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The Manipur-Burma border Earthquake of 22 March 1954

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ABSTRACT. A study of the Manipur-Burma earthquake of 22 March 1954, which was felt over a large part of Eastern India and neighbourhood, has been made using data from all over the world The epicentre has been found as 24°·38N, Long. 95°·15 E and the origin time as 23 h 42 m 12·5 s GMT. The depth of focus using four methods has been calculated as 180 ± 10 km. An isoseismal map has been drawn from macroseismic information collected from India, Burma, East Pakistan and Lhasa. From the direction of first motion, as recorded at different Indian and extra-Indian observatories, the direction of faulting has been determined and discussed. Records of accelerographs at Shillong and Chatra show that the numbers 6 and 4 of the Modified Mercalli scale of intensity at these places correspond to the recorded maximum (horizontal) accelerations of 5 cm sec^{-2} and 2 cm sec^{-2} respectively. These correspond to the minimum acceleration of the ranges as determined by United States Coast and Geodetic Survey from accelerograph data collected during 1930-41.

1. Introduction

The eastern parts of India including the States of Assam, Manipur, Tripura, West Bengal, Bihar, East Pakistan and Burma were rocked by a sharp earthquake on the morning of 22 March 1954. According to preliminary reports, based on data of Indian stations, the epicentre of the earthquake was located by Central Seismological Observatory, Shillong, near Lat. 24°N, Long. 94°E close to Manipur-Burma border. The object of the present paper is to present a detailed account of this earthquake including its revised epicentre, origin time, depth of focus and other aspects based on instrumental and non-instrumental data collected by the Central Seismological Observatory, Shillong.

The earthquake was felt strongly at Shillong soon after 0513 IST and lasted for nearly three minutes. It started with rapid vibrations causing the doors, windows and the frame-structure of the building of the Central Seismological Observatory to produce a rattling sound. The tremors increased in intensity for a few seconds and then decreased for a while. After nearly a minute the vibrations became more violent and longer in period, and the tremors ceased to be felt after a total duration of about three minutes.

Newspaper reports which appeared on the following days indicated that the earthquake was strongly felt over the States of Assam, Manipur, Tripura, West Bengal and East Pakistan. According to one report from Manipur, the shock was of the greatest intensity during the last 20 years. There was no report of any serious damage or loss of life at any place but minor damages like cracking of old walls of buildings and fall of plaster etc were reported from a number of places in the strongly shaken area. These include Shillong, Manipur, Jorhat, north Lakhimpur, Gauhati, Dibrugarh, Lumding, Hailakandi, Calcutta, Comilla and a few places in East Pakistan.

2. Macroseismic reports

Soon after the earthquake, the Central Seismological Observatory at Shillong circulated a number of questionnaire forms to the district authorities in Assam, Bengal, Bihar, east Uttar Pradesh, Orissa, east Madhya Pradesh, north Andhra and collected information about the effects of the earthquake in these parts. The information was supplemented by voluntary observers' reports of the India Meteorological Department, and newspaper reports. Through the kind cooperation of the Director, Pakistan Meteorological Service, reports of voluntary observers from East Pakistan were also made available to the authors. The Director, Burma Meteorological Service, also kindly sent available reports from stations in Burma where the

