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DEFORMATION OF THE INDO - AUSTRALIAN PLATE IN EQUATORIAL INDIAN OCEAN - NEW PERSPECTIVES

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ABSTRACT

Oceanic lithospheric plates are assumed to be rigid except at the boundaries. However evidence for intraplate oceanic deformation in the equatorial Indian ocean challenges this assumption.

Multichannel and single channel seismic profiles between 7^0 N – 10^0 S and 83^0 E – 86^0 E in the Indian Ocean show severely undulated topography south of 1^0S. These seismic profiles indicate long wave length anticlinal basement rises with 1-2 km vertical offset and a series of tight faults and high angle faults as evidence for deformation between Afansy Nikitin seamount and Ninety East ridge. Widely dispersed intraplate seismic activity, plate reconstruction considering the motion of the Rodriguez triple junction, and magmatic and fracture zone anomaly crossings also suggest the existence of a new plate within the Indo-Australian plate marked by a diffuse plate boundary.

The new "Capricorn" plate was recognized to account for these discrepancies within the Indo-Australian plate. The spreading rate differences between the Somalian–Indian and Somalian–Capricorn plate motions indicate the rotation of Indian plate relative to Capricorn plate since at least last 20 Ma. The rotation rate could be 0.110 mm yr-1.

Continuous generation of oceanic crust at SE, SW and central Indian ridge and the collision resistance in the Himalayan region may have initiated the deformation during the hard collision period in early Miocene. After the building of Himalayas, the deformation was onset again at about 8 Ma and repeated with a cyclicity of 3 Ma thereafter deforming the central Indian Oceanic lithosphere intensively.

Keywords: deformation, seismic activity, oceanic crust, Indian plate

INTRODUCTION

In plate tectonics, it is assumed that oceanic lithospheric plates are rigid except at the boundaries and this assumption specially plays an important role in calculating plate velocities. Evidence for intraplate oceanic deformation in the equatorial Indian Ocean challenges this assumption (Figure 1).

Displacement as well as strain rates in this region are the highest known of any purely oceanic plate. As such, this region has drawn much attention of geoscientists during the past decades. Marine seismic stratigraphy, deep sea drill logs, seismicity and plate reconstruction provide a great deal of information on deformation of the Indo-Australian Plate.

Seismic Stratigraphy

Multi- and single-channel seismic profiles between 70N-100S and 830E-860E show smooth seafloor topography north of 70S and severely undulated topography south of 70S. Long wavelength (150-300 km) anticlinal basement rises with 1-2 km vertical offset (east of 860E) and a series of tight folds and high angle faults (5-20 km) exist between Afanasy Nikitin sea mount and Ninety East Ridge (NER) (Figure 2). Twelve such long wavelength folds, more than 500 high angle reverse faults and several small scale folds have been identified within the deformation zone by Krishna *et al.* (2001). These high angle faults are superimposed on some anticlinal basement rises and these faults have a mean length of 10 km.

This deformation zone has been recognized from 100 S -70N latitudes. These crustal disturbances had occurred prior to early Miocene (DeMets *et al.*, 2005).

