

Gas Success along the Margin of East Africa, But Where Is All the Generated Oil?*

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Abstract

Prior to the 1990s, exploration along the East African margin was minimal, partly because conventional geological models predicted a predominance of gas-prone source rocks at trade-wind latitudes along the eastern side of continents. The discovery of significant gas in Lower Cretaceous sands at Songo Songo and in Miocene sands at Mnazi Bay appeared to confirm these opinions. Yet subsequent geochemical analysis of various oil seeps from coastal settings along the margin between Mozambique and northern Tanzania indicated that oil-prone sources were present also. These have been typed to Middle and/or Lower Jurassic sources associated with the Indian Ocean break-up unconformity. From the opposite rift margin in northeast Madagascar large heavy oil accumulations generated from Triassic lacustrine sources are present, with further evidence for Lower-Middle Jurassic restricted-marine oil-prone source rocks associated with the Gondwana break-up seen in oil seeps and shows in exploration wells.

To date, only gas has been found along the coastal margin in commercial volumes (recently in exceedingly large quantities), despite of all the evidence for the presence of oil-prone sources. The seeps and heavy oils identified to date all relate to the rift sequences, whereas trade winds should only significantly affect the post-break-up drift sequences; thus analogies with the Campos and Santos basins of Brazil become applicable. However, problems arise with the application of conventional thermal models because the deep burial of the rift sequences in the offshore places their source rocks into the Gas Window. However, better geothermal modelling using pressure-dependent models supports much deeper oil windows. However, a consequence of such models is that once pressure is released, for example, by subsequent uplift and/or inversion, oils will readily flash to gas. Young pressure relief is widespread in East Africa as result of eastwards tilting along the margin related to the rise of the East Africa Rift System

Unless new models are developed and successfully proven, or unless there are serendipitous discoveries, gas is likely to predominate because of the

inherent nature of the geology of East Africa:

1. The Permo-Carboniferous Sakoa-type source rocks are wet gas-prone at best, regardless of burial history.
2. Any Triassic oil-prone Sakamena-type source rocks, if present, are likely to be post-mature in terms of conventional basin modelling.
3. Widespread Miocene inversion is predicted to have flashed much of the Lower and Middle-Jurassic, and any Triassic or older oils, to gas.
4. Source rocks in the post-Middle Jurassic and Cretaceous offshore drift sequence are likely to be gas-prone as widespread oil-prone kerogens were rare at this time, and the ocean waters off East Africa appear to have been essentially oxic.
5. Thick oil-prone, organic-rich Tertiary sediments are likely to be only present in pro-delta settings, and only rarely – and locally - will they be sufficiently mature for oil generation.
6. Sediments currently accumulating in the offshore deepwater are likely at best to be only generating biogenic gas.

Given the volumes of sediments supplied by the Rufiji and Rovuma rivers, reserves of gas can be expected to keep on growing to limits ultimately determined by the size of the kitchens, wherever and whatever they are. The challenge for oil explorers is to identify the kitchens hosting oil-prone source rocks and to understand the history of maturation and migration of their oils in overpressured settings. In this article, we offer the results of our work on seep oils, the dynamics of the East African basins, and the modelling of the behaviour of hydrocarbons in overpressured basins, as a means of initiating such an exercise.

References Cited

Danforth A., J.W. Granath, J.S. Gross, B.W. Horn, K.J. McDonough, and E. J. Sterne, 2012, A developing province: GEO ExPro, 9, 4, p. 74-78.

Jarvie D., 2004, East Africa rift petroleum systems: Conference on the petroleum potential and investment opportunities in East Africa: EAPC 03, Nairobi, (5-7 March 2003), p. 31-43.

Law C., 2011. Northern Mozambique true wildcat exploration in East Africa: Search and Discovery Article #110157 (2011). Web accessed 22 March 2013. http://www.searchanddiscovery.com/documents/2011/110157law/ndx_law.pdf

Matchette-Downes, C.J., et al. 2004, The greater East African petroleum system: PESGB & HGS Third Annual International Symposium, 'Africa: The Continent of Challenge and Opportunity, London, United Kingdom, 7th & 8th September, 2004.

Uguna, C.N., A.D. Carr, C.E. Snape, W. Meredith, and M. Castro-Díaz, M., 2012, A laboratory pyrolysis study to investigate the effect of water pressure

on hydrocarbon generation and maturation of coals in geological basins: Organic Geochemistry, v. 52, p.103-113.

Websites

Ophir Energy, 2012, Ophir Energy PLC, Annual General Meeting, June 2012. Website accessed 22 March 2013. <http://www.ophir-energy.com>

TPDC, 2003, Petroleum opportunities in Tanzania: Tanzania Petroleum Development Corporation. Website accessed 22 March 2013. <http://www.tpdctz.com>

Wentworth Resources Limited, Website accessed 25 March 2013. <http://www.wentworthresources.com/>

Gas success along the margin of East Africa, but where is all the generated oil?*

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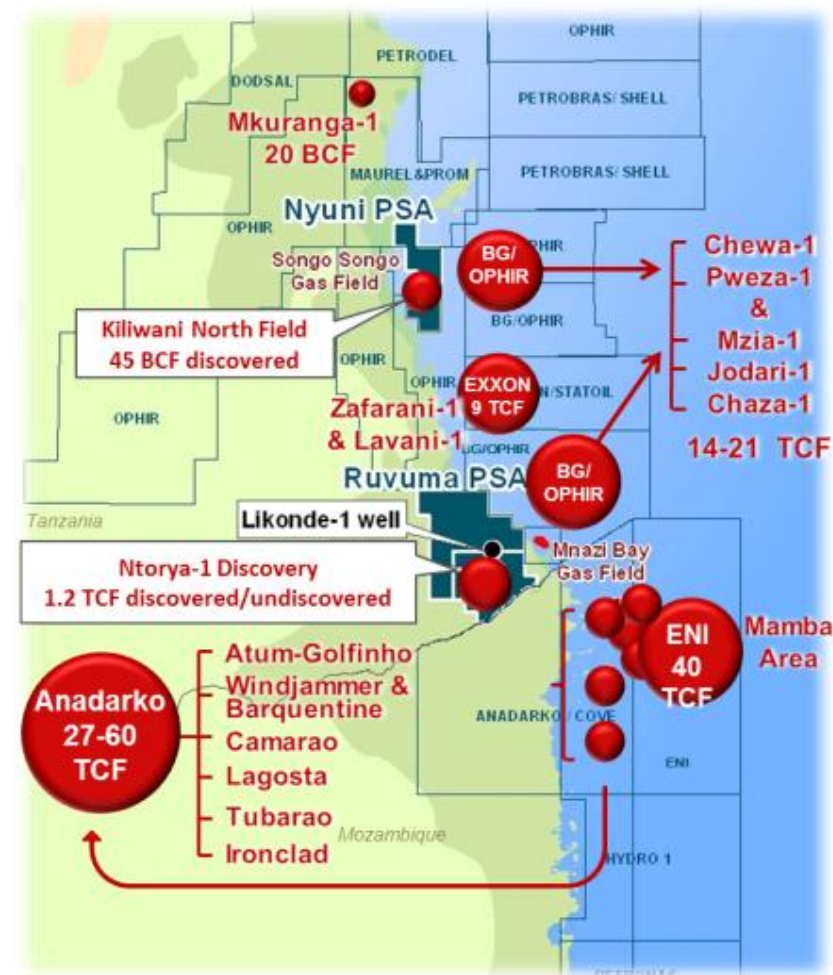
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*Adapted from a presentation given at the East Africa - Petroleum Province of the 21st Century conference, The Geological Society, Burlington House, London, 24-26 October 2012

Aminex / Ndovu has been in East Africa since 2002, focused mainly on Tanzania.

In 2002, the East African margin was an under-explored industry backwater, with little perceived hydrocarbon potential despite having been explored since the early 1950's, and with two gas fields discovered.

Aminex has conducted its own fieldwork with the aid of remote sensing data, and analysed seeps, well cuttings, tarballs and outcrops, to develop a regional understanding of source-rock potential.

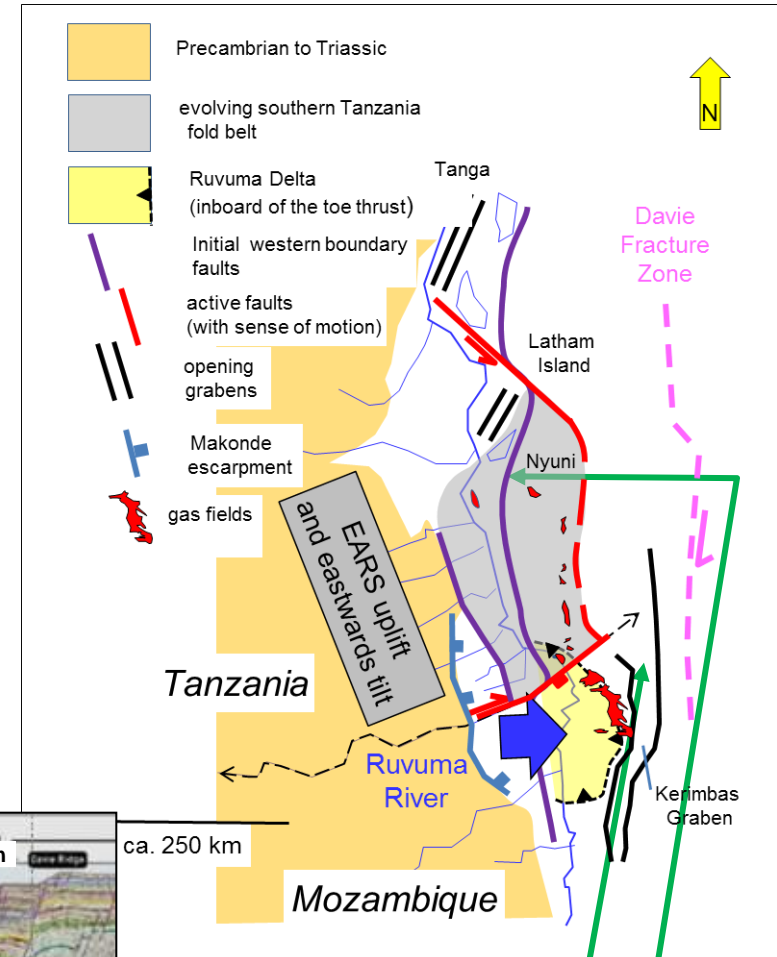


Summary of recently published hydrocarbon discoveries, southern Tanzania

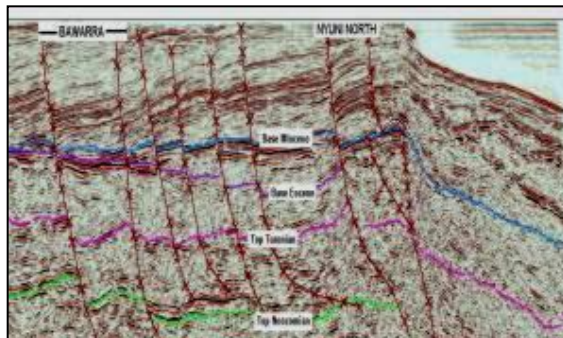
The hydrocarbon geology of Southern Tanzania and Northern Mozambique is determined by two events:

- Uplift and eastwards (oceanwards) tilt associated with development of the East African Rift System (EARS), and
- The formation of the modern Ruvuma Delta.