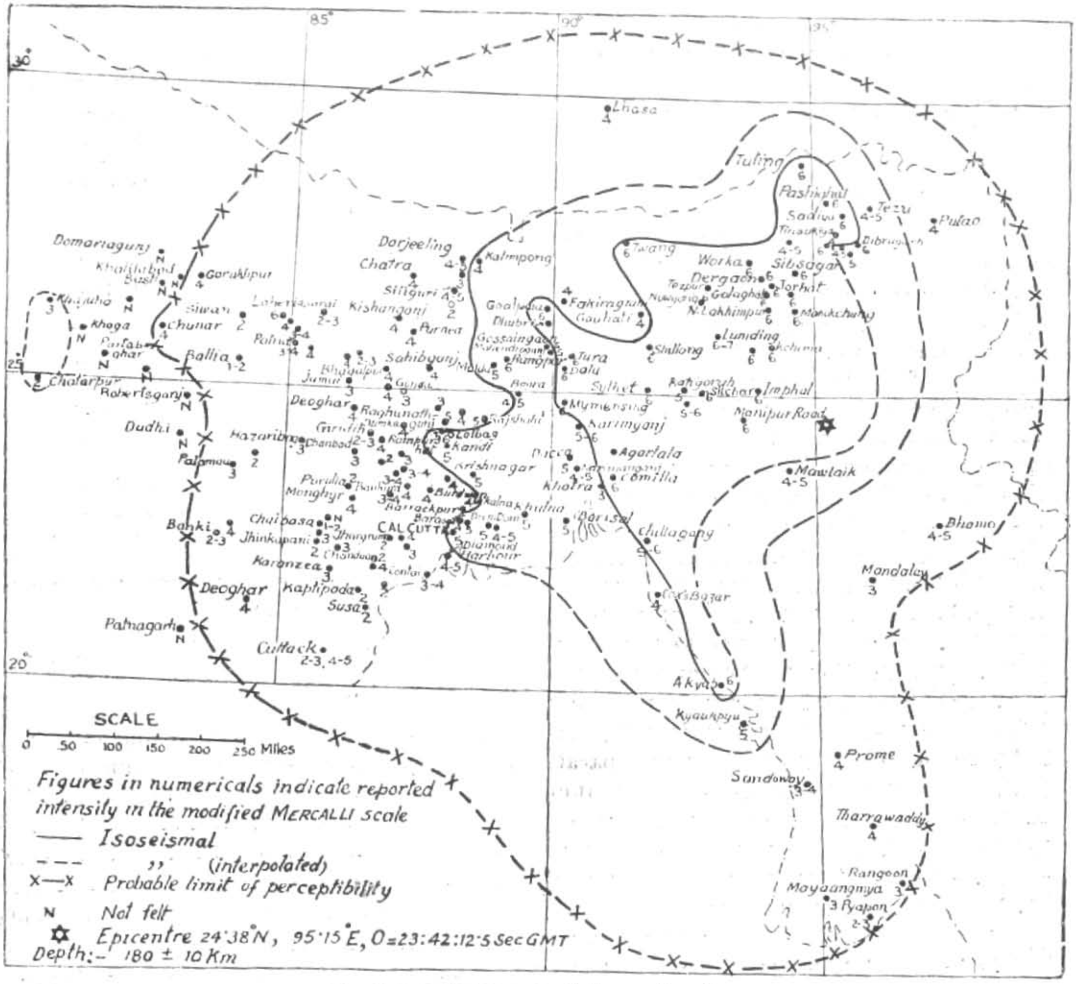

Fig. 1. Isoseismal map of the earthquake

shock was felt. These reports were analysed and an isoseismal map in the Modified Mercalli scale prepared on the basis of these reports, is reproduced in Fig. 1. The following information can be inferred from the map in Fig. 1.

(*i*) Area in India, East Pakistan and Burma over which the shock was strongly felt and minor damage caused at a few places = 119,600 sq. miles.

(*ii*) Probable total area over which the shock was felt = 909,000 sq. miles

(*iii*) Maximum distance from the epicentre where the shock was felt in India = 900 miles

(*iv*) Radius of perceptibility (that is, the average distance from the epicentre upto which the shock was felt = 540 miles (approx.)

The earthquake did not cause any major damage even at places near the epicentre. The maximum intensity reported in Modified Mercalli scale was 6 and this corresponds to only minor damage. The isoseismal map shows that the shock was felt more widely on Indian side when compared with the Burma side. The fall of intensity on the Burma side is rather remarkably rapid. This may be due partly to the alluvial nature of the soil in East Pakistan and India and partly due to the mechanism of faulting at the focus. The latter aspect would be discussed in a later section.

3. Epicentre and origin time

The earthquake was recorded by seismographs all over the world and readings of P and S phases were thus available from a large number of stations well distributed in azimuth and distance with respect to the epicentre. The data used were collected mostly from the station bulletins, United States Coast and Geodetic Survey's fortnightly data sheet and the Directors of some observatories by making special requests. It was apparent from a preliminary perusal of the records of the Indian stations and also from the macroseismic reports that the earthquake was of abnormal focal depth. It was, therefore, decided to use two methods for the determination of the epicentre. The first method used is independent of the depth of focus and travel-time tables and depends on selected pairs of stations in widely separated azimuths where the P phase arrived at or nearly the same time. These stations should, therefore, be practically equidistant from the epicentre. If A, B, C are the direction cosines of the epicentre and (a_1, b_1, c_1), (a_2, b_2, c_2)........, of the various reporting stations, then the distances $\triangle_1$ and $\triangle_2$ between the epicentre and first and second reporting stations are given by

$$\text{Cos}\ \triangle_1 = a_1A+b_1B+c_1C \text{ and}$$

$$\text{Cos}\ \triangle_2 = a_2A+b_2B+c_2C \quad \ldots\ldots \quad (1)$$

If the two stations are equidistant from the epicentre,

$$a_1\,A+b_1\,B+c_1\,C = a_2\,A+b_2\,B+c_2\,C$$

$$\text{or } (a_1-a_2)A+(b_1-b_2)B+(c_1-c_2)C = 0 \quad (2)$$

Similarly, for another pair of equidistant stations with direction cosines (a_3, b_3, c_3) and (a_4, b_4, c_4) *we shall* have

