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Near-ridge intraplate earthquakes in the Indian Ocean

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Abstract

Moment release computation based on a detailed catalog of near-ridge earthquakes between 1912 and 1993 pertaining to the younger lithosphere in the Indian Ocean suggest that the overall seismicity level in the Central Indian Ocean is not significantly higher as compared to the seismicity pattern near the Southwest Indian Ridge (SWIR). The characteristic seismicity pattern along the Southeast Indian Ridge (SEIR) and Central Indian Ridge (CIR) in the Central Indian Ocean over a much wider zone represents the plate-wide stress distribution. Though the seismicity near Chagos Bank appears to be similar to that observed near the Atlantis II Fracture Zone along the Southwest Indian Ridge (SWIR), several lines of evidence, such as more frequent occurrence, geographically wide spread seismicity, consistent faulting pattern and plate motion inversion results, suggest that the Chagos Bank seismicity forms part of the plate-wide stress distribution in the Central Indian Ocean. The present study also demonstrates two examples of highly energetic sequences of events characterized by thrust faulting. While the thrust faulting events near the southern part of the Central Indian Ridge can be inferred due to thermoelastic stresses related to cooling of the lithosphere, the events near the Indomed Fracture Zone on the African plate occur due to slow relative motion along the boundary between Nubia and Somalia, which connects to the SWIR along a diffuse compressional segment. The available mechanisms confirm that the near-ridge seismicity is characterized by dominantly normal faulting in the Indian Ocean. The moment release computed for different ages suggests that a greater fraction of moment release takes place in the 15- to 35-My-old lithosphere.

Keywords: moment release; near-ridge seismicity; source mechanisms; stress distribution; Indian Ocean

1. Introduction

The locations and source properties of earthquakes along mid-oceanic ridges constitute important information related to the processes of crustal accretion and lithospheric spreading. In addition, to this usual tectonic activity along the plate boundary, a significant part of seismicity takes place – off the ridge axis, called 'near-ridge intraplate earthquakes'. Global occurrence of these earthquakes near mid-oceanic ridges has been studied in detail by numerous workers (e.g. Stein, 1978; Bergman and Solomon, 1980, 1984; Wiens and Stein, 1983, 1984; Okal, 1984; Cleotingh and Wortel, 1986; among others). Detailed investigations of these near-ridge events have essentially

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brought out information on the state of stress in the young oceanic lithosphere (age <35 My) and the mechanical properties, such as plate driving forces and rheology of the lithosphere.

Although many intraplate events tend to occur on pre-existing weak zones and reflect localized, rather than global tectonic processes (Bergman and Solomon, 1980), they are reliable indicators of the state of stress in the source region (Bergman, 1986). Of the numerous such locations, special attention has been given by the above workers to the intraplate events occurring near the Central Indian Ridge (CIR) and Southeast Indian Ridge (SEIR) in the Central Indian Ocean. Wiens and Petroy (1990) have reported intense off-ridge seismic swarm activity along the Southwest Indian Ridge (SWIR) between 1925 and 1933. The above investigations were carried out based on the data for different time intervals. In the present study, we attempt a combined analysis of long-term near-ridge seismicity pattern and stress regime along Central, SE and SW Indian Ridges between 1912 and 1993 by including more recent events for the 1984–1993 period.

2. Regional tectonic setting

The topography of the Indian Ocean is dominated by three major active mid-ocean ridge systems which mark the present boundaries of the Indian, African and the Antarctic plates. These three ridge segments meet at the Rodriguez triple junction at 25°S, 70°E in the Central Indian Ocean (Fig. 1). The contrast between the characteristics of the three ridge systems is marked, in the sense that they correspond to significant differences in spreading rates and ridge–transform geometries.

The half-spreading rates for the three ridges, range from 12 to 13 mm/yr along Carlsberg Ridge (McKenzie and Sclater, 1971), 16 to 25 mm/yr along the Central Indian Ridge (Fisher et al., 1971; DeMets et al., 1990), 30 mm/yr along the SE Indian Ridge (Sclater et al., 1981) and 8 mm/yr along the SW Indian Ridge (Sclater et al., 1981). While SEIR is characterized by low seismic activity, both the Southwest and Central Indian Ridges are seismically more active and have numerous transform faults and deep fractures offsetting the ridge axis (Fisher et al., 1971; Sclater et al., 1981).

Recent plate motion data proposed by Gordon et al. (1990) and DeMets et al. (1994) suggest that the Indian and the Australian plates are separated by an equatorial diffuse boundary zone and this diffuse plate boundary is characterized by active intraplate seismicity, deformation of oceanic crust and sediments, and abnormally high heat flow in the Central Indian Ocean (Weissel et al., 1980; Geller et al., 1983; Wiens, 1985; Cochran et al., 1988). The large-scale occurrence of intraplate earthquakes marked by the presence of diffuse boundary zone have been attributed by Bergman and Solomon (1984) to plate-wide tectonic processes peculiar to this region.

3. Distribution of near-ridge seismicity in the Indian Ocean

Several sources of information on near-ridge earthquakes within the young oceanic lithosphere (<35 m.y) in the Indian Ocean were available from previous investigations. Bergman and Solomon (1984) and Wiens and Stein (1984) studied in detail the events occurring between 1964 and 1983 in the Central Indian Ocean region. Stein (1978) reported the swarm activity during 1967 near Chagos Bank. Wiens (1985) studied the historical seismicity and reported pre-1964 events near Chagos Bank. Wiens and Petroy (1990) studied the unusual activity between 1925 and 1933 near the Atlantis II Fracture Zone along the Southwest Indian Ridge. All the above investigations document the events occurring between 1912 and 1983 very well. We updated this data set, by searching for recent near-ridge events in the Indian Ocean occurring between 1984 and 1993 from NOAA epicentral tapes and ISC bulletins. All epicenters have been plotted on detailed bathymetric maps in order to differentiate them from the events occurring along spreading ridge segments or major fracture zones. Our detailed investigations on ridge–axis earthquakes along the slow-spreading ridges in the Indian Ocean (Radha Krishna, 1995; Radha Krishna et al., 1995) suggest that the events are very well correlatable with the

