Geological evolution and hydrocarbon plays of Madagascar (with occasional reference to Australia).

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Abstract

The stratigraphic succession and tectonic history of Madagascar are directly related to the progressive break-up of Gondwana, and the subsequent dismemberment of Eastern Gondwana, and as such, three discrete phases of rifting can be discerned:-

- Uppermost Carboniferous to Upper Permian (Karroo Supergroup): extensional block faulting, consequent upon the closure of the Cape Fold Belt to the south, resulted in horst and graben formation and the deposition of thick syn-rift sequences of glaciogenic, fluvio-deltaic, coal swamp, and terrestrial immature clastics. Differential tectonic movement ceased in end-Permian times, and the early Trias saw the only significant marine incursion in the whole of the Karroo sequence (Middle Sakamena Shales). Terrestrial, clastic deposition continued in a post-rift setting until end-Trias times.

- Lower Jurassic: the resumption of rifting appears to have followed the old NE-SW and N-S Karroo trends but the locus of rifting was located further outboard, such that the Lower Jurassic rifts are largely seen in offshore Madagascar. Initially restricted conditions are indicated by the development of local salt basins and source rocks. Rifting proceeded to sea-floor spreading in the Middle Jurassic as East Gondwana separated from West Gondwana. The drift (sag) phase is represented by a regionally extensive Dogger carbonate platform which, with its sandy littoral equivalents, transgressed unconformably over the inboard block-tilted and eroded Karroo sequence. The carbonate platform was extinguished by fine Upper Jurassic – Lower Cretaceous marine clastics, reflecting the development of the Majunga Basin passive margin and the Morondava Basin passive/transform margin as Eastern Gondwana started to drift south along the Davy Fracture Zone.

- Turonian: the rifting and separation of India+Seychelles from Madagascar in the Turonian resulted in major footwall uplift and down-to-the-west tilting of Madagascar's cratonic hinterland and the start of a long period of deltaic – fluviomarine clastic progradation. A major unconformity and widespread intrusive and extrusive basaltic

magmatism is the only significant indication in Madagascar of this rifting event. Progressive uplift and seaward tilting of the island has continued throughout much of the Tertiary, resulting in subaerial erosion of the updip margin of the Cretaceous wedge; partial or complete loss of landward closure on all pre-existing (inboard) structures; and the progressive elevation of the Tsimiroro and Bemolanga palaeo-oil accumulations to near-surface levels and their consequent inspissation.

The hydrocarbon habitat of Madagascar is dominated by its two large heavy oil/tar accumulations known since the early 1900s:-

- the Bemolanga Tar Sands, reservoired in Triassic Isalo sands cover an area of >400 sq km and have been appraised by over 250 shallow coreholes. Estimated STOIIP ranges from 2-20 billion barrels of which about 1 billion barrels are thought recoverable by open pitmining.
- the Tsimiroro Heavv Oil Field, appraised by over 45 shallow wells, contains STOIIP variously estimated to range from 0.2-5 billion barrels of 11-15 deg. API oil in Triassic Isalo sands draped over a shallow north-south striking basement horst.

Reported field data imply that migration of oil into these traps occurred prior to Turonian magmatism and uplift.
Numerous other surface oil impregnations have been recorded, especially along the faulted southeastern margin of the Morondava Basin and over the plunge of the Cap St. Andre nose.

A total of over 70 exploration wells have been drilled since 1950 in Madagascar, most of which recorded some, albeit weak, indications of oil and gas throughout the stratigraphic column. However, only two wells recovered significant, though non-commercial, flows of hydrocarbons to surface:-

- West Manambolo-1 (1988) flowed 17 mmscfgpd plus some condensate from thin Lower Cretaceous turbiditic sandstones,
- Manandaza-l (1991) recovered 10 barrels of waxy 41 degree API oil from tight, fractured Lower Sakamena sandstones.

Source rocks are present at several stratigraphic levels though none have yet been demonstrated to be of regional extent. Locally significant, coally, gas-prone source rocks are present in the Permian Sakoa Formation and the lower Isalo II ('Lignitic Shale'). Locally significant marine shale, oil-prone source rocks have been proven in the Middle Sakamena of the Manandaza Basin – Karroo Corridor, and in the early Jurassic syn-rift sequence (e.g. Beronono Shale of the southern Majunga Basin). Oil and source rock extract analysis suggests that the Tsimiroro/Bemolanga heavy oils, and the Manandaza light oil are derived from the Middle Sakamena shale. Though rich in outcrop, the Beronono shales have not yet been encountered in the subsurface, although imminent exploration drilling in the deep water Majunga Basin, and licensing of the deep water Manandaza Basin, are predicated upon the presence of these source rocks. The traces of oil and impregnations recovered from Cretaceous sands do not resemble either

Karroo or Bemolanga extracts; they have a mature crude-like biomarker distribution and are thought to have been generated from, as yet unproven, Upper Jurassic – Lower Cretaceous pro-delta source rocks.

Three principal hydrocarbon plays are recognized, corresponding to the tripartite subdivision of the stratigraphic column:-

- in the Karroo, the target is fault/dip structures, draped over basement horsts and charged by co-eval source rocks in the adjacent grabens (Tsimiroro model).
- in the Jurassic, viable structures have only been seen in the offshore. They appear to be halokinetic in origin and are prognosed to be charged from the subjacent Jurassic rift basins.
- in the Cretaceous clastic wedge, there is a trend of large growth faults associated with the underlying Dogger shelf margin, and stratigraphic trapping possibilities in slope or basin floor fans.

Where apparent to the author, parallels between the hydrocarbon geology of Madagascar and Australia will be drawn.

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