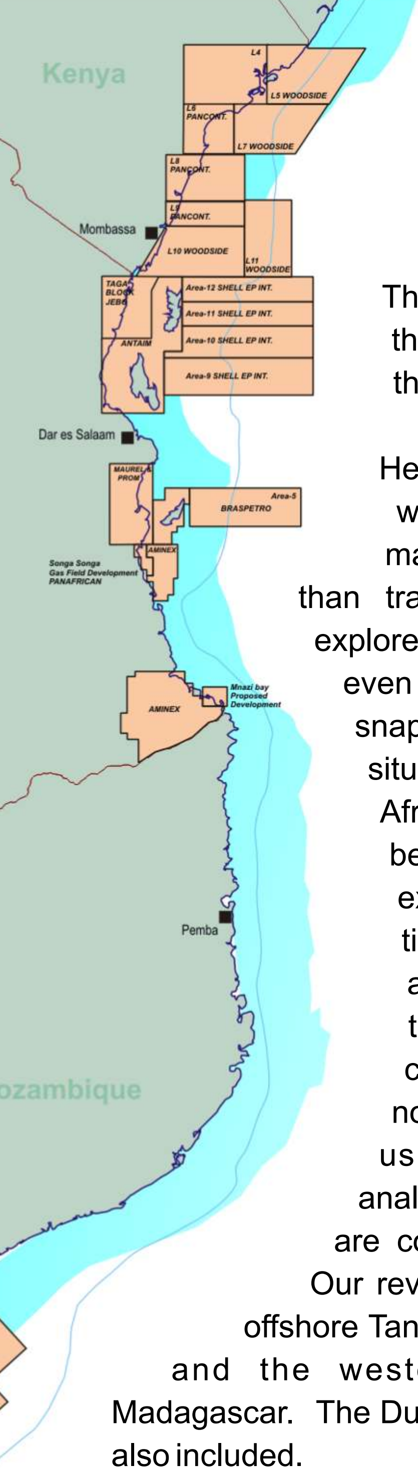

Now is the time for East Africa

By: Chris Matchette-Downes[1], Nick Cameron[2]

The last two years has seen increasing numbers of awards of acreage along the East Africa margin and now, after the initial forays by smaller companies, the majors are active in the area.

Here we outline our reasons why we regard the East Africa margin as far more prospective than traditionally thought and we explore the geological reasons why even more acreage looks set to be snapped up. The deepwater situation is akin to that in West Africa just over 15 years ago just before systematic deepwater exploration began. Since that time, much more is known about the mechanical and thermal evolution of continental margins and it is now a routine matter to predict, using for example gravity analysis, where the 'sweet spots' are compared to the mid 1980s. Our review area is offshore Kenya, offshore Tanzania, offshore Mozambique and the western offshore region of Madagascar. The Durban Basin of South Africa is also included.

