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

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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, Kilawi 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 Madagascars (Bemolanga, Tsimirotro and Maraboal), 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).


4. Less well constrained systems sourced from Middle Jurassic marine shales in Tanzania (Makarawa, Mtumbei and Amboni Formations) and Madagascars (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.
Calub Gas Field: Permo-Trias (Calub Fm) clastic reservoirs, >0.35BCF reserves

Wingayongo paleo-oil field: Kapatimu Fm (Neocomian-Aptian) detrital and transgressive Albian sandstone reservoirs, syn-tectonic Tertiary charge? ~45m tar impregnated sandstone (= paleo oil column? / pre-Tertiary charge?) now exposed in outcrop.

Songo Songo Gas Field: Kapatimu Fm (Neocomian-Aptian) deltaic and transgressive Albian sandstone reservoirs, syn-tectonic Tertiary charge~0.7-0.9TCF reserves, fresh water aquifer.

Bemolanga paleo-oil field: Upper Isalo Fm (Late Triassic - Liassic) sandstone reservoir, pre-Turonian charge, ~+/-2.5B bbls bitumen/tar sands exposed at surface.

Buzi Gas Field: Lower Grudja Fm (Campanian-Maastrichtian) clastic reservoir.

Temane Gas Field: Lower Grudja Fm (Campanian-Maastrichtian) clastic reservoir ~1.8TCF dry gas

Pande Gas Field: Lower Guadja Fm (Campanian-Maastrichtian) clastic reservoir ~2.6TCF dry gas

Termane Gas Field: Lower Guadja Fm (Campanian-Maastrichtian) clastic reservoir ~1.8TCF dry gas

Tsmiroro paleo-oil field: Upper Isalo Fm (Late Triassic - Liassic) sandstone reservoir, pre-Turonian charge, ~+/-4.0B bbls bitumen/tar sands exposed at surface.

Bemolanga paleo-oil field: Upper Isalo Fm (Late Triassic - Liassic) sandstone reservoir, pre-Turonian charge, ~+/-2.5B bbls bitumen/tar sands exposed at surface.

Temane Gas Field: Lower Grudja Fm (Campanian-Maastrichtian) clastic reservoir ~1.8TCF dry gas

Termane Gas Field: Lower Grudja Fm (Campanian-Maastrichtian) clastic reservoir ~1.8TCF dry gas

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

<table>
<thead>
<tr>
<th>Late Cretaceous/Tertiary</th>
<th>Syn-rift lacustrine source facies offshore Yemen, ?Caride (Somalia), NE Seychelles, Cambay (NW India)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Jurassic</td>
<td>Ln</td>
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<tr>
<td>Late Kimmeridgian</td>
<td>Syn-rift restricted clastic source facies, Marib-Jawf (Lam) Saar (Madbi) and Berbera (Daghani) Grabens, Yemen and Northern Somalia</td>
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<tr>
<td></td>
<td>Mobdi</td>
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<tr>
<td>Middle Jurassic</td>
<td>Uarandab</td>
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<td></td>
<td>Marine shelf clastic source facies (Uarandab) Ethiopia/Somalia</td>
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<tr>
<td>Early post-rift</td>
<td>Distal slope-basin &amp; restricted marine carbonate source facies (Ambori, Mtumbei, Bemaraha), Tanzania coastal, Rovuma and Morondava/Majunga Basins, Madagascar</td>
</tr>
<tr>
<td>Early post-rift</td>
<td>Variable, heterogeneous hypersaline (Mbuos) and restricted marine (Berono, Andalia) clastic source facies, coastal Tanzania, Mandawa, Rouxuma, Majunga/Morondava/Seychelles</td>
</tr>
<tr>
<td>Late Jurassic</td>
<td>Syn-rift</td>
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<tr>
<td>Early Triassic</td>
<td>SC light</td>
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<tr>
<td>Late Permian</td>
<td>Slight (isotopically light, saline) source facies (Sakamena, Maj ya Chumui, Bokh), northern Morondava, Kenya &amp; Ethiopia Restricted marine/ marginal source facies (Sakamena, Maj ya Chumui, ?Stigo), Majunga/Morondava, coastal Tanzania, ?coastal Mozambique.</td>
</tr>
<tr>
<td>Early Permian</td>
<td>SC heavy</td>
</tr>
<tr>
<td>Lower Cambrian</td>
<td>Restricted (post salt) carbonate source facies (Early Cambrian Dhahaban), central Oman</td>
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<tr>
<td>Upper Pre-Cambrian</td>
<td>South Haq</td>
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<tr>
<td></td>
<td>Restricted (post salt) carbonate source facies (Early Cambrian Dhahaban), central Oman</td>
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<td></td>
<td>North Haq</td>
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<td></td>
<td>Siliciclast and carbonate intra-salt (Aga Gp/Al Shomou) and pre-salt (Buah, Shuram) source facies south and north-central Oman and ?lobomites facies (?Bilara), Punjab, Bikar-Naguar Basin, Pakistan &amp; India</td>
</tr>
</tbody>
</table>

Bokh Fm (Ethiopia): lacustrine source facies, late/post mature, residual kerogen ~ 1.6%TOC. Sourced Calub gas + isotopically light oils/condensate at Calub & Tabaj seep/show.