$$(a_3-a_4)A+(b_3-b_4)B+(c_3-c_4)C = 0 \quad (3)$$

TABLE 1

Station	Arrival time (GMT) h m s
Brisbane	23 53 40
Scoresby Sund	23 53 40
Riverview	23 53 57
College	23 53 57
Pasadena	23 56 42
Pallisades	23 56 43
Upsala	23 52 22
Tananarive	23 52 25
Quetta	23 47 29
Manila	23 47 33

Equations (2) and (3) are linear and can be solved for A/C and B/C.

Now, $A = \cos\phi\ \cos\lambda$, $B = \cos\phi\ \sin\lambda$
$C = \sin\ \phi$

where ϕ and λ are the latitude and longitude of the epicentre. Solution of equations (2) and (3) therefore give the values of ϕ and λ. If we have more pairs of stations at which the P wave arrived simultaneously we shall have more equations of types (2) and (3) and can find out more intersections, or the whole set of equations can be solved by the method of least squares. In the case under investigations we were able to find out five such pairs of stations. The arrival times of P and S at these stations are given in Table 1.

The various intersections giving the values of ϕ and λ are given in Table 2.

The mean value of ϕ comes out to be 24°·32N and of λ 94°.97E with a standard error of less than 0·2°.

In the second method P readings from a large number of stations, well distributed in azimuth around the epicentre have been used and the epicentre was calculated by the method of Least Squares as described by Tandon (1954). Since the earthquake focus was deep seated, it was necessary first to

TABLE 2

	Brisbane Scoresby Sund	Riverview College	Pasadena Palisades	Upsala Tananarive	Quetta Manila
Brisbane Scoresby Sund		24°.47N 95°.70E	23°.69N 94°.30E	25°.39N 95°.40E	23°.58 N 95°.40E
Riverview College			24°.32N 94°.50E	24°.38N 94°. 30E	23°.48N 95°.12E
Pasadena Palisades				25°.29N 94°.62E	
Upsala Tananarive					24°.16N 95°.40E

Mean = 24°.31 N and 94°.97 E

evaluate the depth of focus. This is discussed in a later section. J.B. Tables (1940) for a depth of focus of 175 km were used. The epicentre thus calculated comes out at $\phi = 24°.38$ N, $\lambda = 95°.15$ E and the origin time, 23h 42m 12·5s GMT. It will be seen that this epicentre is in close agreement with that determined by the first method. We are inclined to accept this as the correct epicentre in view of its small standard error. Table 3 gives the arrival times of P and S waves at the various stations with their calculated distances from the epicentre, azimuth, and also the residuals of P and S (observed travel time—calculated travel time) with respect of J. B. Tables (1940).

4. Depth of focus

Absence of prominent surface waves and presence of large amplitudes of P and S waves on the records of the seismological observatories indicated that the focus of the earthquake was deep seated. The depth of focus has been determined by four methods and these indicate that the depth is 180 ± 10 km. These methods are discussed below.

(*i*) The phases pP, sP, sS which are recorded as a consequence of finite depth of focus of an earthquake, were identified on the seismograms of the Indian Observatories and the intervals pP–P, sP–P, sS–S were tabulated. A large number of foreign stations had also identified these phases and given the data in their station bulletins. In some cases readings which were identified only as i and which fitted with these phases were also used in calculating the depth. The values of these intervals and the depth calculated with the help of J.B. Tables (1940) are given in Table 4. The mean of all the values comes out to be 180 ± 10 km.

(*ii*) It has already been mentioned before that while calculating the epicentre and origin time of the shock by the method of least squares, the travel times appropriate to the proper depth had to be used. To begin with, the depth was put as equal to 192 km. On calculating the residuals for all the stations it was found that the near stations like Tocklai, Shillong, Calcutta, Chatra and New Delhi showed systematic negative residuals of 2 to 3 seconds while the stations between $\triangle = 50°$ and $\triangle = 80°$ were normal. At larger distances there was a tendency for the residuals to be systematically positive. The situation could be improved considerably by adjusting the origin time by about 2 seconds and changing the depth of focus to 175 km. The final residuals given in Table 3 have been calculated after making these adjustments. Proper adjustment of the residuals could not be made by changing the origin time or the depth alone as the residuals for the near stations are more sensitive to change of origin time and not much affected by depth and the distant stations are sensitive to changes in depth and origin time both. This method appeared to indicate that the depth of focus was very nearly 175 km.

