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On the seismicity and tectonic activity of the Bengal basin

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सार — भू-कम्पनीयता के वर्ष 1850-1988 के लिए बंगाल बेसिन की विवर्तनिक क्रिया और ी–तरंग प्रथम गति आँकड़ा के 16 वर्षों (1970-1985) का अध्ययन किया गया। भूकम्पनीयता अध्ययन, तीन भूकम्पी कटिबन्धों जैसे धूबरी भ्रंश (प्रहार उत्तर–दक्षिण), कलकत्ता हिज क्षेत्र (प्रहार उ. पू०–द०प०) और बंगाल बेसिन के मध्य क्षेत्र (प्रहार उ० प०–द०पू०) को व्यक्त करता है। धूबरी भ्रंश की अपेक्षा डाउकी भ्रंश भूकम्पनीय रूप से अपेक्षाकृत कम सक्रिय है। धूबरी भ्रंश और कलकत्ता हिज क्षेत्र की भूकम्पनीयता को सीमित क्षेत्र तक बांध दिया गया है। बंगाल बेसिन के मध्य भाग सहित भूकम्पनीय सक्रियता हिमालय क्षेत्र (27° उ०, 88.5° पू०) से लेकर पूर्वी पट्टी सीमांत (23.8° उ०, 92° पू०) तक व्याप्त है। इससे विवर्तनिक कटिबन्ध का पता चलता है जोकि भारतीय पट्टी के उत्तरपूर्वी अपवाह के साथ सम्बद्ध है। नाभीय प्रक्रिया अध्ययनों से प्रणोद भ्रंशनों का पता चलता है जोकि प्रस्तावित पट्टी के अभिलम्बों के प्रतिबलों को व्यक्त करता है।

ABSTRACT. The tectonic activity of the Bengal basin for years 1850-1988 of seismicity and 16 years (1970-1985) of *P*-wave first motion data have been studied. The seismicity studies reveal three seismic belts such as Dhubri fault (striking N-S), Calcutta hinge zone (striking NE-SW) and the central region of the Bengal basin (striking NW-SE). Dauki fault is comparatively less seismically active than Dhubri fault. The seismicity of Dhubri fault and Calcutta hinge zone are confined to limited extension. The seismic activity along the central portion of the Bengal basin is extending from the Himalayan region (27°N, 88.5°E) to eastern plate margin (23.8°N, 92°E). This appears to be a tectonic belt and is associated with the northeast drifting of Indian plate. The focal mechanism studies reveal thrust faultings showing the stresses to be perpendicular to the proposed belt.

Key words — Seismicity, Tectonic, Bouguer anomaly, Teleseismic.

1. Introduction

The Bengal basin system is located in the northeast corner of Indian shield. The Bengal basin and its adjoining areas have been surveyed in detail by various geophysical methods (Sengupta 1966, Choudhury and Dutta 1973, Mukhopadhyay *et al.* 1986, Mukhopadhyay and Dasgupta 1988). Geophysical findings of different parts of the basin and adjoining areas have been discussed in different contexts revealing the structure of the basin and various faults in the surrounding regions, namely, Kishanganj, Dhubri and Dauki faults (ONGC 1968). Evans (1964) discussed tectonic framework of Assam suggesting movement of Garohills along Dauki fault producing a gap in the continuity of Indian shield which is known as Garo-Raj Mahal gap.

The different basins show different tectonic pattern. Tectonics in Surma basin, West Bengal basin and delta region of Bangladesh are due to differential crustal movement owing to mantle plumes. The tectonic patterns of the region have been changing in different geological ages which are associated with different basins. West Bengal basin show north-south faulting trend (Sengupta 1966, Farah 1973, Rao 1973, Agrawal 1977). Whereas Surma basin show east-west fault pattern and along Burmese arc folding in the sedimentary rocks have been reported north-south faulting trend. However, the central region of the Bengal basin system show faulting pattern mostly striking northwest-southeast.

In the present paper the seismicity and tectonic characteristics of the Bengal basin is studied. Stress distribution and faulting pattern have been studied by focal mechanism solutions. The trend of seismicity and focal mechanism solutions have been discussed in the light of northeast drifting of Indian plate.