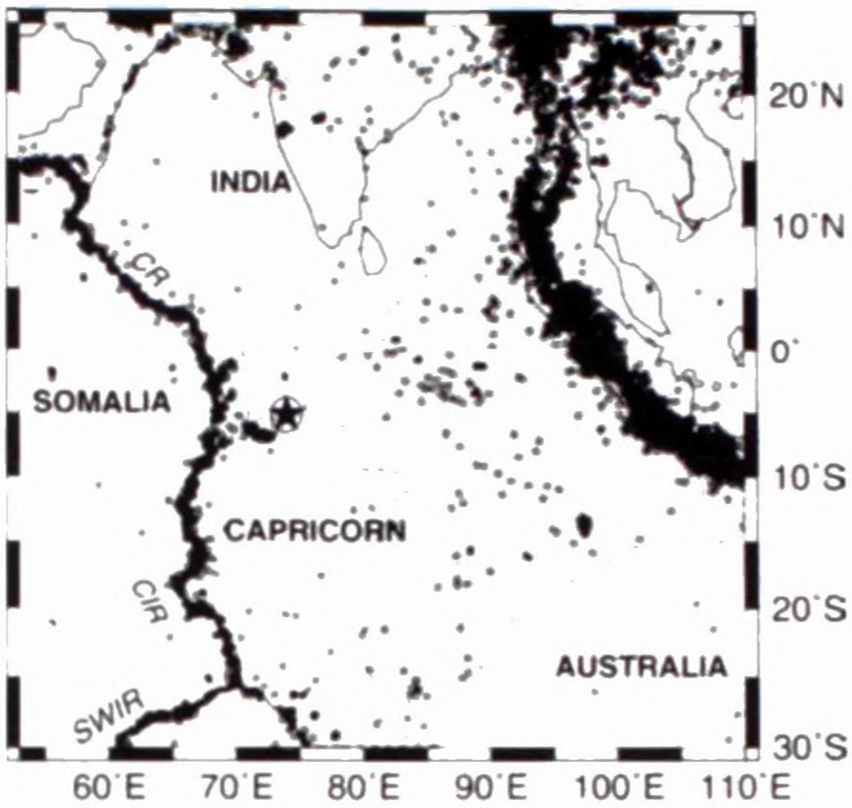

Figure 1: Regional plate geometry. Points indicate earthquakes with foci shallower than 60 km during 1963-2004. Horizontally stripped region indicates convergent diffuse deformation zone. Vertically stripped region at the middle bottom indicates divergent deformation.
SPFZ – St. Paul Fault Zone (After DeMets *et al.*, 2005)

Significant unconformities related to periodic deformation of Upper Miocene (7.5 Ma), and Upper Pleistocene (0.8 Ma) have been recognized generally in the area south of 10S and another lower Pliocene (4 Ma) unconformity from north of 10S (Figures 2, 3 and 4). The Miocene unconformity, which is uniformly folded is well developed in a large region between 10S and 0S. It represents the first phase of long wavelength lithospheric deformation (Figure 5). The Pliocene unconformity represents the 2nd phase of the long wave length fold formation and is developed between 1.50S and 70N. It occurs north of Miocene unconformity area with some degree of overlap. Pleistocene unconformity occurs near the equator with overlapping the previous Pliocene unconformity of Miocene event and a little overlap with both events. (Figure 2) (Krishna *et al.*, 2001). Basaltic crustal deformation and faulting are generally found north of 10S (Figure 2) (Krishna *et al.*, 2001). The reverse faulting which accounts for about 90% of the crustal shortening, modifies the long wavelength fold related to unconformity, producing sharp crest and broad trough morphology. In the Miocene fold region, faults continue only up to Miocene unconformity whereas in Pleistocene fold region, they continue up to Pleistocene unconformity (Figures 2 and 3).

Seismicity

Widely dispersed diffuse intraplate seismic activity is also evident for continued intraplate deformation in the region. Analysis of seismicity in the Bay of Bengal shows that thrust faulting earthquake mechanisms with consistent north dipping fault planes are predominant in the area (Figure 6). This pattern is also analogous to the Himalayan Arc. Seismicity in the southern part of the Indian Ocean shows extensional type of seismicity in the area around 50S, 700E while the compressional type is found in the area between Ninetyeast ridge and Afanasy Nikitin seamount. This pattern indicates the sense of deformation in the diffuse plate boundary. Deformation in the converging eastern part is accommodated by thrust and strike slip faulting whereas the diverging western part is accommodated by normal and strike slip faulting (De Mets *et al.*, 2005).

ODP Leg 116 sites confirm the late Miocene (7.5 Ma) widespread unconformity (Krishna *et al.*, 2001). ODP Leg 116 sites (717-719) in distal Bengal fan records the late Pleistocene (0.8 Ma) unconformity as well as lower Pliocene (4 Ma) event (Figure 7). This drill hole information has been intensively used to date and correlate seismic stratigraphy of the region (Krishna *et al.*, 2001).

