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Carbonate platform growth and demise offshore Central Vietnam: Effects of Early Miocene transgression and subsequent onshore uplift

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ABSTRACT

Miocene carbonate platforms cover a large part of the Central Vietnamese South China Sea margin. Early carbonate deposition took place on two regional platforms separated by a narrow depression developed along the trace of the East Vietnam Boundary Fault Zone. West of the East Vietnam Boundary Fault Zone, the Tuy Hoa Carbonate Platform fringes the continental margin between Da Nang and Nha Trang. Here, platform growth initiated during the Early Miocene and continued until Middle Miocene time when regional uplift led to subaerial exposure, termination of platform growth and karstification. East of the fault zone, the Triton Carbonate Platform was also initiated during the Early Miocene. Carbonate growth thrived during Early and part of Middle Miocene time and a thick, clean Lower and Middle Miocene carbonate succession cover the Triton Horst and the Qui Nhon Ridge. During the Middle Miocene, partial drowning resulted in the split-up of the Triton Carbonate Platform. Repeated partial drowning events throughout the Middle and Late Miocene resulted in westwards retreat of platform growth and eventual platform drowning and termination of carbonate deposition. Modern carbonate growth continues on isolated platforms hosting the Paracel Islands farther seawards. The onset of widespread carbonate deposition largely reflects the Early Miocene transgression of the area linked with early post-rift subsidence and the opening of the South China Sea. The mid-Neogene shift in carbonate deposition is interpreted as a consequence of regional uplift and denudation of central and south Indochina starting during Middle Miocene time when the Tuy Hoa Carbonate Platform became subaerially exposed. Stressed carbonate growth conditions on the Triton Carbonate Platform probably resulted from increased inorganic nutrient input derived from the uplifted mainland, possibly enhanced by deteriorated climatic conditions and rapid sea-level fluctuations promoting platform drowning.

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1. Introduction

Cenozoic carbonates constitute one of the primary targets for petroleum exploration within the South China Sea region (Fulthorpe and Schlanger, 1989; Tyrrell and Christian, 1992; Howes, 1997; Williams, 1997; Doust and Summer, 2007) (Fig. 1). This is also true for the Vietnamese margin where considerable petroleum reserves are found and produced from Miocene carbonates in the Nam Con Son Basin (Matthews et al., 1997). Miocene carbonates have been documented north of the Nam Con Son Basin along the Vietnamese margin (Holland et al., 1992; Roques et al., 1997a; Lee and Watkins, 1998; Fyhn et al., 2009a,b,c). Although little explored, exploration of the Central Vietnamese margin, so far, has focused on Miocene carbonates with a number of oil and gas discoveries made.

We present a first combined study of the system of Neogene carbonate platforms flanking the basins offshore Central Vietnam. The study is based on approximately 13,000 km 2-D seismic data tied to exploration wells (Fig. 2). Seismic data range from vintage data acquired as early as 1974 to data acquired in 2003 constituting an open seismic grid with average line spacing ranging in between 3 and 40 km. The seismic data quality varies. However, data generally has adequate resolution within the targeted Neogene carbonate successions with frequencies ranging from 20 to 50 Hz corresponding to acoustic wavelengths in between *c.* 30 and 100 m and a seismic resolution at best in between *c.* 7 and 25 m.

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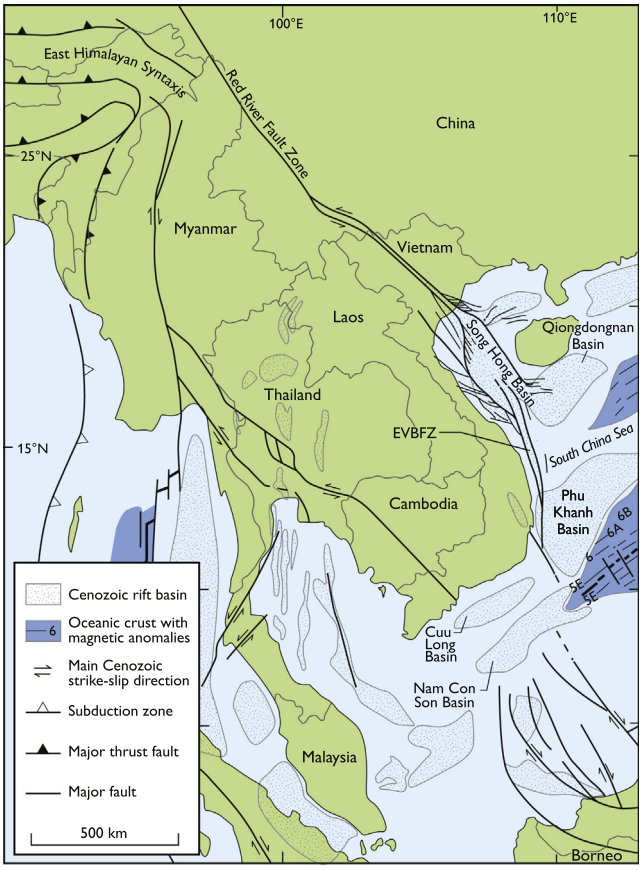

Fig. 1. Map of Indochina and the western part of the South China Sea showing the outline of main basins and Tertiary structures. EVBFZ: East Vietnam Boundary Fault Zone.

