A SEISMOLOGICAL STUDY OF THE BALUCHISTAN (QUETTA) EARTHQUAKE OF MAY 31, 1935. BY K. R. RAMANATHAN, M.A., D.Sc., AND S. M. MUKHERJI, M.Sc., *Colaba Observatory, Bombay.* (With plates 25 to 28.)

INTRODUCTION.

A preliminary account of the earthquake from the geological and general points of view has been published by Mr. W. D. West[1] in the Records of the Geological Survey of India. From the field evidence, Mr. West concluded that "in the case of the present earthquake there is no doubt about the position and extent of the epicentre, since severe damage was confined to a long narrow tract, away from which the intensity of the damage rapidly decreased. This tract extended from Baleli just north-west of Quetta through Dingar and Mastung to Mand-i-Haji and included the Shirinab Valley to the west of the Mastung-Kalat road. It is an area about 68 miles long and 16 miles wide. Within this area there were clearly places where the intensity was greater than elsewhere, notably Dingar and Mastung road and possibly Mand-i-Haji. Since it is well known that earthquakes are more severely felt on alluvium than on solid rock, it is possible that the length of the epicentral area as compared with its breadth has been enhanced to some extent by the fact that it is parallel to the valleys of the district." The surface crack extended from about 30°·3 N., 66°·9 E. to 29°·1 N., 66°·5 E., the centre of the region of maximum disturbance being 29°·7 N. and 66°·7 E. From the seismological evidence, the best position for the epicentre appears to be 29°·6 N., 66°·5 E., slightly to the south-west of the above position, but well within the region of maximum intensity.

The materials available for study.

The following materials were available for the seismological study of the present earthquake.

1. The seismograms (horizontal components only) of the Indian observatories : Bombay, Agra, Calcutta, Hyderabad and Kodaikanal.

[1] W. D. West, "Preliminary geological report of the Baluchistan (Quetta) Earthquake of May 31st, 1935." *Rec. Geol. Surv. Ind.*, LXIX, Pt. 2, p. 203, (1936).

Rec. Geol. Survey India. 73, 483–513, 1939.

2. The seismograms of 15 foreign observatories: Batavia, Chiufeng, Medan, Peichiko, Tokyo, Göttingen, Ivigtut, Pulkovo, Scoresby Sound, Vienna, Adelaide, Melbourne, Sydney, Ottawa and Tacubaya. These seismograms had been obtained from the Directors of the respective observatories by Dr. S. C. Roy and were kindly placed at our disposal for purposes of study.
3. The data of travel-times of the principal phases recorded at 142 observatories, as measured at the observatories themselves and mostly collected at Oxford for the purpose of the International Seismological Summary. These were obtained from Miss Bellamy by the Director of the Geological Survey of India and kindly sent to us. Some data were also taken from observatory bulletins.

The position of the epicentre and the time of origin of the earthquake.

For determining the epicentral time and position of the earthquake, only the arrival-times of the P phase at different observatories were used, as this phase is in general the least subject to uncertainty. As a first approximation, the centre of the region of greatest disturbance in Mr. West's map of isoseismals was assumed to be the epicentre. The distances of the different observatories from the assumed epicentre were calculated from the geographical co-ordinates and using Jeffreys' and Bullen's table of travel-times (published in 1934 in the International Seismological Summary for the year 1930), the times of arrival of P at the different places were calculated and compared with the observed times of arrival. A comparison of the mean residuals (observed minus calculated times) at observatories situated in different azimuths showed in what manner the hypothetical epicentre should be shifted in order to get a better fit and thus, by a process of successive approximation, the best position of the epicentre was determined and the corresponding epicentral time t_0 calculated. The distribution of stations in different directions is markedly non-uniform, the directions best represented being north-west and north-east. Towards the south, the number of stations is few, and even among them, the times of first onset as recorded at the Indian stations were abnormally early. Table 1 shows the residuals P(O-C) at 40 selected stations and also the mean residuals in four different groups of these stations, arranged according to their direction from the focus. The assumed values of the epicentre for which figures are given are (i) 29°·7 N., 66°·7 E., which is very near the middle of the inner region of maximum disturbance marked in his map by Mr. West and (ii) 29°·6 N., 66°·5 E., the epicentre which is found to fit the observations best. The assumed value of t_o or epicentral time is 21h 32m 59s G.M.T. It may be recalled that t_o is not necessarily the actual time of the earthquake; it is the time "which makes $t-t_o$ at short distances proportional to the distance". If the focus is at the surface, the actual time of occurrence or the hypocentral time of the earthquake, according to Jeffreys, is about 5·8 secs. earlier than t_o.

TABLE 1.—*Comparison of Epicentres.*

P_1(O-C)—Epc. 29°·7 N., 66°·7 E. } P(O-C) calculated using geographical co-ordinates
P_2(O-C)—Epc. 29°·6 N., 66°·5 E. } and J. B. tables.

P_2^1(O-C)—Epc. 29°·6 N., 66°·5 E.—P(O-C) calculated with observed travel-times corrected for ellipticity (Bullen's tables) and using Jeffreys' revised tables (1937) of travel-times.

Station.	Azimuth.	Δ_1	P_1(O-C)	Δ_2	P_2(O-C)	P_2^1(O-C)
	°	°	secs.	°	secs.	secs.
Tashkent . .	6	11·8	1·3	11·9	0	0·1
Ekaterinburg .	352	27·5	0·3	27·55	—0·2	—0·4
Moscow . .	320	33·2	0·8	33·2	0·8	0·4
Helsingfors . .	329	41·2	0	41·2	0	1·0
Bergen . .	326	50·5	0·9	50·5	0·9	0·7
Scorsby Sd. . .	339	61·8	1·0	61·8	1·0	1·3
Ivigtut . .	334	75·1	—2·9	75·1	—2·9	—1·4
Mean of 7 stations.	NNE to NW		+0·2		—0·1	+0·2

E

TABLE 1.—*Comparison of Epicentres*—contd.