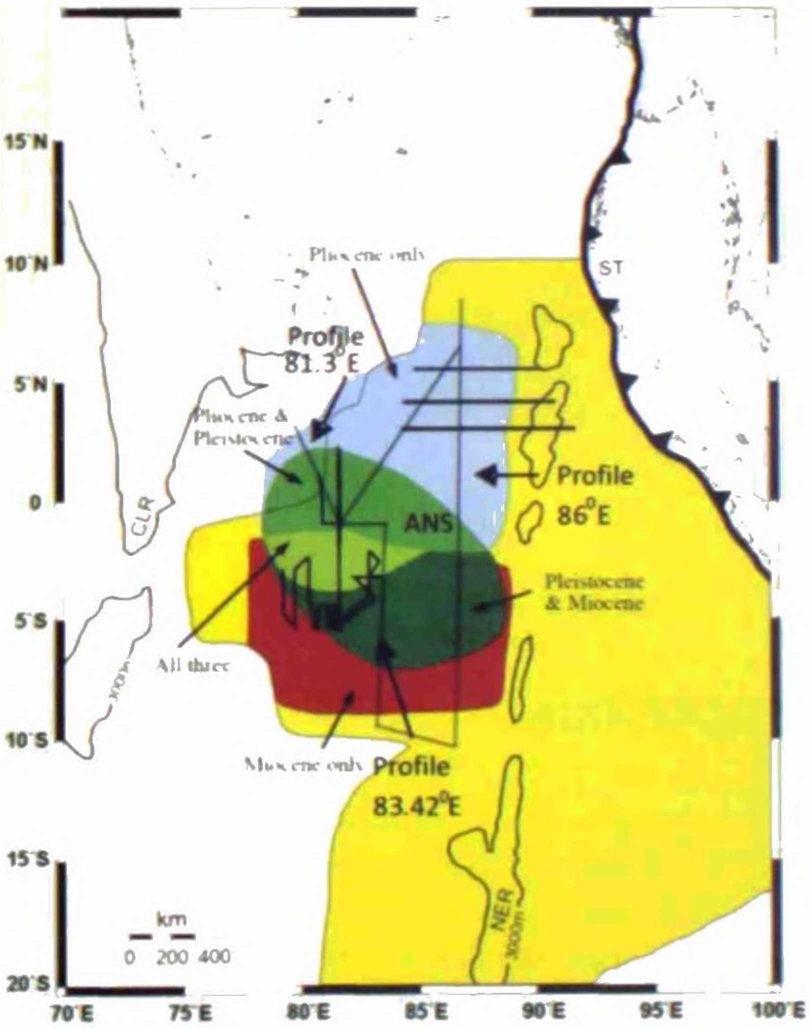

Figure 2: Yellow shading shows possible diffuse plate boundary separating Indian, Australian and Capricon plates. Superimposed on this area are approximate spatial extents of long wave length folding at three different times. Seismic profile lines are shown in lines ANS-Afanasy Nikitin Sea Mount NER- Ninety East Ridge. *Source* – Krishna *et al.*, (2001)

Bore Hole Logging

DSDP site 218 on middle of the Bengal Fan and ODP Leg 116 sites confirm the late Miocene (7.5 Ma) widespread unconformity (Krishna *et. Al.*, 2001). ODP Leg 116 sites (717-719) in distal Bengal Fan records the late Pleistocene (0.8 Ma) unconformity as well as lower Pliocene (4Ma) event (Figure 7). This drill hole information has been intensively used to date and correlate seismic stratigraphy of the region (Krishna *et al.*, 2001).

Magnetic Data and Plate Reconstruction

Plate reconstruction considering the motion of the Rodriguez Triple Junction suggests the existence of another plate (Capricorn plate described below), within the Indo-Australian plate. Capricorn Australian pole indicates that the diffuse boundary between Capricorn – Australian plates does not extend south of the St. Paul Fault Zone (Conder and Forsyth, 2001) (Figure 1). Magnetic anomaly crossings and fracture zone crossings north of Vema fracture zone and south of the fracture zone crosses CIR at 3.20C suggest a wide diffuse Capricorn-Indian boundary between above fracture zones (Figure 1) (DeMets *et al.*, 2005).

