ON EARTHQUAKE FOCAL MECHANISM STUDIES FOR THE BURMESE ARC

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ABSTRACT–*Three main morphological units comprise the Burmese arc: the Indoburman ranges, the Burmese lowlands and the volcanic arc. The Indoburman ranges consist chiefly of colossal accumulations of Paleo–Eocene flysch accreted at plate margin due to successive underthrusting of the turbidites near the Burmese subduction zone where the Indian plate descends below the Burma plate. Across the Burmese lowlands, the Sagaing transform defines another plate margin between the Burma and SE Asian plates. Active deformation, both in crust and deeper lithosphere, below the region is evidenced by geological and geophysical data, recent volcanism and current seismicity. Seismicity data for a period of 25 years (1956–80) are analysed here to define the details of the Burmese Benioff Zone over the 1100 km long strike-length of the Burmese arc. The Benioff Zone dips eastward at about 45° angle and penetrates upto 180 km depths. The seismicity is however, highly subdued in coastal Burma, possibly, due to a fossil plate boundary. An inland seismic zone appears to define the overriding Burma plate. A triangular aseismic wedge in top crust outlines the Burmese forearc basin in Chindwin east of the Indoburman ranges. Results of 45 focal mechanism solutions are examined here to study the deformation pattern at the two plate margins for the Indian, Burma and SE Asian plates. Their results demonstrate that a double seismic zone (like that of Western Pacific arcs) possibly exists in the Burmese Benioff Zone, whose, upper edge is characterized by low-angle thrust events and the lower edge mostly has down-dip tensional events. This result is significant because of the proximity of the Burmese arc to intensely seismic Eastern Himalaya to its immediate north. Most of the Burmese backarc seismicity originates with the Sagaing transform, which according to the focal mechanism studies, undergoes right-lateral slip. Some backarc seismicity also occurs in association with the Shan scarp, which is postulated as a normal fault zone dissecting the Shan plateau of the SE Asian plate against the Burmese lowlands.*

INTRODUCTION

The Burmese arc evolved since the late Mesozoic in consequence to eastward subduction of the Indian lithosphere at the continental margin of SE Asia. It is one of the few regions in Asia and Europe where intermediate depth earthquakes still occur in a land environment. The Burmese arc, together with the Andaman arc further south, acts as an important transitional link between the collisional phase of the Himalaya on the north and the Sunda arc to the south (figure 1); the latter is in direct tectonic continuation with the Western Pacific arc system. Because of economically important resources, gem stones, and oil reserves, Burma attracted the attention of early explorers since the very beginning of this century; as a result two excellent monographs on the Burmese geology and mineral resources were published more than fifty years ago[4,5]. With the advent of plate tectonics, Burma has again been the site of renewed geoscientific studies since the region provides an excellent scope to test various geologic models owing to its transitional tectonic set up between a truly collisional phase (of the Himalaya) and a typical consumptive margin (the Sunda arc), where, surface geology, aerial photographs and interpretation of satellite images put important constraints for any tectonic models chosen.

In the present article a review study is presented in relation particularly to seismicity below the Burmese arc, results of focal mechanism studies, stress pattern and motion along prominent faults etc. The results are next interpreted to study tectonics of the region.

REGIONAL TECTONIC SETTING

The Burmese arc is nearly 1100 km long in north-south direction, convex westward, and comprises of a western foldbelt (called; the Indo-Burman ranges) and the Burmese lowlands further east separated by a prominent thrust (figure 1). The Indo-Burman ranges constitute the Arakan-Yoma, Chin, and Naga hills, which pass northeastward to link them with the Himalaya. Southward the ranges continue into the Andaman, Nicobar and Mentawai Islands in NE Indian Ocean. The foldbelt width exceeds 150 km in its central part, where, a succession of north-south ridges delineate the outer fold axes against the Bengal basin to

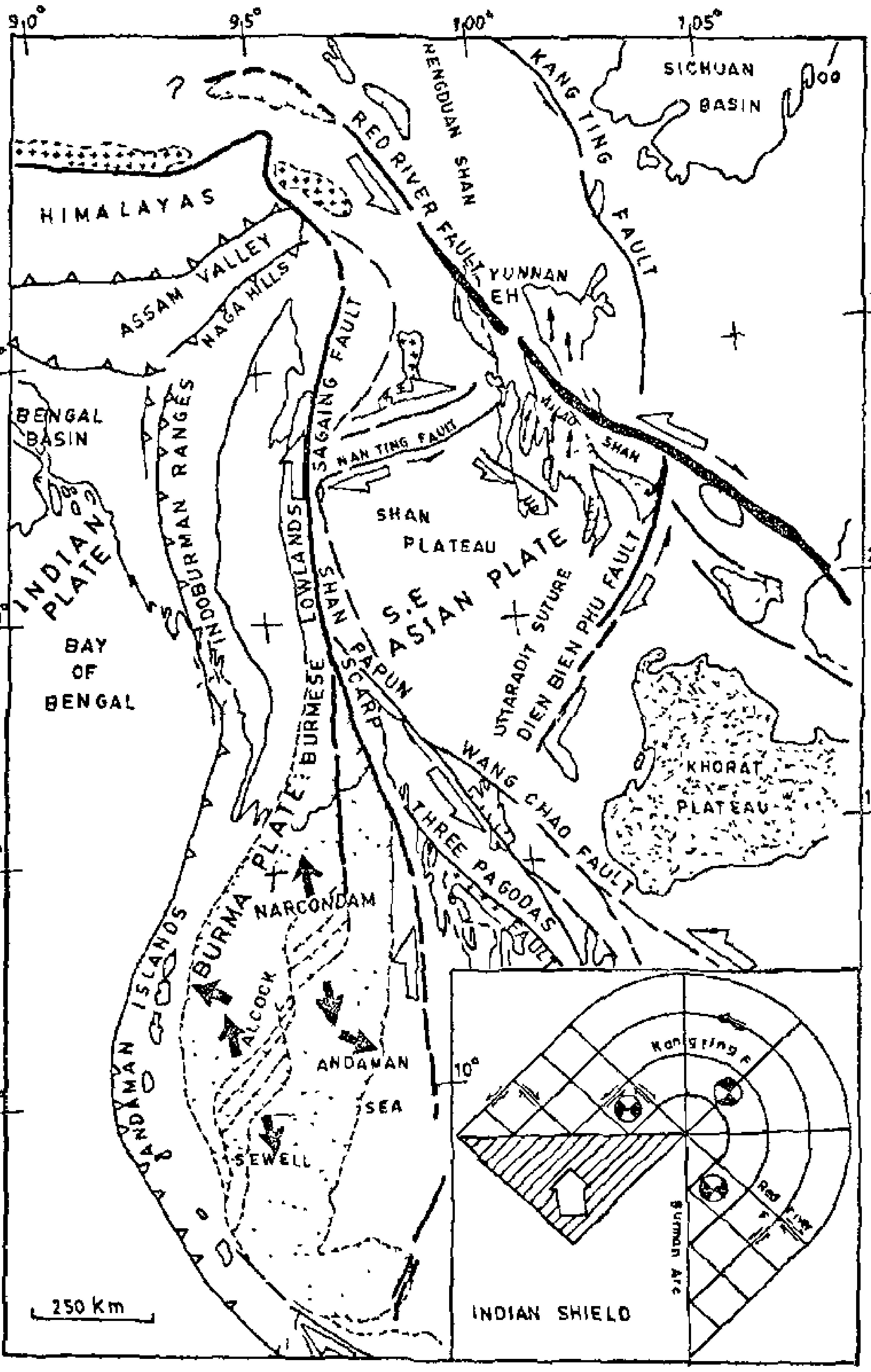


FIGURE 1 Tectonic sketch map for the Burmese-Andaman arcs and adjoining areas in the Himalaya and Indo-China. Large open arrows indicate mid-Tertiary sense of movement, thin black arrows indicate Quaternary movement, thick black arrows indicate sense of spreading below the Andaman Sea in consequence to backarc spreading activity. Stipled areas below the Andaman Sea and Burmese lowlands are inferred positions of new oceanic crust due to the spreading episode. Inset shows thematic plane-strain slip-line fields due to flat-face rigid indentation of the Indian shield at the northeast corner of the Himalaya; some extensive lateral faults are identified. Redrawn after Tapponnier et al.[24].

the west. The north-south fold axes are results of east-west compression acting regionally against the Burmese arc. The Burmese lowlands are divided into the Eastern and Western Troughs by the Burmese volcanic arc[17]. The volcanic arc, like the outer sedimentary arc, also continues southward across the Gulf of Martaban into the active volcanoes seamounts of the Andaman Sea, namely; the Barren-Narcondam, Alcock, Sewell[9] (figure 1). A prominent transform fault the Shan-Sagaing fault, defines the eastern limit of the Burmese lowlands against the Shan plateau that forms a part of the SE Asian plate; the Shan plateau is covered with Mesozoic rocks. The Shan-Sagaing transform connects southward with the Andaman back-arc spreading ridge which has remained active for the last 11 m.y.b.p. Curray *et al.*[6] have proposed a lenticular plate, called the Burma plate, that exists between the Indian plate and the Indo-China block of SE Asia. The origin of the Burma plate relates to the spreading episode under the Andaman Sea. Spreading direction for the short back-arc ridges under the Andaman Sea is schematically shown on figure 1.