Station.	Azimuth.	Δ_1	P_1(O-C)	Δ_2	P_2(O-C)	P_2^1(O-C)
	°	°	secs.	°	secs.	secs.
Pulkovo . .	313	38·7	—0·9	38·7	—0·9	—0·2
Budapest . .	310	40·5	—2·1	40·4	—1·3	—0·7
Vienna . .	312	42·4	—1·9	42·3	—1·1	—0·4
Prague . .	313	43·9	—1·9	43·8	—1·1	—0·7
Jena . . .	314	45·8	—2·1	45·7	—1·3	—0·8
Göttingen . .	314	46·9	—0·7	46·8	0	0·4
Stuttgart . .	312	47·2	—2·1	47·1	—1·3	—0·9
Strasbourg . .	311	48·1	—2·0	48·0	—1·2	—1·0
Besançon . .	309	49·3	—1·1	49·2	—0·3	—0·3
De Bilt . .	315	49·8	0·1	49·7	0·8	0·7
Uccle . . .	313	50·3	—0·7	50·2	0·1	0
Paris . . .	311	51·6	—0·5	51·5	0·3	0·1
Kew . . .	315	53·2	—0·4	53·15	0	—0·3
Mean of 13 stations.	NW		—1·3		—0·6	—0·3
Helwan . .	278	30·6	—3·3	30·4	—1·5	—2·4
Athens . .	285	36·4	—3·2	36·2	—1·5	—1·9
Sofia . . .	295	36·95	—0·5	36·8	1·3	1·5
Entebbe . .	234	44·05	—4·1	43·85	—2·5	—1·0
Algiers . .	296	52·75	—2·1	52·6	—1·1	—1·5
Almeria . .	297	57·0	—1·1	56·9	—0·4	—0·9
Granada . .	298	57·8	—0·9	57·7	0	—0·5
S. Fernando .	298	60·1	—3·2	59·9	—1·8	—2·0
Cape Town . .	220	78·3	—2·7	78·1	—1·7	2·2
Mean of 9 stations.	NW to SW		—2·3		—0·8	—0·7

TABLE 1.—*Comparison of Epicentres*—concld.

Station.	Azimuth.	$\triangle_1$	P_1(O-C)	$\triangle_2$	P_2(O-C)	P_2^1(O-C)
	°	°	secs.	°	secs.	secs.
Calcutta . .	106	20·7	—0·2	20·85	—1·7	—1·7
Phu Lien . .	96	37·0	—0·4	37·2	—2·1	—2·0
Peichico . .	85	44·3	0·9	44·5	—0·7	—0·4
Manila . .	95	52·0	1·6	52·2	0·1	0
Nagasaki . .	70	53·3	1·9	53·5	0·4	0
Hukuoka . .	69	53·5	0·4	53·7	—1·1	—1·5
Tayooka . .	65	56·5	1·5	56·7	0·1	—0·4
Nagaya . .	65	58·3	2·6	58·5	1·2	1·0
Tokyo . .	64	60·35	1·2	60·55	—0·2	—0·1
Mizusawa . .	59	60·4	0·2	60·6	—1·6	—1·5
Amboina . .	109	67·55	0·2	67·7	—1·2	1·2
Mean of 11 stations.	NNE to ESE		0·9		—0·5	—0·5
Mean of 40 stations.			—0·7		—0·6	—0·4

The arcual distances $\triangle$ of the observatories from the epicentres in the above table have been obtained from the geographical co-ordinates and the calculated times of travel P_1(C) and P_2(C) taken from Jeffreys-Bullen tables. In the last column, the differences P_2^1(O-C) have been calculated correcting the observed travel-times for the ellipticity of the earth so as to give results as for the standard sphere (using Bullen's[1] "Tables for reduction of apparent travel-times of P and S seismic waves" and Jeffreys' revised tables of travel-times, 1937).[2] It will be seen that if we adopt as epicentre 29°·7 N., 66°·7 E., there is a considerable difference between the mean residuals from the westerly and easterly groups of observatories and that this difference practically vanishes if we adopt 29°·6 N., 66°·5 E. No appreciable effect is produced on the mean

[1] K. E. Bullen, "Tables for reduction of apparent travel-times of P and S seismic waves" *New Zealand J. Sc. and Tech.*, Vol. XIX, No. 1, pp. 47—54, (1937).

[2] H. Jeffreys, "Further corrections to P, S and SKS Tables" *M. N. R. A. S., Geoph. Suppl.* 4, No. 3, p. 242, (1937).

E 2

residuals by correcting for ellipticity although there are significant differences in individual residuals. From the magnitude of the residuals, it is clear that a correction of—0·5 sec. is necessary for t_o. The corrected value of t_o is $30^d\ 21^h\ 32^m\ 58{\cdot}5^s$ G.M.T.

The frequency distributions of P residuals in the two cases are shown in figs. 1 and 2.

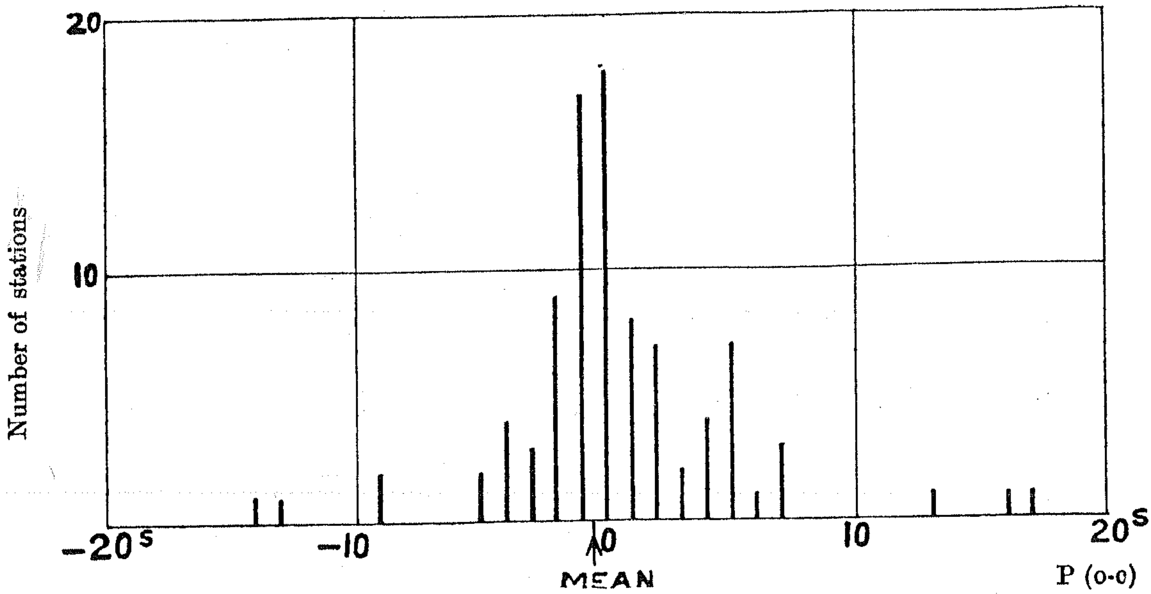

FIG. 1.—P residuals: (O-C) with t_0 assumed to be 21h 32m 59s and using J. B. tables.