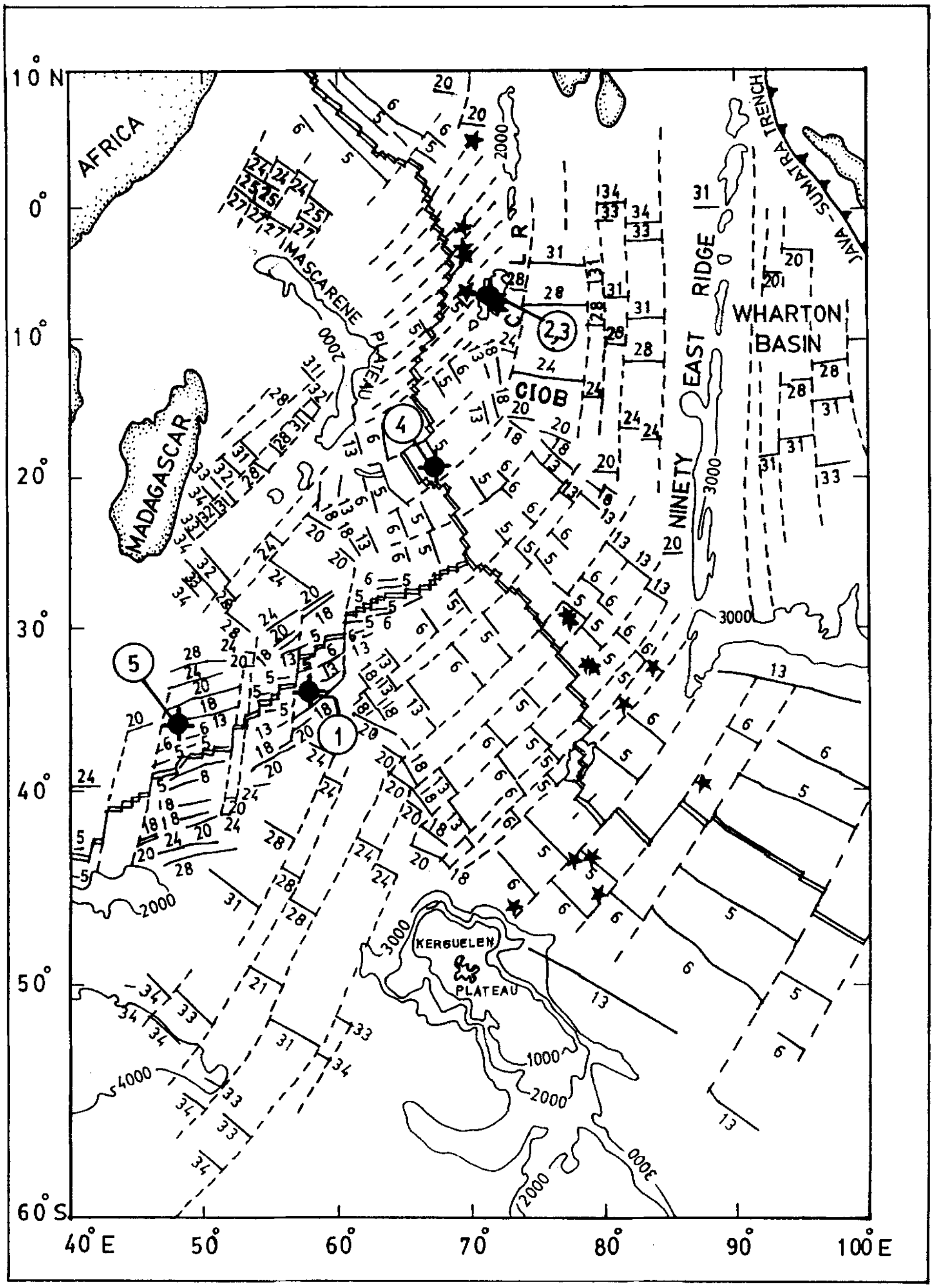

Fig. 1. Tectonic setting of the mid-oceanic ridges in the Indian Ocean modified and redrawn after Royer et al. (1989). The near-ridge intraplate events occurring in the younger lithosphere (<35 My) are shown. Only events with a magnitude (m_b) of >5.0 and well-resolved mechanism solutions are plotted. Stars indicate the locations of single isolated events and large filled circles numbered (*1–5*) show the locations of major intraplate earthquake swarms and sequences. The numbers with lines are magnetic anomalies and dashed lines are fracture zones.

bathymetric trend of major spreading ridges and fracture zones and found to be reasonably well located along the bathymetric expression of the ridge, if they are recorded by at least 15 stations. Based on the distance interval distributions, we observed that post-1980 events in the Indian Ocean may have an epicentral uncertainty of a maximum of 20 km at the teleseismic detection threshold (Radha Krishna and Arora, 1998). Hence, the events we have compiled for the 1984–1993 period were certainly not the result of mislocation and could be included in the catalog of near-ridge seismicity in the Indian Ocean.

3.1. Major intraplate swarms and sequences

The near-ridge seismicity is mostly dominated by five major intraplate swarms and mainshock–aftershock sequences. The time sequences of these five events are shown in Fig. 2. The occurrence of

