Evolution of West Coast of India-A Plate Tectonic Approach

A. Siawal[1], P.P. Dash[1] and H.C. Srivastava[2]
[1]KDM Institute of Petroleum Exploration, ONGC, Dehradun
[2]E & D Directorate, ONGC, Dehradun

ABSTRACT

The evolution of western continental margin of India (WCMI) began with the separation of east and west Gondwanaland. Subsequently sequential separation of Madagascar and Seychelles from mainland is less understood. The imprints of each tectonic episode may have been lost beyond their identification due to Deccan volcanism. In the present study a comprehensive and integrated approach is made to understand tectonic evolution of entire western margin of India (from Kutch in the north to Kerala in the south) within the ambit of Plate tectonic framework. The paper vividly depicts evolution of WCMI through paleotectonic spread maps at some important stratigraphic levels. The study suggests a multi-phase evolution for western continental margin of India. These stages are-1) Pre Break up, 2) extension in Somali basin, 3) initiation of Kerala Basin in the south, 4) initiation of Laxmi Basin towards north, and 5) Deccan volcanic episode,Cambay rift formation, clockwise rotation of Saurashtra Peninsula and break up of Seychelles.

INTRODUCTION

The Western continental margin of India (WCMI) is an Atlantic type divergent margin (Biswas, 1987). The existing set up of the WCMI is the outcome of series of tectonic events including time stretched rift episodes. However, the individual stages of rifting and their effect on the evolution of the margin is yet to be firmed up. Therefore, understanding of the various tectonic events and their reflection on the geological evolution of the area is necessary.

The paper discusses the regional tectonostratigraphic status and salient aspects of the evolution of the WCMI within the framework of plate tectonics integrating the exploratory data gathered by ONGC and other scientific information available through published sources (Fig.1).

Sea-floor spreading anomalies of the Arabian Sea and adjoining western Indian Ocean have been studied by various workers (McKenzie and Sclater, 1971; Whit marsh, 1974; Norton et al., 1979: Bhattacharya et al., 1994). The widely accepted mantle Plume model *(Morgan*, 1981; *Richards et al*., *1989; Campbell & Griffiths, 1990)* for the evolution of WCMI is primarily supported by the presence of continental flood basalt and a trail of volcanic islands in the form of Lakshadweep-

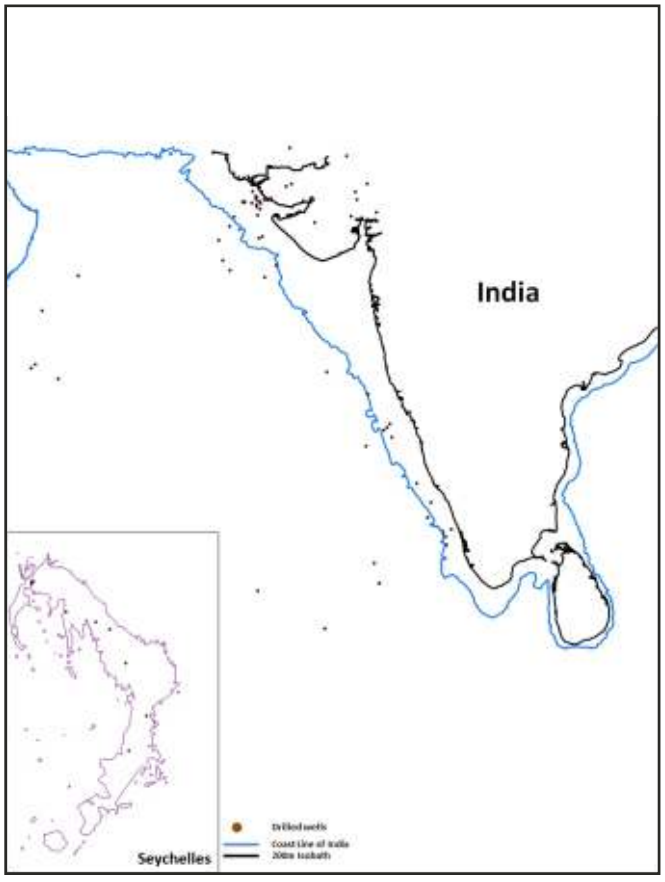


Fig. 1: Data base used for the present work

Chagos Ridge. However some igneous events associated with the dispersion of Gondwanaland vis-a-vis creation of the Indian Ocean are listed below:

i. About 182 Ma, extensive basalt outpourings in southern Africa (Karoo basalts) and their equivalent over Antarctica and 166 Ma magmatic activities over Madagascar (Encarnacion et al., 1996). Based on stratigraphic disposition undated volcanics in one of the well drilled over Saurashtra may be related with Karoo magmatic activity.
ii. Basalts of Rajmahal Trap of 107-118 (Baksi et al., 1987) towards east coast in areas of Mahanadi and Bengal Basin.
iii. Basalts of St. Mary Island of 85.5 Ma (Pandey et al., 2001), dolerite of 89.1+/-0.65ma in Gulf of Mannar (Rathore et al., 2007) and 90 Ma basalt (Torsvik et al., 1998) present along eastern coast of Madagascar. Also basalts of about 110 Ma in one of the well in Kerala-Konkan area.
iv. Mundwara volcanics of about 70 Ma (Rathore et al., 1996) may be precursor for the main Deccan event.
v. The Deccan volcanism, associated with the breakup of the Seychelles micro continent from India (*Mahoney*, 1988) extruded at around 64 Ma.

In view of the prolific hydrocarbon discoveries from Mesozoics in the Indus Basin and the Kohat-Potwar region of Pakistan (Quadri and Shuaib, 1986), the regional evolution of the Western Continental Margin of India (WCMI), particularly in plate tectonic framework, is needed to be studied in detail for a better understanding of the nature and distribution of the Mesozoic sediments along the WCMI. The presence of Mesozoic sediments in the out crops and sub-crops along the western margin of India is well documented (Table 1). However, it remains poorly understood at least in terms of Mesozoic basinal configuration and extent of sedimentation. This is primarily due to thick trap layer overlying the Mesozoics which provided constraint for good seismic imaging of Mesozoic section.

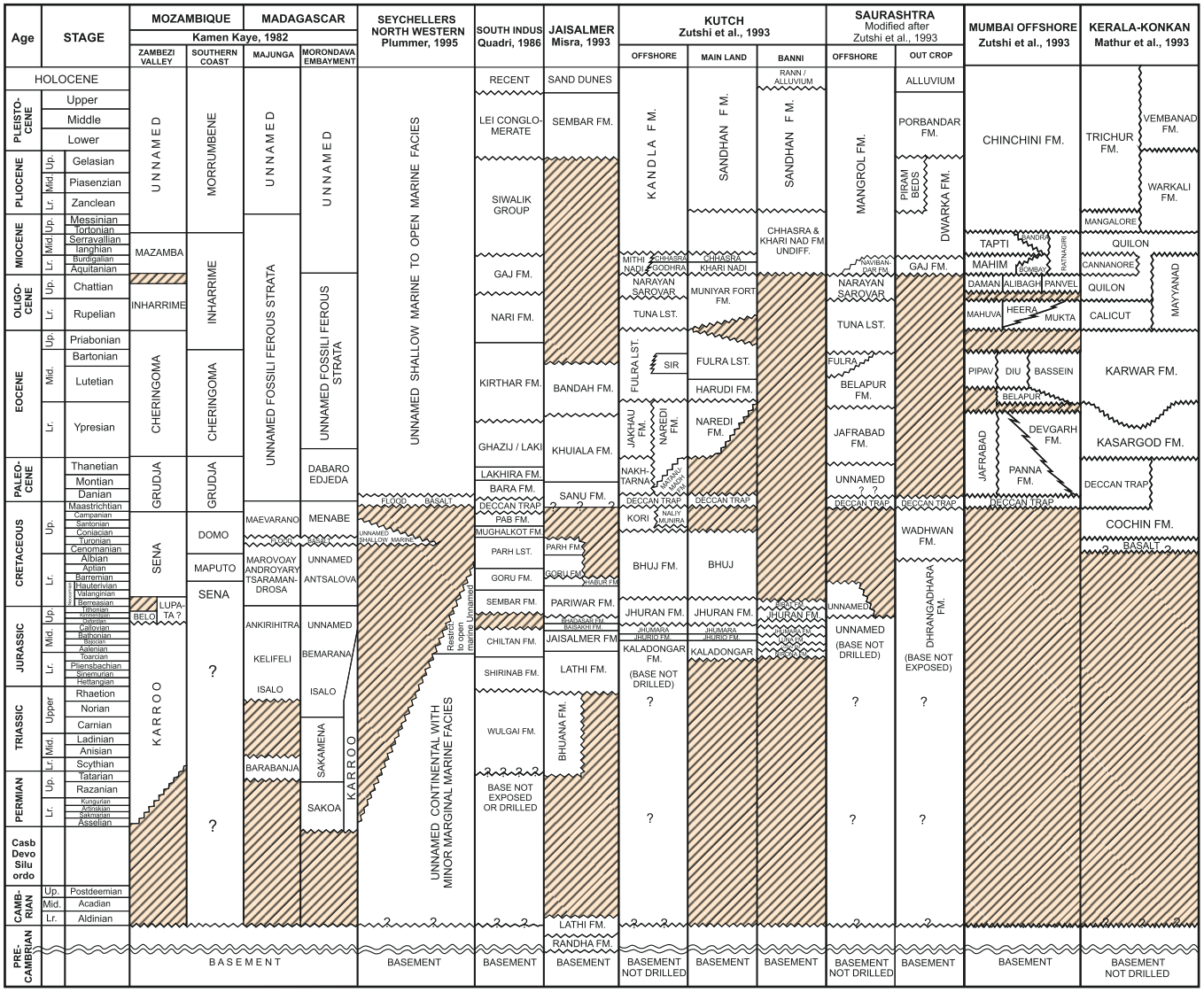
The geology of Kutch region is very intriguing as it witnesses rock records from Jurassic to Recent which are interrupted by number of unconformities and igneous intrusions at different times. However, the basement rocks crop out to the north of Kutch in Nagar Parkar area which lies in Pakistan. The Mesozoic rocks of Kutch have attracted the attention of geologists from world over mainly because of exceptionally rich fossil records of Jurassic Period. The Mesozoic rocks range in age from Middle Jurassic to Late Cretaceous (GSI, 2001) and are bordered by the Deccan Traps to the south and by saline marsh of the Rann of Kutch to the north.

