Pertanika J. Sci. & Technol. 30 (3): 2253 - 2270 (2022)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Facies Mapping of the Holocene Carbonate Complexes in Kepulauan Seribu Java Basin, Indonesia Using Satellite-Derived Data Set

Shafiqah Amir[1,2]*, Haylay Tsegab[1,2], Grisel Jimenez Soto[2] and Ali Imran Azman[2]

[1]*Department of Geosciences, Universiti Teknologi PETRONAS, 32610 UTP, Seri Iskandar, Perak, Malaysia*
[2]*South East Asia Carbonate Laboratory (SEACaRL), Universiti Teknologi PETRONAS, 32610 UTP, Seri Iskandar, Perak, Malaysia*

ABSTRACT

The analog study is common in understanding buried reservoirs and the relationship between architectural complexity and heterogeneity of carbonate deposits. This study processed satellite and false-color images using single-band images and classified them using a supervised classification technique to generate an environmental facies map. Thus, the study's objectives are to map facies distribution in selected carbonate depositional environment and investigate oceanographic parameters that influence the development and evolution of modern carbonates in Holocene Kepulauan Seribu patch reef complexes, Java Basin. The main sub-environments are reef sand apron, subtidal reefal margin, and shallower subtidal lagoon. Annual wind patterns in the Java Basin have influenced the development of carbonate sediment in the Kepulauan Seribu archipelago, resulting in the formation of an isolated carbonate platform pattern with a single crest and asymmetrical dipping flanks. Meanwhile, the salinity of seawater influences the production of modern carbonate deposits as the Java basin is situated at the equator line, where the salinity of the seawater is moderately salty (35‰) and contributes to the favorable conditions for carbonate growth. The analysis of oceanographic elements with the integration of quantified environmental facies distribution is conducted to monitor the deposition of carbonate sediments which gives insight into carbonate distribution on the studied platforms. Satellite-derived facies maps provide an accurate overview of depositional facies patterns at the field scale in the oil and gas industry, enabling geologists to assess the potential of an oil and gas reservoir.

Keywords: Facies map, Holocene carbonate, Landsat imagery, remote sensing, supervised classification

ARTICLE INFO

Article history:
Received: 12 September 2021
Accepted: 15 December 2021
Published: 25 May 2022

DOI: https://doi.org/10.47836/pjst.30.3.28

E-mail addresess:
shafiqah_19000176@utp.edu.my (Shafiqah Amir)
haylay.tsegab@utp.edu.my (Haylay Tsegab)
jimenezsotogrisel@gmail.com (Grisel Jimenez Soto)
imran.azman@utp.edu.my (Ali Imran Azman)
*Corresponding author

ISSN: 0128-7680
e-ISSN: 2231-8526

INTRODUCTION

Landsat satellite imagery is a remote sensing technology utilized to acquire satellite data of objects on Earth's surface. Landsat data is considered user-friendly compared to conventional mapping techniques or hand-drawn mapping (Kaczmarek et al., 2010). Compared to traditional mapping techniques, Landsat image satellites are suitable for producing facies maps, architecturally diverse and heterogeneous (Kaczmarek et al., 2010). Modern-day carbonate environment is often used as an analog for ancient counterpart carbonate settings strived at understanding the pattern of carbonate sediment distribution through dimensional data extraction processes (Harris, 1996; Harris, 2010), asserting that the deposition process for Holocene carbonate settings is similar to the ancient carbonate systems. Therefore, Holocene carbonate sediment distribution patterns are valuable as an analog to studying the heterogeneity of the ancient carbonate system.

This study utilizes Landsat data input from open access sources. It saves the cost of satellite data acquisition and time for data processing. The data generated from this carbonate facies mapping process can provide new insights into sediment distribution patterns, heterogeneity levels, and structure of selected carbonate platforms and potentially serve as a realistic and practical analog for the fossil carbonate oil field reservoirs.

The satellite system distinguishes and classifies objects or features found on the modern-day carbonate platform. The satellite data is collected through reflection and absorption of the electromagnetic spectrum on these features. This research focuses on the extraction of satellite image layers, data processing steps, and visual surveys of carbonate depositional patterns on the platform using spectral and multispectral sensors.

Remote sensing technologies were first used as a tool to monitor and study the development of coral reef populations, sediment composition, and diversity of the reefal system in the 1990s (Andrefouët & Riegl, 2004; Purkis, 2005; Purkis et al., 2007; Riegl et al., 2007). Researchers have used the technology because it possesses sensors capable of capturing clear surface images, providing high-resolution satellite data, and potentially being used to study shallow marine environments with high seawater clarity and a massive amount of carbonate components (Purkis, 2005).

Carbonates are formed primarily in warm, clear tropical to subtropical marine waters' photic zones (up to 200 m). They are mostly formed by organisms through algal photosynthesis or transported in-situ, organically precipitated tests and shells (Wilson, 1997). Light, water temperature, water salinity, depth, sedimentation, and surface exposure are all factors that limit carbonate growth (Ahr, 2011). The photic zone is the ideal environment for carbonate formation.

The study aims to map facies distribution in selected carbonate depositional environment and investigate oceanographic parameters that influence the development and evolution of modern carbonates in Holocene Kepulauan Seribu patch reef complexes, Java Basin. This study has utilized remote sensing methods to obtain aerial photographs and satellite data. Satellite images are needed to process the spectrum bands and generate a satellite-derived environmental facies distribution map.

STUDY AREA

The study area is located northwest of the Java Basin, which is 6º South on the equatorial line of West Java, Indonesia, or 50 km from the Northwest, Jakarta, between 106º 32‘ 53.97“ and 106º 35’ 48.99” East, 5º 34‘ 17.38“ and 5º 37‘ 33.67“ South (cite map). The study area comprises a portion of the Kepulauan Seribu patch reef complexes and two isolated carbonate platforms (Figure 1). The area is located about 59.2 km north of the City of North Jakarta and is surrounded by an ocean with a water depth of about 27.4 m. These isolated carbonate platforms are from the 192 chains of carbonate platforms that exhibit north-south chain patterns. Kepulauan Seribu patch reef complexes show different physiological patterns in the South and North of the islands. The carbonate platforms in the southern part show several large platforms, with lagoons less than 3 m in depth and larger reef sand apron and smaller sand cays with an estimated area of several square kilometers. On the other hand, the carbonate platform in the northern part of the archipelago is smaller and records less than 1 km^2 and no lagoon formation.