TABLE 3

No.	Station	Δ (°)	Azimuth (°)	P m	P s	O–C s	S m	S s	O–C s
1	Tocklai	2·49	339	*i* 0	42·0	— 0·9	..	..	..
2	Shillong	3·14	294	*i* 0	51·5	+ 0·3	..	..	..
3	Calcutta	6·54	256	*i* 1	33·5	— 1·8	*i* 2	42·5	— 6·5
4	Chatra	7·59	291	*i* 1	48·5	— 0·3	*i* 3	16·5	— 4·6
5	Dehra Dun	16·28	295	*e* 3	43·5	+ 4·4	*i* 6	35·5	+ 0·8
6	New Delhi	16·58	289	*i* 3	43·6	— 0·1	*i* 6	35·5	— 5·7
7	Hyderabad	17·05	250	*i* 3	49·5	+ 0·5	6	47·5	— 4·1
8	Madras	18·05	233	*i* 4	2·5	+ 2·3	*i* 7	14·5	+ 1·1
9	Poona	20·64	258	*i* 4	30·5	+ 3·5	*i* 8	11·5	+ 8·9
10	Bombay	21·46	260	*i* 4	41·5	+ 6·4	*i* 8	25·5	+ 8·3
11	Kodaikanal	22·05	233	*i* 4	43·5	+ 2·5	*i* 8	39·5	+11·9
12	Colombo	22·80	223	*i* 4	48·5	+ 0·2	8	24·5	—16·1
13	Quetta	25·72	290	*i* 5	16·5	+ 0·6	9	37·5	+ 7·9
14	Manila	26·20	107	*i* 5	20·5	+ 0·2	*e* 10	13·5 (?)	+36·1
15	Fukuoka	32·07	65	*i* 6	11·4	— 1·5	11	9·6	+ 0·2
16	Djakarta	32·45	158	*i* 6	13·5	— 2·2	*i* 11	15·5	— 0·8
17	Hamada	33·59	63	*i* 6	26·5	+ 1·2	*e* 10	48·5	—45·5
18	Osaka	36·39	64	*e* 6	50·5	+ 3·3	*e* 12	19·5	+ 2·6
19	Nagoya	37·52	63	*i* 7	0·5	+ 2·0	*i* 13	35·5	+ 1·5
20	Matsushiro	38·77	61	*i* 7	7·7	— 1·3	12	42·1	—10·9
21	Tokyo	39·93	63	*i* 7	19·0	+ 0·6	*e* 13	21·5	+11·5
22	Sapporo	42·09	50	*e* 7	34·5	— 1·5	*e* 13	39·5	— 2·4
23	Istanbul	56·74	304	9	27·5	0	*i* 17	6·5	+ 1·7
24	Kiruna	61·91	335	*i* 10	2·5	— 0·6	*i* 18	14·5	+ 3·2
25	Upsala	63·00	327	*i* 10	9·5	— 0·7	*i* 18	23·5	— 1·4
26	Tananarive	63·27	232	*i* 10	12·5	+ 0·5	18	24·5	— 3·7
27	Wien	64·92	313	10	20·5	— 2·3	*e* 18	48·5	— 0·1
28	Zagreb	65·60	315	*i* 10	28·5	+ 1·4	*i* 18	50·5	— 6·4
29	Praha	65·86	316	*i* 10	28·5	— 0·5	*i* 18	57·5	— 2·6
30	Copenhagen	66·17	320	*i* 10	30·5	— 0·4	*i* 19	6·5	+ 2·7
31	Trieste	67·15	310	*i* 10	39·0	+ 2·0	*i* 19	13·7	— 1·9
32	Cheb	67·28	313	*i* 10	32·5	— 5·3	*e,i* 19	14·5	— 2·6
33	Stuttgart	69·48	315	*i* 10	51·5	+ 0·3	19	43·5	+ 0·5
34	Chur	69·72	313	*i* 10	53·8	+ 1·1	*i* 19	43·3	— 2·5
35	Strasbourg	70·45	315	*i* 10	56·5	— 0·6	*i* 19	56·5	+ 2·2
36	Zurich	70·53	314	*i* 10	55·1	— 2·5	*i* 19	50·1	— 5·1
37	Uccle	72·01	317	*i* 11	6·5	0	*e* 20	10·5	— 1·6
38	Durban	74·28	321	*i* 11	19·5	— 0·2	*i* 20	39·5	+ 1·9
39	Kew	74·58	320	*i* 11	41·5	+20·0	*i* 20	41·5	+ 0·5
40	Scoresby Sund	75·69	342	*i* 11	27·5	0	*i* 20	56·5	+ 3·4
41	Brisbane	75·99	129	*i* 11	27·5	— 1·8	*i* 20	59·5	+ 3·1
42	Kerguelen	76·69	197	*i* 11	32·5	— 0·6	..	..	..
43	Rathfarnham Castle	77·29	323	*i* 11	37·5	+ 1·1	21	13·5	+ 2·9
44	Riverview	78·66	135	*i* 11	44·5	+ 0·6	*i* 21	29·5	+ 4·6
45	College	78·80	23	*i* 11	44·5	— 0·2	*i* 21	27·5	+ 1·1
46	Sitka	88·44	25	*i* 12	32·5	— 0·8	..	..	..
47	Seattle	100·87	25	*i* 13	32·5	+ 2·1	..	..	..
48	Hungry Horse	103·04	20	*i* 13	40·5	+ 0·7	..	..	..
49	Pasadena	113·73	30	*e* 14	29·5	+ 2·5	..	..	..
50	Palisades	114·15	360	*i* 14	30·5	+ 1·6	..	..	..

