphical study on the pre-Tertiary sediment in Eastern Indonesia.

The biostratigraphical setting comprises of zonal division age and past depositional environment of the pre-Tertiary sediment from the Ainim river traverse is described in detail by Setyaningsih (2014) using palynological analysis as the main proxy together with foraminifera and nannoplankton analyses. Our results show that the Ainim River traverse occupied the Middle Eocene to the Late Permian age (figure 2). The Middle Eocene age is characterized by planktonic foraminifera *Pseudohastigerina wilcoxensis, Acarinina pentacamerata, Globorotaliodes carcoselensis,* and *Globigerina hagni* and supported by the presence of pollen *Florschuetzia trilobata*. Afterward, the Late Cretaceous is defined by index species *Globotruncana linneiana, Margionotruncana sinuosa, Hedbergella flandini,* and *Dicarinella asymetrica*. This is supported by the presence of calcareous nanoplankton *Microrhabdulus belgicus, Eiffelithus eximius, Micula staurophora, Tranolithus orionatus, Cribrosphaerella ehrenbergii*, and *Prediscosphaera cretacea,* and the presence of Late Cretaceous pollen *Tricolporites acidiferites apoxy, Spiniferites ramosus-furcatus, Amosopollis cruciformis,* and *Manumiella coronata* (Helby et.al, 1987). The Permian age is specifically

characterized by the collection of benthic foraminifera from the Ammodiscus and Ammobaculites groups, which had an age range starting from Perm. This is supported by palinomorphs belonging to the *Protohaploxypinus microcorpus* (Late Permian) zone, such as *Cycadophytes cymbatus*, *Falcisporites australis, Protohaploxynus limpidus, Lunatisporites noviaulensis*, and *Protohaploxynus amplus.*

In addition, detailed biostratigraphy of the studied wells is presented in the project report by Lelono et al. (2009). Compilation of the measured stratigraphic range from the cross-sectional surface rock of the Ainim River track and subsurface data revealed five chronostratigraphic frameworks, including Permian-Triassic, Middle Jurassic, Late Jurassic, Early Cretaceous, and Late Cretaceous.

During the Permian-Triassic, the environment in the southern part of the study area (Wells A-2 and W-4) is deposited in a non-marine (supra-littoral) setting, marked by the occurrence of microflora *Cycadophytes cymbatus, Falcisporites australis, Protohaploxypinus limpidus, Lunatisporites noviaulensis,* and *Aratisporites scabratus*. It then gradually shifted into a deeper setting toward east in littoral (Well W-1, S-1 and R-1) which is supported by the finding of dinoflagellata *Spiniferites ramosus-furcatus* and *Manumiella coronata* together with pollen *Proteacidites* spp., *Amosopollis cruciformis,* and *Tricolporites apoxyexinus*. It finally moved into a neritic environment (Well V-1) as we found benthonic foraminifera *Elphidium* spp., *Ammonia* spp. and moderate arenaceous benthic forams to indicate the environment.

Similar events occurred during the Middle Jurassic (figure 3b) especially for most wells in the northern part of the study area (Wells W-1, S-1, A-2 and M-1). The O-1 and W-4 Wells were deposited in the littoral which then shifted into deeper settings toward the East in the inner neritic (Well R-1) and deeper into the shallow middle neritic with the finding of calcareous benthic forams *Cibicides* spp, *Lenticulina* spp., and *Lagena* spp. toward the northeast (Well V-1).

The Late Jurassic age shows a different pattern of depositional environment than the previous period (figure 3c). The Littoral-inner neritic environment occurred in the southern part of the study area (Wells W-4 and A-2), which gradually shifts into a deeper setting in the inner neritic-shallow middle neritic (Wells V-1, R-1 and O-1) and keeps changing into a deeper marine environment toward the north into outer neritic (Well S-1), which was marked by the finding of abundant calcareous benthic forams *Bolivina* spp., *Uvigerina* spp., *Cassidulina* spp., and *Marginulina* spp.

