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## Surface geological investigation as the initial stage of hydrocarbon exploration in Kei Besar Island, Southern Maluku

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# Surface geological investigation as the initial stage of hydrocarbon exploration in Kei Besar Island, Southern Maluku

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**Abstract.** Kei Islands are known to have hydrocarbon potentials in shallow rock layers, trapped by folds and faults. This potential is characterized by the amount of gas seepage found in Kei Kecil, Kei Besar and Tayandu Island. The study was conducted in central and southern part of Kei Besar Island through outcrop observations and stratigraphic measurements aim to recognize the physical characteristics of rock. Kei Besar Island located in the easternmost part of Australian continental passive margin separated by the extension of Aru Through. Digital Elevation Model of Kei Besar Island shows that the northern part of research area has a steeper morphology than the southern. The stratigraphic characteristic in the central part of research area dominated by clastic limestone showing a shallowing-up stacking pattern. While in the southern part, the lithology dominated by coralline limestone contains many fragments of coral and large foraminifera. Stratigraphic analysis shows that lithology in the study area was formed in carbonate submarine fan which formed Elat Formation. This formation underlain by shallow carbonate rock which contain large foraminifera from Tamangil Formation. Tamangil Formation interfingering with lower part of Weduar Formation. Based on the analysis of surface data above, concluded that subsurface exploration is necessary to reconstruct the petroleum system in research area.

**Keywords:** Kei Besar Island, surface geological investigation, stratigraphy, limestone

## 1. Introduction

Kei Island is located in the east part of Banda Arc. The eastern-most of Kei Islands, Kei Besar, is actually the passive margin of Australia continental crust that separated due to Aru Trough extension. Nerong Strait in between Kei Besar and Kei Kecil was the result of thrust fault at fore-Banda Arc.

A fair hydrocarbon potential is identified from Kei Islands. A regional geology survey conducted by [1] mentioned that the potential hydrocarbon in Kei Islands is gas, formed in a shallow formation and trapped under folds and thrust faults. Hence, an encouraging hydrocarbon prospect awaits underneath. The complex regional structural geology of folds and thrust faults, that later act as structural trap in this petroleum system (Figure 1), was the result of several tectonic events. These facts also become the background of this research to conduct a more thorough observation and interpretation regarding the petroleum system in Kei Islands. Generally, the aim of this research is to obtain the formations



characteristic as well as the stratigraphic relation, thus provides the initial stage reference for another next advanced stage exploration research.

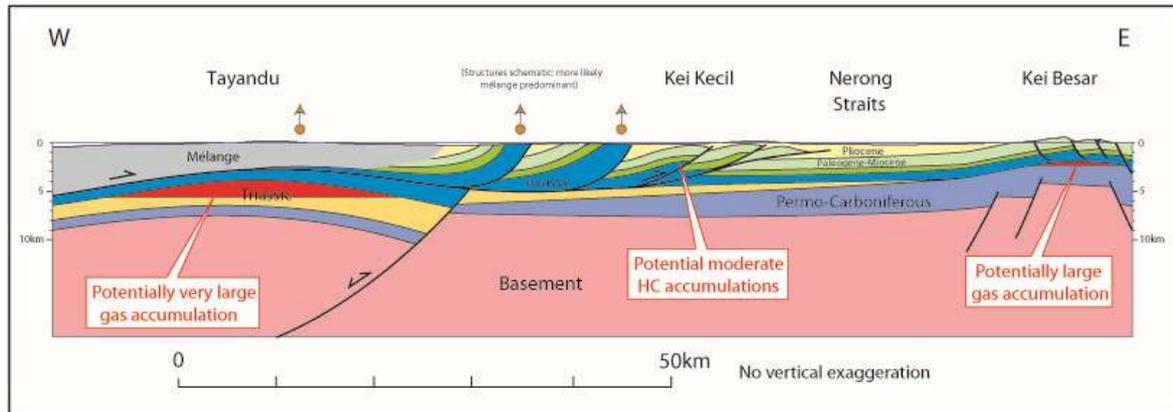


Figure 1. Cross section of Kei Islands that pictured the structural trap at several locations which confines the hydrocarbon [1].