O—C = Observed —Calculated time

TABLE 4

No.	Station	$pP—P$ (sec)	h (km)	$sP—P$ (sec)	h (km)	$sS—S$ (sec)	h (km)	$pPKP—PKP$	h
1	Hyderabad	33·7	190	57	210				
2	Poona	34·5	192	57	190				
3	Bombay	32	168	57·5	190	54	180		
4	Kodaikanal	37	198	53	171	57	186		
5	Colombo	37	192	57	185	57	169		
6	Quetta	34·5	157	56·3	177	56·3	158		
7	Manila	40·5	209						
8	Djakarta	40	193	59	184				
9	Istanbul	45	199	62	179	69	172		
10	Kiruna	43	185	63	182				
11	Upsala	43	184	52	179	68	165		
12	Tananarive					75	184		
13	Wien	36	151			73	179		
14	Zagreb	44	187			79	195		
15	Praha	40	169	65	189	69	165		
16	Copenhagen	46	197						
17	Harbanovo	45	190	62	179	71	171		
18	Trieste			73·5	216				
19	Cheb	41	171	67	195	64	155		
20	Stuttgart	46	201	63	182				
21	Strasbourg	46	192	66	192				
22	Zurich	45·4	189						
23	Uccle	47	197	67	195				
24	Durham	46	192						
25	Rathfarnham Castle	44	183	61	176				
26	Riverview	45	183			80	189		
27	Washington							46	176
	Mean		186		187		174		176

TABLE 5

No.	Station	Δ (°)	Observed travel time of P' (PKP) (T) m	s	Calculated travel time of P' for a surface focus (J. and B.) (t) m	s	$t—T$ (sec)	h (Gutenberg and Richter) (km)	h (J. and B.) (km)
1	Pasadena	113·7	18	19·5	18	40·5	21	164	158
2	Palisades	114·15	18	20·5	18	41·5	21	168	158
3	Fordham	114·3	18	19·5	18	41·7	22·2	179	168
4	Cleveland	114·39	18	20·5	18	41·8	21·3	173	160
5	Columbia	121·83	18	33·5	18	56·3	22·8	177	173
6	Tacubaya	134·3	19	01·5	19	20·1	18·6	173	140
7	Bogota	149·32	19	33·5	19	57·4 (A)	23·9	131(?)	182
8	La Paz	162·48	19	43·5	20	3·3 (E)	19·8	167	148
9	Huancayo	164·74	19	46·5	20	5·5 (E)	19·0	153	142
							Mean	169	159

(*iii*) Travel times of P' (PKP) at the distant stations, preferably near the anti-centre, are very sensitive to changes in depth of focus. A change of depth of 10 km changes the travel time of P' by more than a second. Several stations in the North and South America had recorded the phase P' (PKP), and the difference between the observed arrival times of P' and the calculated arrival times on the basis of a surface focus, was used to calculate the depth. The values obtained from the J.B. Tables (1940) are systematically smaller than those obtained from Gutenberg and Richter's (1936) table. The values are given in Table 5.