Afterward, the Early Cretaceous succession disappeared in most studied wells due to extensive erosion events. The succession only occurred in Well S-1 and A-2 where the sediments were deposited in the deep middle neritic to outer neritic (figure 3d). The Late Cretaceous age is dominated by marine sediment which was deposited in various bathymetries (figure 3e). The inner neritic to shallow middle neritic occurred in the northern part of the study area (Well A-2 and M-1), in addition to the sediment of the Ainim River. It then gradually changes into deeper setting toward Southeast in outer neritic to upper bathyal environment (Well S-1 and W-1). Subsequently, the depositional environment keeps moving into deeper marine setting in bathyal environment toward the Southeast (Well V-1and W-4) with the finding of abundant calcareous benthic forams *Uvigerina* spp., *Bulimina* spp., *Gyroidina* sp., and the occurrence of arenaceous benthic forams *Cyclaminna* spp., and *Bathysiphon* spp. In contrast, the depositional environment toward the further Southeast (Well O-1 and R-1) moved back into a shallower marine environment in the outer neritic to upper bathyal.

4.2 *Role of biostratigraphy through the pre-Tertiary in the Bird's Head region*

Our results show that biostratigraphic data is useful to correlate and characterize the depositional environment of the pre-Tertiary sediment in the Bird's Head region, Papua. The question is, how will the data generated from this study provide new insights on the role of biostratigraphy in supporting hydrocarbon

exploration activities in those area? The results of the sedimentary age and environmental deposition could be used to build a new framework in petroleum geology for the study area. The biostratigraphy data is utilized to generate a paleogeographic map of the area in order to better understand the changes in lithofacies in the area (Bidgood et al. 2015).

The paleogeographic maps as the representation of the depositional environment through time help to better constrain the geological model of the paleoenvironment (Doligez et al. 2011) to support the evaluation of the potential for hydrocarbons in these sedimentary rocks. It is effective to facilitate the recognition of the distribution pattern of potential source rocks, reservoir rocks and caprocks in order to provide more detailed information for identifying favourable plays (Zhang et al. 2019; Strogen et al. 2012).

Our new finding suggests that the shale Ainim Formation in the Permian-Triassic age served as a primary source rock in the study area. Afterward, the fluvial sandstone of the Tipuma Formation in the Middle Jurassic is considered the main reservoir. This was followed by the occurrence of deep marine shale to form caprock during the Late Jurassic age. Finally, the deep marine shale of the Jass Formation in the Late Cretaceous acted as a caprock element in the petroleum system.

As the above case demonstrates, the role of biostratigraphy as a key component in better understanding the geological framework of the pre-Tertiary sediment in the Bird's Head, Papua, is compelling. This new paleogeographic map helps to provide information on crucial elements of the petroleum system, especially the distribution of potential reservoir facies such as Permian-Triassic to Jurassic marginal to non-marine facies and Late Jurassic to Cretaceous submarine systems. This finding is important for the evaluation of the regional petroleum play concept. In this regard, the outcome of this study is very useful for the expansion of hydrocarbon exploration activity in the eastern part of Indonesia.

5 Conclusions

This paper highlights the role of biostratigraphy as a useful tool in petroleum exploration and the future opportunities of its application in petroleum geology. We presented a case from the Lemigas Stratigraphy Group study on the pre-Tertiary sediment of the Bird's Head in Papua as an example. We employed biostratography analyses in this study, including foraminifera, calcareous nannoplankton, and palynomorphs.

Results of this research contribute to the Premian to Cretaceous biostratigraphy, lithostratigraphy, and paleoenvironment of the Bird's Head region in Papua. Correlations are based on the assemblage zone of identified fossil taxa and the environment of deposition among analysed surface samples (Ainim River traverse) and subsurface samples (Wells W-1, S-1, A-2, M-1, O-1, W-4, R-1, and V-1).

This study identified five chronostratigraphic schemes, including Permian-Triassic, Middle Jurassic, Late Jurassic, Early Cretaceous, and Late Cretaceous. The initial depositional environment occurred in a non-marine setting during the Permian-Triassic age. The Early Jurassic age is missing as it is likely to be eroded in the area. The Middle Jurassic in a non-marine environment. Subsequently, during the Late Jurrasic age, the environment shifted to marine a setting. The sediment succession disappeared during the Early Cretaceous age due to massive erosion. Finally, the Late Cretaceous environment was deposited in a marine setting.

From the biostratigraphic data, we produce a paleogeographic map to provide more detailed information on the potential distribution of source rock, reservoir, and seal cap in the study area. Our findings show that the shale Ainim Formation in the Permian-Triassic age serves as a primary source rock, while the fluvial sandstone of the Tipuma Formation in the Middle Jurassic is considered the main reservoir. This was

followed by the occurrence of deep marine shale to form caprock during the Late Jurassic age. Finally, the deep marine shale of the Jass Formation in the Late Cretaceous acted as a caprock element in the petroleum system.

