Seychelles and the Western Indian Ocean Palaeo-Reconstruction by Recourse to Biomarker Assemblages from Significant Oil

Accumulations and Shows in the Present Day Indian Ocean Margin

INTRODUCTION

ndia can also be charted.

sotope ratios. The saturate (aliphatics) values for the

Waxy n-alkane distribution - algal?

ompare well with those of the source rocks – the

atification in the water column /salinity. The amount

varies, perhaps indicating degree of salinity.

Elevated C35 doublet (Pentakishomohopane), again

Diasteranes, therefore source has a clay input, but

he second peak is the R epimer of the C_{29} $\alpha\beta\beta$ sterane.

ermodynamically stable – this and other indicators

would suggest the tars are from a mid mature source

Chris Matchette-Downes East African Exploration Limited, part of the Black Marlin Energy Group of companies United Kingdom, cjmd@eax.com

In the same way that West African geochemical data, (stable isotope measurement and

predict the likely Paleoenvironment of deposition on each side of the Atlantic, the more

e two oil families of Seychelles

Some of these failed rifts persisted to end Triassic

inland sea conditions to persist between Seychelles

Madagascar and East Africa throughout the Lower

Jurassic to early-mid Jurassic times. Periodic sea

conditions to occur from time to time then. From mid

times, eventually Madagascar, with Seychelles

Upper Cretaceous

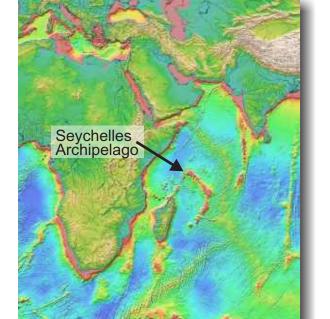
Ref: SEPEC database & Philp 1995

Tertiary source

complex break up of Gondwanaland and the separation of East Africa, Seychelles and

piomarker analysis from gas chromatography-mass spectrometry) derived from oil

accumulations in coastal South America and conjugate West Africa were used to



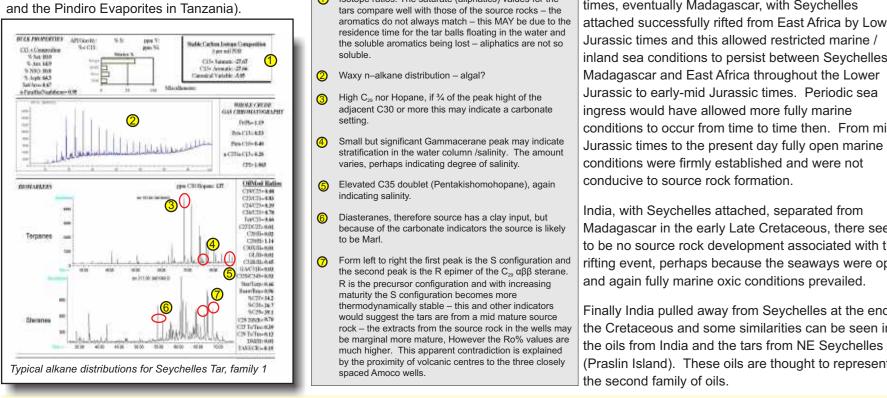
Seychelles

Petroleum

Oil samples and oil show extracts from the limited number of wells and the known seeps are used to help understand the multiphase break up of the East African margin, India and the Seychelles Mirco-Continent.

Seochemical data is presented with current plate tectonic reconstruction models to contribute to the understanding of the rifting sequences that were initiated during the Triassic that have resulted in the present day continental settings with seemingly contradictory oil geochemical signatures.

The initial break up of Gonwanda started in Permian times however rifting was not successful and a series of intermontaine basins were created in which classic terrestrial source rocks developed (eq. Sakamena, and Sakoa formations, Madagascar



Upper Palaezoic, incipient break up

Note the elevated C₂₀ norHopane

peak, presence of Gammacerane

and elevated C₃₅ Hopane doublet,

indicators).

absence of Oleanane and presence

The tars are sourced from a mid-to-

late mature source rock, with a

saline, marl dominated, restricted

Over 4,500 samples have been collected by SNOC (SEPEC).

marine source signature.

of Diasteranes (as well as carbonate

To date evidence for the early failed rift source rocks have not been encountered in Seychelles as the wells drilled thus far have only tagged the top of the exceptionally thick Karoo section. However throughout much of the Western Indian Ocean both Permian coals and Triassic lacustrine shales are recorded. There is also evidence for interior grabens within the Seychelles Plateau and the separation of the Seychelles from both India and Madagascar may also have been related to early Permo-Trias lines of weakness.