Several contrasting views are advanced in literatures about the evolution and current stress regime for the Burmese arc. Brunnschweiler (1966) suggests that the Indo-Burman ranges represent an Alpine tectogene sensu stricto, the main Alpine boundary thrust lies along the western margin of the Burmese lowlands; the latter corresponds geotectonically to the uplifted Tibet plateau. Nandy[19] also supports this view on the basis of interpretation of aerial photographs. The Indo-Burman ranges were erected in the Oligocene although they were hardly affected by the strong movements which folded the Mio-Pliocene sequences of the Burmese lowlands. Mitchell and McKerrow[17] attribute the evolution of the arc to eastward subduction of the Indian lithosphere at the Asian continental margin that was initiated by Late Cretaceous and continuing to the present affecting the subduction zone located west of the Indo-Burman ranges. Curray *et al.*[6] invoke that the Burma plate which includes the Burmese lowlands forms a structural province between the Indo-Burman ranges and the Indo-China block (SE Asian plate). The Burma plate has been created since Middle Miocene consequent to opening of the Andaman Sea by at least 460 km[7]. Tapponnier *et al.*[24] have suggested that active spreading under the Andaman Sea and lateral motion along the Sagaing transform in Burma are consequences of propagating extrusion tectonics in response to rigid indentation by India into Asia at the eastern Himalayan syntaxis. This scheme is illustrated in figure 1 inset. Le Dain *et al.*[16] have inferred that subduction of the Indian plate below the Burmese arc has either stopped recently or occurs aseismically and the hanging lithospheric slab is being dragged north by India through the surrounding lithosphere. Most recently Mukhopadhyay and Dasgupta[18] have shown that seismicity data support active subduction of the Indian plate below the Burmese arc where an east-dipping Benioff zone upto depths of about 180 km extend below the Burmese lowlands. The coastal Burma is, however, far less seismic (see below).

BURMESE ARC SEISMICITY

A major constraint in preparing a detailed seismicity map for Burma is the sparse seismic network in and around Burma, as well as the poor earthquake detectability level, in particular, for small magnitude shocks. Gupta[13], using some statistical figures, has demonstrated that the earthquake detectability level is very poor for Burma, they are $m_b = 5.2$ for all earthquakes which are reported for the region, while for $m_b = 4.5$ only 4% earthquakes are reported. The corresponding figures for the western U.S. are $m_b = 4.5$ and 100%. The situation however, has not changed any significantly over the last 10–15 years. Gupta (ibid) also estimates the error in epicentral determination for Burmese earthquakes; this varies from 2 km for an event of $m_b = 5.0$ that increases to 5 km for $m_b = 4.0$. However, the actual capability of the existing seismic network could well be one order magnitude worse than these statistical figures.

Seismicity maps for Burma have been prepared in the past by several workers considering data from various sources and time periods[23, 11, 3, 25, 15, 16]. It was Santo[23] who first drew attention to the presence of a Benioff zone below the Burmese arc. Keeping in view the limitations of the seismic network and errors involved in epicentral determinations as stated above, Mukhopadhyay and Dasgupta[18] prepared a seismicity map of Burma using ISC data for events with $m_b \geqslant 4.0$, $M_S \geqslant 5.0$ for the period 1964–1980, and with ISS/NOAA data for events with $M_S \geqslant 5.0$ for its immediately preceding period, 1956–63; this map is reproduced in figure 2. Since seismic activity in Burma is not uniform, the map is described in four sectors, of comparable sizes, but having their characteristic tectonic settings. They are: The Naga hills in Sector I in north Burma where the collision process has already taken over the subduction process (cf. Mitchell and McKerrow[17]); Sector II corresponds to the Chin hills as it defines an arcuate trend between north-easterly strike of the Naga hills and typical north-south trend of the Indo-Burman ranges farther south. According to Evans[10] tectonics in the Chin hills is greatly influenced by the foreland spur of the Shillong plateau of the Indian shield; Sector III is for the widest part of the Burmese arc where north-south folds are prevalent in central Burma; whereas, Sector IV pertains to coastal Burma where the arc orientation changes to NW-SE. Figure 2

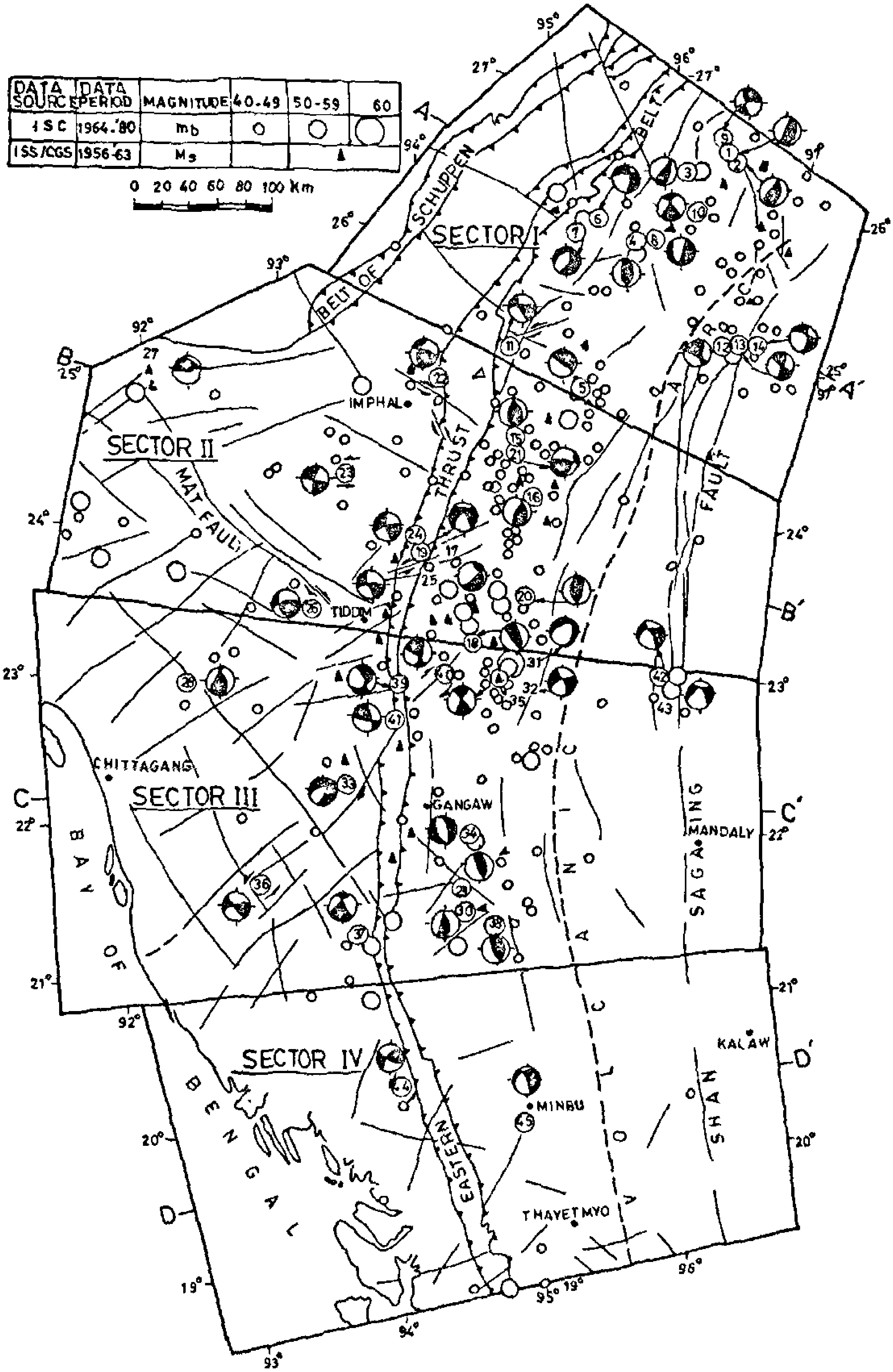


FIGURE 2 Seismicity map for the Burmese arc (redrawn after Mukhopadhyay and Dasgupta[18]; period: 1956–80 (data sources are cited in text). The map is classified into four sectors, I–IV, corresponding to morphologic and tectonic trends of the arc. Sections AA′–DD′, taken across the sectors, are shown on figure 3. Results of 45 focal mechanism solutions are schematically shown on the map, digits refer to the solution numbers listed in table I. Blank and dark areas refer to dilational and compressional quadrants in focal mechanism plots.