(*iv*) Macroseismic information is sometimes useful in calculating the depth of focus. Strong shocks of small focal depths are generally destructive near the epicentre and are not felt over such large areas as shocks of same strength but with large focal depths. The destructivity due to strong shocks of large focal depths is not generally confined to the epicentral region but extends over a wide area. Gutenberg and Richter have given empirical formulae by which depths of focus of an earthquake can be calculated from the maximum MM intensity (intensity in the Modified Mercalli scale) near the epicentre and the radius of perceptibility of the earthquake. The isoseismals are generally not circular and hence the mean radius has to be inferred from the felt area. The radius of perceptibility of the shock as determined from the isoseismal map is about 540 miles (870 km) and the maximum intensity recorded is 6 on the Modified Mercalli scale. The three formulae given by Gutenberg and Richter (1942) therefore give the value of the depth as about 160, 150 and 130 km. As the formulae are empirical and approximate all that we can infer from them is the order of the depth.

The order of depth obtained in this way agrees roughly with the values calculated from the three methods enumerated above.

We have finally adopted a value of 180 ± 10 km as the depth of focus of this shock

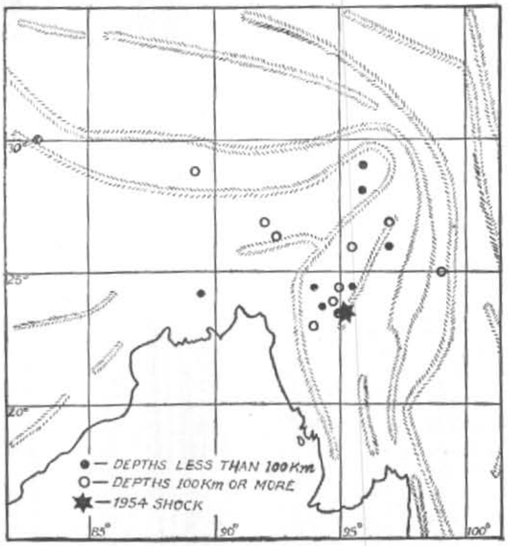

Fig. 2. Epicentres of deep-focus earthquakes

below the surface. It may be mentioned here that the depths of focii of the earlier shocks in this region were usually between 75 and 130 km. A list of some earlier shocks with their epicentres, origin times etc is given in Table 6. The distribution of these shocks is shown in a map in Fig. 2.

5. Magnitude, energy and acceleration

The magnitude of the earthquake as calculated at Pasadena is 7 to $7\frac{1}{4}$. Other values quoted in the B.C. I.S. bulletin are $7\frac{1}{4}$ to $7\frac{1}{2}$ (Upsala), $7\frac{1}{4}$ (De Bilt, Kiruna, Rome and Seattle).

Gutenberg and Richter (1942) have given empirical relation between the magnitude M and energy E of an earthquake. The relation has been subjected to several changes and the final value is expected to be published in future. If we adopt $7\frac{1}{4}$ for M, and use the formula $\log E = 11{\cdot}3 + 1{\cdot}6 M$, we get 8×10^{22} ergs for the energy of the shock. This value appears to be a bit too high from other considerations which are being discussed elsewhere.

The Wenner accelerographs at Shillong and Chatra recorded the earthquake. The

TABLE 6

Date	Epicentre		Origin time			Depth of focus	Magnitude
	(°N)	(°E)	*h*	*m*	*s*	(*km*)	
1906 Aug 31	27	97	14	57	30	100	7
1914 Mar 28	25	99	10	44	48	100	6·9
1926 May 10	26	97	08	19	10	80	6¼
1927 Mar 13	24½	95	16	56	32	130	6½
1932 Aug 14	26	95½	04	39	32	120	7·0
1934 Jun 2	24½	95	05	54	29	130	6½
1935 Mar 21	24¼	89½	00	04	02	80	6¼
1935 Apr 23	24	94¾	16	45	41	110	6¼
1935 May 21	28¾	89¼	04	22	31	140	6¼
1938 Apr 14	23½	95	01	16	35	130	6¾
1938 May 6	24½	95	03	41	08	100	5¾
1939 May 27	24½	94	03	45	44	75	6¾
1940 May 11	23¾	94¼	21	00	20	80	6½
1941 Jan 21	27	92	12	41	48	100	6¾
1941 Jan 27	26½	92½	02	30	16	180	6½
1941 Feb 23	28	96	09	56	40	90	5½
1947 May 8	24	95	18	45	00	65	..
1948 Sep 28	23	94	21	36	53	100	..
1952 Nov 8	30	83	07	06	11	50	..
1954 Mar 22	24	95·15	23	42	12·5	180±10	7-7¼

N–S component at Shillong was out of order during the earthquake and the E–W component at Chatra recorded the vibrations very feebly. The more significant portions of the records of E–W and Z components at Shillong and N-S and Z components at Chatra are reproduced in Fig. 3.

