Reconstruction of Sea Level Change in Indonesia: Preliminary Evidence From Maratua-Kakaban Complex

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Abstract. This research was conducted in Maratua-Kakaban Islands, East Kalimantan, Indonesia. This location was chosen because of its stable tectonic activity and its geographical setting as the front most island in Indonesia. This location is also known as its tourism destination and beautiful scenery. A small island like in Indonesia is prone to climate change, especially sea level changes. This research is needed to formulate adaptation and mitigation of sea level change in Indonesia. This research also important to understanding the global sea change. This research also important from national sovereignty and coastal resources management point of view. This research aims to: (1) identify water level changes evidence by marine terraces analysis, cave morphology and speleothem; (2) define the highest and lowest water level in Maratua Island, and (3) reconstruct the sea water level fluctuation during Holocene. Sea level fluctuation data were interpreted using marine terrace data, marine notch, and cave morphology. The data were collected by field survey using profiling method to find surface topography and measuring sea floor profile using echo sounder. Based on the field measurement, there are major and minor marine terraces found in the ocean floor in 82 and 180 m depth (major), 155 and 205 m depth (minor). Marine terrace also found in +6 m above present sea level. Below, marine notch was found covered with sediment.

1. Introduction

Sea level change is an important issue for small island management. With the changing of sea water level, the borderline will also change, it is important from political and defense (military) point of view. Many countries still have frictions with a neighboring country in regards to their borderline. Sea level change, especially the rising of sea level will cause another disaster. For Indonesia, most of the populated area is located in the coastal area. Sea level rise will cause many areas in the coast submerged. The loss of residence, cultivated land, fishing ground, will cause socio-economic degradation and ecological impacts.

Maratua Island is part of East Kalimantan Province. It is chosen because it is one of the outer Island in Indonesia which is sharing the same borderline with Malaysia and Philippines in the North and Northeast. It is important to find sea level changes record from this Island. Evidence of sea level changes help decision maker to developed policies regarding climate change disaster mitigation, also policies in the accordance of political and defense (military) strategy. Another
reason why Maratua Island is chosen because, from tectonics point of view, this area is relatively stable. Information on sea level changes is still inadequate in Indonesia. This research aims to: (1) identify water level changes evidence by marine terraces analysis, cave morphology and speleothem; (2) define the highest and lowest water level in Maratua Island, and (3) reconstruct the sea water level fluctuation during Holocene.

### 1.1 Quaternary Paleoclimate

According to the Geological Society of America (GSA) Geologic Time Scale, Quarternary period is divided into two epochs, Holocene (present-0.01 Ma) and Pleistocene (0.01-2.6 Ma). Quartenary period characterized by ice cover that periodically developed and ocean mass up to 4oC [3]or [11] 5-6oC. That period is called Glacial period, which the expanding of ice occur100,000 years ago and the interglacial period when the ice melted 10,000 years ago. Now we stand at the end of interglacial which called Holocene [3]. Expansion of ice during glacial freezing ice in the northern hemisphere twice as much as inland, where now we see Antarctic [3]. It resulted in sea level decreasing which uncover a very wide area of dry land. This occurs at 22,000 BP when sea level about -110 m. between high sea level (120,000 BP) and the last maximum Glacial Period, sea level approximately 20 - -60 m from present level and occurring for 100,000 years.

Hope (1976) in [11] report the condition of Puncak Jaya (5030 m asl). At the beginning of the maximum Glacial Period is unknown. Colder condition from present approximately occurred in 40,000 BP with warmer interval 30,000-26,000 BP. The newest cold phase around 20,000-17,000 BP where snowline in Cartenz on 3,550-3,650 m asl. This time range was not difference compares to [10] in Southeast Asia, it was 18,000 BP. There found gravel deposit (perhaps tilloid) in mountain burrow which dates back to older than 40,000 BP, indicating extensive glaciation.

Until 15,000 BP air was very dry and climate inland in cold period. [11], glaciation period started 15,000-14,000 BP. Meanwhile humid high mountains cause the snow fell in the western side of Papua New Guinea. No data available according to the addition of the ice layer. So, it can be to assume that the climate was warmer than present time occurred in 8500-5000 BP. [11], and other researcher reported evidence of a colder climate than present time occurred 5,000 BP which happened in two phase of glaciation. Then ended 1-2 centuries ago with ice retreating record on Mount Jayawijaya. Indifference, [10], in 5000 BP, sea level increases up to +5 m from the present time, it means it was warmer than the present day.