In terms of stratigraphy, Kei Islands has rock formations that is dominated by carbonates, observed from plenty outcrops on the islands. The carbonates overlays on Metamorphic Rock Complex, consists of gneiss-feldspar-quartz-biotite-muscovite that is predicted as Pre-Cambrian products. The strata of the carbonates at Kei Islands itself begins from Elat Formation that is interfingering with Yamtimur Formation, formed at Early-Middle Eocene. Elat Formation consists of calcarenites that reaches 700 meters thick, exposed on the middle and south part of Kei Besar, while Yamtimur Formation is characterized by napal interbedded by calcarenites that thickens upward. Overlaying above those two formations are Tamangil Formation and Weduar Formation, which has interfingering relation. Tamangil Formation consists of limestone with dominant large foraminifera, 50 meters thick and exposed in Tamangil area, Kei Besar, ranging only from Middle to Late Oligocene. Weduar Formation continues to be formed until Middle Miocene, consists of reef limestone, chalk, calcarenite and napal. Weryahan Formation and Matot Tanjung Complex overlay Weduar Formation, composed of beds of clastic limestone, both are formed during Pliocene. The youngest carbonates are Ohoinol Formation and Kei Kecil (Pliocene) that showed the characteristic of shallow marine depositional environment.

The most complex geological structures are formed at Kei Besar [2], including anticlines, sinclines, faults and joints. Basically, the beds inclination does not exceed 35°. Plenty of mud volcanoes are found on islands at the middle part of Kei Islands. This area at least has experienced three orogeny events. The first orogeny took place at Late Eocene that folds Elat Formation and Yamtimur Formation. The second orogeny, during Late Miocene, folds the previous formations even tighter as well as Weduar Formation. Plio-Pleistocene is when the last orogeny took place that caused the folding of Weryahan Formation.

## 2. Research location

In general, the research took place Kei Besar, Southeast Maluku Regency. The observation sites were in Elat, Ohoilim, Werka, and Mata Holat (Figure 2) that represent the whole research area.

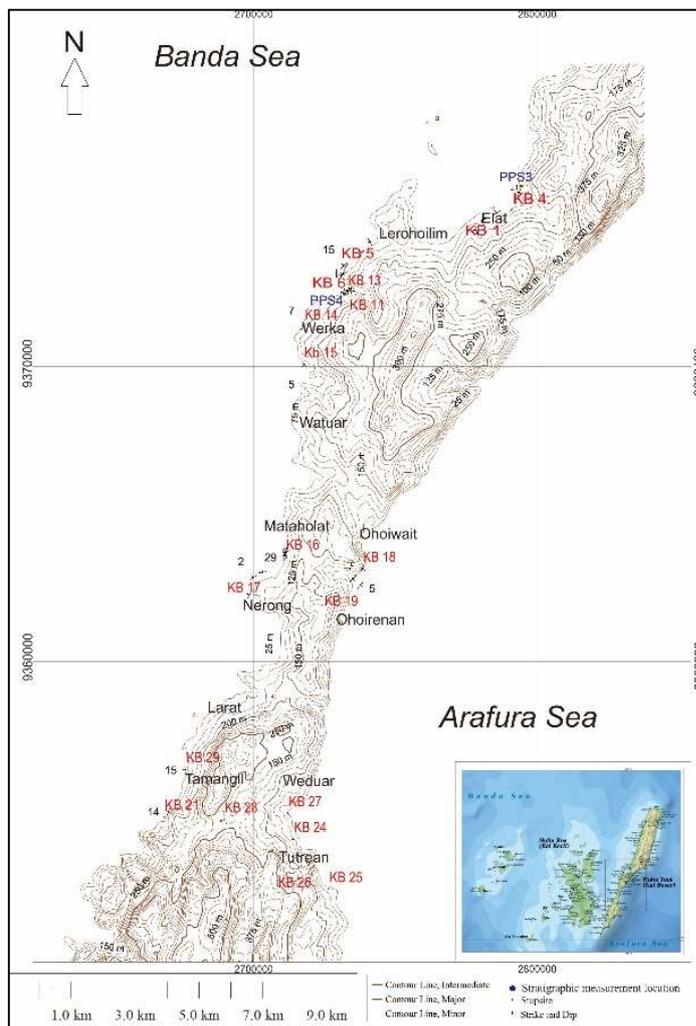


Figure 2. Research area coverage and sampling points.

