Grain size and mineralogical characteristics of reef island sediments in Spermonde Archipelago, Indonesia

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Abstract. This is one of the initiatory studies focusing on grain size and mineral composition of the sediments from islands in the Spermonde Archipelago. The zonation area is represented by four islands in the Spermonde Archipelago: Kayangan Island, Barrang Lompo Island, Kodingareng Lompo Island, and Langkai Island. Sediment samples were collected from the four determined locations with three depth variations for each site (0.5, 1.0 and 1.5 m). The study utilized sediment texture analysis to investigate the physical characteristic of sediments, by applying X-Ray Fluoresence (XRF) for the mineral components exploration. The results revealed the dominance of coarse sand in the sediments from the Spermonde Islands. The identified minerals in the sediment composition are: CaO, SiO, MgO, SrO, TiO_2 and Fe_2O_3. CaO is the most abundant, likely due to the carbonate-producing organisms.
Key Words: carbonate sediments, grain size, X-Ray Fluorescence, reef island.

Introduction. Coral islands are usually formed from the calcareous sediments that lean on the platforms of a conglomerate of petrified corals. The coral construction is biologically formed from surrounding corals. Formation of coral islands passes through 3 pathways, namely: 1) Debris and dead coral sediment accumulate on top of coral reefs through wave and storm, 2) The coral reefs gradually appear due to relative decline in sea level and 3) The seabed beneath the reef is slowly upraised. The tectonic uplift of the coral substrate can produce coral reef islands sizing up to hundreds of meters in diameter (Solihuddin 2017; Muller-Parker 2005).

Coral reef ecosystems are easily found around the coral islands. These ecosystems are provide food and shelter for many organisms, which maintains the coastal and marine areas natural resources and economic value (Aswita et al 2020; Xin et al 2016). On the other hand, however, the climate change and sea level rise are among the concerns that could affect the coral islands in the future.

Coral Islands in Indonesia are usually lowlands, rarely more than 2-3 m above mean sea level, and are composed of calcareous sediments from damaged coral, coralline algae and other carbonate-producing organisms from surrounding coral reefs (Kench & Mann 2017).

Spermonde Archipelago (4°00'S – 6°00'S and 119°00'E – 119°30'E) is located in the southwest of South Sulawesi Province. The archipelago consists of coral islands formed on flat coral reefs localized in shallow marine carbonate platforms (Suriamihardja 2011; Kench & Mann 2017). This archipelago is rich in coral diversity: about 78 genera and sub-genera with a total of 262 species have been identified in the zone. Hutchinson (1945) classified the Spermonde Archipelago with regard to the distribution of its coral reefs. The first zone (inner zone) is the closest zone to the mainland of Sulawesi and is dominated by muddy sand in the bottom substrate. The second zone (middle inner zone) is about 5 km from the mainland of Sulawesi, where the coral reefs are frequent. The third zone (middle inner zone) is about 12.5 km from the mainland where many submerged coral reefs can be found. The fourth zone (outer zone) is about 30 km from the mainland of Sulawesi and includes a coral reef barrier.

The sedimentary characteristics of coral islands are closely related to the boundary between the past and the present. Changes in the control of physical, chemical and biological boundaries can affect the stability of coral islands and the climatic factors. Changes over time can be well documented in the coral reef sediment records. Better knowledge of geomorphology and sedimentology is expected to help improve understanding of the island's response to future changes. However, studies on the sedimentology and geomorphology of the coral islands of the Spermonde Archipelago are very rare (Janßen et al 2017). Therefore, a deeper study of the sedimentology of the Spermonde Archipelago is necessary.

The sedimentological analysis is performed by determining the size of various particles and the chemical composition of an unconsolidated sediment, in order to collect data regarding the conditions of deposition, the sediment origin, the type of environment and the energy associated with the transport mechanism at the time of deposition (Lopez 2017). In the current study, we present the results of a preliminary investigation of sediment physical characteristic studies and mineral contents of sediments from every representing zone of the Spermonde Archipelago (the inner zone, the middle inner zone, the middle outer zone and the outer zone), with the aim to provide implications for the usefulness of sedimentological studies in terms of reconstructions of the environmental and anthropogenic history of islands in the Spermonde Archipelago and similar settings.