Maji ya Chumvi Fm (Kenya): brackish marine source facies, post mature, residual kerogen ~ 1.1%TOC. Sourced extended oil shows in Ria Kalui-1 well.

Rufiji/Stigo Series (Tanzania): source facies undefined in coastal area but presence suggested by shows in Kisangire-1 (characterized by β-carotane).

Karoo (coastal Mozambique): source unknown but presence suggested by high maturity gas fields (Busu, Temrana, Pande & Khusuro).

Sakamena/Upper Irao Fms (Majunga): non-restricted marine to open marine. Oil shows in SOF-1 & MRV-1 geochemically similar to South Morondava oils suggesting an equivalent source but facies and quality poorly constrained.

Maji ya Chumvi Fm (Kenya): brackish marine source facies, post mature, residual kerogen ~ 1.1%TOC. Sourced extended oil shows in Ria Kalui-1 well. 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.

Sakamena Fm (North Moronadava): restricted marine/lagoonal source facies, late/post mature with residual kerogen ~ >1.0% TOC average. Sourced isotopically heavier oils common in the Karoo section of south & central Moronada.

Sakamena Fm (South Morondava): restricted marine/lagoonal source facies, late/post mature with residual kerogen ~ >1.0% TOC average. Sourced isotopically heavier oils common in the Karoo section of south & central Moronada.

Majunga:

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.

Lower Jurassic (coastal Tanzania): source facies and quality unknown but presence suggested by Winganyongo accumulation (~ = ‘highly weathered/biodegraded, restricted biomarkers suggest a lacustrine or isolated lagoonal/Newportian setting’).

Lower Jurassic (offshore Tanzania): source facies and quality unknown but presence suggested by Songo Songo gas and phase separated condensate & oil (~marine paralic-deltaic source facies dominated by land plants).

Mbuo Fm (Mandawa): restricted hypersaline (mixed algal & bacterial) source facies, ~3-9% TOC/300-1000HI. Typsed to oil shows in Mita-1 & Mandawa-1

Lower Jurassic (south Rovuma): source suggested by oil seep (~transitional deltaic dominated by terrestrial organic matter, C28/C29 sterane ratio = early Jurassic/Triassic age).


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.
MIDDLE JURASSIC

Bathonian - Callovian paleogeography

- Bemangahazo - 1
- Morondava
- South Rovuma
- Msimbati
- Mandawa (Mita)
- Wingayongo
- Pemba Is

Bemaraha Fm (Morondava): carbonate slope/basin plain source facies. Possible source of Bemangahazo - 1 oil (= from mature carbonate source)


- Makarawe Fm (coastal Tanzania): source type and quality poorly constrained but locally developed regional facies possible candidate source for Wingayongo.

- Mtumbei Fm (Mondawa): mixed carbonate/clastic facies. Source type and quality poorly constrained but presence suggested by marine carbonate/hard source oil in Mita-1.

- Middle Jurassic (Rovuma): source facies and quality unknown but presence suggested by restricted carbonate sourced oil seeps in the South Rovuma area and Msimbati Island (= C28/C29 sterane ratio suggest Jurassic age) Lower Jurassic alternative source candidate.

- Uarandab Fm (Somalia/Ethiopia): intra-platform basin source facies, algal kerogen 2.75-9.9%/TOC, 687-828 HI

UPPER JURASSIC

Oxfordian - Early Kimmeridgian paleogeography

Source facies and associated oil & gas

- Ftinda
- Wingayongo
- Morondava (Mita)
- Mtumbei
- South Rovuma

**UPPER JURASSIC**

Late Kimmeridgian-Tithonian Paleogeography

Source facies and associated oil & gas

**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

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**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.

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**NEOCOMANIAN**

Late Hauterivian Paleogeography

**Wingayongo Songa Songo Pandeteman**

**?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-1 and Kimbiji East-1 is probably due to drilling additives.

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

Figure 9: LATE CRETACEOUS-TERTIARY ~ Holocene Paleogeography

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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