### 3. Methods

#### 3.1. Pace and compass

One of the methods to support measuring stratigraphic section is pace and compassing. Every length unit, distance and thickness, is measured by rope and recorded on the traverse section. Observing the lithology is also carried out in this method, including rock type, thickness, sedimentary structure, lithology contact and fossil assemblages.

#### 3.2. Measured Stratigraphy Column

The stratigraphy column is built based on the strike and dip of lithology unit. This method will record the rock layers systematically, also provide the information of rock type, rock layer thickness and stacking patterns. Measuring stratigraphy was conducted in Elat and Ohoilim (Figure 2).

#### 3.3. Facies analysis and Depositional environment

The analysis was initiated by determining the facies, utilizing the sedimentology aspect that is provided within the measured stratigraphy column. These facies association are compared to facies model [3] that can support the process to interpret the depositional environment of the formation in research area.

#### 4. Results and Discussion

Banda Arc is sited at the border of three crusts, Indo-Australia, Eurasia and Pacific. Kei Islands is at the most outer margin part of Banda Arc. The outer part of Banda Arc consists of four segments, Timor, Tanimbar, Aru and Seram segments [4], and are thrusting westward.

Basically, the Timor, Tanimbar and Seram most likely have the same geological characteristic and structure, which represent the result of subduction process. On the other hand, Aru is the thrust-front part, thus shows different geological condition among the others. Considering that Kei Island is on the west part of Aru, hence Kei Island is part of the forearc as well. The extensional pattern of Aru Island shows that the thrust front section is situated to the west of Aru Island which possibly separates the Kei Besar from the other islands to the west (Kei Kecil and Tayandu) [5].

##### 4.1. Geomorphology

Kei Besar Island is relatively elongated north-south, where the northern part is steeper than the southern. In the middle part, around Elat and Weduar, the island is narrowing eastward. Figure 3 show the west-east morphological sections from several area and represent the northern, middle and southern part of Kei Besar Island. The north and south area, the hills are steep they reach 500 m above sea level. Whilst, slope in the west is steeper than in the east. But, in the middle part of the island it shows the opposite, where the east slope is steeper than the west.

In terms of morphogenesis, Kei Besar Island is a karst hill. The manifestations are caves and underground water channel, speleothem, and springs.