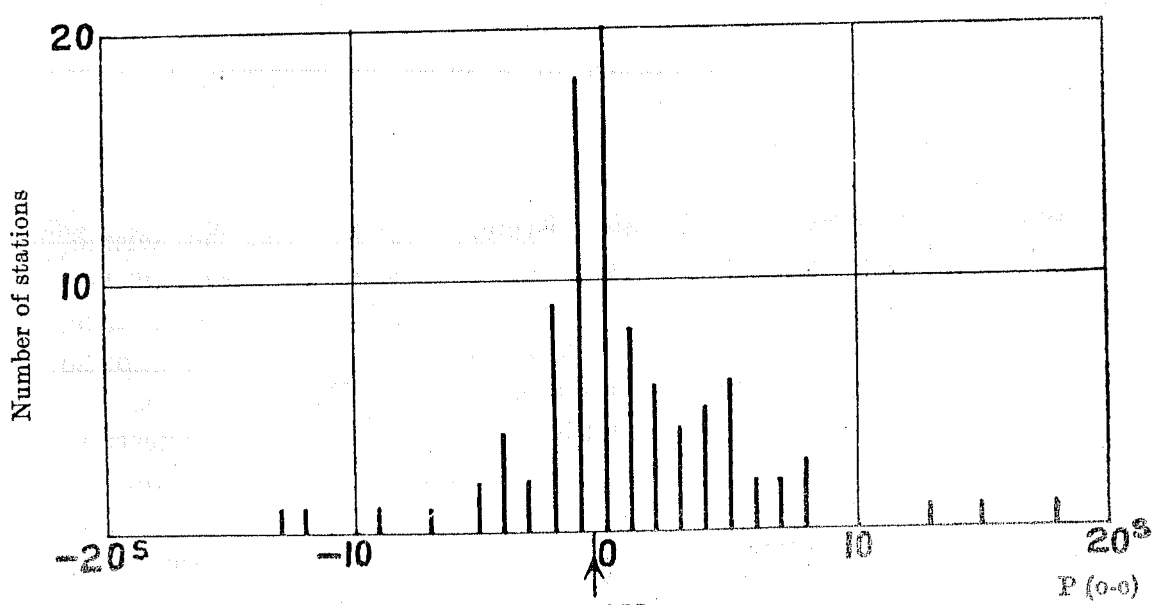

FIG. 2.—P residuals: (O-C) with t_0 assumed to be 21h 32m 59s and using J. B. tables with ellipticity correction.

Some noteworthy features of the seismograms.

The seismograms of this earthquake obtained at the Indian observatories are somewhat complicated. In the Agra Milne-Shaw record there is an impulsive beginning of a phase about 15s after the beginning of the first eP. In the Bombay seismograms, the following phases are recognisable :—

TABLE 2.

Phase.	Time. m	s
eP_1	2	34
iP_2	2	50
iP_3	2	59
i	3	26
i*	3	46
i	4	04
iS_1	5	04
iS_2	5	20
iS_3	5	28

The phase i* marks the beginning of a series of long period oscillations superposed on the much more rapid oscillations usually characteristic of the preliminary phase at this distance. It perhaps corresponds to the beginning of P_g, though one would hardly have expected to see direct P_g at this distance (12°·1). In the seismograms of Hyderabad and Kodaikanal, one notices phases 16 sec. and 14 sec. respectively after the first incidence of disturbance. All these suggest that the shock was a multiple one, the first impulse being feeble and the second one marked iP_2 in Table 2, being the one recorded at the more distant stations. In this connection, reference may be made to the following observations made by Mr. West (*loc. cit.*, p. 212). "At least five to ten seconds before the main shock started, a small tremor was felt which was sufficiently strong to be recognized as an earthquake." This was at a place about four miles north of Quetta. At Quetta itself, "a sentry on duty on top of the Ammunition Depot noticed a shake which he considered to have occurred at least half a minute before the main movement." It must be mentioned, however, that in Calcutta seismograms, there is no evidence of an earlier weak disturbance.

The seismograms of the Indian stations and also of the foreign observatories showed that the amplitudes increased gradually, interrupted by larger and larger impulses and that the surface waves were very large compared with the preliminaries. (Plates 25, 26, 27 and 28).

These features, according to Gutenberg and Richter[1], are suggestive "of extended faulting or more probably, block movement." According to this view, the earthquake was the result not of an instantaneous process but took comparatively longer time during which long-period vibrations were set up, which disturbed the usual short-period waves.

The depth of focus of the earthquake.

The depth of focus of an earthquake to which the normal international tables (Jeffreys-Bullen) apply is not known with exactness but a recent estimate by Jeffreys[2] makes it about 10 km. The destructive nature of the Quetta earthquake and the fact that the long-wave phases in the seismograms were exceptionally well-developed show that the depth of focus of this earthquake was smaller than normal. Seismograms at near observatories (distance less than 10°) with good time-determinations are necessary if the depth of focus of a shallow earthquake is to be determined with any accuracy; in their absence, we have to examine whether any conclusion can be drawn from the "Z phenomenon" or the deviations of S-P residuals from those of a normal earthquake. If the mean value of the residual is positive (this is usually not very different at different distances), the presumption is that the earthquake was shallower than normal. Jeffreys is of opinion that +3 seconds is the maximum possible value of Z, which would occur if the focus

[1] B. Gutenberg and C. F. Richter "On Seismic Waves" (First Paper), *Gerl. Beitr. zur Geoph.*, Vol. 43, p. 73, (1934).

[2] H. Jeffreys, "Further corrections to P, S and SKS Tables" *M. N. R. A. S., Geoph. Suppl.* 4, No. 3, p. 242, (1937).

were at the surface. In a few earthquakes such as the Santa Barbara earthquake of 1925 June 29, and the African Rift Valley earthquake of 1928 June 6, larger values of Z (+8 and +10 seconds respectively) have been obtained but these large values have been explained as being due to possible late reading of the S phase in the former earthquake and to the possible occurrence of two successive shocks within a few seconds of each other in the latter.[1] In the present earthquake, the mean value of Z comes to +5·9 seconds, if we exclude those values of S-P which deviated more than ±15 secs. from the mean. The number of observatories at which the times of arrival of the waves fulfilled this condition was 72. Of these, 56 observatories lay within the range of distance 40° to 60°. The mean residual S-P for these 56 stations alone was +6·1 secs. This large positive value of Z greatly exceeds the maximum of 3 seconds suggested by Jeffreys for a surface focus. To see whether part of the discrepancy might be due to the fact that no correction was made to the travel-times for the ellipticity of the earth, S-P residuals were calculated after applying all the necessary corrections for ellipticity and using Jeffreys' new tables of travel-times of P and S for a *continental surface-focus*[2]. The mean S-P residual was now changed to +3·2 seconds considering all the 72 stations and to +3·7 seconds considering only the stations lying in the range 40° to 60°. There is no large alteration in the nature of the distribution of the residuals about the mean (Figs. 3 and 4). The change

