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My life before I was compressed: Fluid flow histories on the northern Australian convergent margin

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The Bonaparte Basin, North West Shelf of Australia and the Papuan Basin, New Guinea Island, form part of a complex convergence system on Australia's northern plate margin. Late Tertiary convergence between the Indo-Australian and South-East Asian plates has caused significant modification of sedimentary basins along this margin, many which are prospective for hydrocarbon exploration. Both basins have experienced a similar geologic history during Mesozoic Gondwanan rifting of Australia's northern margin (Struckmeyer et al., 1990; 1993), but are currently at different stages of development of a Cainozoic compressional orogeny. At present, the Bonaparte Basin can be characterized as a proto-foreland basin resulting from lithospheric flexure associated with the uplift of Timor Island. The Papuan Basin, on the other hand, has been strongly inverted and is now a well developed fold and thrust belt. These differences provide an ideal opportunity to study how fluid-flow regimes are modified during basin inversion. The basins share a common petroleum system and have experienced very similar fluid-flow histories, despite being more than 2000 kilometres apart. The timing and nature of fluid-flow events is strongly controlled by the tectonic history experienced by each region and when placed in a regional context provide a fundamental understanding of trap fill and preservation through time.

A series of regional fluid-flow events can be used to correlate episodes of formation water flow and hydrocarbon charge in the two regions. Two episodes of formation water flow (W1, W2) and up to five pulses of hydrocarbon charge (H1 to H5) can be discerned. Early gas charge (H1) to extensional structures produced by Mesozoic rifting occurs in both regions (Krieger, 1997; Lisk et al. 1998) and is predicted by published basin modeling results (Kennard et al., 1999). Subsequent widespread oil migration (H2) produces oil columns below these gas caps, with 1-D basin modeling indicating a common Late Eocene time of charge. Geochemical analysis of this initial oil charge, using samples of oil trapped within fluid inclusions, show that palaeo-oils in the Bonaparte Basin are of similar composition to the currently reservoired oils and can be typed to Jurassic source rocks (George et al., 1997, 1998). Similar analyses, however, conducted on samples from the Papuan Basin indicate the palaeo-oils are derived from non-Jurassic source rocks, contrasting the currently reservoired oils that show purely Jurassic derivation.

Reactivation of pre-existing extensional faults following the onset of continent-arc collision was generally detrimental to the preservation of the early hydrocarbon charge. Continent-arc collision occurred much earlier in New Guinea (~25 Ma; Hill and Hall, 2001) compared with the Bonaparte Basin (~3 Ma; Johnston and Bowin, 1981) and this controlled the timing of trap breach. The impact of this event on hydrocarbon retention appears to have been more severe in the Papuan Basin and may have resulted in the complete loss of this early oil charge, as no known live oils correlate geochemically with these palaeo-oils. In the Bonaparte Basin, the palaeo-oils correlate closely with live oils and tend to suggest that some oil columns survived this reactivation event, or that the oils successfully re-migrated to be retained by the system.

In both regions the loss of hydrocarbons was accompanied by flow of hyper-saline brine (W1), the origin of which remains uncertain. In the Bonaparte Basin, the source of this fluid is attributed to Palaeozoic evaporites with migration into the Mesozoic and Cainozoic section facilitated by vertical flow along reactivated faults. Evidence of convective heating events supports a deep (and hot) origin for these fluids (O'Brien et al., 1996, 1999; Lisk et al. 2000). The distribution of saline brines in the Papuan Basin appears to show significant lateral migration and the role of faults as migration conduits is less certain.

The relative timing of brine flow provides a marker to constrain the timing of hydrocarbon charge. In the Papuan Basin, high salinity fluids occur within palaeo-oil columns, indicating loss of oil predates brine flow in order to facilitate ingress of new formation water. By comparison, traps in the Bonaparte Basin that have retained hydrocarbons are devoid of these high salinity fluids.

A second episode of hydrocarbon migration and charge post-dates the brine flow event, probably induced by rapid subsidence in the Neogene. In the Papuan Basin, this promoted hydrocarbon generation that provided both gas (H3) and oil (H4) charge to the compressional traps produced by formation of the Papuan fold belt. The charge appears to have become increasingly gas prone (H5), causing flushing of pre-existing oil columns, particularly in the north west of the fold belt. In the Bonaparte Basin, this second hydrocarbon charge was dominated by gas (H5), but probably included some component of light oil (H4).

The more substantial compressional deformation that typifies the Papuan Basin reflects closer proximity to the continent-arc collision and has been considered analogous to Timor Island rather than the Bonaparte Basin. The foreland basin development of New Guinea may, in some regards, by more analogous with the Bonaparte region, experiencing far field effects of the collision. Trap breach may, therefore, represent a major risk to successful exploration in the foreland if the analogy with the Bonaparte Basin is valid.

Uplift and associated mountain building to create the Papuan fold belt and the island of Timor produced a further significant fluid-flow event. This is most clearly demonstrated in the Papuan Basin where topographically driven ingress of meteoric waters (W2) has diluted the salinity of connate waters and in places produced hydrodynamic tilting of oil-water contacts (Eisenberg, 1993). The presence of a hydrodynamic flow system has also been proposed for parts of the Bonaparte Basin and could be responsible for the loss of hydrocarbons due to water-washing (Newell et al. 1999).

Reconstructing hydrocarbon charge histories in regions with complex tectonics requires coupling of structural and fluid-flow events. Recognition that far field effects play an important role in controlling the behaviour observed at a local or trap scale is fundamental in producing models to assist in describing exploration risk. A whole of life approach is critical to understanding the controls on hydrocarbon charge and retention, with time being the master variable. Integration of skills and expertise with cutting edge technology is needed if the promise of such complex basins is to be fully appreciated.

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