The maximum horizontal and veritcal accelerations recorded at Shillong were about 4·6 cm sec^{-2} corresponding to a period 0·12 sec and 1·2 cm sec^{-2} corresponding to a period 0·24 sec. Those at Chatra were about 2 cm sec^{-2} corresponding to a period 0·44 sec and 0·5 cm sec^{-2} corresponding to a period of 0·4 sec. The ratio of the available horizontal to the vertical accelerations both at Shillong and Chatra is about 4. The prevailing periods in the horizontal and vertical components at Shillong were between 0·1 to 0·14 sec and at Chatra between 0·27 to 0·58 sec respectively.

The durations of the vibrations in the E–W and Z components at Shillong were about one and a half and one minute and in the N–S and Z components at Chatra were about a minute and forty seconds respectively.

The intensity of the shock in Modified Mercalli scale on the ground of the Central Seismological Observatory compound was 6 and at Chatra it was 4. According to computations of the United States Coast and Geodetic Survey from accelerograph data collected during the period 1930–41, the *MM* intensity 6 corresponds to a range of acceleration 5 to 175 cm sec^{-2} and an average value of 40 cm sec^{-2}. For *MM* intensity 4, these are 2 to 46 cm sec^{-2} and 9·3 cm sec^{-2}. These values correspond to one component of the accelerograph, presumably horizontal. The accelerograph at Shillong is a massive masonry pier raised from solid rock at a depth of nearly 30 feet below the general ground level where the *MM* intensity of the earthquake was estimated. The height of the masonry pier is about 10 feet above the foundation. Considering that the lower limit of the range 5 to 175 cm sec^{-2}, represents the conditions on the solid rock and the higher values represent conditions on loose formations of different natures, the

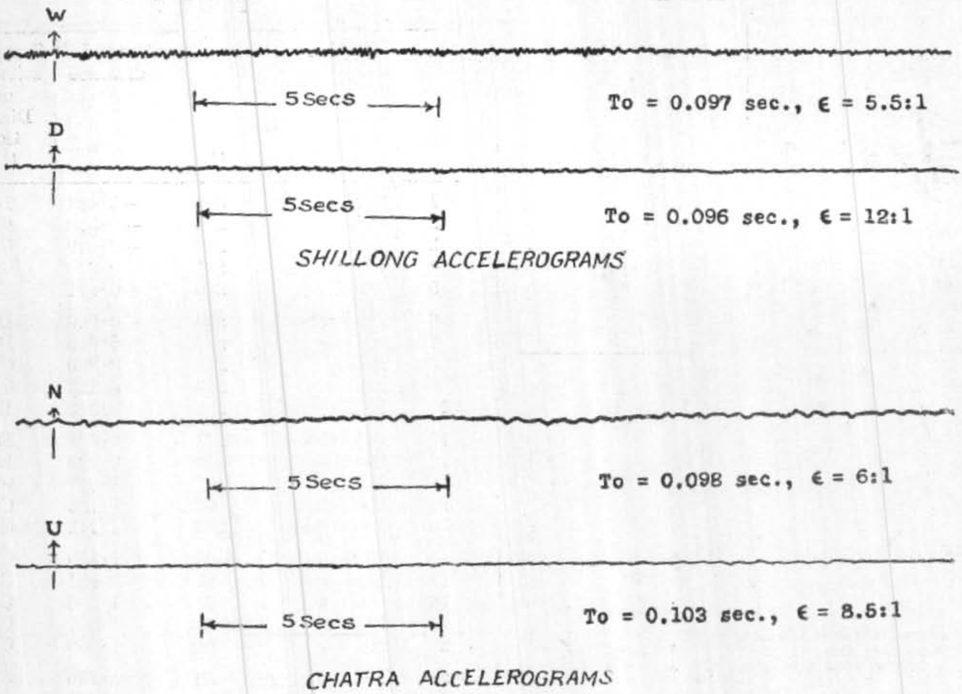

Fig. 3

agreement between the value of the acceleration as recorded at Shillong and the expected value is satisfactory. The masonry pier at Chatra where the accelerograph has been installed is also on solid rock some distance below the ground surface and somewhat under identical conditions as at Shillong. The recorded value of acceleration at Chatra also agrees with the expected value on solid rock.

6. Direction of faulting

Hodgson and Storey (1953) have extended Byerly's method of determining the direction of faulting in normal earthquakes from the direction of ground motion recorded at distant stations, to earthquakes of any focal depth. They have also given tables of external distances for various focal depths and have thus made the methods quite simple for application to deep earthquakes. The data for the direction of first motion (*P*, *PKP*) were available from a number of stations. These are given in Table 7 along with the extended distances, azimuths and the direction of initial motion recorded at these stations. The data have been plotted on a stereographic projection with the anticentre as the pole of projection in Fig. 4.