shows that the seismicity pattern and intensity in these sectors vary significantly depending on the kinematics of subduction of the Indian lithosphere below the Burmese arc. Seismicity is most intense between north and north-central Burma, gradually lessening southward both in intensity and depth of penetration of the Benioff zone (see below); in coastal Burma the activity is highly subdued. The last area may underlie a fossil plate boundary.

The Benioff zone sections under four geotraverses, AA′ through DD′, taken in east-west direction across the four sectors are illustrated on figure 3 (after Mukhopadhyay and Dasgupta[18]. Surface geology and hypocentral pattern of earthquakes underlying the traverses are plotted in correspondence to the tectonic units of the Burmese arc. It is seen from the figure that an inclined seismic zone is common for Sectors I to III, for Sector IV this pattern is almost lost as seismically the sector is largely quiet. The earthquake foci range in depth from shallow to about 180 km; the Benioff zone is defined on the basis of available seismicity data. The foci distribution in the inclined seismic zone suggests that depth of penetration of the subducting Indian lithosphere is about 180 km in Sectors I and II, to 160 km in Sector III, and reduces to about 80 km in Sector IV. Thickness of the Benioff zone is about 60 km below the Burmese lowlands. This gives us an idea about the approximate thickness of the Indian lithosphere as it is carried down with an eastward average dip of about 45°. The Burmese magmatic arc position is also identified in all four geotraverses; this mostly corresponds to the deepest part of the Benioff zone. Further east of the Benioff zone two shallower seismic zones are described under the geotraverses; they relate to seismicity within the overriding Burma plate (figure 3). The shallow seismic zone closest to the Benioff zone occurs below the Chindwin forearc basin; hence it is termed as forearc seismicity. Whereas, a still shallower seismic zone occurring east of the Burmese volcanic arc is defined as the backarc seismicity. Notice that backarc seismicity is most intense in the Jade Mines area in north Burma (Sector I). Also the Shan-Sagaing transform shows appreciable activity throughout its length in Burma. It is not possible however, to demarcate details of the seismic character of this important transform fault since the data availability is rather scarce and poor. It also appears from figure 3 that the forearc and backarc seismic zones are separated by an aseismic zone (earthquake free zone) between them which partly underlies the Burmese molasse basin. The available data further define a triangular "aseismic belt" at shallower depths whose bottom surface correlates to the top of the Benioff zone and the Burma plate seismic slab. The apex of the "aseismic belt" appears to be deflected downward, concordant with the sense of subduction. This bending of the inland seismic slab of the Burma plate is believed to be a consequence of a downward drag experienced by the overriding plate at the subduction zone.

FOCAL MECHANISM STUDY

Source mechanism study for earthquakes occurring below the Burmese arc has been undertaken by various authors over the past two decades (cf. Fitch[11,12]; Rastogi[20], Rastogi *et al.*[21]; Chandra[3]; Das and Filson[81]; Verma *et al.*[25]; Le Dain *et al.*[16]; Mukhopadhyay and Dasgupta[18]; and Biswas and ~~Dasgupta[1]~~). Here we give a summary result of 45 focal mechanism solutions obtained for the Burmese earthquakes occurring at shallow to intermediate depths distributed in all four sectors as identified on figure 2. For Sectors I to III, a total of 43 solutions is reported, whereas, for Sector IV only two solutions are given. Of these, 37 solutions are for the events related to the Burmese Benioff zone, 3 events are for the forearc seismic zone, and the remaining 5 events are from backarc seismic zone (figure 2 for location of these 45 events). The solutions were determined using P-wave (both short and long periods) first-motion directions (as reported in ISC Bulletins) plotted on the lower hemisphere of the focal sphere of stereographic projection by using the (i, Δ) curves of Ritsema[22]. A double-couple source mechanism was assumed. The focal mechanism solutions (after Mukhopadhyay and Dasgupta[18]) are given on figure 4 and the solution parameters are listed in table I. The events for which the focal mechanism solutions have been obtained are also identified in the geotraverse sections given in figure 3. Their main results are discussed below.

Stress Pattern and Faulting in the Benioff Zone

The Burmese Benioff zone presents some very interesting pattern in faulting and stress distribution along its upper and lower edges as well as in shallower parts of the lithosphere. They are:

- Focal mechanism solutions 1–5 in Sector I, 15–18 in Sector II, and 28–30 and 38 in Sector III are recognized as low angle thrust events occurring along the upper edge of the Benioff zone (figures 3 and 4). These solutions indicate pure thrusting along shallow dipping nodal plane (≤30°) towards east to southeast. These events are located from shallow to intermediate depths within the underthrusting lithosphere. Solutions for events 26–28 demonstrate that thrusting continues westward at shallower levels (44–61 km) in the lithosphere underlying western