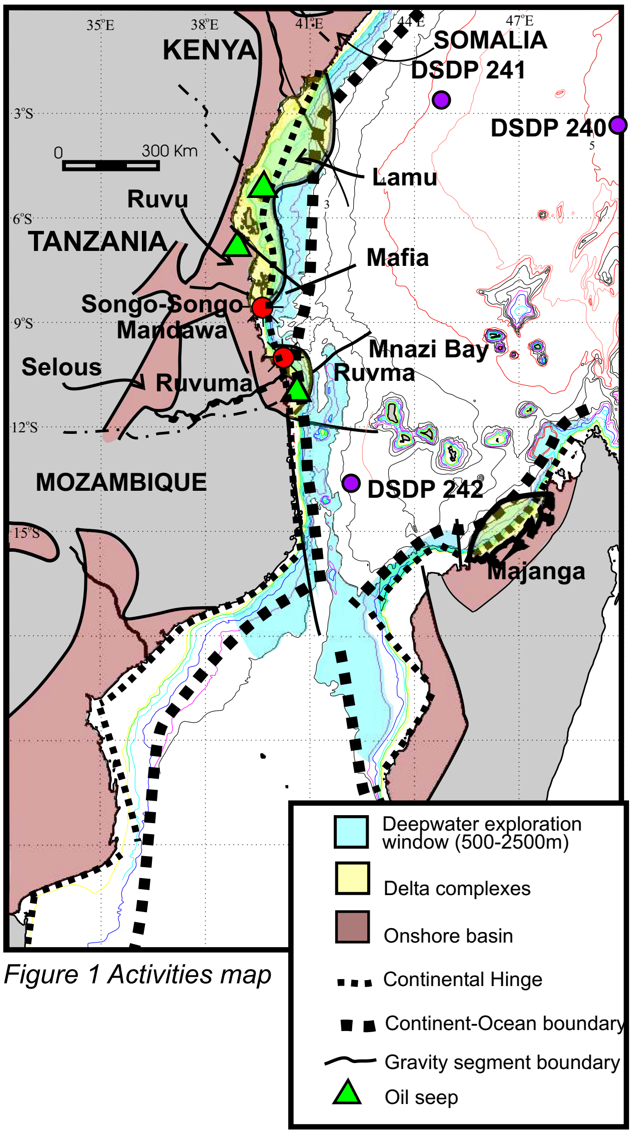

Figure 1 Activities map

An introduction to the geology of the continental margin

East Africa, unlike the three other margins of Africa, has been considered to host few significant source horizons. The two main reasons for this widely held view are the paucity of exposed, quality source rocks and the often erroneous attribution of the failure of dry holes to a lack of source. Yet there are, in reality, as many oil and gas seeps as in West Africa, while western Madagascar hosts one of the world's largest heavy oil accumulations (25,000 MMBOIP, Macgregor and Cameron, 2000). This accumulation is larger than many of the West African basin-margin asphalts.

Reconciliation of the perceived wisdom with the actual reality of the region is readily possible if the exploration consequences of the geological history of East Africa are examined. Firstly, much of the onshore succession is more disrupted than, for example, that along the western margin of Africa. This is because of the presence, not

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of one predominant, start to finish in 35 millions years, rift system, but of a compound rift system evolving over some 180 million years. More seriously, tectonism related to the formation of the East Africa Rift in the last 31 million years appears to have breached previously existing onshore closures and removed through uplift much of the associated source succession from the active Oil Window. Although West Africa also experienced uplift during the later Tertiary, the overall levels of resulting tectonism and disruption are much lower. Finally, and although the exact details are unclear, the impact of the Karoo Plume (183 Ma) severely damaged through forced maturation much of the older source rock section in the Mozambique region. Madagascar has also suffered from the effects of younger volcanism.

A major positive factor is the huge volumes of sediment delivered offshore, notably in the last 31 million years following the onshore uplift associated with the growth of the East Africa Rift and consequent shouldering of the eastern coastal flanks. These sediments include quality sands derived from the basement or from the reworking of Karoo aged clastics. The optimal location for deepwater sand accumulations is, as is the case in West Africa, immediately oceanwards of the Continental Hinge, which is of the main fault defining the continental margin. Although the rivers draining into the Indian Ocean are generally shorter than those draining into the Atlantic, the generally higher topography in the eastern part of the continent, together with high seasonal rainfall, ensures that they carry equal, and in some cases greater, sediment loads. This fact has been overlooked.

As well as extensive areas of accessible deepwater (defined for the purposes of this report as areas where the sea floor lies at depths of between 200 and 2,500 metres; see Figure 1), the region includes some of the world's most lightly explored continental shelves. There are only three deepwater wells in the entire area and all three were dry. These wells are Simba-1 in Kenya (1978, WD 920 metres), Tan Can-1 in Tanzania (1983, WD 250 metres) and Xai Xai W-A (WD 382 metres) in southern Mozambique, that is only one well for each vast country! This almost complete lack of deepwater well control makes it difficult to demonstrate prospectivity and, therefore, to prove the potential of the region beyond all doubt.

Current industry activity

Along the east Africa margin significant accumulation of sediment may be seen outboard of the Continental Hinge in several vast areas along this under-explored region. In the south, following extensive work by JEBCO, the Tugela Cone is now the focus of intense exploration activity; further north the full extent of the Limpopo Cone is being examined by JEBCO outboard of the early BP World Bank Xai Xai Graben test. DNO have joined forces with Wilrusco to explore the Inhaminga permit, Sasol and ENH are developing the Pande and Termane Gas Fields to supply gas to South Africa and PETRONAS are re-visiting the poorly understood Zambezi Delta.

