PS Carbonate Sedimentation Patterns in the South China Sea: An Insight into Miocene Carbonate Morphologies*

Chia Pei Teoh[1] and Georg Warrlich[2]

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[1]School of Earth Sciences, University of Bristol, Bristol, United Kingdom (ct12081@my.bristol.ac.uk)
[2]Sarawak Shell Berhad, Sarawak, Malaysia (g.warrlich@shell.com)

Abstract

South East Asia contains a wide range of carbonate settings ranging from coastal barrier reefs to isolated carbonate platforms; nurtured by clear tropical waters conducive to extensive coral growth and associated production of carbonate sediments. Unique to the region is the occurrence of the East Asian Monsoon, which seasonally reverses atmospheric and ocean surface circulation in the region. This study focused on the responses of sedimentation patterns in carbonate platforms to dominant wave and current directions and to seasonal shifts in ocean surface circulation, using examples within the Spratly Islands and compared those with the Semporna Archipelago in the Celebes Sea. Using Google Earth imagery supplemented with bathymetry and historical climatological data, two ocean surface circulation indicators (wave shadows and wave breakers) and two reef facies classes (reef margins and reef sand aprons), were mapped and quantitatively evaluated. Trends in the orientation of marine facies classes were analyzed in relation to the orientation of surface-water movement indicators.

The marine facies classes were found to preferentially align with the surface circulation indicators: thicker reef margins develop where more breaking waves are observed, sand aprons tended to align with the direction of wave shadows. A bimodal and a unimodal distribution of marine facies class orientations were found for the Spratly Islands and Semporana Archipelago respectively. Within the bimodal distribution of the Spratly islands, an asymmetry, which correlates with the stronger northeasterly winds associated with the winter East Asian Monsoon season, was observed. The uni-modal sediment pattern trend in the Semporana archipelago suggests a strong surface-circulation control relative to other factors in this region; sheltered by the island of Borneo, the archipelago experiences mostly unidirectional surface-water movement throughout the year despite the East Asian Monsoon. These findings from the contemporary South China and Celebes Sea were then applied to the subsurface carbonate platforms of Central Luconiain order to improve reservoir architecture and facies pattern prediction.

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Carbonate sedimentation patterns in the South China Sea: An insight into Miocene carbonate morphologies

Chia Pei TEOH[1], Georg WARRLICH[2]

j.teoh@tamu.edu, School of Earth Sciences, University of Bristol[1] ; g.warrlich@shell.com, Sarawak Shell Berhad[2]

Abstract

South East Asia contains a wide range of carbonate settings ranging from coastal barrier reefs to isolated carbonate platforms; nurtured by clear tropical waters conducive to extensive coral growth and associated production of carbonate sediments. Unique to the region is the occurrence of the East Asian Monsoon, which seasonally reverses atmospheric and ocean surface circulation in the region. This study focused on the responses of sedimentation patterns in carbonate platforms to dominant wave and current directions and to seasonal shifts in ocean surface circulation, using examples within the Spratly Islands and compared those with the Semporna Archipelago in the Celebes Sea. Using Google Earth imagery supplemented with bathymetry and historical climatological data, two ocean surface circulation indicators (wave shadows and wave breakers) and two reef facies classes (reef margins and reef sand aprons), were mapped and quantitatively evaluated. Trends in the orientation of marine facies classes were analyzed in relation to the orientation of surface-water movement indicators.

The marine facies classes were found to preferentially align with the surface circulation indicators: thicker reef margins develop where more breaking waves are observed, sand aprons tended to align with the direction of wave shadows. A bimodal and a unimodal distribution of marine facies class orientations were found for the Spratly Islands and Semporna Archipelago respectively. Within the bimodal distribution of the Spratly islands, an asymmetry which correlates with the stronger northeasterly winds associated with the winter East Asian Monsoon season was observed. The uni-modal sediment pattern trend in the Semporana archipelago suggests a strong surface-circulation control relative to other factors in this region; sheltered by the island of Borneo, the archipelago experiences mostly unidirectional surface-water movement throughout the year despite the East Asian Monsoon. These findings from the contemporary South China and Celebes Sea were then applied to the subsurface carbonate platforms of Central Luconia in order to improve reservoir architecture and facies pattern prediction.