2. Geology and tectonics

The geology of the basin is concealed by alluvium cover and sedimentary rocks. However, major geological features have been derived through geophysical observations (Sengupta 1966, Farah 1973, Agrawal 1977, Roybarman 1983, Verma and Kumar 1987). The geology of the region and adjoining areas is shown in Fig. 1. Geological formations at Raj Mahal and Garohills are exposed. Raj Mahal volcanic show their continuation towards Bengal basin and lies over the depressed Indian shield. It extends southward below the surface for at least 100 km below the tertiary sediments of Bengal basin (Sengupta 1966). The geophysical investigation reveals the nature of sedimentary formations, their ages and thicknesses. It has been reported that the thickness and nature of sedimentation are different at different places.

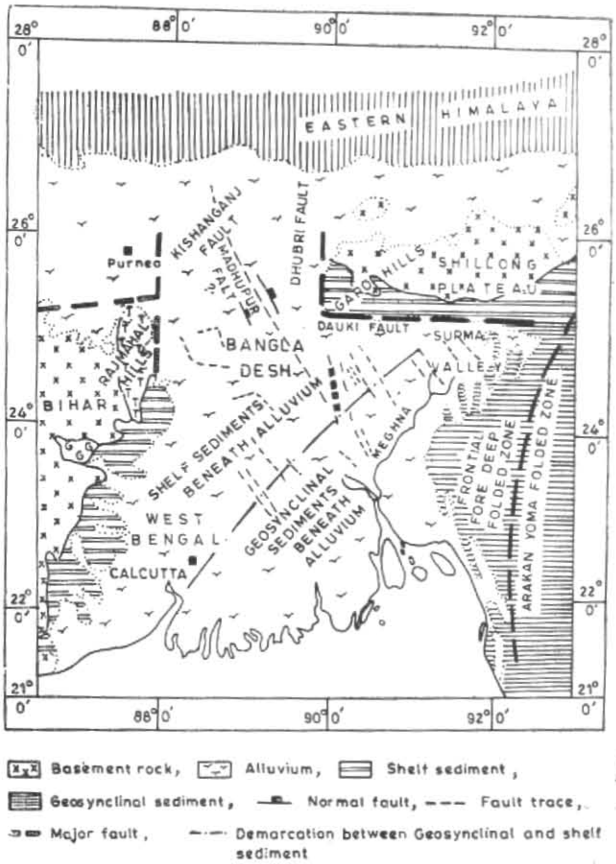


Fig. 1. Geology and tectonic map of Bengal basin system and adjoining areas

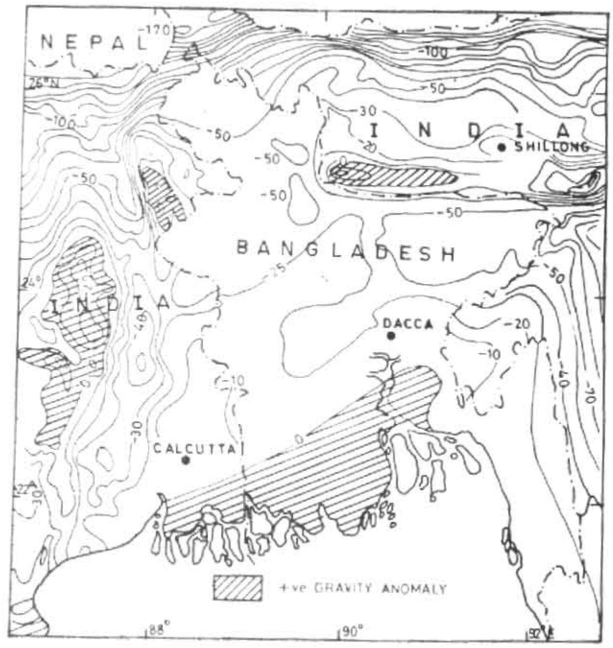


Fig. 2. Bouguer gravity map of the Bengal basin system and its adjoining areas [*Source*, NGRI Bouguer anomaly map 1964, Western Economic and Social Commission for Asia and Pacific (ESCAP) 1967]. For Indian region the contour interval is 10 mgal whereas for Bangla Desh it is 25 mgal. Positive gravity anomaly is indicated by hatched lines

In the north of the basin the basement rock of the Shillong plateau is present showing Archean quartzites slates and schists with masses of granitic instructions, and basic inter-bedded traps. The basement rocks are overlain by horizontal Eocene and stones. To the east of the basin are Tripura and Chittagong hills. These are composed of sediments of Paleocene through Pliocene age which almost includes Siwalik system. Tectonic characteristics of the basin is different at different places. The outer region of the basin show three major faults which are known as Kisanganj, Dhubri and Dauki faults. Verma and Kumar (1987) reported Madhupur fault which has not been reported in the tectonic map of India prepared by Geological Survey of India and Oil and Natural Gas Commission. The composite tectonic map of the region is shown in Fig. 1. The Chittagong and Tripura hills are formed by folded sediments whose folding axis form an arc convex towards the west. The northern Tripura hills show a series of plunging anticlines which die out under the overlapping crescent sediments of the Sylhet basin.

