

A study on the evolution of Indian Ocean Triple Junction and the process of deformation in the Central Indian Basin.

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Abstract - It is generally presumed that the intraplate deformation in the Central Indian Basin (CIB) is a direct consequence of spreading across the South East Indian Ridge and the resistance to shortening at the continental collision between India and Asia. The deformation effects, viz., folded and faulted oceanic basement/sediments, high localized heat flow, intraplate seismicity are well reported over a narrow band in the equatorial region of the basin (5° N to 8° S, 80° E to 90° E), probably, for the reason that this part is directly south of the 'hard' continent-to-continent collision that is taking place since early Miocene at the northern edge of the Indian plate. Nevertheless, some observed ambiguities, particularly the wide spread seismicity reported between Indian peninsula and Australia, the episodic character suggested for the deformation and the fact that the folded/faulted deformation fabric is reported over a wide area covering the northern Bengal fan, the Nicobar fan and the Wharton basin, suggest that the stress acting on the Indian plate cannot be explained by symmetrical spreading across the South East Indian Ridge (SEIR) alone. A simple study based on the evolution of Indian Ocean Triple Junction (IOTJ) indicates that the differential spreading across the Central Indian, South West and South East Indian Ridges plays a vital role in the deformation process.

INTRODUCTION

The equatorial region of the Central Indian Basin (CIB, 5° N to 8° S, 80° E to 90° E, Fig.1) is undergoing tectonic deformation since the late Miocene, as a deviation from classical Plate Tectonic Theory, according to which such a deformation should generally occur at the convergent or divergent boundaries of plate margins and not in the interior of a plate. An extensive study has been made during the last two decades over this intraplate deformation and the results agree in general that the Indian Plate is currently under a N-S compression as a result of two mutually opposing forces, the continued spreading across the SE Indian Ridge (SEIR) and the resistance to the shortening across the Himalayas at the Northern end of the plate (COCHRAN *et al.*, 1987,1988).

Seismic reflection data (Fig.2 for example) indicate folded and faulted oceanic basement and the overlying sediments in the deformation zone, reported initially by EITTREIM and EWING (1972) and subsequently by several others (WEISSEL *et al.*, 1980; GELLER *et al.*, 1983; LEVCHENKO, 1989; CURRAY and MUNASINGHE, 1989; BULL and SCRUTTON, 1990). Two sets of these folds are generally observed; long wave length (100-300Kms), large amplitude (1-2Kms) folds in the basement and the sediments and short wave length (25Kms) generally occurring over the crest of the large amplitude anticlines. The short wave length undulations are generally bounded by high angle faults (EITTREIM and EWING, 1972) at an azimuth of nearly 100° (WEISSEL *et al.*, 1980) giving an appearance of folded and faulted blocks separated by undeformed strata. Recent studies made by BULL and SCRUTTON (1990) suggest that these high angle reverse faults extend to the uppermost mantle and that they are actually the reactivated normal faults formed at the spreading axis of the SE Indian ridge at which this lithosphere was originated around 60- 90Ma.

High seismicity (STOVER, 1966; SYKES, 1970; STEIN and OKAL,1978) with compressional and strike slip earth quakes (BERGMAN and SOLMON,1985) and high localised heat flow(WEISSEL *et al.*,1980 and GELLER *et al.*,1983) are associated with this deformation zone.