By [10], in Last Maximum Glaciation (18,000) BP, South East Asia still in form of SoutEast Asia Continent because of the low level of the sea, -130 even -180 below present datum. In this period, Sout East Asia became a wide land which connected Borneo, Jaca, Sumatera, and Malaysia Peninsula. Many evidence of Sunda and Sahul Shelf by Molengraff (1922) and Fairbridge (1953) in [11]. This evidence meanly the occurrence of water drainage. Bangka and Belitung, the area near Malaysia, exist paleo drainage channel. On 12,500 and 11,000 BP, global sea level rise took place so flooded Sahul Shelf which dries before.

In Papua the last glacial maxima modeled by Yokohama et al (2001) in [3] paleo-shoreline model in 22,000 BP for Sahul and Sunda Shelf. With conditioning tectonics parameter and water mass, Arafura extends to the west toward the island of Aru and Australia. Can be seen until now that beaches in Papua are very steep.

Sealevel changes are still underway. In 18 century since the beginning of Industrial revolution, human activity become climate change motor. Human activities affect the erosion, deposition, and isostasy. Land reclamation, dredging, offshore mining, waste disposing of, etc also will affect water volume, basin volume, temperature and geoid configuration [10]. Study conducted by [8] for relative sealevel change (RSL) from tide gauge and salt marsh sediment sequences in 200
years ago, using global sea level rise in a 20th century. Sealevel rise derived from ice / arctic ice, probably 0.3 mm/a, different with [5] was 0.7 [8].

1.2. Sealevel Change in South East Asia

Sea level is always fluctuation. The example of it is high and low tide because of moon gravitation that occurs every day. Fluctuation of sea level can also be affected by the topographic change because of density alteration (temperature and salinity), runoff, seasonal variety of sea level gradient and inter-ocean balance. There is also meteorological and oceanographic fluctuation caused by atmospheric pressure, wind, evaporation, precipitation, and El Nino-La Nina. Earthquake and sudden changes of earth surface can generate a tsunami which can cause sea level change. Even there is one very short period of sea level called seiches (standing wave).

There is much theory developed for long-term sea level change, as such Milankovitch Cycle Theory. This theory describes three things experienced by earth so generate climate change which later on resulting sea level change as the result of the difference in solar radiation on earth, called eccentricity, obliquity, and precession. Where in order to fulfill one cycle it needs tens to hundreds of thousands of years. Tjia and Mastura theory said that there are for factors that affect sea level change, there are sea volume, changes of an oceanic basin, sea water temperature changes, and geoid configuration [10]. Indirectly anthropogenic activities recorded at least two centuries ago since the industrial revolution speed up the change of these factors.

South East Asia has unique landscape as the effect of climate during Quaternary [11]. This geologic time specifically was written by Verstappen, Hope [11,3] even a lot of Holocene Period was written by Tjia and Mastura and Horton, et al [10,4]. Sea level fluctuation in the Huon Peninsula, Papua New Guinea based on dating using uranium-series in coral reef by Champbell and Shackleton [2], gave much information about mean sea level rise. High temperature correlated with sea level and low of oxygen (ration 18O-16O, the result shows high and low fluctuation between two peaks of an interglacial (8,000 and 125,000 BP).

Sidhàll et al (2006) in [10] show further sea level fluctuation in until 80,000 BP. During 80,000 BP until the present, there was nine occurrence of sea level rise and eight occurrences of sea level declining. The result from Sidhàll et al (2006) has the same pattern with [2] in the rise or declining of sea level which is reported by Chambell (135,000 BP-0). 135,000 BP is the peak of a Glacial period where the sea level was in -130 m, same as glasial 18,000 BP. The peak of interglacial around 125,000, where sea level was +6 m above present datum. Both presented the sealevel rising between two interglacial peak and slowly declining in the Glacial period 18,000 BP.

Study about Quaternary sea-level pioneered by Scrivenor (1931) in [10], which fluctuated between -100 below datum and rising up to +15 m. But Haile (1975) corrected that the max sea level in Quaternary was no more than +6m. If there was evidence showing more than +6m, it supposed to be the result of tectonic uplifting. This pro and contra continued until +5 m of sea level during Holocene were found in Malaysia Peninsula [10].

Publication by Geyh et al (1979) and Steif (1979) in [10]. As the result of dating from the shoreline in MalakaSrait in Post Last Glacial (Holocene). Sealevel started to rise at the beginning of Holocene (9,840 ± 300 BP) in -53.4 – -53.7 m below datum. Then in 4,000 BP rise up to +6 - +7m then declined up to -15m above 8,000 BP for several hundred years.

