Extinct and near extinct Petroleum Systems of the East African Coastal Basins

[1] DRD Boote & [2] CJ Matchette-Downes

[1] *David Boote Consulting Ltd., London SW18 2HN, (davidboote@elsyngeroad.fsnet.co.uk)*
[2] *East African Exploration Ltd., Marlow SL7 1DH, (cjmd@ea-x.com)*

Hydrocarbon exploration in the coastal basins of East Africa has been very disappointing. Despite a significant number of exploration tests, only four marginally commercial gas accumulations have been found so far (*Figure 1*) in Ethiopia (Calub ~0.3TCF), Tanzania (Songo Songo ~0.8TCF) and Mozambique (Pande ~2.6TCF and Temane ~1.8TCF) with a number of more recent discoveries (Inharrosa/Mozambique, Manzi Bay, Kiliwani North-1 & Makuranga-1/coastal Tanzania). However oil shows and seeps are quite common in many of the basins with several exhumed oil fields in Tanzania (Wingayongo) and Madagascar (Bemolanga, Tsimiroro and Maraboaly), testifying to once very prolific Permo-Trias and Lower-Middle Jurassic sourced petroleum systems (*Figure 2*). These include:

(1) Permo-Trias Sakamena (saline lacustrine) sourced systems in northern Morondava (Madagascar), NE and coastal Kenya (Maji ya Chumvi equivalent source), Somalia (Bokh Formation) and perhaps Tanzania, with a characteristically light isotopic signature (*Figures 2 & 3*).
(2) Permo-Trias Sakamena (lagoonal marine) sourced system in the southern Morondava and (?)Majunga Basins of Madagascar and ?Tanzania (*Figures 2 & 3*).
(3) More extensive Lower Jurassic (synrift) petroleum systems in the Majunga and Morondava Basins (Andafia and Beronono lagoonal-restricted marine shale source rocks), Mandawa and Rovuma Basins in coastal Tanzania and northern Mozambique (Mbuo Claystone and equivalent source). *Figures 2 & 4*.
(4) Less well constrained systems sourced from Middle Jurassic marine shales in Tanzania (Makarawa, Mtumbei and Amboni Formations) and Madagascar (basinal equivalent of the Bemaraha Formation). *Figures 2 & 5*.
(5) Oxfordian-Kimmeridgian transgressive marine shale sourced systems in central and northern Somalia (Uarandab and Gahodleh Fm clastic source facies) and Lower Madbi equivalent in Yemen (*Figures 2 & 6*).
(6) Late Kimmeridgian-Tithonian syn-rift systems sourced from the Daghani Shale Fm of Northern Somalia (Berbera Basin), equivalent to the prolific Lam and Upper Madbi sourced systems of the Marib-Jawf and Saar Basins in Yemen (*Figures 2 & 7*).
(7) The Cretaceous and Tertiary interval along the entire East African sea-board appears to lack any significant regional source. However oil and gas has migrated up from underlying Jurassic source rocks to charge Neocomian-Albian sandstone reservoirs at Songo Songo and Wingayongo, sealed by overpressured Cretaceous shales. Further south in Mozambique, Campanian-Maastrichtian sands at Pande-Temane and Buzi reservoir dry gas assumed to have come from a deeper, highly mature source (?Karoo). *Figure 8.*
(8) The Sharmah-1 discovery in the Gulf of Aden (offshore Yemen) was charged by a restricted marine Tertiary source. Although this has not yet been identified, the most likely candidate is locally developed Oligocene syn-rift shales. Further south, evidence of a Tertiary source is limited to weak oil and gas shows in the Coriole Basin (offshore Somalia) and rather ambiguous seep/tar balls in the Rovuma Basin and Seychelles (*Figures 2 & 9*).

All these petroleum systems appear to have developed during the late Mesozoic and early Tertiary, many to be dispersed by regional tilting, uplift and unroofing (*Figure 10*).