Biswas (1980) presented an overview and evolutionary pattern of rift basins of western India. Biswas (1987) has discussed the sequential development of the Kutch basin and its regional tectonic framework. ONGC after comprehensive studies gave detailed account of litho-stratigraphy of Kutch (Zutshi et al., 1993), Cambay (Pandey et al., 1993), Mumbai (Zutshi et al., 1993) and Kerala-Konkan (Mathur et al., 1993) basins. Zutshi et al., (1999) attempted to reconstruct the Cretaceous Basin in Kerala–Konkan area based on seismic data interpretation.

Siawal et al., (2006) based on synthesis of geoscientific data prepared paleo-tectonic maps at major stratigraphic intervals and suggested multiphase evolutionary history for WCMI. Siawal et al., (2003, 2007 & 2014) made anattempt to constrain the zone of continent ocean boundary based on seismic data along with gravity variations. They also identified seismic signatures favoring existence of oceanic crust in Laxmi basin.

An attempt has been made to reconstruct the pre-breakup assembly of India, Laxmi Ridge, Seychelles & Madagascar. For this purpose the line of COB as identified by Siawal et al., (2014) based on presence of SDR's on either flanks of Laxmi ridge is considerd. These zones have been extended around the ridge. For Seychelles plateau and Madagascar areas, in the absence of geophysical

Table 1: Stratigraphy of basins associated with western continental margin of India



data, 200m isobath has been considered. All the available out crop and drill well data along with data from public domain has been integrated. Such identified pieces have been brought together considering earlier reconstructions (Bhattacharya et al., 1994, Whitemarsh, 1974 &Torsvik, et al., 2001).

Besides above discussed technical foreground, the present work also considers aspects which are critical for India-centric reconstruction. These are: (a) anticlockwise rotation of the Saurashtra block so that it is brought back to its original position and it fits in at the concavity seen along the west coast (Krishnan, 1960, Zutshi et al., 1998, Sethna et al., 2001), (b) Mesozoic exposures (inlier) of Dhrangadhara Formation over Saurashtra peninsula (c) Severe compressive environment in and around Kutch (d) Presence of continental sliver in the form of Laxmi Ridge (e) Presence of marine sediments of Cretaceous age (Bagh Beds) in Narmada Basin (f) Presence of Mesozoic sediments over Seychelles plateau. However corresponding sediment towards northeast remains speculative.

Evolution of the WCMI

ONGC's Tectonic Map of India (Siawal et al., 2003) reaffirms the nucleation of the Archean cratons along with a chain of Proterozoic mobile belts with contrasting geological characteristics and distinct geophysical properties which makes it a very heterogeneous lithosphere. Along the western

margin, juxtaposition of India and Madagascar is favoured based on the geophysical anomalies and common geological features (Raval and Veeraswamy, 2003).

Based on palaeomagnetic, petrological, geological, geochronological and geochemical data, it is concluded that the Late Precambrian granitic rocks of Seychelles are very similar to and are well correlated with those of the Arabian-Nubian shield, and that the Seychelles first occupied the eastern end of the Horn of Africa and have drifted to the present position since the continental break-up (Kanenori et al., 1994). Torsvik et al., (2001), while working on Rodinia Supercontinent formation based on match of palaeomagnetic poles from ca. 750 Ma magmatic rocks in Seychelles & NW India (Malani) placed these regions only 600 km apart. The position of Seychelles at this time marks the incipient formation of a microcontinent because there is no evidence for older continental crust than the 750–755 Ma granitoid rocks in this region. Meyerhoff and Kamen-Kaye (1981) interpreted the Mascarene Ridge to be a relict island arc similar in origin to those in the western Pacific Ocean. Seismic refraction lines on Seychelles Bank confirm the presence of granite under a considerable portion of the bank. Saya de Malha Bank (also on the Mascarene Ridge), appears to be composed of volcanic rocks capped by coral (Meyerhoff and Kamen-Kaye, 1981). It is suggested that the two areas are structurally independent (Shor GG Jr, Pollard DD, 1963).

Plummer et al., (1993, 1994 & 1995) discussed the tectono-stratigraphy of the Seychelles microcontinent including paleogeography and hydrocarbon prospectivity based on subsurface record of four wells. He identified sedimentary strata ranging in age from Triassic to Recent punctuated with multiple unconformities. Triassic rocks have been encountered only in one well (Reith Bank-1) situated in the extreme western part of the plateau. Plummer identified three rift-drift sequences punctuated with conspicuous unconformities. Madagascar remained an integral part of Indian landmass until Late Cretaceous. Presence of Late Cretaceous basalt, along the eastern margin of Madagascar as well as along south western margin of India (St Mary Island), marks the beginning of its separation from Indian landmass. However, absence of sediments along eastern margin of Madagascar is a conspicuous observation by many earlier workers. The separation of India and Madagascar is rather less understood though Sinha Roy (1982) suggested its southward movement along a transcurrent fault. Drilling results of DSDP site 239 situated on the abysal plane of Mascarene Basin 290km east of Madagascar, yielded the Campanian age for oldest sediments overlying basalt (Quilty, 1992). While the magnetic anomaly 32 corresponding to 72Ma has been identified to the west of site 239. However, magnetic anomalies have not been identified in its conjugate Indian part.

Geophysical constraints around Laxmi Ridge indicate that Moho may be at a depth of 21 km, suggesting its continental affinity (Naini and Talwani, 1982). Siawal et al., (2014) observed presence of SDR's on either sides of the ridge vis-à-vis its conjugate Indian margin. This re-affirms the continental nature. Bhattacharya et al., (1994) have identified magnetic lineation related with sea floor spreading in the Laxmi Basin. The oldest isochron identified A-31 and A28 respectively (corresponds to 73 Ma while the youngest 66Ma) suggesting that the spreading in the basin initiated during Late Cretaceous (Santonian) and continued until the eruption of Deccan Trap that if a hotspot exists within a moderate distance of a ridge, the ridge moves through ridge jumps and remains in a very close vicinity of the hotspot. The same phenomena has been observed in Mascarene Basin and Deccan eruption resulted in southward jump of spreading ridge (between Laxmi and Seychelles) while spreading between Laxmi Ridge and India ceased (Dyment, 1998).