The outcome of this research shows that palynomorphs, calcareous nannoplankton, and foraminifera are all key biostratigraphic indicators used in the pre-Tertiary sediment through the Bird's Head region. They display incredible biodiversity and preservation in allowing biostratigraphic correlation in the studied area. Thus, biostratigraphy remains an important role in the construction of geologic models for hydrocarbon exploration. In the future, it will be a useful tool to support the search for new reserves, especially in the eastern part of Indonesia.

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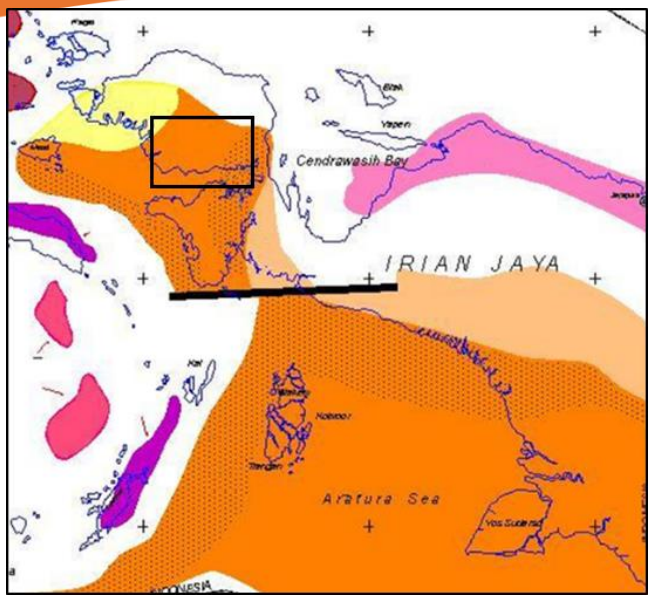

Figure 1. Research area located in the Bintuni Basin, the Bird's Head region, Papua

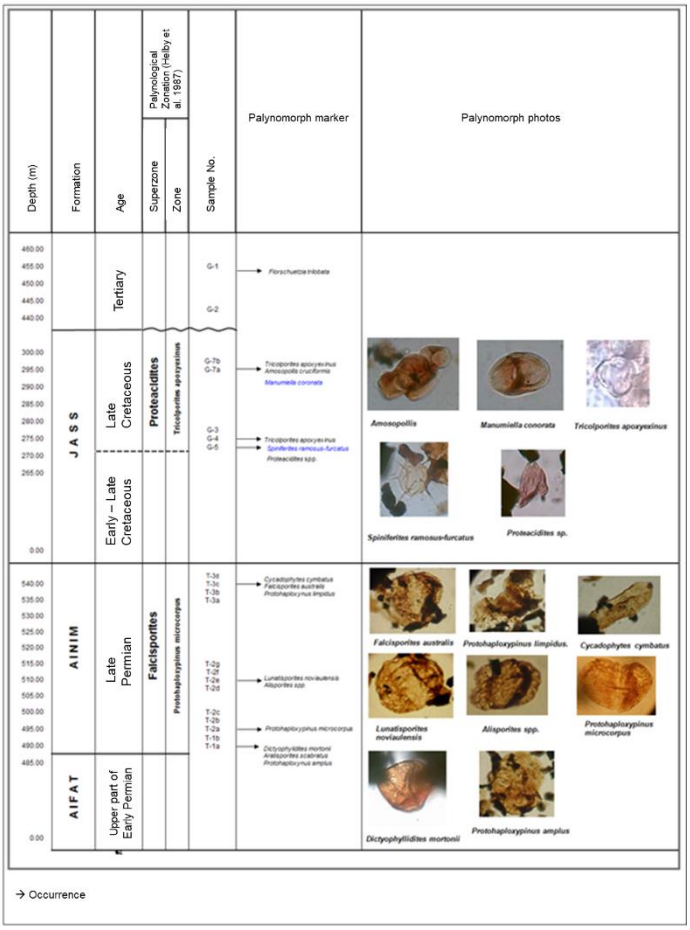

Figure 2. Palinostratigraphic summary of the Ainim River traverse (unscaled)