Malaysia Peninsula sea level construction curve from shoreline dating using radiometric by Tjia and Fujii (1922) in [10] show three area which has data distribution represent high and low sea level fluctuation. Sealevel change started in 6,000 BP and rose to reach the highest sea level in 4,500-3,600 BP as +4.5 m above present sea level. Then moderate sea level lasted for 600-700 years until 2,200 BP reached +2.8 m. Low sea level peak occurred in 3,000 BP (+4.5 m above
present sea level). Meanwhile, present sea level is lower than sea level peak during the middle period, that reached 2m above mean sea level.

De Klerk (1983) in [11] conducted a study in Southwest Celebes with stable tectonism. Time and water level rise are the same as described by [10]. Highest Holocene (+5m) occurs in 4,500 BP, followed by sea level declining until +3m around 3,000 BP and +1 m around 2,000 BP. Moreover, there was small rising between 2,000 and 700 BP (+2m) and between 1,500 and 1,000 BP (+1m).

The range of Holocene Period according to [4], minimum sea level (-22.15±0.55 m) took place in 9,700 – 9,250 BP. In Mid Holocene 4,850 – 4,450 BP went to 4.87±0.57 m. The average sea level rising 5.5 mm/year and the steady sea level declining was -1.1 mm/year. This model is in accordance with Geyh et al (1979) in [10]. Moreover, compared to [10], it is different because there is no evidence the occurrence of second sea level peak.

Even Horton et al [4], work with a limited sample, that condition was not affected by sample contamination or error. The difference in determining cold/warm and wet/dry variation concern the actual spatial differentiation (regional individuality). So, unjustifiably to extrapolating data for another region in order to generalize paleoclimatic condition [11].

1.3. Holocene Interglacial Fluctuation Evidence

Sea level fluctuation generating field evidence such as multilevel abrasion. Several mentioned by [10]. Landak Island: 3.5 m up to 4 and 1.7 m. Kijal Trengganu Island: 0.7m; 3.5m; and 5.5 m above present tide position. Pinang Island Southern Shore: 0.5m; 1.25m; and 2.3-2.4m above present highest tide. Sample dating in Pinang Island represents 2,420±80 BP for a sample taken in 0.7m and 3,110±100 BP for a sample taken in 1.5m. In Keluang Hill, Trengganu: In a row from the bottom up was a 0.7m platform; 1m notch; 1.25 platform and notch; 3m platform and notch. Oyster sampled from 3m was from 5,480±130 BP, meanwhile, organisms from 1.65m was from 24,070±70 BP. There is multilevel abrasion in Bangka Cape, Mersing Johor. The flat part above bedrock is 0.4-0.5m; then 1m; 2.24m; and 5, above high tide. Notch with fish-hook profile associated with low and middle abrasion level.

1.4. Cave Development

Cave developed in thousands and millions of years. Inside it, recorded the evidence of environmental condition during the development of the cave. The record can be seen from morphology, geochemistry, lithology, sediment, and speleothems. Stalagmites grow layer by layer very slowly from the deepwater falling from cave roof. The water falling from the roof had already contacted with atmosphere, soil, and a layer of rock before emerging in a conduit system, dripping as drip water. A stalagmite of uniform diameter is evidence of uniform growth rate over a long period of time, also implies that the stalagmites grew with uniform drip rates and chemistry [13].

Cave occur as a natural sediment trap, where water brings sediment into the cave through runoff and overland flow. This process left remarkable layers of sediment in cave floor. Detail inspection through each layer of sediment could reveal the past of the cave and its surrounding environment. Cave developed by dissolution of carbonate rock by aggressive water. The position and settings of the cave can trace back the initial condition during the development of the cave including the process of the development and factors controlling it.

Carbonate island has distinct characteristics compared to carbonate landscape inland. The same characteristic for both systems is the solutional process drive the forming of the landscape. While the inland karst cave development is driven by water movement from the surface to subsurface and by water table, carbonate island cave developed by mixing of salt and fresh water (mixing water). Cave formed by mixing water is called hypogenic cave [9], these caves lack sinking stream inputs or conduits carrying turbulent flow to discrete springs because they are uncoupled from the surface hydrology [7].
Furthermore, Carbonate Island Karst Model was developed, which emphasized on several principal aspects like mentioned below [7]:

1. Mixing of fresh water and seawater occurs at the fresh-water lens boundaries.
2. Glacio-eustasy has moved the fresh-water lens up and down over 100 m.
3. Local tectonic movement can overprint the glacio-eustatic sea level effects, adding complexity to the record.
4. The karst is eogenetic, i.e., it has developed in carbonate rocks that are young and have never been buried below the range of meteoric diagenesis.
5. Carbonate islands can be divided into four categories based on the basement/sea-level relationship.