In Tanzania, Pan-Africa, Aminex, Maurel et Prom, Shell, PETROBRAS, JEBCO and Antrim International are evaluating source reservoir complexes in axial to distal Continental Hinge settings. Pan-Africa's Songo Songo gas field is due on stream in May 2002.

To the north, in Kenya, Dana, Woodside, PanContinental, Afrex and JEBCO are examining the same Tertiary turbidites in the Lamu basin region where some 12 km plus of sediments have been recorded.

East Coast Africa is oil-prone

The richest well and outcrop-attested source rocks in the East Africa region are associated with the mid-Jurassic rift-drift transition section of the Somali Basin and the syn-rift, lacustrine units within the Middle Sakamena of Western Madagascar. Kimmeridgian aged source rocks are present in the Maurice Ewing Bank (now west of the Falklands) and marine early Cretaceous units characterise the south coast basins of South Africa. Other source occurrences are outlined by Barnard and Thompson (1992).

Palaeoclimate modelling by Pasta *et al*. (1992, figure 10) predicts for the Triassic and Jurassic the presence of upwelling settings along the southern margin of the Tethys. Optimal environments for source rock accumulation, namely transgressive shallow seas and paralic lakes, are shown. Since the East African source units of these ages also occur in the Middle East and west India, it is expected that the source section extends offshore into the present day deepwater outwards to the COB, provided that there was no sea floor topography such as might have been produced by contemporaneous volcanism. The excellent quality of these source rocks in Tanzania bodes well for the existence of similar quality sources offshore, as does the description of high quality, age equivalent sources in western Madagascar (Clark and Ramanampisoa, 2002).

Possible Kimmeridgian sourced oil has been found in the offshore Durban Basin (Matchette-Downes, 2002 & Singh and McLachlan, 2003).

In Mozambique oil shows have been reported above the Continental Hinge in the in the Inhambane province and gas was found in the Beira-1 well. Shows are being investigated throughout the length of Tanzania where a complex multiple source scenario is emerging. This scenario is expected to extend in to Kenya where significant gas shows have already been examined.

A key question for the deepwater is whether there are any significant developments of oil-prone source rocks within the post-middle Jurassic drift section. Middle Eocene and Campanian sources are present in Tanzania (Cope, 2000, figure 5 and p. 46), but their offshore extent is unknown. This is also true of the Cretaceous source sections in Somalia, Kenya, Mozambique and Madagascar (Morondava Basin) noted by Bernard and Thompson (1992, p. 402-403).

DSDP corehole results for the Somali and Mozambique Basins located, at best, only poor to moderate quality sources anywhere within the penetrated sections, but there are only eight holes (Schlich *et al*., 1974, figure 2), two of which were at the same location and only two of which (Sites 241 in the Somali Basin and 249 on the Mozambique Ridge) entered the pre-Tertiary. The basal sections of both these coreholes provided the best TOC levels.

In Mozambique anoxia continued in shelf settings into the earliest Coniacian (c. 88 Ma,