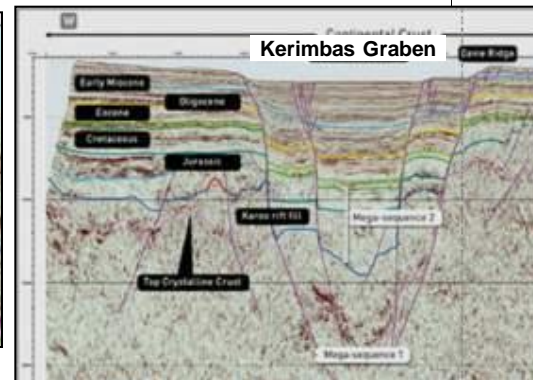
Illustrated are two results of these events, namely, offshore inversion and the opening of grabens. Both have an effect on hydrocarbon maturation and migration through reduction of source kitchen pressures.



**Modern tectonics,
southern Tanzania**



West-East seismic profile, Nyuni Licence Block, illustrating young shelf-edge inversion.

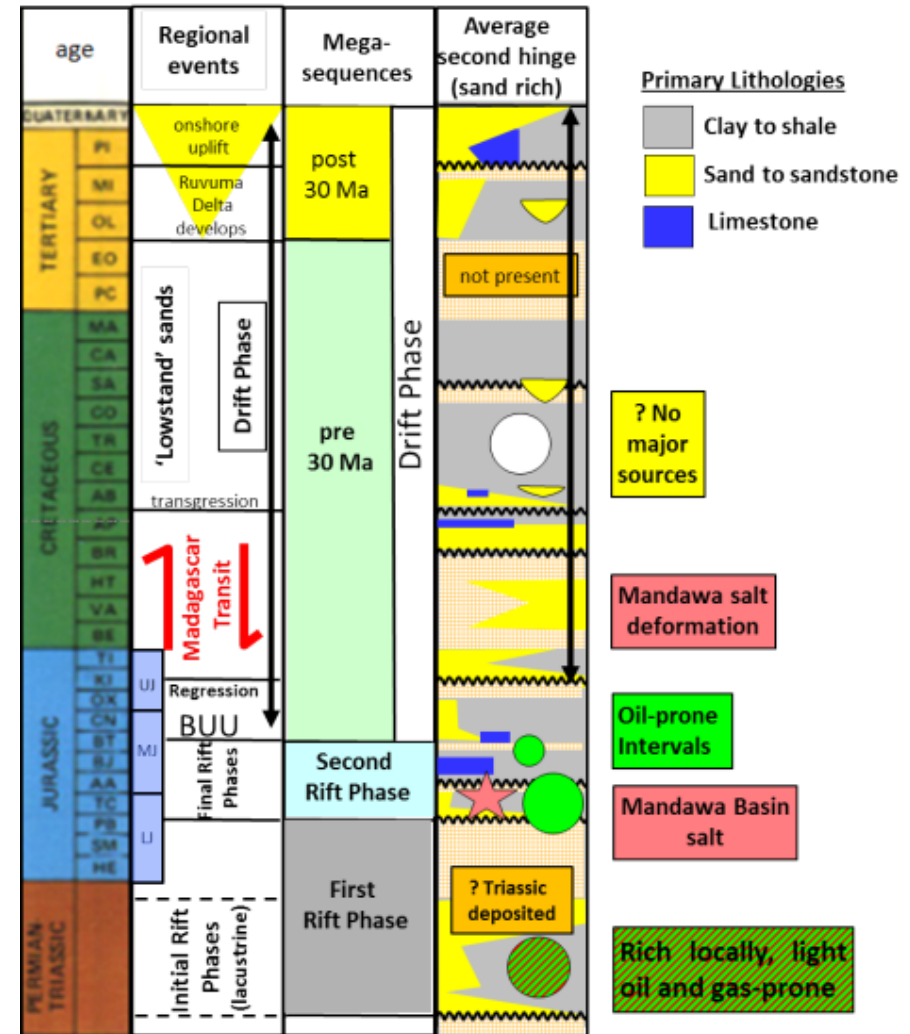


Ongoing rifting, Danforth et al., 2012

Two rift phases are evident, from the Permo-Triassic (“Karoo”), and Lower – Middle Jurassic, (Gondwana “breakup unconformity”), followed by a drift phase.

Subsequent subsidence was interrupted by the transit of Madagascar during the Lower Cretaceous.

The younger Tertiary saw the growth of the modern Ruvuma Delta, and from the Pliocene the onset of regional tilt to the east with its associated disruptive effects.



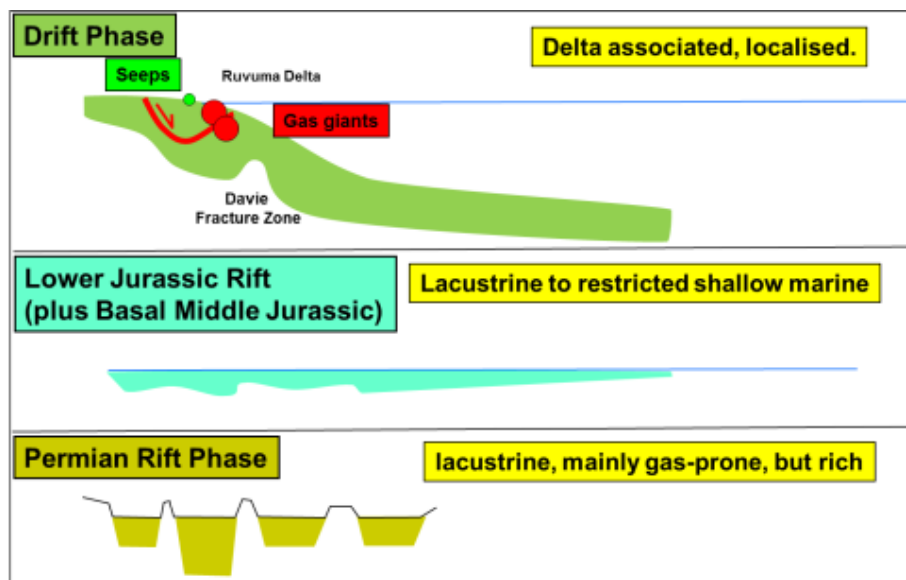
Summary stratigraphic column and key tectonic events.

Source rock intersections/well penetrations and outcrops along the margin are few, but we believe two regional sources dominate.

- Permian lacustrine shales (“Karoo”)
- Lower to Basal Middle Jurassic (L/bM.Jurassic) (lacustrine to shallow marine, hypersaline shales and marls).

There is some evidence for younger Tertiary and Upper Cretaceous marine / delta-related sources, but aside from the issue of thermal maturity, there is no published data to suggest that such sources are regionally significant, and the only indication for such sources comes from the occasional presence of oleanane.

Biogenic gas sources are possible in pro-delta settings, and may be regionally present along the margin, but despite anecdotal support, there has been no published evidence to date demonstrating that any such sources are regionally developed and generating significant volumes of gas.



Potential regional source rock facies and their settings, both proven and suspected.

Aminex believes that the lack of shallow marine and onshore hydrocarbon discoveries along the margin does not reflect a lack of prospectivity, but can be attributed to disproportionately high cost and logistical difficulty of acquiring sufficient volumes of quality seismic to sufficiently de-risk exploration wells.

There is plenty of evidence from seeps, cuttings, slicks, analogue geological settings, etc., to clearly demonstrate beyond doubt that oils have been generated throughout the region, albeit in uncertain quantities.

A simple calculation indicates the potential volumes of Lower to basal Middle Jurassic oil that *may* have been generated:

- Basinal area of 900x250 km = 225,000 km²;
- 75% of the area hosts source rocks, = 168, 750 km²
- Average net thickness of 20m.

Net source rock volume = 3,375 km³

- Yield (S₂) = 10kg/tonne (TOC = 2%, HI=500)
- 70% transformation at maturity of 1% R₀
- Expulsion to trap efficiency = 10%

Approximately 56 Billion bbls of oil could have been generated from Lower to basal Middle Jurassic source rocks, migrated, and have been available for entrapment.

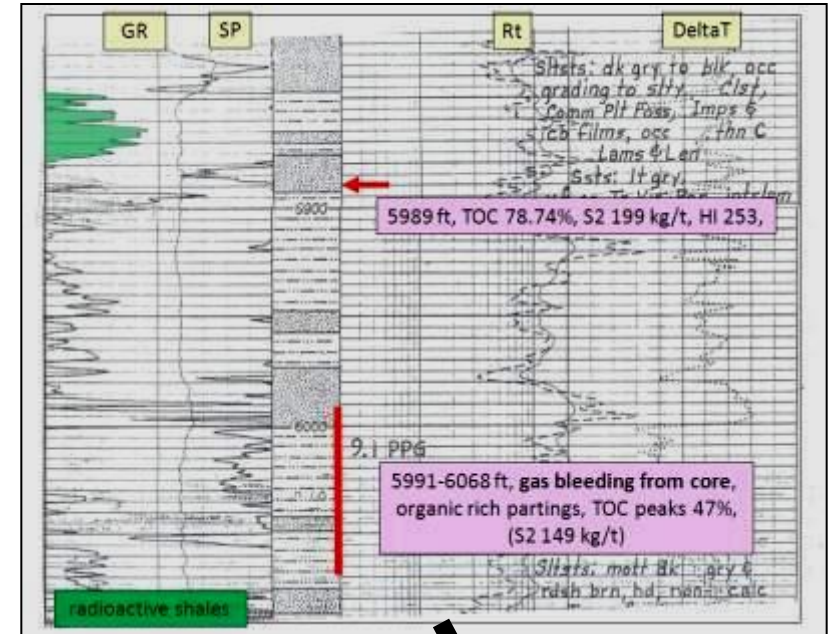
This would be equivalent to 336 Tcf of gas from the L-basal M. Jurassic alone.....

Some oil will have been displaced by later gas emplacement (perhaps to surface as seeps), but where is all this oil and gas, not to mention hydrocarbon contributions from the “Karoo” and possibly the Tertiary?

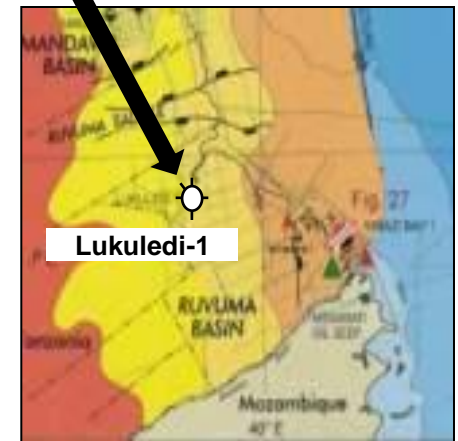
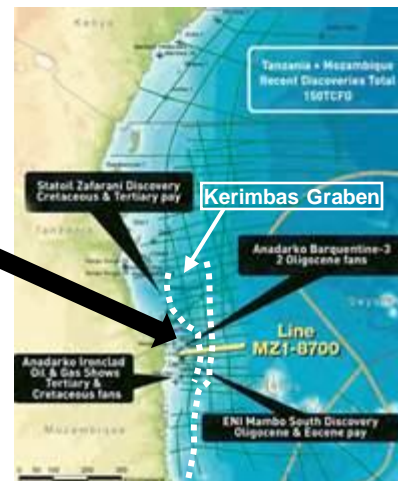
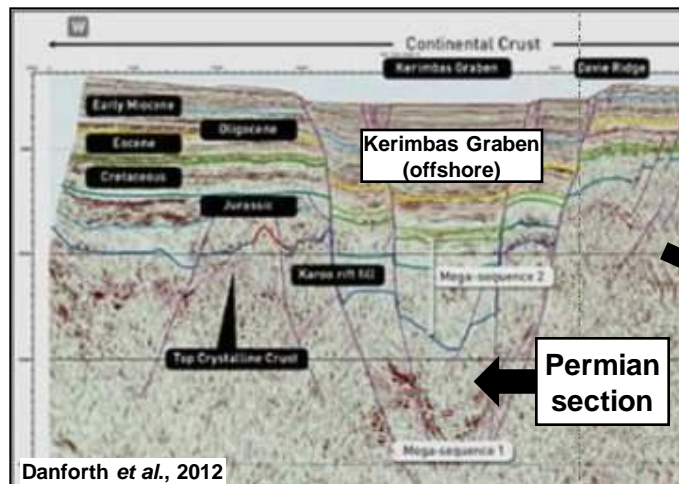
As well as from the interior Permo-Trias rifts, e.g., Selous-Ruvu Basin, a rich Permian source is known from the Lukuledi-1 well in the onshore Ruvuma Basin of southeast Tanzania. This well was cored, and detailed records as to source quality exist.

