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Southwestern Continental Margin of India: A Poly-Rift Basin

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Summary

Continental Rifting is often the first phase in the construction of a new ocean basin. They often develop as a set of shears, approximately 120º apart from one another- a triple junction, one of which may ultimately fail to develop beyond a set of extensional basins. Paucity of knowledge about sub-basalt geology of the South-Western Continental Margin of India (SWCMI) from seismic and drill data, crippled plate tectonic reconstructions and thereby limited the understanding of pre-Deccan basin-forming and basin-modifying tectonics (Kingston, 1983). Consequently, integration of deep seismics, gravity, magnetics and revision and synthesis of regional tectono-stratigraphic models permitted the proposal of a new paradigm of poly-rift system for the southwestern continental margin of India.

Introduction

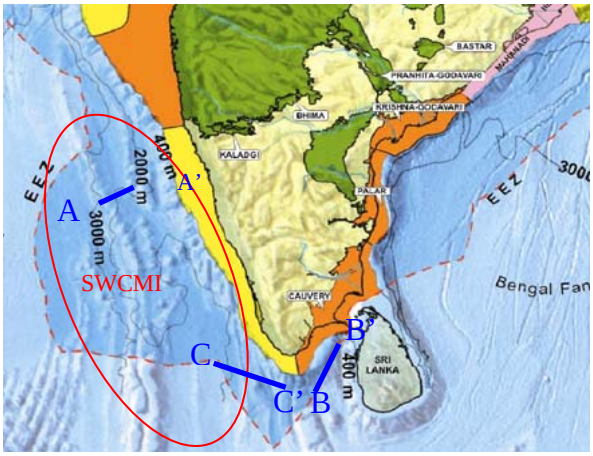

Fig.1 Location map of the SouthWestern Continental Margin of India (SWCMI).

Majority of India's hydrocarbon reserves are contributed by sediments associated with rifts and failed rifts. This fact brought the southwestern continental margin of India (SWCMI) under the scanner, as this margin under-went considerable crustal unrest in the geological past. Two rifting episodes, i.e. the Madagascar and Seychelles breakup had been recorded for the region inspite of the paucity of sub-basalt information from drilling and seismic imaging. However, recent attempts through long offset seismics to gather information about deeper sediments opened the purview for further revision of the tectono-stratigraphy of the region.

The orientation of the Mahanadi, Godavari, Kuruduvadi and Kayana rift-systems prior to India's breakup from Madagascar and Seychelles were sub-parallel to India's west coast. The fact, that crustal unrest during the breakup of Madagascar and Seychelles took place along the South-Western Continental Margin of India (SWCMI), rather than the other sub-parallel mobile zones viz., Mahanadi, Godavari, Kurduvadi and Kayana rift-systems, suggests that this margin was a much weaker and pre-existing mobile belt. Consequently, tectonic reconstructions imply atleast four episodes of rifting, of which three are visible on deep seismic imagery. EM modeling studies proposed the presence of a triple junction south of Kanya-Kumari, with its failed-rift-arm situated in the Mannar Basin (Raval and Veeraswamy, 2003). Seismic, gravity and magnetics indicate a sedimentary thickness of more than 6.0 second two-way-time for Mannar basin and SWCMI (Fig. 5). When all these evidences are amalgamated, a new paradigm of multi-episodic rejuvenations for SWCMI emerged.