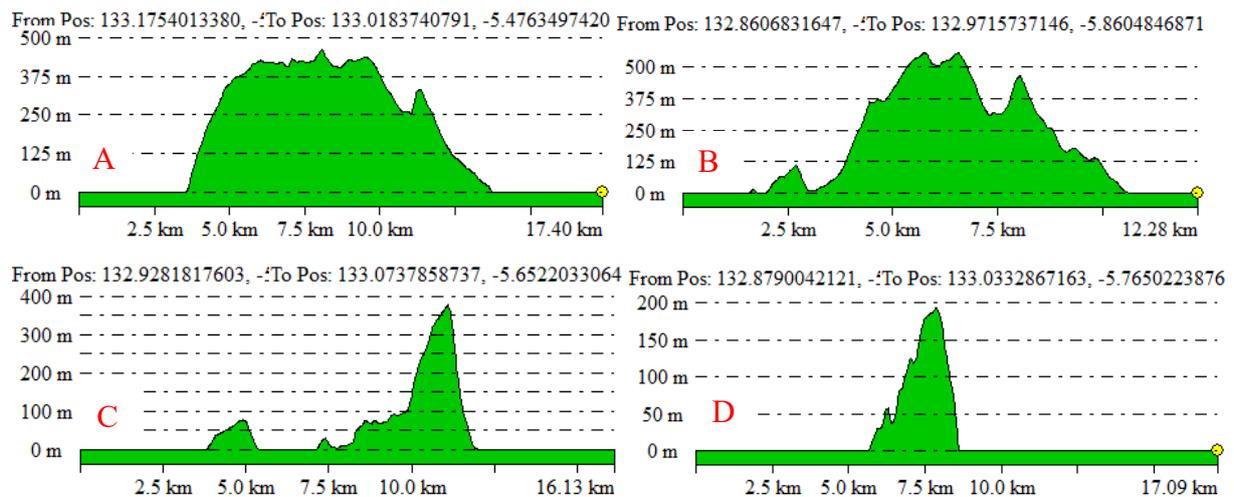


Figure 3. West-east morphological sections from several location. A. northern area and B. southern area of Kei Besar Island, while C. Elat and D. Weduar are in the middle part of Kei Besar Island.

##### 4.2. Stratigraphy

The field observation was carried out from several area that are composed of Elat Formation, Tamangil Formation and Weduar Formation. Whilst, the measured stratigraphy section was conducted only from Elat Formation due to the vast distribution of this formation among the research area.

###### 4.2.1. Elat Formation.

In general, Elat Formation is composed of intercalating calcarenite and calcilutite. Both facies are described below:

###### a. Calcarenite

The hand specimen of this facies is brownish-white and consist of fine to medium sand grain, it has parallel and wavy laminations. Nodules of massive clay grains are found on some fine sand intervals; the orientation is parallel to beds. The microfossil analysis mentioned that there are only small amounts

of foraminifera, most of them are benthic foraminifera of *Bolivina* and *Uvigerina*. Rarely found planktonic foraminifera are from *Globigerina* and *Orbulina* genus.

#### b. Calcilutite

On a fresh outcrop, the facies shows greyish-white color, but on a weathered outcrop, it is brownish. This facies is composed of carbonate grains from silt to clay and laminated. Basically, the calcilutite is interbedded within the calcarenite. But, in some location, it was found more dominant and massive. There were no foraminifera found from the microfossil observation.

The measured stratigraphy section was obtained from two locations, PPS3 and PPS4, respectively from Wakatran Village, Elat and Udar Village, Ohoilim. Generally, the beds are dipping relatively to the south with less than 30°. Considering the strike and dip, the beds are most likely are younger southward, thus, stratigraphically PPS3 is older (under) than PPS4.

Since the fossil cannot be used as the depositional environment indicator, so it was determined from the stacking patterns which later are compared to the carbonate slope model [3]. On elastic carbonates depositional systems, sedimentary structures are not clearly defined because it was dismissed during diagenesis.

A typical of subaqueous slope is shown by an intercalating or interbedded of coarse grain and fine grain facies. Turbidite sequences are hardly observed, but the lower part of Bouma Sequence (Ta – Tb) was identified from debris sediments.

PPS3 shows that Elat Formation is composed of intercalating calcarenite and calcilutite. The calcarenite is 5-20 cm thick and consist of fine sand grain, it has a non-erosional contact with the underlying rock. Beds, thin beds, lamination and wavy lamination are identified from this interval, where calcilutite is thinning upward. The stacking pattern is coarsening upward. Thus, Elat Formation in PPS3 is interpreted as a product of outer fan – carbonate submarine fan.

On the other hand, PPS4 shows calcilutite that interbed within the calcarenite. The calcarenite is 20-50 cm thick, it even reached more than 100 cm in several layers, where it has non-erosional contact. The facies is composed of fine grains and grading to coarser grain upward, and has bedding sediment structure. The calcilutite, as interbeds, at the lower part are very thin layers (less than 1 cm), thickened at the middle part and turned into thin layers again at the upper part.