The section was immature, but modelling indicates it will be gas mature immediately off structure.

By extrapolation, the Permian will be at peak to post-maturity in the grabens developed offshore.



Lukuledi-1 Permian source rocks



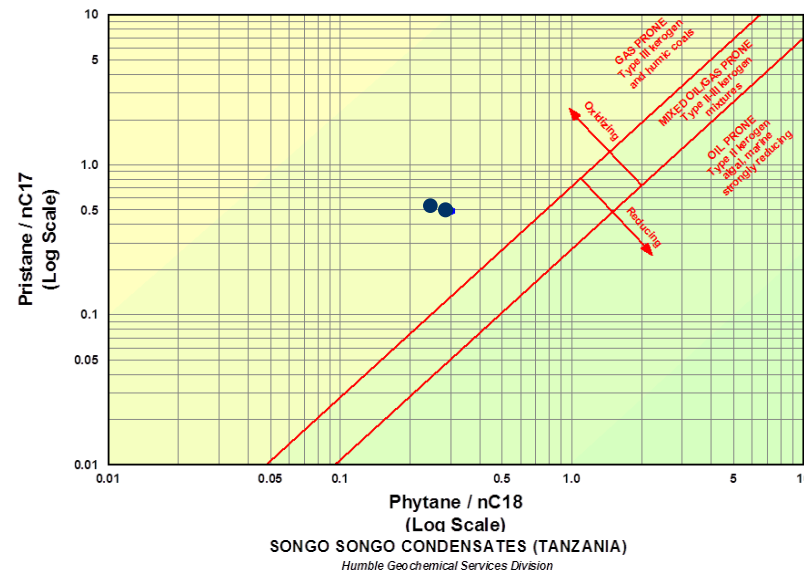
Source: TPDC

Songo Songo gas field has long been known to have minor amounts of associated condensate, occasionally misreported as oil in the original drilling reports of early development wells.

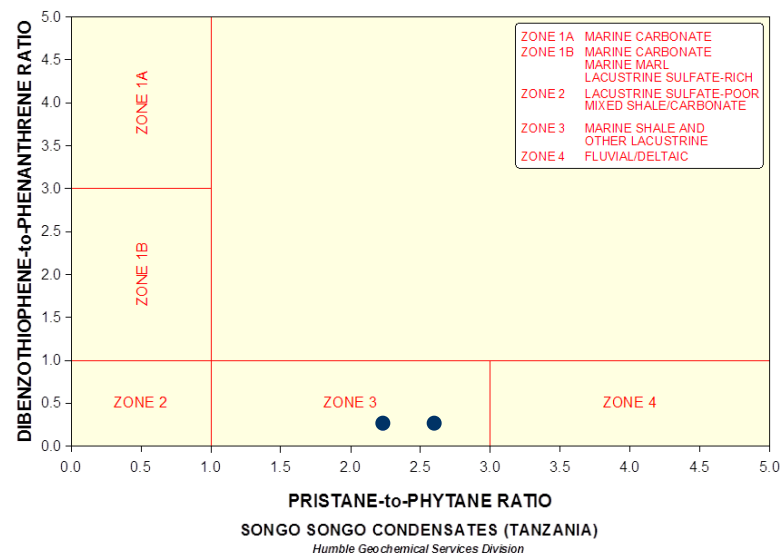
Dan Jarvie (2004) of Humble Geochemical Services found that the condensate at Songo Songo has high pristane/nC₁₇ and phytane/nC₁₈ ratios typical of terrestrial sourced oils, but the host facies is marine, indicating a migrant fractionated condensate from a deeper oil system.

Work on condensate associated with gas at Songo Songo, Kiliwani North, and Ntorya-1 gas fields and discoveries has shown that the condensate and a proportion of the gas is likely derived from fractionation of oils, rather than simply a mature gas-prone source rock.

GAS CHROMATOGRAPHY DATA
INFERRED SOURCE ROCK KERGEN TYPE AND DEPOSITIONAL ENVIRONMENT



ASSESSMENT OF INFERRED SOURCE ROCK LITHOFACIES
based on Gas Chromatographic Analyses of Oils



Source rock exposure at outcrop is minimal; analysis of oil and gas seeps, tar balls from the coast and shows from well cuttings (including dry holes and wells classified as “dry, no shows”), has been key to understanding source-rock potential.

Tanzania

Makarawe: Tarry bitumens – Karoo age / Jurassic
Tundaau: Oil seep - Jurassic
Pemba # 5: Oil shows - Jurassic
Kiwangwa: Tarry bitumens – Jurassic?
Zanzibar: Gas shows -
Tancan: Gas shows
Mafia Island: Oil & gas shows
Okuza island: Oil shows - Jurassic
Nyuni Island & well: Oil & gas shows - Jurassic
Lipwapwatawre: Oil seep
Mikandani: Oil seep
Kisangire: Oil shows - Jurassic
Wingayongo: Oil seep – Jurassic
Wingayingo #1 & #2 - 30m & 40m of tar sand
Ruhoi River (5km from Wingayongo) - Oil seep
Lukuliro: Gas shows - tars, sands in wells
Songo Songo: Gas reservoir & condensate. 845 Bcf (3P) & Jurassic oil?
Nyuni well & island – Oil seep and shows - Jurassic
Mita Gamma: Oil shows
Mandawa: Oil shows
Mbuo: Oil shows
Mnazi Bay: Gas reservoir. 1 Tcf (GIIP)
Msimbati: Oil seep

Kenya

Pandangua #1: Oil shows
Ria Kalui: Tarry bitumens – Permo Triassic / fish beds
Cities wells offshore Kenya: Oil shows
Oil & gas seeps

Mozambique

Rovuma basin: Oil seeps



Source: TPDC

After: C.Matchette-Downes et al., 2004, pers. Comm. 2012



Kilwa Masoko oil seep, low tide, June 2002



Makukwa gas seep, Mnazi Peninsula, June 2002



Newly found oil seep at Location X being sampled June 2012



Oil seep samples from Location X, and Ntorya-1 condensate samples, June 2012

Oil-soaked reservoir sand, Wingayongo oil seep, Rufiji Trough, August 2004



Oil soaked sand, Tundaua oil seep, western Pemba Island, August 2003



Tarballs from foreshore of Nyuni, and Okuza Islands, June 2003.

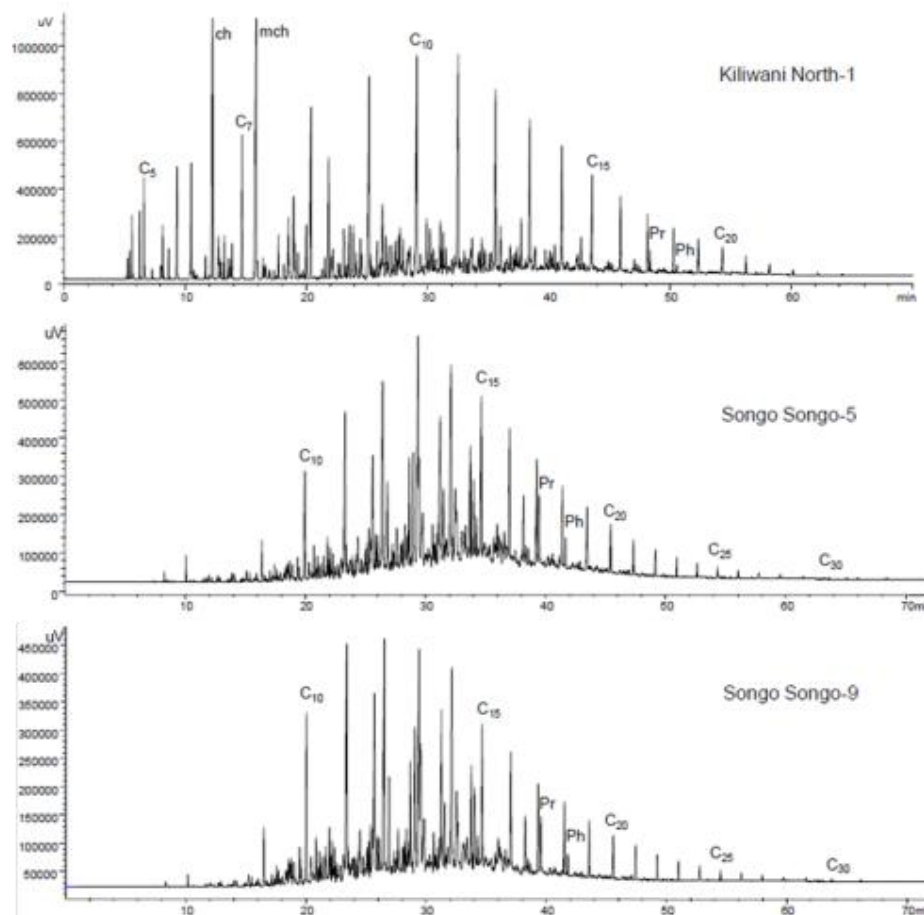


Ntorya-1 flaring gas with condensate at sunset, Ruvuma Basin, Southern Tanzania, June 2012

Gas chromatographs show 3 condensates with variable compositions.

Kiliwani North-1 condensate contains more gasoline (C_5 to C_7) hydrocarbons than either of the samples from Songo Songo.

The Songo Songo samples show alkane hydrocarbons extending up to C_{30} , suggesting some oil component in solution in the condensate.



Gas chromatographs showing correlation of gas condensates from Kiliwani North and Songo Songo gas fields, coastal Tanzania.

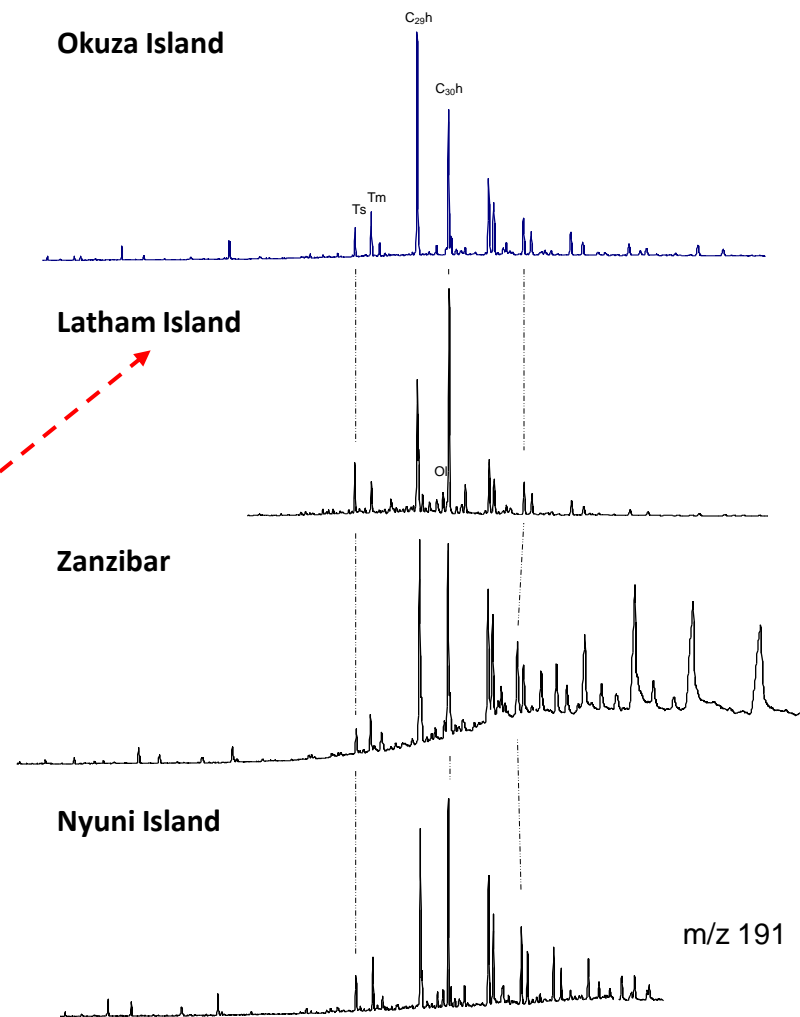
Okuza Island, Zanzibar and Nyuni Island triterpane biomarkers are very similar.