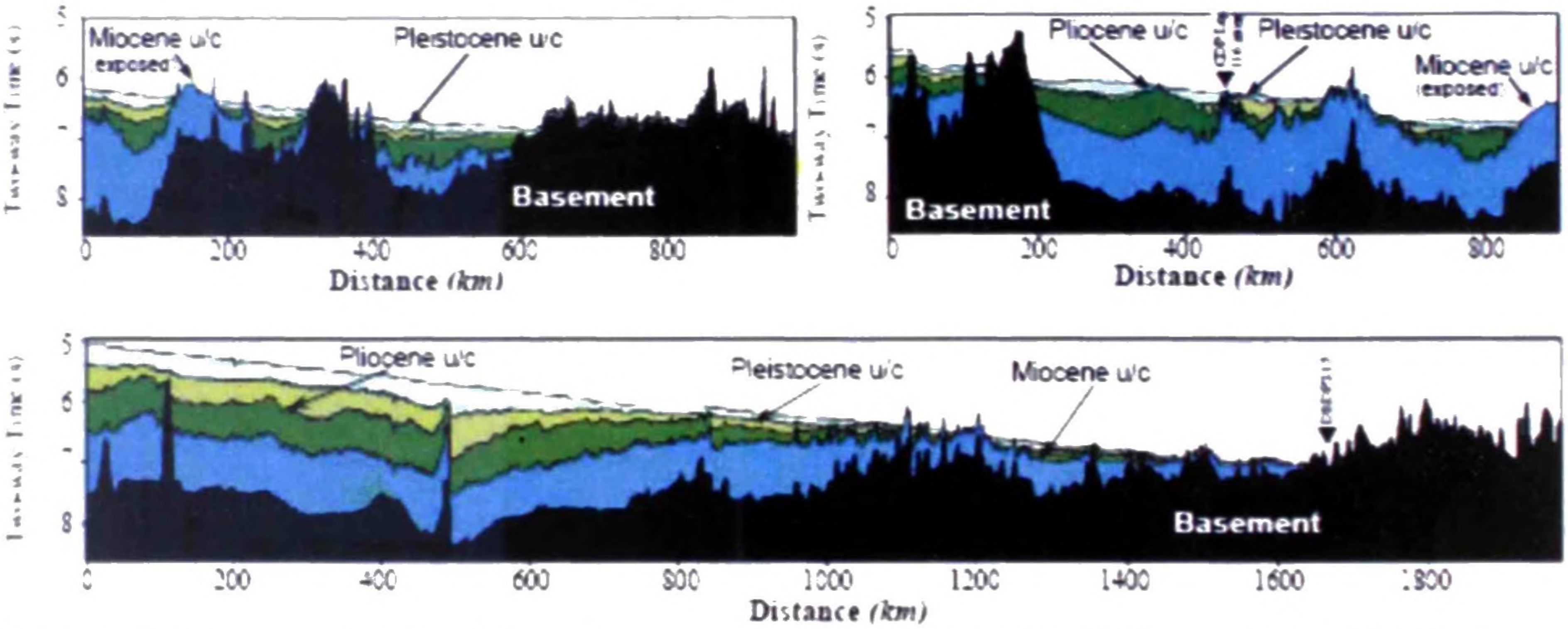

Figure 3: Line drawings of interpreted seismic data along profiles 81.50 E, 83.7 0 E and 870E. Panels outlined 1,2, 3 and 4 are in Figure 4 and show how unconformities have recorded the formation of long wave length folding along the profiles. Source: Krishna *et al.*, (2001)

Interpretation of Intraplate Deformation

Intraplate seismicity, inconsistency of plate motion data of the Southwest Indian Ridge (SWIR), Central Indian Ridge (CIR), and Southeast Indian Ridge (SEIR) with plate closure, and their misfits with kinematic plate models suggest internal deformation of the Indo-Australian Plate. Multi channel reflection seismic (MCS) surveys in the Central Indian Basin and the Wharton Basin confirm this hypothesis (De Mets, *et al.*, 2005, Krishna *et al.*, 2001).

These observations were initially explained with an additional plate boundary along the Ninety-East Ridge and intersected the SEIR at 800E. Although it improved the misfit to the SEIR, it could not explain the misfit along the CIR and seismicity in the CIB. A broad diffuse boundary between the Java Trench near 50S was proposed and by this boundary the Indo-Australian Plate was divided into an Indian Plate and Australian Plate. This geometry improved plate closure and explained the extensional seismicity along the Chagos Bank in the western bank of the CIB. It also explained the compressional seismicity and other deformation in the east of the CIB across the Ninety-East Ridge. However, this diffuse new plate boundary still had misfits to data along the SEIR. Deformation near the easternmost part of the SEIR caused much of these misfits.

To account for these further misfits an additional diffuse plate boundary was proposed within the Australian plate. It divides the Indo–Australian plate into three component plates, Indian, Australian and Capricorn, and extends SSW from the Java Trench as a nearly 2,000 km wide diffuse boundary and intersects the SEIR (Figure 1). This new plate boundary does explain seismicity along the Ninety East Ridge and near the SEIR and also possibly explains the misfit of data along the SEIR into plate motion models. However, there was still a discrepancy in the Australian–Capricorn pole location.

