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SOME TYPICAL EARTHQUAKES OF NORTH AND WEST UTTAR PRADESH

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INTRODUCTION

Most of the destructive earthquakes in Uttar Pardesh occur in the hilly region around Lat. 30°N, and Long. 80°E and are in all probability associated with the thrusts in the middle Himalayas. As a matter of fact a number of shocks exceeding magnitude 5 originate from this region every year and are responsible for its high seismicity. The areas of West Uttar Pradesh located south of the Himalayas are comparatively less seismic but earthquakes of moderate intensity have been reported from the region during recent times. These are associated with the Moradabad fault and other unknown faults in the basement rocks below the alluvium. In addition to these strong earthquakes originating in the Western Himalayas, deep focus earthquakes from the Hindukush are often felt over the region but seldom cause any significant damage to structures. Table 1 gives a list of important earthquakes which affected the region during the past. Data on these earthquakes upto the year 1869 has been taken from T. Oldham's (1883) Catalogue of Indian earthquakes. For the remaining shocks the chief sources of information have been, "The Seismicity of the Earth" by Gutenberg and Richter (1954). The International Seismological Summary, B. C. I. S. (Strasbourg), The Seismological Bulletin of the International Seismological Institute, Edinborough. The epicentre cards issued by U. S. C. G. S. and the Monthly Seismological Bulletin of the India Meteorological Department. The data provided by the table, though useful in many ways, is not sufficient for undertaking a detailed study of the seismicity of the region. It is not possible to correlate this data with any degree of certainty with known tectonic features of the region as some important parameters like the depth of focii and fault plane solutions for most of the earthquakes are not available. Even the location of epicenters lacks the precision required for detailed seismicity studies. In order to help such studies a detailed study of three typical earthquakes which affected the region during recent times has been undertaken in this paper. All the three earthquakes occured along different fault systems and their study is expected to throw light on the chief characteristics of the faults responsible for their occurrence. These shocks are—

1. The Bulandshahar Earthquake of 10th October, 1956.
2. The Kapkote Earthquake of 28th December, 1958.
3. The Moradabad Earthquake of 15th August, 1966.

METHODS USED FOR DETERMINING THE EPICENTRAL PARAMETERS

Epicenter and Origin-time—Epicenters and origin times, depth of focii and magnitudes for all the three shocks has been determined by USCGS, BCIS and ISC from teleseismic data but it was found necessary to redetermine these parameters more accurately using the data of both near and teleseismic stations. Starting with the approximate value of the epicenter as determined on an 18″ metal globe the final epicenter and origin time were obtained by the method of least squares as described by Bullen (1959). In the case of the Bulandshahar and Kapkote earthquakes a number of station pairs were available at which the P-wave arrived at the same time and it was possible to check on the results by using the station pair method, which has the advantage of being independent of travel time tables.

1. B–7/50 Safdarjung Enclave, New Delhi-16.

TABLE I

SN	Date of occurrence	Brief description of important effects	Epicenter Lat. N	Long. E	Origin time	Depth of focus	Mag.
1	1720 July 15	Considerable damage in Delhi, followed by aftershocks.	New Delhi.				
2	1764 June 4	Many houses overthrown and large number of men and cattle killed.	Banks of Ganges.				
3	1803 May 22	.	Upper Ganges.				
4	1803 Sep 6	Very violent at Muttra. Extensive damage and earth fissures. Damage in Delhi, followed by aftershocks.	Probably near Muthra along the fault in the Aravalli.				
5	1809	Vishnu Ganga river blocked by landslides.	Garhwal				
6	1816 May 26	Felt in hills and plains of U.P.	Gauhati				
7	1825 May 22	Felt sharply at Delhi with rumbling noise.	—				
8	1830 Jul 17	Smartly felt at Delhi. Last of three earthquakes in Four months.					
9	1831 Oct 24	Felt at Delhi. Lasted a minute. Felt more severaly towards South and Southwest.	Near Delhi.				
10	1831 Dec 25	Felt at Loherghat	Kumaon				
11	1832 Jul 2	—do—	Kumaon				
12	1832 Aug 18	—do—	Kumaon				
13	1832 Sep 23	—do—	Kumaon				
14	1833 May 30	—do—	Kumaon				
15	1833 Sep 20	Felt at Meerut					
16	1835 Jan 4	Felt at Lohaghat					
17	1835 Jan 14	Felt at Lohaghat	Kumaon				
18	1842 Jan 16	Felt at Muttra, Mainpuri, Jampore Chunari & Sultanpur.					
19	1842 Mar 5	Felt over West U.P. Simla, Houses at Dehra Dun and Mussori damage.	Near Mussorie				
20	1842 June 4	Violent trembling at Delhi, Accompanied by rumbling noise.					