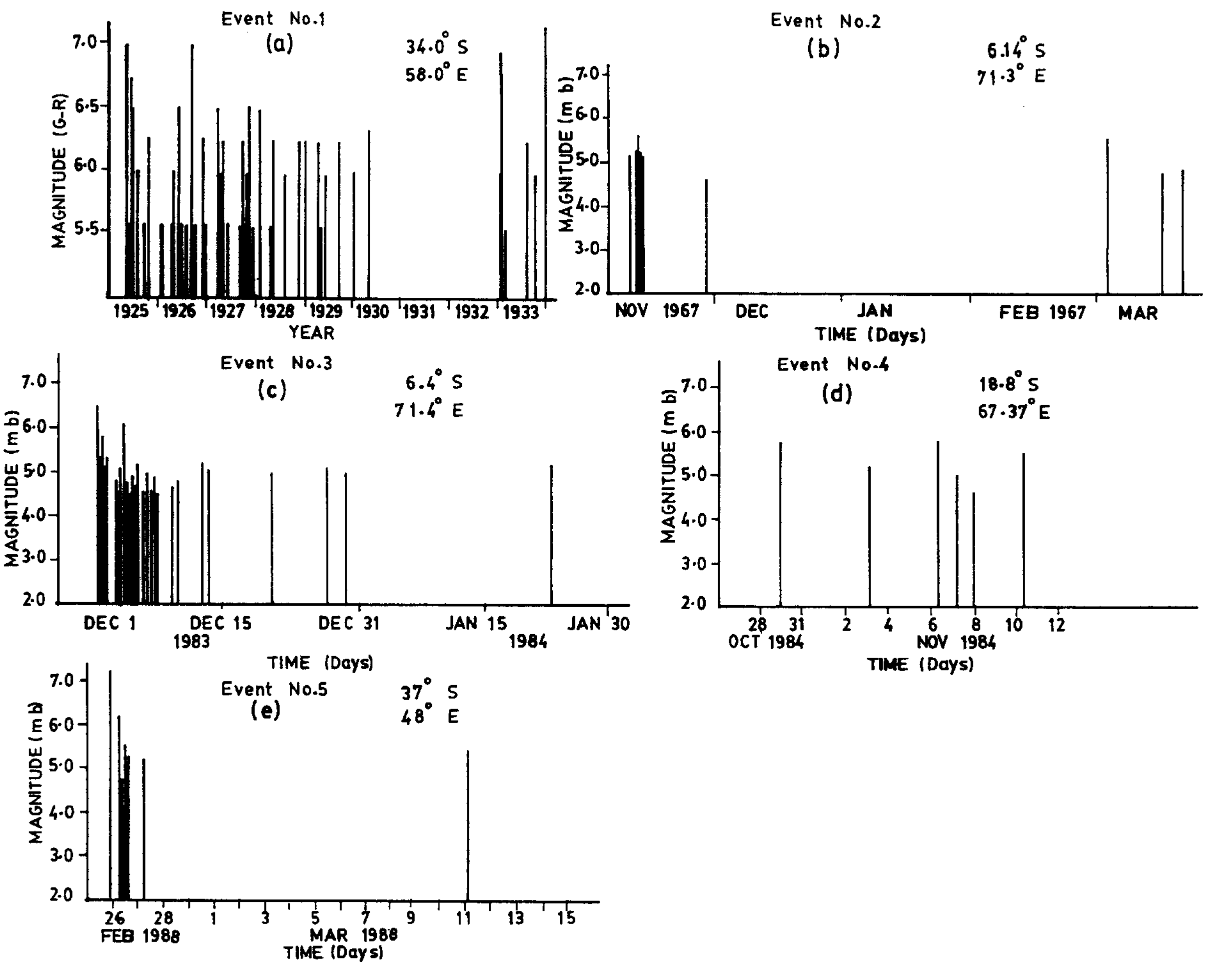

Fig. 2. Time sequences of five major near-ridge intraplate swarms or sequences observed in the Indian Ocean. The location of these events is shown in Fig. 1. (a) The time history of the 1925–1933 intraplate swarm which occurred near the Atlantis II Fracture Zone (Wiens and Petroy, 1990). (b) The time history of the intraplate swarm which occurred near Chagos Bank during 1967 (Stein, 1978). (c) The history of the largest sequence of events near Chagos Bank during 1983. The main event is very strong and has a wide rupture zone (Wiens, 1985). (d) The sequence of events which occurred during 1984 along the southern part of the Central Indian Ridge between the Marie-Celeste and Egeria Fracture Zones. (e) The sequence of events which occurred during 1988 near the Indomed Fracture Zone on the African plate. Details are discussed in the text.

major swarm activity between 1925 and 1933 (Fig. 2a) near the Atlantis II Fracture Zone has been interpreted by Wiens and Petroy (1990) in terms of thermoelastic stresses enhanced by bending moments associated with the transform fault. This swarm event was characterized by an enormous moment release and the seismicity in this region experienced another burst of events between 1977 and 1983. Stein (1978) reported the occurrence of swarm event (6°S and 71°E, Fig. 2b) at the Chagos Bank during 1967 and attributed this to an isolated reactivation of a fracture remaining from the separation of the Chagos Bank from the Mascarene Plateau. After 1970, the Chagos Bank became quiescent for 13 years until the large-scale occurrence of seismic activity starting from 30 November 1983 (Fig. 2c), and continued until the end of 1984. The first event of this sequence is the highest in magnitude (m_b) of 6.6 and has a rupture zone extending to a depth of 30 km (Wiens and Stein, 1984). The aftershock activity included nearly 78 events clustered near the southwest Chagos Bank. This intense seismic activity has been explained in terms of massive internal deformation of the Indian plate (Wiens and Stein, 1984). In the present study, we report two more new locations characterized by appreciable seismic activity. Near the southern part of the Central Indian Ridge east of the spreading segment between Egeria and Marie-Celeste Fracture Zones (18.8°S and 67.3°E, Fig. 2d), a sequence of 6 events occurred between October and November 1984. Along the Southwest Indian Ridge near the Indomed Fracture Zone (37°S and 48°E, Fig. 2e), a total of 13 events occurred between 1988 and 1991. The first event on 26 February 1988 had a magnitude (m_b) of 6.2. The aftershocks closely followed for 15 days and the seismic activity continued until February 1991 (Fig. 2e). The ISC location parameters of the last two sequences of events are given in Table 1. In both the regions, the events are located at a distance of 100–150 km from the spreading axis and some of these have been recorded at more than 100 stations with a location uncertainty of less than 10 km. The bathymetry also confirms that these events were

Table 1
ISC location parameters of 21 near-ridge events which occurred between 1984 and 1993 and are utilized in the present study

Solution no.	Date	Time	Latitude (°N)	Longitude (°E)	Depth (km)	Magnitude (m_b)	No. of arrivals
1	21.03.1984	0827:51.5	−43.90	77.94	10	5.7	302
2	20.10.1984	2350:46.4	−18.91	67.42	10	5.8	161
3	03.11.1984	0233:16.2	−18.86	67.38	10	5.2	189
4	06.11.1984	0758:51.3	−18.84	67.33	10	5.8	529
5	07.11.1984	0211:42.1	−18.83	67.39	10	5.1	151
6	07.11.1984	2143:40.8	−18.88	67.37	10	4.7	55
7	10.11.1984	0755:31.6	−18.85	67.39	10	5.6	252
8	26.02.1988	0617:31.9	−37.28	48.01	10	6.2	602
9	26.02.1988	0916:31.7	−37.16	47.85	10	4.6	12
10	26.02.1988	0930:09.6	−37.36	47.76	10	4.8	34
11	26.02.1988	1135:19.1	−36.95	47.80	10	4.5	9
12	26.02.1988	1342:27.2	−37.19	47.80	10	5.5	137
13	26.02.1988	1752:34.9	−37.14	47.78	10	5.3	99
14	27.02.1988	0532:56.2	−37.25	47.98	10	5.2	81
15	11.03.1988	0236:59.1	−37.41	47.9	10	5.4	49
16	30.07.1988	1626:23.8	−33.12	83.81	10	5.1	99
17	24.11.1988	1139:18.0	−37.32	47.73	10	5.0	49
18	24.06.1989	0832:02.0	−37.08	17.89	10	4.6	11
19	14.05.1990	0652:11.7	−37.31	47.75	10	5.4	142
20	22.12.1990	0737:10.6	−37.46	48.02	10	4.6	16
21	21.02.1991	2111:37.7	−37.03	47.90	10	4.5	15

not mislocated from the ridge axis or nearby fracture zone, but occurred on a lithosphere as young as 10–21 My.