Introduction

This study focuses on the responses of sedimentation patterns in carbonate platforms to dominant wave and current directions and to seasonal shifts in ocean surface circulation, using examples within the Spratly Islands and compared those with the Semporna Archipelago in the Celebes Sea. The region is unique for its occurrence of the East Asian Monsoon, which seasonally reverses atmospheric and ocean surface circulation in the region (Lau & Yang, 1997). These findings from the contemporary South China and Celebes Sea were then applied to the subsurface carbonate platforms of Central Luconia to determine how palaeocurrents affect the geomorphology of carbonate platforms. Central Luconia is a geological province located on the Sarawak Shelf. Extensive seismic mapping of the area reveals more than 240 carbonate platforms of mostly Late Miocene age. (Kosa et al., 2015)

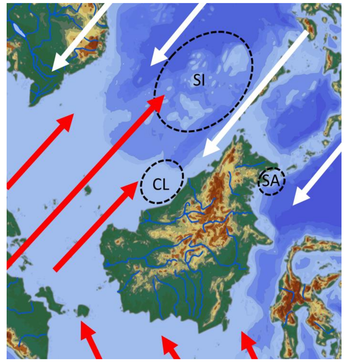

Figure 1: Map of study areas and monsoonal wind directions during the Northern Hemisphere summer (red arrows) and winter (white arrows,).
SI – Spratley Islands, **CL** – Central Luconia, **SA** – Semporna Archipelago.

Methods

Modern Carbonates

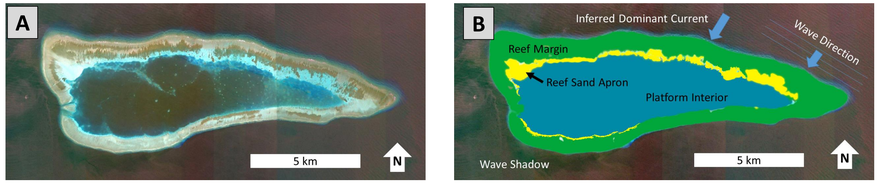

Figure 2: (A) Unprocessed and uninterpreted aerial image of East Reef, Spratly Islands.
(B) Processed and interpreted aerial image of East Reef, Spratly Islands.
The dominant surface current for this platform is interpreted to flow towards the S, SW, based on the S trending reef sand apron, and the reef margin being thickest on the N and NE sector.

Four criteria were noted in aerial images of modern carbonate platforms: **1)** Surface current direction **2)** Orientation and length of widest reef margin **3)** Orientation and length of reef sand aprons **4)** Date of acquisition of aerial image.

These criteria were measured based on methods of Rankey and Garza-Perez (2012), and Purkis et al. (2012), and then analyzed holistically with historical climate data to interpret how well surface currents for each carbonate platform correlate with the East Asian monsoon. The dominant monsoon direction was noted to occur during the winter (flowing to the SW).

These modern examples of the effect of currents in creating wider reef margins and orienting the sand aprons were used as analogs for the Central Luconia Miocene carbonates. Thus, we infer that in the Miocene, the direction of prograding carbonate wedges also indicate the direction of surface currents.

Miocene Carbonates

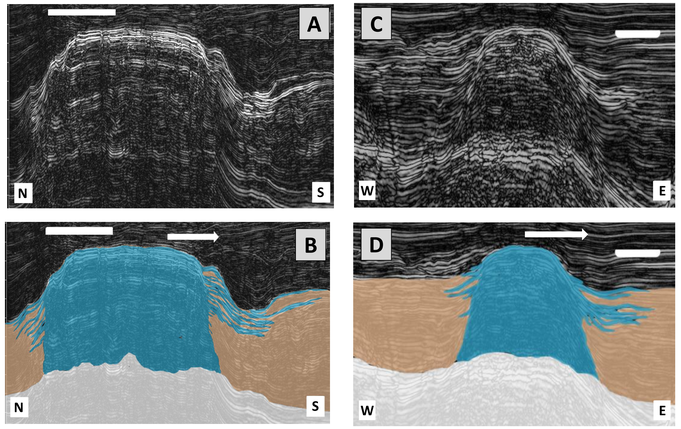

Figure 3: [A] Uninterpreted Seismic reflectivity cross section cutting across the N-S axis of a carbonate platform in Central Luconia. Horizontal scale bar indicates 3 km. Vertical axis in Two-way-time, 1400 ms total.