The study area, approximately 26.3 km^2, covers selected carbonate platform sand the recorded shallow ocean. The area of the respective carbonate platform is not much different. However, the present-day Putri Island carbonate platform is measured to have an area of 7.02 km^2 with a length of 7.9 km and a width of 7.05 km compared to Pulau Bira, measuring 5.84 km^2 with a length and width of the platform of 7.21 km and 5.31 km respectively. Most platforms have only one sand cay or small island. A small-sized lagoon at 1452 m^2 is observed in the western part of Putri Besar Island. However, the average present-day carbonate platformsin the area have no lagoon formation due to Kepulauan Seribu being tectonically a deep, shallow-water back-arc basin with a north-south faulting pattern.

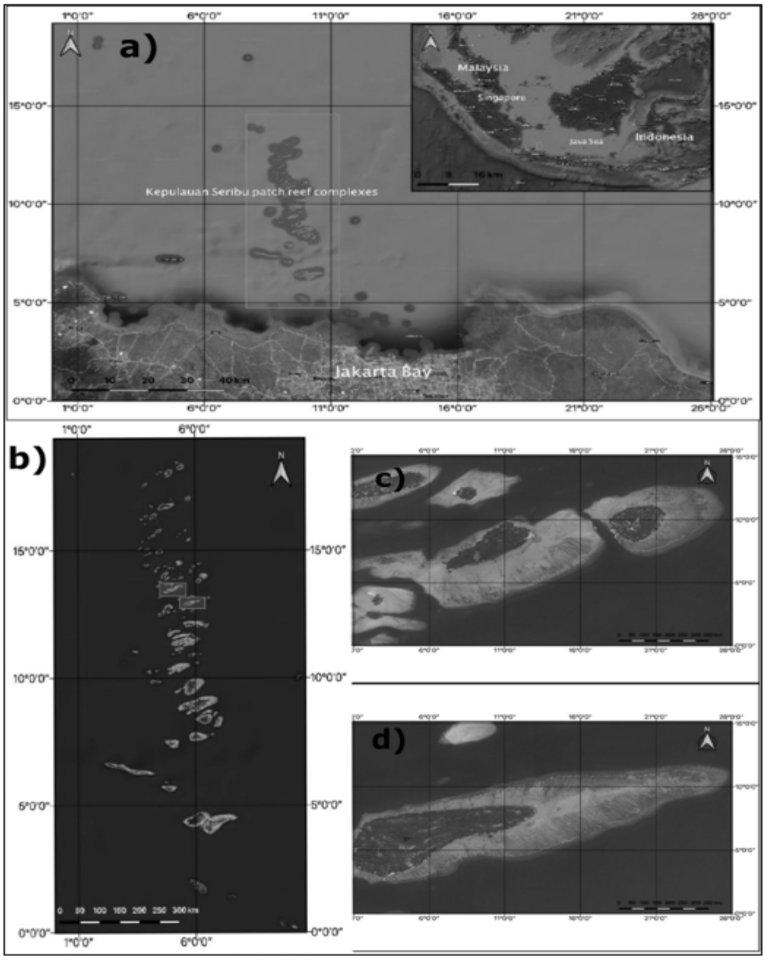

Figure 1. Study area as indicated in the red box (a) Holocene Kepulauan Seribu patch reef complexes, North-West Java Basin, Indonesia. (b) Location of selected present-day carbonate platforms; Pulau Putri and Pulau Bira. (c) and (d) Chosen Holocene carbonate platforms of Putri and Bira Islands in an aerial view from sources of Open Street Map and Bing Aerial

METHODOLOGY

Remote sensing is one of the most widely used geophysical methods for exploring oil and gas as well as minerals and natural resources (Hoover et al., 1995). Solar sources induce electromagnetic radiation, classified into seven spectrum regions: radio waves, microwaves, infrared (IR), visible light, ultraviolet (UV), X-rays, and gamma rays. Remote sensing technology works with the help of sensors to detect the electromagnetic spectrum, which is divided into visible light (0.4–0.7 μm), near-reflected infrared (0.77–0.90 μm), mid-reflected infrared (1.55–1.75 μm), thermal infrared (10.40–12.50 μm) and microwaves (1 mm–1 m) (Murai, 1993). Waves detected by sensors are recorded through digital data for processing and producing an image for an area of interest (Hoover et al., 1995). According to Kaczmarek et al. (2010), remote sensing technology plays a role in measuring the electromagnetic radiation emitted by solar energy to the Earth's surface and is reflected in the satellite's sensors. The wavelength data obtained from the earth's surface are analyzed to determine the geomorphological features and functions of the surface area.

Data Acquisition

The satellite images used in this study are obtained from open access on Google Hybrid, Bing Aerial, Google Road, and Open Street maps. The acquired aerial images were within 15 m–15 cm for Google Hybrid, 30 m multispectral Landsat images, and 15 m Landsat panchromatic images for Google Road (Figure 1). Aerial photographs of the study area were captured in December 2015 [Figure 1(a)]. Meanwhile, aerial photographs taken via Aerial Bing open access do not reveal the date of the photo.

The satellite images in Figures 1(c) and 1(d) are accessed through a combination of hybrid data, Aerial Bing, and Open Street map to acquire a clearer Holocene carbonate platform image without the interruption of noises and cloud coverage. OpenStreet map uses high-resolution satellite images; Landsat 7 possesses an Enhanced Thematic Mapper Plus (ETM +) sensor, which enables the mapping of a wide range of areas as compared to the Thematic Mapper (TM) sensors used in Landsat 4 and 5 (Masek et al., 2001). Landsat satellite imagery could potentially be a tool for monitoring the development of modern-day carbonate platforms located in shallow marine. Kaczmarek et al. (2010) discuss that the potential for water penetration is closely associated with TM spectral band and visible wavelength, in which they assert that solar radiation affects the wavelength, potential penetration, and reflection of waves from the earth's surface to the sensors. Practically, a short wave has a high penetration potential. Kaczmarek et al. (2010) demonstrated that the TM 3 (red band) had a penetration potential of about 5 m (16 ft) as compared to the TM 1 (blue band), capable of penetrating the surface to about 20 m (66 ft) and the TM 2 (green band) reported a penetration potential of 10 m (33 ft). However, TM 4 to TM 7 bands were noted to have no penetration potential due to longer wave absorption by the water bodies. Hence, it is often found that water bodies with deeper depths are difficult to identify features found at the bottom of the ocean as satellite images suffer from a lack of data to categorize the features of water bodies. Geologists and explorationists attribute the uncertainty of data and derivative products to areas with deep water depths (Kaczmarek et al., 2010). Whereas Aerial Bing utilizes Bird's eye view approach that captures 45º ground-level images and applies a ground-level sample distance (GSD) of 10 cm per pixel, permitting more detailed present-day carbonate platform images and geomorphological features (Yu et al., 2017).