Origin of the Rifts

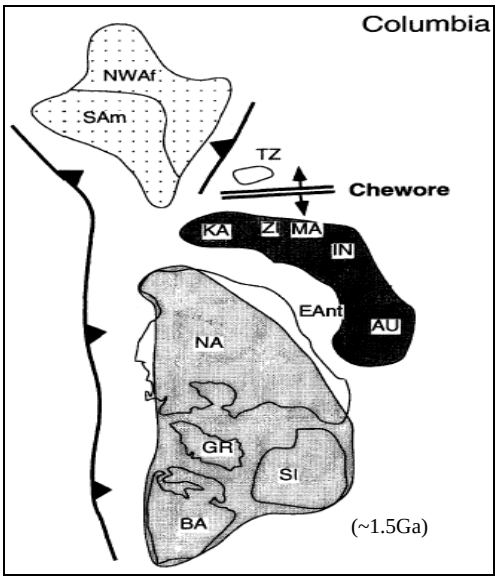

Fig 1. Reconstruction of the Columbia supercontinent (~1.5Ga). SI-Siberia; BA-Baltica; GR-Greenland; EAnt-coastal zone of East Antarctica correlative with marginal orogenic belts in Australia, India and South Africa but separated during post-Pangea rifting; AU-Australia; NA-North America; IN-India; MA-Madagascar; 21-Zimbabwe; KA-Kalahari; SAm-South America; NWAf-Northwestern and central Africa; TZ-Tanzania (from Rogers and Santosh, 2001).

The Indian plate has been a part of the Earth's tectonic history from the time of the first supercontinent, Ur ~3.0 Ga (Rogers and Santosh, 2001). At around 1.9 Ga, the cratons that formed expanded Ur, Atlantica, Artica and Nena accreted together to form the supercontinent Columbia (Fig. 1). Deep seismic has identified the Kurduvadi and Kayana rifts below the Deccan basalts (Fig. 2). The mafic igneous suites of the Mahanadi and Godavari rifts in India have been correlated with the Belt-Purcell and Uinta rifts respectively, of the Columbia region of North America, circa 1.5Ga (Rogers and Santosh, 2001). The horizontal stresses that led to the separation of Nena and Atlantica from Columbia, 1.6Ga -1.4Ga, led to the formation of these mesoproterozoic rifts in India that extend into East Antarctica and N. America. The Unkar, Apache and Pahrump rifts of N. America would most probably be related to the Indian west coast, Kurudvadi and Kayana rifts. The Kurudvadi and Kayana rifts along with the Indian west coast, although unproven, are suggested to contain mesoproterozoic sedimentary sequences like the Mahanadi and Godavari grabens. Furthermore, these already weak mobile belts would have been reactivated by later tectonic events as they tend to channelise stresses into them, unlike the more stable cratons (Veeraswamy and Raval, 2004).

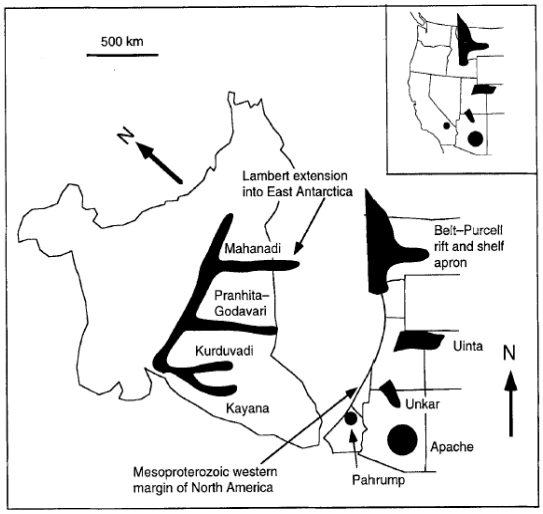

Fig. 2 Rifts in eastern India (left) and western North America (right), ~ 1.5Ga. Arrows show present north for each area (from Rogers and Santosh, 2001).

Paleogeographic Reconstruction and Interpretation

The Gondwana reconstruction of the continents during the Jurassic (Fig. 3a), shows the presence of sub-parallel failed rifts in the Morondova, Mascarene basins, Mahanadi and Godavari trends, all of which witnessed sedimentation from the Permo-Carboniferous, if not older, and have the same trend as the west coast of India (Plummer, 1994). The paleo-drainage for all these rifts at that time was sourced from Antarctica and drained towards the Nubian plate.