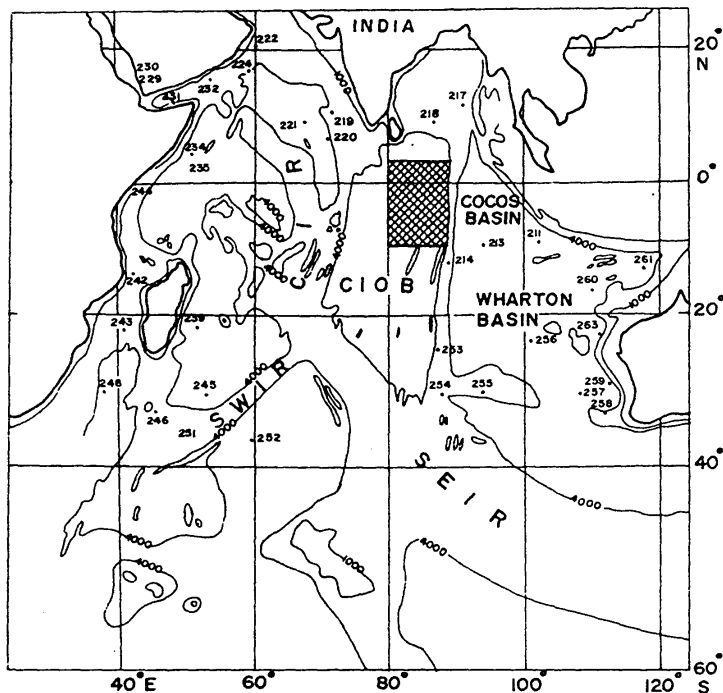


Fig. 1. Location map of the Central Indian Ocean Basin (CIOB). Area of active deformation shown in hatches. SWIR = South West Indian Ridge, SEIR = South East Indian Ridge, CIR = Central Indian Ridge (Modified from Schlich, 1982)

Recent studies on leg 116 of the Ocean Drilling Program (COCHRAN *et al.*,1987;1988) indicate that the sediments in the deformed block mainly comprise of a sequence of turbidites originating mainly from the apex of Bengal Fan in the North and also from the eastern continental margin of India. Bio-stratigraphic studies of the sediments reveal an early Miocene (17 Ma age) for the onset of the deformation. In a recent study, CURRAY and MUNASINGHE (1989) reported that the onset of deformation can be correlated over a wide area in the Bengal Fan, stretching as far as Ceylon on the west and atleast upto 8 deg north in the Northern Bengal Fan.

Though studies during the past two decades established the timing of the intraplate deformation in the equatorial region with more certainty, there is still a considerable disagreement about its spatial extent and the nature and causes of this peculiar tectonics. Most of the authors are of the view that the axis of major compression is in a N-S direction and that the deformation is presently confined to a narrow zone, between 5° North to 8° South bounded by the Chagos Laccadiv Ridge on the west and 90 East Ridge in the east. However, observations related to the intraplate seismicity provided a wide range of explanations. STOVER (1966) and SYKES (1970) delineated a NW-SE trending zone of epicentres extending for several hundred kilometers from