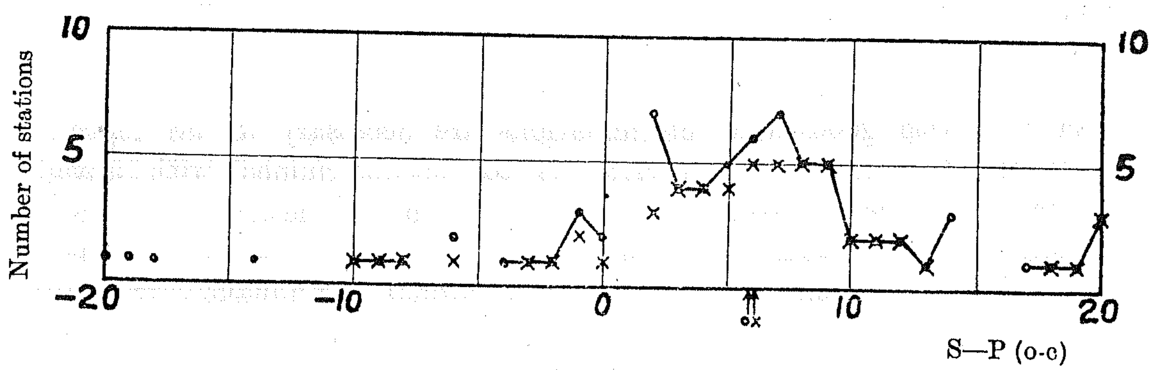

FIG. 3.—"S-P" residuals using normal J. B. table. t_0 assumed to be 32m 59s. • • • • • • • • • All stations; × × × × stations between 40° and 60°.

[1] E. Tillotson, "The African Rift Valley Earthquake of 1928 January 6" *M. N. R. A. S. Geoph. Suppl.* 4, No. 1, p. 92, (1937).
E. Tillotson "Further note on the African Rift Valley Earthquake of 1928 January 6," *M. N. R. A. S. Geoph. Suppl.* 4, No. 4, p. 315 (1938).
[2] H. Jeffreys, *Loc. cit.*

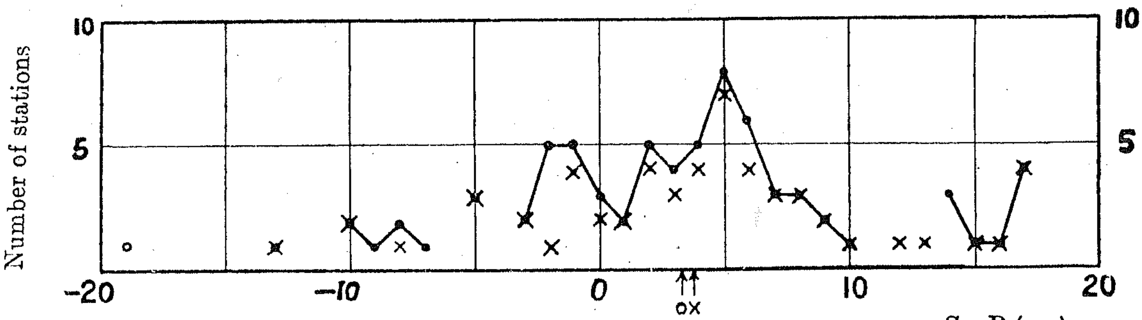

FIG. 4.—" S-P " residuals using Jeffreys' ' continental surface focus table.' t_0 assumed to be 32m 59 s. • • • • • • • • All stations ; × × × × stations between 40° and 60°.

of residual from +5·9 secs. to +3·2 secs. points to a position of the focus nearer the surface than that of a normal earthquake. There still remains too large a mean residual S-P to be attributed to accidental error. Figs. 3 and 4 show that there are two prominent peaks in the curve of residuals which are separated from each other by an interval of about 6 secs. It is probable that these features are a consequence of the fact that the shock was not a simple one originating within a small area at a definite instant, but was the result of a comparatively protracted process.

The energy of the earthquake.

To estimate the energy of an earthquake, various methods have been used. When the earthquake is shallow, most of the energy is in the form of long waves, and an estimate of the energy of these waves will therefore give a lower limit for the energy of the earthquake. We use the following simple relation which has often been used for this purpose.

E=Mean energy per unit volume $\times 2\pi$ R sin $\triangle \times$ thickness of layer in which the long waves travel $\times$ length of wave-train.

$$=4\,\pi^3 \rho\, R \sin \triangle \int \frac{a^2 HV}{T^2}\, dt.^*$$

*The numerical factor 8 is often used instead of 4 in this expression. Since the mean energy during an oscillation, which is partly kinetic and partly potential is equal to the maximum kinetic energy, its value per unit volume is $\frac{\frac{1}{2}\rho \times 4\pi^2 a^2}{T^2}$. This multiplied by 2π R sin $\triangle$ gives only $\frac{4\pi^3\rho a^2 R \sin \triangle}{T^2}$.

where E is the energy conveyed by the long waves,

ρ the density of the surface layer of the earth ($\doteqdot 3$ gm/c.c.),
$\triangle$ the angular distance of the observing station from the source,
H the thickness of the layer,
a the amplitude of the waves,
T their period,

and V the velocity of the waves ($\doteqdot 3{\cdot}5 \times 10^5$ cm/sec.). There can be some doubt as to what value of H should be adopted. If it is taken as the depth of penetration of Rayleigh waves, $H = \frac{7{\cdot}06\lambda}{2\pi} = 1{\cdot}12\lambda$ according to Jeffreys, provided **a** is now taken to be the horizontal displacement. When the period of the waves is 10 to 12 sec., this depth is about 43 km. For a similar calculation, Tillotson[1] used for H the thickness of the granitic layer assuming it to be 13 km. We shall adopt a value of 15 km. in our calculation.