Material and Method

Description of the study site. This is a detailed study of the sedimentology of four islands located in the Spermonde Archipelago (Figure 1), namely Kayangan Island, Barrang Lompo Island, Kodingareng Lompo Island, and Langkai Island. The listed islands are vegetated (Kench & Mann 2017).

Kayangan Island is included in the inner zone of the Spermonde Archipelago with an area of 2.6 ha and the sampling location is at S: 05.114248°; 119.400269°. Barrang Lompo Island is a part of the middle inner zone of the Spermonde Archipelago with an area of 12.5 ha and the sampling location is at S: 05.04929°; E: 119.32918°. Kodingareng Lompo island represents the middle outer of the Spermonde Archipelago, with an area of 14.4 ha, and the sampling location is S: 05.14822°; E: 119.26516°. Langkai Island belongs to the outer zone of Spermonde Archipelago, with an area of 16.2 ha, and the sampling location is S: 05.03237°; E: 119.09522°.

Sediment sampling for each island was carried out in the middle of the respective island. Position sampling used a handheld Global Positioning System (Garmin 78S GPSMAP). Each point was excavated with gaps of 0.5, 1 and 1.5 m depth, where the depth from the island's surface was measured using a roll meter. Next, the samples were inserted into sample bag that being tagged according to the origin site and taken to the laboratory.

Sediment sampling and sediment sample analysis were performed during September 2018–December 2020. Sample analysis was carried out at the Water Productivity & Quality Laboratory, Faculty of Marine Sciences and Fisheries, Hasanuddin University and at the Radiation Chemistry Laboratory and XRD & XRF Laboratory, Faculty of Mathematics and Natural Sciences, Hasanuddin University.