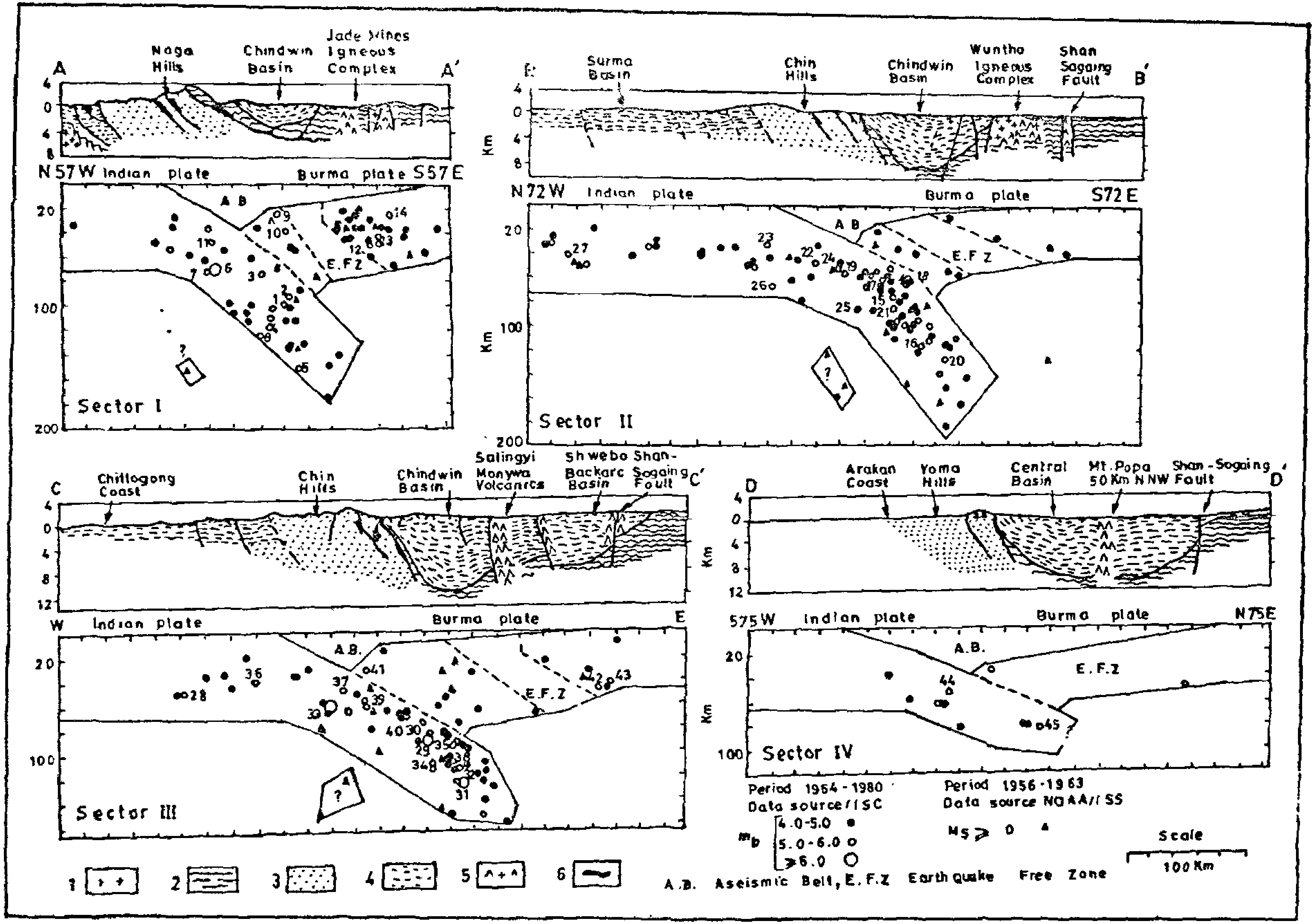


FIGURE 3 Geotraverses, AA' through DD', taken across the Burmese arc in *different sectors as identified on* figure 2. The geotraverses illustrate surface geology, tectonic units, and their underlying seismic zones. The earthquake events were *projected onto a vertical plane below the geotraverses from both north and south areas* within individual sectors. The *Indian plane can* be seen to underthrust the Burma plate eastward. Digits refer to focal mechanism solutions plotted on figure 4 and listed in table 1. Geologic index: 1, crystalline basement; 2, metamorphics; 3, flysch; 4, molasse; 5, volcanics; 6, *ophiolites. (Redrawn after* Mukhopadhyay and *Dasgupta*[14]).

parts of the Indo-Burman ranges in the Tripura-Chittagong hills where E-W shortening must have produced N-S folds of Plio-Pleistocene age in top crust.

Focal mechanism solutions 6–8 in Sector I, 19 in Sector II, 31–34 in Sector III and 45 in Sector IV are recognized as down-dip tensional events occurring at the lower edge of the Benioff zone (figures 3 and 4). The solutions mostly suggest normal faulting (with a component of right-lateral slip) along steeply dipping nodal planes oriented subparallel to the strike of the Burmese arc. Such normal faulting generally occurs below the zone of thrusting in all sectors. From this (shallow-angle thrusting along the upper edge and down-dip tensional events at the lower edge of the subducting lithosphere) we infer

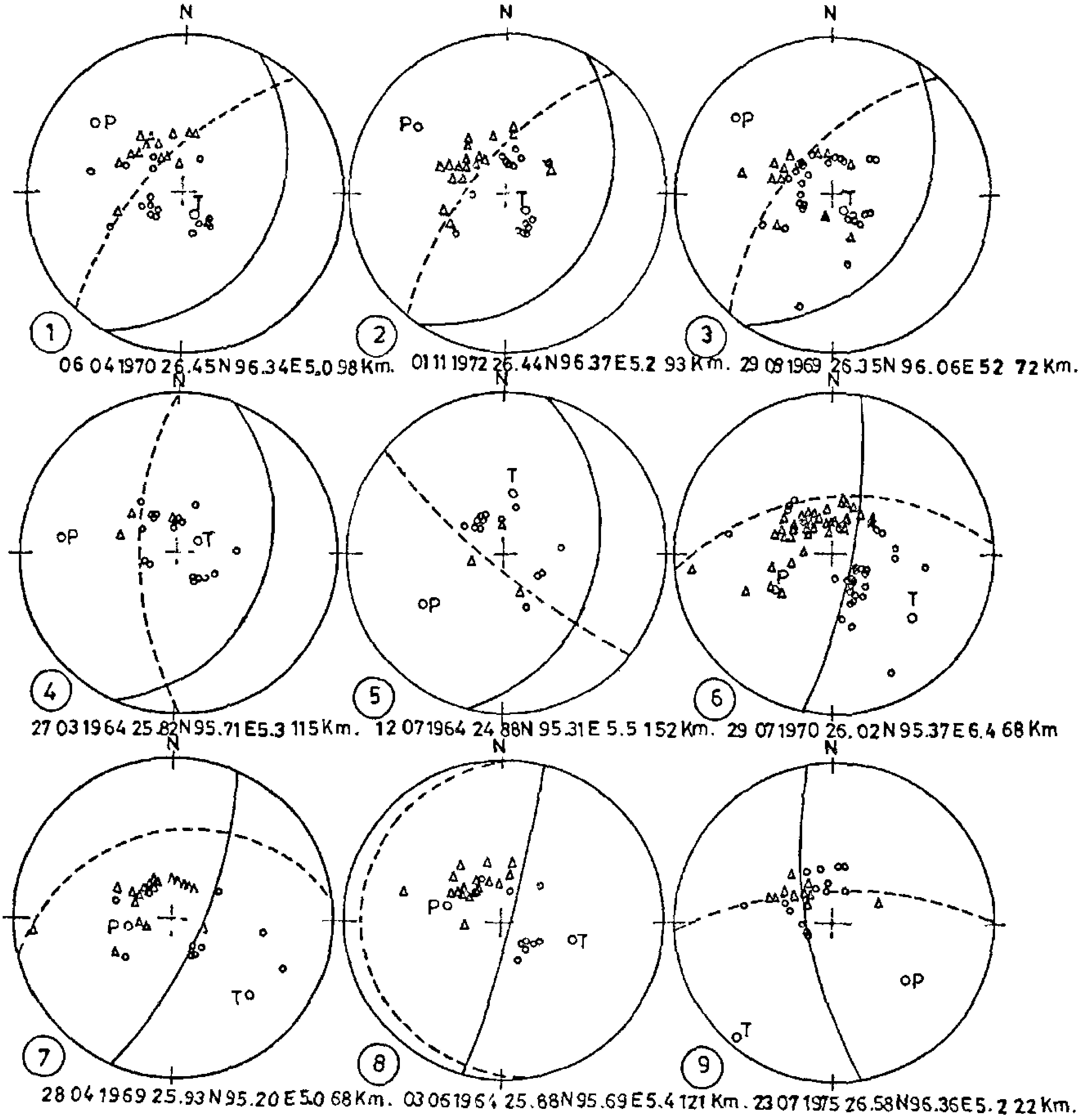
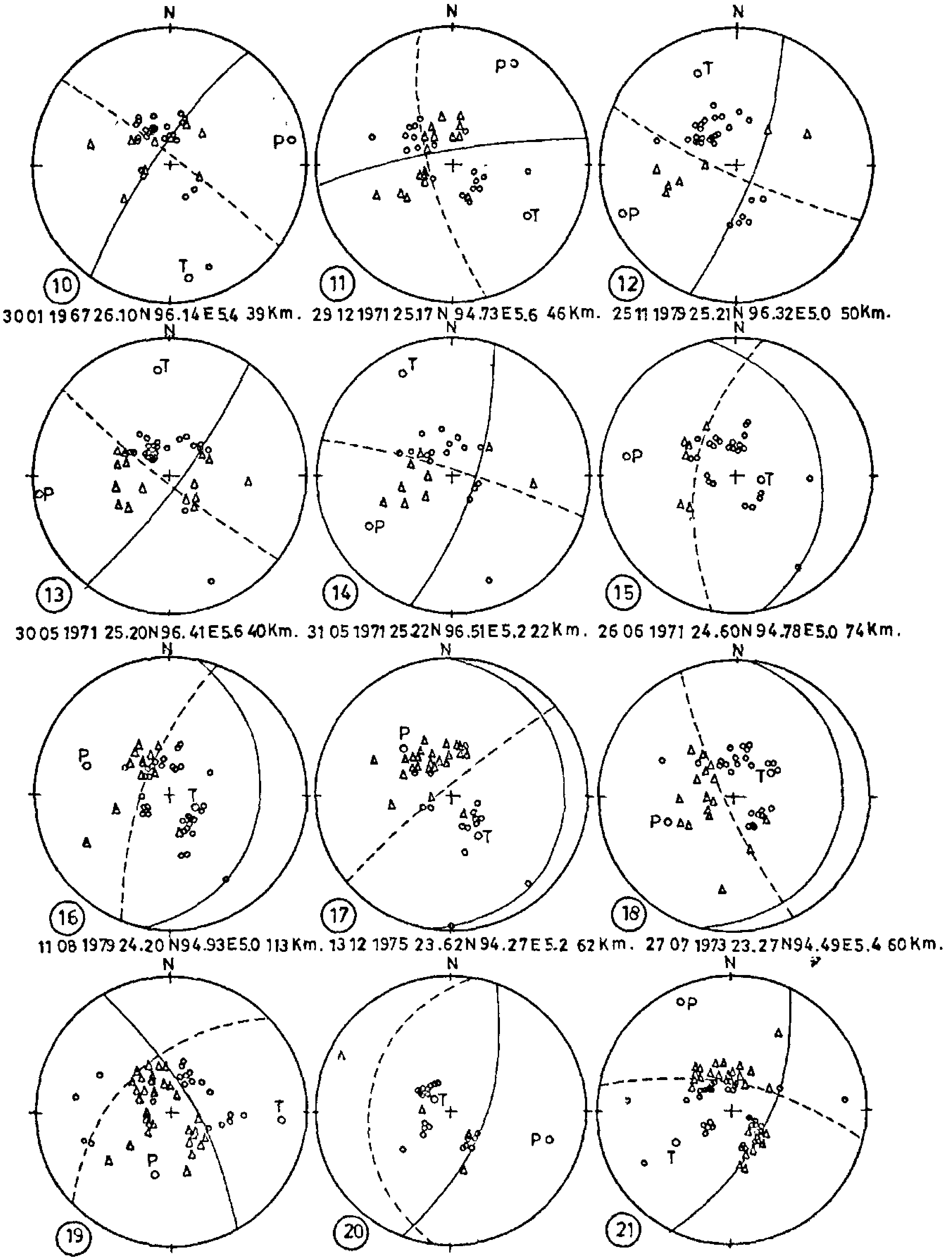