The oldest sediments encountered by wells in the SWCMI were of Late Cretaceous Age (Santonian, 85±1 Ma). However, the greatest evidence for a weakened crust in the SWCMI is that the basalts in St. Mary's Island and dykes in Karnataka and Kerala (both in southwestern India) have been correlated with the extensive basalts seen in eastern Madagascar, circa 90 Ma. As seen in Fig. 3b, the coast parallel Late Cretaceous volcanics in Madagascar (de Wit, 2003), appear to have been sub-parallel to the other mesoproterozoic rifts. This helps to postulate that the India-Madagascar rift was in a well-advanced stage at that time, and this weakness in the crust led to splitting between Madagascar and India as opposed to the other sub-parallel rifts.

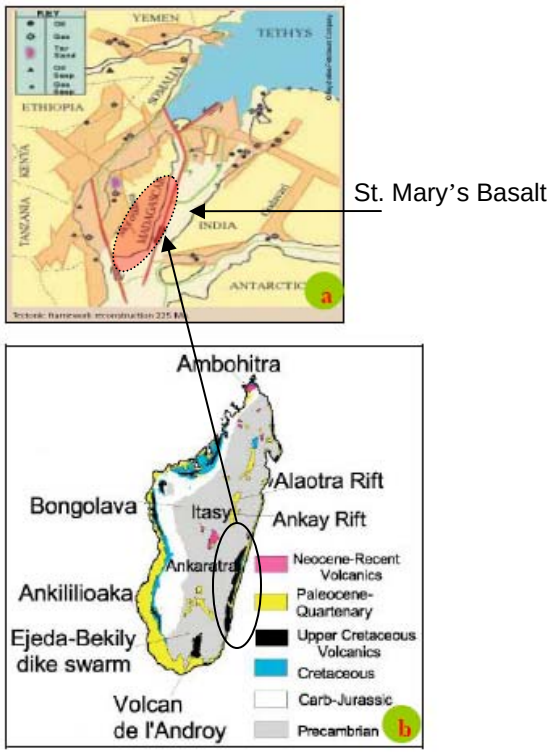

Fig. 3 (a) Geometric relation of the rifts during the Jurassic. (b) Geologic map of Madagascar showing the coast parallel Upper Cretaceous Volcanics (from de Wit, 2003).

Fig. 4 is a seismic profile in the SWCMI, showing a thick sedimentary pile and possibly signatures of the India-Madagascar rift. The KT and Santonian markers, shown in the section, indicate that the initial easterly basinal tilt was followed by a compressional event resulting in the present day inverted grabenal trends. These structures, interpreted to have been formed due to the Indo-Eurasian collisional tectonics, are the primary targets under focus for Mesozoic exploration.

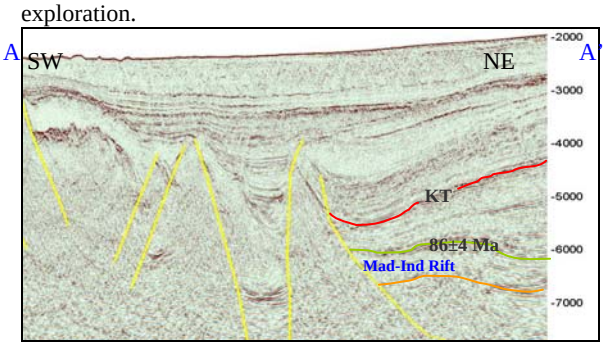

Fig. 4 Seismic from the western offshore region of India showing thick sedimentary pile and possibly the India-Madagascar rift.

Onshore geologic studies and wells drilled in the Mannar basin, Sri Lanka had encountered Jurassic sediments, extending to the deeper offshore region. These sediments are seen to extend into southwestern margin of India with the help of long offset regional seismic (Fig. 5).