Despite the comparative lack of exploration success so far in this vast coastal (onshore & shallow offshore) region, drilling densities are low. This analysis suggests there may be a few key geological plays remaining with very significant potential. These include:

- *geometrically robust structural and stratigraphic traps with plastic salt or overpressured shale seals in areas of limited post-charge uplift/exhumation and*
- *prominent late formed structural traps with plastic seals able to collect and retain gas released by unroofing associated pressure reduction, from fractured high maturity source rocks and gas charged formation water.*

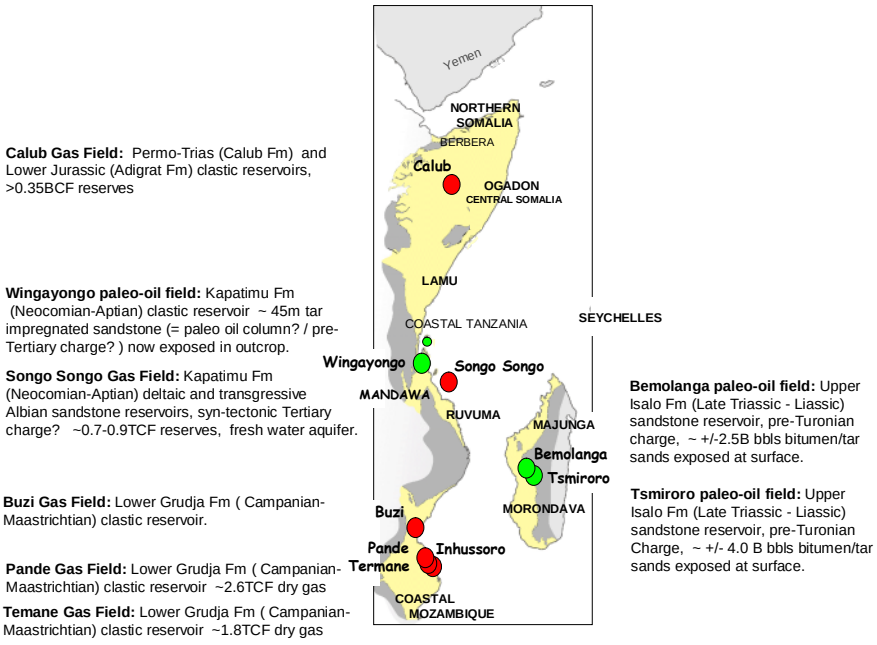


Figure 1: East African Coastal Basins (location map). Main sedimentary basins highlighted with key gas fields and oil sands (paleo-oil accumulations).

Tentative Oil Families ~ East African Coastal Basins

Late Cretaceous/Tertiary		Syn-rift lacustrine source facies offshore Yemen, ?Cariole (Somalia), NE Seychelles, Cambay (NW India)
Upper Jurassic *Late Kimmeridgian - Tithonian*	Lam	Syn-rift restricted clastic source facies, Marib-Jawf (Lam) Saar (Madbi) and Berbera (Daghani) Grabens, Yemen and Northern Somalia
	Mabdi	
Oxfordian-Early Kimmeridgian	Uarandab	Marine shelf clastic source facies (Uarandab) Ethiopia/Somalia
Middle Jurassic	Early post-rift	Distal slope-basin & restricted marine carbonate source facies (Amboni, Mtumbei, Bemaraha), Tanzania coastal,Rovuma and Morondava / Majunga Basins, Madagascar
	? early post-rift	
Lower Jurassic	Syn-rift	Variable, heterogeneous hypersaline (Mbuo) and restricted marine (Beronono, Andafia) clastic source facies, coastal Tanzania, Mandawa, Rovuma, Majunga/Morondava & Seychelles
	? syn-rift	
Early Triassic-Late Permian	δC *light*	Lacustrine (isotopically light, saline) source facies (Sakamena, Maji ya Chumui, Bokh), northern Morondava, Kenya & Ethiopia
	δC *heavy*	Resticted marine /lagoonal source facies (Sakamena,Maji ya Chumui, ?Stigo), Majunga/Morondava, coastal Tanzania, ?coastal Mozambique.
	undetermined	
Lower Cambrian - Upper Pre-Cambrian	Q oils	Restricted (post salt) carbonate source facies (Early Cambrian Dhahaban), central Oman
	North Huqf	Siliceous and carbonate intra-salt (Ara Gp/Al Shomou) and pre-salt (Buah, Shuram) source facies south and north-central Oman and ?dolomites facies (?Bilara), Punjab/ Bikaner-Naguar Basin, Pakistan & India
	South Huqf	

Figure 2: Tentative Oil Families, East African Coastal Basins. Oil shows, seeps and tar sands encountered in the onshore and shallow offshore of the East African seaboard are shown tentatively grouped into discrete families based upon a diverse geochemical data set, and constrained by their stratigraphic distribution. Based in part on information from GeoMark Research Ltd., Mpanju 2000, Kagya 1996, 2000, Matchette-Downes 2005, 2007, Maende & Mpanju, 2003, Mpanju & Philp 1994, Ntomola & Abrahansen 1987.