FIGURE 4 Plots for 45 focal mechanism solutions for earthquake events located in the Burmese arc (redrawn after Mukhopadhyay and Dasgupta[18]). Solid circle and triangle symbols indicate compressional and dilatational first motions of P-waves respectively. P and T correspond to the P and T axes. The parameters for focal mechanism solutions are listed in table I. The nodal plane identified by solid line is the preferred fault plane.



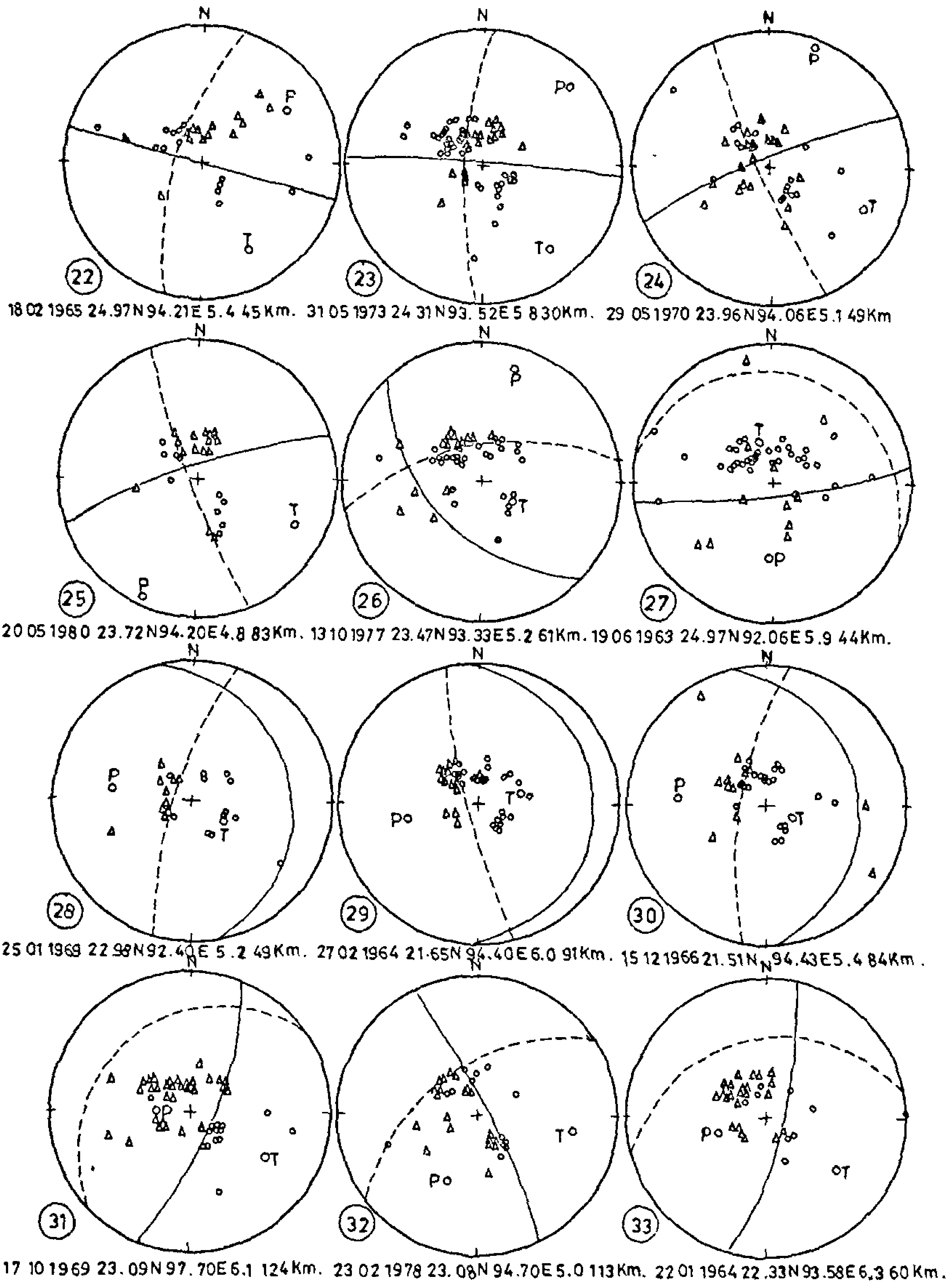
30 01 1967 26.10N96.14E5.4 39Km. 29 12 1971 25.17N 94.73E5.6 46Km. 25 11 1979 25.21N 96.32E5.0 50Km.

30 05 1971 25.20N96.41E5.6 40Km. 31 05 1971 25.22N 96.51E5.2 22Km. 26 06 1971 24.60N94.78E5.0 74Km.

11 08 1979 24.20 N94.93E5.0 113Km. 13 12 1975 23.62N94.27E5.2 62Km. 27 07 1973 23.27N94.49E5.4 60Km.

21 05 1975 23.86N94.09E5.3 51Km. 04 07 1973 23.60N94.86E5.0 126Km. 29 05 1979 24.50N94.74E5.2 82Km.

FIGURE 4 (continued)



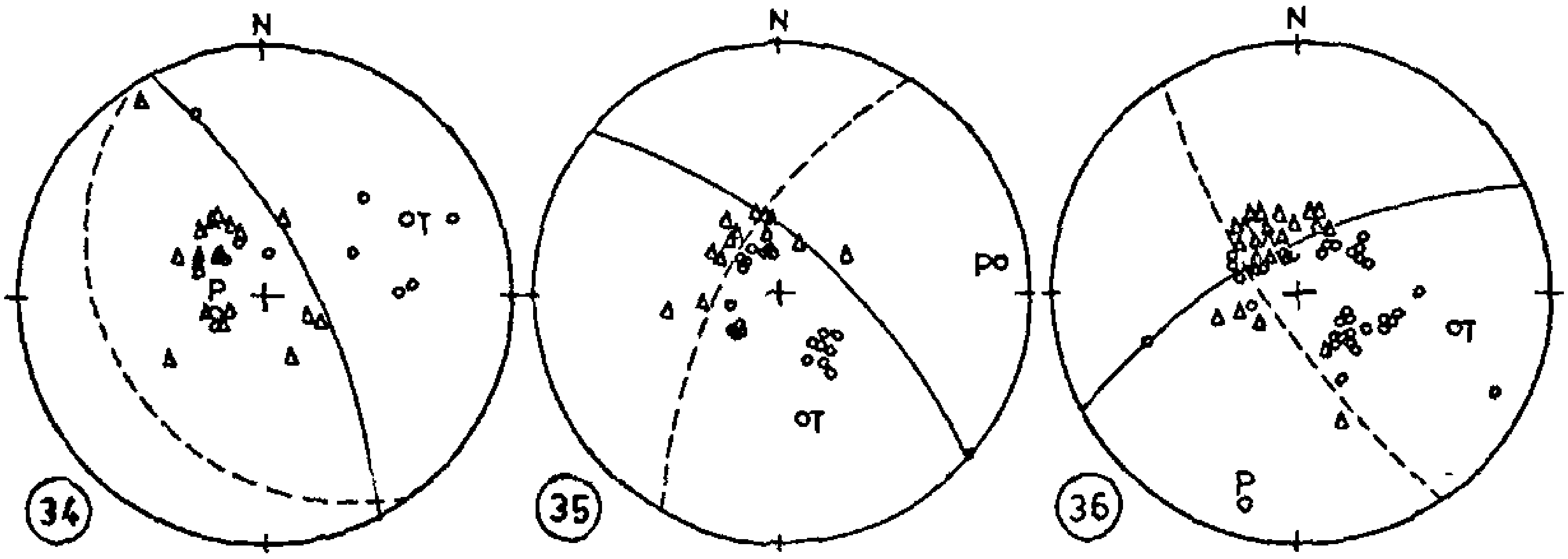
18 02 1965 24.97N94.21E 5.4 45Km. 31 05 1973 24 31N93. 52E5 8 30Km. 29 05 1970 23.96N94.06E5.1 49Km