$T_m > T_s$ and C_{29} norhopane are frequently larger than C_{30} hopane, typical of oils derived from carbonate source rocks.

The Latham Island sample contains oleanane, a biomarker typical of oils derived from Tertiary sources - if the sample really was a fresh oil and not a tanker washing.



Fresh tarball samples collected from Latham Island, January 2003.



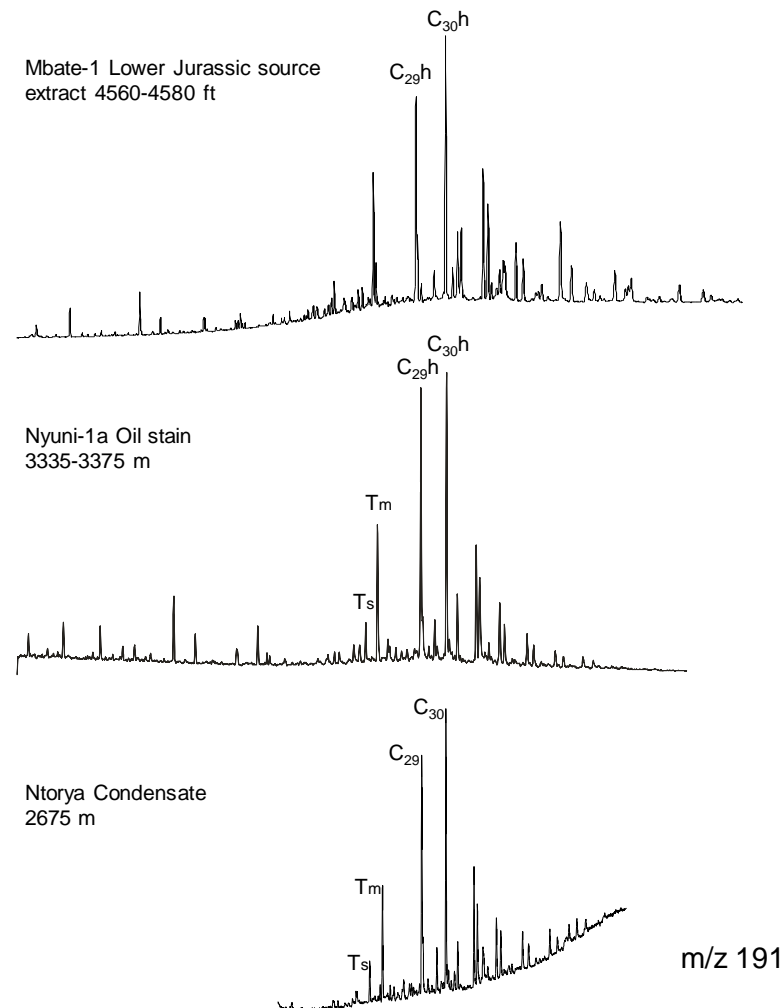
GCMS correlation of tarball extracts, coastal Tanzania

Mbate-1 Lower Jurassic source interval, Nyuni-1 hydrocarbons (oil stains) and Ntorya-1 (condensate) have very similar biomarkers.

The terpane biomarkers contain some features characteristic of hydrocarbons derived from carbonate source rocks.

Maturities are variable, but mainly main to late oil window.

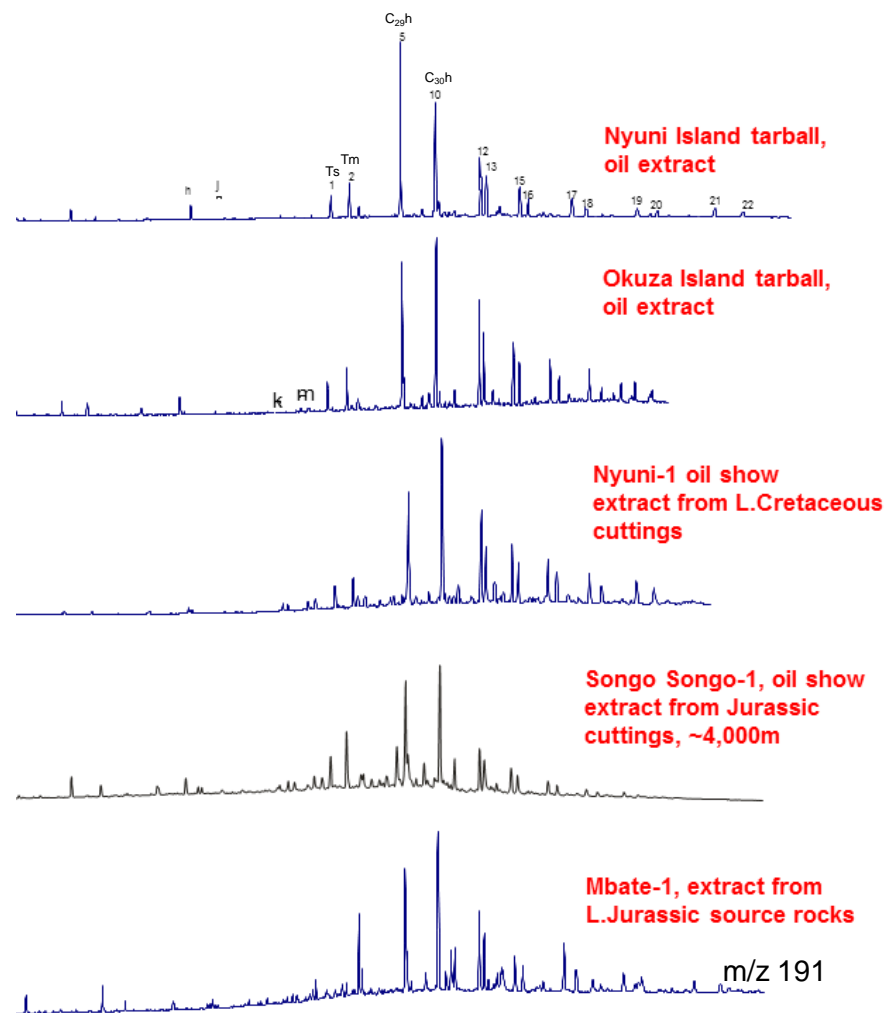
Main oil source is thought to be L/bM.Jurassic in age.



GCMS correlation of Lower Jurassic source (Mbate-1), Nyuni-1 subsurface oil shows, and Ntorya-1 condensate sample, coastal Tanzania.

Nearly all of the seeps and shows from onshore and offshore Tanzania have similar GC and GCMS analyses and similar isotope ratios, indicating a common source of L/bM. Jurassic age.

The formations from which the cuttings were obtained did not have hydrocarbon source potential and were also thermally immature for hydrocarbon generation. This means the sampled oil shows are of migrant origin.

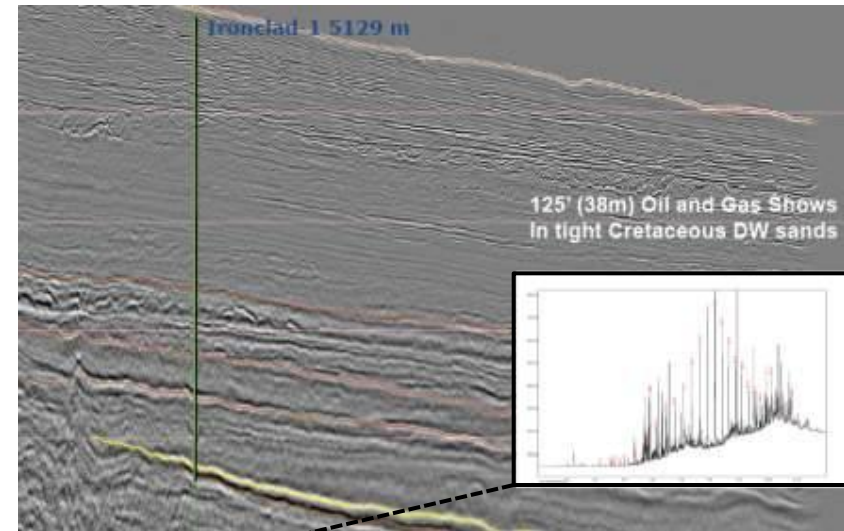


GCMS correlation of tarball, seep and Lower Jurassic source extracts, coastal Tanzania

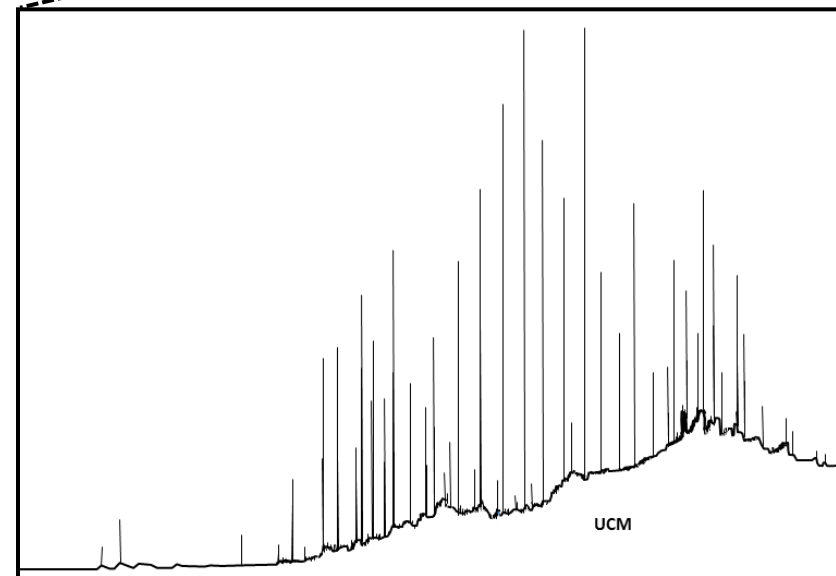
Anadarko have published a low-resolution GC image of the oil from Ironclad-1 offshore Mozambique, alongside a seismic section showing an Upper Cretaceous reservoir interval, but no information as to the likely source rock for the oil was disclosed.

The published figure illustrating the Ironclad-1 oil appears to show degradation, due to the presence of a UCM (unresolved Complex Material) hump.

The mechanism of degradation (biodegradation / de-asphaltisation / polymerisation) is uncertain - there appears no obvious reason from the seismic for it to be biodegraded.