Pre-Breakup Assembly: The outbreak of volcanic activity (Karoo Volcanics) during 198 -173 Ma in South Africa from Mozambique to Natal Sea (Cox, 1989) and Antarctica (Encarnacion et al., 1996)

marks the beginning of the rift which led to separation of eastern and western Gondwanaland. India, along with Madagascar, during this phase is visualized to have constituted a contiguous area and occupied peripheral position within the framework of Eastern Gondwanaland (Fig 2).

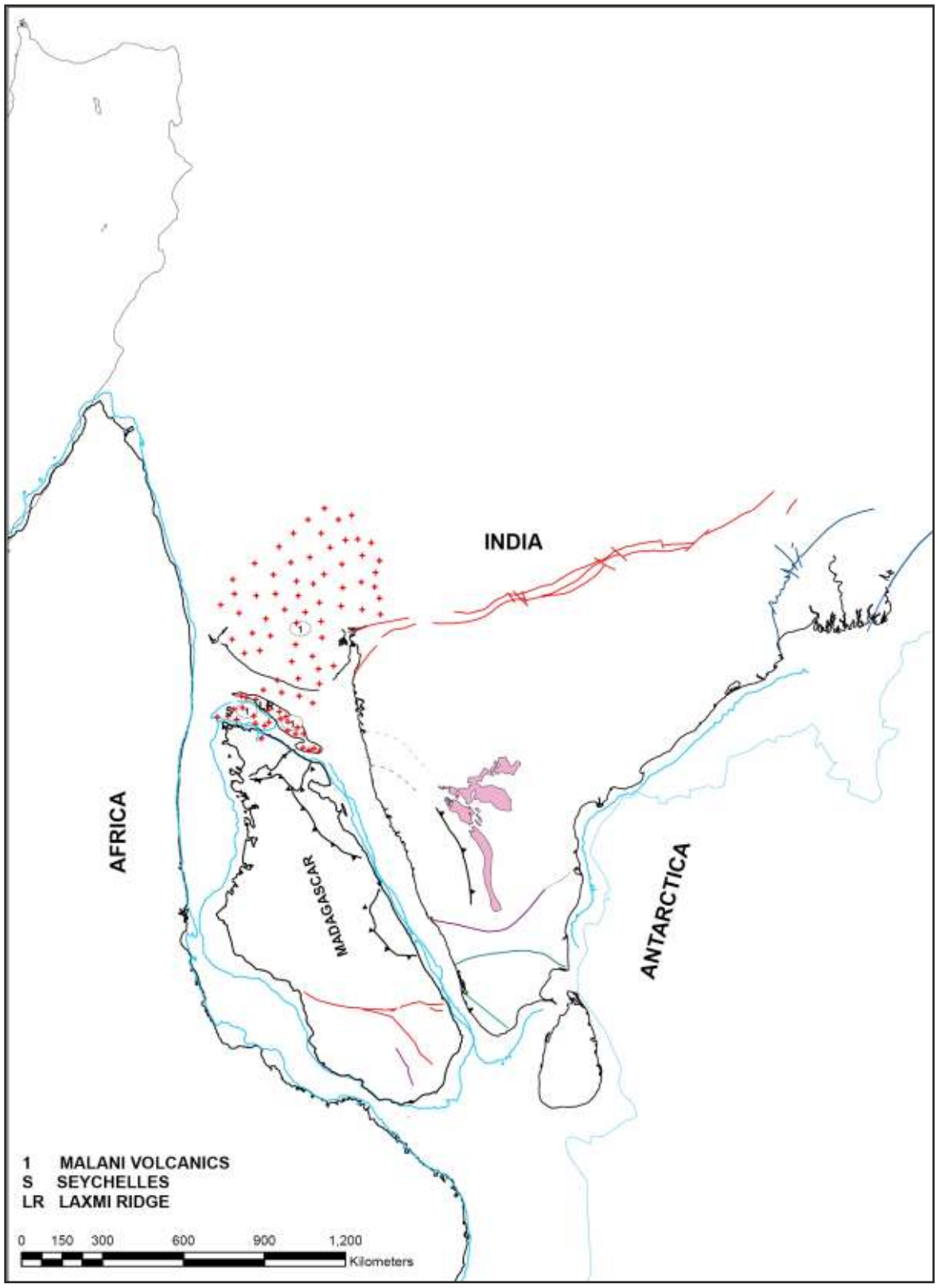


Fig. 2: Pre-Breakup reconstruction of India-Seychelles-Laxmi Ridge-Madagascar-Africa assembly

In the present work a generally accepted reconstructions (Norton, I.O., Sclater, J.G., 1979; Besse et al., 1988; Molnar, P. et al., 1988) have been followed where Madagascar is positioned west of India with Seychelles occupying a position between Madagascar and Kutch-Saurashtra.

Agarwal et al., (1992) and Pandey et al., (1997) have discussed tectonic similarities and palaeotectonic affinities of India and Madagascar. In all earlier reconstructions not much attention is given to Kutch-Saurashtra area and has been shown to be occupying its present position. Present day centering of earthquakes in this area is indicative of its floundering nature. In the present wok, we have favoured an anti-clockwise movement of Saurashtra block to bring it back to its assumed palaeo-position. Saurashtra came to its present day position through a clockwise rotation during post-trappean period as evidenced from the paleomagnetic studies of dykes from Saurashtra peninsula (Sethna, et al., 2001).

Based on the work of Kanenori et al., (1994) and the Rodinia reconstruction of Tosvik et al., (2001), it is envisaged that the MalaniVolcanics covered most part of the Southern Rajasthan, some part of southern Indus, Laxmi Ridge and Seychelles. The successive stages in evolutionary history are discussed sequentially.

Late Triassic: During this period, development of Neo Tethys continued. The Tethys existed along the northern margin of India and extended westward between Arabia and Iran. An arm of this rift extended southward between Africa and Madagascar. It is pertinent to mention that there is no evidence for development of ocean-floor of this age between Africa and Madagascar. However, this crustal extension may have resulted in development of Dhow Fracture Zone and Davie Fracture Zone and facilitated departure of Africa from India.

In the Majunga embayment of Madagascar, outcrops of cross bedded continental sandstone and intercalated clays of Isalo Formation (Kamen-Kaye, 1982) are the representative sedimentary deposits. The subcrop occurrence of Wulgai Formation (shale and limestone of outer shelf) encountered in well Nabisar-A in Pakistan part (South Indus) and the time equivalent Bhuana formation (fluvial to shallow marine) as encountered in a well in Jaisalmer Basin represent the Triassic age in the Indian part. It may, however, be emphasized here that Triassic rocks sofar remain speculative in Kutch Basin. Although, a number of wells have been drilled for hydrocarbon exploration in Kutch Basin and some of them have penetrated the entire sequence up to granitic basement (considered to be of Malani age), but so far no sedimentary strata older than Nirona Formation of Aalenian age has been encountered. The Triassics were not encountered in the drilled wells of Bikaner-Nagaur sub-basin where Palana Formation of Early Paleocene unconformably overlies the Bhadaura Formation of Permian age. To the west of Indian sub-continent, the separation of Iran block from Arabia led to the development of stable shelf over Arabia which continued throughout the Mesozoic era (Beydoun et al., 1992). During Late Triassic, limestone of Elphinstone Group was deposited over areas of Oman and Abu Dhabi with isolated patches of evaporites; clastics (epiric-sea) of Minjur Formation was deposited over the shelf of Kuwait and Arabia (Gealy, 1988).

In the present work, Triassic sediments are shown to be restricted to the north of (proto) Allah Bund Fault. Bhuana Formation of Permo-Triassic age towards north in Rajasthan vis-à-vis with Karoos of Madagascar represent a continuous depositional realm. The Kutch-Saurashtra region was not yet under sedimentation during this period. But a continuous sedimentary realm prevailed from north to south covering north western part of Seychelles and western part of Madagascar which were under continental sedimentation. Nagar Parker hill is a basement high and it acted as a provenance during Jurassic period (Wynne, 1872; Biswas, 1987). Fig.3 shows the relative paleo-geographic positions of India, Laxmi Ridge, Seychelles, Madagascar and Africa and the regional facies distribution reconstructed in the present work.