20 05 1980 23.72N94.20E4.8 83Km. 13 10 1977 23.47N93.33E5.2 61Km. 19 06 1963 24.97N92.06E5.9 44Km.

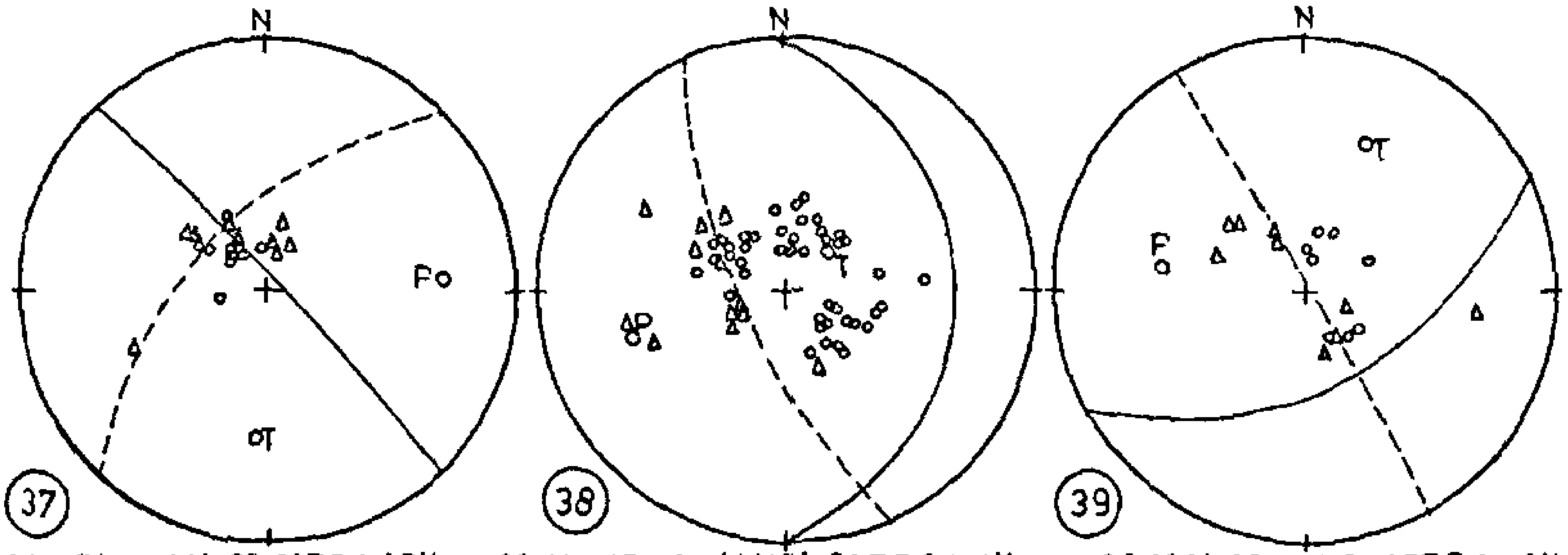
25 01 1969 22.98N92.40E 5.2 49Km. 27 02 1964 21.65N 94.40E6.0 91Km. 15 12 1966 21.51N 94.43E5.4 84Km.

17 10 1969 23.09N97.70E6.1 124Km. 23 02 1978 23.08N 94.70E5.0 113Km. 22 01 1964 22.33N93.58E6.3 60Km.

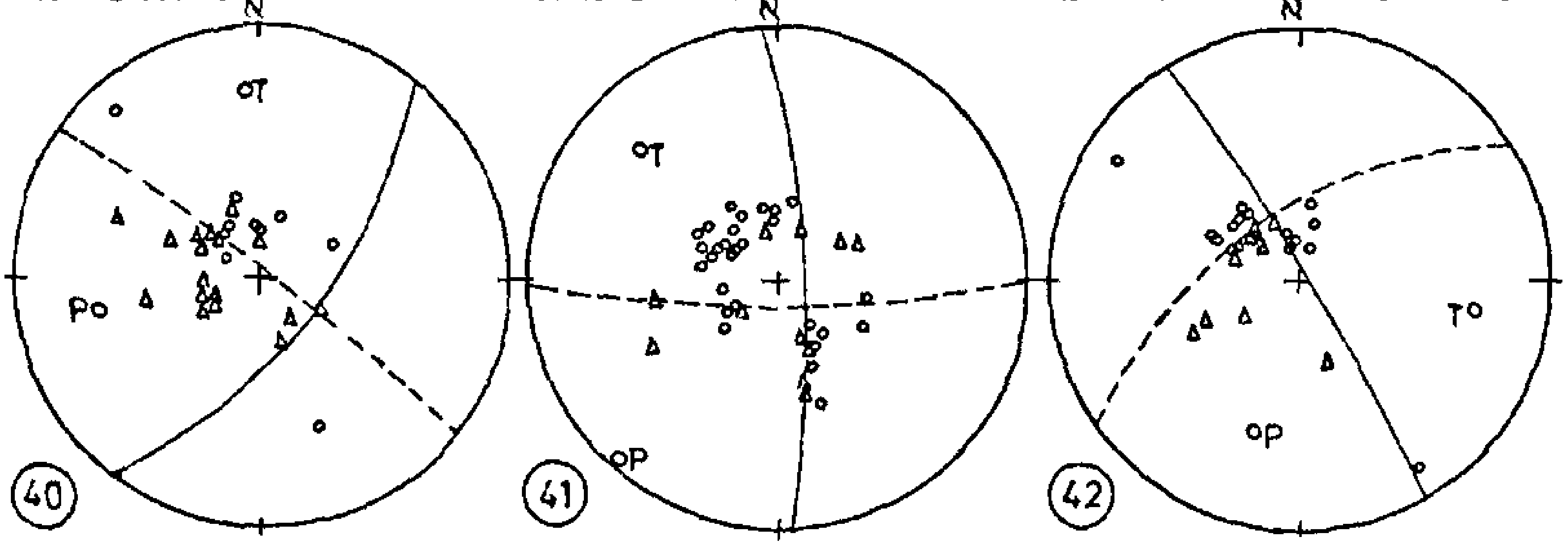
FIGURE 4 (continued)