Qualitative Assessment of Geomorphic Patterns

Selected carbonate platforms are qualitatively analyzed to illustrate the environmental facies geometric patterns of selected carbonate platforms. Platform images are interpreted by creating satellite-derived facies maps using Quantum Geographical Information System (QGIS3.10) to characterize the spectrum of patterns on each platform.

RESULTS AND DISCUSSION

The visual survey technique used in this study attempts to interpret geological features in terms of shape, size, and distribution of surface brightness on the respective modern carbonate platforms. In addition, this technique helps to provide the geomorphological information found on the platforms by analyzing the individual image band used in the satellite image data for this research.

The mapping scheme generated three major sub-depositional environments; subtidal reef margin/sparse coral, shallower subtidal part lagoon/platform margin, and sand apron, to demonstrate the geomorphic characteristics of the build-ups (Rankey, 2016). The reef sand apron is classified into three classes; sand apron with sparse seagrass, sand apron without seagrass, and sand apron with dense seagrass as a supervised classification technique defined by Utami et al. (2018). Schlager and Purkis (2013) discuss that this method is useful and plausible even without ground-truthing. The visual observance was carried out by using satellite images of Bira Island and Putri Island. Based on this observation, there are discrepancies between the respective build-ups. Among the discrepancies discovered were abundant reefs, distribution of sand aprons, and appearances of the sand cay or small island. A semi-quantitative analysis is also carried out in the study area. This method is used to deduce seascape patterns based on geomorphic facies' spectral character, width, length, and orientation. By minimizing potential errors, correct facies can be mapped rigorously.

Visible and Near-Infrared Image Bands

Based on the visual survey method performed on the processed satellite images, various geological or geomorphological features and depths of water bodies can be observed. The brightness distribution of a feature on the surface of the present-day carbonate platform is also varied based on its reflection potential from the surface. Satellite imagery using the blue band presents geomorphological features with different brightness distributions of different features. It is evident when shallow-water features are seen to be brighter than vegetation due to the chlorophyll content in the plants effectively absorbing the blue band [Figures 2(a) &2(b)]. The brightness of the blue band is brighter than the red band satellite image.

Figure 2 illustrates the feature of a shallow water body with a shallower depth of color than the deep ocean. However, color differences can be observed between vegetation features of the blue band and green band, where satellite images with green bands exhibit brighter images as compared to the blue band [Figures 2(c) & 2(d)]. It makes it easy for researchers to study and analyze the differences in the features of the study area.

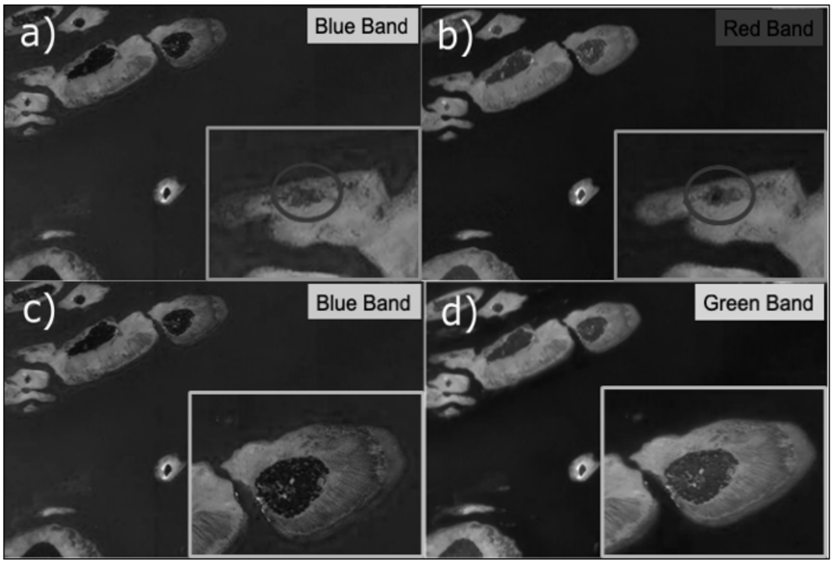

Figure 2. Satellite imagery with a) blue band, b) red band, and d) green band. Satellite imagery with a) blue band and b) red band, which represent shallow lagoon feature as highlighted in the red circle. Satellite imagery with c) blue band and d) green band which represent vegetated landmass feature as shown in the green box

In general, chlorophyll content contributes to the vegetation features on the Earth's surface that effectively absorb red and blue radiation (Vincent, 1997). Satellite images with the red band display dark color, which represents vegetation on the surface of the present-day carbonate platform, but the feature does not dominate the entire platform. The darkest color is recorded as a body of water due to the high absorption rate in the open sea or shallow lagoon [Figure 2(b)]. However, sediment shows the brightest light level due to higher wave reflectivity than the feature's absorption.

Pseudo-Color Images

Pseudo-color satellite images of the blue, green, and red bands were utilized in this study to further examine and decipher the geological features of the carbonate platform in greater detail by increasing the distance in the color space between successive grey levels. Based on the visual observances made on the satellite images in Figures 3 and 4, no uncommon features were detected on the surface of the present-day carbonate platforms. Satellite images with pseudo-color (blue band) still display all the features on the surface of the earth with varying colors and brightness levels [Figure 3(a)]. However, slight differences can be observed in the pseudo-color satellite image (green band), where small islands exhibited faded blue color [Figure 3(b)] as compared to the pseudo-color image (blue band).

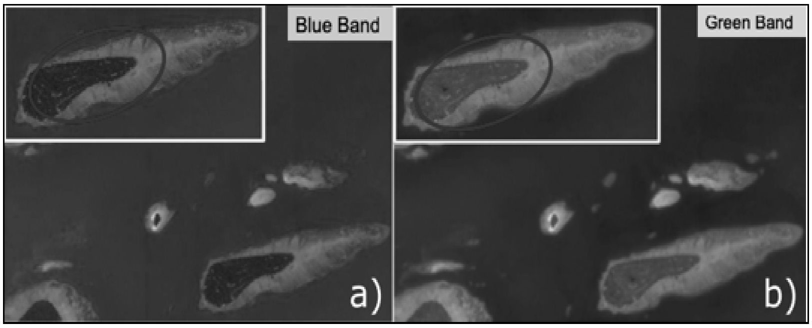

Figure 3. Satellite imagery with pseudo-color of a) blue band and b) green band which represent small island feature as highlighted in the red circle

Meanwhile, the pseudo-color image (red band) reveals minor reefal features than the pseudo-color satellite image of the blue and green bands (Figure 4). However, the sedimentary features are seen more clearly through the pseudo-color image (red band) than the pseudo-color image of the blue and green bands.

