Continuous monitoring of seismicity by Indian permanent seismological observatory at Maitri

National Geophysical Research Institute, Council of Scientific and Industrial Research (CSIR), Hyderabad-500 007, India
*[Email: ecm@ngri.res.in]

Maitri, Antarctica Seismological observatory has gone global by becoming one of the permanent stations in Antarctic Seismic Web Resource (AnSWeR). The global seismic events recorded at Maitri since inception show an increasing trend of seismic activity in and around Antarctica specifically in the larger oceanic part of the Indian Plate. Some significant observations made during the XXI, XXII and XXIII Indian Antarctic Expeditions (IAE) are presented here as representative observations. The MOHO (Mohorovicic Discontinuity or often simply referred to as the "Moho") depth (an average depth of 8 kilometers beneath the ocean basin and at an average depth of about 32 kilometers beneath the continents at which seismic waves change velocity) beneath Maitri has also been estimated to be 40 km using receiver function analysis with 67 receiver functions and 108 events. The increasing seismic activity in and around Antarctica and along the oceanic ridges in the Indian Ocean confirm the emerging deforming zone in the Indian Ocean between India and Antarctica. This increased seismic activity in this region gives an insight into the spreading rates of the ridges and reorganization of plate boundaries.

[Key words: Digital Broad Band Seismometer, SEISAN, local seismicity, Mid-oceanic ridges]

Introduction

The classic Triple junction in the Indian Ocean named as Rodrigues Triple junction (RTJ) where the three plates Somalia-Antarctica-Indo-Australia diffuse plate boundary meet makes an interesting study of sources of seismicity in the Indian Ocean and hence the Indian Plate Kinematics. The three mid-ocean ridge (MOR) systems that form the Triple junction are (i) South West Indian Ridge (SWIR), (ii) South East Indian Ridge (SEIR), and (iii) Central Indian Ridge (CIR) and its northwestern continuation Carlsberg Ridge (CR). They strikingly illustrate the complexities of applying ideal rigid plate tectonics to ocean plates. Many earthquakes of magnitude 6 or 7 have occurred in this century near the Ninety East Ridge (90ER) and give a rate of seismic moment release comparable to that along the San Andreas Fault in California1.

The history of earthquakes and their seismic fault plane solution analysis reveal that most of the faults in the Indian Ocean are strike–slip faults and a few are thrust faults near the Indo-Australia diffuse plate boundary. There is no normal fault solution has been reported so far. Earlier plate motion models treated the area as containing oceanic lithosphere from African, Indo- Australian, and Antarctic plates interacting with neighboring Eurasian and Arabian plates. However, it was recognized that the true picture was more complex. Although much has been learned using marine geophysical and seismological data and described by geologic plate motion models based on magnetic anomalies, transform azimuths, and earthquake slip vectors. The kinematics are poorly characterized compared to simpler regions, which inhibits understanding of the regional dynamics.

Seismic data acquisition and analysis

The seismological observatory had a state-of-the-art Broad Band Seismic System with Guralp CMG-3ESP Sensor and High Resolution Digital Data Acquisition System RT 72A 121-03 from Refraction Technology Inc., USA till 2005 and the observatory was upgraded during XXV Indian Antarctic Expedition (IAE) (January 2006) with the new Broadband Seismometer, Geotech KS-2000M with Geotech-Smart 24R Digitizer. The 3- Component short-period seismometers have also been installed by making use of the RT 121 System with the Reftech DAS unit and the observatory is continuously operational till date. The acquired Digital Broad Band seismic data were processed and analysed using SEISAN software.
The devastating Sumatra earthquake (9.2Mb) on the December 26, 2004 and the Macquarie Island, Antarctic plate earthquake (8.1Mb) of December 23, 2004 were clearly recorded at Maitri Observatory. The most recent Indo-Pakistan border region earthquake (7.6Mb) was also very clearly recorded, which are all the indicators of the quality of the seismic data obtained from Maitri Seismic Observatory.

The respective seismograms of above earthquakes are shown in Figures 1, 2 and 3. Some significant observations made during the XXI (2002), XXII (2003) and XXIII (2004) IAE are presented here. The global seismic events recorded during these periods are shown in figures 4, 5 and 6. From these global maps it is evident that the seismicity is on the increase in the Indian Ocean Basin. Apart from the number of events even the magnitude of these earthquakes are also between 5 and 6. The histograms shown in figures 7 and 10 depict the time distribution of the number of events during 2002 and 2004 respectively. Figures 8, 9 and 11 show the number of earthquakes vs magnitude for the years 2002, 2003 and 2004 respectively. From these histograms it is evident that the number of earthquakes of magnitude 5 to 6 are about 150, 200 and more than 200 in 2002, 2003 and 2004 respectively. This relatively high magnitude of earthquakes in the study region indicates the deforming zone in the larger part of the Indian Ocean.

An interesting observation was the number of earthquakes seems to increase during the months between June and September. This has been observed in all the three years from 2002 to 2004. This needs a rigorous investigation to determine whether there is a rise in seismic activities during these periods or these are instrument errors. This also would be confirmed if
the other nearby stations’ records is verified. The figure 12 shows the estimated MOHO depth beneath Maitri. This was estimated to be about 40 km using Receiver Function Analysis. For this analysis 67 receiver functions and 108 events were used.

**Results and discussion**

The seismicity and tectonics of Indian Ocean basin and the evidence for internal deformation of Indian plate are described using earthquake mechanisms as follows. The Indian plate deviates significantly from an ideal rigid plate, even given that much of the oceanic seismicity and deformation near the equator is now recognized to be part of the plate’s diffuse southern boundary. Its continental boundaries to the north and west are also broad deformation zones. In addition, earthquakes occur within peninsular India south of 15° N and the adjacent oceanic lithosphere north of the diffuse boundary zone. The continental crust along the west coast appears to be fixed\(^3,4\).