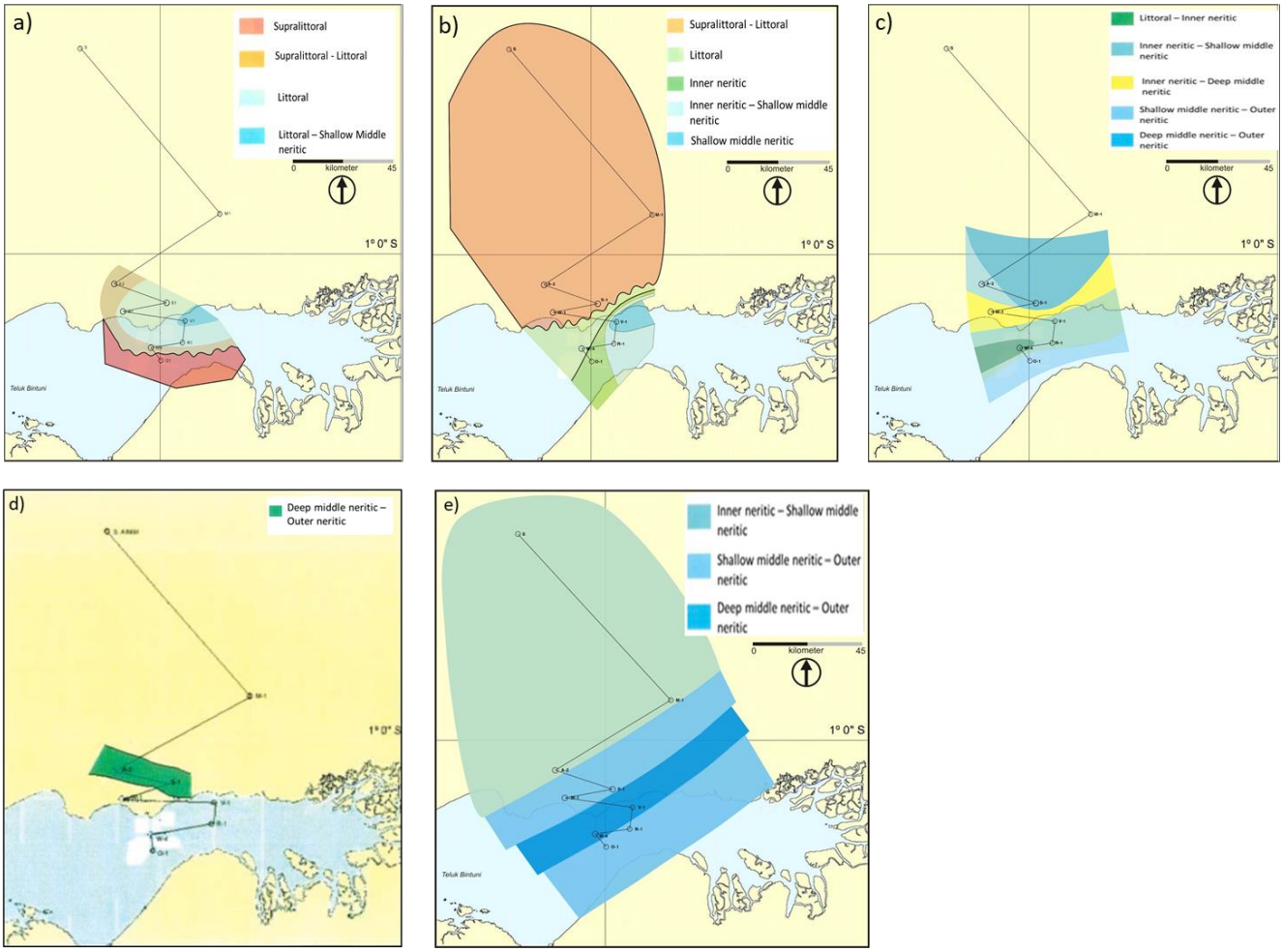

Figure 3. Paleoenvironment map covering Permian to Cretaceous age which was generated from the biostratigraphy data of the studied area: a) Permian to Triassic age (255 Ma); b) Middle Jurrasic age (161 Ma); c) Late Jurrasic age (145.5 Ma; d) Early Cretaceous age (99.6 Ma); and e) Late Cretaceous age (66 Ma; Lelono et al. 2009).