

Carbonate sedimentology of Seribu Islands patch reef complex: a literature review

D A Utami¹ and A R Hakim²

¹ Geotechnology Research Center, Indonesian Institute of Sciences, Bandung 40135, Indonesia.

² Center for Integrated Research in Environmental Geoscience, Bandung Ocean Technology Research and Management, Bandung 40135, Indonesia

E-mail: dwi.amanda.utami@rwth-aachen.de

Abstract. Many oil and gas reservoirs in the world are reserved in fossil carbonate sediment. Knowledge of modern carbonate sedimentology is important for a better understanding of ancient carbonate sedimentation. Equatorial coral reefs comprise almost half of the world coral reef production, and yet their dynamics, distributions, and cycles are still not well understood. Contrary to their subtropical counterpart, South East Asian carbonate system is known to be strongly influenced by the combination of oceanographic and climatic conditions. Hence carbonate sediments in the tropics have a distinct depositional system, and ought to be treated differently since common distribution models were developed from the (sub-tropical) Atlantic and Pacific regions. This paper systematically summarizes carbonate sediment studies in Seribu Islands and its dominant oceanographic configuration to provide insights and a sense of research direction in the future.

1. Introduction

Major hydrocarbon production in the world is known from drowned carbonate reservoir. Recent carbonate sedimentation is a useful study that can lead to a better comprehension of fossil carbonate sediment. Interpretation of ancient carbonate, carbonate outcrop, carbonate reservoir interior, evaluation of porosity and permeability, are often built from modern carbonate sediment distribution model. Studies of modern carbonate sediment and platform are in abundance for these reasons. Most carbonate sediment studies are located in the Atlantic; the Florida Reef Tract [1,2], Belize atoll and barrier reefs [3, 4], Great Bahama Bank [5–7] and in the Pacific; Bikini Atoll [8], the Hawaiian chain [9,10], French Polynesia [11,12], Cook Islands [13], Great Barrier Reef [14], and South Pacific [15]. However, Southeast Asia equatorial carbonates are quite different from their subtropical counterparts e.g. abundance of coral and lack of non-skeletal grains, therefore they have to be re-examined as distinct depositional systems [16–18]. Studies of modern carbonate systems in Kepulauan Seribu typically focus on their biota and ecology [19–26], with only a few focusing on carbonate sedimentology [18, 27–29].

Almost half of the world's coral reefs production and greatest coral species diversity exist in modern equatorial carbonate of Southeast Asia [16,26,30,31]. The combination of oceanographic and temperature conditions, low marine salinities, major tectonism including back-arc, fore-arc, intra-arc, passive margins and foreland areas [32], elastics and nutrient influx, and relative sea-level changes, strongly affect local and regional Southeast Asia carbonate production [17]. Umbgrove was the first to recognize the influence of monsoon on reef development of Kepulauan Seribu [26]. The bimodal of



monsoon wind-driven current and wave climate exert significant influence on reef growth, and they are reflected on the islands geometry and more systematical development carbonate facies sediment.

Studies in Kepulauan Seribu, focused on carbonate sedimentation, have been conducted by previous workers [27-29]. Their study emphasizes on sediment depositional environment and carbonate facies and found a notably absent of coated grains which is notoriously in contrast with the Atlantic and Arabic-Persian Gulf [33,34]. Regional lithofacies map of Kepulauan Seribu [29] shows that the lithofacies is distributed in a series of concentric and some symmetrical band parallels to the near reef. Recent sediment studies proved that the long-held sediment pattern concept has evolved from simple concentric-parallel to a diverse scheme due to the complex suite of an autogenic factor [35,36]. Therefore, a more up to date and detailed study of sediment in Kepulauan Seribu is needed for this reason. This literature is aimed to systematically summarize carbonate sediment studies in the Kepulauan Seribu and to provide insights and sense of research direction in the future.