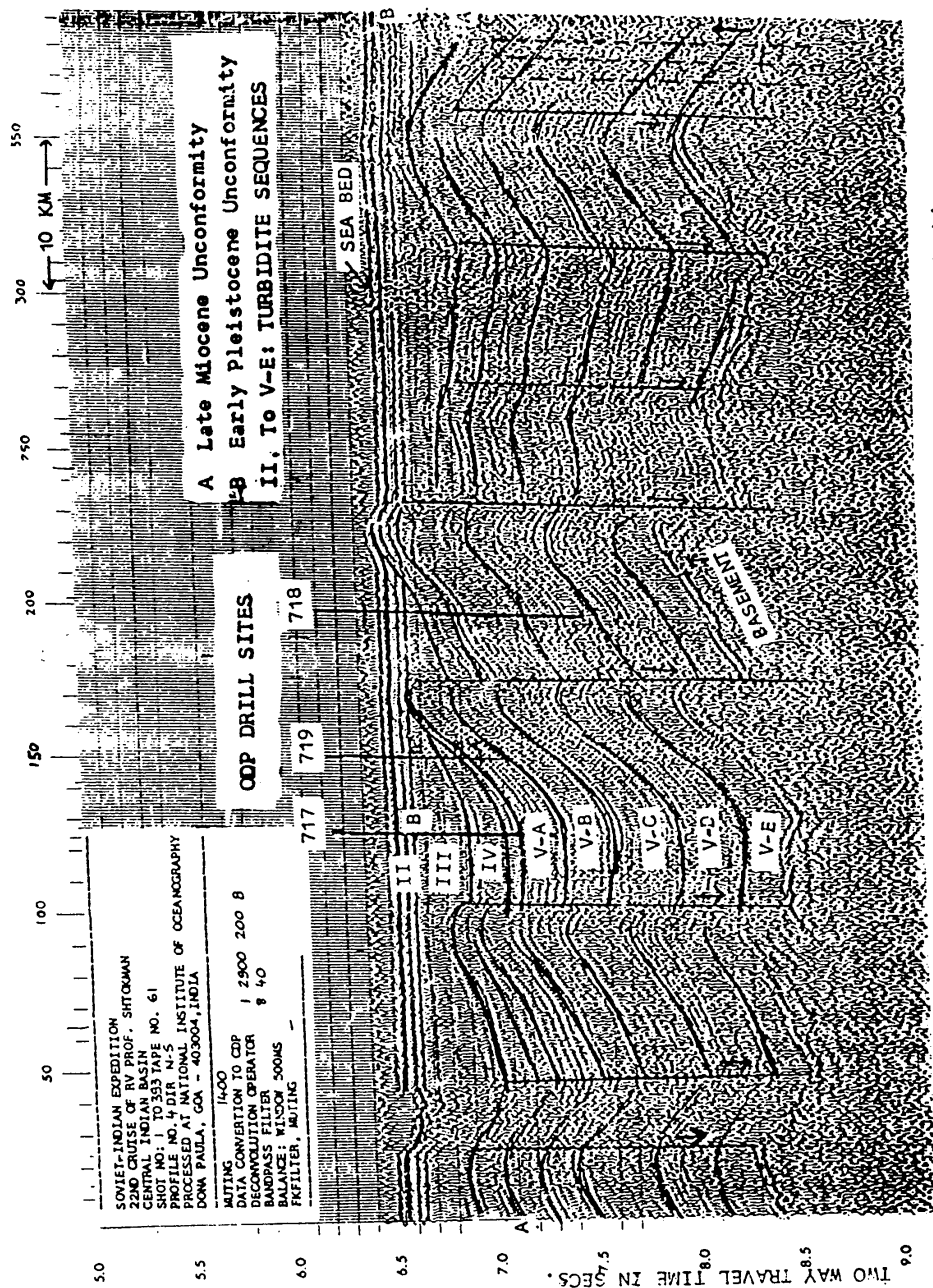


Fig. 2. Single channel airgun seismic reflection record over the deformation zone in the equatorial Indian Ocean (around 1° S and 81.5° E), Profile direction N-S.

Ceylon to the Cocos basin (Fig.1). SYKES (1970) is of the view that this zone might be extending from the Indian peninsula to the Australian continent and postulated a nascent subduction zone in this direction. STEIN and OKAL (1978) reported that the seismicity is aligned along the northern segment (5° N to 10° S) of the 90 East Ridge, the ridge acting as a diffuse boundary separating the Indian Plate from the Australian Plate on the east.

While NEPROCHNOV *et al.*, (1988) and LEVCHENKO (1989) proposed a NE-SW diffuse zone of high seismicity in the equatorial region with a predominantly N-S compression, (WEINS *et al.*, 1985) suggest a more complex zone of deformation with extension near the Chagos Laccadive Ridge, compression in the Central Indian Basin and strike slip motion along the 90 East Ridge. WEISSEL *et al.*, (1980) observed that the basement undulations in the equatorial Indian Ocean change from ENE - WSW near the 90 East Ridge, to nearly EW or WNW-ESE in the southern part. They are of the view that the deformation might be prevailing in the other parts of the Indian Plate which might not be readily recognised due to the absence of thick strata of sediments such as the Fan Turbidites which are ideal reflectors for delineating the deformation in the underlying basement. LEVCHENKO (1989) proposes an episodic character to the intraplate deformation in the Indian Ocean, representing short pulses of seismic activity separated by stable conditions.

It appears from the above observations that though the deformation in the equatorial Indian Ocean may be a direct consequence of the collision of Indian and Asian Plates in the North, some ambiguities mentioned above suggest that the forces acting on the plate from south might be from different source than the symmetrically spreading South East Indian Ridge. It is in this connection we tried to briefly look into the evolution of the Indian Ocean Triple Junction (IOTJ) so as to study the effect of spreading across the three mid oceanic ridges on the process of deformation.