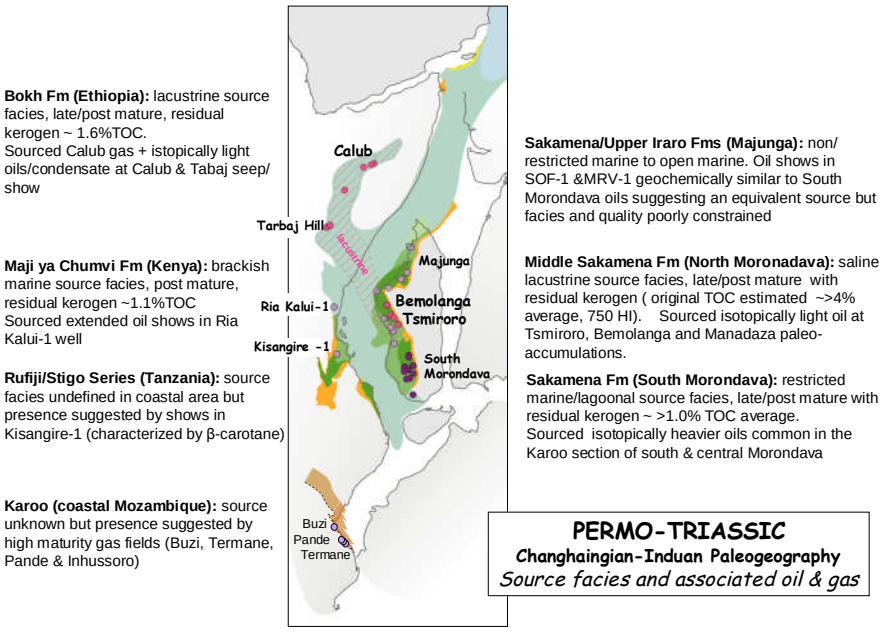


Figure 3: PERMO-TRIASSIC ~ *Changhaingian-Induan Paleogeography.* Source facies and associated oil & gas occurrences are summarized and recognized oil groups attributed to the Permo-Trias are highlighted by coloured dots (~ see figure 2 for key). Based in part on information from Geomark Research Ltd.