Glacio-eustasy has repeatedly moved sea level vertically at least 130 m during the Quaternary in the tectonically stable setting of islands like Bermuda and the Bahamas. Therefore, the freshwater lens, and its dissolution environments has similarly migrated [7].

2. Method

2.1 Study Area

Karstic Island of Maratua-Kakaban Complex was chosen because of its tectonic stability and its position as a foremost island in Indonesia which represent socio-economic, military and defense strategic position. Maratua is situated in offshore of Berau-East Kalimantan, the location is shown in Fig 1.

![Figure 1. Study Location (Red Box)](image)

2.2 Types of equipment

Tools used in this research include field equipment and laboratory equipment. The main tools used in this research are listed in Table 1 below.

| Tools            | Function                      |
|------------------|-------------------------------|
| **Field Equipment** |                               |
| GPS              | Positioning                   |
| Telemetric laser | Cave mapping                 |
| Caving equipment | Cave mapping                 |
| Compass          | Mapping                       |
| Altimeter        | Positioning (elevation)       |
| Total station    | Positioning (elevation, coordinate) |
| Diving equipment | Cave mapping                 |
2.3. Data and Data Collection Technique

2.3.1. Evidence of Sea Level from Marine Terraces
Marine terraces are first interpreted from high-resolution ALOS satellite imagery. Interpretation then will be checked through fieldwork by using a total station. Important data will be collected during fieldwork is the elevation of terraces. Terrace elevation is the main data to understand the sea level still stand that ever happened during the Holocene. Preliminary interpretation shows that there are two marine terraces are encountered in Maratua Island.

2.3.2. Evidence of Sea Level from Marine Notch
Marine notches in coastal cliffs are indicators of relative sea-level change. Marine Notches will be identified in the field survey and plotted by using GPS. The position and elevation of marine notches are important to reconstruct the past environmental condition. Elevation of the notch will be identified through Total Station measurement.

2.3.3. Evidence of Sea Level from Cave Morphology
Cave develops near groundwater level, therefore cave level is associated with sea level still stand. This research will find sea level evidence from cave level and speleothems. Speleothems usually develop in the vadose zone. If stalagmite is inundated, it indicates that there has been sea level rise surrounding the area. Cave morphology data is plotted by GPS, and mapped by using compass, altimeter and telemetric laser ranging equipment. Caving with groups of research member is needed to accomplish the data. Cave diving is conducted to map the inundated cave

3. Finding and Discussion
The survey in Maratua-Kakaban Island encompassed surface and subsurface survey, regarding the endokarst and exokarst features. Endokarst and exokarst features also resemble the changes in Maratua-Kakaban Island environmental changes, especially the sea level change during Holocene.

Several caves and karst features found in the study area (Fig.2, there was also cave which is located under the present sea level. So many dolines also found scattered across the island which represents clearly the influence of marine process. Marine terraces found circling around the island, which indicated past sea level activities. Surface profiling was conducted in order to represent the surface configuration of the island-like illustrated in Fig 3. Maratua Island is separated by a lagoon which has a small island inside.

In order to give a relevance to the data, sea bottom profiling was also conducted to find the evidence of sea level changes submerged under the sea level. There are four tracks we used to obtain the data (shown in Fig.4). The tracks were chosen based on the area representation which we thought will produce the same pattern. Based on echo sounder data, four hypsography (Fig. 5-8) were created to represent the data.
Figure 2. Cave in Maratua (up) and Halo Tabung Cave, Kakaban (Bottom)

Figure 3. Surface Profile Across Maratua Island

Figure 4. Track for Underwater Profiling
Figure 5. Hypsography of Sea Depth in Track 1 (Maratua Lagoon)

Figure 6. Hypsography of Sea Depth in Track 2 (Maratua Terrace)

Figure 7. Hypsography of Sea Depth in Track 3 (Derawan-Pandjang Island)
Complete data as a basis to describe the sea level changes in Maratua-Kakaban is needed, so comprehensive analysis can be achieved. In order to do that, analysis of fossils is needed. Several fossils can be found throughout the area. Above the marine terrace in Maratua Island, so many *Tridagnasp* fossils can be found (Fig. 9). Many other fossils of the marine organism also found trapped in the sediments which are still easy to be recognized. It is an indication that the rock is still young.

