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Morphological indicators of structural control, relative sea-level fluctuations and platform drowning on present-day and Miocene carbonate platforms

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ABSTRACT

The morphology of Carbonate platforms may be influenced by tectonic activity and eustatic variations. 3D seismic data and satellite imagery are used in order to investigate the morphological similarities between present-day carbonates platforms, East of Borneo Island and Miocene carbonate platforms of the South China Sea. The morphological similarities exhibit platform fragmentation, that could be caused by subtle faulting, sufficient to drown reef rims; platform contraction, which is a result of back-stepping of the reef margin during a relative sea level rise and polygonal patterns in internal lagoons, described as mesh reefs in modern platforms and possibly interpreted as karst in Miocene platforms.

Vertical movements may trigger the formation of new geomorphological conditions that modify the distribution of coral growth with respect to the new hydrodynamic conditions in space and time. These movements (uplift and tilting) reduce and localize the space necessary for the coral ecosystem, explaining the contraction leading to drowning of parts of and, ultimately, the whole platform.

1. Introduction

Carbonate platform drowning, although recognized as a paradox (Schlager, 1981), has been recorded and documented in fossil carbonate platforms (Tucker and Wright, 1990; Zampetti et al., 2004; Schlager, 2005). Platform drowning is attributed to a rapid relative sea level rise that results in flooding of the platform and a deepening of the depositional environments to below the photic zone (Blanchon and Shaw, 1995; Mallisson et al., 2003; Kennedy and Woodroffe, 2002, 2004; Schlager, 2005; Abbey et al., 2011; Camoin et al., 2012; Deschamps et al., 2012) or a rapid uplift (Cabioch et al., 1998; Kennedy and Woodroffe, 2002; Bosence, 2005; Navarro et al., 2012; Li et al., in press). Such flooding events commonly lead to back-stepping and re-orientation of the platform margin (Schlager, 2005).

Most of the Miocene platforms of the South China Sea and, in particular, of the Central Luconia Province of Sarawak (Fig. 1), have been interpreted as having drowned (Grötsch et al., 1993; Vahrenkamp et al., 2004a,b; Zampetti et al., 2004; Fournier et al., 2005; Ting et al., 2011). The events that would have led to drowning of the Miocene platforms are still unclear but it seems that syn-depositional tectonics may have played a significant role (Ting et al., 2011, 2012). A number of morphological phenomena observed on the Miocene platforms, and, more specifically, on the Mega-Platform, documented in the context of a study of high-resolution 3D seismic by Sarawak Shell Bhd. (Ting et al., 2010, 2011, 2012), support this suggestion. This study allowed (1) generating a 3D reconstruction of the Mega-Platform, (2) establishing the history of back-stepping of the platform margin, and of contraction and fragmentation of the platform and (3) mapping facies distribution at various stages of the platform evolution.

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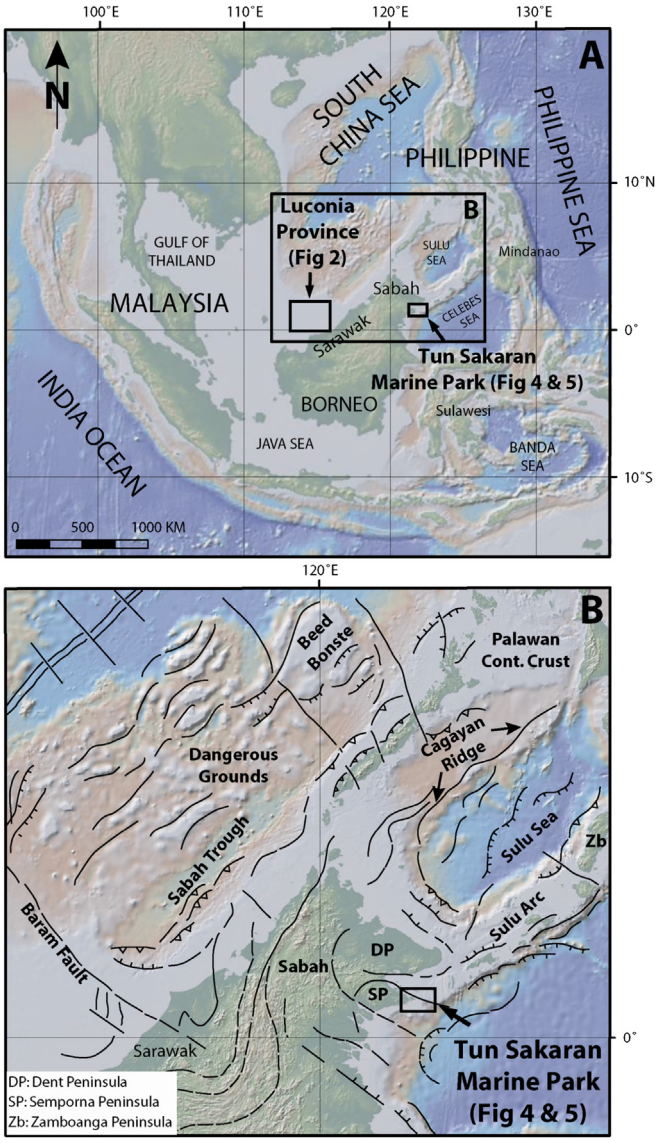

Figure 1. (A) Map of study area showing the location of the Central Luconia province and the location of the Tun Sakaran Marine Park, Sabah, Malaysia. (B) The main tectonic elements are highlighted on the detailed map.