3. Formation of basin

The Bengal basin system is composed of many basins such as West Bengal basin, Surma basin etc which are evolved in different geological periods. All the basins combined together form the Bengal basin system.

During Cretacerus, India was on the southern hemisphere at 48°S which started drifting towards north. During course of drifting towards north the eastern region passed over hot spots. The hot spots were covered by Indian subcontinent for millions of years which made upper mantle unstable (McKenzie and Sclater 1971). The eruption in the region took place by rising of hot material into the crust. Hobson (1929) has identified 28 eruption in the Raj Mahal region, which covers very large area of the basin. West Bengal basin is the result of this volcanic eruptions where sedimentary thickness are found 20,000 ft (6.8 km), thick. At some places the Molten material could not come to the surface. These can be identified at the surface by high gravity anomaly. The plumes are associated with low gravity which are produced by sinking of the region.

4. Gravity anomaly

Bouguer anomaly pattern for the region is shown in Fig. 2 (NGRI 1964 and ESCAP 1967). The Bouguer anomalies over the Bengal basin and adjoining areas show three distinct contour trends reflecting the major structural trend; an east-west over the Shillong plateau, north-south over Raj Mahal and northeast-southwest over the deltaic region of Bangladesh. These areas show positive gravity anomaly which are ranging 25 mgal to

TABLE 1

Catalogue of earthquakes of Bengal basin and adjoining areas (21.5° N - 27.5° N and 86.5° E - 92.0° E) of magnitude ⩾ 4.0 from 1850-1988