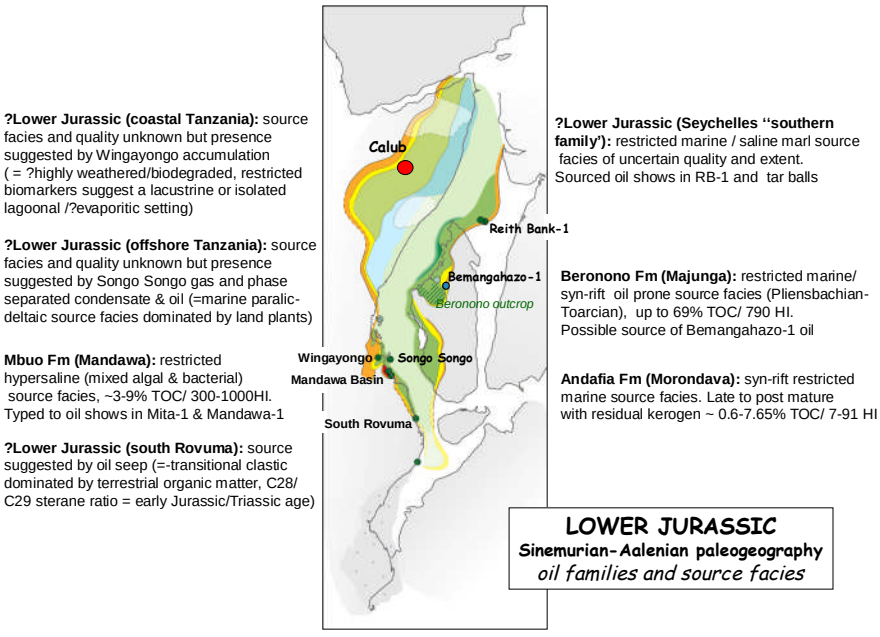


Figure 4: LOWER JURASSIC ~ *Sinemurian-Aalenian paleogeograph.* Source rocks and oil & gas occurrences attributed to the Lower Jurassic are summarized and recognized oil groups highlighted by coloured dots (~ see figure 2 for key). Based in part on information from GeoMark Research Ltd., Kagya 1996, 2000, Matchette-Downes 2005, 2007, Maende & Mpanju, 2003, Mpanju 2000, Mpanju & Philp 1994 and Ntomola & Abrahansen 1987.

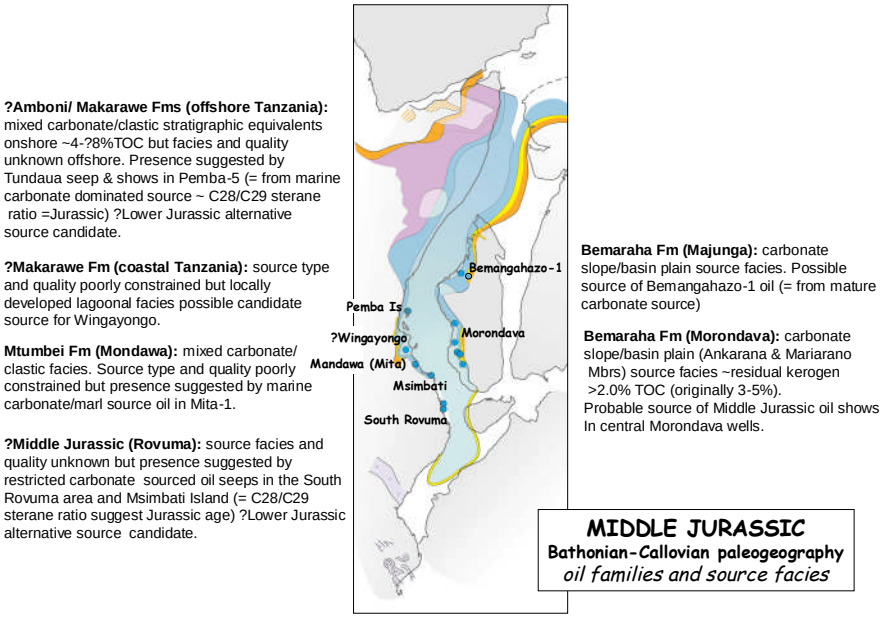


Figure 5: MIDDLE JURASSIC ~ *Bathonian-Callovian paleogeography.* Source rocks and oil & gas occurrences attributed to the Middle Jurassic are summarized and recognized oil groups highlighted by coloured dots (~ see figure 2 for key). Based in part on information from Geomark Research Ltd., Kagya 1996, 2000, Matchette-Downes 2005, 2007, Maende & Mpanju, 2003, Mpanju 2000, Mpanju & Philp 1994 and Ntomola & Abrahansen 1987.