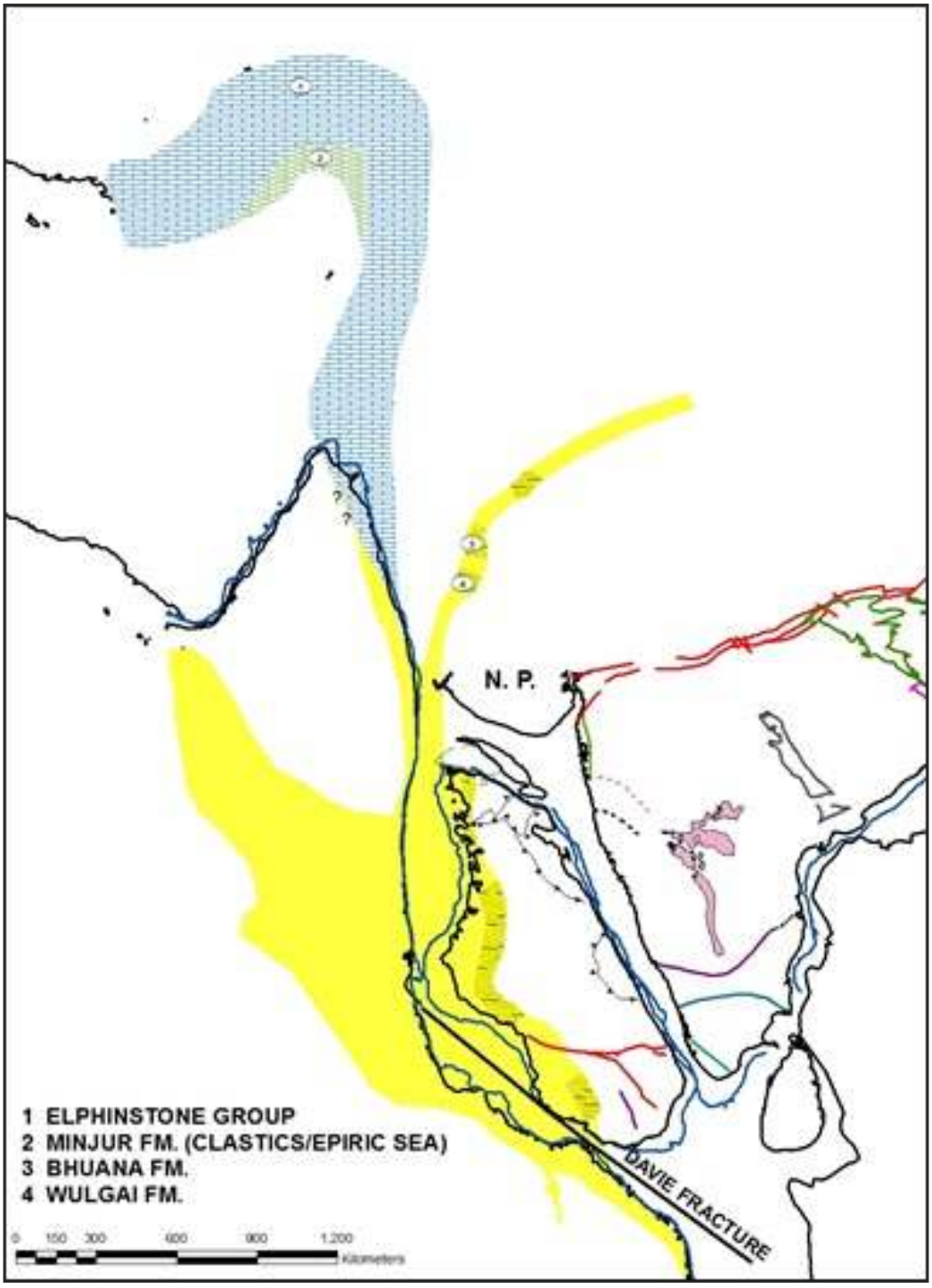


Fig. 3: Reconstruction of Late Triassic

Middle Jurassic (~170Ma): The regional plate tectonic reconstruction of 170 Ma (Fig. 4) represents a period of pre-drift (between Africa & Madagascar) relaxation phase involving crustal stretching. Jaisalmer Formation (clastics intercalated with carbonates / marginal marine to shallow marine) in Jaisalmer Basin and Miajlar sub basin of Rajasthan and Shirinab Formation (clastics / marginal marine) in the Pakistan part (well Nabisar-A) indicates development of Rajasthan shelf. Kutch region received first continental sedimentation in the form of Nirona and Lodai Formations. However, Saurashtra region did not experience any sedimentation during this period.

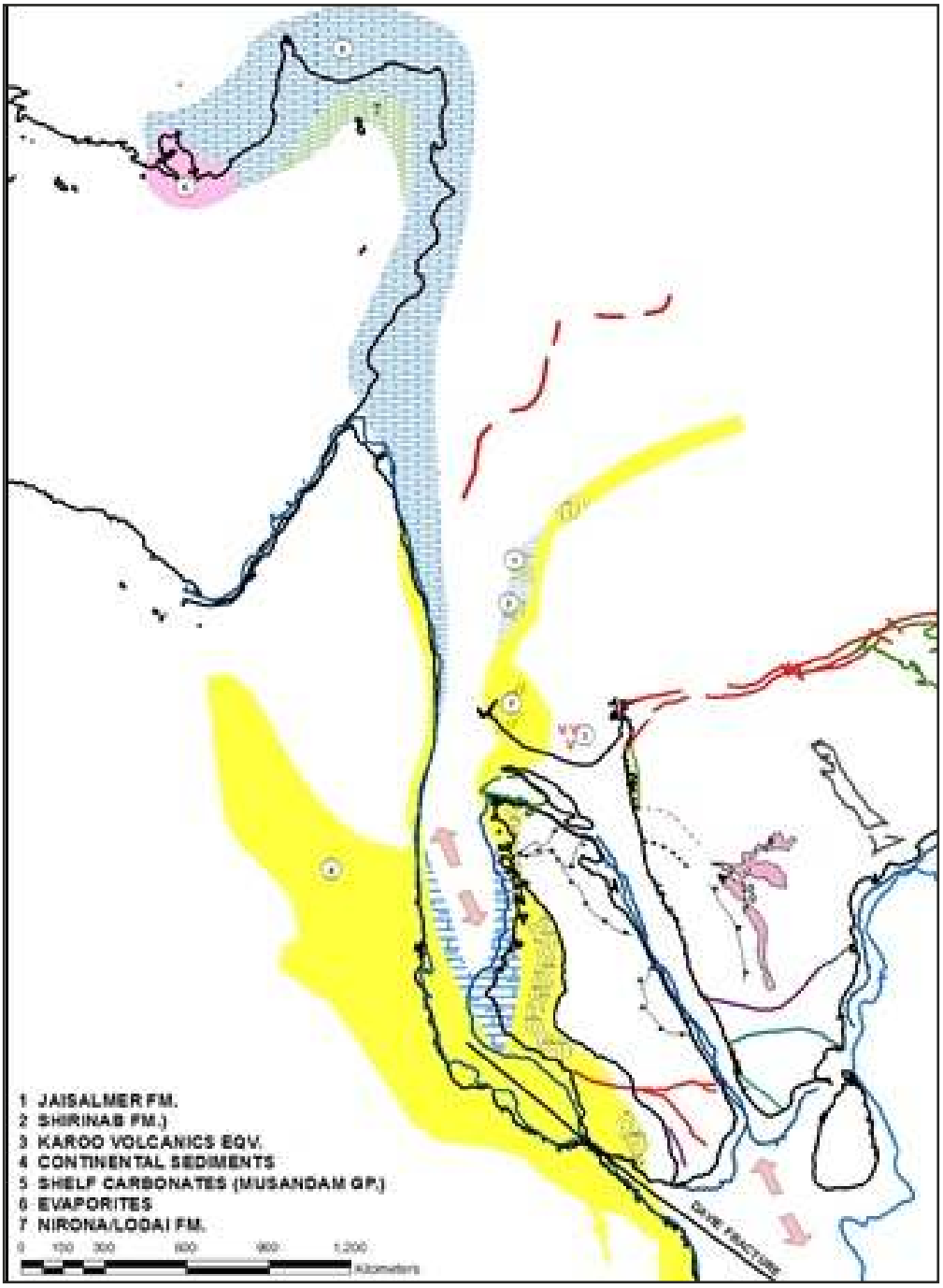


Fig. 4: Reconstruction of Middle Jurassic (170Ma)

The outbreak of volcanic activity during 198-173 Ma in South Africa from Mozambique to Natal sea (Cox, 1989) and Antarctica (Encarnacion et al., 1996) marks the beginning of separation between eastern and western Gondwanaland. The volcanic tuffs encountered in one of the wells of Saurashtra region is considered as the equivalent of Karoo volcanics. The eastern part of Africa continued to receive continental sedimentation as evidenced from the outcrop and subcrop data. Data from the three drilled wells (Reith Bank-A, Owen Bank-A and Seagullshoals-A) of north western Seychelles (Plummer, 1994) and from the drilled wells of Majunga Basin of western Madagascar (Kamen Kaye, 1982) proves presence of shallow marine carbonates of Bajocian age which suggests that the tongue of the Tethys invaded through Africa and Madagascar southwards covering the stretched crust.