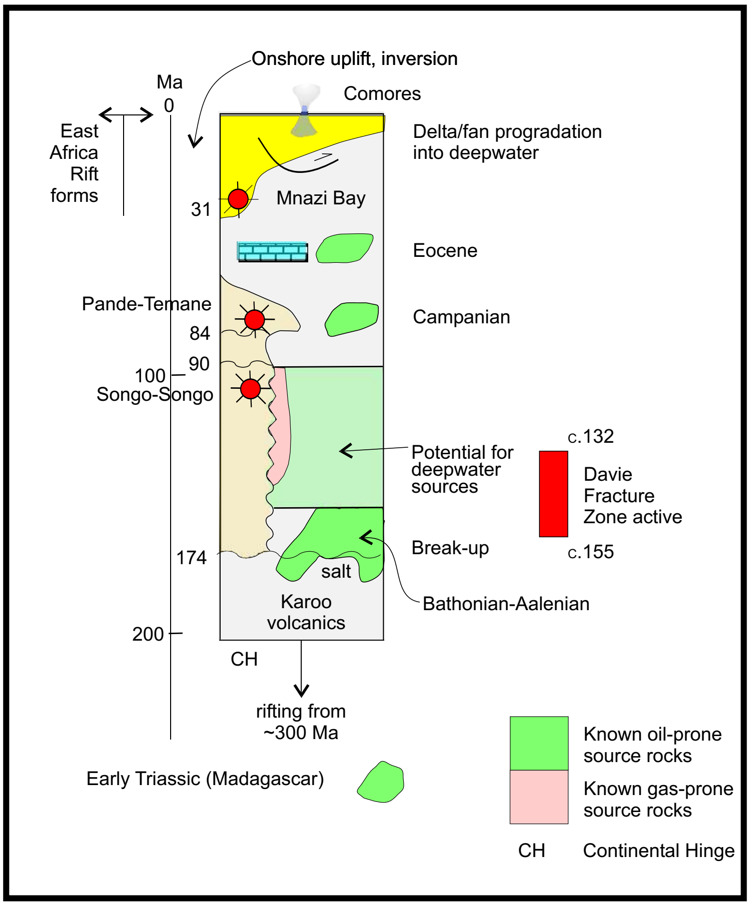

Figure 2. Diagrammatic play stratigraphy for the Somali and Mozambique Basins.

Dingle *et al*., 1983, figure 99) and source horizons are present in the 15A (Turonian) seismic sequence in the Bredasdorp Basin of South Africa (Davies, 1997, figure 3). These two observations, when combined with the constraints imposed by the quoted DSDP coreholes, suggest that widespread anoxia continued in protected settings until the Turonian (say 90 Ma). Figure 2 summarises the resulting play fabric.

World class, early Cretaceous aged source rocks have also been encountered in Antarctic DSDP sites in the Weddell Sea of Antarctica.

PresRo® and its exploration significance

PresRo® is the only commercially available package that allows the effects of overpressure on source rock maturation to be taken into account. PresRo modelling is a straightforward approach that describes the effects of reactions in restricted space. Where there is no escape for maturation products then the reaction process cannot proceed. The net effect of this is to hold the Oil Window open a lot longer in terms of time and temperature stresses. The result is that much of the deepwater source section placed by conventional basin modelling in the Gas Window is now regarded, on the basis of the new technique, as still positioned in the Oil Window. More details may be found in Carr (1999).

There are also profound implications for footwall and hanging wall traps along the