Date	Location		Magnitude	Date	Location		Magnitude
	Lat. (°N)	Long. (°E)	*M*		Lat. (°N)	Long. (°E)	*M*
07 May 1850	22.6	88.4	4.3	15 Sep 1967	27.4	91.8	5.8
09 Feb 1851	22.6	88.4	5.7	10 Nov 1967	25.5	91.7	4.4
May 1852	27.0	88.3	7.0	14 Nov 1967	24.0	91.5	5.1
16 Mar 1858	21.5	87.0	4.3	12 Jun 1968	24.9	91.9	5.3
16 Feb 1861	22.6	88.4	5.7	18 Aug 1968	26.4	90.6	5.2
18 Jun 1862	22.0	88.3	5.0	27 Dec 1968	24.1	91.6	5.2
29 Mar 1863	27.0	88.3	5.7	03 May 1969	23.0	86.6	5.7
08 Jun 1863	27.0	88.3	5.0	01 Jun 1969	25.8	91.8	5.0
11 Aug 1863	27.0	88.3	5.0	11 Nov 1969	26.3	91.7	4.5
23 Jan 1866	21.8	87.8	5.0	25 Jul 1970	25.7	88.5	5.2
23 May 1866	25.0	87.0	5.6	28 Aug 1970	24.6	91.7	4.9
10 Jan 1869	26.0	90.0	6.3	02 Feb 1971	23.8	91.8	5.4
23 Mar 1869	27.0	88.0	4.3	31 Oct 1971	26.2	90.7	4.6
09 Jun 1869	22.6	88.4	4.3	21 Aug 1972	27.2	88.0	4.8
09 Aug 1869	27.0	88.3	5.7	21 Aug 1972	27.2	88.0	5.1
26 Apr 1875	27.0	88.3	4.3	06 Nov 1972	27.0	88.7	4.8
14 Jul 1885	24.0	90.0	5.7	02 Nov 1973	25.7	91.6	4.8
24 Jul 1885	25.0	89.2	5.7	15 May 1974	25.5	91.8	4.5
23 Dec 1888	22.6	88.4	4.3	21 Sep 1974	25.7	90.9	4.7
25 Sep 1889	27.0	88.3	6.3	17 Jan 1977	26.4	90.5	4.9
12 Jun 1897	26.0	91.0	8.7	05 Jun 1977	26.1	88.4	4.7
29 Sep 1906	22.6	88.4	5.0	13 Jan 1979	27.4	91.9	4.4
06 Dec 1906	22.6	88.4	5.0	28 Jan 1979	24.9	91.0	4.9
09 Sep 1923	25.3	91.0	7.1	26 Feb 1979	26.0	91.2	4.3
02 Jul 1930	25.5	90.0	7.1	02 Apr 1979	26.5	90.7	4.4
24 Mar 1932	25.0	90.0	5.6	11 Apr 1979	25.9	88.8	4.7
27 Mar 1932	24.5	92.0	5.6	19 Jun 1979	26.7	87.5	5.2
09 Nov 1932	26.5	92.0	5.6	29 Jul 1979	26.8	91.8	4.5
06 Mar 1933	26.0	90.5	5.6	11 Jun 1980	25.8	90.3	4.9
21 Mar 1935	24.2	89.5	6.3	30 Oct 1980	23.9	91.5	4.6
11 Feb 1936	27.5	87.0	5.6	19 Nov 1980	27.4	88.8	6.0
29 Jan 1938	27.5	87.0	5.5	01 Dec 1980	22.1	90.9	4.7
21 Jan 1941	27.0	92.0	6.8	22 Dec 1980	26.7	89.6	4.4
17 Apr 1955	26.5	90.0	4.5	19 Mar 1981	26.3	90.5	4.8
29 Aug 1955	26.0	90.5	4.3	26 Mar 1981	22.3	89.1	4.9
20 Sep 1955	27.5	90.0	5.7	21 Jun 1981	27.2	87.1	4.0
23 Nov 1955	26.5	90.0	5.0	20 Nov 1981	21.7	90.8	4.1
12 Jun 1956	24.8	90.9	5.3	28 Jan 1982	25.5	90.9	4.4
09 Feb 1958	25.0	90.5	5.0	26 Feb 1982	25.8	90.6	4.6
13 Feb 1958	27.5	92.0	5.5	05 Apr 1982	27.4	88.8	5.0
15 Dec 1959	27.0	88.0	4.3	20 Jun 1982	26.2	89.9	4.5
21 Aug 1960	27.0	88.5	5.5	06 Jul 1982	25.9	90.3	5.0
18 Feb 1964	27.5	91.1	5.6	18 Aug 1982	27.0	89.3	4.6
27 Mar 1964	27.2	89.3	6.3	31 Aug 1982	25.4	91.5	5.0
15 Apr 1964	21.7	88.0	5.5	21 Sep 1982	25.2	91.3	4.0
12 Jan 1965	27.3	87.7	5.3	18 Nov 1982	26.4	91.8	4.8
06 Nov 1965	27.1	91.7	4.3	30 Dec 1982	26.0	91.7	4.9
24 Feb 1966	26.3	91.5	5.1	30 Dec 1982	26.3	91.7	4.6
23 Mar 1966	25.9	90.0	4.4	19 Jan 1983	25.5	91.4	4.8
23 Apr 1966	26.0	90.4	4.7	23 Jul 1983	25.4	91.3	4.7
26 Jun 1966	26.2	91.8	4.8	17 Nov 1983	25.2	91.7	4.4
30 Jan 1967	25.4	90.5	5.0	23 Dec 1983	25.9	87.9	4.3
16 Jul 1967	23.5	87.5	4.3	21 May 1984	23.7	91.5	5.2
06 Sep 1967	24.1	91.7	5.0	30 Sep 1984	25.4	91.5	5.0

TABLE 1 (*Contd.*)

Date	Location		Magnitude
	Lat. (°N)	Long. (°E)	M
07 Jan 1985	27.1	91.9	5.4
20 Jan 1985	27.2	91.8	4.6
20 Jan 1985	27.1	91.9	4.6
17 Jun 1985	25.7	90.2	4.6
02 Oct 1985	27.2	89.7	4.4
03 Nov 1985	23.6	91.5	4.7
07 Jan 1986	27.4	88.4	4.7
19 Feb 1986	25.1	91.1	5.2
14 Oct 1986	25.0	91.9	4.6
22 Oct 1987	27.1	89.1	4.2
06 Feb 1988	24.7	91.6	5.8
06 Feb 1988	24.7	91.6	5.8
28 Feb 1988	24.7	90.5	4.6
27 Mar 1988	27.1	88.4	4.1
20 Apr 1988	27.0	86.7	5.4
25 Apr 1988	26.9	86.5	4.7
30 Apr 1988	25.9	91.6	4.2
10 May 1988	25.3	90.9	4.4
26 May 1988	27.5	88.6	4.7
20 Aug 1938	26.7	86.6	6.4
04 Sep 1988	26.3	91.8	4.4
27 Sep 1988	27.2	88.4	5.0
13 Dec 1988	27.1	87.9	4.4

50 mgal. Thus the basin is surrounded from three sides by positive gravity anomaly. The range of Bouguer anomalies for the Bengal basin is 0 to —25 mgal which increases towards east. The large negative anomalies in the eastern region have been interpreted in terms of plate subduction. The thickness of the sediments in the eastern part of the basin has been estimated to be about 10 km but may be as thick as 15 km at the subduction zone (Mukhopadhyay and Dasgupta 1988). The structures showing high and low gravity values may be explained as a result of intrusion of upper mantle into the crust and sinking of the respective adjoining areas.