Towards west in Arabia & Iran, passive margin conditions continued with deposition of shelf carbonates of Musandam Group along with isolated patches of evaporites (Alsharhan et al., 2000).

Late Jurassic (150Ma): Presence of E-W magnetic anomaly M-22 (150 Ma) in Somali Basin (Segoufin, 1978 & Simson et al**.**, 1979) and Natal sea marks the separation of Africa from Madagascar and northerly drift of Africa along Davis Fracture Zone (Fig. 5) and consequently Somali Basin was opened. While in response to the development of Natal Basin between Africa, India and Antarctica, Cauvery Basin was initiated and Gulf of Mannar came into existence (Fig. 5) Thicker syn-rift sediments in Cauvery basin towards south also suggests opening of the basin from south (Rangaraju et al**.**, 1993). In the Gulf of Mannar, continental

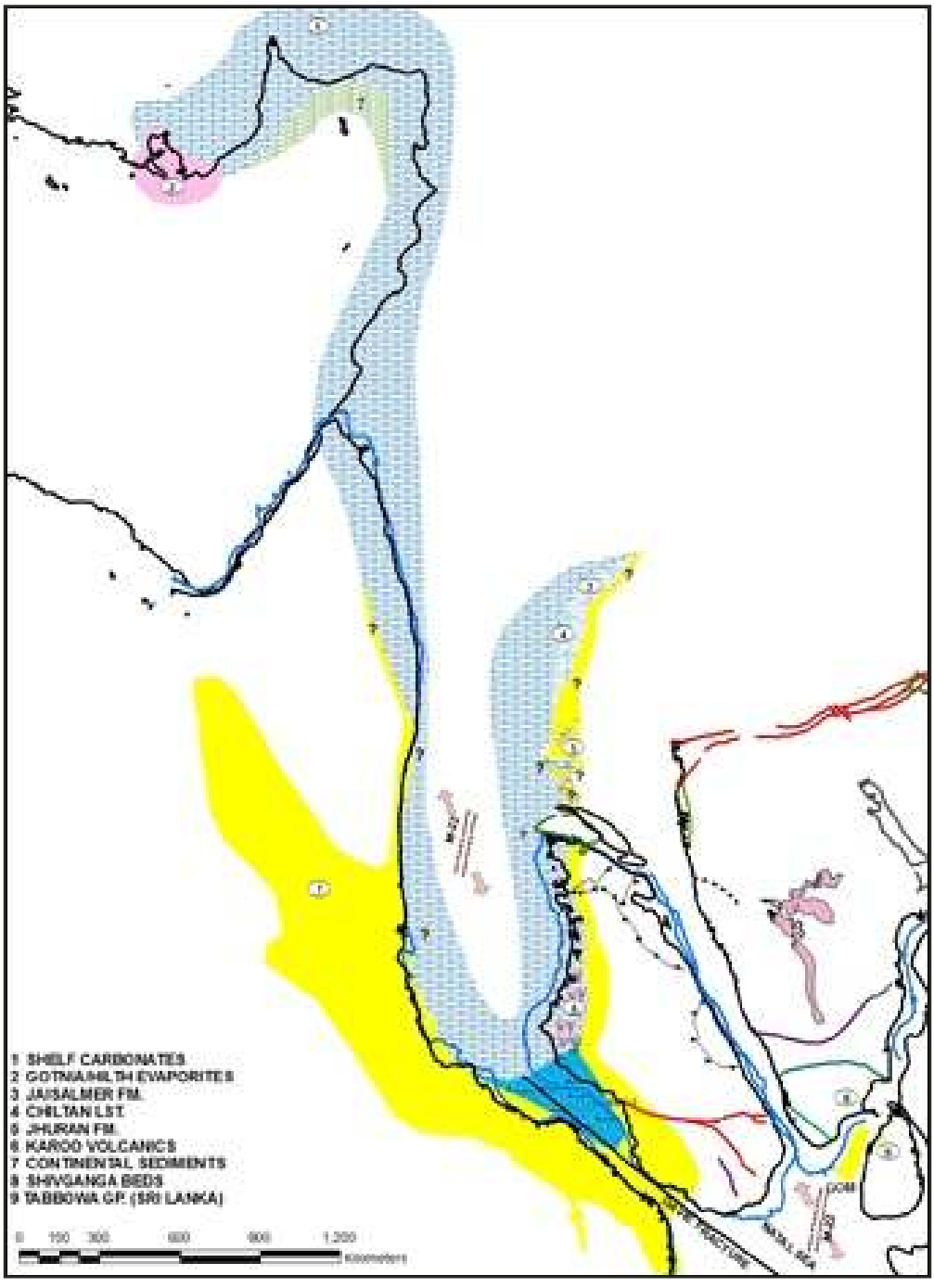


Fig. 5: Reconstruction of Late Jurassic (150 Ma)

clastics got deposited. Tabbowa Group of Sri Lanka is their counterpart. During this period Mozambique– Madagascar 'Geosyncline' (Kamen-Kaye, 1982 & 1983) is visualized to have formed as contiguous part of the western Indian shelf (Rajasthan & Kutch) with an uniform depositional realm.

Jhuran Formation (greenish grey sandstone with occasional Trigonia beds, grey shale and calcareous sandstone) of Argovian – Neocomian age was deposited in the Kutch basin. However, in the Kutch offshore part, only in the shallow water Kutch region, carbonates were encountered in the drilled wells. Its lower boundary with Jhumara Formation is marked by oolitic band (Dhosaoolite) which is conglomeratic in nature. Oolitic Limestone at the top of Jaisalmer Formation is suggestive of comparable conditions of deposition. Chiltan Limestone was deposited around well Nabisar-A (Pakistan). Presence of marine Jurassic rocks (carbonates) in the NW sector of Seychelles and in NE sector of the Majunga embayment (northern Madagascar) suggests it to be a contiguous part of western Indian sedimentary domain.

Late Cretaceous (~90Ma): The tectonic reconstruction during Turonian (~90 Ma) representswide spread occurrence of basalts (Fig. 6) of about 90 Ma age along the eastern margin of Madagascar (Torsvik et