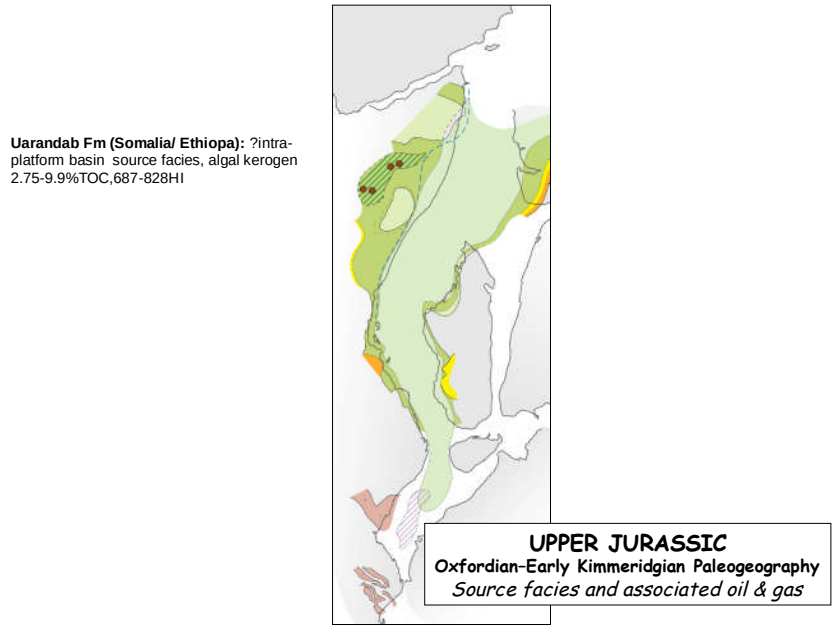
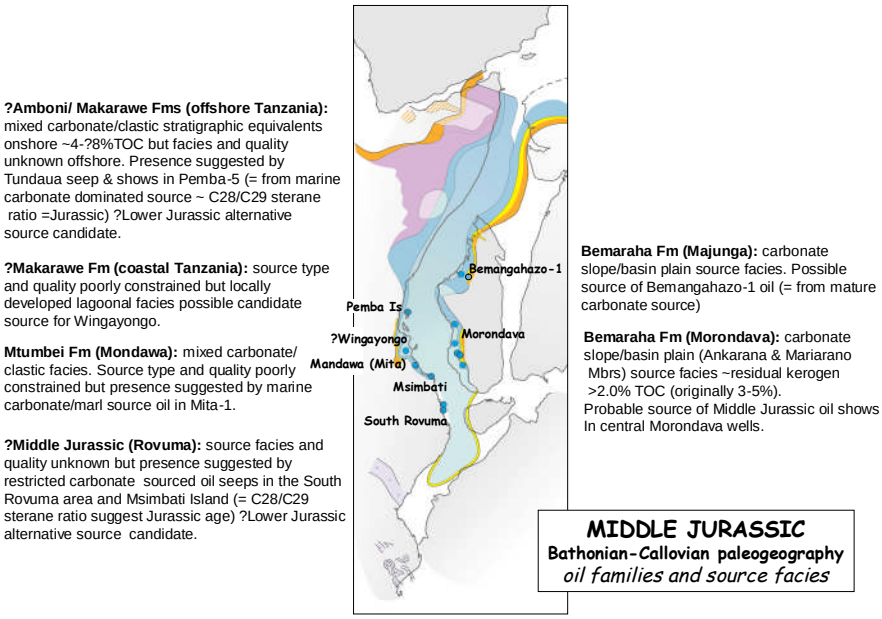


Figure 6: UPPER JURASSIC ~ *Oxfordian-Early Kimmeridgian Paleogeography.*
Source facies and associated oil & gas occurrences attributed to the Oxfordian/Early Kimmeridgian are summarized and recognized oil groups highlighted by coloured dots (~ see figure 2 for key). Based in part on information from GeoMark Research Ltd.



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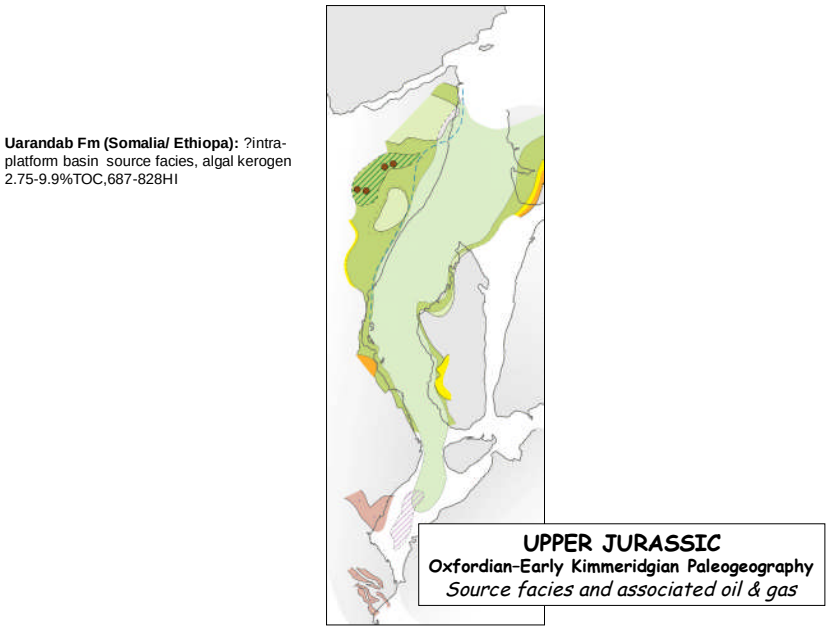