Putting in the appropriate numerical values for the Quetta earthquake as recorded at Bombay, $\triangle = 1340$ km., $T = 10$ to 12 sec. and H the assumed thickness of the granitic layer $= 1{\cdot}5 \times 10^6$ cm. In the EW seismogram at Bombay, some of the excursions of the spot of light went outside the paper and one can therefore obtain only a lower limit to the energy of the waves. The integral $\int \frac{a^2 dt}{T^2}$ evaluated from the EW seismogram comes to be about 5×10^{-3} cm^2/sec. In the NS component record also, the vibrations have been apparently obstructed on one side and we can only say that the value of the integral should have been greater than 5×10^{-3} cm^2/sec. According to Rayleigh's theory of surface-waves, the amplitude of vertical movement should be about 1·5 times that of the horizontal in the direction of propagation. Actually the observed proportion is often different from this and in the absence of a vertical component seismogram, the value of $\int \frac{a^2 dt}{T^2}$ corresponding to the vertical component has been assumed to be about 5×10^{-3} cm^2/sec. The total value of $\int \frac{a^2 dt}{T^2}$ from all the three

[1] E. Tillotson, "On an earthquake near Imotski," *M. N. R. A. S.*, 2, 8, p. 426, (1931).

components is therefore greater than $1 \cdot 5 \times 10^{-2}$ $cm^2/sec.$ and the computed energy of the long waves of the earthquake greater than $3 \cdot 2 \times 10^{20}$ ergs. In a similar way, computing from the only available (E-W) component at Kodaikanal in South India and multiplying by 3, the energy of the long waves there was found to be $1 \cdot 5 \times 10^{21}$ ergs.

From the Göttingen ($\triangle = 46^\circ \cdot 8$) records, the energy of the long waves in the different components was computed to be as follows :—

Component.	Computed energy in ergs.
N-S	$1 \cdot 1 \times 10^{20}$
E-W	$1 \cdot 4 \times 10^{20}$
Z	$0 \cdot 9 \times 10^{20}$
Total . .	$3 \cdot 4 \times 10^{20}$

No doubt there are considerable differences in the recorded amplitudes depending on the crustal structure at the recording station but the above values nevertheless give an approximate idea of the energy of the earthquake; it is clear that the energy must have been of the order of 10^{21} ergs.

(2) An attempt has been recently made by the Pasadena seismologists[1] to introduce an instrumental magnitude scale for earthquakes. The scale is logarithmic and is based on the measured maximum amplitudes in the recorded traces of the shock in a standard seismograph. If the maximum amplitudes due to two similar earthquakes recorded at the same distance are in the ratio 10^m : 1, the magnitude of the first shock is said to exceed that of the second by m. When the seismographs are situated at different distances and are of different makes, even then the traces can be made use of to give an idea of the magnitude of the quake if the ground amplitude can be deduced from the trace. The equation connecting the maximum ground amplitude and the magnitude is (1) $M = \log a - \log A_o - 2 \cdot 5$ where M is the magnitude of the earthquake, 'a' is the maximum recorded ground amplitude and A_o is a constant depending on the distance of the station from the earthquake centre, being the maximum amplitude in millimetres

[1] B. Gutenberg and C. F. Richter "On Seismic Waves" (Third Paper), *Gerl. Beitr. zur Geoph.*, Vol. 47, p. 119, (1936).

in the recorded trace of a standard torsion seismometer by a shock of magnitude 0. Gutenberg and Richter have drawn a curve showing the relation between A_o and $\triangle$ and we extract below for convenience a small table showing this relation.

TABLE 3.

Distances in degrees. $\triangle$	log A_o
1	—3·1
2·5	—4·0
5	—5·0
10	—5·8
20	—6·5
45	—7·0
100	—7·5
150	—8·0

The energy of the earthquake E being proportional to the square of the amplitude the relation between energy and magnitude is expressed by the relation

$$\log E - \log E_o = 2M$$

where E_o is the energy of an earthquake of magnitude 0.

The following table gives the recorded maximum horizontal ground movements at a few observatories due to the Quetta earthquake and the corresponding calculated values of the magnitude.

TABLE 4.

Station.	$\triangle$	Maximum horizontal amplitude.	M
	°	μ	
Budapest	40·4	614	7·2
Zagreb	42·3	756	7·4
Hongkong	45·2	c.400	7·1
Barcelona	52·5	580	7·5
Kew	53·1	>450	>7·4
S. Fernando	59·9	250	7·1
Melbourne	99·5	157	7·2
			7·3

Taking 7·3 to be the magnitude of the earthquake, its energy E is given by

$$\log E = 14{\cdot}6 + \log E_o$$

To determine E absolutely, we require to know E_o the energy of a shock of magnitude 0. This was first estimated by Richter to be 10^6 ergs, but was later modified by Gutenberg and Richter to 10^7 to 10^8 ergs. Taking E_o to be 10^7 ergs, $E = 4{\cdot}0 \times 10^{21}$ ergs.

(3) We can also determine the approximate energy of the earthquake from the area over which the shock was felt. Assuming from his Pasadena experience that the lower limit of perceptibility of an earthquake corresponds to an acceleration of 250 milligals (0·25 cm/sec^2) or a recorded maximum amplitude of 5 mm. in the seismogram of a standard torsion seismometer, Richter[1] gives the following table showing the relation between the radius of the felt area and the magnitude of the earthquake.

TABLE 5.

Mean radius of felt area (km.) .	150	250	360	530	770	1,060
Magnitude	5·0	5·5	6·0	6·5	7·0	7·5

According to West, the area over which the Quetta earthquake was felt was approximately 105,000 sq. miles and its mean radius is therefore 295 km. According to above table, the magnitude would only be 5·7 which is obviously too low. It is probable, as West has pointed out, that owing to the fact that the earthquake occurred at night when people were asleep it was not felt over as wide an area as it would have been during daytime.

Remembering the fact that the energies of the most intense earthquakes such as the Assam earthquake of 1897 have been estimated to be above 10^{25} ergs, the present earthquake had less than $\frac{1}{2000}$ as much energy as the most intense shocks recorded in recent years.

[1] C. F. Richter, "An Instrumental Earthquake Magnitude Scale," *Bull. Seism. Soc. Amer.*, Vol. 25, No. 1, p. 18, (1935).

The times of travel of the different phases as recorded at the various observatories are given in a collected form in table 6.

Table

Epicentre: 29°·6 N. 66°·5 E.
T_o: 1935 May 30—21h 32m 585 s. G. M. T.