Basically, the formation is coarsening upward. The lower part is interpreted as the product of transition to middle fan-submarine carbonate fan, whilst the upper part is part of middle fan-submarine carbonate fan. Hence, stratigraphically, Elat Formation is shallowing upward deposited during Middle-Upper Eocene [2].

#### 4.2.2. Tamangil Formation

Basically, the interfingering Tamangil Formation and Weduar Fromation is overlaying Elat Formation unconformably and both were deposited during Middle-Upper Oligocene [2]. The outcrops are found in Tamangil Nuhuten Village, one of the observation sites has a 5 m outcrop. The fresh outcrops show whitish-brown color, while the weathered samples are brown. The rock orientation was hardly identified. Large foraminifera are abundant, mostly 0.5-3 cm and elongated (Figure 4). It is also mentioned in a previous study [6] that Formasi Tamangil has high number of large foraminifera. Based on the petrography, these large foraminifera are *Lepidocyclus*. Calcareous algae are also present.



Figure 4. Outcrop sample of Tamangil Formation, *Lepidocyclina* is abundance.

#### 4.2.3. Weduar Formation

The lower part of Weduar Formation is interfingering with Tamangil Formation. Regional geology map shows that Weduar Formation has direct contact to Elat Formation. Unfortunately, there were no exposed and distinct contact between those formations from the field, as well as the contact between Elat Formation and Tamangil.

Weduar Formation on the field is brownish-white of a compact reefal limestone (Figure 5 and 6). This outcrop shows the presence of coral fragments, algae and mollusc fragments. Chalky limestone can be found in Weduar and Tutrean area, it is white and consists of very fine grains. At the coastal part of Tamangil and Larat, there is outcrop of calcarenite. The outcrop shows beds with 30 cm average bed thickness, brownish-white, with bedding and cross-bedding. Another outcrop of calcarenite at the border between Mata Holat and Nerong area. The calcarenite consist of fine-sand grain, shows wavy and swaley cross stratification (Figure 7) as the indicator of shallow marine environment that is influenced by fair weather-storm wave base. The bed is gently sloping for less than 20°. These described facies characteristics from the field are typical of lower part of Weduar Formation [6] and interpreted as the product of shallow marine depositional environment that was deposited during Middle Oligocene – Middle Miocene [2].



Figure 5. Thin section of Weduar Formation coralline limestone taken from Tamangil area, shows the abundance of large foraminifera.

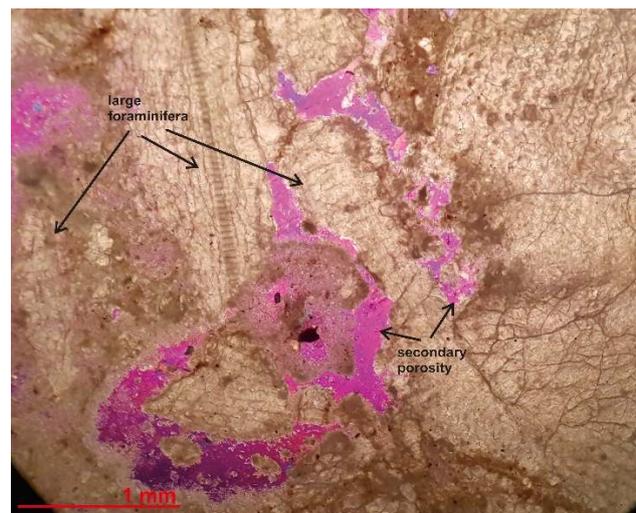


Figure 6. The intense secondary porosity shown in Weduar Formation rock sample taken from Weduar area.

#### 4.3. Structural Geology

Several structural geology features, which are faults and folds, are identified during the field observation from Elat Formation. Normal fault, that also developed dragfold, was distinctly observed in Elat area, the fault plane orientation is at N 175°E/75° (Figure 7). Nonetheless, the shear joint is absent in the field, thus, fault determination is hardly done. Fold was identified in Mata Holat, it is known to be the product of the first period Eocene orogeny that folded Yamtimur Formation and Elat Formation [2]. Both anticline and syncline are clearly outcropped along the coast of Tanjung Mata Holat.