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Lam Fm (Marib-Jawf, North Yemen): restricted marine syn-rift source facies with associated (hypersaline?) source,

Madbi Fm (Saar/ Masilah, South Yemen): restricted marine syn-rift source facies

Daghani Fm (Berbera, North Somalia): restricted marine syn-rift source facies

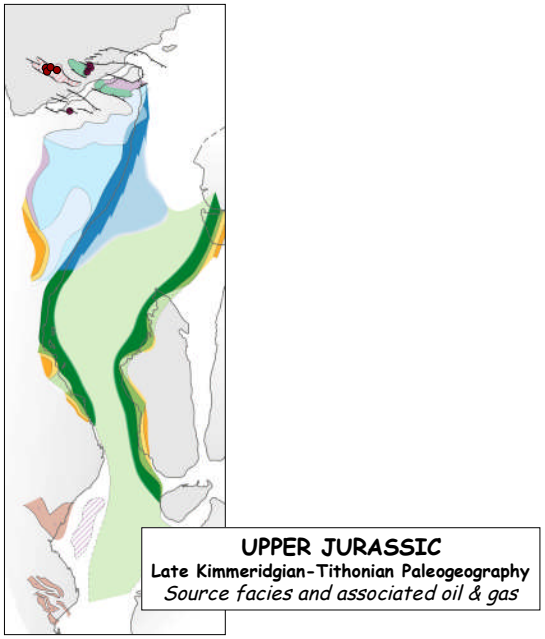


Figure 7: UPPER JURASSIC ~ *Late Kimmeridgian-Tithonian Paleogeography*
Source facies and associated oil & gas occurrences attributed to the Late Kimmeridgian-Tithonian are summarized and recognized oil groups highlighted by coloured dots (~ see figure 2 for key). Based in part on information from GeoMark Research Ltd.

?Cretaceous shales (coastal Tanzania): typically with low TOC content and only locally with possible limited gas generating capability. Elevated TOC/sapropel content apparently encountered in Campanian-Maastrichtian shales of Kisarawa, Kimbiji Main-1and Kimbiji East-1 is probably due to drilling additives.

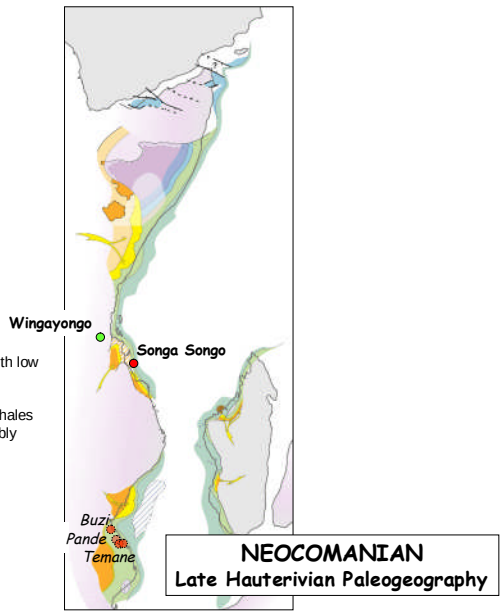


Figure 8: NEOCOMANIAN ~ *Late Hauterivian Paleogeography.* Gas fields and paleo-oil accumulations reservoired in the Cretaceous are highlighted.