TETHYS

SEYCHELLES

MICROCONTINE

The Seychelles Oils

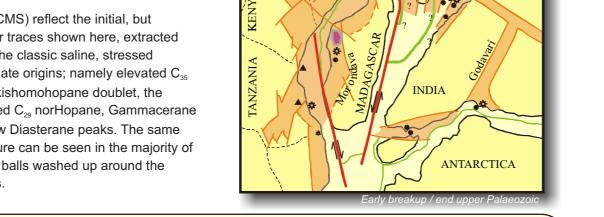
Madagascar

Tanzania

The coal mined in South Africa and found in Madagascar in Mozambique and Tanzania is of Permian age. The lacustrine Sakamena formation found to the south on Madagascar is believed to be the source of the giant Tsimiroro and Belomanga biodegraded oil deposits (fig GCMS - source contender 1a). The Triassic lacustrine Majiya-Chumvi Fish beds were encountered in Ria Kulai #1, southern and conjugate Kenya and the oil shows here from Tanzania (fig GCMS source contender 1a) are also believed to be derived from a Triassic lacustrine source. It is anticipated that a deeper Karoo exists under Seychelles EEZ; however the Liassic oil biomarker signature is so dominant it would mask any lacustrine oil input, if it were present. Upper Triassic, near exhausted, source rocks were encountered in the Reith Bank #1 well. (TOCs up to 6.7%).

Seychelles' oils (see GCMS) and source rocks seeGCMS) reflect the initial, but successful phase of rifting (200ma) and the biomarker traces shown here, extracted from side wall cores, clearly show an oil extract with the classic saline, stressed

carbonate origins; namely elevated C₃₅ Pentakishomohopane doublet, the elevated C₂₉ norHopane, Gammacerane and low Diasterane peaks. The same signature can be seen in the majority of the tar balls washed up around the

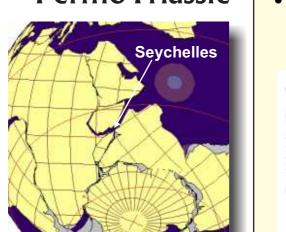


Contender 1a

conditions were firmly established and were not conducive to source rock formation.

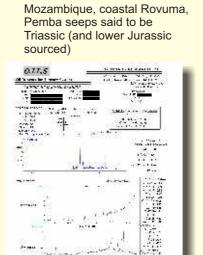
India, with Seychelles attached, separated from ecause of the carbonate indicators the source is likely Madagascar in the early Late Cretaceous, there seems to be no source rock development associated with this Form left to right the first peak is the S configuration and rifting event, perhaps because the seaways were open R is the precursor configuration and with increasing and again fully marine oxic conditions prevailed.

Finally India pulled away from Seychelles at the end of ck – the extracts from the source rock in the wells may the Cretaceous and some similarities can be seen in be marginal more mature, However the Ro% values are the oils from India and the tars from NE Seychelles by the proximity of volcanic centres to the three closely (Praslin Island). These oils are thought to represent the second family of oils.

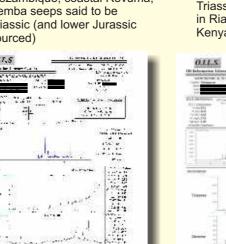


Oils, Madagascar & Tanzania Lacustrine derived oil Low maturity oil

 Other occurrences Mozambique, coastal Royuma. Pemba seeps said to be Triassic (and lower Jurassic



Source Rocks Mid Triassic Pindiro evaporates (10% TOC) Permian source rocks. Lake Nvasa. Tanzania Maii-va-Chumvi. Permoin Ria. Kalui #1. southern



Triassic, lacustrine fish beds

Permo Triassic lacustrine

Insufficient Sample Material

resent day hydrocarbon accumulations on the flanks The development of world class source rocks can be seen on both sides of of a former inland sea / lake complex at Liassic time the rift margin. The Liassic of Tanzania, for example in the Mandawa basin Type I source rocks exhibit TOC values up to 8.7%. The Liassic in Seychelles AMOCO wells reach 5.8%, however the HI values are low due to elevated maturity in the well location. The following figure shows GCMS data for two oils collected from Northern Tanzania (fig Contender 1b). Similar oil extracts have been collected in Kenya.

CV - 1.99

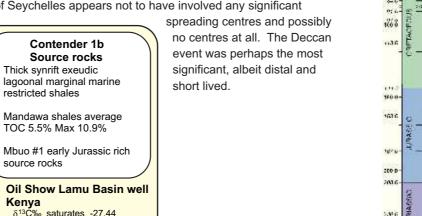
Pemba # 5 oil show (11,237 ft)

39469ic. marine, carbonate dominated

nterestingly the thermal maturity of all Seychelles' oil extracts and the tars is low. This implies a low geothermal stress from the Liassic, or earlier, onwards. (fig GCMS of Seychelles oil). The initial phase of rifting did not involve oceanic spreading ridges and consequent high heat flow. Fastern Gondwanaland

moved obliquely along the Davies Fracture Zone. There were no spreading centres. The rifting of Seychelles from Madagascar in the vicinity of Seychelles appears not to have involved any significant Contender 1 Contender 1b Source rocks Western Indian Ocean Margin, nick synrift exeudic Lower Mesozoic Oils; Tanzania, Kenya