5. Seismicity

Reliable seismicity map for the basin is difficult to prepare because of poor distribution of recording stations in the adjoining areas. Gupta (1976) has shown that earthquake detectability levels for the Burmese seismic zone and its adjoining area are extremely poor. The earthquakes of magnitudes $M \geqslant 5.0$ are reported in the bulletins with a very small number of smaller magnitude earthquakes. This suggest incompleteness of lower magnitude earthquake catalogues. In view of the above it is very difficult to study seismic characteristics of the region. However, certain conclusions can be drawn if along duration of seismicity data are studied. In order to study the seismicity of the region (21.3° N-27.5°N and 86.5° E-92°E), one hundred and thirty nine years of seismicity data has been considered. The seismicity data has been taken from Chandra (1977), National Geophysical Data Centre (NGDC), Colorado, Boulder

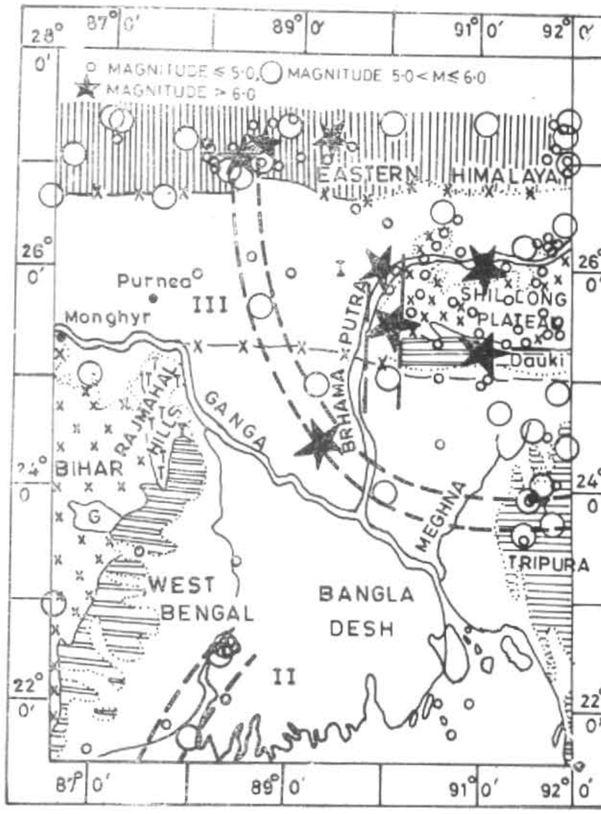


Fig. 3. Seismicity map of the Bengal basin and its adjoining areas showing earthquakes since 1850 to 1988. 'o' denotes earthquakes with magnitude $\leqslant 5.0$, 'O' represents the range $5.0 < M \leqslant 6.0$ and * denotes earthquakes of magnitude > 6.0. The magnitude from the macroseismic effect has been derived using Gutenberg and Richter (1956) relation. Three seismically active zones are identified and marked by sector 1 to 3

and the Regional Catalogues of Earthquakes. All the earthquakes of the considered region are listed in Table 1. The magnitude and epicentre of old earthquakes have been derived from macroseismic observations. A very few earthquakes are available for the basin areas reporting P-wave first motion data in the ISC bulletins. For focal mechanism studies the P-wave first motion data has been taken from *Bulletin of International Seismological Centre*.

The seismicity for the region for period 1850-1988 with events $M \geqslant 4.0$ is shown in Fig. 3. The seismicities of the north and east of the basin are associated with Himalayan and Burmese thrust. The distribution of seismic activity of the basin system may be classified into three sectors.

Sector 1 is the seismic activity associated with Dhubri fault striking north-south. This is located to the north of the Bengal basin. Sector 2 is the seismicity associated with the Calcutta hinge zone which strike northeast-southwest. Sector 3 is the arcual shaped seismic belt passes through the central portion of the Bengal basin striking almost northwest-southeast. The seismic activity of the region is low. The largest earthquake of Bengal basin system is Pabana earthquake of 21 March 1935 which was of magnitude 6.3.