Law, 2011 & various Anadarko press releases, 2011-2012



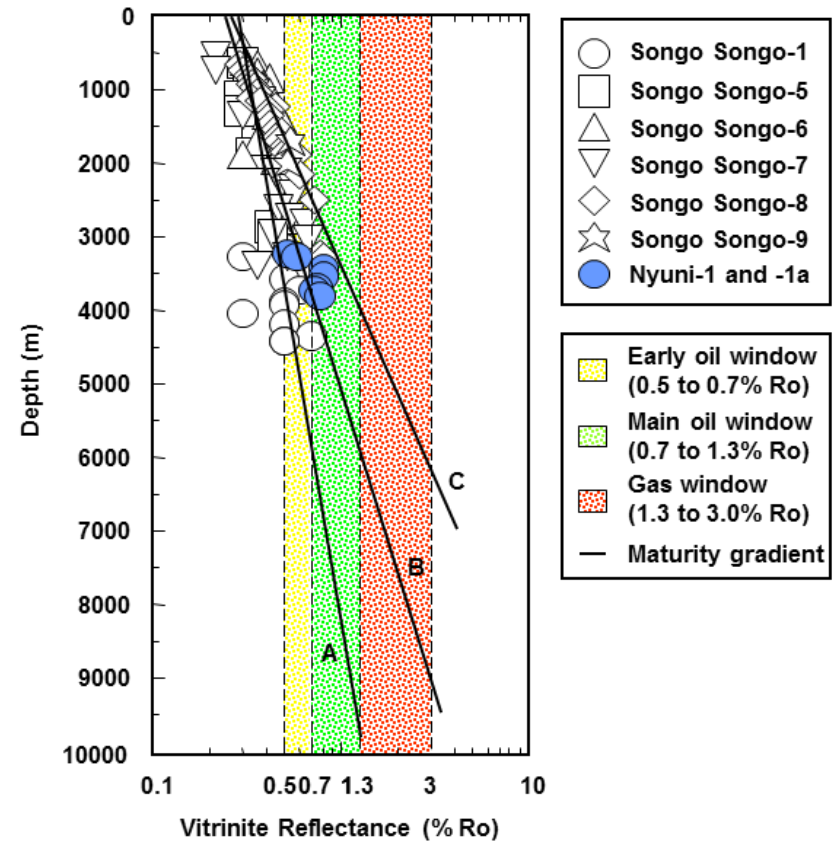
UCM = Unresolved Complex Material hump

Vitrinite reflectance values from Songo Songo and Nyuni-1 show variable maturity gradients (% R_o), reflecting significant differences over a relatively small area.

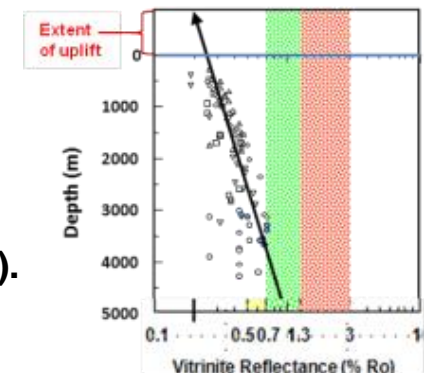
The deeper L/bM.Jurassic source is not penetrated in any of the wells, and is likely more mature than the measured samples.

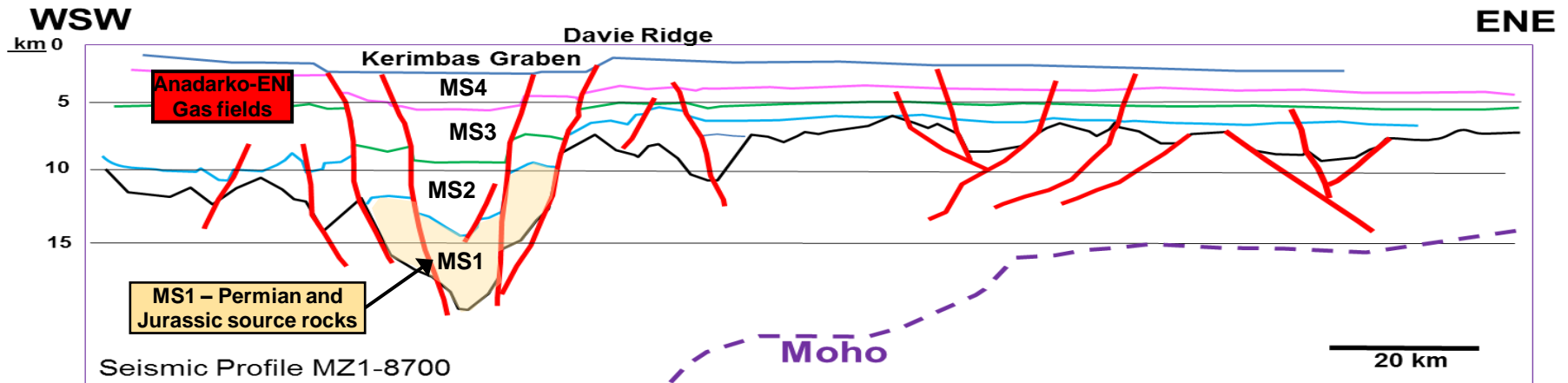
The L/bM.Jurassic source, if present beneath the gradient A wells, could be in the oil window, whereas the same source is more likely to be in the gas window in gradient C wells.

As the stratigraphy is similar in the wells, the different maturity gradients would appear to indicate both different thermal and uplift histories, with a total average uplift of 800m, as defined by vitrinite reflectance maturity gradient (Ro).



Vitrinite reflectance values from various Songo Songo wells and Nyuni-1, (also indicating average uplift of approx. 800m).





From Danforth et al., 2012

There is evidence of two main rift phases for deposition of source rocks.

This ION regional dip line shows the location of possibly the most voluminous kitchen in the Tanzania/Mozambique border region. It will contain both the Permian and Lower Jurassic sources.

The Permo-Trias, as at Lukuledi-1, is lacustrine with light waxy oil and prolific gas potential.

The L/bM.Jurassic is a restricted marine environment associated with the final Gondwanaland breakup.

Ruvuma Delta

Mega-sequence 4. East Africa uplift, Late Paleocene to Miocene multiple regressive successions: widespread, multi-phase submarine fan deposition – the current Paleocene, Oligocene and Eocene target reservoirs.

Drift

Mega-sequence 3. Passive margin, Late Cretaceous to Eocene late drift sequences: widespread transgressive shales encasing retro-gradational channel/fan reservoir systems.

Madagascar transit

Mega-sequence 2. Transform margin, Late Jurassic to Mid-Cretaceous early drift sequences: restricted anoxic shales overlain by multiple, high-gradient regressive pulses comprising mounded, variable-amplitude reflection character (proximal slope channel/fan systems).

Rifting (two phases)

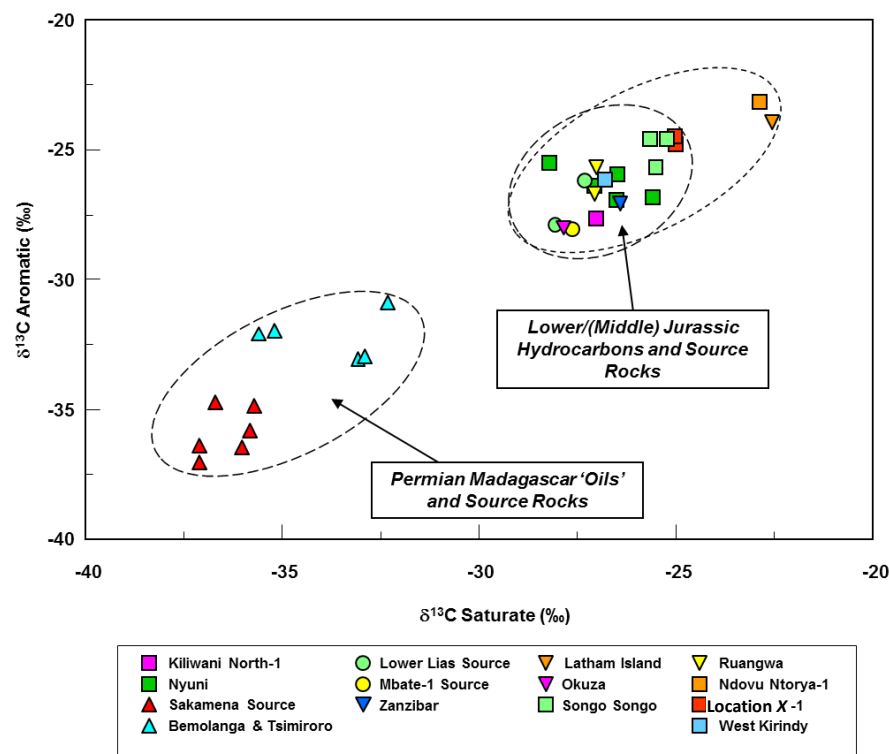
Mega-sequence 1. Syn-rift, Permo-Triassic to Early Jurassic extension with early rift fill; deposition localized in mini-graben; commonly topped with high-amplitude, laterally continuous seismic reflections (potential mature source rocks).

By plotting the saturate-aromatic carbon isotope data from all the oils and extracted oil components from condensates, two distinct oil families show up on Sofer plots.

The Mnazi Bay/Msimbati samples, from a Tertiary reservoir, plot close to Songo Songo suggesting an inverted Jurassic oil, despite the anecdotes of a possible Tertiary source.

We have no saturate-aromatic data for Likonde-1, but Likonde-1 methane isotope data suggests an R_o of 1.5% from the isotope data, similar to Kiliwani North-1.

Location X is an evaporated condensate, having lost the lighter components through pressure loss with inversion, and migration, i.e., fractionation. The location is to the West of current onshore licences in Tanzania.



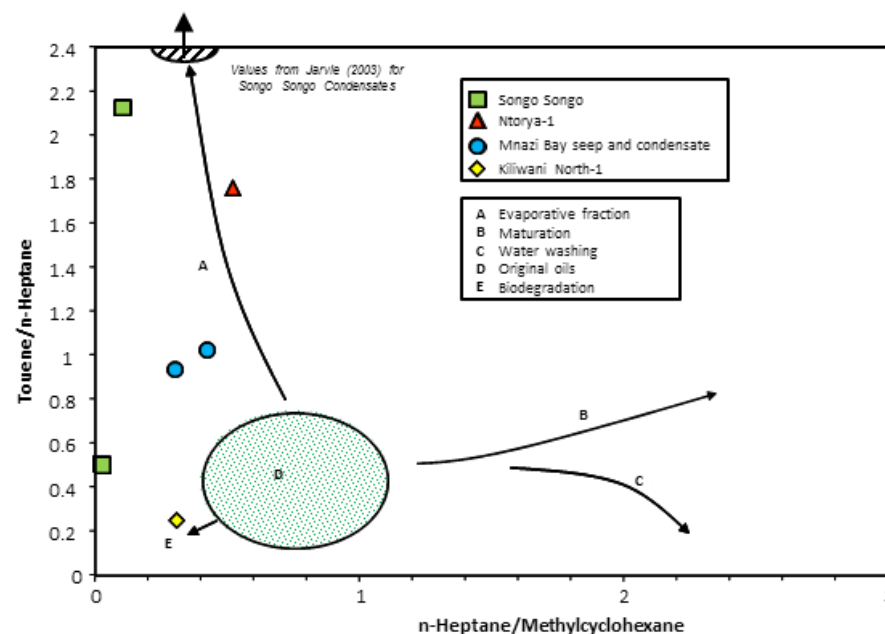
Note that some of the hydrocarbons may be coming from the Permian - the gas at Kiliwani North-1 is R_o of 1.5% from the isotope data.

A gasoline plot of ratios of methylcyclohexane to Toluene from various condensate samples demonstrates the evidence for fractionation.