δ¹³C‰ aromatics -26.82

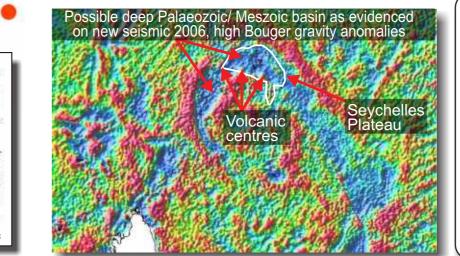


Nater well sample,

moco wells

some 400km,away from

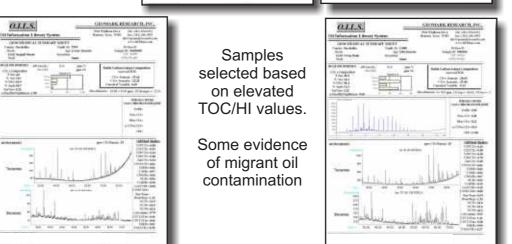
Seychelles source rocks



The source rocks of Seychelles /iable source rocks Non-source rocks -(Reith Bank) Owen Bank (Seagull Shoals

MOCO well data indicate that the pre and early rift sequences contain the source roo * Wells drilled near volcanic centre. Offshore source intervals likely to be very much less mature



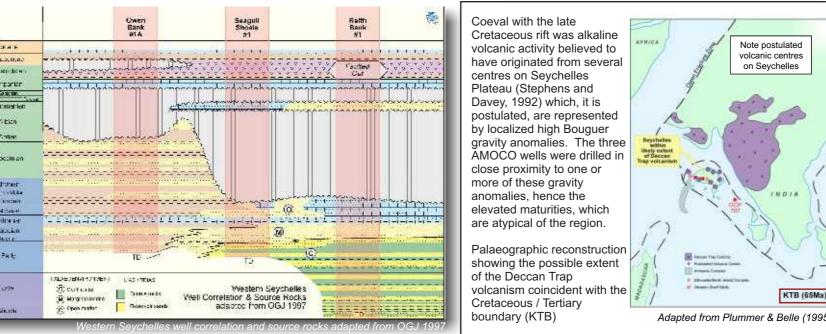


The Cretaceous, openmarine no source rocks The next phase of rifting occurred in the Cretaceous

(92Ma) and in this phase the Seychelles and India separated from Madagascar as the Mascarene Basin opened, this seems to have been a relatively guick event with the spreading centre well to the south of Seychelles. The resultant Mascarene Basin was fully marine early on in the rifting and no source rocks appear to be associated with this event. Oxic open ocean conditions prevailed hroughout the Cretaceous, this was not conducive to source rock formation.

The Kimbaji wells in Tanzania have often been cited as the type examples for Cretaceous source and closer inspection of the well data clearly shows that no source rocks whatsoever are present. (Ref. CJ Matchette Downes, Entebbe 2005). None of the Amoco (or Enterprise) wells on Seychelles, TOTAL's Simba #1 deep water well in Kenya the recent Nyuni well encountered a Cretaceous source. Only low values and type III/IV kerogens were reported in these wells and in Madagascar.

So there are no Cretaceous oils to chart the Cretaceous



Recent work on source rocks and migrant oils from Sevchelles undertaken by GeoMark Research has demonstrated a positive correlation between the well data (source and shows) tar balls and contaminant oil in the Coetivy water well, indicating the presence of a regionally extensive and potent Karoo source rock system.

alsoPlateau wide basaltic cover, thickest in the Constant Bank #1 well drilled by Enterprise (1.300m based on their VSO data). These isolated but significant volcanic intrusions are thought to be associated with both the Deccan event and rupturing of the thick continental crust, allowing leakage, (eg Comoros, Northern Madagascar and Seychelles volcanoes) to the surface. There appears to be an association with volcanic centres and the Banks and the main Plateau. These positive areas (the Plateau and Banks) may have been under pinned or buoyed up by the volcanics. The surrounding

The Tertiary

areas having floundered some 2km.

The associated heating event is thought to be the only regional heating event that affected the Karroo source rocks and the greatest effect was on the Sevchelles Plateau and on the Banks. Away from the Plateau and Banks the heat pulse associated with the greater Deccan is thought to be less and would explain why the migrant oils exhibit such low maturity (Rc 0.7%)

The final phase of separation occurred at the end of the Cretaceous (64Ma). It

The Third Oil Contender - Oil Family

has been argued that there was a ridge jump from the Mascerane to the Carlsbad

Ridge. This event also broadly coincided with localized extrusive volcanics on Seychelles

e.g. Silhouette Island and North Island and sills within one of the Amoco wells. There was

A possible Bombay anologue could exist in the NE Seychelles based on the presence of the Tertiary derived Tars and remnant geological fabric.