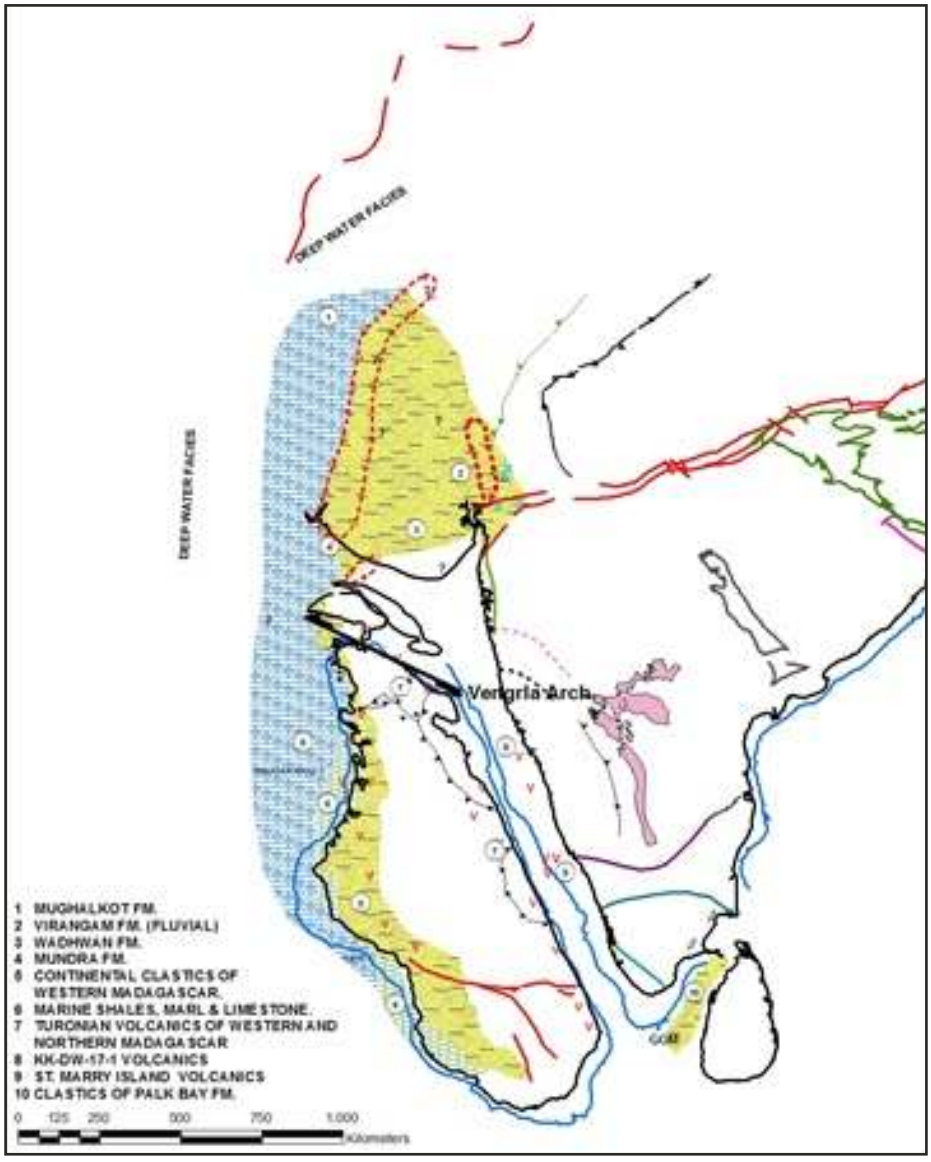


Fig. 6: Reconstruction of Late Cretaceous (90 Ma)

al., 1998), about 85.5 Ma dykes from St. Mary island off India and some dykes in Kerala mark separation of India and Madagascar. Further, older basalt encountered in one of the deep water well of Kerala-Konkan sector (K-Ar age of whole rock basalt at 2345.09 m. of 102 +/- 2.6 ma) may be of similar affinity.

Plummer et al., (1993) proposed a 'transform rifting' of Madagascar and Seychelles / India. Within the Late Cretaceous succession in deep water between the Seychelles and Platte banks wrench faults were identified which originated during sinistral translation of the basement affecting the rift between Madagascar and Seychelles / India (Plummer et al., 1993). Consideration of left lateral movement along the fault is important as it suggests opening of Mesozoic Basin of Kerala–Konkan from south and narrowing towards north. Moreover, this translation is visualized to have created severe compression to the east with reactivation of the Vengurla arch forming the fore ground for southward restriction of Deccan volcanics. In northwestern part of India, fluvial sedimentation continued in the form of Bhuj Formation in Kutch and Wadhwan &Viramgam formations eastward. In the Pakistan part, shallow marine limestones of Mughalkot Formation were recorded from the wells Dabbocreek-A and Karachi-A. Towards south, in north western Seychelles, marginal marine clastics were encountered in the drilled wells. In western Madagascar, two drilled wells (Mariarano-A & SER-A) recorded marine clastics along with marls and limestone. In the Gulf of Mannar, Palk Bay Formation got deposited.

Late Cretaceous (70Ma): Presence of NE-SW structural elements in Kerala-Konkan area (Pangtey, et al., 1996) are suggestive of an oblique opening of the basin from south with relative northward movement of India. This view is supported by restricted Late Cretaceous sediments (Cochin Formation) only in the southern part of the basin. An erosional unconformity interpreted based on occurrence of reworked Maastrichtian foraminiferal record in one of the drilled wells in Kerala-Konkan sector (Mathur et al., 1993) suggests an uplift phase during this period corresponds to uplift in the areas of Seychelles due to transcurrent movement between Madagascar and Seychelles, during this period (Plummer, 1994). Sinha-Roy (1982) also suggested that eastern edge of Madagascar had originated as a transform margin.

During this period volcanic activity in the form of Mundwara complex took place (Fig.7). Basalt and gabbro of this complex yielded an age of 70 Ma (Rathore et aI., 1996). In this work, it is considered that sedimentary input in Kutch basin has either become negligible or seized during this period. Absence of younger than Santonian age for Bhuj sandstone supports this assumption. The deposition of Kori Formation (limestone) of Coniacian-Maastrichtian age supports reduction of clastic input. The magnetic anomaly 28-33 corresponding to about 74 to 63 Ma (Bhattacharya et al., 1994) suggests the initiation of rift (Laxmi Basin) between Saurashtra and Laxmi ridge during this period (Fig. 7). Saurashtra has remained connected with mainland and Gulf of Cambay was yet to open. Possibility of a sea entry upto the Narmada basin through this rift cannot be ruled out. This assumption brings out an exploration avenue in the form of envisaged Late Cretaceous sediments in the Tapti Daman area.

Deccan Volcanism (65Ma): This was the period of wide spread Deccan volcanic activity (Fig. 8). The age of initiation of Deccan volcanics by the reunion hotspot is placed at 65-67 my (Courtillot et aI., 1988). Presence of basalts of similar ages over the areas of Seychelles (Devey et al., 1992), presently located on the other side of Carlsberg ridge, suggests it to be part of composite assembly of western India at least until Deccan volcanism.

Until Deccan activity, sea floor spreading was continued in Laxmi and Mascarene basins as is evident from the record of magnetic anomaly A-28 in these areas (Talwani and Reif., 1998; Bhattacharya et al., 1994). However, with the wide spread plume related volcanic activity the spreading

in these areas got aborted and the ridge jumped southward between Seychelles on one side with Laxmi ridge and India on the other side. As a result Seychelles micro-continent rifted and drifted away from India. Simultaneously this part of India witnessed two major tectonic changes, i.e. opening of Mumbai region due to departure of Seychelles & rifting and opening of Cambay basin.

The presence of Deccan volcanics over Seychelles is important in terms of establishing paleogeograophic connections. Noticeably it is not known on the other side of Allah Bund Fault. In the well Nabisar-A (Pakistan), Upper Cretaceous strata are missing. The observation of Wynne (1872) that Trap deposition took place over irregular 'Jurassic' surface becomes relevant.