2. Sedimentology and Environment Configuration

Kepulauan Seribu is a chain of reef islands located in the Java Sea, north of Jakarta. It is believed to be patch reef complexes consist of about 400 platforms in which about a quarter of them possess a coral island/cay [37]. The physiography of Kepulauan Seribu consists of sand cay, reef flat, lagoon, 'growing edge', reef slope, and channel [27]. Development of carbonate sand shoals and patch reef in the Java Sea start on the NNE-SSW oriented ridges incised by the Holocene transgression, while higher energy current transported detritus off the platform contribute to maintaining the relief, geometry, and build up distribution in the Kepulauan Seribu [18]. [28] assure that the proclaim NNE – SSW trend within the platform is not fault related though [38] believed that the eastern margin of Kepulauan Seribu is surrounded by the still active Seribu Fault, also known as Thousand Island Fault with basement fault scarp dips into the Sunda Basin. Kepulauan Seribu reef growth model is considered to be reef frame with flattened inverted cone which only occupies a very small proportion of the total sediment, while for the bulk sediment is the reef flank and reef flat sediments which mostly generated from growing edges [27]. Umbgrove was the first precursor of reef sediment study in Kepulauan Seribu and noticed the coral rich diversity in the area [26], followed by later works that provided detailed account of the coral communities present in the Seribu Island [39,40]. The first modern attempts to study carbonate sediment in Kepulauan Seribu were established by Ongkosongo et al. [40]. Major carbonate facies in Kepulauan Seribu were mapped based on grab sample and dive by Scrutton [27] and Jordan [29], complemented by Park et al. [28] to give insight of the carbonate vertical growth in Kepulauan Seribu from sediment cores study.

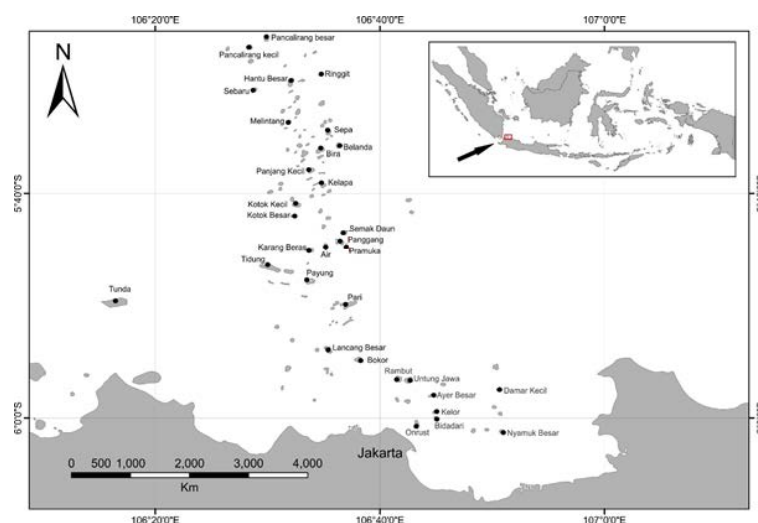


Figure 1. Kepulauan Seribu complex in Java Sea.

The morphology of Kepulauan Seribu is closely spaced reefs in the northern part and a large reef in the southern part, with consistent steep, generally excess 75 degree reef flank [27]. Based on systematical sample data collected from a series of traverses across four islands in Kepulauan Seribu, [27] revealed sediment of Kepulauan Seribu composed mainly of skeletal grain, mostly coral and mollusk. Red algae and green algae also present as minor constituents, with calcified green algae, *Halimeda*, that are common and less red algae emerge as encrusting growth on a piece of coral or mollusk shell. Echinoid and foraminifera present about 2–3% from total sediment component. The echinoid generally robust, thick spine reefal variety but test is rapidly broken leaving the only fragment to remain. The foraminiferas are usually whole and include a variety of the genera characteristic on Indo-Pacific reef such as *Amphistegina*, *Homotrema*, *Calcarina*, *Peneroplis*, *Miliolids*, *Elphidium*, and *Marginopora*. Carbonate mud is restricted in occurrence which is only in the deepest part of the lagoon and its origin is uncertain, whether it is derived from degradation of skeletal grains on the reef flat, bacterial induced precipitation, or disintegration of codiacean green algae. The presence of non-skeletal grains is restricted to only rare pellets and aggregates due to the cementing together of grains by red algae or Serpulid. The dominant sedimentary facies in Kepulauan Seribu [27] are Coral – Mollusk Facies, Coral – Halimeda Facies, and Shelf Facies. The Coral – Mollusk Facies is deposited on the reef top, including sand cay, reef flat, and lagoon. This facies consist of skeletal sand and gravel, with corals make 30–70% of the total constituent, mollusk 10–50%, and the rest are abraded grain. The Coral – Halimeda Facies is on the reef flank; composed of 80% coral, dominant mollusk, and 20–50% *Halimeda*. This facies is typically poor sorting and grains abrasion is absent. The Shelf Facies is located in the inter-reef which forms limit of the reefal facies. This facies consists of shell debris with notable mollusk, echinoids, and foraminifera. The faunal assemblages in Shelf Facies are more delicate bivalves shell, foraminifera, and small thin spin burrowing echinoid.