Sevchelles was adjacent to the Bombay High

with the Cambay basin to the North. The oils from these two regions are known to be derived from Tertiary source rocks with a considerable amount of higher plant/terrestrial

input. It is perhaps no coincidence that some of the tars washed up on the Northern Islands, Praslin in particular, are perhaps also derived from a local Tertiary source yet to be encountered by the drill bit. The analysis of the Praslin tars reveals the presence of large amounts of Oleanane and

other higher plant biomarkers. (See GCMS of Praslin tar vs. Bombay High Oil).

These highly waxy oils have all the characteristics of classic higher plant derived oil. The suggestion is that, prior to break up, a precursor basin existed with ideal conditions for the development and accumulation of pant debris, there are many examples. As the basin

pulled apart three areas of accumulation resulted; Cambay, Bombay High and NE Seychelles and the right conditions for the accumulation and preservation of plant matter continued into the Oligocene and then the accumulations of organic matter were drowned.

At the moment there are no wells in Northern Seychelles to test this hypothesis unlike for the Liassic and Upper Triassic source rocks found in the AMOCO wells on the

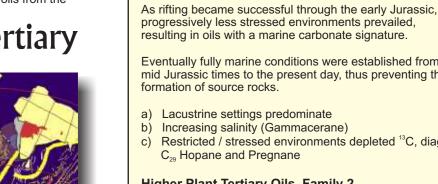
south western flank of the Plateau. Both oils are waxy and share similarities, so care is needed when determining the origin of tar balls. The 'northern' family (family 2) of tar balls are more mature (Rc 1%) perhaps

reflecting a greater heat input from the more proximal, but waning Deccan event. GCIRMS is perhaps the best way to distinguish the two families. It is therefore perhaps possible to

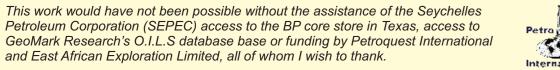
speculate that there is a conjugate Bombay/Cambay source kitchen in Northern Sevchelles. As the western Indian Ocean margin is explored there will be a greater number of oil samples available to

tighten this early correlation. It would be difficult to separate a mix of older lacustrine oils from the overlying Liassic oils



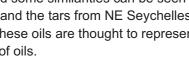


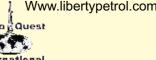
elict graben structures allowed the accumulation of significant quantities of higher plant matter with high lipid content at times of optimal sea level, giving rise to highly enriched source rocks and the ential to generate significant quantities of oil eg Bombay High (5.5 billion bbls, 15.8 tcf) Cambay sin (2.0 billion bbls, 3 tcf)and Indus Basin oils. Could such a play exist in the NE Seychelles given











promatics do not always match - this MAY be due to the attached successfully rifted from East Africa by Lower

residence time for the tar balls floating in the water and the soluble aromatics being lost – aliphatics are not so

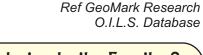
Jurassic times and this allowed restricted marine /

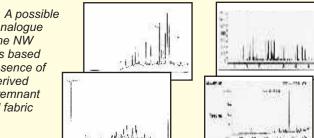
adjacent C30 or more this may indicate a carbonate ingress would have allowed more fully marine

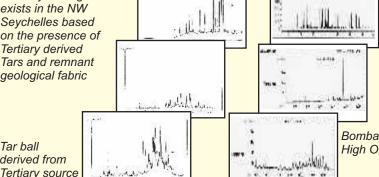


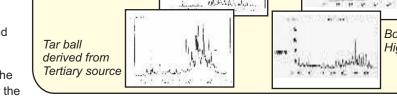


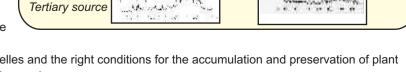
Seychelles



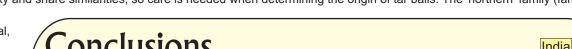










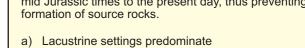


terior/failed rifts Oil family 1a & 1b board of the western Indian Ocean and early conjugate

East Indian Ocean Hinge the source rocks were deposited interior / failed rifts (eg Selous, Ruyu, Mandawa, uvuma, Lamu, etc) and the presence of these nontaine basins can be evidenced through analysis f the resultant oils. (Tsimiroro and Bemolanga 26 billion

Eventually fully marine conditions were established from

nid Jurassic times to the present day, thus preventing the



Restricted / stressed environments depleted ¹³C, diagnostic biomarker assemblages: C₃₅ Hopanes,

ligher Plant Tertiary Oils, Family 2

the presence of Tertiary derived tar balls and similar palaeography?