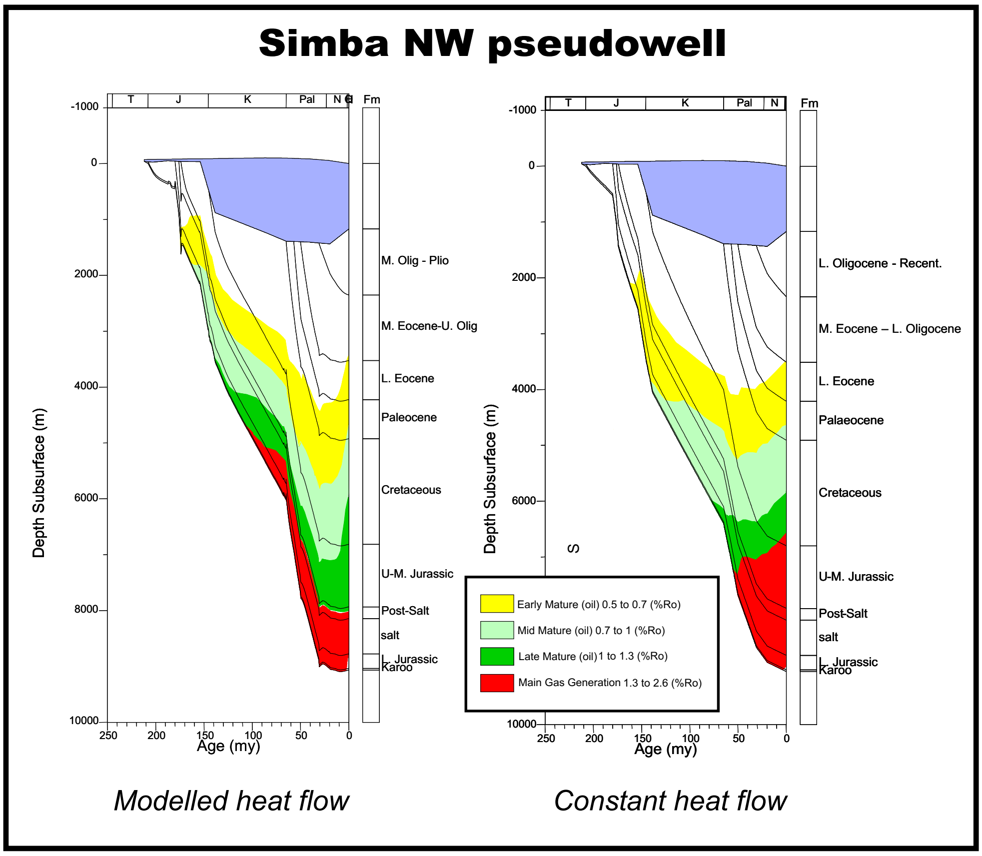

Figure 3. Simba NW pseudowell

Continental Hinge since overpressure reductions associated with tectonic movements could result in almost instantaneous gas and oil deliveries to traps, the nature of the charge depending on the characteristics of the source section. Many of the coastal oil and gas accumulations, for the example the reserves for the Pande and Temane Gas Fields, are considered to be derived by this process.

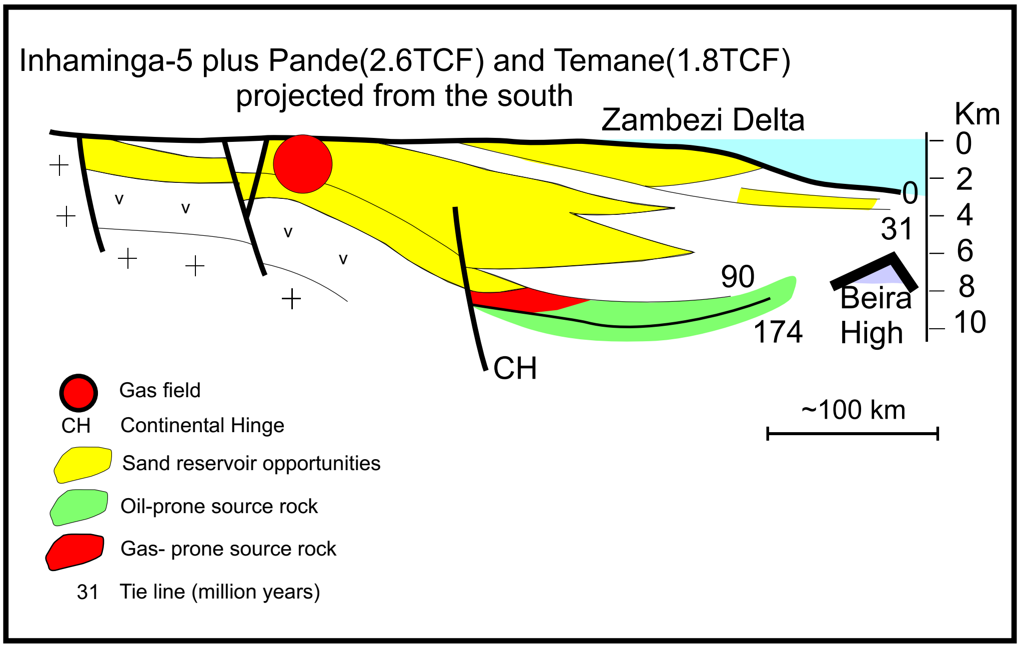

Figure 4. Mozambique Basin composite cross-section illustrating the play potential (based on Coster et al., 1989).

Satellite gravity defined segments

Examination of the satellite gravity shows that the East African and Madagascar margins are segmented by abrupt boundaries, many of which relate to feature inherited from the Pre-Cambrian framework. Each segment is named after a prominent topographic feature such as an island or major river or, where appropriate, after a recognised discrete sedimentary basin (*show an example figure say the Pemba segment, figure 5*). In positioning the segment boundaries, the greatest weight has been placed on patterns of free-air gravity, and the positions are thus strongly influenced by bathymetry. Bouguer gravity provides a sensitive tool for study of the continent-ocean transition, and hence for locating the continent-ocean boundary (COB). The COB is normally envisaged as a line separating continental from oceanic crust, but the reality is that the transition extends over a zone which may be narrow (less than 50 km) or wide (several hundreds of kilometres). Bouguer gravity maps provide information on the rate of the transition, as well as its location. Bathymetry and gravity jointly can also allow qualitative estimates to be made of the location of the 'Continental Hinge'. This zone, usually expressed as a single fault line, defines the shoreward limit of major extension. It can be a permanent bathymetric feature, but may be masked by later progradation.