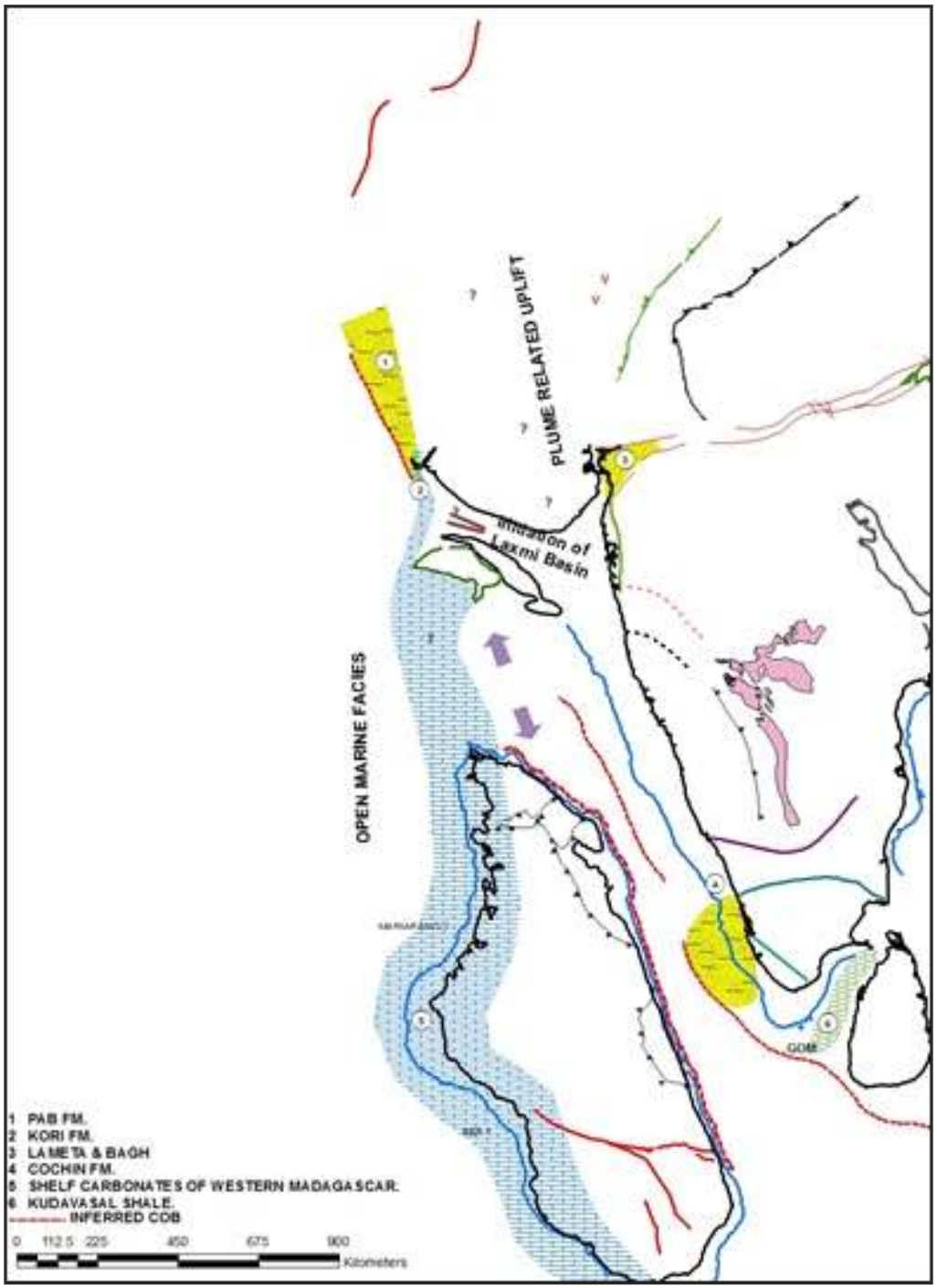


Fig. 7: Reconstruction of Late Cretaceous (70 Ma)

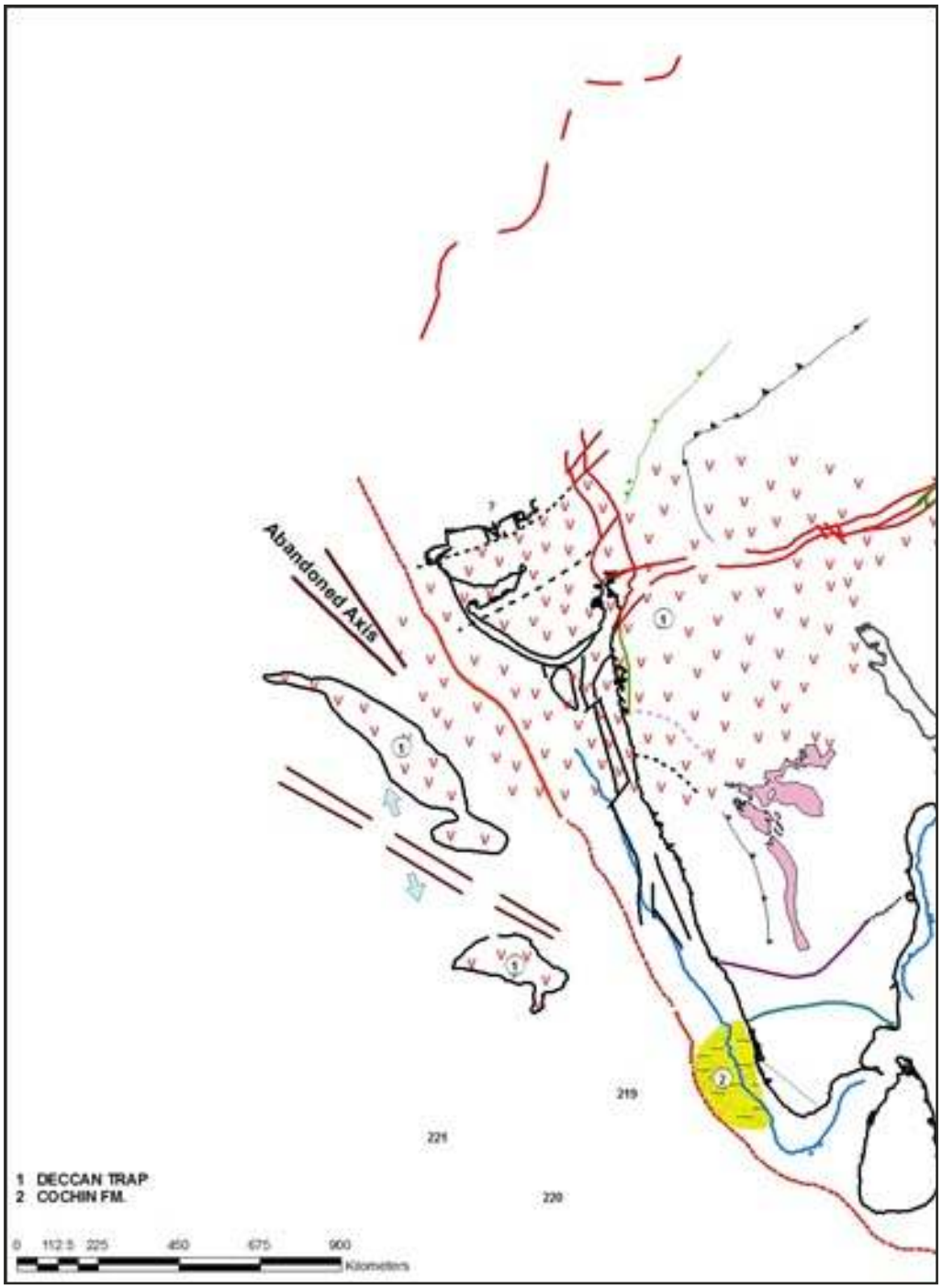


Fig. 8: Reconstruction of 65 Ma (Deccan Volcanism)

Sethna et al., (2001) after studying a curved dyke near Amreli by detailed paleomagnetic investigation suggested a clockwise rotation of Saurashtra block by about 35°. Krishnan (1960) and Zutshi et al., (1998) had also postulated that paleoposition of Saurashtra was to the south of its present day position and it occupied the present day Surat depression. Hence, in the present work it is envisaged that with the opening of Cambay basin, Saurashtra moved in a clockwise direction and acute compression was created in the regions of Kutch as Nagar Parkar high was acting as buttress and prevented stress transfer to further north.

Post Deccan Volcanism: Post eruptive uplift of continental areas continued during this period as

Indian Plate, during its northward drift, moved over reunion hotspot. This has also resulted in development of Chagos-Laccadive Ridge. In the areas of Kutch main land, Matanomadh Formation was deposited under terrestrial conditions while in the basinal part, Nakhtarna Formation (limestone with alternations of silty claystone) was deposited. Clastics of Panna Formation got deposited in the basinal areas of Mumbai offshore Basin, while isolated highs (like Mumbai High) escaped sedimentation (Fig-9).

In Cambay Rift, Olpad was getting deposited due to erosion of the uplifted western rift shoulder (Radhanpur Arch) and Cambay shales were deposited in a lagoonal environment. The present location of Deccan plateau at an elevation of over 1500m is primarily the result of post volcanism uplift along the plume flanks (Campbell and Griffith,1990). As Seychelles drifted southward, a continuous marine system was established and limestone of Devgarh Formation was deposited while in the Saurashtra offshore part alternating sequence of limestone and shale of Jafarabad Formation was deposited. Further west, Paleocene limestone is encountered in GSDW-5-A suggesting Laxmi Ridge as a positive feature during this period.