Indian Ocean Triple Junction (IOTJ)

The IOTJ, presently located at $25^{\circ} 42'$ S and 70° E is the meeting point of the three mid-oceanic ridges, the Central Indian Ridge (CIR), the South East Indian Ridge (SEIR) and the South West Indian Ridge (SWIR) that separate the three major plates, the African, Indian and Antarctic plates. The spreading half rate across the CIR is nearly 25 mm/year in $N60^{\circ}$ E and 30 mm/year in a $N47^{\circ}$ E across SEIR while across SWIR it is 7.5 mm/year in $N3^{\circ}$ W direction. While bathymetry and magnetic data suggest a symmetrical spreading with a well defined median valley across SEIR and CIR, that across SWIR indicate slow, oblique and even episodic spreading with a high axial deep that manifests only during active pulses of motion between African and Antarctic plates (TAPSCOTT *et al.*, 1980). The tectonic setting at IOTJ is in fact similar to the Galapagos Triple Junction in the equatorial Pacific where the Pacific, Cocos and Nazca plates are separated by two fast spreading and a relatively slow spreading centre, the Galapagos spreading centre (SEARLE and FRANCHETEAU, 1986).

The evolution of IOTJ is closely related to the break up of Gondwana land, particularly since the Palaeocene when the IOTJ was clearly established (Fig.3). The IOTJ has moved for nearly 16° NE to East over a period of 65Ma at an average rate of 3.8 cm/year. Calculations made for different stages indicate (Table 1A, Fig.4A) significant variation both in the direction and rate of migration of IOTJ since Palaeocene (65Ma), with a maximum rate of nearly 6.75 cms/year between the period from Palaeocene to early Eocene (53Ma) and a minimum rate of 1.8 cms/year since early Oligocene (38 Ma) to the present. There is a marked change in the direction of migration from ENE to east since early Oligocene (Fig 4A). On a smaller scale for the last eight million years, corresponding to late Miocene, with which we are more interested in the present context, the rate of eastward migration is faster for the period between 8 to 6 Ma (3.78 cms/year, Fig 4B, Table 1B), with the average rate of 2.8 cms/year, nearly equal to

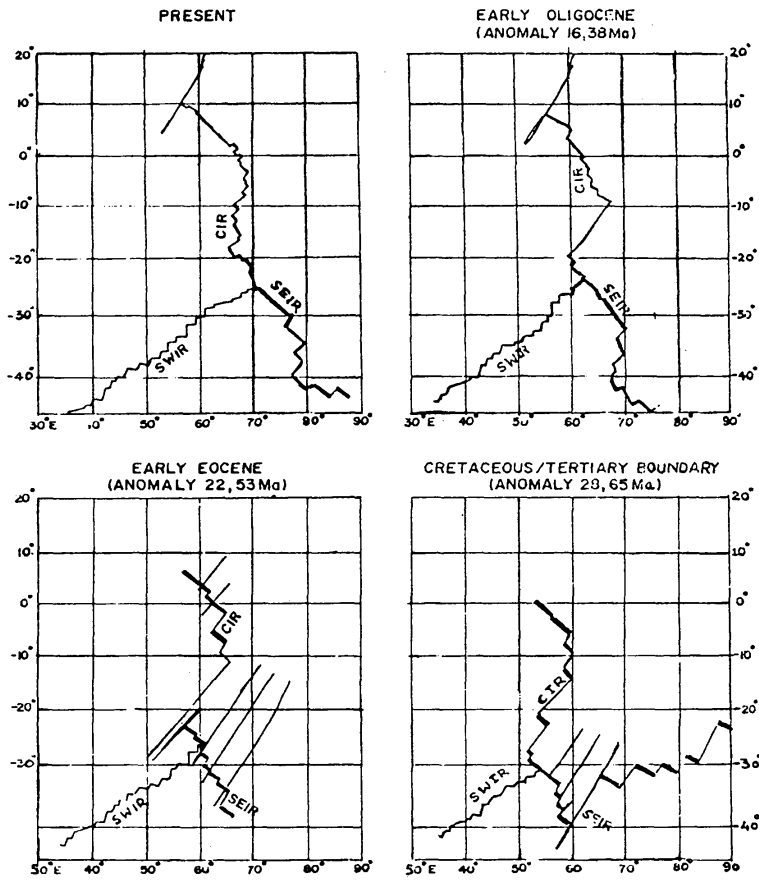


Fig. 3. Evolution of Indian Ocean Triple Junction (IOT) since Palaeocene (Modified from Norton and Sclater, 1979)