Station.	△	Comp.	P	P (O-C) J. B.	P (O-C) J. (1937).	Comp.	S	S (O-C)
	°		m. s.	s.	s.		m. s.	s.
Samarkand	9·9		?				e 4 21	10
Dehra Dun	10·0	N	2 51 ?	30			4 21	8
Agra	10·45	E	i 2 12	—15	—15		i 4 02	—21
		E	i 2 27	0	0		i 4 17	—6
Andijan	11·5		?				e 3 24	
Tashkent	11·9		i 2 47	0	0			
Bombay	12·1	N, E	i 2 34	—16	—15		5 04 ?	—1
		N, E	i 2 50	0	1		5 20 ?	15
			i 2 59	9	0			
Hyderabad	16·3		i 3 29	—16	—15		i 6 44	—2
			i 3 41	—4	—3			
			i 3 45	0	1			
Baku	17·3		i 4 03	5	5			
Calcutta	20·85	E	i 4 37	—2	—2	N, E	8 09	—15
							8 24	0
Tiflis	21·3		i 4 46	2	3		i 8 43	10
Kodaikanal	21·9	E	i 4 38	—12	—11	E	i 8 36	—8
		E	i 4 52	2	3			
Ksara	26·3		i 5 31	—1	—1		10 10	7
Ekaterinburg	27·55		i 5 43	0	0		i 10 29	5
Yalta	29·5		6 01	0	—1		11 10	14
Simferpol	29·7		6 03	1	0		11 14	15
Sebastopol	30·0		6 05	0	—1		11 17	13
Helwan	30·4		6 07	—2	—3		i 11 48	38
Moskow	33·2		e 6 34	1	0		12 00	6
Bucarest	35·0		e 6 54	5	4		13 01	40
Athens	36·2		6 58	—1	—2		12 39	0
Sofia	36·8		e 7 06	2	1			
Phu Lien	37·2		e 7 06	—2	—2		e 12 19	—35
Lemberg	37·7	E	e 7 25	13	13	E	e 13 34	32
		N	e 7 28	16	16	E	e 13 49	47
Pulkovo	38·7	N, E, Z	i 7 22	1	2		e 13 22	5
Belgrade	39·1		e 7 24	0	0			
			7 25	1	1			

6.

	PP	PPP	Pc P		SS	SSS		L	M		Other phases and remarks.
	m. s.	m. s.	m. s.		m. s.	m. s.		m.	m.		
											Pn or P* ? ? 14 m 00 s.
								5·1	5·9		First movement towards E.
											Sn or P* ? ? 13 m 01 s.
								5·9	6·3		*i* 5m 42s ; first movement towards E and S.
					6 59			8·4			*i* 3m 53s ; ? 3m 49s.
	4 53 5 10 }		8 39		8 49			10·2	11·6		*i* 8m 32s; first movement towards E.
	i 4 57				8 57			10·5	19·5		*i* 9m 18s, 13m 19s; (?) 11m 45s.
	5 03				9 16			10·6	11·9		*i* 5m 10s ; 8m 57s (Pc P ?)
		7 13			12 49				22·0 23·5 22·0		
								e 20·1 *e* 20·9 }	25·7 31·5 }		
	i 8 51		*i* 9 31					18·5 20·0 }	23·5		
								i 19·3 19·6 }	21·6		*i* 11m 42s, 14m 27s ; 16m 56s (SSS ?); ? 28m 13s.

TABLE

Station.	△	Comp.	P	P (O-C) J. B.	P (O-C) J. (1937).	Comp.	S	S (O-C).		PP	PPP	Pc P
	°		m. s.	s.	s.		m. s.	s.		m. s.	m. s.	m. s.
Medan . . .	40·05		7 49	17	18		14 04	27				
Budapest . .	40·4		7 34	—1	—1		14 12	30				
Helsingfors . .	41·2		*i* 7 42	—1	1		14 02	8				
Tarente . . .	41·2		7 28	—14	—13		14 36	42				
Konigsberg . .	41·3		*e* 7 48	5	6		14 08	13		9 11	9 41	
Chiufeng . .	41·5		*e* 7 49	4	5		*e* 13 56	—2				*i* 9 36
							i 14 12	14				
Vienna . . .	42·3		*i* 7 50	—1	0		14 14	4		9 24	10 08	*i* 9 34
Zagreb . . .	42·3		*e* 7 50	—1	—1		14 39	29		9 32		
Hongkong . .	43·2		7 53	—5	—5		14 21	—3		9 30	9 59	
Laibach . . .	43·3		*e* 8 01	2	2		*i* 15 01	36				
Prague . . .	43·8		8 02	—1	—1		*e* 15 05	32				
Trieste . . .	43·85		*e*, *i* 8 02	—1	—1		*i* 14 40	6				
Entebbe . . .	43·85		8 01	—3	—1		14 33	—1				
Peichico . . .	44·5	N, E, Z	*i* 8 08	0	0	N, E, Z	14 50	7		9 44	10 20	9 32
										9 56		
Treviso . . .	44·95		*i* 8 17	5	5		*i* 15 01	11				
Cheb . . .	45·1		*e* 8 19	5	6		*e* 15 01	10				
							e 15 31	40				
Padova . . .	45·2		8 12	—2	—2		14 50	—3				
Florence . . .	45·6		*i* 8 22	5	5		15 01	·3				
Prato . . .	45·7		*i* 8 22	4	1		14 53	—7				
Jena . . .	45·7		*e* 8 17	—1	—1		15 01	1				
Gottingen . .	46·8	E, Z	*i* 8 27	0	1	N, E	*i* 15 17	1		10 25		9 38
			m 8 34	7	7		*i* 15 22	6				
			e 8 36	9	9		*e* 15 24	8				
Chur . . .	46·8		*e* 8 25	—2	—2		15 33	17				
Hamburg . .	47·0		*e* 8 28	—1	0		15 20	1				
Tunis . . .	47·0		*i* 8 25	7	7							
Stuttgart . .	47·1		*e* 8 28	—1	—1		*i* 15 13	—7				

6—contd.

	PS	SS	SSS		G	L	M		Other phases and remarks.
	m. s.	m. s.	m. s.		m. s.	m.	m.		
						i 19·5	} 22·8		*i* 10m 41s.
						20·8			
					17 0		25·0		
	14 31		17 31						*i* 14m 36s, 16m 26s ; *e* 18m 18s.
		i 16 46				*i* 20·1	} 24·3	}	*i* Sc S 17m 48s.
						i 20·4	25·7		
		17 21			17 41	19·5	} 33·0		*i* 8m 26s ; PcS 13m 28s ScS 17m 54s. Compression.
						20·7			
						21·4	29·6		*e* PPPP 10m 31s ; *i* 12m 04s ; *e* 7m 56s, 8m 36s, 9m 05s, 12m 19s ; ScS 18m 27s ; 18m 20s, 19m 23s.
						20·9	26·5		10m 51s, 12m 38s ; 31·2m.
						24·1	30·0		*i* 10m 49s, 12m 15s.
						19·0	33·5		*e* SSS ? 18m 15s.
	i 15 20	}	18 50			21·0	} 30·5		Sc S 18m 03s ; *i* 8m 53s, 10m 52s, 12m 08s, 10m 45s, 11m 31s, 12m 58s : 19m 33s, 15m 05s.
	15 43					21·6			
							27·0		
		17 26	18 44			*i* 21·3	26·3	}	*i* 8m 26s, 8m 32s, 15m 08s, Compression
							31·1		
						26·0	29·5		
		18 07				21·0	29·5		*e* 9m 01s, 11m 17s 15m 35s : *i* 10m 41s.
	15 52	18 42			19 07 }	21·8	} 30·0		*i* 9m 25s. Compression.
					19 12	22·3			
	15 56	*e* 19 20				22·3	} 29·0		
						23·0			
									16m 50s.
						30·0			*i* 9m 18s ; *e* 13m 31s, 22m 20s.