1	2	3	4		5	6	7
21	1843 Apr 11	Felt at Hardwar, Landaur, Delhi & Meerut.	Near Mussorie.				
22	1852 Mar 31	Felt over N.W.U.P. Severe at Meerut; Clocks stopped.	Moradabad fault.				
23	1864 Aug 30	Two smart shocks felt at Lucknow. Slight at Patna.					
24	1902 Jun 16		31 N	79 E			
25	1906 Jun 13		31	79			
26	1916 Aug 28	All houses collapsed at Dharchula	30	81	062930		7.5
27	1925 Nov 6		26.5	81.5	192045		5½
28	1926 Jul 27		30.5	80.5	072336		6
29	1927 Oct 8		30.5	80.5	133428		6
30	1930 Jun 25		25.0	77.5	004900		5–6
31	1935 Mar 3		29.6	80.4	221559		5–8
32	1935 Mar 15		29.6	80.4	103752		5–6
33	1936 May 27		28.4	83.3	061918		6
34	1937 Apr 30		30.0	81.5	193255		5–6
35	1940 Apr 10		30.0	81.5	081739		5–6
36	1945 Jun 4		30.3	80.8	120855		5
37	1947 Aug 19		31.2	79.9	100706		5–6
38	1949 Feb 5		31.2	79.9	083520		5–6
39	1952 Nov 8		27.9	82.2	104154		5–6
40	1953 Feb 23		29.5	81.3	004608		6.0
41	1953 Aug 20		27.9	82.2	015825		6.0
42	1954 Sep 4		28.3	83.8	064345		6¼
43	1954 Sep 4		28.3	83.8	064514		6¼–6¾
44	1956 Oct 10		28.2	77.7	153136		6½
45	1958 Dec 28		30.0	79.9	053438		6¼
46	1958 Dec 31		30.1	79.9	035515		6
47	1960 Aug 27	Minor property damage at Delhi.	28.2	77.4	153859		6.0
48	1961 Dec 24		28.8	81.5	071330		5–6
49	1962 Jul 13		30.9	79.6	050109		5–6
50	1962 Jul 14		30.4	79.5	155854		5–6
51	1963 Jan 30		29.4	80.9	103350		5–6
52	1963 Nov 27		30.8	79.1	211040		5.1
53	1964 May 24		30.1	82.1	0050		5.1
54	1964 May 24		30.1	80.7	004603		6.2
55	1964 Oct 6		29.0	81.0	201935		5.2
56	1964 Dec 20		29.5	81.3	802143		5.1
57	1964 Dec 20		29.5	81.3	033136		5.2
58	1965 May 13		29.8	80.5	101515		5.1
59	1965 Jun 1		27.0	83.0	075230		5.7
60	1965 Nov 18		29.9	80.3	024128		5.2
61	1966 Mar 6		31.6	80.5	021057		5.4
62	1966 Mar 6		31.6	80.5	021557		6.1

1	2	3	4		5	6	7
63	1966 Jun 27		29.7	80.9	104109		6.1
64	1966 Jun 27		29.8	80.9	104743		5.3
65	1966 Jun 27		29.8	80.7	104950.0		5.8
66	1966 Jun 27		29.7	81.0	105918		6.0
67	1966 Jun 27		29.7	80.8	112143		5.4
68	1966 Jun 28		29.4	81.1	154337		5.4
69	1966 Aug 15		28.7	78.9	021534		5.8
70	1966 Oct 13		31.0	80.1	124242		5.2
71	1966 Dec 16		29.6	81.0	205214		5.9
72	1966 Dec 16		29.7	81.0	221249.2		5.4
73	1966 Dec 18		29.6	81.0	224238		5.0
74	1966 Dec 21		29.4	81.0	221059		5.4
75	1968 Jan 5		30.2	80.2	060240.5		5.3
76	1968 May 27		29.7	80.4	183557		5.1
77	1968 May 31		29.9	80.0	030136		5.7
78	1969 May 3		30.2	79.9	062022		5.3
79	1969 Mar 5		29.2	81.1	111506		5.2
80	1969 Jun 22		30.6	$79.4\frac{3}{8}$	013324		5.4
81	1970 Feb 12		29.4	81.6	015151		5.4

Magnitude—The magnitudes of the shocks had been determined by a number of stations in the world, but it was redetermined with the help of records of standard Wood Anderson Seismographs of the Indian network of stations. It has been found that the magnitudes so determined are usually about 1/2 unit higher than obtained by other stations. After making due corrections to these values, an average magnitude was worked out for all the shocks.

Depth of Focus—The precise determination of the depth of focus of an earthquake with its focus within the crust is not always possible with the help of seismometric data. Accurate determination is possible only if data of stations located very close to the epicenter is available. Estimates based on teleseismic data or on the basis of phases caused by reflections of waves close to the epicenter often give very divergent results. Macroseismic data can be usefully utilised to give fairly good estimates for the depth. Several empirical formulae using the maximum intensity at the epicenter *Io*, the Magnitude of the shock *M*, and the radius of perceptibility *r* are available for this purpose. Gutenberg and Richter (1942) gave the following two formulae—

$$6 \log \frac{r}{h} = Io - 1.5$$

$$3.6 \log \frac{r}{h} = M - 2.2$$

Karnik (1964) and Shebalin (1961)

have given the following empirical formulae:

$$M = 0.6\ Io + \log h + 0.4$$

$$M = 0.7\ Io + 2.3 \log h - 2.0$$

The depth of focii in all the cases was obtained with the help of the above four relations and checked with the help of seismometric data whereever possible.

FAULT PLANE SOLUTIONS

Byerly's (1938) method as modified by Hodgson and Storey (1953) has been used in finding the strike dip and the nature of faulting. The method uses a sterographic projection with the anticenter f as the pole in which the directions of first motion are plotted at their respective azimuths and at the calculated value of the extended distance for the appropriate depth of focus. The compressions and dilatations are then separated by two circles passing through the epicenter and satisfying the condition of orthogonality. One of the circles represents the fault plane and the other the auxiliary plane. It is not possible to distinguish between the fault plane circle and the auxiliary circle and the decision about the correct solution is generally based on geological and macroseismic evidence. In some cases where observations are lacking it is possible to draw only one circle but the other can be drawn by taking the orthogonality criteria into consideration. Difficulties are also created by inconsistent observations. The strike of the fault is given by the tangent to the circle at the epicentre and the dip δ is calculated by the formula $\delta = \tan^{-1} 2r$ where r is the radius of the circle. If the fault plane circle encloses compressions, it is a normal fault, but if it encloses dilatations it is a reverse or thrust fault. In cases where the two circles interesect at right angles the type of motion is mainly of the strike slip type and if they touch tangentially it is entirely dip slip. Cases in between the two have both strike and dip slip components.