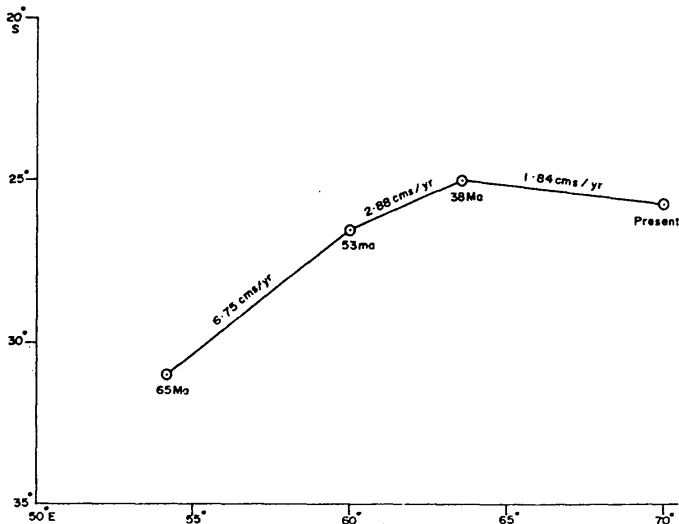


Fig. 4a. Variation in the direction and rate of migration of IOT since 65Ma to the present (Calculations made from Norton and Sclater, 1979)

the spreading rates across SEIR and CIR. Most of the earlier studies (TAPSCOTT *et al.*, 1980, SCLATER *et al.*, 1981, PATRIAT and PARSON, 1989) reported lengthening of SWIR in the evolution of IOTJ, though there are different view regarding the shortening of SEIR in this process. The net result of this lengthening SWIR with its slow and intermittant spreading (TAPSCOTT *et al.* 1980), with two fast spreading centres (SEIR and CIR) on either side, is a triangle of oceanic crust migrating east ward with the IOTJ at its apex, a situation almost similar to the extensively studied Galapagos spreading centre in the equitorial Pacific (HEY *et al.*, 1986). Using GLORIA long range side scan sonar and SEABEAM data, SEARLE and FRANCHETEAU, (1986) suggest on the basis of the Propagating Rift Hypothesis of HEY (1977), that the Galapagos spreading centre

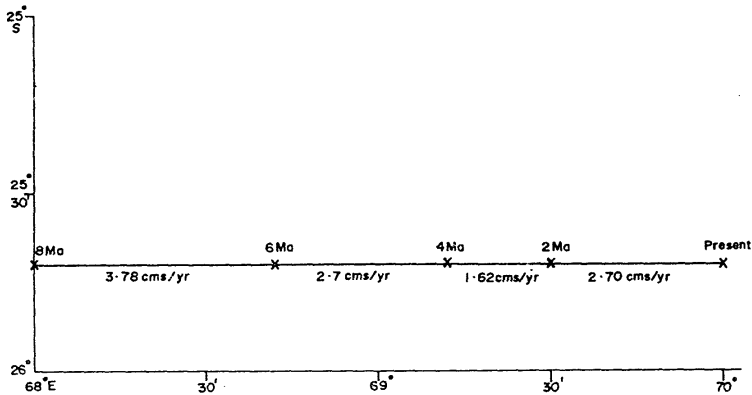


Fig. 4b. Variation in the direction and rate of eastward migration of IOTJ since late Miocene (Calculations made from Tapscoett *et al.*, 1980)

Table 1. Evolution of the Indian Ocean Triple Junction (IOTJ)

A) Palaeocene to the present (Calculations based on the paper by NORTON and SCLATER, 1979)