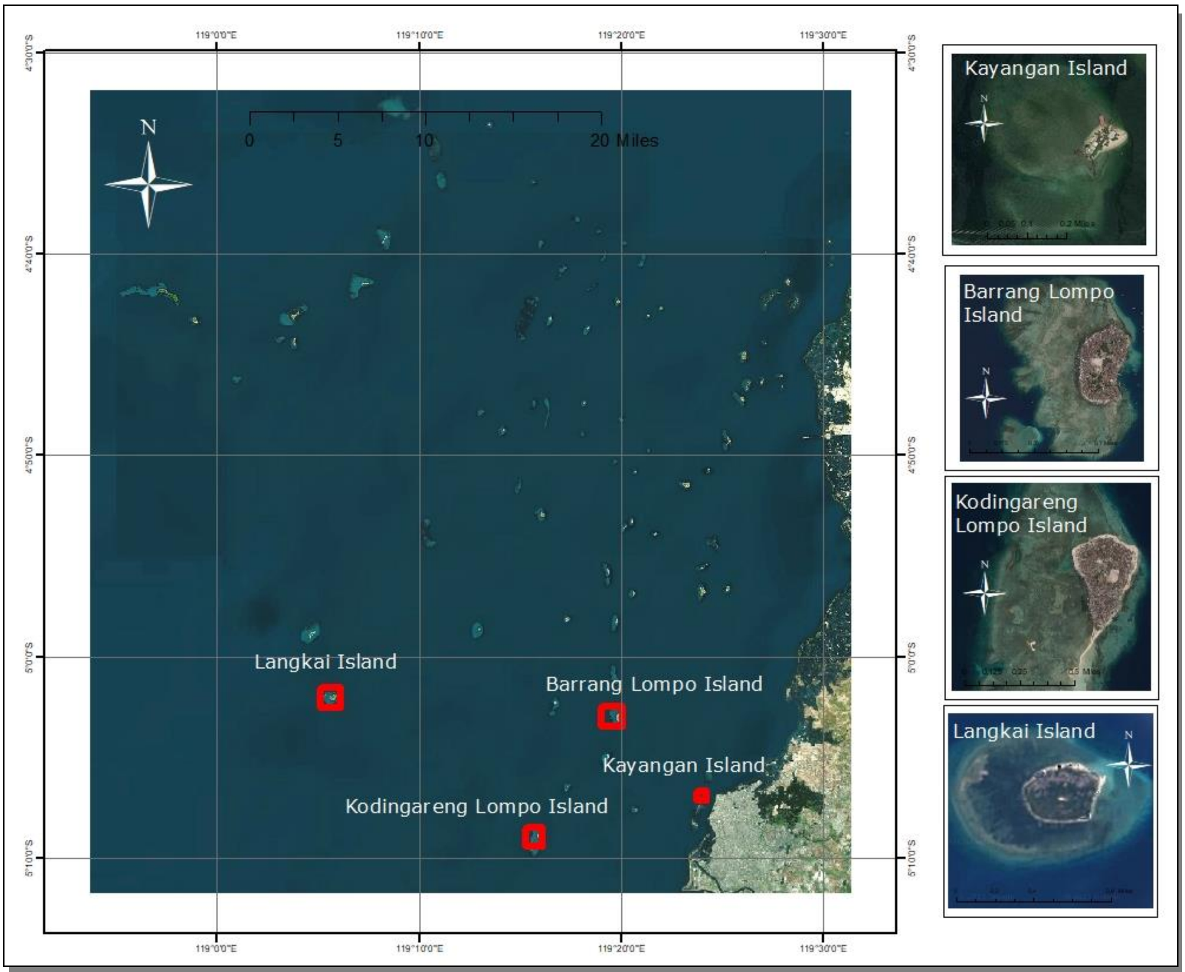


Figure 1. Spermonde Archipelago. Parts marked with red boxes (left) are the sampling sites (right).

Sediment texture analysis. The sediments were dried in the oven at 40°C for 48 hours (Janßen et al 2017). The sediments separation based on grain size was performed using a stratified dry sieving device (ASTM-E11 Prüf-Sieb). The sieving process applied the mesh sizes: >2,000 μm; 2,000-1,000 μm; 1,000-500 μm; 500-250 μm; 250-125 μm; 125-63 μm and <63 μm. The sediment classification (gravel, very coarse sand, coarse sand, medium sand, fine sand, very fine sand and silt) followed Wenworth (1922) by applying three replicates for each source of samples (Table 1). The classification aimed to holistically depict the physical characteristic of sediments based on the predominance, textural group identification and sorting of sediment (Janßen et al 2017). Distribution of sediment's grain size is explained based on the physical parameter (Das 2016; Okeyode & Jibiri 2013):

Average size of sediment's grain

$$Mz = \frac{Ø_{16}+Ø_{50}+Ø_{84}}{3}$$

Standard deviation

$$SD\ (\sigma_I) = \frac{Ø_{84}-Ø_{16}}{4} + \frac{Ø_{95}-Ø_{5}}{6.6}$$

Table 1
Suggested descriptive terminology of sediment classification (Folk & Ward 1957)

Sorting (σ_1)	
Very well sorted	<0.35
Well sorted	0.35-0.50
Moderately well sorted	0.50-0.70
Moderately sorted	0.70-1.00
Poorly sorted	1.00-2.00
Very poorly sorted	2.00-4.00
Extremely poorly sorted	>4.00

Sediment analysis using XRF. Crushed samples were compressed under high pressure for several minutes to form measured pellet (Meftah & Mahboub 2019). Furthermore, the sample analysis employed a Thermo Fisher Scientific ARL QUANT'X EDXRF Analyzer.

Statistical analysis. A statistical evaluation was run by applying the GRADISTAT Program (Blott & Pye 2001).

