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Onshore to offshore trends in carbonate sequence development, diagenesis and reservoir quality across a land-attached shelf in SE Asia

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ABSTRACT

Although isolated Miocene buildups in SE Asia commonly form prolific hydrocarbon reservoirs, their equivalents on clastic-dominated land-attached shelves remain poorly known and underexplored. Here, onshore to offshore trends in carbonate development and reservoir quality are assessed across the NW Borneo shelf through study of surface outcrops and subsurface wells. A multidisciplinary programme of fieldwork, petrography and geochemical analyses allowed evaluation of spatio-temporal variations in deposition, diagenesis and pore system development, together with an assessment of controlling influences. In addition to field logging and sample collection >200 samples were studied via transmitted light, cathodoluminescent and scanning electron microscopy together with stable isotopic characterisation (O, C and Sr).

Carbonates developed as localised low-, and higher-relief buildups, as well as more continuous sheet-like deposits in near-coast to shelf margin positions. Molluscs, corals, larger benthic foraminifera and coralline algae are common constituents. Most samples show evidence for marine micritisation, and just in shelf margin positions isopachous cements. However, burial diagenesis predominates in the form of compaction, neomorphism, fracturing, late leaching and dolomitisation. Near-coastal carbonates commonly contain siliciclastics, as do some shelf margin deposits that interdigitate with, or are covered in siliciclastics. Some early, probable meteoric leaching affected inner shelf deposits prior to pervasive neomorphic to blocky/poikilotopic calcite cement formation. On the basis of δ^{18}O V-PDB values of −4.5 to −7.9‰ equivalent to δ^{18}O V-SMOW values of 0 to −4‰ at 25–40 °C and δ^{13}C V-PDB values of −0.6 to +1.6‰ cementation probably reflects alteration from terrestrial groundwaters in meteoric aquifers derived from the humid landmass of Borneo. Despite this cementation, moderate energy inner- to mid-shelf grainstones from the core of mounded carbonates still retain, or have enhanced porosity (<8%) over their lower energy counterparts (<4% porosity). Retention of primary porosity and/or late burial dissolution (often associated with saddle dolomite formation) enhancing predominantly primary and minor secondary porosity is key to reservoir quality development in outer-shelf deposits. Best porosity (<20–35%) is in high energy grainstones and rudstones from outer-shelf to shelf-margin positions that experienced minimal clastic influx, most commonly from backstepping to aggradational carbonate sequences. Although stable isotopes for shelf margin calcite cements are consistent with precipitation from marine-derived fluids (δ^{18}O V-PDB values of −3.6 to −5.4‰), those for the late dolomites are suggestive of fluids of meteoric origin (δ^{18}O V-PDB values of −5.2 to −7.4‰ equivalent to values of −0.3 to −6.3‰ V-SMOW at 40–60 °C). Critical factors for reservoir quality development in carbonates from siliciclastic-dominated shelves in the equatorial tropics are: (1) development and preservation of primary porosity, (2) cementation associated with meteoric aquifers draining large humid equatorial landmasses, and (3) burial leaching and fluid pathways.

1. Introduction

Isolated Miocene buildups in SE Asia commonly form prolific hydrocarbon reservoirs (Epting, 1980; Fulthorpe and Schlanger,

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1989; Vahrenkamp et al., 2004; Bachtel et al., 2004), however, their equivalents on clastic-dominated land-attached shelves remain poorly known and underexplored (Wilson, 2002, 2012; Wilson and Lokier, 2002). Although 69% of the 250 shallow water or shelfal/neritic carbonate formations of Tertiary age in SE Asia developed as attached systems, 83% of economic hydrocarbon discoveries by formation to date, and >96% of reserves are in isolated carbonates (Wilson and Hall, 2010). Does this apparent mismatch in SE Asian carbonate systems development versus their reservoir development reflect: (1) underevaluation, (2) paucity of reservoir development, (3) lack of trap formation, or (4) 'failure' of other aspects of petroleum system development all within attached carbonate systems? The hypothesis here is that potential reservoir development in attached carbonate systems from predominantly clastic shelves in SE Asia will be strongly influenced by local environmental conditions associated with their development in the equatorial tropics adjacent to large landmasses. Additionally, there may be significant variations in carbonate and potential reservoir development across broad land-attached shelves. Local environmental conditions that may all influence depositional and post-depositional basin margin carbonate development in the equatorial tropics include significant and near-continuous influx of siliciclastics and/or nutrients together with sustained large-scale palaeoaquifer flow (Hendry et al., 1999; Wilson and Lokier, 2002; Wilson, 2002, 2005, 2008, 2011, 2012; Madden and Wilson, 2012).