4. Focal mechanism solutions

A detailed catalog of 43 intraplate earthquakes occurring on a lithosphere younger than 35 My between 1912 and 1993, for which the focal mechanism solutions are available is given in Table 2. The solutions for the Central, Southeast and Southwest Indian Ridges are shown in Figs. 3–6.

The near-ridge earthquakes along the Central Indian Ridge (Fig. 3) can be classified into two groups, one nearest to the ridge (events 1 and 6–9) occurring on a lithosphere of about 12 My of age showing predominantly right–lateral strike–slip faulting on northeast striking nodal planes parallel to the trend of the fracture zones, and the other, the intense Chagos Bank seismicity occurring in two major episodes of seismic activity. Except for the earthquake of 10 November 1967 (event 3), which has a pure strike–slip solution, all other Chagos Bank events (events 2, 4, 5 and 10–13) show predominant normal faulting and have east–west dipping nodal planes with T-axes oblique to the spreading direction (Wiens and Stein, 1984). A recent plate motion model predicts a north–south extension of 6 mm/yr in this region (Gordon et al., 1990; DeMets et al., 1994). The sequence of 6 events occurring between October and November 1984 near the spreading ridge segment between the Egeria and Marie-Celeste Fracture Zones in the southern part of the Central Indian Ridge (Fig. 4) have two well-constrained mechanism solutions (events 19 and 20). These events show predominantly thrust faulting with P-axes oriented perpendicular to the spreading ridge axis.

The near-ridge events (events 21–29) along the SE Indian Ridge shown in Fig. 5 were studied in detail by Bergman et al. (1984), which show predominantly normal faulting. Two additional events presented in this study (events 30 and 31) have similar faulting pattern, all having T-axes almost parallel to the spreading ridge axis.

In contrast to the scattered seismicity observed near the Central and SE Indian Ridges, the SW Indian Ridge is characterized by the occurrence of concentrated regions of major intraplate seismic activity as shown in Fig. 6a,b. The most prolific intraplate swarm events occurred between 1925 and 1933 at 34°S, 58°E near the Atlantis II Fracture Zone, and later seismic activity between 1977 and 1983, showed normal faulting with strike–slip component (events 32–38) and the solutions do not exhibit any preferred orientation of the T-axis with spreading direction (Wiens and Petroy, 1990). The observed intraplate events (events 39–43) on the African plate at 37°S, 48°E near Indomed Fracture Zone show thrust faulting mechanisms with little strike–slip components. The P-axis in all the five available mechanisms orients obliquely to the spreading direction.

5. Total seismic moment release for recent sequences of events

The sum of the seismic moments associated with a given sequence provides a measure of the total amount of deformation. The total moment release has been computed for the two recent sequences of events shown in Figs. 4 and 6a in order to estimate the strain rates. For events for which seismic moments of CMT solutions were not available, these were calculated from the surface wave or body wave magnitudes using the empirical regression formula for oceanic intraplate earthquakes given by Bergman (1986) as:

$$\mathrm{Log}_{10} M_0 = 1.12 M_\mathrm{S} + 18.67$$

$$\mathrm{Log}_{10} M_0 = 2.35 m_\mathrm{b} + 11.71$$

The magnitude of strain rate can be estimated by dividing the moment sum by rigidity and volume (Molnar, 1983). The clustering of events shown in Fig. 6a near the Indomed Fracture Zone along the SWIR, occur in a region of 60 km^2 and at a depth of 10 km. The total moment release is 1.86×10^{26} dyn cm and considering the rigidity as 3.3×10^{11} dyn cm^{-2}, we obtained a strain rate of 3.67×10^{-13} S^{-1} averaged over 81 years for the 1912–1993 period. The total seismic moment release calculated for events shown in Fig. 4 near the southern part of the Central Indian Ridge is

Table 2
Focal mechanism solutions of 43 near-ridge intraplate events in the Indian Ocean