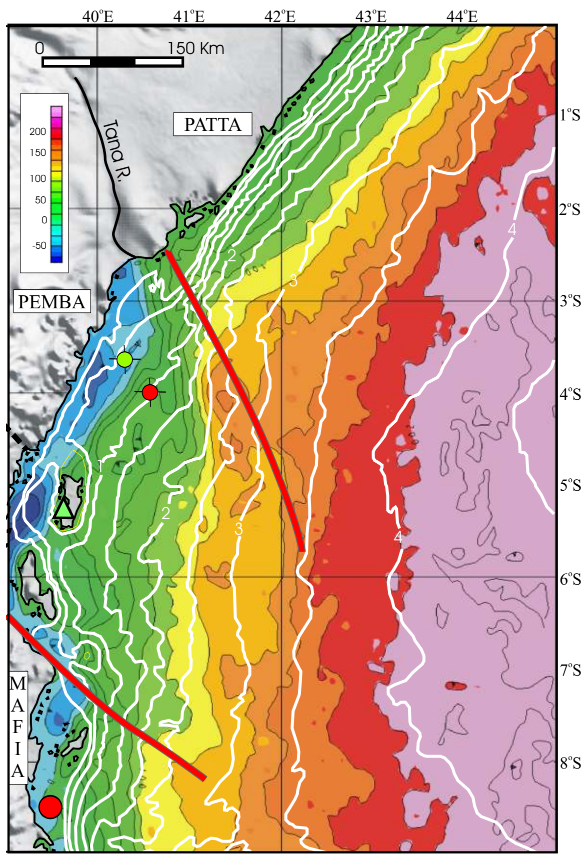

Figure 5 East Africa margin Quadrangle 1 (Patta, Pemba and Mafia segments), Bouguer gravity. Prepared from gridded satellite-derived free-air gravity and bathymetry (Sandwell, 2000).

Comparisons with West Africa

In the last fifteen or so years the importance of continental margin hinge lines in creating and preserving deepwater plays has become apparent. For West Africa, the pioneer papers on the mechanics of hinge line formation are by Karner *et al*. (1997; 2003). In West Africa, the details of the relationship between the distribution of fields and the track of what is known there as the Atlantic Hinge, have yet to be published. However, visual examination of the positions of the fields reveals the following hinge-related play types:

- Tilted fault blocks in the rift section with either dip-slope reworked clastics and /or crestal lacustrine carbonate reservoirs.
- Drapes above the tilted fault block crests within the rift-drift transition sequence.
- Grainstone and sands shoaling above and along the flanks of the crests.
- Marine sand pondings in lows located landwards of the hinge line.
- Salt-related closures controlled by the underlying hinge.
- Deepwater channels and fans downdip of the hinge.

Figure 5 in Cameron *et al*. (1999) introduces the location controls for these traps. There are no equivalent papers for East Africa, but the gravity segment analysis demonstrates that the same principles will apply.

The table below reveals, using formational names for the comparison, that the two margins experienced common evolutionary events, although marine conditions were present rather earlier in the rift history than in West Africa. With these similarities and the presence of an analogous Continental Margin hinge line together with multiple deepwater fan systems, the future for East Africa is encouraging.

Event	Angola (Kwanza Basin)	West coast Madagascar
Pre-rift (?)	Karroo	Basement / pre-Karroo
Syn-rift (half-grabens)	Aquia / Falcão *	Sakoa to Sakamena
Syn-rift (sag basins)	Falcão / Lukunga *(lacustrine)	Isalo / Beronono (marine by end)
Transitional	Cuvo and Loeme (marine by end)	Bemaraha (includes a salt)
Drift (continental margins form)	Pinda to Cunga	late Jurassic to Eo-Oligocene[1]
East Africa Rift 1	Quifangondo	Eo-Oligocene[1]
East Africa Rift 2	Quifangondo / Quelo	Miocene to present[1]

* the half-graben to sag basin transitions is diachronous between Angolan gravity segments.

[1] comparison with the east coast of Africa.

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