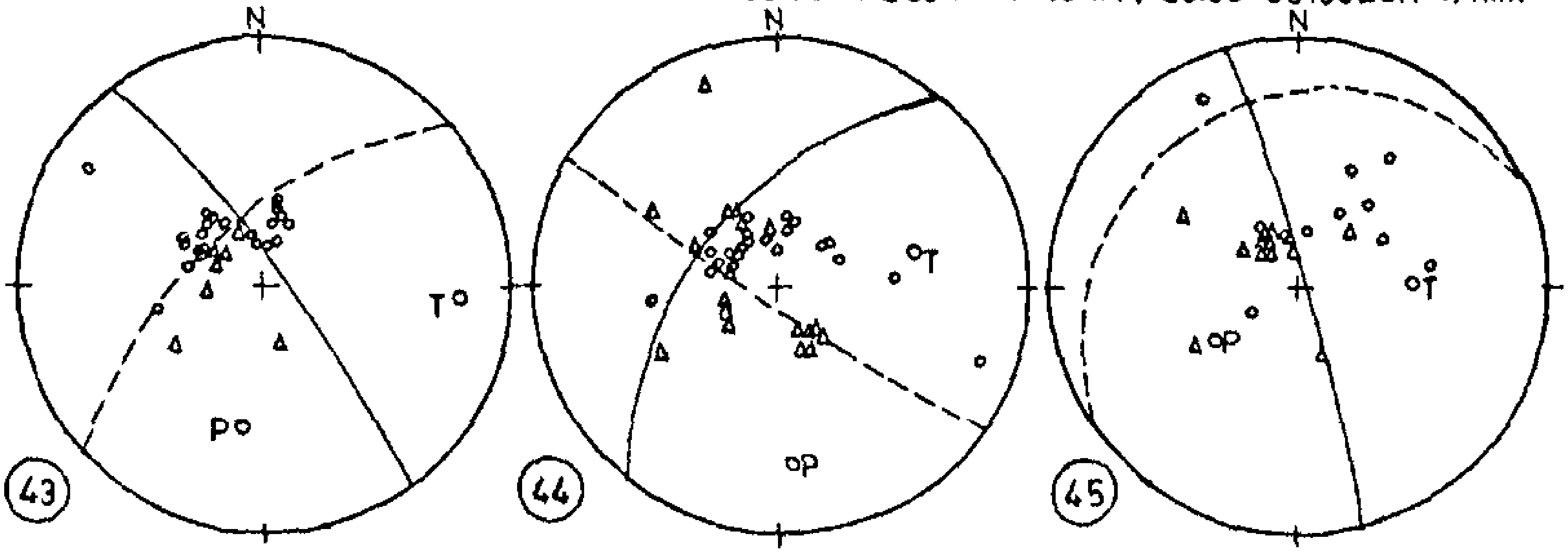
15 12 1965 22.00N94.47E 5.2 109Km. 03 02 1978 23.02N94.70E 5.1 92Km. 12 05 1977 21.68N 92.96E 5.4 39Km.



05 04 1974 21.33N 93.68E 5.0 47Km. 08 07 1975 21.42N94.62E 5.9 112Km. 13 06 1964 23.00N93.95E 5.2 60Km.



22 10 1966 23.04N94.28E 5.1 72Km. 20 11 1980 22.74N 93.92E 5.2 30Km. 14 10 1971 23.06N95.86E 5.1 47Km.



10 10 1971 23 00N95 92E4.9 46Km. 15 02 1967 20.33N 93.99E 5.4 55Km. 01 06 1965 20 13N94.83E 5.2 81Km.

FIGURE 4 (continued)

TABLE 1 Parameters of fault-plane solutions of earthquakes*

No.	Date	Epicentre		Depth (km)	Magnitude (M$_0$)	P axis		T axis		B axis		Nodal plane 1			Nodal plane 2		
		Lat. °N	Long. °E			Pl°	Az°	Pl°	Az°	Pl°	Az°	S°	D°	Dd°	S°	D°	Dd°
1	06–04–1970	26.45	96.34	98	5.0	18	309	72	142	06	40	N30E	28	120	N43E	64	313
2	01–11–1972	26.44	96.37	93	5.2	19	307	71	135	04	38	N32E	26	121	N40E	64	310
3	29–08–1969	26.35	96.06	72	5.2	13	308	77	143	04	39	N32E	32	122	N42E	58	312
4	27–03–1964	25.82	95.71	115	5.3	16	276	72	62	10	184	N23%	30	113	N2W	62	268
5	12–07–1964	24.88	95.31	152	5.5	28	240	48	08	27	145	N16E	30	106	N51W	78	219
6	29–07–1970	26.02	95.37	68	6.4	46	239	24	126	49	26	N11E	76	101	N85E	50	355
7	28–04–1969	25.93	95.20	68	5.0	57	257	21	133	23	33	N24E	70	114	N77E	31	347
8	03–06–1964	25.88	95.69	121	5.4	50	288	40	102	03	194	N14E	84	104	N9W	06	261
9	23–07–1975	26.58	96.36	22	5.2	30	126	04	221	59	317	N10W	72	260	N88E	66	358
10	30–01–1967	26.10	96.14	39	5.4	06	80	12	172	76	320	N36E	78	306	N54W	85	36
11	29–12–1971	25.17	94.73	46	5.6	07	32	21	124	68	286	N80E	80	350	N14W	70	256
12	25–11–1979	25.21	96.32	50	5.0	05	246	18	338	71	144	N23E	74	113	N67W	80	203
13	30–05–1971	25.20	96.41	40	5.6	02	262	12	353	77	165	N37E	80	127	N52W	82	218
14	31–05–1971	25.22	96.51	22	5.2	18	240	10	333	69	91	N17E	70	107	N74W	84	16
15	26–06–1971	24.60	94.78	74	5.0	11	280	69	100	08	06	N10W	26	80	N10E	56	280
16	11–08–1979	24.20	94.93	113	5.0	22	288	67	116	03	19	N11E	22	102	N20E	68	290
17	13–12–1975	23.62	94.27	62	5.2	37	314	50	145	06	48	N5E	09	95	N50E	84	320
18	27–07–1973	23.27	94.49	60	5.4	32	250	56	56	08	156	N10E	12	100	N24W	78	246
19	21–05–1975	23.86	94.09	51	5.3	40	196	12	95	42	350	N29W	70	61	N45E	48	315
20	04–07–1973	23.60	94.86	126	5.0	16	105	72	310	07	196	N20E	60	110	N5E	30	275
21	29–05–1979	24 50	94.74	82	5.2	03	336	40	241	60	70	N26E	60	116	N79W	65	11

22	18-02-1965	24.97	94.21	45	5.4	17	58	17	153	66	288	N74W	90		N16E	66	286
23	31-05-1973	24.31	93.52	30	5.8	08	48	14	139	73	287	N86W	86	04	N3E	74	273
24	29-05-1970	23.96	94.06	49	5.1	01	22	15	112	76	294	N67E	80	337	N25W	80	245
25	20-05-1980	23.72	94.20	83	4.8	04	204	14	114	75	300	N71E	78	341	N20W	82	250
26	13-10-1977	23.47	93.33	61	5.2	06	16	59	114	31	282	N45W	48	225	N79E	58	349
27	19-06-1963	24.97	92.06	44	5.9	35	175	54	349	02	84	N83E	80	173	N72W	10	19
28	25-01-1969	22.98	92.40	49	5.2	29	280	60	118	08	14	N12W	18	78	N16E	74	286
29	27-02-1964	21.65	94.40	91	6.0	35	258	54	73	02	166	N	10	90	N14W	80	256
30	15-12-1966	21.51	94.43	84	5.4	25	274	65	108	06	06	N8W	21	82	N9E	70	279
31	17-10-1969	23.09	94.70	124	6.1	63	276	25	120	09	26	N22E	70	112	N48E	22	318
32	23-02-1978	23.08	94.70	113	5.0	35	203	18	98	48	345	N28W	80	62	N54E	50	324
33	22-01-1964	22.33	93.58	60	6.3	54	254	25	123	24	22	N14E	74	104	N74E	30	344
34	15-12-1965	22.00	94.47	109	5.2	66	254	23	60	03	152	N26W	68	64	N38W	22	234
35	03-02-1978	23 02	94.70	92	5.1	06	81	37	170	52	347	N48W	66	42	N28E	62	298
36	12-05-1977	21.68	92.96	39	5.4	07	195	27	102	61	299	N62E	66	332	N34W	76	236
37	05-04-1974	21.33	93.68	47	5.0	19	85	28	185	55	326	N44W	84	46	N43E	56	313
38	08-07-1975	21.42	94.62	112	5.9	25	251	63	50	08	159	N	22	90	N24W	70	256
39	13-06-1964	23.00	93.95	60	5.2	40	278	24	24	49	144	N63E	50	153	N31W	86	59
40	22-10-1966	23.04	94.28	72	5.1	12	259	15	356	63	118	N39E	63	129	N52E	85	38
41	20-11-1980	22.74	93.92	30	5.2	02	222	16	314	74	125	N3W	77	87	N89E	80	179
42	14-10-1971	23.06	95.86	47	5.1	27	196	18	98	57	340	N31W	84	59	N55E	58	325
43	10-10-1971	23.00	95.92	46	4.9	29	189	12	92	57	343	N36W	78	54	N47E	60	317
44	15-02-1967	20.33	93.99	51	5.4	20	176	28	74	53	295	N38E	54	308	N56W	84	214
45	01-06-1965	20.13	94.83	81	5.2	47	240	39	86	13	344	N17W	85	73	N52E	14	322

*Pl = Plunge, Az = Azimuth, S = Strike, D = Dip, Dd = Dip direction.

that focal mechanism results strongly suggest for a "double seismic zone" in the Burmese subduction zone, as is characteristic for the Western Pacific arcs (cf. Kawakatsu[14]). In order to know the details for the postulated double seismic zone in Burma, capability of the local seismic network must be improved. The double seismic zone in the Burmese subduction zone, if ultimately proved, should be of much interest because of its proximity to the collisional zone in the Himalaya as they represent quite diagonistic lithospheric kinematics in their respective areas.