Ref. no.	Date	Time	Latitude (°N)	Longitude (°E)	m_b	M_S	M_0	Depth (km)	Mechanism			Type of faulting	Age (My)	Reference	
									Strike	Dip	Slip				
Central Indian Ridge															
1	02.01.1957	2058:44	−6.3	69.7	–	5.7	14.0	14	35	90	180	S.S	12	W1	
2	12.09.1965	2207:37	−6.5	70.8	6.1	6.0	33.0	18	263	44	246	N	35	BS	
3	10.11.1967	1838:34	−6.03	71.34	5.2	–	3.0	18	234	76	191	S.S	35	BS	
4	11.11.1967	1155:56	−6.02	71.36	5.3	5.2	3.7	17	264	50	261	N	35	BS	
5	02.03.1968	2202:24.2	−6.09	71.41	5.5	5.4	7.7	13	284	52	280	N	35	BS	
6	31.03.1970	1818:28.0	−3.8	69.7	5.5	5.5	15.0	12	248	62	217	S.S	12	WS	
7	25.04.1970	0343:30.3	−6.41	69.8	5.1	5.1	3.5	15	320	78	330	S.S	12	WS	
8	17.11.1973	1051:21.8	−1.60	69.83	5.5	5.5	7.4	19	278	55	322	S.S	15	WS	
9	20.05.1978	0715:24.4	−3.48	69.7	5.3	4.9	2.8	–	240	75	180	S.S	12	WS	
10	12.12.1981	2331:10.9	−44.89	70.15	5.5	5.1	2.3	15	60	50	307	N	35	BS	
11	30.11.1983	1746.04	−6.89	72.12	6.6	7.5	1800	16	90	45	270	N	35	WS	
12	01.12.1983	0545:42.9	−6.60	71.41	5.8	5.6	4.95	10	310	46	317	N	35	DZ1	TS
13	01.12.1983	2229:36.4	−6.67	71.76	5.3	5.3	5.01	26	71	41	232	N	35	DZ1	TS
14	03.12.1983	1743:14.8	−6.45	71.27	6.1	6.3	31.3	12	303	37	313	N	35	DZ1	TS
15	12.12.1983	1723:16.5	−6.55	71.44	5.2	5.2	2.36	32	92	44	245	N	35	DZ1	TS
16	29.12.1983	0551:42.4	−6.72	71.33	5.0	5.2	1.25	10	100	46	225	N	35	DZ1	TS
17	05.04.1984	0301:33.7	−6.84	72.37	5.2	5.3	1.8	10	284	38	301	N	35	DZ3	TS
18	26.04.1984	1011:12.0	−6.40	71.60	5.8	5.3	2.45	10	299	39	300	N	35	DZ3	TS
19	06.11.1984	0758:51.3	−18.85	67.33	5.8	5.8	9.08	10	139	35	78	T	10	DZ4	TS
20	10.11.1984	0755:31.6	−18.85	67.37	5.6	5.3	0.56	10	148	24	84	T	10	DZ4	TS
Southeast Indian Ridge															
21	19.12.1965	2206:33.9	−32.24	78.87	5.5	–	13.3	11	300	68	304	N	4	BS	
22	17.02.1966	1147:57.3	−12.20	79.93	6.0	–	75.0	12	276	60	290	N	4	BS	
23	08.10.1968	0743:22.8	−39.85	87.74	5.8	5.8	20.3	9	6	54	269	N	5	BS	
24	03.05.1973	2311:04	−46.14	73.22	5.5	5.5	8.7	16	185	50	253	N	27	BS	
25	19.09.1975	0337:11	−34.74	81.88	5.9	6.1	38.7	18	241	63	275	N	13	BS	
26	02.11.1976	0713:17	−29.36	77.65	5.8	–	76.6	14	231	37	282	N	9	BS	
27	02.11.1976	1119:15	−29.24	77.79	5.6	–	6.1	14	249	41	293	N	10	BS	
28	22.05.1979	0155:55.8	−43.83	79.00	5.5	5.1	4.2	17	197	49	280	N	9	BS	
29	24.09.1981	2109:42.6	−45.65	79.86	5.4	5.5	4.4	11	142	37	247	N	14	BS	
30	21.01.1984	0827:51.5	−43.90	77.94	5.7	5.7	12.2	10	1	41	254	N	9	DZ2	TS
31	30.07.1988	1626:23.1	−33.12	83.81	5.1	5.1	0.80	10	15	42	227	N	21	DZ6	TS
Southwest Indian Ridge near 34°S, 58°E															
32	03.05.1925	2259.08	−33.58	58.14	–	7.0	350	11	75	80	245	N	21	WP	
33	02.09.1926	0121:51	−34.03	58.06	–	7.0	550	18	125	60	290	N	21	WP	
34	21.01.1933	1921:12	−33.47	57.75	–	7.0	1800	20	5	65	295	N	21	WP	
35	07.10.1949	1202:22	−33.62	57.75	–	6.75	160	16	30	59	293	N	21	WP	
36	14.12.1977	0300:14	−33.78	57.82	5.5	–	2.6	15	17	50	278	N	21	WP	
37	10.04.1982	0647:52	−33.89	58.02	5.6	5.4	2.6	12	119	34	309	N	21	WP	
38	08.09.1982	2112:26	−34.17	58.02	5.4	5.2	4.0	17	77	81	240	N	21	WP	
Southwest Indian Ridge near 37°S, 48°E															
39	26.02.1988	0617:31.9	−37.28	48.01	6.2	6.7	180	10	318	33	89	T	21	DZ5	TS
40	26.02.1988	1342:27.2	−37.19	47.8	5.5	5.2	1.1	10	310	35	79	T	21	DZ5	TS
41	26.02.1988	1752:34.9	−37.14	47.78	5.3	5.2	1.0	10	298	20	41	T	21	DZ5	TS
42	11.03.1988	0236:59.1	−37.41	47.99	5.4	5.6	1.1	10	303	31	51	T	21	DZ5	TS
43	14.05.1990	0652:01.7	−37.31	47.75	5.4	5.2	1.4	10	351	32	140	T	21	DZ7	TS

Table includes mechanisms of recent Events for the 1984–1993 period utilized in the present study. Moments are given in 10^{24} dyn cm. W1 = Wiens (1985); BS = Bergman and Solomon (1984); WS, Wiens and Stein (1984): WP = Wiens and Petroy (1990).
DZ1 = Dziewonski et al. (1984); DZ2 = Dziewonski et al. (1985a); DZ3 = Dziewonski et al. (1985b); DZ4 = Dziewonski et al. (1985c). DZ5 = Dziewonski et al. (1989a): DZ6 = Dziewonski et al. (1989b): DZ7 = Dziewonski et al. (1991); TS = additional events used in this study.