THE BULANDSHAHAR EARTHQUAKE OF 10th OCT. 1956

This earthquake occurred at about 2100 hours and was felt throughout North West Uttar Pradesh and adjoining area and caused minor property damage at Buland

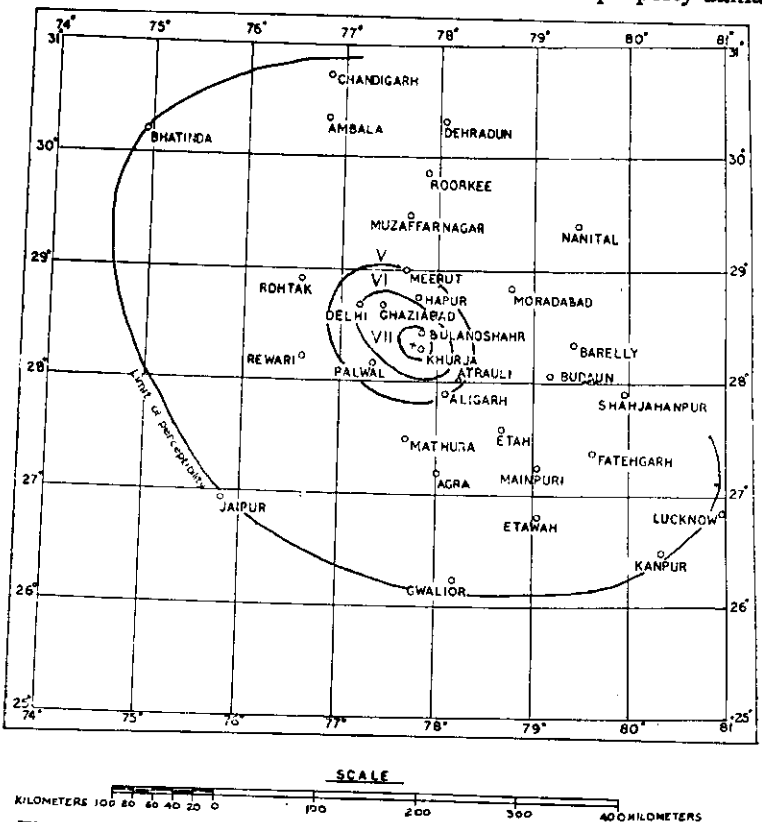

Fig. 1. Iso seismals of the Bulandshahar Earthquake of October 10 1956.

Shahar and Khurja. It was strongly felt at Delhi where a large number of people rushed out into the open for safety. Minor cracks also appeared in a few buildings. A preliminary report describing the macroseismic effects of the earthquake has already been published by Dr. A.G. Jhingran, according to which "the shock was perceptible over a substantially wide region which according to newspaper reports included Chandigarh, Ambala, Jaipur, Gwalior, Dholpur, Alwar, Aligarh, Kanpur and Lucknow." The earthquake was most destructive in and around the towns of Bulandshahar and Khurja where a number of kutcha buildings were destroyed and some pucca buildings developed cracks. The worst affected village were Dhansura, Dungarpur, Belona and Jhaghar to the west of Kali Nadi. It is clear that the maximum intensity in the Modified Mercalli Scale exceeded VII and reached VIII close to the epicentre. In Delhi the intensity was close to VI. Fig. 1, which is based on newspaper reports, gives the approximate delineation of isoseismals V, VI and VII and the limit of perceptibility.

Table 2 gives the relevant data used in determining the epicentre, origin time and the fault plane solution of the earthquake. Jeffreys and Bullen Travel Time Tables (1940) have been used while computing the parameters according to methods outlined earlier. The final results obtained by the least square method are

Epicenter Lat. 28.3°N, Long. 77.8°N

Origin time 15h 31m 15.5s GMT

It will be seen from Table 1 that the *P* wave arrived simultaneously at a number of pairs of station located in widely different azimuths. The epicenter could thus be determined also by the station pair method without the help of any travel time tables. The coordinates of the epicenter thus obtained are Lat. 28.4°N, Long. 77.9°E which differ from the earlier result by only 0.1 degrees.

Magnitude—The magnitude of the shock as determined from the records of standard Wood Anderson seismographs installed at the Indian observatories worked out as follows—

Shillong	6.8
Vizianagram	7.0
Bokaro	6.8
Chatra	7.3

giving an average value of nearly 7 which seems to be on the higher side. The magnitude reported by some foreign stations like Kiruna and Uppsala was 6.4 and 6.5 respectively. A value of 6.5 for the magnitude of this shock seems to be reasonable and has been adopted.

Depth of focus—The presence of large surface waves on all seismograms showed that the focus was not deep seated. In the seismograms of Chatra, Shillong, Vizianagram, Bombay and Poona a prominent phase could easily be recognise 6 to 7 seconds after the first arrival. The station bulletins of the observatories at Uppsala, Skalstugar Stuttgart, Messtelten, Besancon and M' Bor also reported a prominent phase 6, 5, 7, 6, 4 and 7 seconds respectively after P. If this phase is interpreted as P the depth of focus is about 15 kms.

The relevant macroseismic data about the earthquake is

Magnitude	=6.5
Max. Intensity *Io*	=VIII
Radius of perceptibility	=300 kms.