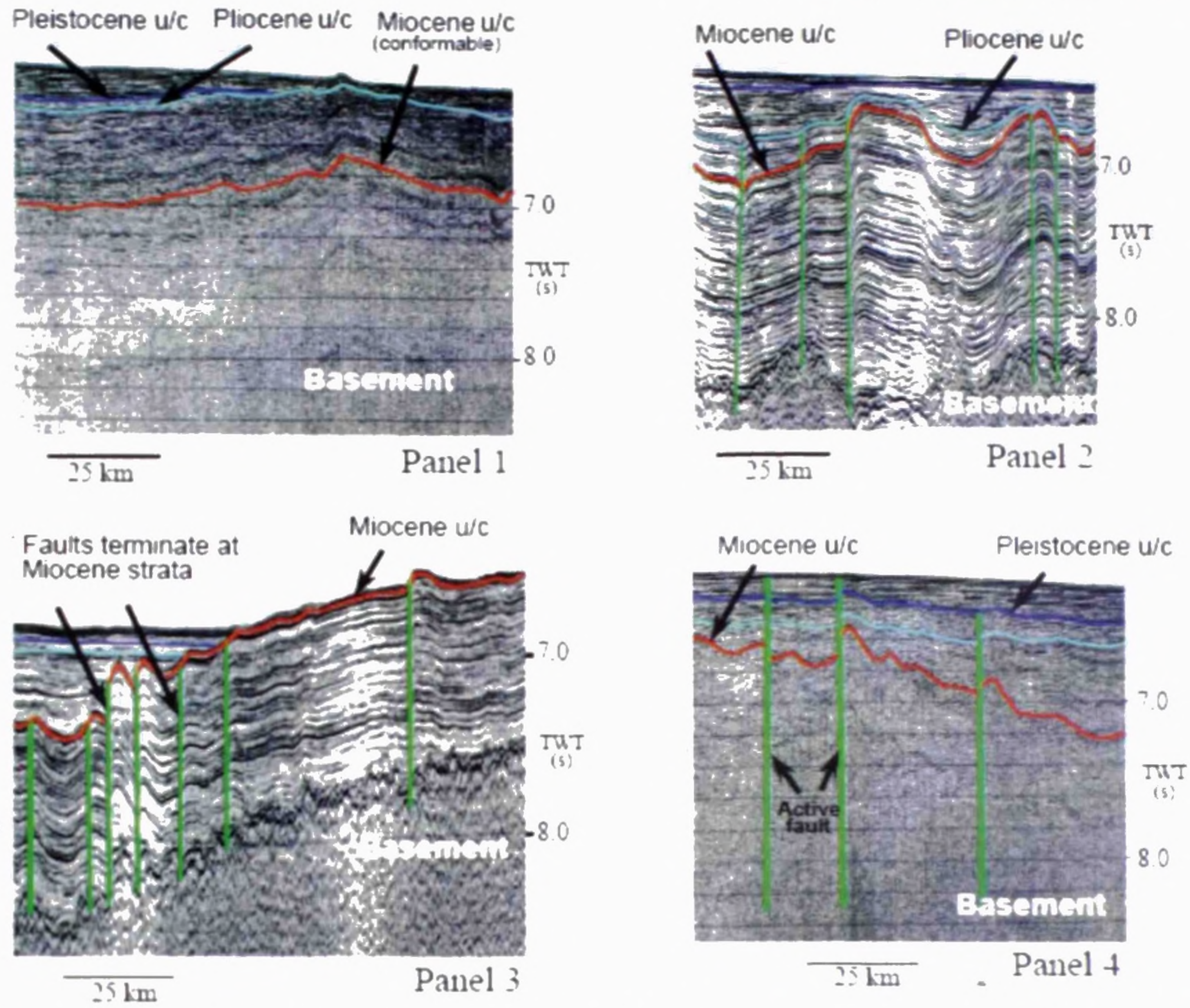

Figure 4: Seismic reflection profiles showing long wavelength folding occurred in different phases in different areas of the deformation zone

- * Panel 1 – Part of profile 81.3°E near the equator
- * Panel 2 – Part of profile 81.3°E at 2°S
- * Panel 3 – Part of profile 81.3°E at 4.5°S
- * Panel 4 – Part of profile 83.7°E at 1.5°S

(Source - Krishna *et al.*, 2001)