Based on data analysis and literature study, Derawan and Maratua Island were built from Coralline Limestone during Holocene. Borneo Island came from Great Eurasia continent which was moved and form Java and Southern part of Borneo. This development continued during Pliocene by tectonics movements which causing Borneo Island uplifted, followed by Pleistocene when uncertain tides occur. Towards the Northeast, there is a fault zone which caused the uplifting of the old corraline basement which formed Derawan Islands. According to Bemmelen [1], Derawan Island which consists Maratua, seen from its physiography, is the Northwestern part of Borneo which is included in Borneo Island Shelf.

Study area had experienced a fold younger than Samarinda Fold. The Island encountered two folding, after Miocene and after Pliocene. The folding in Maratua then followed by uplifting. The younger folding occurs along the Northeast Coast of Borneo, it is along Sesayap River up to TanjungSelor Coast. Along with that coast, we can find viral and atoll in the offshore as a ruminant of young volcanism.

Based on the hypsography, we can interpret that there are two major marine terraces in the depth of 82 and 180 meters below present sea level. Based on the same hypsography, we can map the terraces as the ancient shoreline as a part of Borneo Shelf (Fig. 10). Interpretation of the map indicated that Kakaban-Maratua has already separated from Borneo main Island at least since the shoreline in the position of 180 m depth. The low water level 18000 years ago until reaching -180 m from present sea level caused Southeast Asia still in a form of the continent [10]. This stage is a part of MIS (Marine Isotopic Stages) 2. Another terrace found in 80 m below present sea level indicating the ancient
shoreline 400-5500 years ago [12]. 18000 years ago, Borneo still become a huge continent togerther with Java, Sumatra, and Malaya which is called Sunda Shelf. Based on study from [12], Sunda Shelf and Celebes Island were never become one continent.

Figure 10. Ancient Shoreline in Maratua-Kakaban Island

A geological condition in Maratua-Kakaban which is formed by limestone indicated that these Island used to be a shallow water or shelf. Past environment information can be traced back from fossils and old terraces found in ±6-9 m above present sea level (MIS 1). (Fig. 9). Bivalve fossils (Fig. 11) found scattered across the island, especially in the ancient terrace indicating that that place used to be a tidal flat with low energy waveor lagoon. Based on fossils found in the ancient terrace, Maratua Island developed in reef crest, lagoon, backreef, and forereef.

There are three island typology based on their forming. Reef, Coral, and Key Island. Reef Island formed by loose material from reef degradation. Island including in this category are Derawan, Sangalaki, and Semama Island. Coral island made up from massive carbonate rock. Maratua and Kakaban Island are the examples from this typology. As for Key Island Typology was formed by loose and fine sediment such as mud. The example of this type of island is Semut Island located in the middle if Maratua Lagoon. Based on this typology, it makes sense why only in Maratua and Kakaban Island we can find a cave. Because cave developed in thick and massive carbonate rock. Based on cave morphology we can determine the past environment condition during the development of the cave. The development of caves found in Maratua and Kakaban is controlled by structure and consist of a single passage. In Maratua, we can find a vertical cave in the ancient marine terrace. The passage continues below the present sea level (Fig.2 bottom).

Halo Tabung Cave is (Fig. 2 bottom) one of the evidence that there is sea level change controlling the development of the island. Cave formed in a thick and massive carbonate rock by the works of water. Several theories regarding the development of cave have been introducing by Mylroie in several publications. In carbonate island, most caves developed in the distal margin of freshwater lens, under the flank of the enclosing landmass, so they are called flank margin caves [6]. Halo Tabung used to develop above the seawater level, it means, during the development of Halo Tabung cave, the sea level located below present sea level. Cave developed in thousands and millions of years. Inside it, recorded the evidence of environmental condition during the development of the cave. The record can be seen from morphology, geochemistry, lithology, sediment, and speleothems. Stalagmites grow layer by layer very slowly from the deepwater falling from cave roof. The water falling from the roof had already contacted with atmosphere, soil, and a layer of rock before emerging in a conduit system, dripping as drip water. A stalagmites with uniform diameter is evidence of uniform growth rate over a long period of time, also implies that the stalagmites grew with uniform drip rates and chemistry [13]. So, it is important to crosscheck this preliminary result with evidence derived from cave speleothem in order to find the environment condition during the cave development. One of the important information is an atmospheric condition which correlated with an oceanographic condition.
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