Most condensates (e.g. Songo Songo, Ntorya-1, Mnazi Bay-1) show evidence of evaporative fractionation (due to pressure reduction during the Pliocene structural inversion).

Carbon isotope (methane-ethane) analyses (not shown) indicate that the gas fraction formed at maturities $>1.3\%$ R_o , which is more mature than the oil/condensate data, which have variable maturities from saturate biomarkers mainly 0.7 to 1.0% R_o .

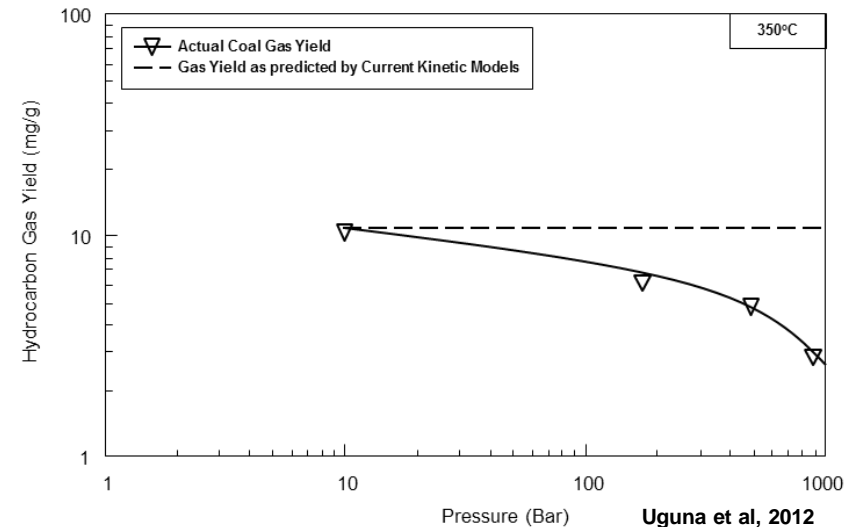
We consider this separation of maturities as indicative of co-migration from our two primary sources ("Karoo" and L/bM.Jurassic).



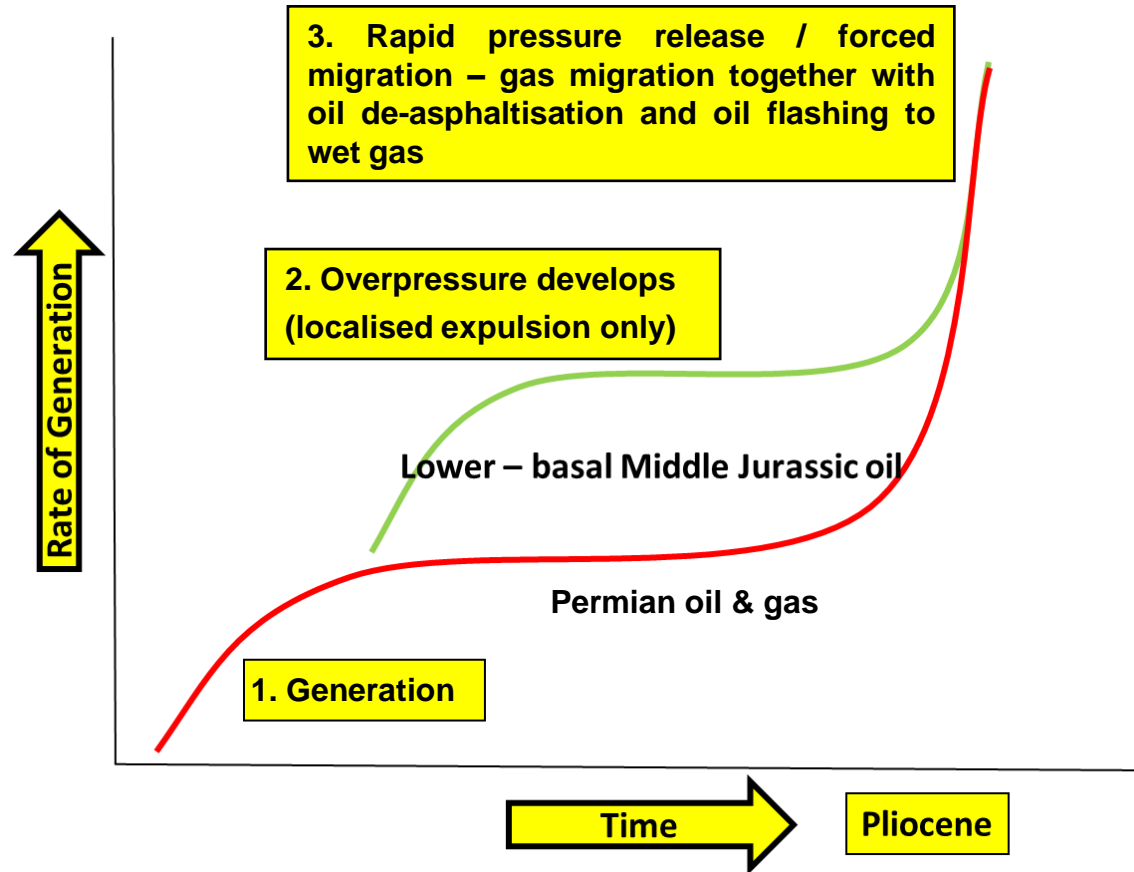
A problem of the Permo-Trias rift source rocks underlying the L/bM.Jurassic rift source rocks is one of higher than oil-window-maturity gases potentially flushing already generated L/bM.Jurassic oils from traps, or preventing migration of such oils into already gas-charged traps.

At Kiliwani North-1, we have clear evidence from carbon isotope maturities of the individual gas components of the gas being generated at a maturity of 1.5% R_o – which is considered unlikely for a present day depth of 5,000-7,000m for the L/bM.Jurassic.

Thus we can interpret the result as Permo-Triassic gas flushing a L/bM.Jurassic-generated oil, simultaneous to the oil being flashed to a gas condensate as a result of contemporaneous structural inversion.



- **Current kinetic models say that (water) pressure does not control the volume of hydrocarbon generated by kerogens in geological basins.**
- **However physical chemists tell us the opposite, in that water pressure in basins should retard volume expansion reactions such as hydrocarbon generation, maturation and oil-to-gas cracking.**
- **Experimental work indeed shows that water pressure retards hydrocarbon generation entirely as predicted by physical chemistry.**
- **The high pressures that form during subsidence restrict extensive gas generation.**
- **Pressure reduction mechanisms, e.g. East African Pliocene inversion, are therefore extremely important in generating large volumes of gas.**



Summary diagram illustrating principle of oil de-asphaltisation with pressure decrease (as, for example, during tectonic inversion).

As inversion proceeds, so heat flow increases, and the pressure in the system drops – together this results in the generation of gas under lower pressure conditions.

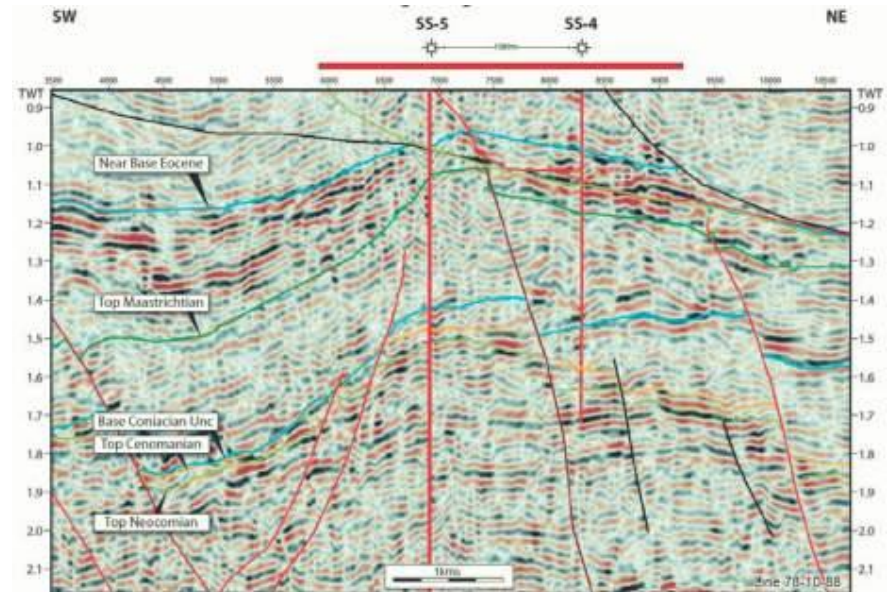
Exploration Progress

Inversion tectonics will also influence sedimentology and reservoir distribution.

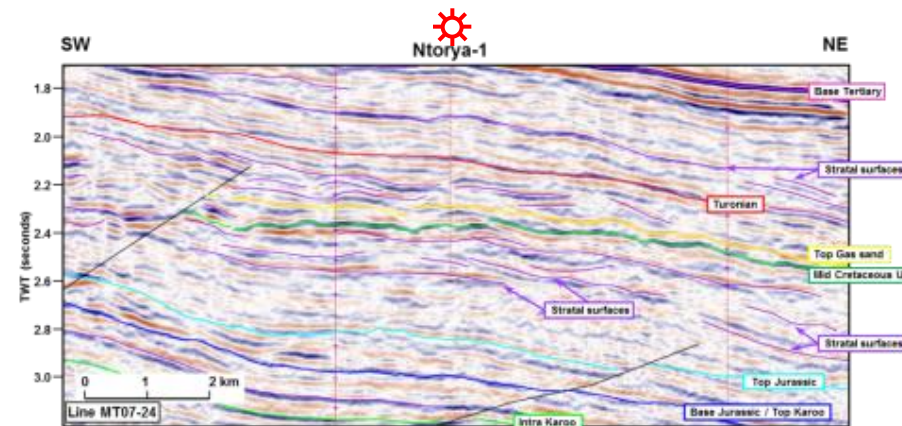
It is significant that recent discoveries on- and offshore are primarily stratigraphic and not structural – early wells were drilled on limited seismic (if not pure stratigraphic research wells); all were targeted on structural features – Songo Songo, Mnazi Bay, Latham Island, Nyuni, etc.

The Songo Songo-1 Neocomian discovery in 1974 promoted the structural play potential; however, whilst the uppermost Neocomian has excellent reservoir potential where preserved at Songo Songo and Kiliwani North-1, it has not proven so good elsewhere along the margin.