The data document a very dynamic growth history of the carbonate system in the region. Factors such as regional Early Miocene transgression of structural highs along the Central Vietnamese margin combined with a warm climate probably catalyzed massive carbonate platform growth. Onshore uplift and erosion linked with volcanism and associated inorganic nutrient pollution in the platform areas is interpreted as the primary mechanism governing the subsequent platform demise and drowning. The Cenozoic evolution of basins and highs together with Neogene volcanism and onshore uplift are therefore described initially before treating the Neogene carbonate growth.

2. Setting and structural framework

Cenozoic carbonates are widespread around the South China Sea, present from the Chinese margin in the north to offshore Borneo in the south (Epting, 1989; Fulthorpe and Schlanger, 1989; Erlich et al., 1990). In the south, platform growth began during Late Eocene and Oligocene time and locally continues to the present (Epting, 1980; Moss and Wilson, 1998; Wilson et al., 1999; Fournier et al., 2005; Vahrenkamp et al., 2004; Bachtel et al., 2004). Farther north along the Vietnamese and Chinese margins, widespread carbonate deposition initiated during the Early Miocene probably due to the absence of fully-marine conditions until the final stage of the South China Sea opening (Mayall et al., 1997; Matthews et al., 1997; Fyhn et al., 2009a,b; Wu et al., 2009; Yubo et al., 2011). Oceanographic and climatic changes, terrigenous sediment supply, inorganic nutrient levels, volcanism, uplift and relative sea level fluctuations are factors interpreted to have had a significant influence on local and regional Neogene platform growth and demise in SE Asia (Fournier et al., 2004; Fournier et al., 2005; Fyhn et al., 2009b; Sattler et al., 2009; Wilson, 2011). Carbonate platforms may therefore record information fundamental to unraveling the tectonic development of various regions and are useful indicators for local and global climatic and oceanographic changes.

2.1. Cenozoic basin development

Cenozoic basin development along the Central Vietnamese margin initiated through Paleogene rifting (Marquis et al., 1997; Roques et al., 1997a,b; Lee and Watkins, 1998; Clift and Sun, 2006; Fyhn et al., 2009a,c; Zhu et al., 2010). The exact timing of rift initiation is poorly constrained due to: (1) the scarcity of deep wells penetrating the oldest syn-rift succession and (2) the low biostratigraphic resolution of most of these non-marine rift systems. The significant crustal extension along the margin has been viewed in context with either the extension leading to the opening of the South China Sea and/or lateral movements along the Vietnamese margin linked with the India-Eurasia collision (Taylor and Hayes, 1980; Tapponnier et al., 1982; Roques et al., 1997a; Fyhn et al., 2009a) (Fig. 1). The East Vietnam Boundary Fault Zone can be mapped seismically along the margin. In the study area it forms the Quang Ngai Graben – an elongated rift forming the southernmost extension of the Song Hong Basin filled by Paleogene syn-rift deposits. The fault zone also delineates a coast-parallel Neogene depocenter and seems to have been a controlling lineament for the depositional system along this part of the margin (Fig. 2).

Underlying the Triton Horst (or Guangle Uplift) to the Paracel Islands (or Xisha Uplift) (Figs. 2 and 3) and adjacent basins are a number of grabens and half-grabens filled by tentatively dated Paleogene syn-rift deposits initially noted by Roques et al. (1997a) and Dang and Sladen (1997). Seismic resolution of the syn-rift succession on the uplifts is often only moderate, partly due to damping of the acoustic energy by the thick overlying carbonate succession. The Paleogene rift-system becomes more pronounced towards the Qiongdongnan and the Phu Khanh Basins to the north and south filled by an up to several kilometers thick syn-rift succession confined to major grabens and half-grabens often measuring several tens of kilometers across (Fig. 4).

The syn- and post-rift successions on and along the Triton Horst are separated by an unconformity in places marked by distinct reflector truncations. The entire syn-rift succession tends to be strongly deformed and compressional deformation is tentatively interpreted in places affecting the top of the syn-rift succession (Fig. 4). This may record a compressional pulse towards the end of the Paleogene possibly comparable to similar events in the Cuu Long and the northern Song Hong Basins to the south and north, respectively (Rangin et al., 1995; Fyhn et al., 2009a).

Kilometer-thick Neogene deposits deeply bury the syn-rift succession in large parts of the area. Farthest to the east, the thickness of the Neogene generally decreases due to the distal setting leaving Paleogene rift sediments and basement more shallowly buried. The kilometer-thick Neogene succession and the overall Neogene transgressional trend leading to the modern bathymetric outline of the area indicate the Neogene as a period of generally rapid subsidence.

The Neogene succession is dominated by siliciclastic deposits in the basin centers and to the west along the Vietnamese margin (Fig. 3). The clastic sediments tend to thin seaward on the Triton Horst and in the Phu Khanh Basin reflecting the increasing distance to the source areas.

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