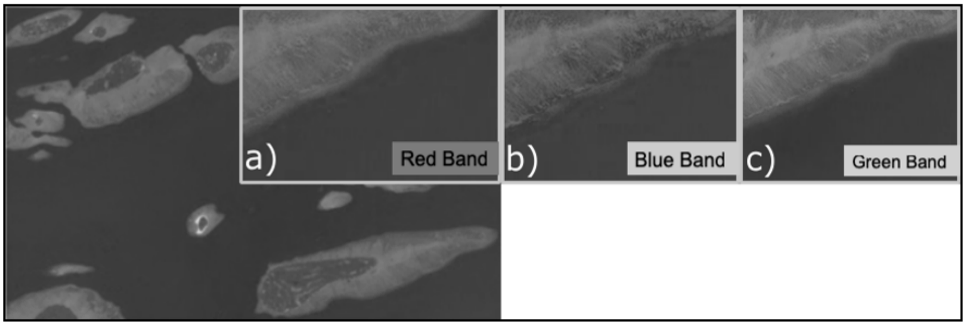

Figure 4. Satellite imagery with pseudo-color of a) red band, b) blue band, and c) green band which represents reefal feature as shown in the pink box

Color Combination of Visible Bands

Visual surveys of satellite images and interpretations of band images are very practical. However, the interpretation of geomorphological features on the present-day carbonate platform is based on the spectrum used and the brightness distribution of the features. In this study, multispectral images were added to enhance the discrimination of existing spectral images.

In general, the basic spectral bands commonly used in the satellite system consist of three main bands, blue, green, and red. The spectral bands help researchers to clarify geomorphological features of the Holocene carbonate platform that are viewed through satellite or aerial photographs, such as small islands, vegetation, water bodies, sediment, lagoons, and more.

Based on satellite images with bands 1, 2, and 4, the sedimentary features of the Holocene carbonate platform have the brightest distribution of brightness. Meanwhile, shallow water features such as lagoons are distinguished by light blue color [Figure 5(a)]. The open ocean displays the darkest levels of brightness. Small islands or landmass is distinguished by brownish.

Satellite images of bands 1, 3, and 4 [Figure 5(b)] exhibit small islands and reefal features in brackish color. At the same time, water bodies such as the open ocean are displayed in dark green, and sedimentary features remain as the brightest object on the platforms.

Bands 3, 4, and 2 are used in satellite images in Figure 5(c), where small islands, sand cays, and reefal are displayed in dark blue. The water body features are of the old mauve color, while the sediment features are exhibited in magenta color. As satellite images with bands 3, 4, and 2 do not utilize the blue band, researchers have a predicament distinguishing shallow water bodies from deep water as described about satellite images in Figures 5(a) and 5(b).

Kaczmarek et al. (2010) demonstrated that the usage of Landsat satellite data with a resolution of 28.5 m (93.5 ft) was eligible for accomplishing uniformity in the distribution of facies in conjunction with collected sediment data. High-resolution satellite images have the best absorption potential and enable researchers to review and interpret the carbonate features found in water bodies, especially in shallow marine areas. Multispectral satellite images with the blue band are most suitable for usage in facies mapping for Holocene carbonate platforms such as in Kepulauan Seribu modern reef complexes (Chalabi et al., 2012).

Satellite-Derived Facies Maps

Satellite imagery reveals varieties in geomorphic sizes, shapes, and patterns found on the present-day carbonate platforms. Based on visual inspection of the satellite image, various geomorphic elements can be seen and aligned as anticipated on the Holocene carbonate platform of the Kepulauan Seribu. Jordan Jr. (1998) reassures that the platform-margin reefs are inboard of deep open ocean and forereefs characterized by spurs and grooves. Platform-margin reefs are commonly seen as orangish or reddish on satellite imagery. Meanwhile, the sand aprons area looks white or bright blue in the image and is characterized by bare, shallow, gravelly, and sandy, albeit there are patch reefs and seagrass patches. The reef sand apron that passes through the interior platform is interpreted to have deeper shades of blue, which the sea level is deeper than reef sand aprons and may include patch reefs.

Interpreted satellite images and satellite-derived facies maps of geomorphic elements from a representative suite of images (Figures 6 & 7) illustrate some of the characteristics of selected carbonate build-ups. Bira's present-day carbonate platform can be elongated [Figure 6(a)] and have a narrow reef (14%) and wide reef sand apron (59%) [Figure 6(b)]. Putri platform and Bira platform are characterized by vegetated landmass or small islands, approximately 31% and 27%, respectively (Figures 6 & 7). These different geomorphic elements on each platform have a range of abundances, sizes, configurations, and relations. Reefal at both platforms is not dominant and can be discontinuous. Meanwhile, reefal in the Bira platform is continuous around all or most platforms. A shallow reef sand apron is evident between the reefal and the landmass or small island.

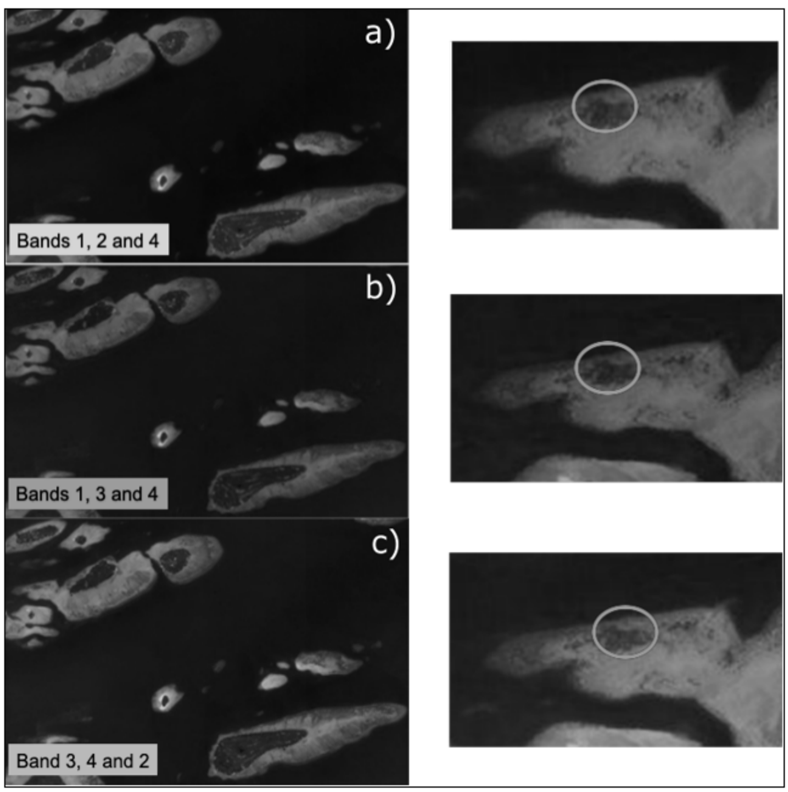

Figure 5. Satellite imagery with a combination of multispectral bands of a) 1, 2, and 4 bands, b) 1, 3, and 4 bands, and c) 3, 4, and 2 bands, which provide insight to differentiate geomorphological features in selected present-day carbonate platforms in Kepulauan Seribu.