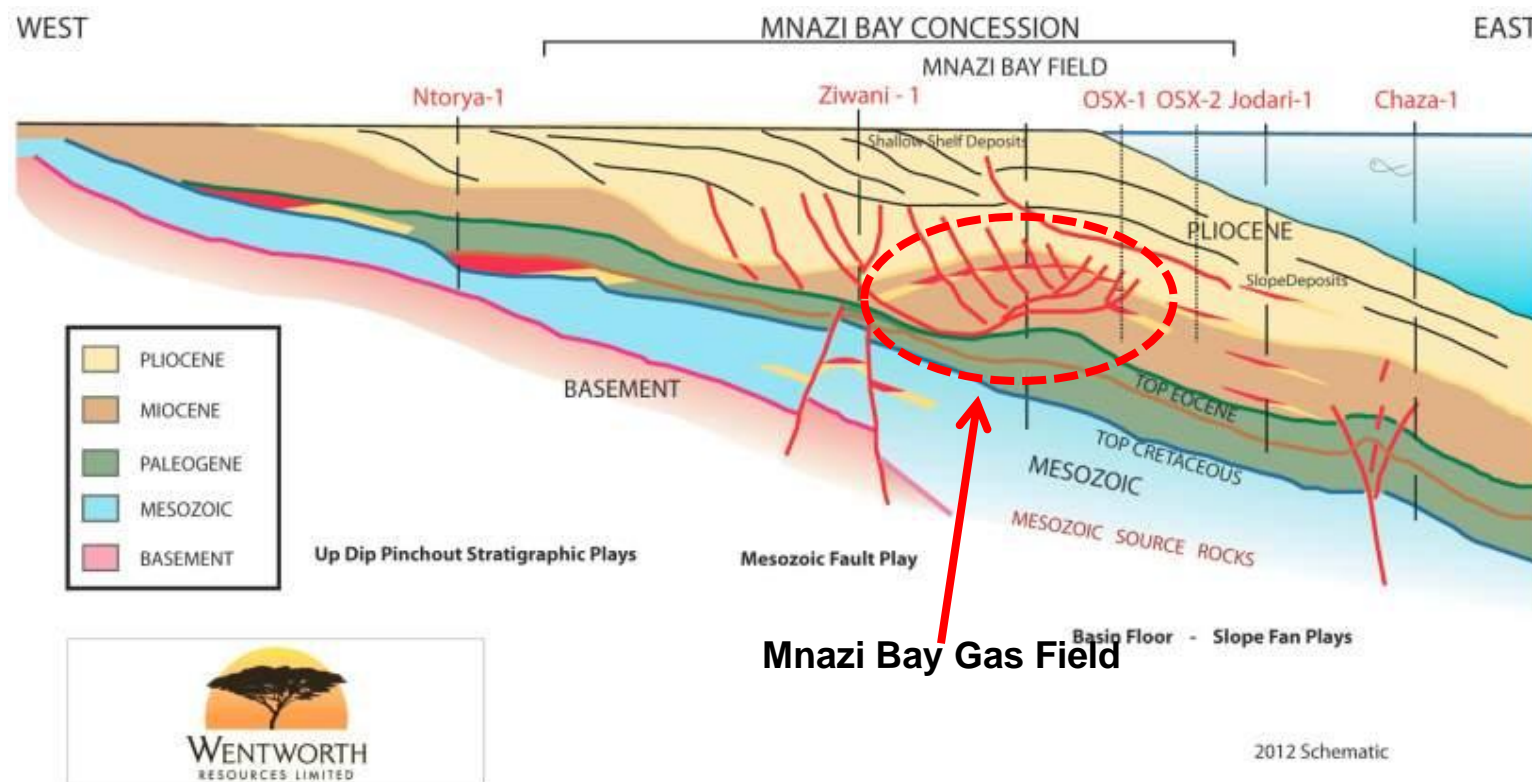
The Aptian/Albian, where present, despite variable thickness as at Songo Songo and Kiliwani North, can have good reservoir quality, as at Mukuranga, Mocimboa, Likonde, and Ntorya. The high degree of stratigraphic influence is hard to identify with confidence in the absence of well data on much of the low-quality seismic available on the shelf.



Seismic cross-section across Songo Songo gas field, offshore Tanzania (structural trap).



Seismic cross-section across Ntorya gas discovery, Ruvuma basin, onshore Tanzania (stratigraphic trap).



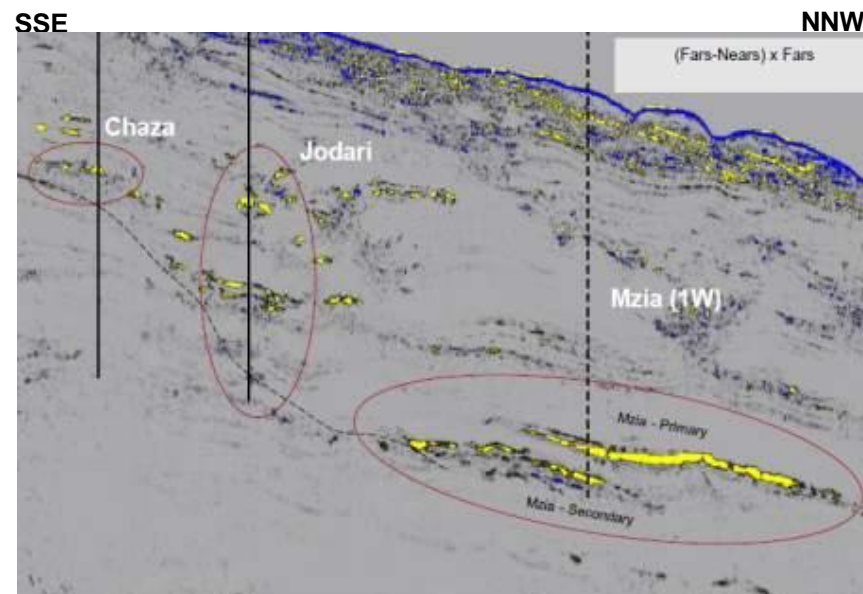
**Structural cross-section across Mnazi Bay gas field, offshore Tanzania
(structural /stratigraphic trap),**

Mnazi Bay was drilled originally in 1982 by Agip/Amoco as a structural target based on limited seismic; however, the reservoir sands are discrete Tertiary channels within a structurally inverted anticline.

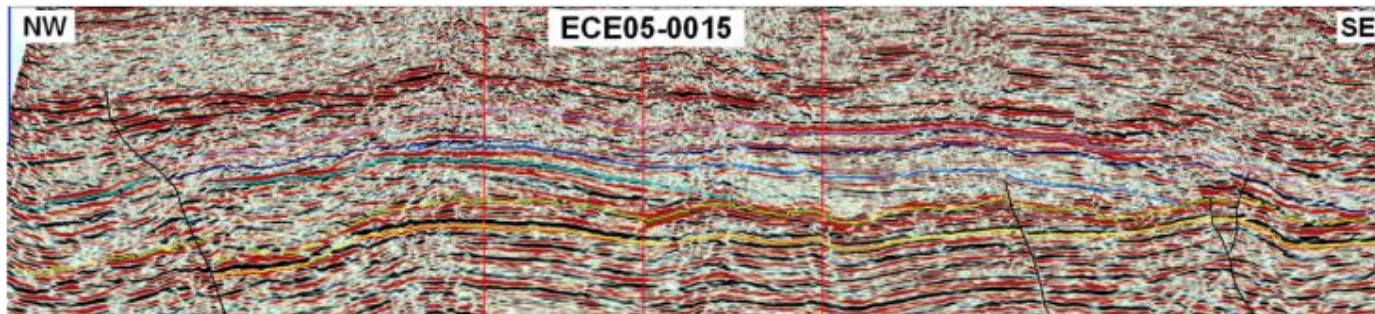
Recent deepwater exploration has been phenomenally successful, albeit for gas rather than oil, primarily because of state-of-the-art 2D (and 3D) seismic in the unrestricted marine environment enabling use of multi-streamer, long offset acquisition.

Techniques, such as AVO, Seismic Inversion, etc., enable de-risking of structural traps and pure stratigraphic traps in terms of facies and fluid prediction.

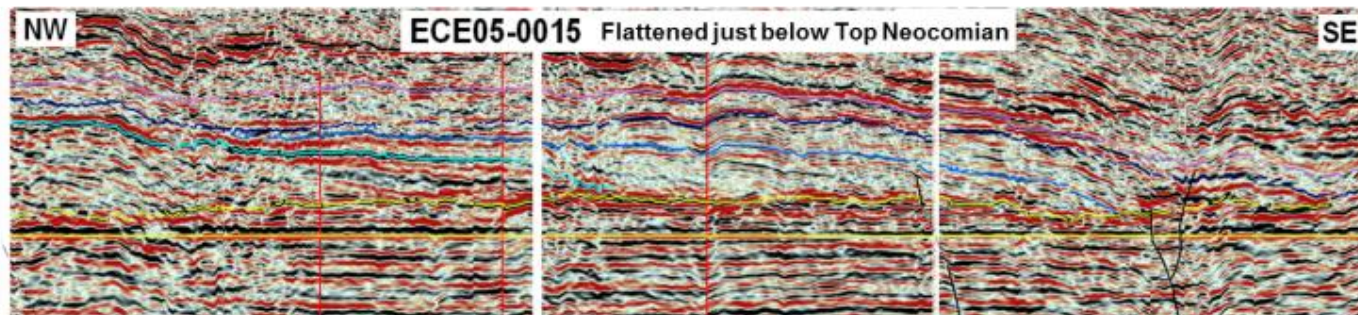
Recent deepwater successes give definitive evidence for mid-Cretaceous to recent sands crossing the shelf zone into deepwater. More modern 2D seismic onshore and on the marine shelf is beginning to image such sands with increasing confidence - but they are virtually completely untested by drilling.



Seismic profile across Block 1, offshore Tanzania, showing intraslope channel plays (Ophir Energy, 2012).



Clinofolds can be observed on the shelf prograding from a generally northwest source in the region of the Rufiji Delta, with apparently bright amplitudes on the upper surfaces.



The potential exists for areally extensive hydrocarbon-charged sheet sand deposits; there are no wells in this environment, away from structural highs, that have deliberately tested such a depositional environments due to previously poor quality seismic, and lack of drilling rigs.

Shelfal and onshore stratigraphic traps are still hard to define with confidence, due to prohibitive seismic acquisition costs, operational logistics, and relatively limited choice of appropriate contractors, although this is beginning to improve. Additionally, migration pathways for L/bM.Jurassic are potentially limited in extent, and underlain by higher maturity Permo-Triassic Karoo.

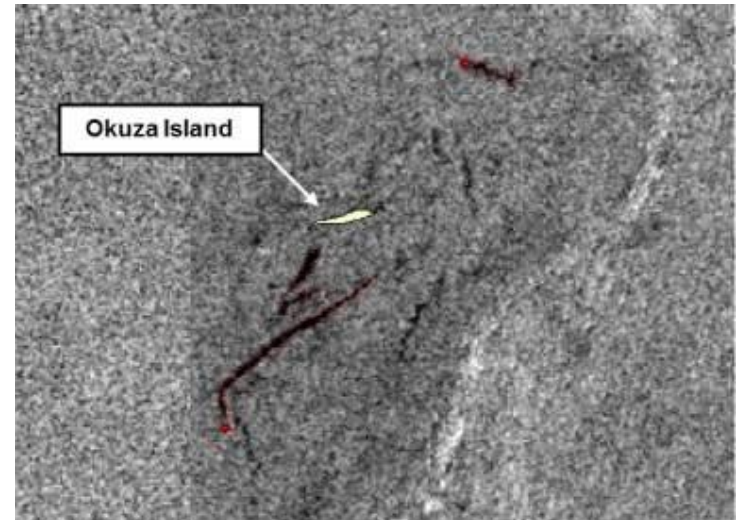
The high failure rate of past wells in the onshore and shallow marine settings is due to lack of quality seismic to properly image stratigraphy and to sufficiently de-risk prospects.

The regional geochemistry tells us that the history of inversion has caused flashing and flushing of trapped hydrocarbons.

The greater maturity of the underlying Permo-Trias Karoo may also cause additional flushing of trapped L/bM.Jurassic hydrocarbons.

Despite flashing and flushing there remains potential for significant oil entrapment by long-range migration westwards towards the shelf and onshore environments, and eastwards in deepwater on periphery of the basin where maturities are lower – assuming that seafloor was in existence at L/bM.Jurassic when restricted marine conditions existed.

Evidence for this is seen in the prolific abundance of seeps and shows all along the coastal margin, as far westwards as the recent Location X seep. (The abundance of tarballs, and slicks from satellite imagery may be evidence for offshore seeps in the East.)



Potential oil slicks offshore Okuza Island and reef, Nyuni PSA, identified from SAR studies.