Similar observations have recently been made on present-day carbonate platforms of the Celebes Sea, east of the Island of Borneo and may serve as analogues to the phenomena observed on the Miocene platforms. The recent evolution of carbonate platforms of the Tun Sakaran Marine Park, east of Sabah, Malaysia (Fig. 1), was the subject of a remote sensing analysis at SEACARL, Universiti Technologi PETRONAS (Pierson et al., 2010, 2012; Chalabi, 2012). The various steps in the recent evolution of these modern platforms have led to margin back-stepping, platform contraction and fragmentation but also possibly to a widespread colonization of the platform lagoons by corals that form a particular type of reticulated or cellular reefs, termed "Lagoon pattern reefs" (Chevalier in Battistini et al., 1975; Wood, 2001; Montagne et al., 2013) or "Mesh reefs" (Stoddart, 1969).

While the Miocene carbonate platforms were drowning, lateral reservoir distribution and heterogeneity, as well as reservoir properties changed drastically. It is therefore important to understand the mechanisms that have led to platform drowning so that reservoir distribution and properties in the Miocene hydrocarbon fields of the South China Sea can be predicted and modelled correctly. Sea level fluctuations are indeed attributed to global, eustatic variations but also to tectonic-related causes. It is likely that the orientation and location of reef fringes in the Miocene carbonate platforms follows the trend of the buried tilted basement blocks in the Luconia region (Figs. 2 and 3). In the present-day example presented in this paper, the tectonic structures may also indirectly affect the vertical movements of the reef margins (Steuer et al., 2014). The southern part of the Sulu Archipelago – currently supposed to be a part of a continental sliver forming the Zamboanga Peninsula (Pubellier et al., 1991a,b) – separated from Mainland China during the middle to late Miocene opening of the Sulu Sea (Rangin et al., 1990a,b). This area is still active today as demonstrated by seismicity and global positioning system data (Sapin et al., 2013). However, the rate of basement vertical motion is unclear.

This paper therefore aims at (1) presenting a comparative analysis of similarities and differences in the morphologies and sedimentary systems observed in the Miocene and present-day platforms, (2) interpreting the morphological phenomena observed on the modern and fossil platforms and (3) performing a comparative analysis of the mechanisms responsible for the evolution of the modern vs. Miocene platforms, especially during their demise.

2. Study areas

2.1. Miocene carbonate platforms

Carbonate platforms of middle to late Miocene age are distributed over a large area of the South China Sea. More than 200 Miocene carbonate platforms have been seismically mapped in the Central Luconia Province, on the Sarawak shelf, off the northwest coast of the island of Borneo (Fig. 1). With about 55 of these platforms found to be hydrocarbon-bearing, the central Luconia Province is one of the major gas-producing areas in Malaysia (Yamin Ali and Abolins, 1999; Epting, 1980, 1989).

Structurally, the Central Luconia Province is in an intermediate position between areas of extensive tectonic activity characterized by subsidence and faulting in the north and zones of pronounced Early to Mid-Tertiary compressional tectonic in the south (Epting, 1980). The Miocene carbonate platforms of Central Luconia developed on a series of fault blocks or horsts formed during a phase of crustal extension that created the South China Sea Basin (Taylor and Hayes, 1983). Continuous subsidence of the substratum allowed these carbonate platforms to grow up to significant thicknesses, such as the Mega Platform, that reaches a thickness of 1200 m (Vahrenkamp et al., 2004a). The Mega Platform is a 30-× 50-km-large carbonate platform located in the northern part of the Central Luconia province. A total of six build-ups make up the Mega Platform complex and are referred to in this study as Mega Platform build-ups MPB-1 to –6 (Fig. 2).

The Miocene platforms of Central Luconia grew in three major phases in response to relative sea level fluctuations (Epting, 1980, 1989; Wilson et al., 1999): an out-building phase, during which carbonates prograded seaward, an up-building phase characterized by vertical aggradation and an in-building phase during which the platforms contracted in size and eventually died out. Gas-bearing reservoirs mainly include intervals deposited during the up-building and in-building phases.

Shallow water carbonates and reefs of the South China Sea that developed during the Late Oligocene and Early–Middle Miocene were strongly influenced by structural patterns provided by a complex plate tectonic history (Fulthorpe and Schlanger, 1989; Steuer et al., 2014). Several authors have indicated the influence of tectonics on Central Luconia build-up development (e.g. Doust, 1981; Zampetti et al., 2004; Coca, 2006; Wilson et al., 2002).