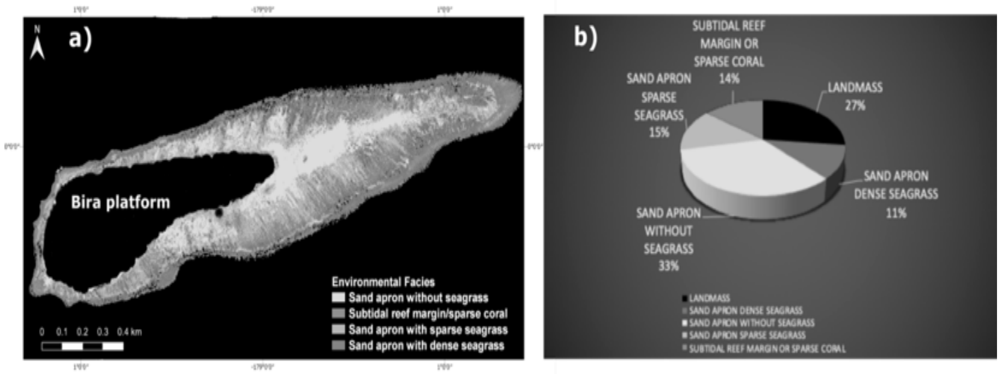

Figure 6. a) Satellite-derived facies map of Bira platform showing environmental facies with depositional environment overlays and b) Spatial facies percentages of Bira platform calculated from the Landsat-derived facies map

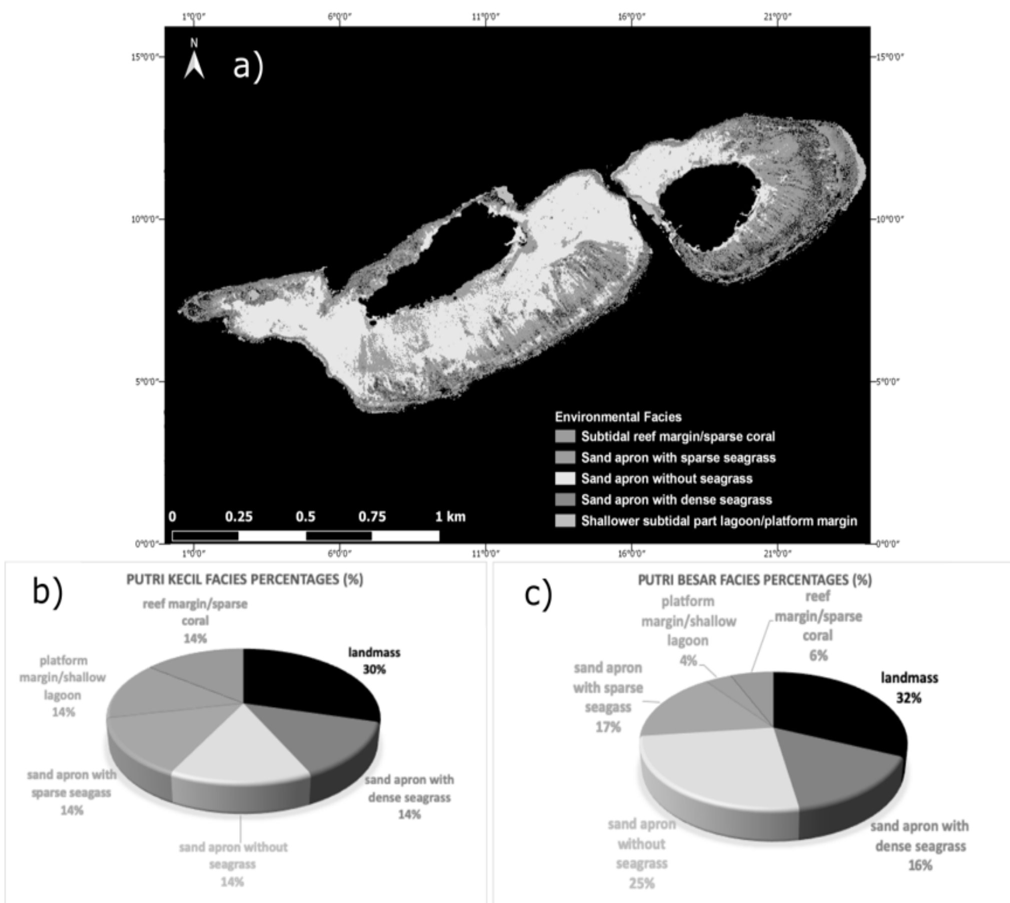

Figure 7. a) Satellite-derived facies map of Putri platform generated by utilizing supervise classification, b) Spatial facies percentages of Putri Kecil platform calculated from satellite-derived facies map, and c) Spatial facies percentages of Putri Besar platform calculated from satellite-derived facies map

Quantitative Facies Analysis

Quantitative physics analysis was performed on two selected carbonate platforms, namely the Bira and the Putri platforms. Satellite images from aerial photographs without sediment carbonate sample data show the total distribution of facies produced from the combined classification of TM bands and satellite image processing with a resolution of 15 mfrom the Holocene Kepulauan Seribu complexes. This quantitative analysis was performed toidentify the potential of carbonate reservoirs based on the amount of uniformity (homogeneous/heterogeneous) distribution of facies from the two currently selected carbonate platforms located in the North-West Java Basin.

The total distribution of facies in the two selected carbonate platforms is summarized in Table 1. The table shows the differences in the distribution of facies and their uniformity on both platforms. The high number of facies distribution in a carbonate platform causes the level of a platform to be classified as a reservoir potentially accumulatinghydrocarbon sources is predicted to be lower meanwhile carbonate reservoirs categorized as potential hydrocarbon reservoirs are characterized by a more uniform distribution of facies (Chalabi et al. 2012). For example, the Bira platform and Putri platform are characterized by 5 and 6 classes of carbonate facies where the uniformity distribution is homogeneous and is categorized as a present-day platform that has the potential to be a carbonate reservoir. However, the number of facies distributions recorded is still inaccurate due to sediment carbonate sampling. Furthermore, the accuracy analysis of the total carbonate facies in the research area has not been carried out due to several natural disaster factors and pandemic coronavirus in the Indonesia.