[C] Uninterpreted Seismic reflectivity cross section cutting across the E-W axis of a carbonate platform in Central Luconia. Horizontal scale bar indicates 3 km. Vertical axis in Two-way-time, 1250 ms total.

[B] [D] Interpreted seismic line, with carbonate body (turquoise), pre-burial carbonate platform burial siliciclastics (brown), and base carbonate (white) highlighted.

White arrow above platform on interpreted seismic indicate inferred dominant palaeocurrent direction

Two criteria were noted in seismic cross sections of Miocene carbonate platforms **1)** Prograding Carbonate Wedges **2)** Slope angle.

The length, thickness, and number of prograding carbonate wedges and the slope dip on each flank of the carbonate platform was measured and recorded. Prograding carbonate edges are fingers of carbonate material which extend outwards from the carbonate platform. These features are often asymmetrical, a consequence of being attenuated by surface currents.

To more closely correlate results between modern and Miocene carbonates, seismic attribute co-rendering of select Miocene platforms has been used to bring out lateral facies variations. Instantaneous Frequency and Instantaneous Phase was found to produce the best results.

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University of BRISTOL

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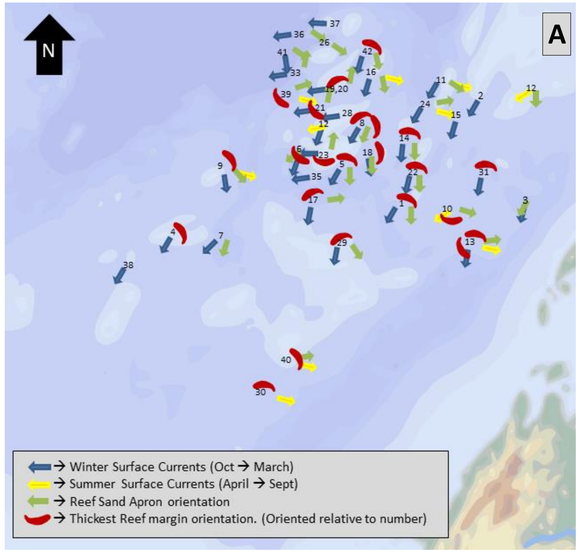
Results

Modern Carbonates



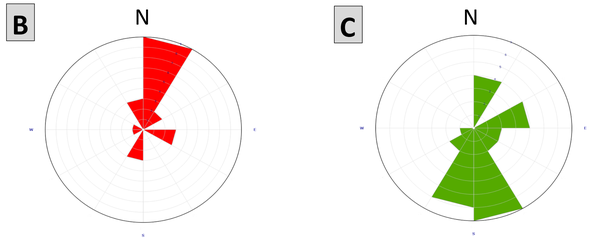


Figure 4: [A] Map showing sampled carbonate build-ups within the Spratly Islands and observed orientations of reef sand aprons, thickest reef margin, winter surface currents, and summer surface currents.
[B] – Rose diagram showing inferred surface current origin directions based on orientation of sand reef aprons. (n=28)
[C] – Rose diagram showing inferred surface current origin directions based on orientation of thickest reef margins. (n=22)

Miocene Carbonates

An asymmetry of the prograding carbonate edges and orientation of steepest flank can be observed in all carbonate platforms observed, with alignment of features along a NW-SE and N-S trend, with more features recorded with a NW-SE trend. Thus, it is inferred that the dominant monsoon wind direction was flowing from the NW to the SE during the Miocene.