Kepulauan Seribu is classified as middle shelf patch reef complex [29,41]. Kepulauan Seribu manifests itself as a Holocene stage of periodic reef growth that occurs on the edge of a fault block on the Sunda Shelf [29]. Reef-related depositional environments occur in Kepulauan seribu are island and shoals, reef flat, reef flat lagoons, reef and small crags of reef growth, and reef sediment slopes, interreef lagoon, and middle shelf [29]. Based on 300 bottom samples, sediments in Kepulauan Seribu have been analyzed by using “lithofacies”; a terminology in the sense that unconsolidated sediments are mapped as equivalent rock types with equivalent terminology: reef facies, near reef facies, interreef lagoonal facies, middle shelf, and inner shelf [29]. The Reef Facies is coral encrusting red algae boundstone with an infilling matrix of coral mixed skeletal packstone consist of organic framework with an interstitial fill of muddy sediment. The distribution of reef facies corresponds to the size and shape of the platform. The Near Reef Facies is coral mixed skeletal grainstones with branching coral fragments and coral benthonic foraminiferal packstones with branching coral fragments, which exist in the near reef environments include reef top sediments and reef sediment slope deposit, and characterized by coarsest and purest carbonate sediment along with sand apron and coral debris. The Inter-reef Lagoonal Facies is argillaceous foraminiferal molluscan packstone with goethite nodules, typified by its content of mud (over two-third of which is terrigenous), goethite nodules, argillaceous material, and faunal constituent. The Middle Shelf Facies is the arenaceous benthonic foraminiferal molluscan shales with goethite nodules, consist of terrigenous muds rich in foraminifera and mollusks (with associated goethite nodules) and some of the sediments are rich in volcanic sands. The Inner ShelfFacies is mollusk bearing shales which contain less than 10% carbonate material, dominated by silt and clay size grain sediment.

Another perspective of vertical carbonate accumulation is given based on 3 shallow cores from 2 islands in Kepulauan Seribu [28]. The sediment in the cores is coral dominated with minor red algae, green algae and lack of fines. The present Java Sea is the product of an early Holocene transgression [28]. 8,000 years BP connection to the Java Sea is forged. Pattern of slight fall in sea level from the highest Holocene level dated at about 4,000 years BP and confirm by coral dating 4440 years BP. Evidence from all cores from both islands for thick build up in the 25-30m core was interpreted to be

the Pleistocene/early Holocene storm and tidal currents, accumulated reef-fall carbonate sediment since initial post-Pleistocene transgression 10,000 years ago. Based on the coral, two sequences of sedimentation can be inferred. The first sequence is from 0–20m when the Wisconsin glacial rise in sea level outpaced reef development marked by terrigenous, muddy, skeletal sand with limited coral representing earliest patchy reef growth 10,000–7,000 years BP. The second sequence is from >20–32.8m when the period of reef growth dominance as the rate of post glacial sea level rise (ca. 4,500 years BP) pronounced by proliferated Coral sp and more evidence of skeletal grainstone/rudstone. It can be inferred from [28] that reefal carbonate build ups are characterized by initially high rates of vertical growth 5 – 10mm/years followed by outbuilding and reef enlargement as the response for Holocene sea level rise.