The values of depth of focus obtained according to the different formulae given earlier are—

TABLE 2

Earthquake of 10th October 1956

S.N.	Station	Observed P–time (GMT)	Degrees	Azimuth Z	Residue O–C (sec)	Comp. or dilatation	Extended distance
1	2	3	4	5	6	7	8
1	New Delhi	iP 153151	0.57	320	+4		
2	Dehra Dun	i 153237	2.02	005	+6	D	.094
3	Bokaro	i 153344	8.47	119	+2	C	.261
4	Chatra	i 153336	8.43	97	−6	C	.260
5	Queeta	e 153357	9.70	284	−2	D	.297
6	Poona	153408	10.35	202	0	C	.320
7	Bombay	e 153409	10.43	207	0	C	.323
8	Vizianagram	i 153420	11.35	151	−2	D	.352
9	Shillong	e 153439	12.85	99	−3	C	.402
10	Namangam	153450	13.63	340	−2		
11	Tashkent	e 15353.5	14.75	334	−4	(D)	.461
12	Frounse	153506	14.78	350	−2		
13	Madras	e 153513	15.40	171	−3	D	.477
14	Tiflis	153750	29.97	306	+5.3		
15	Irkutsk	e 153759	31.03	32	+2	D	1.280
16	Sverdlovsk	153758	31.01	341	+1		
17	Ksara	153842	36.15	290	+1		
18	Jerusalem	153849	36.62	286	+4	(C)	1.377
19	Simpfersopsl	e 153905	38.29	308	+1	D	1.400
20	Moscow	e 153911	39.68	325	0		
21	Helwyn	i 153919	40.43	284	+2	D	1.428
22	Kandilli	e 153926	41.58	301	−1		
23	Leningrad	e 153954	44.98	328	0	(D)	1.492
24	Matsushiro	154041.6	50.94	59	+1	D	1.492
25	Upsala	154041	51.07	326	−1	D	1.610
26	Kiruna	154049	51.92	336	+1	D	1.630
27	Praha	ei 154050	52.03	313	+1		
28	Messima	i 154050	52.13	298	0	C	
29	Jena	e 154103	53.83	314	+1		
30	Skalstingan	i 154105	54.18	330	0	D	1.683
31	Firenze Xim	i 154106	54.59	311	−2		
32	Tananairine	e 154114	55.32	216	+1	(D)	1.711
33	Astrida	i 154115	55.43	244	+1	D	1.714
34	Stuttgart	i 154114	55.50	316	0	D	1.716
35	Lwiro	e 154118	55.97	246	0	D	1.726
36	Karlsruke	e 154119	55.99	312	+1	D	
37	Strasbourg	e 154121.5	56.47	312	0	D	1.740
38	Besancon	i 154145	57.82	310	−1	D	
39	Kew	i 154154	61.22	316	0	D	1.870
40	Relizane	e 154215	64.37	298	0		
41	Rathfarxham Caslle	154216	64.48	319		D	
42	Tammanrasset	154216	64.58	283	−1	D	1.97
43	Granada		67.2	301		C	
44	Pretoria	i 154303	71.85	226	+1	D	2.18
45	Pietermaritzberg	i 154311	73.28	222	0	C	2.23
46	Kumberky	i 154327	75.9	226	+1	C	2.33
47	Rabaul	e 154341	78.35	101	+2		
48	Grahamstown	i 154310	78.1	222		C	2.40
49	College	i 154350	80.62	18	−1	C	2.511

h=20 kms (Karnik)
h=20 km (Shebalin)
h=25 kms } Gutenberg.
h=20 kms }

A value of 20 kms for the depth of focus seems to be reasonable.

FAULT PLANE SOLUTION

In Table 1 column 7 the direction of motion of the first arrival at some Indian and foreign stations has been given. These have been plotted at the appropriate azimuths and extended distances in fig. 2. Using the method outlined earlier the compression

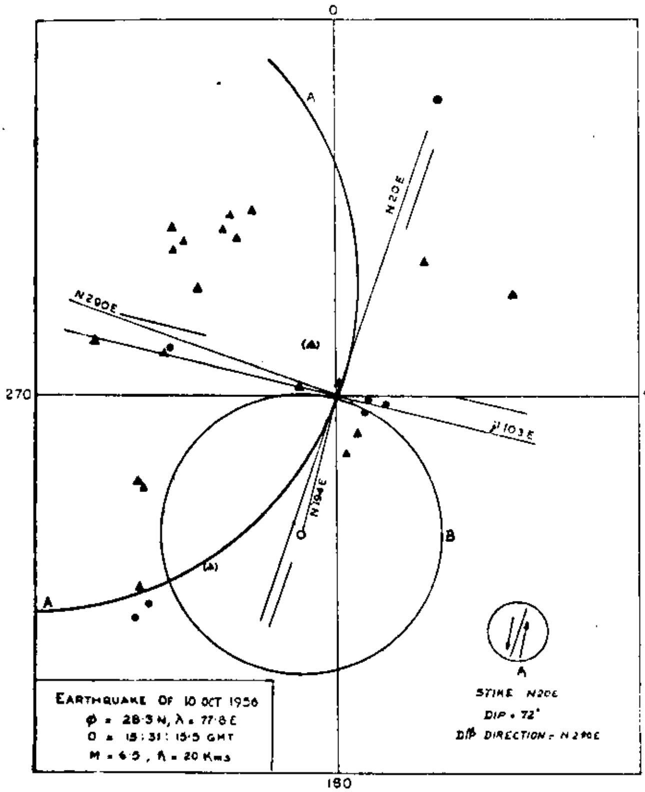

Fig. 2. Fault plane solution of Bulandshahar earthquake of October 10, 1956

and dilatations have been separated by two circles, both of which could represent the fault plane circle. Out of a total of 36 observations two observations, that of Irkutsk and Matsushiro do not fit.