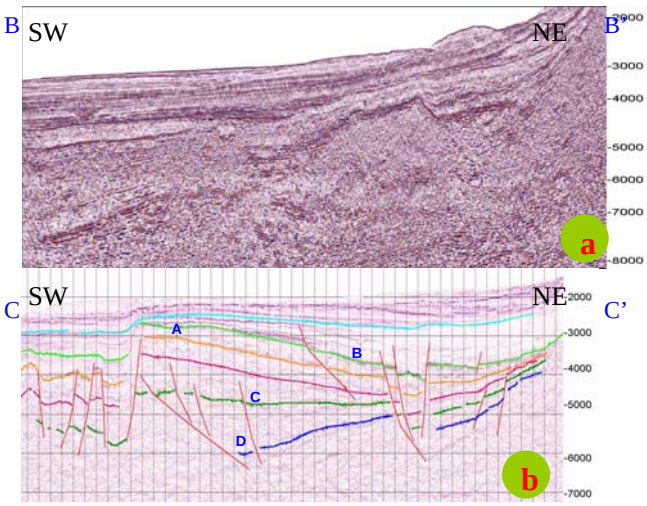

Fig. 5 (a) Shows a seismic line in the Mannar Basin of Sri Lanka where Jurassic sediments were drilled. (b) Seismic line in the southwestern Indian basin, where Jurassic sediments are conjectured to be present. **A**-structural inversion due to the Himalayan collision, **B**-KT boundary, **C**- End of Karoo rift (?), **D**-Karoo rift & Older (?)

Gravity-magnetic modeling in this area indicated about 7km of sedimentary thickness. All this points to the existence of a Western Indian rift, which had been created during the mesoproterozoic extension, and had been reactivated many times in its history, peaking during the periods of heavy sedimentation.

Tectonic episode	Continents involved	Age	Reference
Meso-Proterozoic Rifts	Breakup of Nena and Atlantica from Columbia	1.5Ga	Rogers and Santosh, 2001.
East-West Gondwana Breakup (Karoo)	Breakup of East Gondwana from West Gondwana.	170Ma	Norton and Sclater, 1979.
India-Madagascar Breakup	Breakup of Madagascar from India-Seychelles.	84Ma	Norton and Sclater, 1979.
India-Seychelles Breakup	Breakup of Seychelles from India.	65Ma	Norton and Sclater, 1979.
Himalayan Orogeny	Collision of India with Eurasia	40Ma	Norton and Sclater, 1979.

Table 1 shows a tectonic event chart based upon the interpretation from integrated geophysical and regional geologic studies.

Paleo-Environment and Source Rocks:

Detailed study of satellite-derived free-air gravity data and shipborne magnetic data inferred that the Northern Natal Valley acted as a spreading center between the Mozambique Ridge and Africa from 133-125.3 Ma (Tikku, 2001). However, the 167.2Ma (Fig. 6) reconstruction shows that the Mozambique Ridge acted as an independent microplate much earlier than the existence of the spreading center in the Northern Natal Valley (Marks and Tikku, 2001, Cox, 1992 and Tikku et al., 2002). The Mozambique ridge acted as a barrier for deep water circulation between the Mozambique proto-ocean and Weddell Sea until 125 Ma, creating suitable conditions for the deposition of source rocks. Cores collected from the wells drilled during ODP leg 113, on the continental slope north of Dronning Maud Land, have indicated anaerobic bottom water conditions during Valanginian to Hauterivian (Mutterlose and Wise, 1990). This restricted condition would have been ideal to preserve shales with considerable organic content which is akin to the present day Caspian Sea.