In Kerala-Konkan part of western margin, Kasargod Formation was deposited with some uplift, as is

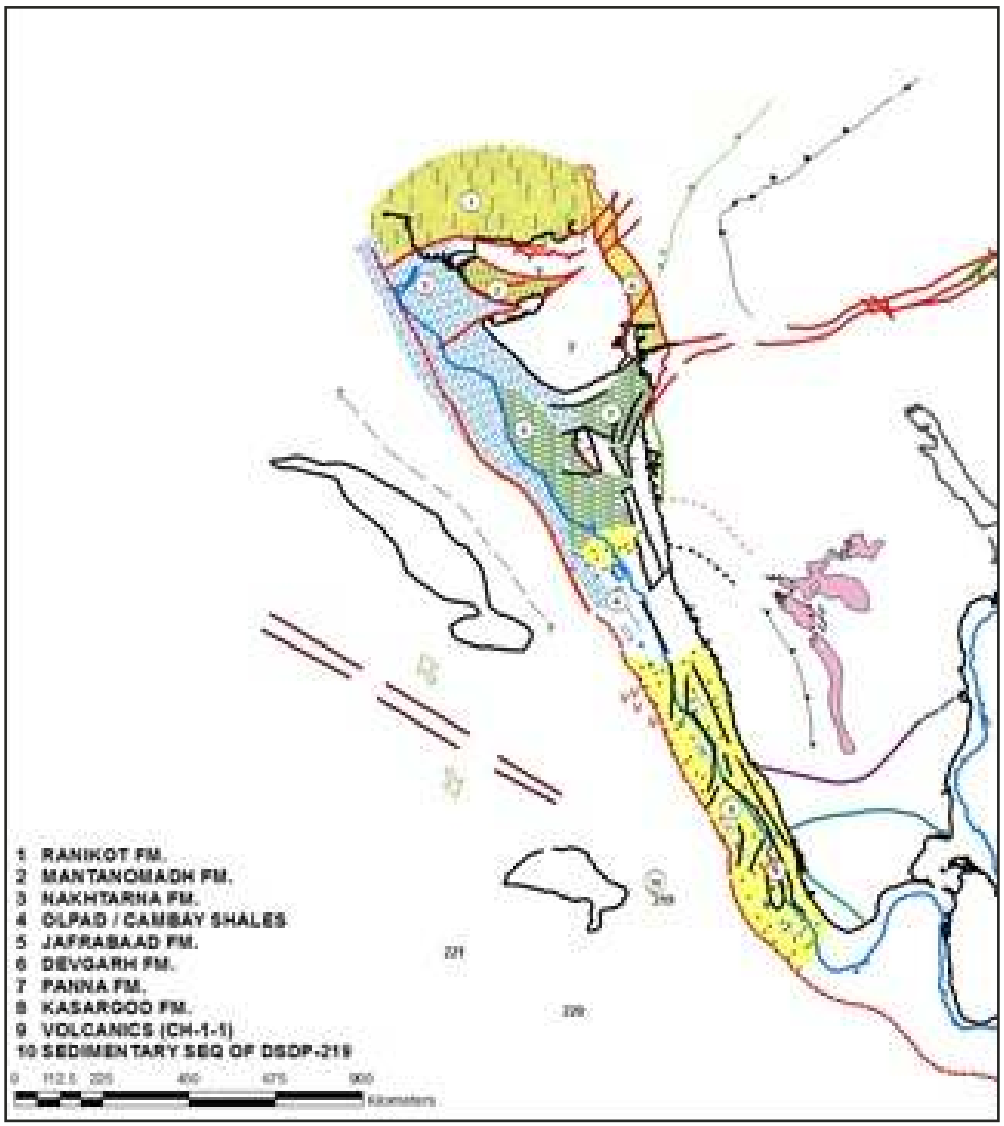


Fig. 9: Reconstruction of 60 Ma (Post Deccan Volcanism)

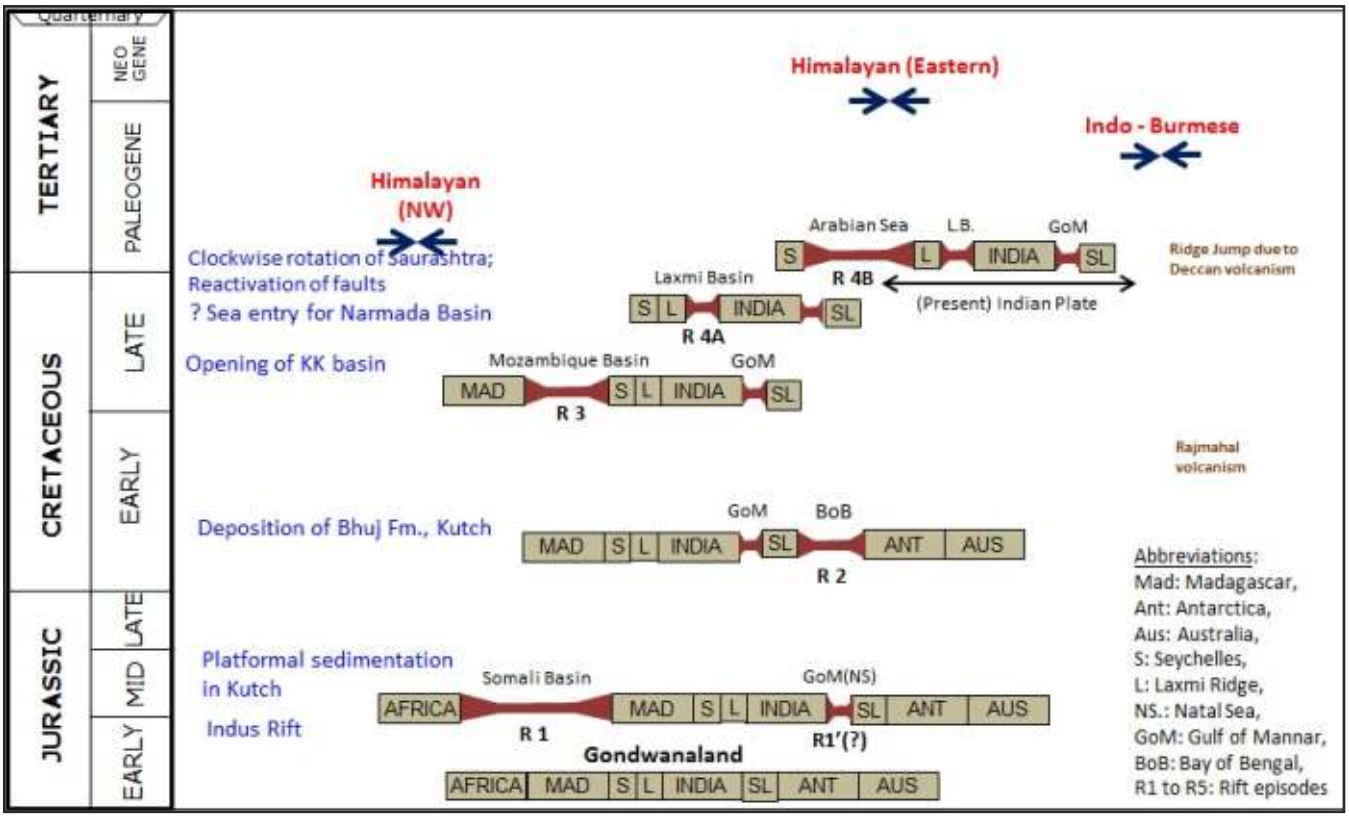
suggested by bio-stratigraphic record (Mathur et el, 1993). However, it witnessed intrusions of basic rocks as is present in one of the drilled wells. These intrusives are dated to be of 54 Ma by Mathur et al., (1993). At site 219, Late Paleocene represent near shore shallow water sedimentation which may have provenance from Seychelles as no other land mass was available nearby to contribute.

SUMMARY

Present work vividly brings out multi-phase evolutionary history for the WCMI through plate tectonic reconstructions at eight major stratigraphic levels. The tectono-magmatic events involved in evolutionary history of WCMI are summarized in Table-2. The salient points are summarized below:

1. Evolution of WCMI began with the East and West Gondwanaland separation and development of Somali Basin. During this period Kutch area remained contiguous with Indus shelf of Pakistan-Rajasthan and Madagascar.
2. Madagascar separated from India during Late Cretaceous. However Seychelles remained attached with India. Hence development of Mesozoic basin (Kerala Basin) remained restricted to the southern part of WCMI. The absence of Late Jurassic sediments in Kerala Basin, though present over Srilanka (Tabbowa Group) and Cauvery Basin (Sivaganga beds), is suggestive of late opening for Kerala Basin.
3. During Late Cretaceous period (A-28 to A-33), an arm of the rift extended between Seychelles and Indian landmass. It remained active until outburst of Deccan. However its southeastward extent of this arm remained speculative.
4. Deccan lava outpour was accompanied with complete plate reorganization as the spreading ridge jumped southward between Seychelles and Laxmi ridge with the formation of proto Carlsberg Ridge.
5. Out pour of lava also resulted in detachment of Saurashtra from mainland with initiation of

Table 2: Tectonic evolution summary of WCMI



Cambay Rift. With this Saurashtra moved northwestward with clockwise rotation resulting in acute compression in the areas of Kutch. This also explains present compressive environment in Kutch area.

6. Later period witnessed evolution of WCMI under passive margin condition. However it was associated with formation of a trail of magmatic events owing to plume interaction with this part of crust. Subsequently uplift of Western Ghats (Radhakrishna, 1991) along with development of Indus fan system has resulted in present set up of WCMI.

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