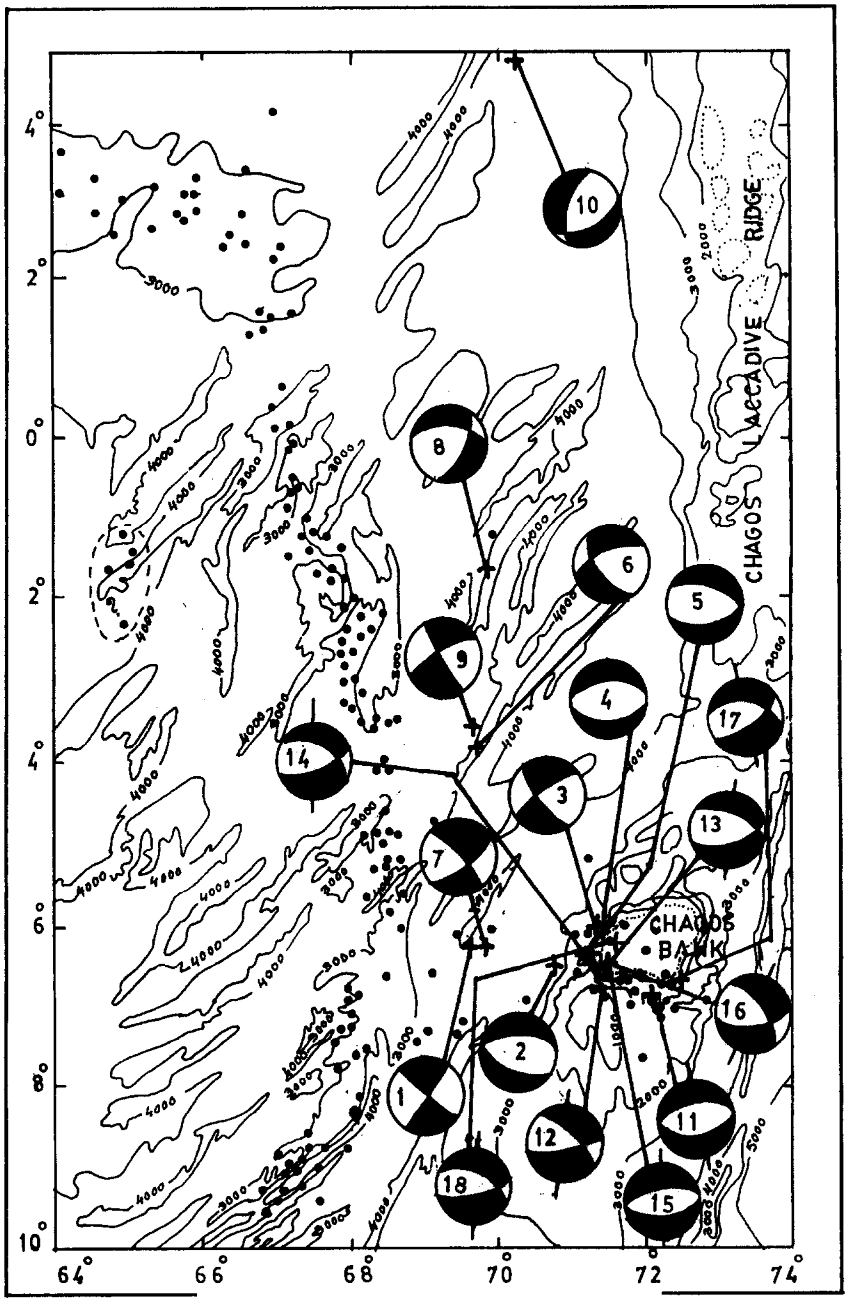

Fig. 3. Near-ridge seismicity observed along the northern part of the Central Indian Ridge. Filled circles are earthquakes which occurred on the ridge between 1964 and 1993. Crosses indicate events with mechanism solutions. The events encircled and question marked have large location uncertainties. Details of solutions are given in Table 2. The Chagos Bank seismicity (*2–5* and *11–18*) is characterized by dominantly normal faulting mechanisms with the *T*-axis mostly oriented in a N–S direction.

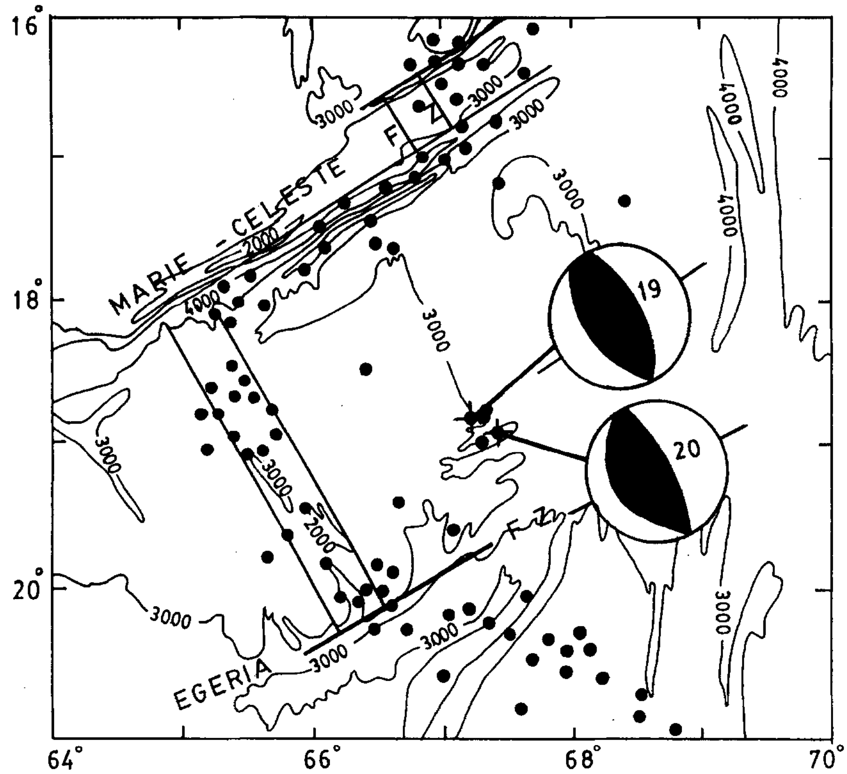

Fig. 4. Near-ridge seismicity observed along southern part of the Central Indian Ridge. Symbols are the same as in Fig. 3. The sequence contain two mechanisms (*19–20*) showing thrust faulting with the *P*-axis oriented perpendicular to the spreading axis.

0.39×10^{26} dyn cm and gives a long-term strain rate in the order of 7.7×10^{-14} S^{-1}. These strain rates are higher than the estimated strain rate of 10^{-15} S^{-1} for the seismically active Ninety East Ridge (Wiens and Stein, 1983), confirming that the near-ridge deformation involves a high level of stress in young lithosphere.

6. Relation of age to the mechanisms and moment release

For the mechanisms of events presented in Table 2, the ages of the lithosphere were obtained from the published anomaly identifications by Fisher et al. (1971), Sclater et al. (1981), Fisher and Sclater (1983) and compiled age data given by Royer et al. (1989). The age data assigned for each event are uncertain due to errors in location of events, errors in the identification of magnetic anomalies and the spreading rate. For all the events listed in Table 2, the errors in location would be 10–20 km. For a very slow spreading rate of 1 mm/yr, the corresponding age uncertainty would be less than 2 My. Wiens and Stein (1984) assigned a typical uncertainty of 2 My in their estimates of age. Since the events in Table 2 contain most of the larger near-ridge intraplate earthquakes and almost all the events occur within the plate interior, away from the major fracture zones, the uncertainties in age should be less than 2–3 My. We show, in Fig. 7a,b, the variation of mechanism type and total moment release with lithospheric age. These figures suggest that the near-ridge earthquakes in the Indian Ocean are dominated by extensive normal faulting events and that a large fraction of moment release takes place in the lithosphere of between 21 and 35 My of age.