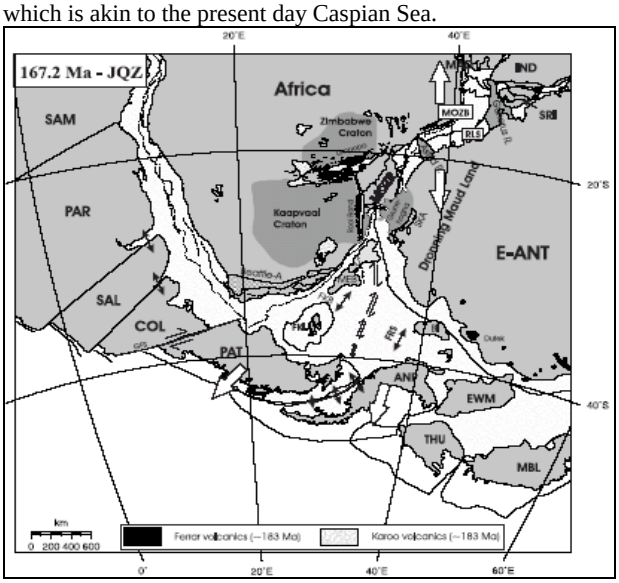

Fig 6. 167.2 Ma (JQZ) reconstruction for the break-up of Gondwana (from Konig, 2005).

After 125Ma, spreading ceased between Africa and the Mozambique Ridge, and the Southwest Indian Ridge evolved with the initiation of spreading between the Mozambique Ridge and Antarctica (Konig, 2005). By virtue of being in southern hemisphere, the west coast of East Gondwana would have experienced oceanic upwelling due to Ekman spiral phenomenon leading to high organic productivity during Cretaceous period. Followed by this is the global anoxic event at the Cenomanian – Turonian boundary, coinciding with the India-Madagascar rift.

Conclusion

Tectonic Reconstructions show that the Western Continental margin of India owes its origin to the mesoproterozoic extensions that were responsible for the formation of Morondova, Mascarene, Mahanadi and Pranhita-Godavari rifts (Fig. 7). All these mobile belts had been rejuvenated many times through geologic history resulting in correlatable stratigraphy and some were taken advantage of during the ultimate breakup of the continents. The correlatable basalts in Madagascar and Southwest India and finally the position of the breakup of India from Madagascar prove that the SWCMI was a far more developed rift system than the Mahanadi and Godavari. All this proves that the Western Continental Margin of India has had a long eventful history and unlike contemporary understanding did not form by chance during India's breakup from Madagascar and Seychelles.

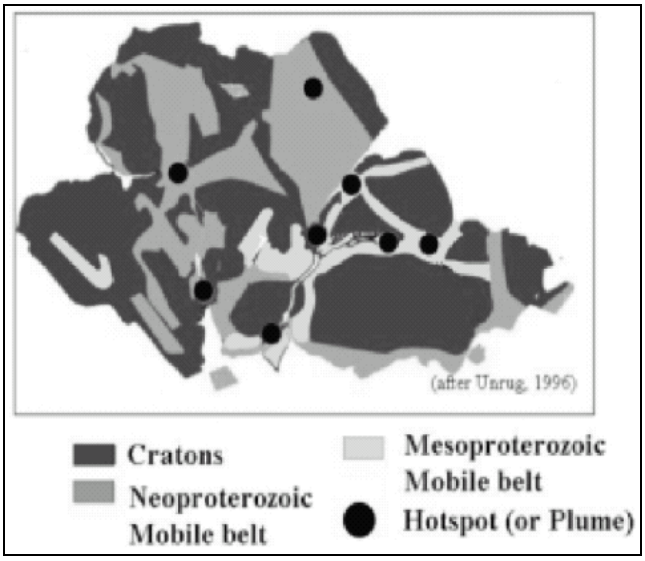

Fig 7. Transcontinental mobile belts with hot spots (modified from Unrug, 1996 by Veeraswamy and Raval, 2004).

The anoxic environment in the proto-Mozambique Ocean during the Valanginian-Hautervian period would have been ideal to preserve shales of very high organic content. Also, the later coincidence of the global anoxic event at the Cenomanian-Turonian Boundary during the breakup of Madagascar from India would be beneficial to generate more potential source rocks for the region.

Tectonic synthesis developed by integrating regional seismic, well information and plate-tectonic reconstruction studies indicate the existence of multi-episodic rifts coinciding with global anoxic events, thus providing a high

possibility for the presence of Mesozoic source rocks along the south western continental margin of India.

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