Results

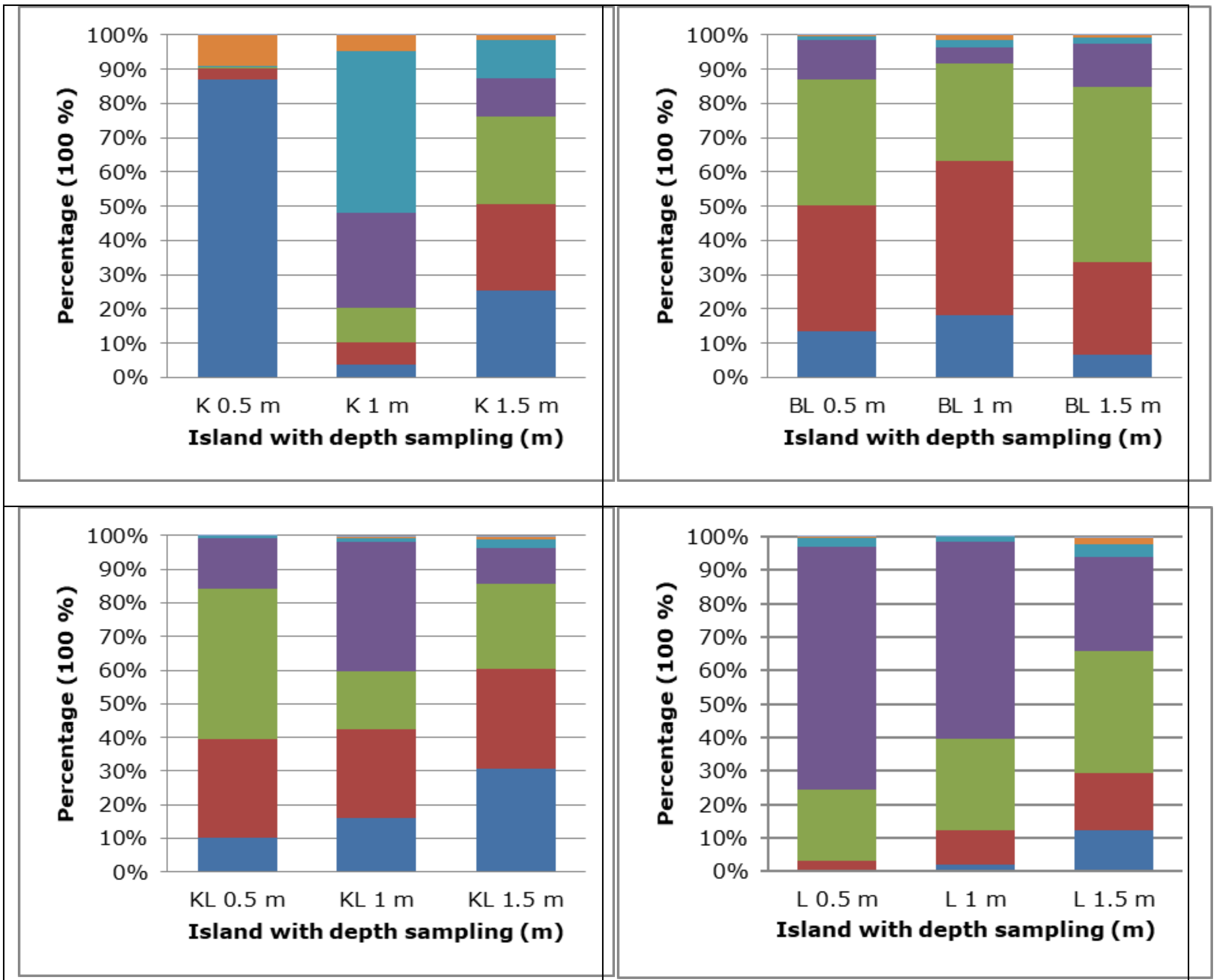
Sediment texture analysis. The sediment grain-size characteristic indicates the gravel-to-fine sand size distribution. The texture of all collected samples was identified: coarse sand dominates the grain-size, while fine sand is the least size. In the following, the physical sediment characteristics of several islands for every depth are described in detail.

Kayangan Island. The grain size distribution of the Kayangan Island sediments is dominated by gravel at a depth of 0.5 m (>2,000 μm), by fine sand at 1 m depth (125-250 μm) and by coarse sand at 1.5 m depth (500-1,000 μm) (Figure 2). For the textural groups of various depths, to the depth of 0.5 m corresponds gravel, to 1 m depth corresponds slightly gravelly sand and to 1.5 m depth gravelly sand (Table 1). Referring to sorting, sediment at a depth of 0.5 m includes moderately sorted sediment, 1.0 m depth is poorly sorted sediment, and 1.5 m depth is classified as poorly sorted sediment.

Barrang Lompo Island. Barrang Lompo Island (Figure 2) has a predominance of coarse sand (500-1,000 μm) in samples from depths of 0.5 m and 1.5 m, while the sample from a depth of 1 m is dominated by very coarse sand (1,000-2,000 μm). The textural group identification in the sediments indicates gravelly sand for all depths samples (Table 1). Based on the sorting, all depths sediment samples are moderately sorted.