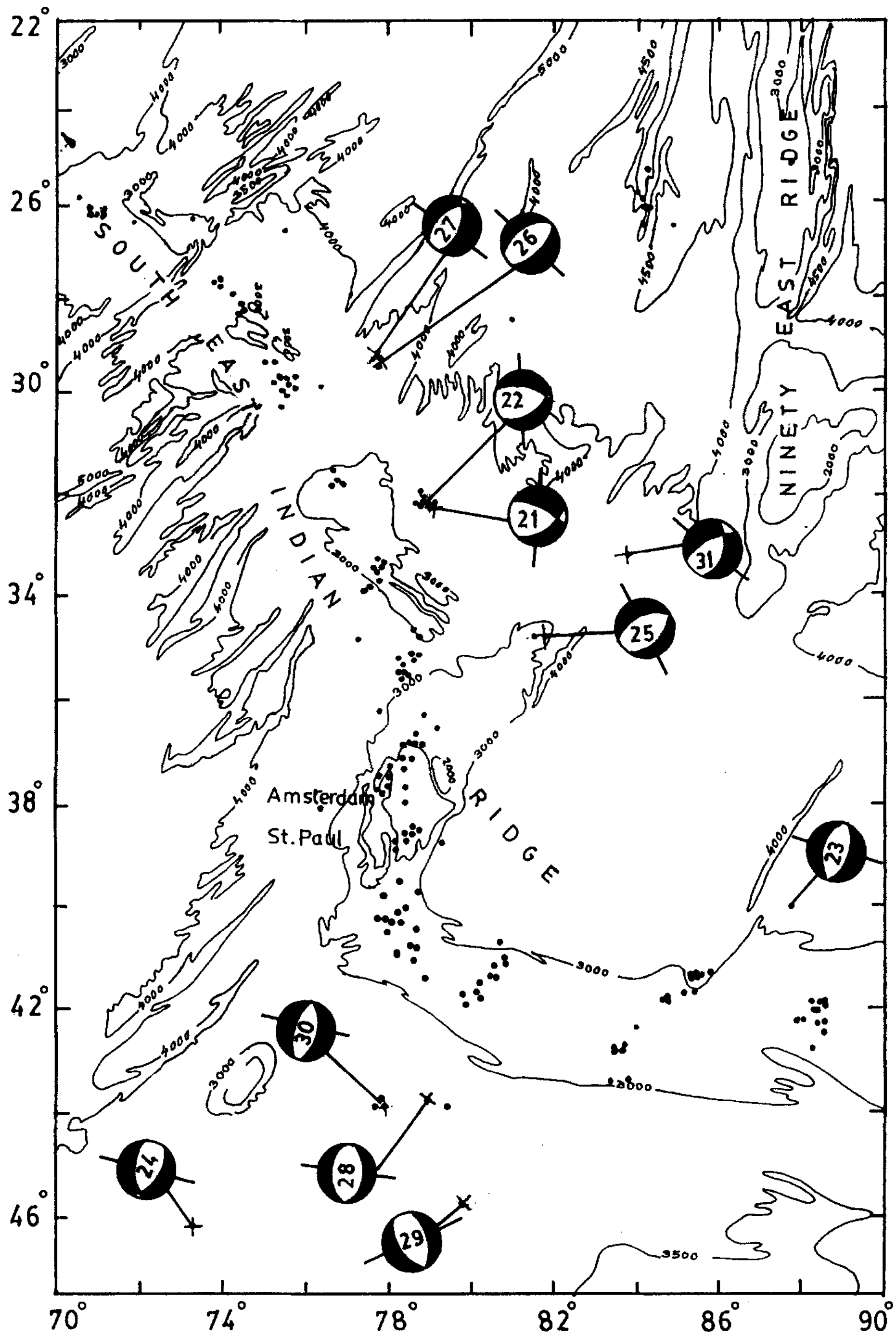

Fig. 5. Near-ridge seismicity observed along South East Indian Ridge. Symbols are the same as in Fig. 3. Solutions *30* and *31* are from the present study and solutions *21–29* are from Bergman et al. (1984). All the events show dominantly normal faulting with the *T*-axis oriented parallel to the spreading ridge.

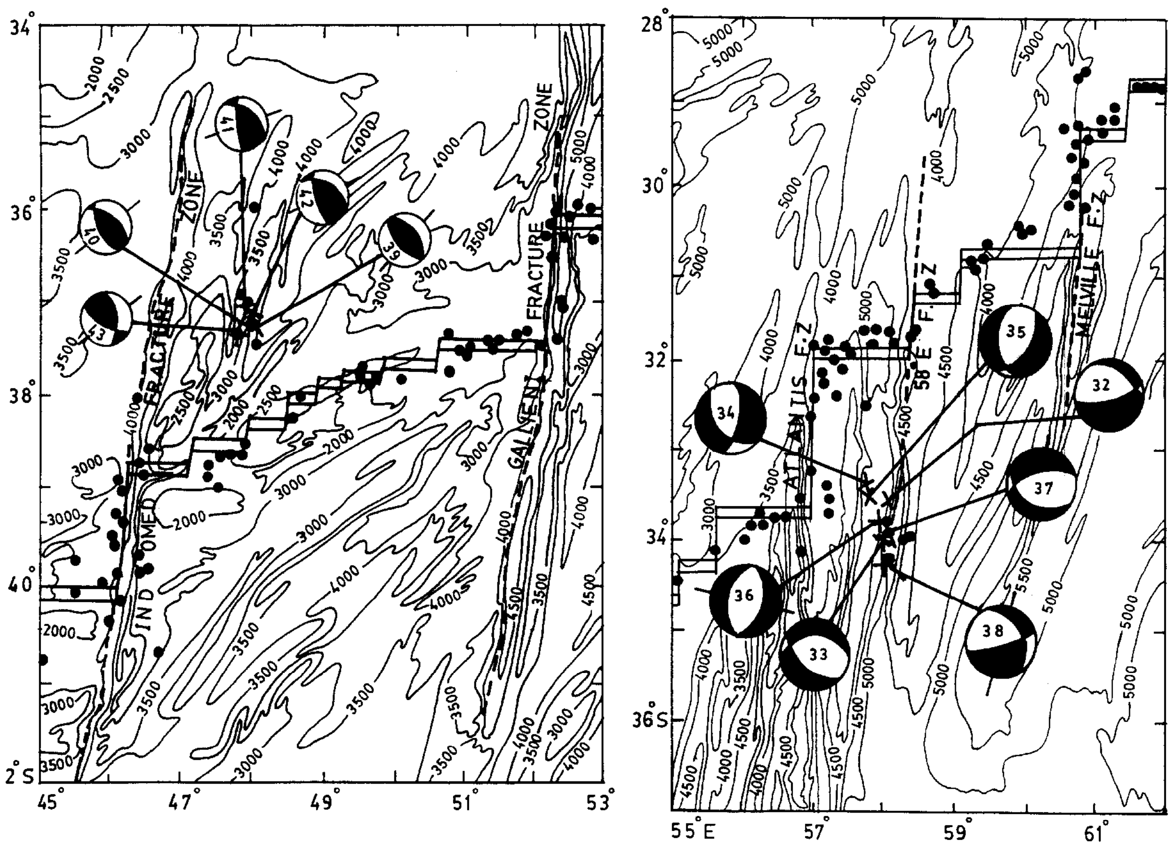

Fig. 6. Near-ridge seismicity observed along the Southwest Indian Ridge. Symbols are the same as in Fig. 3. The seismicity is characterized by the occurrence of highly energetic intraplate swarm/sequence of events concentrated in two regions on either side of the ridge. The mechanisms (*32–38*) near the Atlantis II Fracture Zone show predominantly normal faulting with no preferred orientation of the *T*-axis (Wiens and Petroy, 1990). The mechanism solutions (*39–43*) near the Indomed Fracture Zone on the African plate show thrust faulting with an uniformly oriented direction of the *P*-axis oblique to the spreading direction.