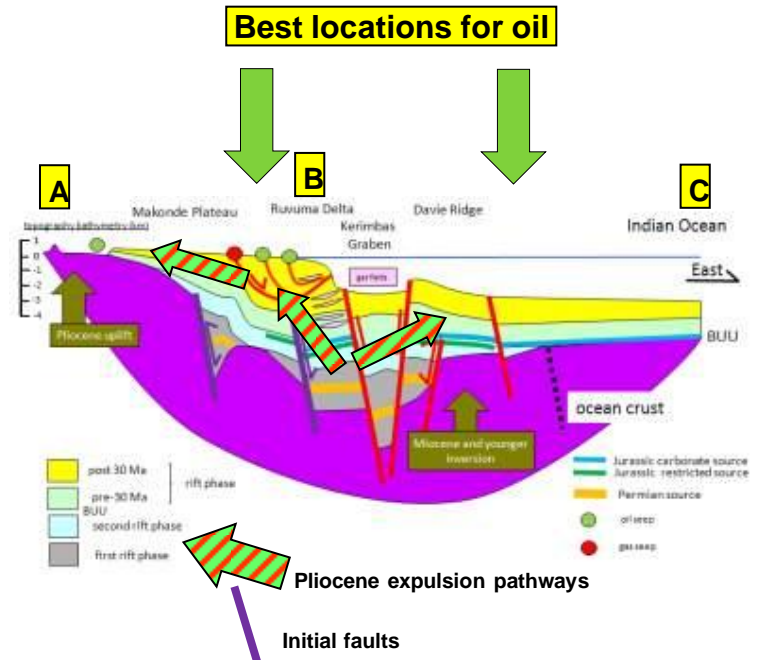


"Tar mat" on reefal foreshore at low tide, Nyuni Island, Nyuni PSA, June 2002.

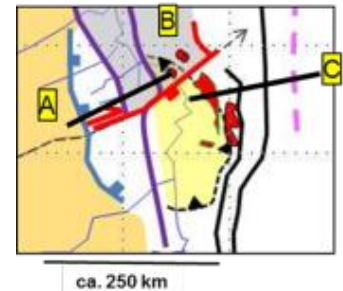
The schematic dip profile summarises our understanding of the petroleum geology of the Ruvuma region, and is essentially representative of much of the coastal margin of East Africa.

We envisage effectively continuous burial of the Permian and L/bM.Jurassic source successions until the beginning of the Pliocene, when uplift, accompanied by extensional faulting and eastwards tilting, allowed the sudden release of deeply buried and now overpressured hydrocarbons into the shallow section.

Gas is the dominant product, given the nature of the Permian section, and the previously illustrated burial and inversion history of the L/bM.Jurassic in the East.



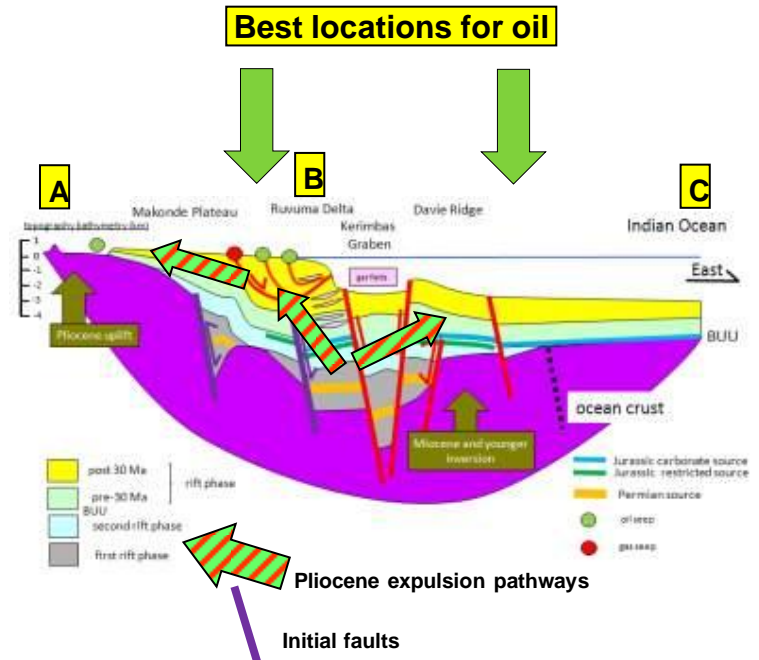
Schematic dip profile across offshore Ruvuma Basin, southern Tanzania, showing preferred locations for oil potential.



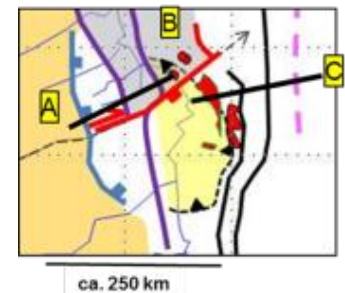
The expected immense volume of Pliocene-released gas reduces the chances of discovering oil since both phases of hydrocarbons were effectively released simultaneously, and any oils will tend to be flushed out of traps by high pressure Permian-sourced gas.

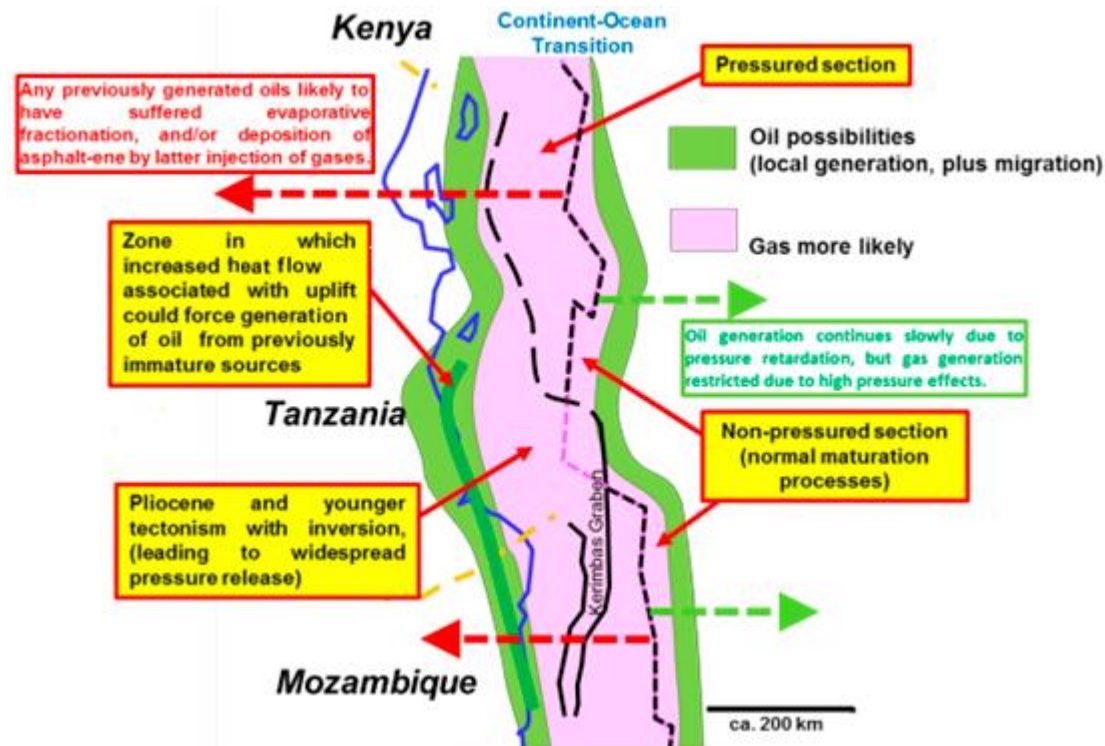
The best chances of finding oil as opposed to gas relate to older source kitchen release-events during which time the L/bM.Jurassic was still in the oil window. Protected early traps associated with the coastal hinge line provide the best locations - (many oil seeps and well locations with oil shows are associated with this deep hinge).

There may also be depocentre flank regions where the L/bM.Jurassic remained in the oil window during Pliocene tectonism. In the East, heat flows following rifting may limit this potential.



Schematic dip profile across offshore Ruvuma Basin, southern Tanzania, showing preferred locations for oil potential.





Lower to basal Middle Jurassic source rock presence and propensity for expulsion of oil versus gas. (Permian source potential has not been considered, nor that of the Cretaceous or Tertiary.)

The median black line shows the estimated boundary between younger tectonism to the West and mainly continued subsidence to the East.

In the absence of data, the Continent-Ocean Transition is a general representation, as is the eastern limit of overpressure, and that of the gas zone.

- Geochemical analyses of oil and gas seeps and shows suggest that significant oil has been generated along the coastal margin of much of East Africa, with most evidence pointing to a Lower – basal Middle Jurassic source, whose oils were expelled westwards and possibly eastwards by flashing and flushing.
- There is also sound evidence for significant Permian gas generation along the East African Margin.
- Better seismic is needed onshore and in the shallow marine offshore to sufficiently de-risk exploration wells, and specifically target stratigraphic traps that are believed likely to lie along preferential oil migration pathways.
- The industry must simply try harder to find oil - better (and cheaper) seismic on the shallow-marine shelf and onshore is a start, and already increasing contractor competition shows encouraging signs of progress, but is not the answer in itself.
- Publishing of results, and gradually increased access to data will increase regional understanding, and de-risking of plays.

- Danforth A., J. W. Granath, J. S. Gross, B. W. Horn K. J. McDonough and E. J. Sterne, 2012. A developing province. GEO ExPro, 9, 4, p. 74-78.
- Jarvie D. 2004. East Africa Rift Petroleum Systems. Conference on the Petroleum Potential and investment Opportunities in East Africa (EAPC '03, Nairobi, 5-7 March 2003), p. 31-43.
- Law C., 2011. Northern Mozambique true wildcat exploration in East Africa. http://www.searchanddiscovery.com/documents/2011/110157law/ndx_law.pdf.
- Matchette-Downes, C.J., et al 2004. The Greater East African Petroleum System. PESGB & HGS Third Annual International Symposium "Africa: The Continent of Challenge and Opportunity" London, United Kingdom 7th & 8th September, 2004.
- Ophir Energy, 2012. Ophir Energy PLC, Annual General Meeting, June 2012. <http://www.ophir-energy.com/media/1775/Ophir%20AGM%20Presentation%20-%20FINAL.pdf>
- TPDC, 2003. Petroleum Opportunities in Tanzania. Tanzania Petroleum Development Corporation.
- TPDC, <http://www.tpdz-tz.com/tpdc/>
- Uguna, C. N., Carr, A. D., Snape, C. E., Meredith, W., Castro-Díaz, M., 2012a. A laboratory pyrolysis study to investigate the effect of water pressure on hydrocarbon generation and maturation of coals in geological basins. Organic Geochemistry 52, 103-113.
- Wentworth Resources Limited, <http://www.google.co.uk/imgres?q=tanzania+%22deepwater+seismic&start=280&hl=en&sa=X&biw=1920&bih=899&tbn=isch&prmd=imvns&tbnid=i47ZsdxiJE4DEM:&imgrefurl=http://www.stockopedia.co.uk/content/tanzania-28710/&docid=nNV15JiITi8-uM&imgurl=http://i45.tinypic.com/2akiwrr.png&w=1143&h=444&ei=PJYCUMu0HYqY1AWKIdnrDw&zoom=1&iact=hc&vpx=1513&vpy=657&dur=5562&hovh=140&hovw=361&tx=243&ty=137&sig=103849198146122522303&page=6&tbnh=68&tbnw=176&ndsp=60&ved=1t:429,r:31,s:280,i:101>



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Geolnsight Ltd.

Nick Cameron

Ntorya-1, Ruvuma PSA, flowing 139 bpd condensate and 20MMcfd on test through a 1" choke, June 2012.