The total distribution of facies present in the carbonates of selected platforms is recorded in Table 1. The Bira platform records a perimeter of about 5.84 km. The larger the perimeter of a carbonate platform, the more complex the total distribution of facies on the platform is recorded (Harris & Vlaswinkel, 2008). Putri Kecil platform has a parameter of about 2.53 km, where the carbonate perimeter of this platform is recorded as the smallest compared to the Bira platform and Putri Besar platform. According to Harris and Vlaswinkel (2008), the small perimeter of the platform carbonate does not show such significant diversity of facies, and the total distribution of facies is also more uniform. The Putri Besar platform recorded a perimeter of about 4.49 km and is the second-largest carbonate platform after the Bira platform. These two carbonate platforms show the more homogeneous distribution of facies following the large perimeter of the platform. Chalabi et al. (2012) proved that the range of diversity of carbonate facies distribution in a platform is closely related to the number of facies distributed in the platform.

However, based on the results of quantitative analysis in the latest research shows the uniformity of the total distribution of facies in Bira, Putri Kecil, and Putri Besar carbonate platforms, where the range of facies diversity recorded is low (five facies classes for the

Bira platformand six facies classes for Putri Besar and Putri Kecil platform). Quantitative analysis of the total distribution of facies aims to investigate the relationship between the size of a carbonate platform and the heterogeneity facies distribution that has been successfully recorded. The authors found that the size of a carbonate platform did not affect the distribution of carbonate facies on the platform. This statement is in line with Harris and Vlaswinkel (2008), who argues that parameters such as platform size do not affect the distribution of facies in a carbonate build-up.

Table 1
Tabulation information of facies distribution on respective Holocene carbonate platforms

Percentage of each facies (%)	Bira platform	Putri Kecil platform	Putri Besar platform
Island/sand cay	27	30	32
Shallow lagoon/platform margin	none	14	4
Subtidal reef margin/sparse coral	14	14	6
Sand apron with dense seagrass	11	14	16
Sand apron without seagrass	33	14	25
Sand apron with sparse seagrass	15	14	17

Oceanographic Elements

This research was conducted in the Kepulauan Seribu patch reef complexes near Jakarta Bay in the Northwestern part of the Java Basin, Indonesia. The Kepulauan Seribu archipelago area is classified into three zones defined by Cleary and Hoeksema (2006): inshore, mid-shore, and offshore. Areas near Jakarta Bay (inshore zone) show high nutrient content levels (De Voogd & Cleary, 2008). The mid-shore zone is 22–40 km from Jakarta, and more than 60 km is categorized as an offshore zone. These three zones are characterized by varying levels of sea depth, where the inshore zone is classified as shallow with a depth of several meters up to a maximum depth of 30 m. Meanwhile, the mid-shore zone indicates a depth of more than 50 m and the offshore zone far from the coast has a seawater depth of more than 40 m (Figure 8).

According to Ali and Abolins (1999), carbonate build-ups are divided into two types: conical build-up and platform build-up based on geometric elements and morphology. The current research conducted in the Kepulauan Seribu archipelago is one of the Holocene-age build-up platforms in the Java Basin. Therefore, it has the potential to be utilized as a reference for the analog study. The Kepulauan Seribu build-up platform was growing on fault-bounded regional highs, an ideal region for the growth and development of carbonate platform build-ups (Hamilton, 1979; Prior, 1986; Jordan Jr., 1998). The archipelago shows the position of modern carbonate build-ups experiencing uplifting due to a tectonic setting before the regional block that extends from the South to the North direction. In terms of geological and morphological elements, the archipelago forms a large-sized carbonate platform (Figure 8) with a West-East platform orientation caused by biological parameters; the bidirectional monsoon winds that blow across the Java Basin every year. From the top view of the aerial photograph, it can be observed that the present-day carbonate platform is characterized by a flatter top of the platform (Figure 8).