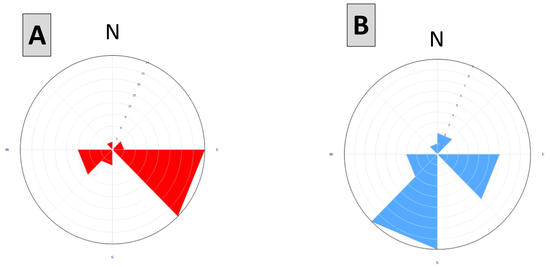


Figure 5: Rose diagrams showing the inferred surface current direction in Central Luconia based on:
[B] – Orientation and number of carbonate wings. (n = 47)
[C] – Orientation of steepest slope dip. (n = 21)

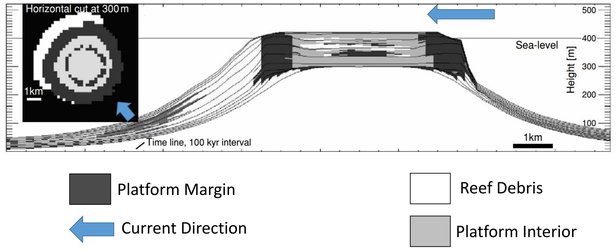


Figure 6: Stratigraphic forward modelling (CARBONATE 3D) output after 820 kyr runtime, showing the effect of wind direction on the distribution of reef facies on an isolated carbonate platform. Windward margin shows greater steepness relative to leeward margin, with greater deposition of reef debris on shallower leeward margin. (Modified from Warrlich et al., 2002)

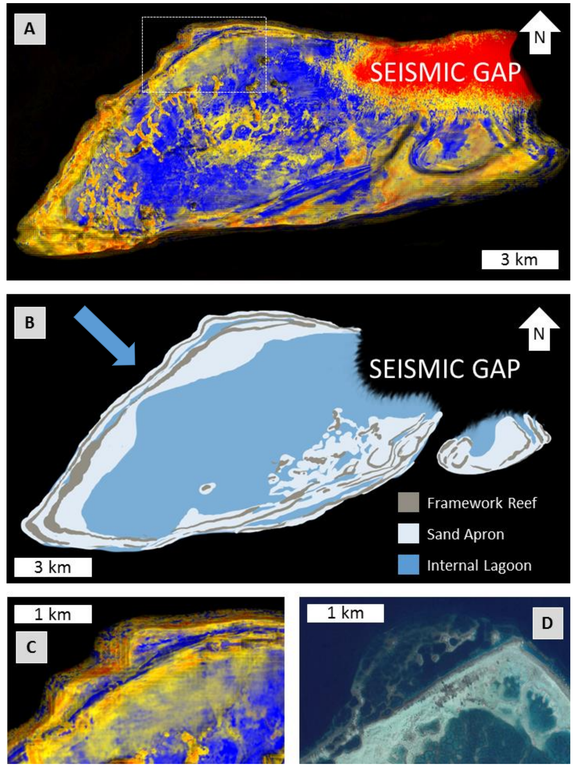


Figure 7: [A] Map of a Central Luconia Miocene carbonate platform (Field A) showing variations in lateral facies picked out by co-rendering the Instantaneous Phase and Instantaneous Frequency seismic attributes. Carbonate platform features including sand aprons and reef margins are more readily recognizable. Dashed box indicates extent of zoom-in view (in **[C]**).
[B] Interpretation of carbonate facies of Field A, showing the lateral distribution of depositional environments. Karst/dentritic features omitted. Arrow denotes inferred palaeocurrent direction.
[C] Close up view of multiple reef margins and sand apron features in co-rendered seismic attribute map of Field A.
[D] Part of the northern shore of Selakan Island in the Semporna Archipelago showing multiple reef margins, sand aprons and interior lagoon, showing strong similarity to features in **[C]**

Conclusions and Future Work

Sedimentation patterns in carbonate platforms are strongly correlated to wave and current directions in the region. In bimodal seasonally shifting systems, one direction tends to dominate. Within the Spratly Islands, observed features tended to align along a northeast-southwest trend, with northeasterly currents showing dominance; consistent with the East Asian Monsoon. Within the Miocene Central Luconia carbonate platforms, observed features tended to align along an inferred SE – S flowing palaeocurrent. These findings have the potential to improve reservoir architecture and facies pattern prediction in similar isolated carbonate platforms.

Future work includes seismic attribute co-rendering of more carbonate platforms within Central Luconia.

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