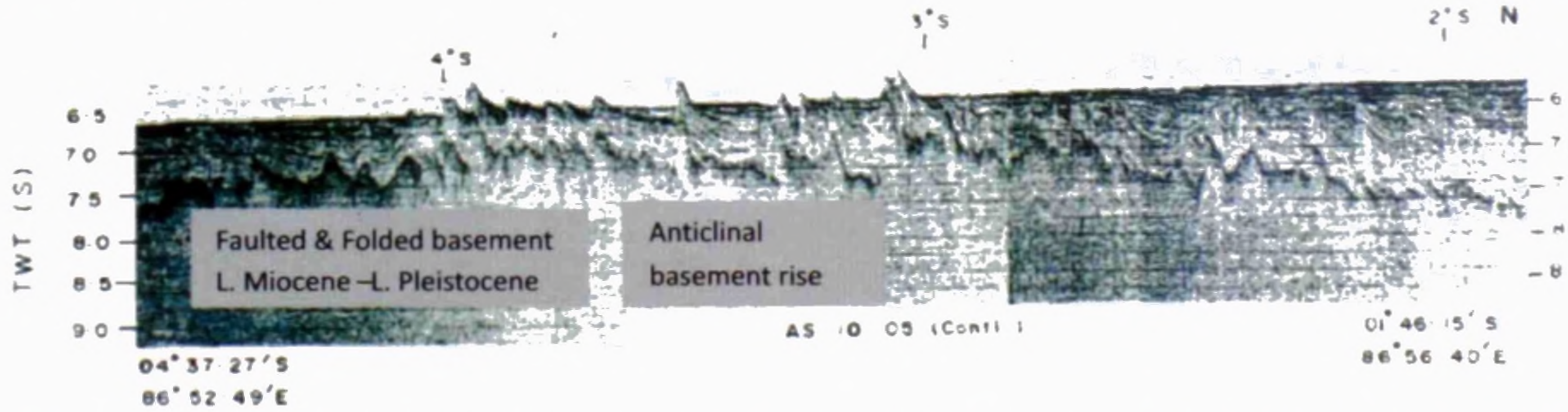

Figure 5: Long wave length anticlinal basement rises and high angle faults along a N-S seismic line across the deformation zone between Afanasy – Nikitin sea mount and Ninetyeast Ridge (Source – Krishna, 1998)

To resolve this issue, the extension of the new boundary was limited to the St. Paul fault zone based on new data (Conder and Forsyth 2001).

The motion between the Indian and Capricon plates has been deduced by considering the motion between Indian and Somalian Plates at 20 distinct points. The astronomically calibrated ages for magnetic reversals younger than 12.9 Ma suggest slowing down of the Indian–Somalia spreading rate from 31-28 mm/yr near 7.9 Ma and later speeding up to 31mm/yr near 3.6 Ma, slowing down of the Capricorn-Somalia from 40-36 mm/yr near 11 Ma and later speeding up to 38 mm/yr near 5.1 Ma and 40 mm/yr near 2.6 Ma. These changes in relative plate motions between the Somalian–Indian and Somalian-Capricorn plates indicate a rotation of the Indian plate with respect to the Capricorn between (about a pole located near 40 S 750 E) last 20 Ma – 8 Ma at a rate of 0.110 - 010 mm/yr, and at a increased rate of 0.280 - 010 mm/yr at ~8 Ma (Demets *et al.*, 2005). The onset of this rapid rotation coincides with widespread thrust faulting in the Central Indian Basin.