Fig. 3 — The most recent Indo-Pakistan border region earthquake (7.6Mb) on October 8, 2005 was also very clearly recorded at Maitri.

Fig. 4 — Epimap of Global seismic activities recorded at Maitri Seismological Observatory during XXI Indian Antarctic Expedition (2002).
The earthquakes, such as Koyna (M 6.3) 1967, and Latur (Ms 6.4) 1993 events, were very destructive. Although the area seems geodetically relatively rigid, the deformation may be significant. These earthquakes are viewed as internal deformation of the Indian plate, since they are well south of the seismic zone where the 2001 Bhuj (Mw 7.7) earthquakes occurred, that may be part of the diffuse India–Eurasia boundary. A new platelet Capricorn has been proposed in the central-western Indian Ocean with a broad, diffuse boundary. This newly emerging plate in the Indian Ocean may be due to the result of frequent plate boundary reorganizations in the past and these boundary forces complicate the

Fig. 5 — Epimap of Global seismic activities recorded at Maitri Seismological Observatory during XXII Indian Antarctic Expedition (2003).

Fig. 6 — Epimap of Global seismic activities recorded at Maitri Seismological Observatory during XXIII Indian Antarctic Expedition (2004).
kinematic interpretations and may also contribute to
the non-rigid behaviour of the Indian plate and Indian
Ocean Basin.

The high magnitude of the present-day regional
stress field of the Indian plate results from the unique
dynamic situation in which the Indian plate now finds
itself. There are several factors that account for this
high stress magnitude. Age variations, such as
encountered along the Sunda trench, induce
significant variations in net boundary forces. Coupled
with the curved geometry of the plate boundary, these
conditions are capable of concentrating stresses to
kilobar levels. From the required torque balance found that the Indian plate is undergoing a
considerable net resistance at the Himalayan collision
zone. There is also considerable net resistance at other
large segments of the convergent boundaries of the
Indian plate. This applies in particular to the Banda
arc and to the northwestern part of the Sunda arc. In
combination with ridge push, these features explain

![Graph showing the time distribution of earthquakes recorded at Maitri during 2002.](image)

**Fig. 7** — Histogram showing the time distribution of the total number of 416 earthquakes recorded at Maitri during 2002.

![Graph showing the frequency distribution of magnitudes of earthquakes recorded at Maitri during 2002.](image)

**Fig. 8** — Histogram showing the frequency distribution of the magnitudes of earthquakes recorded at Maitri during 2002.

![Graph showing the frequency distribution of magnitudes of earthquakes recorded at Maitri during 2003.](image)

**Fig. 9** — Histogram showing the frequency distribution of the magnitudes of earthquakes recorded at Maitri during 2003.
why compression is the dominant stress mode in the plate. A very detailed study of depths of oceanic intraplate bending earthquakes10 gives strong independent evidence for the existence of intraplate stresses of a few kbar in a more general sense.

As representative of seismic prone regions, the South Sandwich Islands, which are in 16 to 25 degrees distance from Seismic Observatory (MAIT), recorded about 29 earthquakes of magnitude ranging from 4.1 to 7.5. The Scotia Sea region, which falls between 20 to 24 degrees distance from Maitri, experienced 19 earthquakes of magnitudes ranging from 4.2 to 5.9. A total number of 380 earthquakes were recorded in 2002 alone. Minor to semi major earthquakes of magnitude varying from 3.5 to 4.5 within Antarctica have also been recorded. The increasing seismic activity in and around Antarctica and along the oceanic ridges in the Indian Ocean confirm the emerging deforming zone in the Indian Ocean between India and Antarctica. This increased

![Monthly distribution of 270 earthquakes recorded at Maitri in 2004](image)

Fig. 10 — Histogram showing the time distribution of the total number of 270 earthquakes recorded at Maitri during 2004.

![No. of Earthquakes Vs Magnitude](image)

Fig. 11 — Histogram showing the frequency distribution of the magnitudes of the earthquakes recorded at Maitri during 2004.
seismic activity in this region gives an insight into the spreading rates of the ridges and reorganization of plate boundaries. This is shown in figure 13. The figure 14 shows the Antarctic map (AnSWeR) of permanent digital broadband seismometers that are functional.

Fig. 12 — MOHO depth estimation beneath Maitri.

Fig. 13 — 29 earthquakes of magnitude ranging from 4.1 to 7.5 from seismic prone regions, the South Sandwich Islands, which are in 16 to 25 degrees distance from Seismic Observatory (MAIT), that were recorded at Maitri during 2002. The red rectangular box indicates the South Sandwich Islands.
Conclusion

The history of the earthquakes recorded at Maitri and their fault plane solution analysis reveal that most faults in the Indian Ocean, specifically along the ridges are strike–slip faults and a few are thrust faults near the Indo-Australian diffused plate boundary. The seismic data recorded since 1997 and their analyses clearly show an increasing trend of the seismicity in and around Antarctica. The significant result is the increasing seismicity along the ridges in the Indian Ocean and the spreading rates of them, which are of concern for the seismotectonics study and the Indian plate kinematics. The present analysis also corroborates the evidence of deforming zone in between India and Antarctica.

Acknowledgements

The authors record their due thanks to Dr.H.K.Gupta, former Secretary, Department of Ocean Development, Govt.of India for launching this scientific program and constant support. Authors also thank Dr V.P. Dimri, Director, NGRI, Hyderabad for permitting to publish this paper.

References