If the circle A represents the fault plane it would mean a reverse fault striking N 20 E and dipping towards N290°E at an angle of 79°. The motion was almost strike slip with very little dip component.

The circle B represents a reverse fault striking N103E and dipping towards N194E at an angle of 72°. The motion was predominently strike slip. Considering the trend of the Aravalli below the alluvium in the Gangetic plains the solution A seems more likely.

THE KAPKOTE EARTHQUAKE OF DEC. 28, 1958.

The greatest damage to structures due to this shock was caused at Kapkote, a small town about 70 miles from Almora. Here about a dozen houses are reported to have been razed to the ground. The NES Blocks and the State Allopathic Hospital suffered serious damage. Newspaper reports indicated that the shock was strongly felt at Almora, Mukhim, Lakhpal, and Dehradun. At Moradabad it is reported to have knocked down some telephone poles and moved furniture while at Dehra Dun traffic came to a standstill. The other places from which the shock was reported felt include Pilibhit, Ambala, Simla, Chandigarh, Ranikhet, Meerut, Mukteshwar, Najibabad, Hissar and Lucknow. The shock was felt only mildly at Delhi generally by persons on top of buildings. Some persons ran out of their houses as doors and windows rattled.

Within the meizoseismal area a few earth fissures and landslides were reported. Considering this and the damage to structures close to the epicenter it is surmised that the maximum intensity reached was certainly MM-VIII. Since the shock was felt in Delhi and Lucknow, the radius of perceptibility must have been close to 350 kms.

Table 3 gives the relevant data used in determining the epicentre and origin time by the method of least squares. Residuals of P are given in column 4 and the direction of first motion of the vertical component in column 7. The final results regarding the epicenter and the origin time are :

Epicenter : Lat. 30°00′ N, Long. 79°58′ E

Origin time : 05 h. 34 m. 42.0 s. GMT.

Magnitude—The magnitude of the shock as computed from the maximum trace amplitude recorded by Standard Wood-And erson Seismographs of Indian stations was as follows :—

Shillong	6
Tocklai	6½
Bokaro	6½
Port Blair	6¼
Vizianagram	7

giving an average value of about 6½. The magnitude reported by some foreign stations reported by some foreign stations was as follows—

Uppsala 6.4, Praha 6¾, Matsushiro 6½, Moscow 6, Kew 6½. Considering all these facts, a value of 6½ has been adopted for the magnitude.

DEPTH OF FOCII

Since the phase $\bar{P}$ was clearly recorded at all the Indian stations located within $\Delta=10°$, it was obvious that the focus lay in the granitic layer. A prominent phase was also recorded about 12 seconds after the first arrival at most of the Indian stations. Assuming this phase to be $s\bar{P}$ the depth of focus comes out to be about 30 kms. This is also corroborated by the fact that travel times appropriate for a depth of 33 kms. gave the best fit in the epicentral determination.

Depth of focus as determined from macroseismic data gave the following values—

h=27.5 kms. (Gutenberg's formulae)

h=22 km.

h=22 km. Karnik

h=18 km. Shebalin

TABLE 3

Earthquake of 28th Dec. 1958

S.N.	Station	Observed P time (GMT)	Degrees	Azimuth Z	Residual O–C (Sec)	Comp. or Dilatation	Extended distance
1	2	3	4	5	6	7	8
1	Dehra Dun	053514	1.70	285	+4.3	D	.016
2	Agra	053535	3.35	210	+1.7	D	.084
3	Lahore	053538	5.02	290	+1.0	C	.142
4	Chatra	053626	7.05	110	+0.5	D	.211
5	Bokaro	053638	8.07	138	−1.7	D	.244
6	Lhasa	053702	9.67	86	+0.2	C	.293
7	Queeta	053720	11.28	272	−3.9	C	
8	Shillong	053723	11.47	108	−3.4	C	.353
9	Andidjan	053735	12.40	332	−4.0		
10	Hyderabad	053736	12.57	185	6.2	D	
11	Karachi	053737	12.50	248	−3.3		
12	Poona	053738	12.70	206	−4.0	D	.390
13	Stalingabad	053738	12.60	316	−3.6		
14	Namangan	053741	12.85	331	−4.0		
15	Bombay	053742	12.83	211	−2.7		
16	Chittagong	053745	13.15	119	−4.0		
17	Tashkent	053800	14.23	326	−3.1		
18	Madras	053837	16.92	177	−0.7	D	.535
19	Kunming	053921	20.73	96	−1.1	C	.896
20	Chengtu	053922	20.75	79	−0.3	C	.896
21	Port Blair	053937	21.75	142	+4.6	C	1.01
22	Pastow	054021	26.60	55	+1.9	C	1.169
23	Makhatchkulu	054038	28.95	306	−2.3		
24	Goris	054042	29.07	298	+0.6		
25	Sverdolovsk	054050	30.06	339	−0.2		
26	Cantor	054055	30.57	92	+0.2	C	1.260
27	Tibilisi	054056	30.60	301	+1.0		
28	Peking	054100	31.12	58	+0.3	C	1.272
29	Nanking	054118	33.22	74	0	C	1.313
30	Zose	054138	35.37	75	+1.6	C	1.350
31	Jerusalem	054158	38.00	282	−0.6		
32	Changchum	054201	38.33	53	−0.3	C	1.391
33	Simpferspol	054205	38.80	305	−0.2	C	1.398
34	Moscow	054210	39.41	323	−0.3		
35	Vladivostok	054241	43.07	55	+0.5		
36	Pulkovo	054252	44.50	327	0		
37	Yakutsk	054258	45.33	28	−0.6		
38	Lwow	054305	46.08	313	+0.4		
39	Apatity	054309	46.48	337	+1.3		
40	Matsushiro	054323	38.50	63	−0.6		
41	Upsala	054340	50.75	325	−2.8	C	1.594
42	Kuruna	054345	51.17	335	+1.0	C	1.603
43	Rome	054407	54.62	302	−2.6	C	1.684
44	Magadan	054414	55.03	33	+1.4		
45	Stuttgart	054417	55.81	311	−1.2	C	1.714
46	Lwiro	054438	58.40	245	+1.4		
47	Kew	054438	61.33	315	−2.7	C	1.862
48	Resolute	054624	75.52	358	−0.8	C	2.298
49	College	054640	78.41	19	−1.0		
50	Brisbave	054742	90.22	121	+1.6		
51	Hungry Hoose	054828	101.40	14	−0.6		