Kodingareng Lompo Island*.* On Kodingareng Lompo Island (Figure 2), the sediments originating from a depth of 0.5, 1 and 1.5 m are dominated by coarse sand (500-1,000 μm), medium sand and very coarse sand, respectively. The textural group of the identified sediment samples is dominated by gravelly sand, found at the depths of 0.5 m and 1 m, and by sandy gravel, at a depth of 1.5 m (Table 1). Sorting identification classifies the sediments from the two highest depths as poorly sorted, while the deepest sediment remains moderately sorted.

Langkai Island*.* Sediments from Langkai island are dominated by medium sand (250-500 μm) at the depths of 0.5 m and 1 m and by coarse sand (500-1,000 μm) at a depth of 1.5 m. Textural group of the 0.5 and 1 m depth samples were identified as slightly gravelly sand and samples from 1.5 m depth as gravelly sand (Table 1). Based on the sorting, at the depths of 0.5, 1 and 1.5 m there are well sorted, moderately well sorted and poorly sorted sediments, respectively.



K = Kayangan Island	BL = Barrang Lompo Island	KL = Kodingareng Lompo Island
L = Langkai Island		
Silt (<63 μm)	Medium sand (250-500 μm)	Gravel (>2,000 μm)
Very fine sand (63-125 μm)	Coarse sand (500-1,000 μm)	
Fine sand (125-250 μm)	Very coarse sand (1,000-2,000 μm)	

Figure 2. Grain size percentage of the sediments obtained from the sampling sites.

Table 1

Grain size distribution of sediments from sampling sites

(Origin) Island	*Depth (m)*	*Mean grain size (μm)*	*SD (μm)*	*Textural group*	*Grain distribution (μm)**
Kayangan	0.5	2,308.4	1.837	Gravel	2,694.0
Kayangan	1	2,41.9	2.053	Slightly gravelly sand	1,022.1
Kayangan	1.5	859.0	2.633	Gravelly sand	2,451.1
Barrang Lompo	0.5	889.9	1.776	Gravelly sand	2,178.1
Barrang Lompo	1	1,080.1	1.949	Gravelly sand	2,323.6
Barrang Lompo	1.5	735.5	1.724	Gravelly sand	1,342.9
Kodingareng Lompo	0.5	753.2	1.760	Gravelly sand	2,001.1
Kodingareng Lompo	1	701.6	2.301	Gravelly sand	2,270.1
Kodingareng Lompo	1.5	1,106.4	2.079	Sandy gravel	2,509.0
Langkai	0.5	363.2	1.410	Slightly gravelly sand	632.9
Langkai	1	394.8	1.602	Slightly gravelly sand	1,080.7
Langkai	1.5	598.5	2.213	Gravelly sand	2,134.5

* D90 percentile average.

Sediment analysis using XRF. X-ray Fluorescence Spectrometry (XRF) was utilized to determine the elemental composition (%) in the form of oxide compounds (Oyedotun 2016).