TABLE 2

ISC parameters of earthquakes for Bengal basin and Dhubri fault

Event	Date	Origin time h	m	s	Epicentre (°N) (°E)	Focal depth (km)	Magnitude
1	25 Jul 1970	01	35	26.0	25.72, 88.58	32	5.1
2	02 Feb 1971	07	59	55.8	23.71, 91.66	37	5.4
3	23 Jun 1976	15	38	42.7	21.18, 88.62	50	5.0
4	31 Aug 1982	10	42	45.5	25.38, 91.46	32	5.0
5	19 Jan 1983	12	09	33.3	25.46, 91.36	10	4.8
6	03 Nov 1985	03	57	52 0	23.61, 91.52	09	4.7

TABLE 3

Focal mechanism solutions for the earthquakes reported in Table 2

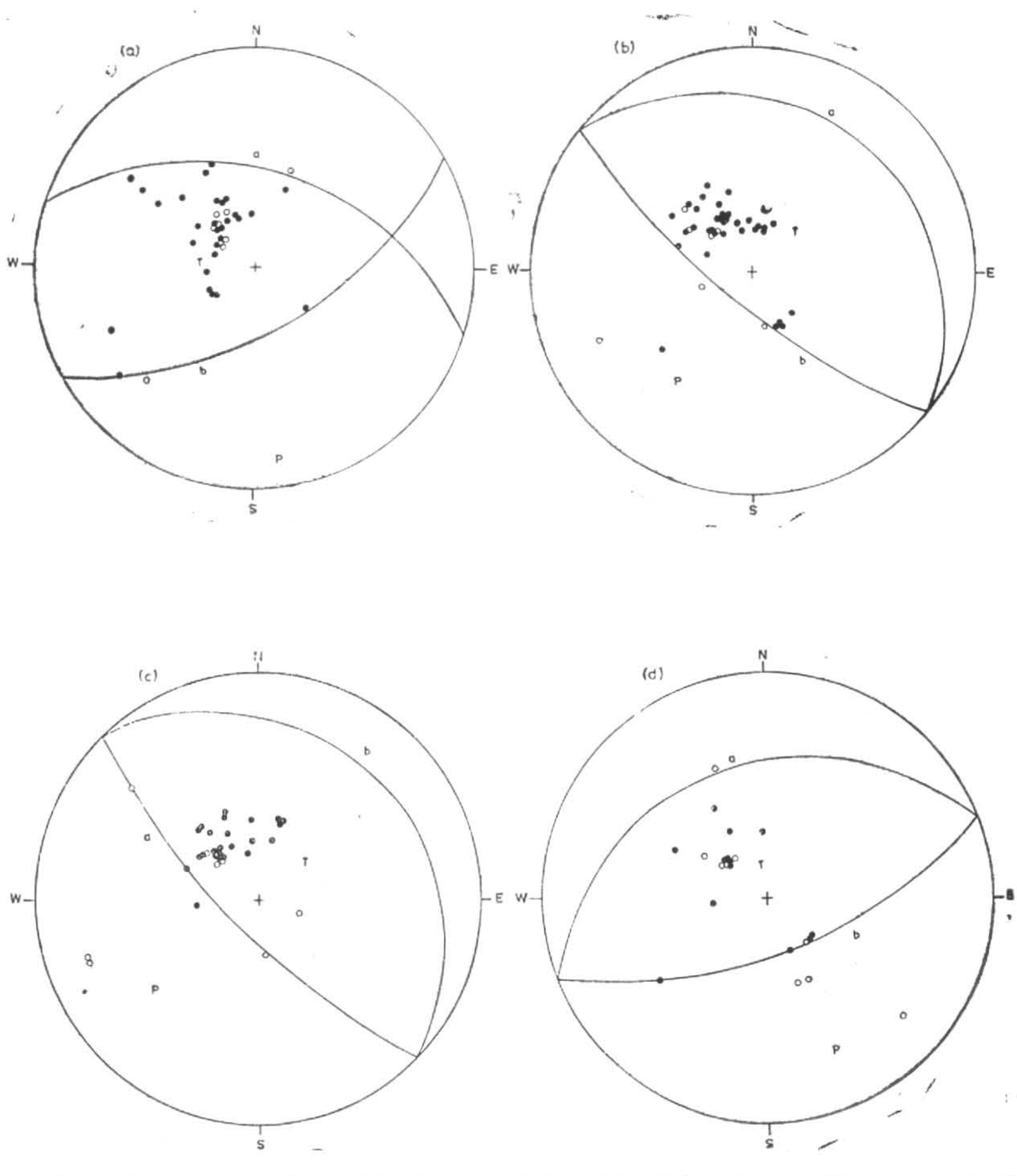
Event No.	Plane '*a*' Strike	Dip Drn.	Dip	Plane '*b*' Strike	Dip Drn.	Dip	*P*-axis Dip	Azimuth	*T*-axis Dip	Azimuth	*B*-axis Dip	Azimuth
1	N74W	016	41	N58E	152	58	08	172	62	276	25	076
2	N52W	218	73	N52W	038	16	28	218	61	038	00	308
3	N44W	225	74	N44W	045	16	28	225	62	045	00	316
4	N69E	338	23	N69E	158	60	16	158	74	338	00	069
5	N66E	336	72	N66E	156	16	26	338	62	156	00	067
6	N60W	210	86	N60W	030	04	48	030	38	210	00	300