Herein, the deposition, diagenesis and reservoir quality of Miocene carbonates from across the broad (>100 km wide) siliciclastic-dominated shelf of NW Borneo, offshore Sarawak, is assessed (Fig. 1). As the world's third largest island, with significant Neogene uplift and a humid equatorial climate, the terrestrial runoff from Borneo results in some of the most globally significant annual discharges of freshwater, clastics and nutrients to the surrounding seas (Hall and Nichols, 2002). Basins around Borneo conservatively contain up to 9 km of sediment derived from the island (Hamilton, 1979), and the sediment supplied during the Neogene is similar to that per unit area of the Himalayas (Hall and Nichols, 2002). Although excessive clastic influx can be detrimental to carbonate production, recent studies have shown that many carbonate producers can adapt to a significant influx (Wilson and Lokier, 2002; Sanders and Baron-Szabo, 2005; Hallock, 2005; Wilson, 2005; Lokier et al., 2009). A range of modern and Tertiary carbonate systems have been documented from the predominantly clastic shelves of Borneo, including delta-front patch reefs, coastal fringing reefs, admixed carbonate-siliciclastic biostromes, intra-shelf reefs or buildups, and shelf margin buildups or barrier systems (Agostinelli et al., 1990; Netherwood and Wight, 1992; Ali, 1995; Roberts and Sydow, 1996; Noad, 2001; Tomascik et al., 1997; Wilson et al., 1999; Wilson and Lokier, 2002; Hook and Wilson, 2003; Wilson, 2005; Saller et al., 2010). Recent studies have shown that large-scale sustained palaeoaquifer flow has significantly impacted the diagenesis of carbonate systems from

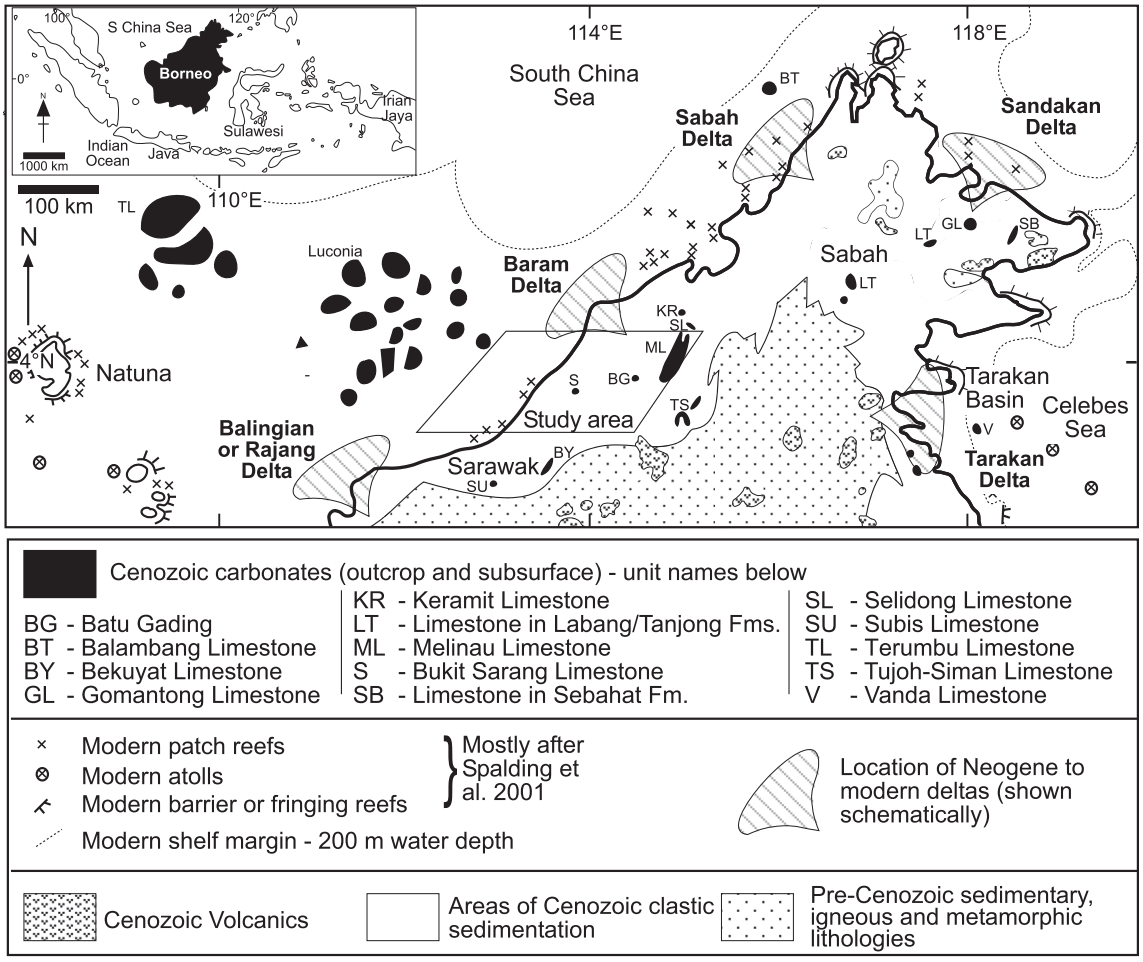

Figure 1. Simplified geological map of north Borneo showing the location of the research area. Major outcropping and subsurface Cenozoic and modern carbonates are illustrated, as are areas of Cenozoic delta progradation (modified from Wilson et al., 1999; Spalding et al., 2001; Wilson, 2002; Madden and Wilson, 2012).