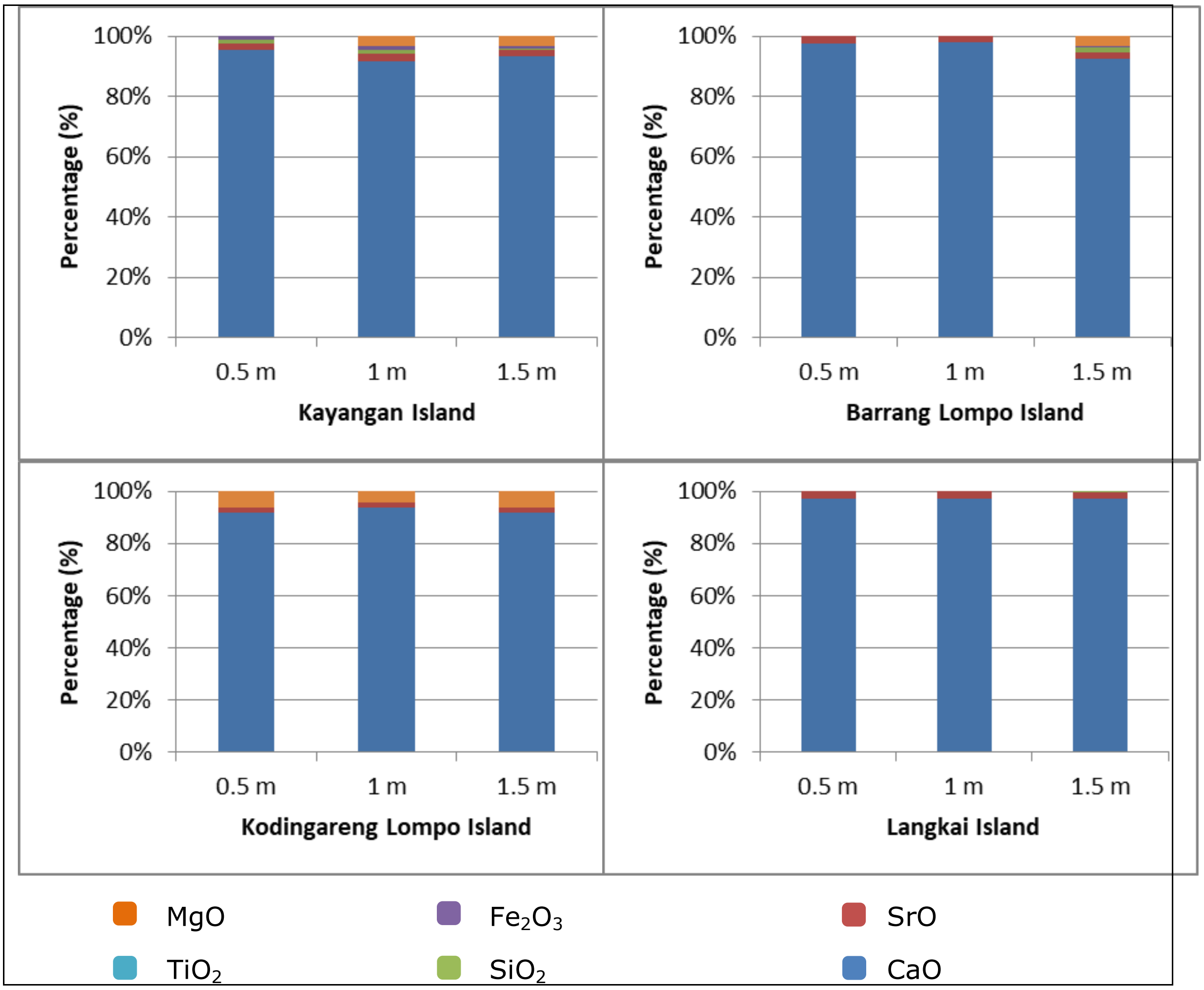


Figure 3. Chemical composition of sediments from Spermonde Archipelago.

According to Figure 3, the sampled sediments in the four islands contain CaO, SrO, SiO_2, Fe_2O_3, TiO_2 and MgO. The samples from Kayangan Island and Barrang Lompo Island contain all these oxides, while in the samples from Kodingareng Lompo Island there were identified CaO, SrO and MgO, and in those from Langkai Island were found CaO, SrO, SiO_2 and TiO_2, CaO had the highest overall.

Discussion

Sediment texture analysis. Table 1 presents sediments with varying grain sizes (expressed in D90 values) obtained from Kayangan Island, Barrang Lompo Island, Kodingareng Lompo Island, and Langkai Island with a depth of 0.5, 1 and 1.5 m. This could indicate excessive deposition of sediment which led to the formation of islands. Similar data were also obtained by Janβen et al (2017), on Panamgangang Island, Tambakulu Island, Suranti Island and Panambungan Island which are included in the Spermonde Archipelago. The difference in average sediment size and sorting can be caused by oceanographic conditions and the sediment deposition process in the Spermonde Archipelago (Wang et al 2020). During the deposition process, corals form irregular spherical sediments or sticks, and calcareous algae such as *Halimeda* form flat plate sediments. The coral and *Halimeda* were damaged differently under mechanical stress, the entire *Acropora* colony broke into trunks and then immediately became sand, while the *Halimeda* plate broke first into two or three fragments and then became dust (Jones & Edean 1977).