F

TABLE

Station.	△	Comp.	P	P (O-C) J. B.	P (O-C) J. (1937).	Comp.	S	S (O-C)		PP	PPP	Pc P
	°		m. s.	s.	s.		m. s.	s.		m. s.	m. s.	m. s.
Zurich . . .	47·45		e 8 31	—1	—1		e 15 44	19				
Karlsruhe . .	47·6		i 8 38	5	5		e 15 41	14				
Strasbourg . .	48·0		8 35	—1	—1		i 15 29	—4				
Basel . . .	48·2		e 8 37	—1	—1							
Taihoku . . .	48·6		8 39	—2	—2		15 51	10				
Newchatel . .	48·6		e 8 37	—4	—4		e 16 02	21				
Besanca . . .	49·2		e 8 45	0	0		e 15 31	—19				
De Bilt . . .	49·75		8 50	1	0		16 07	10				
Jinsen . . .	49·9		e 8 42	—9	—9		i 16 04	1				
Marseilles . .	49·9		8 23	—28	—28		16 03	3				
Uccle . . .	50·24		8 53	0 }	0 }	}	16 13	9			11 08	
			8 54	1 }	1 }							
Bergen . . .	50·5		i 8 56	1	1		16 13	5			11 45	
Lille . . .	51·1		e 9 04	3	4		16 50	34				
Paris . . .	51·5		i 9 03	0	0	E	16 14	—7				
Tannanarive . .	51·8		e 8 56	—9	—7		16 16	—9				
Manila . . .	52·2	E, Z	i 9 08	0	0	N, E	16 50	21		11 05		
Barcelona . .	52·5		9 09	—1	—2		16 40	5				
Algiers . . .	52·6		i 9 10	—1	—1		i 16 41	5				
Batavia . . .	52·7	Z	e 9 19	7	8		16 48	10				
Kew . . .	53·15	Z	i 9 15	0	0	N, E	i 16 52	8 }	}			Z 10 24
							17 06	22 }				
Nagasaki . .	53·5		9 18	0	0							
Hukuoka . .	53·7		9 18	—1 }	—2 }	}	16 56	4 }	}			
			9 20	1 }	0 }		17 00	8 }				
Oxford . . .	53·7		9 23	4	4		17 02	10				
Durham . . .	53·8		9 27	7	7		16 57	4				
Tortosa . . .	53·8		i 9 16	—4	—4		17 01	8				

6—*contd.*

	PS	SS	SSS		G	L	M		Other phases and remarks.
	m. s.	m s.	m. s.		m. s.	m.	m.		
						26·3	31·0		
						22·0	31·0		
		19 26				26·1			Assumed —30s as time correction.
						22·0			
						28·3	31·9		SS (?) 19m 55s.
					21 01				
	16 42					25·0	32·1		*i* 12m 09s, 13m 22s, 17m 03s.
						24·3	35·0		*i* 13m 19s.
						27·0			
	16 52					25·0	32·0		
						26·2	30·7		
	17 05					23·1	29·8		
					22 01 ?		33·0		
						26·7 }	30·7		*i* ScS 18m 49s. Beginning uncertain due to microseisms.
						27·0 }			
					21 50	26·0	39·2		*i* 9m 20s, 12m 21s, 17m 14s, 17m 23s, 20m 50s, 21m 36s, 24m 12s. Dilatation.
							30·6		PPP (?) 12m 37s ? 21m 02s.
						20·7	30·9 }		? 21m 02s.
							33·9 }		
	17 26						33·0		
									? 23m 33s.

F 2

TABLE

Station.	△	Comp.	P	P (O-C) J. B.	P (O-C) J. (1937).	Comp.	S	S (O-C)		PP	PPP	Pc P
	°		m. s.	s.	s.		m. s.	s.		m s.	m. s.	m. s
Stonyhurst . .	54·35		9 26	2	2		17 02	2				
Edinburgh . .	54·7		*i* 9 27	1	0		*i* 17 12	7				
Liverpool . .	54·7		*i* 9 31	5	4		*i* 17 11	6				
Alicante . . .	55·0		*e* 9 31	2	2		*i* 17 29	20		11 41	12 44	
			i 9 36	7	7							
Rathfarnham Castle	56·65		*i* 9 43	2	2		*i* 17 41	10				
Toyooka . .	56·7	Z	9 41	0	0	N	17 42	10				
		E	9 43	2	2	E	17 44	12				
		N	9 46	5	5	Z	17 46	14				
Almeria . . .	56·9		*i* 9 42	0	—1		*i* 17 48	13		11 57		
Sumoto . . .	57·1	N	9 39	—5	—5	N	17 44	7				
		E, Z	*i* 9 44	0	—1	Z	17 45	8				
						E	17 46	9				
Kobe . . .	57·25	Z	*e* 9 42	—3	—3	N, Z, E	17 41	2			13 07	10 36
		N, E	*e* 9 45	0	0		17 42	3				
							17 54	15				
							18 02	23				
							18 03	24				
Toledo . . .	57·4		*e* 9 42	—4	—4		17 43	2		11 58		
			i 9 46	0	—1					12 10		
Granada . . .	57·7		*i* 9 48	0	—1		*i* 17 49	3		12 21		10 45
Malaga . .	58·45		9 50	—4	—4		18 00	4		12 14		
							18 17	21				
Nagaya . .	58·5		9 55	1	1		18 04	8				
Sanfernando .	59·9	Z	*i* 10 02	—2	—2	E	*i* 18 36	21			*i* 13 24	
			10 04	0	0		*i* 18 37	22				
Serrado Pilar . .	60·4		10 05	—3	—2		18 20	—1				
Tokyo . . .	60·55	N, E	*e* 10 08	0	0	N	18 27	4				
Mizusawa . .	60·6		*e* 10 07	—2	—2		18 38	14				
Coimbra . .	60·6		*e* 9 56	—13	—12		18 14	—10				
Scorsby Sund . .	61·8	Z	*i* 10 18	1	1		18 40	14		12 31		10 58
							i 18 53	27				
Amboina . .	67·7		10 55	—1	1		19 46	—7				