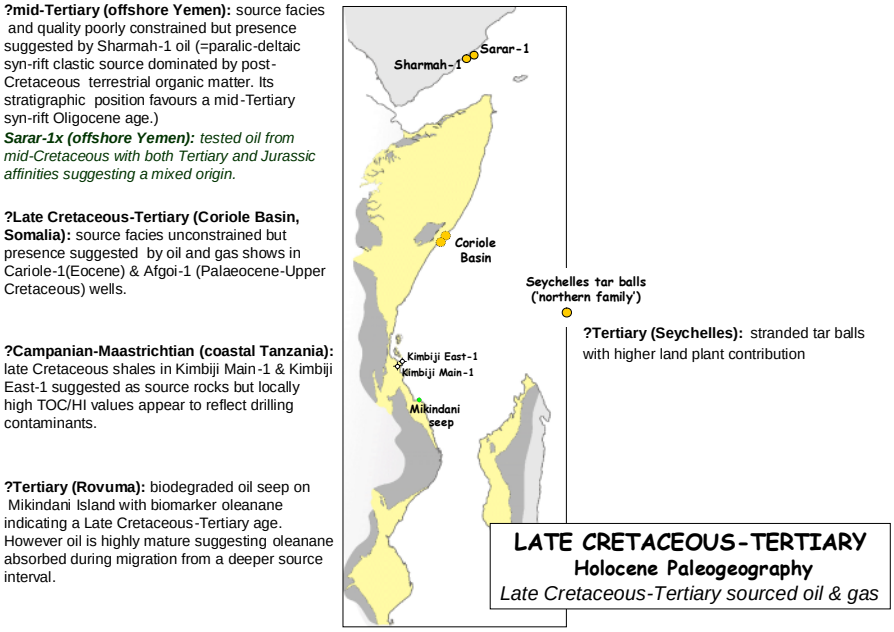
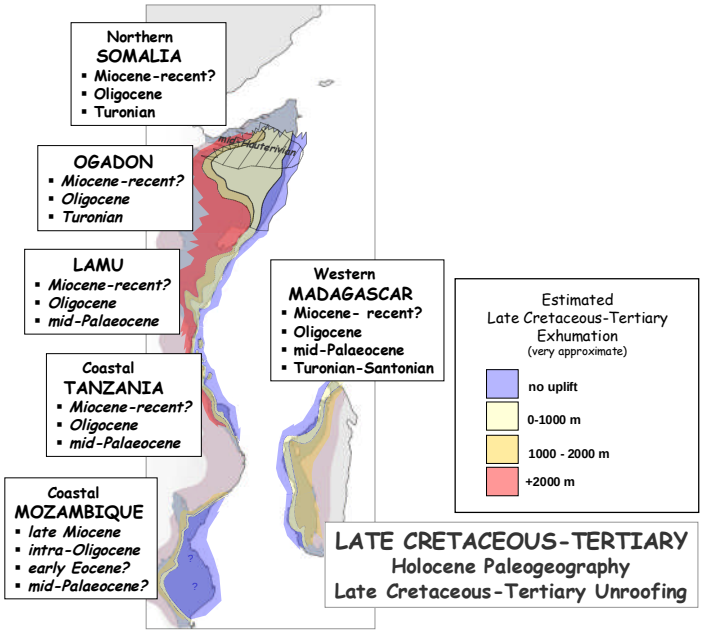


Figure 9: LATE CRETACEOUS-TERTIARY ~ *Holocene Paleogeography*
Oil & gas occurrences attributed to the Late Cretaceous-Tertiary (defined by the presence of the biomarker Oleanane and/or stratigraphic position) are summarized and recognized oil groups highlighted by coloured dots (~ see figure 2 for key). Based in part on information from Geomark Research Ltd., Matchette-Downes 2005, 2007, Maende & Mpanju, 2003, Mpanju 2000 and Mpanju & Philp 1994



Note: *Uplift/Unroofing Events are generalized & approximate*

Figure 10: LATE CRETACEOUS-TERTIARY *Holocene Paleogeography*
Late Cretaceous-Tertiary Unroofing. The composite amount of Late Cretaceous-Tertiary unroofing was calculated by comparing well based maturity profiles within each basin with a 'standard' well profile representing a minimal amount of uplift. The difference provided a relative estimate of exhumation assuming a common basin-wide thermal gradient/heat flow. The map presents a very generalized view of unroofing, variably constrained by data quality and well control. More significant periods of uplift and erosion summarized for each basin are based on a regional 2nd order sequence analysis and are very provisional.

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