6. Focal mechanism and stress pattern

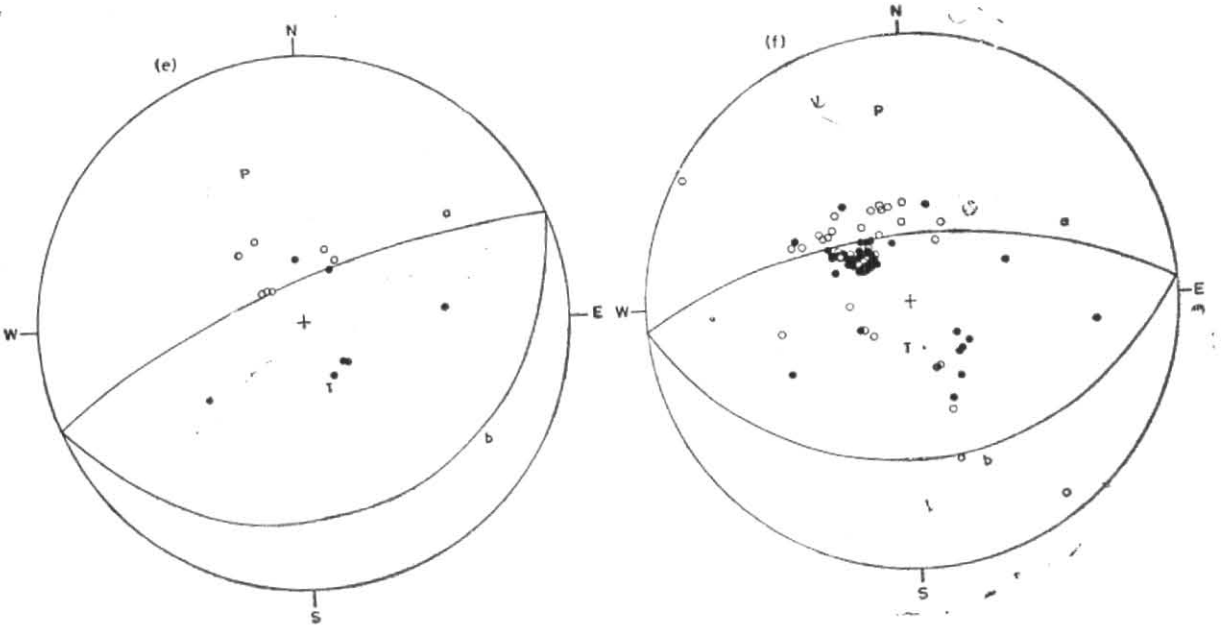
Tectonic motions and stress distribution pattern in the Bengal basin are inferred through fault plane solutions. Six new focal mechanisms of earthquakes of the Bengal basin and adjoining areas are determined using *P*-wave first-motion data as reported in ISC bulletins. ISC parameters of the considered earthquakes are shown in Table 2. Focal mechanism solutions for the events are shown in Figs. 4 (a-f) in which filled circles represent first-motion compressions and open circles first-motion dilatations. The reliability of the solutions depends on the percentage of inconsistency of observations. In the present case it varies from 10 to 15%. Such inconsistencies may be due to difficulty in reading observations on short period seismograms at teleseismic distances. Table 2 shows the orientation of the nodal planes and *P*, *B* and *T* axes. The fault plane has been designated by '*a*' and auxiliary plane by '*b*'. Of the considered events four earthquakes are from the Bengal basin and two are from Dauki fault. In the basin forces are acting towards northeast whereas in Dauki fault it is towards southeast. The direction of stresses deduced from fault plane solutions are shown in Fig. 5.