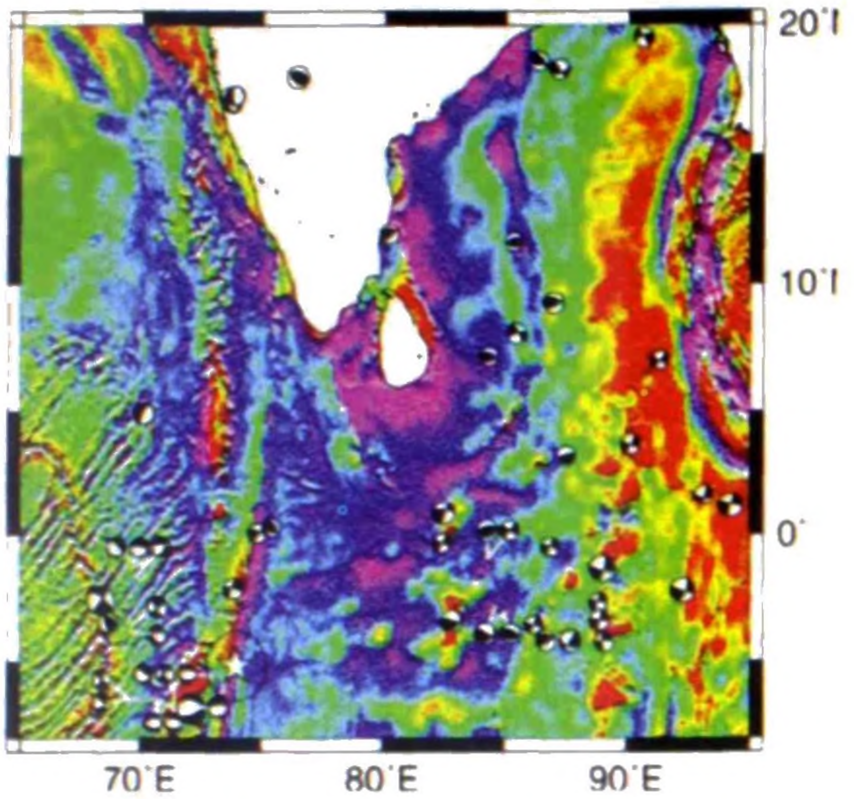

Figure 6: Earthquake focal mechanisms
Source De Mets *et al.*, (2005)

Additional India–Capricorn motion is in between 8-20 Ma which conflicts with the seismic stratigraphy and deep sea drilling (Krishna *et al.*, 2001) and they were mainly accommodated by the eastward motion across CIB before the onset of northward motion after 8 Ma. Torques acting on the edges of the Capricorn Plate due to the difference in spreading rates of Indian–Somalian and Capricorn–Somalian boundaries may attribute to the beginning of the Indian-Capricorn motion from 8 Ma. According to paleo magnetic data, this motion since 8 Ma appears steady with little indication of episodic motion (Demets *et al.*, 2005).

Chronology and Extent of Plate Deformation

Plate kinematics show eastward motion of the Capricorn plate relative to the Indian plate between 20-15Ma and records a period of no motion between 15–8 Ma (De Mets *et al.*, 2005). Analysis of seismic stratigraphy of the Bengal Fan sediment revealed that the equatorial oceanic lithoshphere deformation was multi phase with major events in Miocene (8.0-7.5 Ma), Pliocene (5.0-4.0 Ma) and Pleistocene (0.8 Ma) and some smaller events in between. Data show a shift in the deformation from 10 S in Miocene to the equatorial region in Pleistocene (Figure 2). The deformation in the northeastern part (840 E and north of equator) appears to have been quasi continuous since Pliocene (Krishna *et al.*, 2001). However Demets *et al.*, (2005) have found no evidence based on plate kinematic data for above hypothesized episodic motion after 8 Ma. Also their convergence rate significantly exceeds the convergence estimated by the marine seismic profiles.

According to the plate reconstructions of Gordon *et al.*, (1998) the relative motion accommodated across the CIB was only 1 mm/yr from 18-11 Ma. But their reconstructions indicates a faster rate (about 6 mm/yr) between 20-18 Ma which is coincident with the rapid denudation of the Tibetian Plateau. These calculations are more or less consistent with the plate kinematic calculations based on the magnetic anomaly crossings and fracture zone crossings by De Mets *et al.*, (2005). The plate motion rate was increased to about 4 mm/yr, especially in the 100 S and 81.50 E, between 11-3 Ma. This rate further increased to about 6 mm/yr after 3 Ma especially in NNE area. These rates are consistent with attaining the Tibetian Plateau to its maximum elevation at about 8 Ma, which caused increase in plate motion rate (Gordon *et al.*, 1998).