These formulae give an average value of about 22 kms. Considering the value of 30 kms obtained from seismometric data, a value of $h=25\pm$ has been adopted for the depth.

Fault Plane Solution—Column 7 of Table 3 gives the direction of the first motion in the vertical component. These have been plotted on an sterographic projection at the proper azimuths and extended distances as shown in fig. 3. Two circles *A*

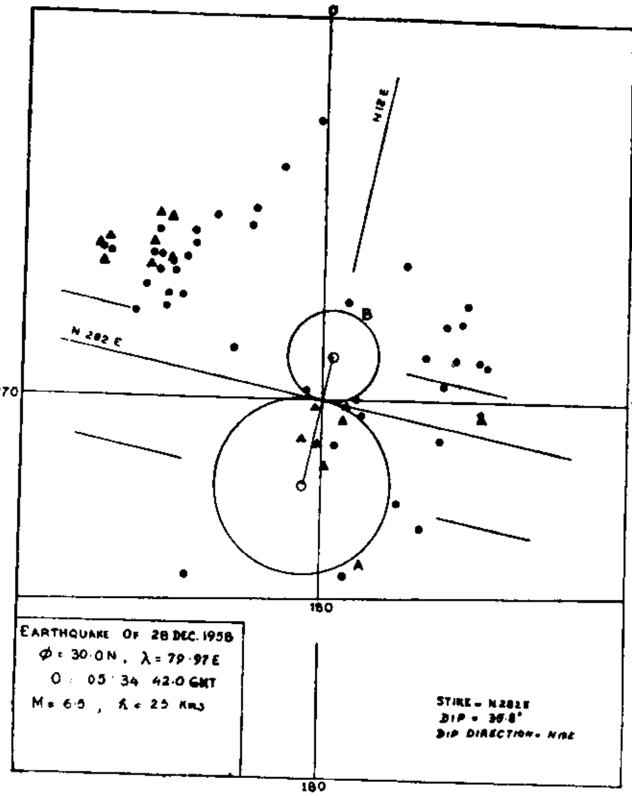

Fig. 3. Fault-plane solution of Kap Kote earthquake of December 28, 1958.

and *B* have been drawn separating the compressions and dilatation according to the method outlined earlier. It was possible only to draw the circle *A* while the circle *B* has been drawn with the help of the orthogonality criteria. No other circle would satisfy the criteria. There are about 7 observations in the North-west sector which do not fit in with the surrounding data. Both the circles *A* and *B* can represent the fault plane. In either case the circle would represent a thrust fault striking N 282 E. Considering the geology of the region the circle *B* appears to be correct solution which would mean a thrust fault striking N 282 E and dipping towards N 12 E at an angle of 36°, the motion during the earthquake being entirely dip slip.

THE MORADABAD EARTHQUAKE OF 15TH AUGUST 1966

This earthquake occurred on the morning of Aug. 15, 1966 and was felt extensively in West Uttar Pradesh. In Moradabad about 30 persons were injured, 15 of them seriously in house collapses following the earthquake. A few well built houses also suffered minor damage. Cracks also appeared in some buildings in Bareilly and Meerut. The shock was also reported to have been felt at Agra, Delhi, Nainital, Simla Dehra Dun and Mukteshwar. Considering all these reports the maximum intensity in the epicentral region was about VI M.M. and the radius of perceptibility about 250 kms.

The epicentral parameters given by international organisations were as follows—

USCGS Epc : 28.7 N, 78.9 E; h=53 Kms.; Mag : 5.6
0=02h 15m 34.4s GMT

I. S. S. Epc : 28.67 N, 78.93 E; h=5±8 kms.
Mag : 5.6, O=02h 15m 28.0±1.3s

The epicenter was redetermined taking into account the data of Indian stations and it was found that shifting the epicenter about 10 kms. to the south of the USCGS epicentre would satisfy the Indian data better. The magnitude as determined by the records of Indian stations also worked out to be higher than that determined by USCGS. The epicentral parameters finally adopted are Epc : 28.6°N, 78.9°E, *O*=02h 15m 33.8s, Mag.=5.8.

Depth of focus—The depth of focus determined by USCGS and I. S. S. was 53 kms and 5 kms and hence no final conclusion could be drawn. An examination of the records of Indian stations showed that surface waves were well recorded and the phase *P̄* was clearly recorded at stations located within $\frac{1}{2}\Delta=10°$. This showed that the focus was located within the granitic layer. Phases like pP or sP could not be clearly identified and hence the only method possible for the assessment of the depth of focus depended on macroseismic observations.