Focal mechanism solutions 11 in Sector I, 22–26 in Sector II, 36, 37 and 40 in Sector III, and 44 in Sector IV are recognized as lateral faulting events; they correspond to transverse faults/lineaments crossing the Burmese arc locally in NW-SE directions. Events 22–26, 39 and 40 correlate to such mapped faults (figure 2); event 26 occurred in association with the well known Mat fault. Similarly, events 39 and 40 occurred in intimate association with another mapped but unnamed transverse fault crossing the Indo-Burman ranges. It is likely that some of these transverse faults may extend towards the Himalaya on the north to northwest across the Bengal basin and Assam foredeep as they have the appearances of "arc-arc fault" in some areas where geological mapping is more complete (cf. Nandy[19]).

Faulting and Stress Pattern in Burmese Forearc and Backarc Seismic Zones

Only two events 9 and 10 are available for the Chindwin forearc seismic zone, both indicate strike-slip mechanism along steeply dipping NNE oriented nodal planes. This implies that the overriding Burma plate is in relative motion in respect of the Indian lithosphere.

Focal mechanism solutions 12–14 in Sector I belong to earthquakes in backarc seismic zone which suggest right-lateral shear along steeply dipping NNE oriented nodal planes. This is in agreement with the slip motion known for the Sagaing transform. Events 42 and 43 in Sector III are located some distance further east; dominant east-west tensional stress is indicated by their focal mechanism solutions. Mukhopadhyay and Dasgupta[18] have interpreted these as due to westward normal faulting at the Shan scarp. The Shan plateau belonging to the SE Asian plate is believed to have been uplifted in respect of the Burmese lowlands against the Shan scarp.

CONCLUDING REMARKS

The Burmese arc seismicity is an outcome of eastward underthrusting of the Indian lithosphere below the Burma plate. The Sagaing transform outlines the east margin of the Burma plate against the Shan plateau belonging to the SE Asian plate further east. The Burma plate evolution is related to backarc spreading below the Andaman Sea since the Neogene. Detailed analysis of the Burmese arc seismicity (for the period 1956–80) reviewed here illustrates that an inclined seismic zone, defining the Benioff zone, is present throughout Burma; dip of the Benioff zone is about 45°. Depth of penetration of the Benioff zone extends to depths of about 180 km. An inland seismic slab defines the seismic zones in the overriding Burma plate. A crustal seismic zone some 60–80 km east of the Benioff zone correlates the backarc activity. A triangular aseismic wedge in top of the crust outlines the Central Burma molasse basin east of the Indo-Burman ranges. Focal mechanism solutions for some 45 events show that the Burmese Benioff zone may comprise a double seismic zone; low-angle thrust events are characteristic of the upper edge of the Benioff zone, whereas, down-dip tensional events occur along its lower edge. Most of the backarc seismicity is accounted for by the activity of the Sagaing transform or by the Shan scarp normal fault at the west margin of the SE Asian plate.

REFERENCES

1. Biswas, S. and Dasgupta, A., Distribution of stresses in the Himalayan and the Burmese arcs. *Gerlands Beitr. Geophys.*, 1989, **98** (3.S.), 223–239.
2. Brunnschweiler, R. D., On the geology of the Indoburman ranges. *J. Geol. Soc. India*, 1966, **13**, 137–194.
3. Chandra, U., Seismicity, earthquake mechanism and tectonics of Burma, 20°N–28°N. *Geophys. J. R. Astron. Soc.*, 1975, **40**, 367–381.
4. Chhibber, H. L., *Geology of Burma*, MacMillan, London, 1934a, p. 538.
5. Chhibber, H. L., *Mineral Resources of Burma*, MacMillan, London, 1934b, p. 320.
6. Curray, J. R. *et al.*, Tectonics of the Andaman Sea and Burma. *Am. Assoc. Pet. Geol. Memoir*, 1979, **29**, 189–198.
7. Curray, J. R., Emmel, F. J., Moore, D. G. and Raitt, R. W., Structure, tectonics, and geological history of the northeastern Indian Ocean. in *The Ocean Basins and Margins* eds. Nairn, A.E.M. and Stehli, F.G.), Plenum, New York 1982, vol. 6, pp. 399–450.
8. Das, S. and Filson, J. R., On the tectonics of Asia. *Earth Planet. Sci. Lett.*, 1975, **28**, 241–253.
9. Dasgupta, S., Mukhopadhyay, M. and Nandy, D. R., Magmatism and tectonic setting in the Burmese-Andaman arc, *Indian J. Geol.*, 1990, 62(2), 117–141.
10. Evans, P., The tectonic framework of Assam. *J. Geol. Soc. India*, 1964, **5**, 80–96.
11. Fitch, T. J., Earthquake mechanisms in the Himalayan, Burmese, and Andaman regions and continental tectonics in Central Asia. *J. Geophys. Res.*, 1970, **75**, 2699–2709.
12. Fitch, T. J., Plate convergence, transcurrent faults, and internal deformation adjacent to southeast Asia and the Western Pacific. *J. Geophys. Res.*, 1972, **77**, 4432–4460.

13. Gupta, H. K., Seismological investigations and the tectonics of the Kashmir—Hindukush–Pamair region. *Atti. Accad. Naz. Lincei, Roma*, 1976, **21**, 43–66.
14. Kawakatsu, H., Double seismic zone in Tonga. *Nature*, 1985, **316**, 53–55.
15. Khattri, K. N., Rogers, A. M., Perkins, D. M and Algermissen, S T., A seismic hazard map of India and adjacent areas. *Tectonophysics*, 1984, **108**, 93–134.
16. Le Dain, A. Y., Tapponnier, P. and Molnar, P., Active faulting and tectonics of Burma and surrounding regions. *J. Geophys. Res.*, 1984, **89**, 453–472.
17. Mitchell, A. H. G. and McKerrow, W. S., Analogous evolution of the Burma Orogen and the Scottish Caledonides. *Geol. Soc. Am. Bull.*, 1975, **86**, 305–315.
18. Mukhopadhyay, M. and Dasgupta, S., Deep structure and tectonics of the Burmese arc: Constraints from earthquake and gravity data. *Tectonophysics*, 1988, **149**, 299–322.
19. Nandy, D. R., Tectonic patterns in northeastern India. *Indian J. Earth Sci.*, 1980, **7**, 103–107.
20. Rastogi, B. K., Source mechanism studies of earthquakes and contemporary tectonics in Himalaya and nearby regions. *Bull. Internatl. Inst. Seismol. Earthquake Eng., Tokyo*. 1976, **14**, 99–134.
21. Rastogi, B. K., Singh, J. and Verma, R. K., Earthquake mechanisms and tectonics in the Assam-Burma region. *Tectonophysics*, 1973, **18**, 355–366.
22. Ritsema, A. R., (i,△) - Curves for bodily seismic waves of any focal depth. *Verh. 54, Lemb. Meteor. Geof., Djakarta (Indonesia)*, 1958.
23. Santo, T., On the characteristic seismicity in South Asia from Hindukush to Burma. *Bull Internatl. Inst. Seismol. Earthquake Eng*, 1969, **6**, 81–93.
24. Tapponnier, P., Peltzer, G. and Armijo, R., On the mechanics of the collision between India and Asia in *Collision Tectonics* (eds. Coward, M P. and Rus, A.C.), Geological Soc. Sp, 1986, pp. 115–157.
25. Verma, R. K., Mukhopadhyay, M and Ahluwalia, M. S., Earthquake mechanisms and tectonic features of northern Burma *Tectonophysics*, 1976, **32**, 387–399.