Period	Position of IOTJ Lat	Long	Age and (anomaly No.)	Spreading rate Cms/year
Palaeocene	31° S	54° 6' E	65 Ma (28)	---
Early Eocene	26.5° S	60° E	53 Ma (22)	6.75
Early Oligocene	25° S	63.52° E	38 Ma (16)	2.88
Present	25.7° S	70° E		1.84
			AVERAGE	3.80

B) Late Miocene to the present (Calculations based on the paper by TAPSCOTT *et al.*, 1980)

Age	Position of IOTJ *Lat (°)	Long (°)	Spreading rate Cms/year
8Ma	25.7 S	68 E	---
6Ma	25.7 S	68.7 E	3.78
4Ma	25.7 S	69.02 E	2.70
2Ma	25.7 S	70 E	1.62
			AVERAGE
			2.70

* Position Calculations are not accurate enough to determine very small variations in latitude of the order of less than 2 min (0.03 deg.)

(equivalent to SWIR) is propagating westward in an episodic pattern, with intermittent rapid propagation followed by phases of non-propagation. The IOTJ is a relatively less studied area. Recent studies made by PATRIAT and COURTILOT (1984) have shown a relationship between the variability in the spreading rates across the three ridges of the IOTJ and the migration of the Triple Junction. PATRIAT and PARSON (1989) on the basis of SEABEAM surveys indicate a discontinuous propagation of SWIR. The simple study made above on the evolutionary stages of the IOTJ clearly shows that the differential spreading across the three midocean ridges has a vital role in the tectonics of the CIB. The study also shows a distinct reduction in the northward migration of IOTJ since the post collision period and also a faster eastward migration from 8 to 6 Ma corresponding to the onset of deformation.

DISCUSSION

The intraplate deformation in the central Indian basin (CIB) is more clearly manifested within a narrow band in the equatorial region (5° N to 8° S) between Chagos Laccadiv Ridge and 90 East Ridge. This may be mainly due to the fact that the maximum resistance to the seafloor spreading is encountered north of this region at the 'hard' continent-to-continent collision between Indian and Asian plates since late Miocene, in contrast to the rest of the north east Indian Ocean where subduction beneath the Sunda trench is the predominant factor. The thick stratified turbidites of the Bengal Fan in this region are good reflectors of this deformation observed on the seismic reflection records at a normal vertical exaggeration of 25:1. However the wide spread seismicity extending from Indian Peninsula to Australia (SYKES, 1970), the large aerial extent of the deformation fabric covering the northern Bengal Fan (CURRAY and MUNASINGHE, 1989) Nicobar Fan (BOWLES *et al.*, 1978), and the Wharton Basin (WEISSEL *et al.*, 1980) and its episodic nature (LEVCHENKO, 1989) suggest that the stress acting on the Indian plate can be better explained by variable spreading across the SEIR, CIR and SWIR ridges. Though the oceanic crust affected by the deformation was formed at the SEIR around 60 to 90 Ma, the late Miocene deformation might be related more to the combined effect of spreading across the three ridges, which is evident from the NE to eastward migration of the IOTJ. In a recent study based on seafloor spreading magnetic anomalies (Nos 21 to 25) and fracture zones delineated east of the IOTJ, KAMESH RAJU and RAMPRASAD (1989) observed the evolution of the IOTJ and the reorientation of SEIR and CIR during the Eocene are the major processes that have influenced the evolution of ocean floor in the Central Indian basin. The wide spread seismicity and large aerial extent of the deformation fabric might thus be explained in terms of the variable spreading across the three ridges of the IOTJ. Though highly speculative at this stage, the episodic character of the deformation, suggested by LEVCHENKO (1989) may be related to the episodic spreading across the south west Indian ridge. While LEVCHENKO (1989) attributes episodic deformation to the episodic motion of lithospheric plates at their convergence, we feel that it is related to the episodic propagation of SWIR at IOTJ. This episodic propagation of a spreading centre, has been found to be true by extensive GLORIA and SEABEAM surveys in the identical case of the Galapagos Triple Junction (SEARLE and FRANCHTEAU, 1986). It is however difficult with the present geophysical data available on IOTJ to explain how the episodic propagation of SWIR and the deformation are exactly related to each other.

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