Composition. Several components such as the bodies of carbonate-producing organisms, shells, skeletons, scleractinian corals, *Halimeda*, *Penicillus*, red-calcareous algae, mollusks, foraminifera and echinoderms are often found in the reef sediments. Fragments of spongy, tunicate or octocoral spicules, brachiopod shells, bryozoa, serpulids and crustacean carapace are occasionally found. Pelagic organisms such as planktonic foraminifera and coccoliths can also be found occasionally (rarely) in very small amounts in reef sediments (Gischler 2011).

Various types of coral are found in the Spermonde Archipelago, such as *Acropora formosa*, *Seriatopora stellate*, *Acropora stellate*, *Acropora macrostoma*, *Acropora sarmentosa*, *Porites columnaris*, and *Porites mayeri* (Nurdin et al 2015). These species allegedly play an important role in the formation of coral islands in the Spermonde Archipelago. Muller-Parker (2005) stated that coral islands consist of coral skeletons originating from coral reefs adjacent to the island.

Chemical composition of sediment. Figure 3 illustrates that the most abundant compound in the sediments from the studied locations is CaO, which can be derived from the carbonate-producing organisms ($CaCO_3$). The major producers of carbonate in marine environments are the hard corals, crustose, coralline algae and halimeda (Hamylton 2014). The content of CaO, SrO, SiO_2, Fe_2O_3, TiO_2 and MgO can also originate from the sea water which is carried along with the sediment, during the sediment deposition process. Li & Schoonmaker (2003) quantified the content of several important minerals (such as Ca, Sr, Si, Fe, Ti and Mg) in the sea water.

The presence of Mg and $CaCO_3$ in the sediments is also likely originating from shellfish. He et al (2019) found significant Ca, C, Na, F, Mg, Al, S and Br in the inner sample of *Mactra veneriformis* shells analyzed using the Scanning Electron Microscopy with Energy Dispersive Spectroscopy (SEM-EDS). Diatom also allegedly contributes the presence of Si in the sediments. Some diatom species that contain silica are *Bacteriastrum furcatum*, *Chaetoceros convolutes*, *Chaetoceros pelagicus*, *Chaetoceros* sp. I cf. *vixvisibilis*, *Chaetoceros* sp. 2, *Chaetoceros* sp. 3, *Corethron criophilum*, *Coscinodiscus granii*, *Hemiaulus sinensis*, *Lauderia borealis*, *Leptocylindrus danicus*, *Rhizosolenia alata*, *S. costatum*, *Stephanopyxis palmeriana*, *Thalassiosira aestivalis*, *Thalassiosira oceanica*, *Thalassiosira nordenskioeldii*, *Thalassiosira partheneia*, *T. pseudonana*, and *Thalassiosira rotula* (Conley & Kilham 1989). Future studies on the geomorphology and sedimentology of coral islands and their response to changes are required (Janβen et al 2017).

Conclusions. Coarse sand dominates the characteristic physics of sediments on several islands in the Spermonde Archipelago. The difference in sediment characteristics of each zone in the Spermonde Archipelago remains unclear, thus, more sampling locations to better represent the sediment characteristics of the Spermonde Islands is important in the future. The mineral content found in Spermonde Archipelago are CaO, SiO, MgO, SrO TiO_2 and Fe_2O_3. CaO is the most abundant mineral found in the islands which can be derived from carbonate-producing organisms, so that it becomes a crucial mineral in the formation of Spermonde Archipelago.

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Conflict of interest. The authors declare no conflict of interest.

References

Aswita D., Suryadarma I. G. P., Suyanto S., Herawan T., 2020 The natural resources potency of marine ecotourism as an environmental education source. GeoJournal of tourism and Geosites 31(3):996-1003.