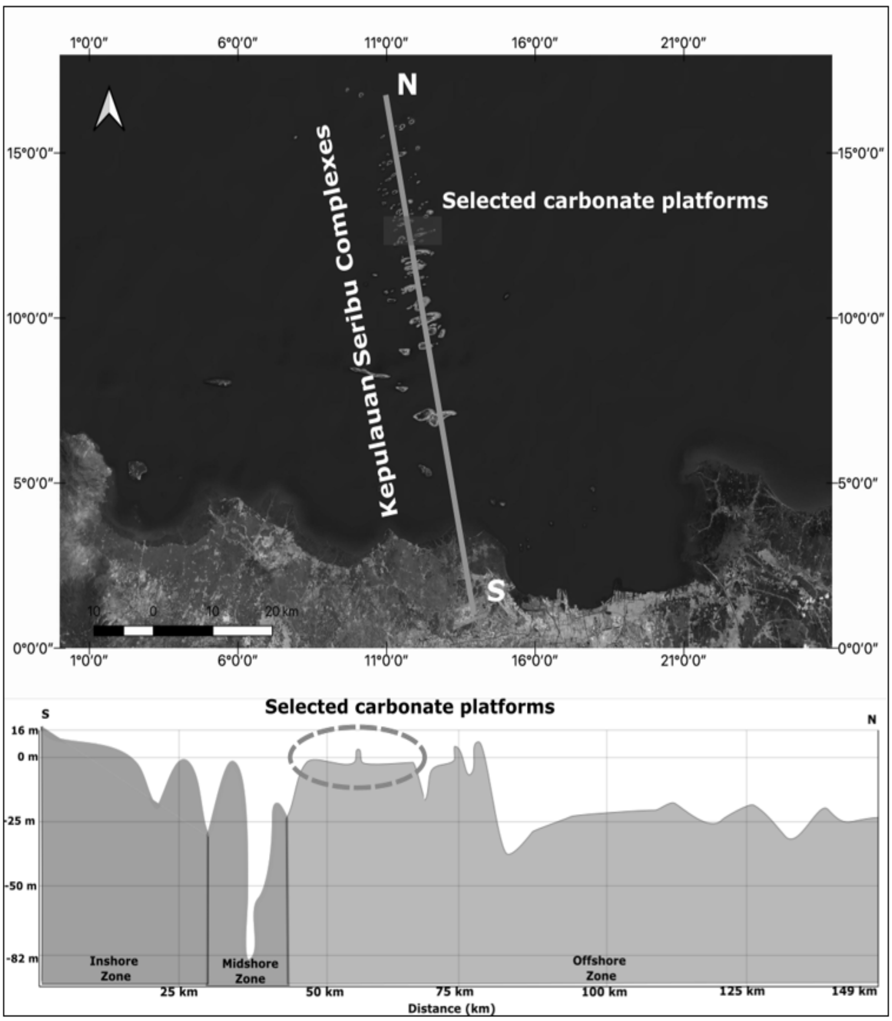

Figure 8. Cross-section from the onshore zone to the offshore zone

Indonesia's position is between two continents, Australia, and Asia's continental plate, separated by two oceans; the Pacific Ocean and the Indian Ocean, which eventually affect the monsoon winds that blow through the Kepulauan Seribu modern-day carbonate build-ups throughout the year. Further details on the orogenic effects and physical characteristics affecting monsoon winds in Indonesia are explained in detail in the paper by Tjasyono et al. (2008). Bidirectional monsoon winds are divided into western monsoon and eastern monsoon.

Jordan Jr (1998) described the Java Basin used to experience two seasons, namely the monsoon season and the dry season, due to the factors of monsoon wind exchange and followed by changes in the surface water flow of the Java Sea. Jordan Jr (1998), Naseer (2003), and Poerbandono (2016) agreed that the formation of carbonate build-ups strongly depends on seasonal wind and current ocean directions. The statement is supported by the data of a 20-year rainfall distribution study conducted by Tjasyono et al. (2008), which proves that the Java Sea experienced frequent rainfall from December to May and the least rain from June to November throughout the year.

Due to the annual wind pattern in the Java Basin, which highly impacted the formation and deposition of carbonate sediment in the Kepulauan Seribu archipelago, this phenomenon forms an individual carbonate platform pattern that comprises a single crest and asymmetrical dipping flanks. It is especially evident if observations are made on selected carbonate platforms (Bira and Putri platforms) which have two different sides: windward and leeward flanks. Both sides are also characterized by the accumulation of different skeletal carbonate sediments. However, the windward is characterized by a steeper flank than leeward due to the shape of the platform or a bidirectional monsoon pattern that contributes to the platform orientation pattern. The pattern can be viewed on most modern carbonate platforms.

In addition to the factor of bidirectional monsoon winds, another parameter contributing to the formation of modern carbonate build-ups is the salinity level of seawater. The salinity of the seawater influences the favorable condition for growing carbonate platforms. The salinity rate in the Java basin is uniform throughout the year. It, in turn, applies to ideal conditions for the formation and deposition of carbonates in the Java Sea (Figure 9). The salinity of the seawater in the Java Sea is recorded as moderately saline because of Java basin is located at the equator line, where the salinity of the seawater is 35 ‰.The high salinity value recorded at the equator is also due to the high evaporation process and the high rainfall rate in the Java basin (Prawirowardoyo, 1996).

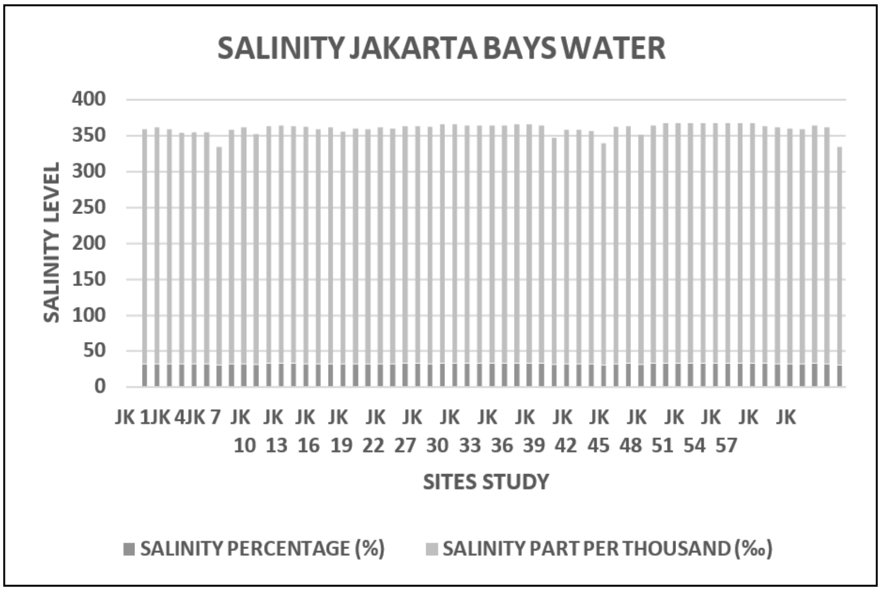

Figure 9. The salinity level of Jakarta Bay was modified by Williams et al. (2000)

CONCLUSION

This paper intends to describe and illustrate a satellite-based approach for mapping facies distribution. Landsat spectral data supervised classifications, and qualitative assessment of geomorphic patterns was utilized to demonstrate the facies distribution of selected Holocene carbonate platforms. In addition, satellite-derived facies maps were presented for the Putri and Bira platforms.

The supervised classification method applied for the mapping of environmental facies provides a holistic result by using quantitative and qualitative data, enabling the creation of sensible facies distribution maps. For example, the satellite-derived facies map provides insight into the diversity of carbonate facies and facies distribution on Indonesia's Kepulauan Seribu platform. Satellite-derived facies maps, meanwhile, offer a perfect description of depositionalfacies trends at the field scale in the oil and gas industry, thus allowing geologists or geophysiciststo evaluate the quality and potential of an oil and gas reservoir.

Biological parameters such as monsoon winds and salinity rate control the patterns of carbonate formation in the shallow marine area of the Holocene, Kepulauan Seribu archipelago.

ACKNOWLEDGMENT

The authors are thankful to Southeast Asia Carbonate Laboratory (SEACaRL), Geoscience Department, Universiti Teknologi PETRONAS (UTP) for facilities and financial support.

REFERENCES

Ahr, W. M. (2011). *Geology of carbonate reservoirs: The identification, description andcharacterization of hydrocarbon reservoirs in carbonate rocks*. John Wiley & Sons.

Ali, M. Y., & Abolins, P. (1999). Central luconia province. *The Petroleum Geology and Resources of Malaysia, 1*, 369-392.

Andrefouet, S., & Riegl, B. (2004). Remote sensing: A key tool for interdisciplinary assessment of coral reef processes. *Coral Reefs, 23*(1), 1-4. https://doi.org/10.1007/s00338-003-0360-z

Chalabi, A., Pierson, B., & Ab Talib, J. (2012). Remote Sensing analysis of recent carbonate platforms, east of Sabah: Potential analogues for Miocene carbonate platforms of the South China Sea. *Indonesian Journal on Geoscience, 7*(3), 123-135.