As mentioned earlier the maximum intensity Io was VII M.M. and the radius of perceptibility was about 250 kms. The various formulae mentioned earlier give the following values for *h*

h=16 (Karnik)
h=18 (Shebalin)
h=30 } (Gutenberg)
h=25 }

giving an average of about 22 kms.

Fault Plane Solution—The data used in determining the direction of faulting is given in Table 4. In fig 4 the compressions and dilatations have been plotted at the

TABLE 4

Moradabad Earthquake of Aug. 15, 1966

S.N.	Station		Observed P-time (GMT)	Degrees	Azimuth Z	Residue O–C (sec)	Comp. or dilatation	Extended distance
1	2		3	4	5	6	7	8
1	New Delhi	i	211559.0	1.51	271	+3.5	C	0.13
2	Jwalamukhi	i	21632	3.90	325		DSE	.133
3	Nurpur	i	21640.3	4.48	325		DSE	.149
4	Mukerian	i	21747	4.35	320		DSE	.143
5	Chatra	iP	21722.6	7.52			D	.231
6	Shillong	i	21820	11.94	(102)		W	.374
7	Khorog	e	21805	10.75	327	−0.5	D	0.333
8	Poona	i	2188 .0	11.11	206	−2.5	C	0.346
9	Bombay	i	21809.0	11.22	211		C	0.348
10	Dushanbe	i	21832.0	12.99	322	−3.8	C	0.406
11	Przhevalsk	i	21846.0	13.79	358	−0.2	D	0.431
12	Semipalatinsk	i	22022.4	21.72	02	+0.7	D	1.016

1	2		3	4	5	6	7	8
13	Fort Blair	i	22020	21.26	139		C	.991
14	Shillong	i	22036.2	23.07	279	+1.0	D	1.073
15	Tehran	i	22040.5	24.30	294	−6.6	D	1.114
16	Tabriz	e	22129.0	28.67	298	+1.4	D	1.228
17	Kuovabad	i	22133.0	21.19	303	+0.8	D	1.242
18	Sverdlovsk	i	22148.0	30.95	340	+0.3	D	1.277
19	Kastamonu	i	22255.0	38.68	301	+0.8	D	[illegible]
20	Simperapal	e	22255.0	38.85	307	−0.6	D	1.407
21	St Paraskevi	i	22341.6	44.39	298	+0.6	D	1.482
22	Pulkovo	i	2242 .0	45.11	328	+15.5	D	1.494
23	Campulong	e	22348.0	45.28	307	−0.1	D	1.497
24	Vamos	i	22359.1	46.39	293	+2.2	D	1.516
25	Athen's	i	22357.1	46.48	296	−0.5	D	1.518
26	Yakutsk	i	2242 .0	46.93	30	+1.2	D	1.526
27	Apatity	i	2245 .0	47.40	338	+0.5	C	1.535
28	Kajani	i	2249 .3	47.89	333	+0.8	D	1.544
29	Ninmijaur	i	22410.0	48.04	327	+0.4	D	1.547
30	Valsamata	i	22414.6	48.91	297	−2.0	D	[illegible]
31	Ciacow	i	22417.0	48.95	313	+0.2	D	1.565
32	Kirkenes	i	224214	49.54	340	+0.3	D	1.576
33	Sadankyla	i	22421.9	49.60	336	+0.3	D	1.577
34	Kevo	i	22428.8	50.50	339	+0.4	D	1.598
35	Tikai	i	22429.0	50.80	18	−1.7	C	1.605
36	Vienna	i	22435.0	51.27	310	+0.4	D	1.616
37	Uppsala	i	22433.9	51.32	325	−0.8	D	1.67
38	Karlskrona	i	22438.1	51.96	321	−1.6	D	1.630
39	Kuuna	i	22440.0	51.99	336	+0.2	D	1.631
40	Yuzno-Sakha Linsk	i	22442.0	52.14	51	+0.8	C	1.633
41	Pruhonice	i	22444.0	52.43	313	+0.7	D	1.641
42	Tromso	i	22448.0	53.06	338	+0.2	D	1.656
43	Kasperake Horg	i	22448.0	53.08	312	−0.2	D	1.656
44	Maxa	i	22457.0	54.28	314	+0.1	D	1.686
45	Skalstugan	i	22457.0	54.36	330	−0.3	D	1.689
46	Kongoberg	i	2254 .2	55.32	325	−0.3	D	1.711
47	Karlsruhe	e	22514	56.48	312	+1.1	D	1.741
48	Lwiro	i	22517.4	57.02	246	+2.1	D	1.754
49	Dourbes	i	22531.3	58.81	314	+2.0	D	1.802
50	Garchi	i	22538.2	63.28	311	−1.3	D	1.844
51	Chilika	i	22545.0	61.25	230	−1.4	D	1.871
52	[illegible]	i	[illegible]	[illegible]	320	+0.5	D	1.910
53	Nord	i	22554.6	[illegible]	351	−0.5	D	1.923
54	Brokin Hill	i	22610.0	64.94	236	−1.0	D	[illegible]
55	Tammanrasuit	i	22613.0	65.45	284	−1.2	D	[illegible]
56	Alert	e	22625.0	67.49	355	−1.3	D	2.054
57	Valantia	i	22626.7	67.54	318	−0.1	D	2.069
58	Aulrayo	i	22635.0	68.67	231	+0.4	D	2.089
59	Ifrane	i	22644.0	70.22	298	+0.1	D	2.135
60	Kalginli	i	22649.1	71.69	142	−3.7	D	2.180
61	Avervios	i	22654.6	72.08	299	−0.5	D	2.192
62	Warramanga Array	i	22654.5	72.10	126	−1.0	D	2.192
63	Pretoria	i	22659.0	72.83	227	−0.7	D	2.215
64	Sa Da Bandiena	i	22722.5	76.59	245	+1.0	C	2.347
65	Windhock	i	22732.0	78.39	236	+0.7	D	2.414
66	Charter Towns	i	22745.4	81.06	111	−0.3	D	2.533
67	Frobisher Bay	e	22801	84.37	346	−0.8	D	2.676
68	Baker Lake	e	22816	87.24	358	0.0	D	2.782