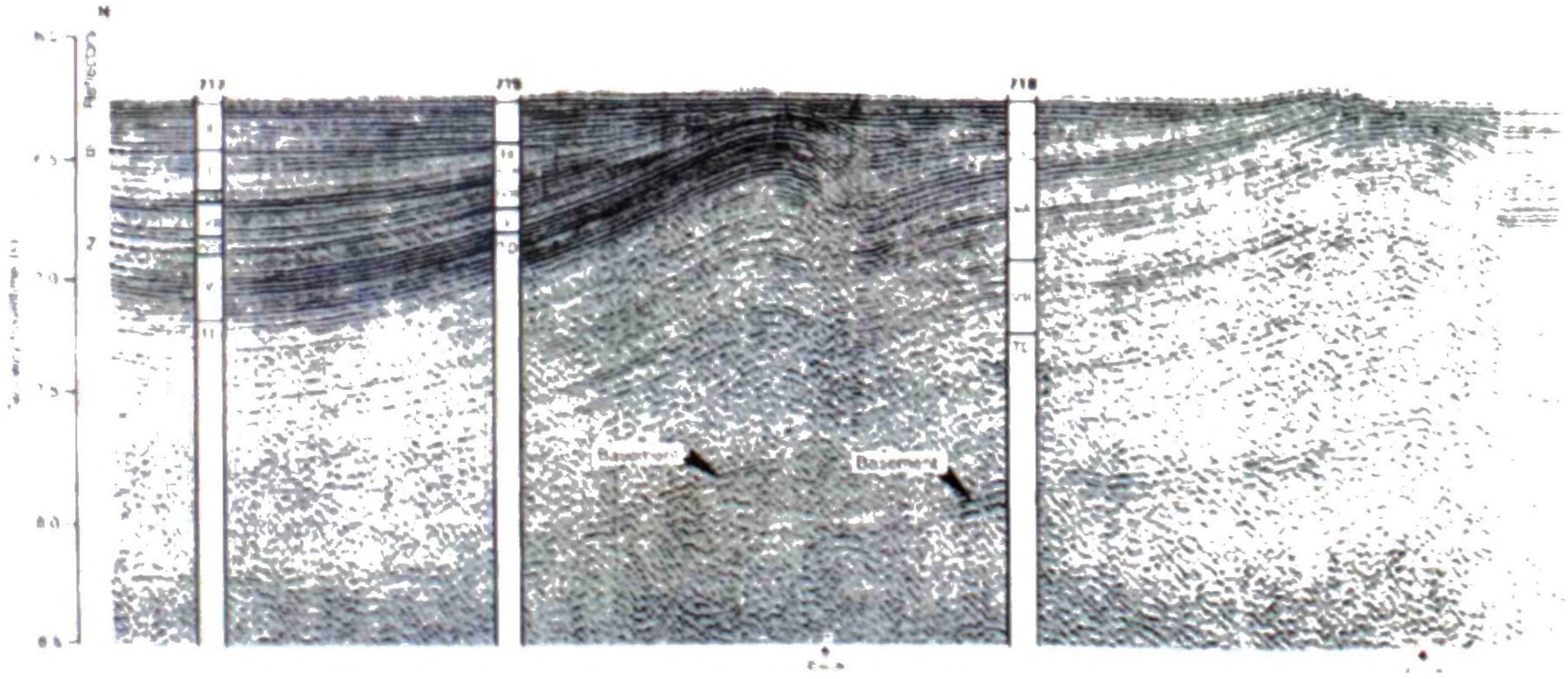

Figure 7: Single channel seismic line running N-S through ODP Leg 116 sites. Notice the basement folding, faulting and unconformities. (Source: Cochran *et al.*, 1989)

During the period 20-11 Ma, the motion was mainly eastward and therefore the deformation that occurred was mainly E-W simple shearing (Gordon *et al.*, 1998). Orman *et al.*, (1995) have calculated the crustal shortening based on the reverse fault displacements in seismic reflection analysis (Contribution from long wavelength basement undulations is small). This analysis records a shortening of 11.2 km at 78.80E between 0.80N and 6.60S. Mean vertical offset of faults along this line is 73.3m. Offset decreases towards north and south of the line defining a high deformation zone at the middle. Along a NS line at 81.50 E the shortening is 27.4 km.

The continuous generation of new oceanic plate along the SEIR CIR and SWIR, subduction along the Sundra-Java–Sumatra Trench and the collisonal resistance in the Himalayan region may have initiated the deformation prior to the uplift of the Himalyas. After building of the Himalayas, the deformation activity was onset again at about 8 Ma and this deformed the Central Indian Oceanic lithosphere intensively. This activity has recurred during early Pliocene (4 Ma) and late Pleistocene (0.8 Ma) with a cyclicity of 3 Ma. The accumulation of compressional forces continues even today and release of these stresses by means of deformation takes place depending on the strength and rheology of the oceanic lithosphere and possible changes in the direction of the forces. Being a relatively young oceanic lithosphere (<50 Ma old), intense tectonic forces could have deformed the Indian oceanic lithosphere.

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