Cleary, D. F., & Hoeksema, B. W. (2006). Coral diversity across a disturbance gradient in the Pulau Seribu reef complex off Jakarta, Indonesia. In D. L. Hawksworth & A. T. Bull (Eds.), *Marine, Freshwater, and Wetlands Biodiversity Conservation* (pp. 285-306). Springer. https://doi.org/10.1007/978-1-4020-5734-2_19

De Voogd, N. J., & Cleary, D. F. (2008). An analysis of sponge diversity and distribution at three taxonomic levels in the Thousand Islands/Jakarta Bay reef complex, West-Java, Indonesia. *Marine Ecology, 29*(2), 205-215. https://doi.org/10.1111/j.1439-0485.2008.00238.x

Hamilton, W. B. (1979). *Tectonics of the Indonesian region.* USGS Publication.

Harris, P. M. (1996). Reef styles of modern carbonate platforms. *Bulletin of Canadian Petroleum Geology, 44*(1), 72-81. https://doi.org/10.35767/gscpgbull.44.1.072

Harris, P. M. (2010). Delineating and quantifying depositional facies patterns in carbonatereservoirs: Insight from modern analogs. *AAPG Bulletin, 94*(1), 61-86. https://doi.org/10.1306/07060909014

Harris, P. M. M., & Vlaswinkel, B. (2008). Modern isolated carbonate platforms: Templates for quantifying facies attributes of hydrocarbon reservoirs. In J. Lukasik & J. A. Simo (Eds.), *Controls on Carbonate Platform and Reef Development* (Vol. 89, pp. 323-341). SEPM Special Publication. https://doi.org/10.2110/pec.08.89.0323

Hoover, D. B., Klein, D. P., Campbell, D. C., & du Bray, E. (1995). Geophysical methods in exploration and mineral environmental investigations. *Preliminary compilation of descriptive geoenvironmental mineral deposit models: USGS Open-File Report, 95*(831), 19-27.

Jordan Jr, C. F. (1998). *The sedimentology of Kepulauan Seribu: A modern patch reef complexin the west Java Sea, Indonesia*. Indonesian Petroleum Association.

Kaczmarek, S. E., Hicks, M. K., Fullmer, S. M., Steffen, K. L., & Bachtel, S. L. (2010). Mapping facies distributions on modern carbonate platforms through integration of multispectral Landsat data, statistics-based unsupervised classifications, and surface sediment data. *AAPG Bulletin, 94*(10), 1581-1606. https://doi.org/10.1306/04061009175

Masek, J. G., Honzak, M., Goward, S. N., Liu, P., & Pak, E. (2001). Landsat-7 ETM+ as an observatory for land cover: Initial radiometric and geometric comparisons with Landsat-5 Thematic Mapper. *Remote Sensing of Environment, 78*(1-2), 118-130. https://doi.org/10.1016/S0034-4257(01)00254-1

Murai, S. (1993). *Remote sensing notes*. Japan Association of Remote Sensing.

Naseer, A. (2003). *The integrated growth response of coral reefs to environmental forcing: Morphometric analysis of coral reefs of the Maldives* (Doctoral dissertation). Dalhousie University, Canada.

Poerbandono. (2016). Wind characteristics and the associated risk of erosion in Seribu Islands patch reef complexes, Java Sea, Indonesia. In *AIP Conference Proceedings* (Vol. 1730, No. 1, p. 080001). AIP Publishing LLC. https://doi.org/10.1063/1.4947416

Prawirowardoyo, S. (1996). *Meteorologi*. Penerbit ITB.

Prior, S. W. (1986). *Bima Field, Indonesia, a sleeping giant*. Circum Pacific Council Publications.

Purkis, S. J. (2005). A reef-up approach to classifying coral habitats from IKONOS imagery. *IEEE Transactions on Geoscience and Remote Sensing, 43*(6), 1375-1390. https://doi.org/10.1109/TGRS.2005.845646

Purkis, S. J., Kohler, K. E., Riegl, B. M., & Rohmann, S. O. (2007). The statistics of natural shapes in modern coral reef landscapes. *The Journal of Geology, 115*(5), 493-508.

Rankey, E. C. (2016). On facies belts and facies mosaics: Holocene isolated platforms, South China Sea. *Sedimentology, 63*(7), 2190-2216. https://doi.org/10.1111/sed.12302

Riegl, B. M., Halfar, J., Purkis, S. J., & Godinez-Orta, L. (2007). Sedimentary facies of the eastern Pacific's northernmost reef-like setting (Cabo Pulmo, Mexico). *Marine Geology, 236*(1-2), 61-77. https://doi.org/10.1016/j.margeo.2006.09.021

Schlager, W., & Purkis, S. J. (2013). Bucket structure in carbonate accumulations of the Maldive, Chagos and Laccadive archipelagos. *International Journal of Earth Sciences, 102*(8), 2225-2238. https://doi.org/10.1007/s00531-013-0913-5

Tjasyono, H. K. B., Gernowo, R., Sri Woro, B. H., & Ina, J. (2008, September 16-18). The character of rainfall in the Indonesian monsoon. In *The International Symposium on Equatorial Monsoon System* (pp. 1-11). Yogyakarta, Indonesia.

Utami, D. A., Reuning, L., & Cahyarini, S. Y. (2018). Satellite-and field-based facies mapping of isolated carbonate platforms from the Kepulauan Seribu Complex, Indonesia. *The Depositional Record, 4*(2), 255-273. https://doi.org/10.1002/dep2.47

Vincent, R. K. (1997). *Fundamentals of geological and environmental remote sensing*. Prentice Hall.

Williams, T. M., Rees, J. G., & Setiapermana, D. (2000). Metals and trace organic compounds in sediments and waters of Jakarta Bay and the Pulau Seribu Complex, Indonesia. *Marine Pollution Bulletin, 40*(3), 277-285.

Wilson, J. L. (1997). Carbonate depositional environments and diagenesis. In I. Palaz & K. J. Marfurt (Eds.), *Carbonate Seismology* (pp. 9-28). Society of Exploration Geophysicists.

Yu, S. L., Westfechtel, T., Hamada, R., Ohno, K., & Tadokoro, S. (2017). Vehicle detection and localization on bird's eye view elevation images using convolutional neural network. In *2017 IEEE International Symposium on Safety, Security and Rescue Robotics (SSRR)* (pp. 102-109). IEEE Publishing. https://doi.org/10.1109/SSRR.2017.8088147