7. Discussions

The area has under gone different stages of geological evolution forming different basins at different times which are well reflected by geological and geophysical evidences. The seismicity and faulting pattern of the region are different for different basin. The present tectonic activity of the basin system shows different trend as shown in Fig. 3. The Shillong plateau is surrounded by Dhubri fault in the west and Dauki fault in the south showing high positive gravity anomaly. The basement rock is composed of Archean quartzites with masses of granitic intrusions and basic interbeded traps. These rocks are more brittle than the surroundings and hence can easily produce earthquakes if subjected to stresses. Hatherton (1971) reported that the area of thick granitic layer to be seismically more active and produce comparatively larger earthquakes than other region of Hikurangi margin. In view of the above, it may be advocated that the seismicity of Shillong plateau is due to region being compressed by northeast drifting of Indian plate and lying between the Himalayan trench to the north and the Burmese arc trench to the east. As the Shillong plateau is more brittle in nature than the surroundings the area is showing high seismic activity. Fig. 3 demonstrates the Dhubri fault to be more active than Dauki fault which is very difficult to explain. The seismic activity of sector 1 is associated with Dhubri fault striking north-south. This fault is well reflected by gravity anomalies of the region. It has produced earthquakes of magnitude $M \geqslant 6.0$ up to depth of 40 km. The earthquakes of this fault are of tectonic origin and may be treated as intraplate earthquakes. The seismicity of



Figs. 4 (a-d). Lower hemisphere stereographic projection for six fault plane solutions of the considered areas. The solid and open circles indicate, respectively, first motion compressions and dilatations. *P*, *T* and *B* correspond to pressure, tension axes and null point, respectively "*a*" and "*b*" are fault and auxiliary planes. The solution parameters are given in Table 2



Figs. 4 (e&f). Lower hemisphere stereographic projection for six fault plane solutions of the considered areas. The solid and open circles indicate, respectively, first motion compressions and dilatations. *P*, *T* and *B* correspond to pressure, tension axes and null point, respectively "*a*" "*b*" are fault and auxiliary planes. The solution parameters are given in Table 2

Fig. 5. Direction of stresses in the Bengal basin derived from focal mechanism solution

sector 2 is associated with Calcutta hinge zone which strikes northeast-southwest. In this sector medium size earthquakes of magnitude up to 5.5 have been reported. The focal depth for the earthquakes have been reported to be 50 km. The thickness of sedimentary rock along the hinge zone is of the order of 20,000 ft (ONGC 1968). The high thickness of sedimentary rocks may be due to unstable upper mantle which may be also responsible for earthquake generation in the crust. The fault plane solution for the event No. 3 reveals the strike of the fault trending northwest-southeast which is perpendicular to the strike of the seismic zone. In view of the above, it may be advocated that probably instability in the upper mantle is the cause for the accumulation of energy for earthquake generation, but the triggering action is due to northeast drifting of Indian plate.

The seismicity of the central portion of the Bengal basin is of arcual shaped striking northwest-southeast. The central portion of the basin shows a number of faults striking northwest-southeast (Morgan and McIntyre 1959) which are coinciding with strike of sector 3 and also Madhupur fault. Verma and Kumar (1987) have raised doubt over the existence of Madhupur fault. Most of the earthquakes are of magnitude more than 5. One large earthquake of magnitude 6.3 occurred in 1935. The focal depth for all the events are within the crust. The depression in the basin is reported to be of V-shaped coinciding with the seismicity trend. This is further supported by magnetic anomalies which reflects the depth of Raj Mahal trap to be increasing towards the central portion of the basin. The high activity at the both the ends of the belt which is observed around 27°N, 88.5°E and 23.8°N, 92°E may be the result of the interaction of this new depressed zone with Himalayan thrust and Burmese arc, respectively. The fault plane solutions reveal thrust faulting with *P*-axis perpendicular to the proposed belt. The seismicity trend passing through the central portion of the basin is not localized phenomena. Though the earthquakes are confined to the crustal zone only, however, the distribution trend of earthquakes, fault plane solutions and their magnitudes suggest that a new tectonic belt might be developing in the region.

8. Conclusions

In view of the orientation of seismic activity and fault plane solutions the following conclusions may be drawn :

(*i*) The *P* axes are shallow dipping in the basin which are directed towards northeast in the basin.

(*ii*) A new tectonic belt is developing across the Bengal basin system.

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