Blott S. J., Pye K., 2001 GRADISTAT: a grain size distribution and statistics package for the analysis of unconsolidated sediments. Earth Surface Processes and Landforms 26:1237-1248.
Conley J. D., Kilham S. K., 1989 Differences in silica content between marine and freshwater diatoms. Limnology and Oceanography 34(1):205-213.
Das G. K., 2016 Sediment grain size. In: Encyclopedia of estuaries (Encyclopedia of earth science). Michael J. K. (ed), Springer Reference, 576 p.
Folk R. L., Ward W. C., 1957 Brazos river bar: a study in the significance of grain size parameters. Journal of Sedimentary Petrology 27:3–26.
Gischler E., 2011 Sediment properties. In: Encyclopedia of modern coral reef. Hopley D. (ed), Springer Science, 1005 p.
Hamylton S., 2014 Will coral islands maintain their growth over the next century? A deterministic model of sediment availability at lady Elliot Island, great barrier reef. PLOS ONE 9(4): e94067, doi:10.1371/journal.pone.0094067.
He C., Zhang B., Wei L., Yu W., Jiang Q., Wang X., Guo W., Wang W., 2019 Silicon dioxide (SiO_2) is the most important component of spots on the inner surface of *Mactra veneriformis* shells. Frontiers in Marine Science 6(651):1-8.
Hutchinson D. R., 1945 Coral reef and cays of the Makassar Straits. Headquarters Allied Air Forces, Intelligence Memorandum, 82 p.
Janßen A., Wizemann A., Klicpera A., Satari D. Y., Westphal H., Mann T., 2017 Sediment composition and facies of coral reef islands in the Spermonde Archipelago, Indonesia. Frontiers in Marine Science 4(144):1-13.
Jones O. A., Edean R., 1977 Biology and geology of coral reefs. Academic Press, USA, 84 p.
Kench P. S., Mann T., 2017 Reef island evolution and dynamic: insights from the Indian and pacific oceans and perspectives for the Spermonde Archipelago. Frontiers in Marine Science 4(145):1-17.
Li Y.-H., Schoonmaker J. E., 2003 Treatise on geochemistry, chemical composition and mineralogy of marine sediments. Elsevier, 35 p.
Lopez G. I., 2017 Grain size analysis. In: encyclopedia of geoarchaeology. Gilbert A. S. (ed), Springer, New York, 341 p.
Meftah N., Mahboub M. S., 2019 Spectroscopic characterizations of sand dunes minerals of El-Oued (Northeast Algerian Sahara) by FTIR, XRF and XRD analyses. Silicon 12:147-153.
Muliawan A., Jumardi R., Fernando R., Lutfi M., 2019 comparison analysis of kanaan sand, loktunggul sand, and sambera sand using the methods of XRD and XRF. Journal of Physics: Conference Series 1277(012040):1-5.
Muller-Parker G., 2005 Coral reef islands. In: Encyclopedia of coastal science. Schwartz M. L. (ed). Encyclopedia of Earth Science Series, Springer, Dordrecht, 342 p.
Nurdin N., Komatsu T., Yamano H., Arafat G., Rani C., Akbar M., 2015 Spectral clustering of coral reefs on the Small Islands, Spermonde Archipelago, Indonesia. Physical Science International Journal 5(1):1-11.
Okeyode I. C., Jibiri N. N., 2013 Grain size analysis of sediments from Ogun River, South Western Nigeria. Earth Science Research 2(1):43-51.
Oyedotun T. D. T., 2016 Historical mining signatures: geochemical and mineralogical evaluation of sediments in three coastal–estuarine systems. Journal of Coastal Zone Management 19(3):1-6.
Solihuddin T., 2017 Atoll reef geomorphology of Sagori Island, SE Sulawesi: A reconnaissance study. Indonesian Journal on Geoscience 4(3):181-191.
Suriamihardja D. A., 2011 Coral reef island of spermonde: morphodynamics and prospect. Proceedings of the Sixth International Conference on Asian and Pacific Coast, pp. 162-174.
Wang C., Chen M., Qi H., Intasen W., Kanchanapant A., 2020 Grain-size distribution of surface sediments in the Chanthaburi Coast, Thailand and implications for the sedimentary dynamic environment. Journal of Marine Science and Engineering 8(242):1-16.
Wentwoth C. K., 1922 A scale of grade and class terms for clastic sediments. Journal of Geology 30:377-392.

Xin L. H., Adzis K. A. A., Hyde J., Cob Z. C., 2016 Growth performance of *Acropora formosa* in natural reefs and coral nurseries for reef restoration. AACL Bioflux 9(5):1090-1100.

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