appropriate azimuth and extended distance on a stereographic projections. Circles A and B which satisfy the orthogonality criteria separate the compressions and dilatations. Any of the two circles could represent the fault plane. If the circle A represents the fault plane it would mean a normal fault striking about E–W and dipping towards south at an angle of 50°. The motion during the earthquake was predominently strike slip (anticlockwise). If the circle B represents the fault plane it would mean a normal fault striking N 343 E and dipping towards N 83 E at an angle of 70°, the motion being predominently strike slip (clockwise). The solution A agrees generally with the direction of the Moradabad fault (near Moradabad) as discovered by the Oil and Natural Gas Commission, and is therefore the more probable solution.

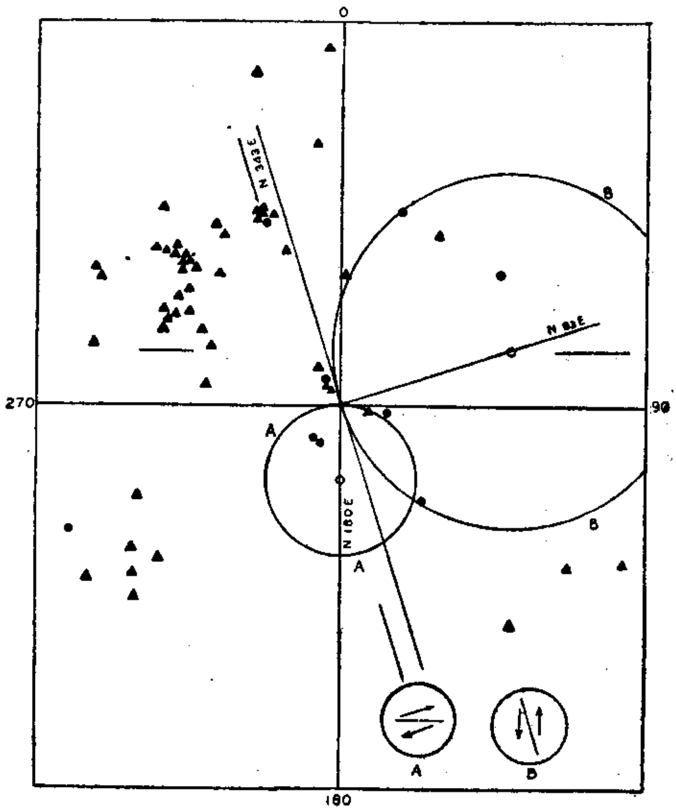

Fig. 4. Fault plane solution of Moradabad earthquake of August 15, 1966.

Conclusion—Table 5 gives a summary of the results obtained for the three earthquakes studied in this paper.

TABLE 5

Date	Epicentre Long. °N	Lat °E	Origin time G.M.T. h. m s.	Mag	h kms.	I_0	r kms.	Strike	Dip	Dip Dir.	Type of motion
10.10.56	28.3	77.8	153115.3	6.5	20	VIII	300	N20E	79°	N290E	Reverse strike slip.
28.12.58	30	79°58	053442.0	6.5	25	VIII	350	N282E	36°	N12E	Thrust DipSlip.
15. 8.66	28.6	78.9	021533.8	5.8	22	VII	250	N270E	50°	N180E	Normal Strike slip.

The results summarised in Table 5 confirm that earthquakes in North and West Uttar Pradesh mainly occur along three tectonic features as described below—

(1) The NW-SE aligned thrust faults of the Himalayas almost parallel to the trend of the Himalayas in the region. These are characterised by a predominently dip-slip type of faulting along faults dipping towards NNE to NE at low angles. The focal floors are close to the base of the granitic layer in the region i.e. about 25 to 30 kms deep. The largest number of shocks occur close to Lat 30°E and long. 80°E and the maximum magnitude has never exceeded 7.5.

(2) Among the transverse faults which meet the Himalayas at right angles the Moradabad fault passes through the region and has shown recent seismic activity. The trend of the fault close to Moradabad as evidenced by the earthquake of 15.8.66 is almost E-W and it dips at an angle of about 50° towards south. The motion along the fault during earthquakes is predominently strike slip. Historical records also reveal that the fault has been active in the past but the magnitude has never exceeded 6.0. The depth of focil is around 20 kms and appears close to the base of the granitic layer.

(3) The earthquake of 10th Oct 1956 occurred along a fault striking NNE-NE which is almost parallel to the trend of the Aravallis below the Indogangetic alluvium in the region. The fault appears to be a reverse fault dipping rather steeply towards NW and the motion predominently strike slip. Historical records show that a destructive earthquake occurred close to the town of Muttra and is located to the southwest of the epicentre of this shock. It is very probable that this earthquake also originated along the same fault. The occurrence of these earthquakes confirms the active nature of this fault along which earthquakes may occur in future. The depth of focus as revealed by the earthquake under study seems to be around 20 kms which too is close to the base of the granitic layer. The highest magnitude was probably associated with the Muttra earthquake of 1803 and close to 7.

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