Many believe that monsoon plays an important role in the sedimentation process in Kepulauan Seribu. Umbgrove was the first to recognize the influence of monsoon on reef development in Kepulauan Seribu [26]. His conclusion was based on his observation of an asymmetric development of reef flat and sand cays around some islands along the southwest coasts of Java and Sumatra. Investigation of Poerbandono shows that many sand cays in Kepulauan Seribu is at risk of erosion due to unequal balance of monsoon wind force [37]. The occurrence of east monsoon wind is predominant, but the hypothetical bed shear stresses from west monsoon winds are beyond the range critical values for erosion [37]. Even so, the persistence of east monsoon wind is thought to dominate the process of sediment transport and overwhelms the extreme wind magnitudes during monsoon which would result in an inequitable shift of cay beach sands between the two opposing monsoons [37]. Monsoonal storms do create much chopiness but their short periodicity and low amplitude suggest they are unlikely to affect the sea bottom, although a combination of storm and wave energy may do so [28].

Furthermore, the heavy monsoonal rains is responsible for the large volume of sediment discharge onto Sunda Shelf, which may dilute carbonate accumulation, or more commonly overwhelmed completely through suffocation of the filter feeding coral community [18].

Table 1. A tabular summary of sedimentology in Kep. Seribu classified mainly into three categories.

Depositional environment [27]		Facies [27]		3rd dimension (core) [18]
Sand cay Present on most of the reefs, consist of wave and wind accumulated skeletal sand deposits	Island Low lying, with max elevation 3m above sea level	Coral-Mollusk facies (reef top) Characterized by sediments comprised of skeletal sands and gravels	Reef facies Consist of an organic framework with an interstitial fill of muddy sediment	31.5m Post Pleistocene unconformity surface marked by sharp boundary and color changes
Reef flat Area of very shallow water shelving gently from the beaches to a depth 1-3m on the deepest part	Reef flat Usually exposed during low tide	Coral – <i>Halimeda</i> facies (reef flank) Coral comprise more than 80%, <i>Halimeda</i> is common although patchy	Near reef facies Include reef flat, beaches/island, and reef flat lagoon which are characterized by relatively coarsest and purest carbonate sediment available	20m – 31.5m Coral proliferate, skeletal grainstone and rudstone more evidence, marks the transition of dominance reef growth as the rate of post glacial rise in sea level
Growing edge Typified by prolific growth of living coral. Relatively restricted area marking the break between reef flat and steep reef slope	Reefs Grow to extend from sea level down to about 15m, form a steep reef slope	Shelf facies (inter reef) Silty clays with significant shell debris, notably mollusk, echinoid, and foram	Inter reef lagoonal facies Typified by its content of mud, goethite nodule,	Lower part – 20m Terrigenous, muddy, skeletal sand. Contain limited range of coral,

Reef slope Dramatic drop from the growing edge down to the sea floor. Average 70-75deg, but locally steeper	Reef sediment slope The base of continuous reef development	argillaceous material, and faunal constituent Middle shelf Rich in foraminifera and mollusks, some of them rich in volcanic sand	represent earliest patchy reef growth 10.000 – 7.000 years BP when the Wisconsin glacial rise in sea level outpaced carbonate bank/reef development.
Lagoon Develop on many of the coral reefs. Bottom profiles are gently shelving down to max reported 12m	Inter reef lagoon Deeper waters between reefs	Inner shelf Contain <10% carbonate material, dominated by grain size silt and clay	
Intra platform channel Narrow channel separating reefs which are so close together	Middle shelf Consist of terrigenous mud deposition		

3. Summary

Carbonate sediment in Kepulauan Seribu mainly composed of skeletal components dominated by coral fragments, with abundant mollusk shells, *Halimeda* flakes, echinoderm spines, red algae, and foraminifera tests. Non-skeletal grains are very rare, restricted to only aggregates and fecal pellet with no ooid present; which differentiate carbonate in Kepulauan Seribu with its Pacific and Atlantic carbonate counterpart. The bimodal of monsoon wind-driven current and wave climate exert significant influence on reef growth, and they are reflected on the Kepulauan Seribu islands geometry and more systematical development carbonate facies sediment. Recent Kepulauan Seribu carbonate research with more detail sediment data and a different approach is necessary to enrich our understanding of tropical SE Asia carbonate system.

Acknowledgments

The authors are grateful to Lediyanca Lintjewas for support during poster presentation at GCGE 2017 Conference. We thank GCGE 2017 Committee and an anonymous reviewer for their comments that improved this paper.

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