Two circles A and B have been drawn separating the zones of compression and rarefaction. There are no discrepancies except at Perth. But the initial movement at this station seems to be uncertain as the *P* residual of the station is about + 7 seconds. According to theory, anyone of the circles can represent the fault plane, the other representing the auxiliary plane.

If the circle A represents the fault plane, the displacement was along a reverse fault striking N50°E and dipping to NW at an angle of 60°. The motion must have taken place in this plane along a line striking N78°E such that the hanging wall side moved NE and up.

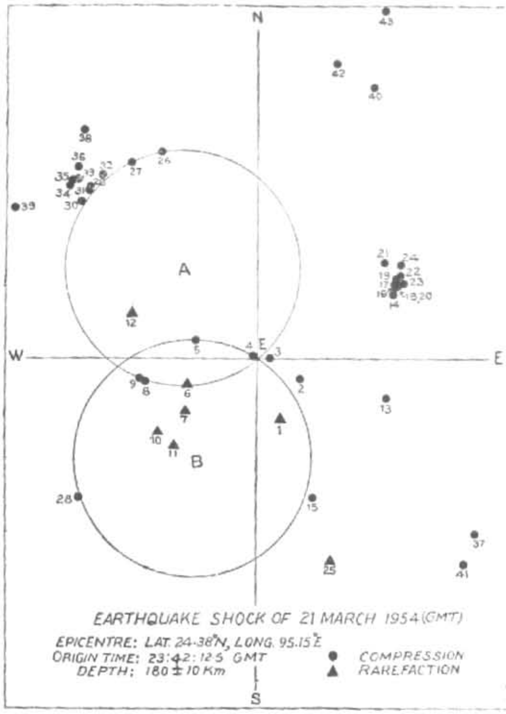

Fig. 4. Direction of faulting

If the circle B represents the fault plane, it would still represent a reverse fault striking N124°E and dipping to SW at an angle of 61°. The direction of motion lies in this plane along a line striking N140°E, the hanging wall side moving up and SW.

Considering the isoseismal map of the earthquake (Fig. 1) and clustering of the isoseismals towards the SE side of the epicentre, it seems more probable that circle A represents the correct solution.

TABLE 7

No.	Station	Azimuth (°)	Extended distance	Compression(C) or Dilatation (D)
1	Tocklai	339	—0·484	D
2	Shillong	294	—0·358	C
3	Calcutta	256	—0·039	C
4	Chatra	291	0·030	C
5	Delhi	289	0·471	C
6	Hyderabad	250	0·566	D
7	Madras	233	0·655	D
8	Poona	258	0·860	C
9	Bombay	260	0·888	C
10	Kodaikanal	233	0·919	D
11	Colombo	223	0·928	D
12	Quetta	290	0·995	D
13	Manila	107	1·017	C
14	Fukuoka	65	1·136	C
15	Djakarta	158	1·142	C
16	Hamada	63	1·159	C
17	Sumoto	63	1·191	C
18	Osaka	64	1·200	C
19	Nagano	60	1·207	C
20	Hikone	64	1·209	C
21	Nagoya	53	1·216	C
22	Maebasi	60	1·241	C
23	Tokyo	63	1·248	C
24	Miyoka	57	1·278	C
25	Perth	160	1·635	D?
26	Kiruna	335	1·702	C
27	Upsala	327	1·729	C
28	Tananarive	232	1·708	C
29	Praha	316	1·805	C
30	Vienna	313	1·779	C
31	Zagreb	315	1·798	C
32	Copenhagen	320	1·814	C
33	Stuttgart	315	1·907	C
34	Chur	313	1·914	C
35	Zurich	314	1·937	C
36	Uccle	317	1·982	C
37	Brisbane	129	2·113	C
38	Rathfarnham Castle	323	2·159	C
39	Algier Univ	320	2·164	C
40	College	23	2·215	C
41	Riverview	135	2·209	C
42	Resolute Bay	5	2·301	C
43	Hungry Horse	20	2·763	C

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REFERENCES

Gutenberg, B. and Richter, C. 1936 *Bull. seism. Soc. Amer.*, **26**, pp 341-390.
1942 *ibid*, **32**, pp. 163-191.
Hodgson, J.H. and Storey, R.S. 1953 *Bull. seism. Soc. Amer.*, **43**, pp. 49-61.
Jeffreys, H. and Bullen, K.E. 1940 *Seismological Tables.*
Tandon, A.N. 1954 *Indian J. Met. Geophys.*, **5**, 2, pp. 95-137.