7. Discussion

Oceanic intraplate earthquakes, frequently associated with disturbed regions, are reliable indicators of stress field in the source region (Bergman, 1986). Certain characteristic features of intraplate earthquakes observed in the Central Indian Ocean by previous workers are: occurrence of normal faulting events on either side of the SEIR with *T*-axes parallel to the spreading ridge; normal faulting events with N–S oriented *T*-axes near Chagos Bank; strike–slip events with one of the nodal planes parallel to the trend of the fracture zones just east of the CIR; and thrust and strike–slip events with *P*-axes oriented along NW–SE regional stress field direction in the Intense Deformation Zone and the Ninety East Ridge region. This high level of seismicity observed in the Central Indian Ocean has been mainly attributed to plate-wide stress distribution and internal deformation (Bergman and Solomon, 1980, 1984; Wiens and Stein, 1984; Wiens, 1985). This is true for the older part of lithosphere (>35 My) confined to the Intense Deformation Zone in the Central Indian Ocean Basin and Ninety East Ridge region, where compressive regional stress field dominates. However, a combined analysis of near-ridge seismicity confined to the lithosphere <35 My in the Central Indian Ocean and SWIR reveals that: (1) the near-ridge events confine only to a short period of 21 years (1964–1984) in the Central Indian Ocean and during this time period very few events

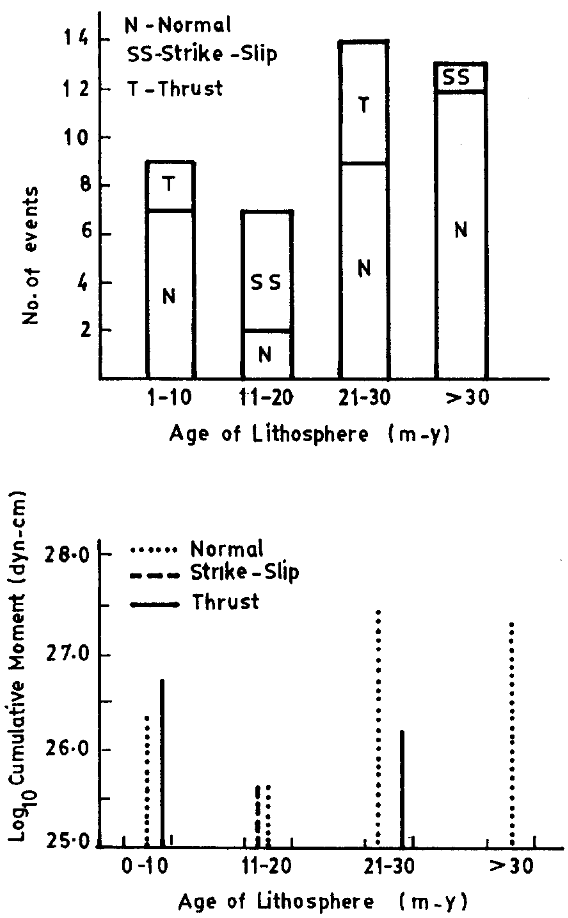

Fig. 7. Type of faulting and moment release of near-ridge events in the Indian Ocean as a function of lithosphere age.

occurred near the SWIR; and (2) the long-term moment release for the 1912–1993 period due to near-ridge seismicity in both these regions is comparable.

The characteristic difference in the seismicity pattern between these two regions is: while events near the SWIR are highly clustered and confined to two locations on either side of the ridge, the events in the Central Indian Ocean are highly scattered. The seismicity pattern of particular importance is the consistently occurring normal faulting events with T-axes parallel to the spreading ridge over a much wider zone along the SEIR (Bergman et al., 1984). Two more recent events (events 30 and 31) also give a similar faulting pattern. While the events on the Antarctic plate have been attributed to release of thermal and bending stresses associated with residual depth anomaly (Okal, 1981; Bergman et al., 1984), the Indian plate events represent the regional stress distribution as pointed out by Bergman et al. (1984). Though the seismicity near the Chagos Bank region appears to be similar to the seismicity observed near the Atlantis II Fracture Zone, in that: (1) both the regions have experienced highly energetic episodes of events concentrated in a much smaller region; (2) both regions have intraplate swarm events with no associated volcanism; (3) both occur along extensions of major fracture zones off-setting the nearby spreading ridge; (4) the fracture zones near to these regions are characterized by anomalously low moment release giving very low slip rates (Radha Krishna, 1995; Radha Krishna et al., 1995), the Chagos Bank seismicity is distinctly different and could be related to the plate-wide stress field based on several lines of evidence, such as more frequent occurrence of events, geographically widespread seismicity, consistent faulting pattern and plate motion inversion results indicating relative motion between India and Australia. The thrust faulting events (19 and 20) shown in Fig. 4 have P-axes oriented in the direction of spreading and occur at a depth of 10 km and on the lithosphere of 10 My of age. These events might be due to thermoelastic stresses related to cooling of the lithosphere. The thrust faulting events (events 39–43) near the Indomed Fracture Zone shown in Fig. 6a occur on a lithosphere of 21 My of age and show P-axes oblique to the spreading direction. These events could be related to very slow relative motion between the boundary separating Nubia and Somalia on the African plate. While this boundary is extensional along its northern part (the East African Rift), recent plate motion results by Dezhi et al. (1994) indicate that it should connect to the SWIR along a diffuse compressional segment.

8. Conclusions

Moment release computations based on a detailed catalog of near-ridge earthquakes pertaining to the younger lithosphere in the Indian Ocean suggest that the overall seismicity level in the Central Indian Ocean is not significantly higher as compared to the seismicity near the SWIR over a longer time interval (1912–1993). The characteristic seismicity pattern along the SEIR and CIR in the Central Indian Ocean over a much wider zone represents the plate-wide stress distribution as observed by others. Though the Chagos Bank seismicity appears to be similar to the seismicity observed near Atlantis II Fracture Zone along the SWIR, several lines of evidence, such as more frequent occurrence, scattered nature of seismicity, consistent faulting pattern and plate motion inversion results suggest that the Chagos Bank seismicity forms part of the plate-wide stress distribution in the Central Indian Ocean. The present study also demonstrates two examples of highly energetic sequences of events characterized by thrust faulting. While the thrust faulting events near the southern part of the CIR can be inferred due to thermoelastic stresses related to cooling of the lithosphere, the events near the Indomed Fracture Zone on the African plate have been attributed to slow relative motion between the boundary separating Nubia and Somalia which connects to the SWIR along a diffuse compressional segment. The available mechanisms suggest that the near-ridge seismicity in the Indian Ocean is characterized by dominantly normal faulting. The moment release computed for different ages suggests that a greater fraction of moment release takes place in the 15- to 35-My-old lithosphere.

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