Study [6] has mentioned that the features of Post-Pliocene Orogeny in Kei Besar Island mostly are normal faults. The fault has cut through the Eocene to Pliocene rock intervals. This orogeny period is claimed to be the only massive deformation, at least since Eocene.



Figure 7. Swaley cross stratification within Weduar Formation shown on outcrop in Nerong area. Landscape outcrop view (left) and up-closed view (right). The feature is the indicator of a shallow marine product, in between fair weather – storm wave base zone.



Figure 8. Normal fault that also developed dragfold in Elat area.

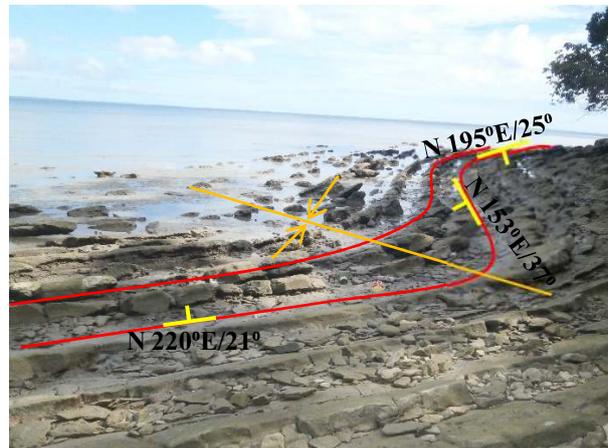


Figure 9. Anticline and syncline feature that is found along the Tanjung Mata Holat Beach.

#### 4.4. Petroleum System of Kei Besar Island

The pre-Tertiary and Tertiary sediments in several sediment basins in eastern Indonesia are proven hydrocarbon yielding rocks [7]. The reservoir rocks are mostly derived from the Mesozoic and Tertiary sediments that are composed of sandstones and carbonates. These reservoirs are mostly trapped by thrust faults and normal faults. Moreover, some reservoirs are also stratigraphically trapped as the buildup carbonates are sealed by pelagic shales.

Regarding the possibility of hydrocarbon prospect in Kei Islands, study [1] mentioned that there are gas seepages at some location in Kei Islands, the Tayandu and Yamtimur (Kei Besar Island) area. Outcrops in Kei Besar shows sequence of carbonate rocks that are shallowing upward and has the age of Paleogene through Quaternary. Based on the subsurface data interpretation [1], underlying these carbonates are the Mesozoic and Paleozoic rocks that has typical characteristic of the Tanimbar stratigraphic sequences. These pre-Tertiary rocks are believed to have important roles in Kei Islands petroleum system, which are the source rock and happen to be the reservoir rock as well. The Miocene anticline and syncline of Kei Besar Island suits best as the structural trap in the petroleum system.

The Paleogene carbonates is also assumed as a potential in term of petroleum system. Deep marine limestones (Elat Formation) is a potential reservoir rock, considering the good secondary porosity (shown from thin section, figure 5&6), which is also the characteristic within reservoirs in sediment basins in eastern Indonesia. Further laboratory analysis is required to confirm this assumption.

## 5. Conclusion

The carbonates in Kei Island, in terms of stratigraphy, basically is shallowing upward. Elat Middle-Upper Miocene Formation consist of intercalating calcarenite and calcilutite that is deposited on Outer-Middle Carbonate Sub-marine Fan. Tamangil Formation, that has characteristic of large foraminifera, is overlaying Elat Formation and also interfingering with the lower part of Weduar Formation. Both Tamangil Formation and Weduar Formation are typical product of shallow marine depositional environment. The upper part of Weduar Formation consists of reefal limestone and chalky limestone. Potential reservoirs are targeted within the thick Elat Formation which also has structural trap mechanism. It is highly recommended to conduct advance lab analysis and geophysical survey in Kei Island in order to observe the subsurface geological condition.

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