6—*contd.*

	PS	SS	SSS		G	L	M		Other phases and remarks.
	m. s.	m. s.	m. s.		m. s.	m.	m.		
		21 13			? 22 15	26·0	35·0		*i* 17m 17s ; Sc S 19m 14s.
					? 22 25		36·0		
						28·6			
						26·5	31·1		
					? 22 47		34·8	}	
							38·5		
		21 46			? 22 56	*e* 26·6	56·3		
							32·8	}	
							37·8		
					?*e*22 41		35·7	}	*i* 10m 14s, 18m 35s, 20m 07s, 22m 31s, 20m 09s.
							37·5		
							38·0		
							39·5		
	18 13				? 22 55		54·6		
						28·4	46·5		
		21 56	24 20			28·4			? 11m 12s; *e* 26m 22s ; ScS (?) 20m 05s.
					23 35		35·2		? 11m 22s.
					? 25 02	29·0	32·0		Pc P (?) 10 32; ? 23m 06s, Dilatation.
						28·0			
						28·0	33·5		
						31·6			
	19 13	22 41	25 14		25 54	*i* 29·6 }	33·7		*e* 14m 55s. Dilatation.
						30·0 }	34·8		
						31·0 }			
						36·0			

TABLE

Station.	Δ	Comp.	P	P (O-C) J. B.	P (O-C) J. (1937.)	Comp.	S	S (O-C).	PP	PPP	PKP	PKKP
	°		m. s.	s.	s.		m. s.	s.	m. s.	m. s.	m. s.	m. s.
Ivigtut . .	75·1	Z	e 11 38	—3	—1		21 23	2				
Perth . .	77·3						21 36	—10	14 51			
Cape Town .	78·1		11 56	—2	2		21 34	—21				
Sitka . .	91·4		e 13 07 }	3	4 }		i 24 12	3	e 16 15	18 42		
			e 13 26 }	22	23 }							
Halifax .	93·0		e 13 13	2	3		24 12	—12	16 49			
Adelaide . .	93·6											
Burlington .	97·3		13 38 }	7	8 }		25 31	28	18 11			
			13 40 }	9	10 }							
Ottawa . .	97·5		e 13 39	7	8				17 25	19 31		
Saskatoon .	98·05		13 49	15	15							
Oak Ridge .	98·15		i 13 39	4	5		25 11	1	17 19			
Weston .	98·3											
Melbourne .	99·5						25 11	—12				
Ithaca . .	100·3								e 18 31			
Toronto .	100·35		e 13 56	11								
Buffalo . .	100·8		e 13 48	1					e 17 49	? 20 21		
Victoria . .	101·5		14 09	18								
Philadelphia .	101·9		14 05 }	12 }			25 36	—7	17 49 }			
			14 15 }	22 }					18 06 }			
Riverview .	102·0						? 25 26	—18	18 13			
Sydney . .	102·0								18 19			
Pennsylvania .	102·25							[14]				

6—*contd.*

	SKS	SKKS	PS	PPS	SS	SSS	G	L	M		Other phases and remarks.
	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m.	m.		
			22 15		26 25	29 54	30·6	N, E,Z *i* 35·9 }	41·2		Compression.
								Z *e* 36·5 }			
			22 01		26 01			36·0	56·3		Assumed clock correction of +4m.
								36·6	43·5		
	i 23 43				*e* 30 45		37 28	*e* 45·3 }			
								e 45·5 }			
								45·0			SS (?) 29m 55s *i* 27m 09s.
	i 23 38		*e* 25 19			? 34 09	39·4	45·3			
	24 31				32 01			44·9 }			
								47·7 }			
	i 24 33				31 25		? 39 25	47·0			*e* 42m. 13s.
	24 17				32 01			47·0			
	24 37										
	i 24 36								53·1		34m 01s.
	e 24 14					36 21	41·0	44·0 }	55·5 }		*i* 24m 39s, 27m 54s, 29m 35s, 44m 38s, 45m 47s.
								47·2 }	60·0 }		
								50·1 }			
	24 25 }										*e* 27m 13s.
	24 49 }										
	24 30		27 04					48·8			
			i 26 43	*e* 27 29							*e* 22m 25s.
		i 24 58						42 08	60·6		
	24 31 }		27 07		33 16 }			48·0			*e* 20m 48s.
	24 48 }				33 17 }						
	25 01							? 44·4	66·7		
								49·6	67·3		*i* 29m 31s.
	i 24 50							50·0	63·3		*i* 31m 31s, 33m 13s.

TABLE

Station.	△	Comp.	P	P (O-C) J. B.	P (O-C) J. (1937.)	Comp.	S	S (O-C).	PP	PPP	PKP	PKKP
	°		m. s.	s.	s.		m. s.	s.	m. s.	m. s.	m. s.	m. s.
Seattle . .	102·35							[—5]	18 09			
Pittsburg .	103·4		e 14 29	30				[—12]	e 18 13	20 26		
Georgetown .	103·55		e 14 00	0				[—6]	e 18 15	20 51		
Bozeman .	104·7								e 18 23			29 49
Chicago .	104·7			[—12]				[—5] [—37] }	18 24		e 17 49	?30 09
Charlottes Ville	104·9							[—7] [—5] }	e 18 18			
Florissant .	108·3	Z	e 14 22	—1		N	i 26 22	[—9]	i 18 52			i 29 48
St. Louis .	108·4		e 18 46	23		N, E	i 26 27	[—7]				e 29 46
Columbia .	109·4							[15]	e 19 11			
Denver . .	110·3							[—19]		e 21 30		
Ukiah . .	110·7						27 17		e 19 21			
Berkeley .	112·0		e, i 14 48 i 14 50	8 10 }			i 27 07 27 42 e, i 27 44 }		i 19 04	i 22 07		
Little Rock .	112·6			[6]		E	e 27 06 e 27 09 }	[—10] [—7]	e 19 14 e 19 15	21 43 e21 45 }	N18 32 e18 35 }	
Tinemaha .	113·2			[7]					e 19 31		e18 35	e 29 30
Honolulu .	113·4						27 03 27 14 }		20 09 e 20 13	22 15 }		
San Juan .	113·8			[+7]				[17]	e 20 13		18 36	
Pasadena .	116·1			[13]		Z	e 27 50	[—1]	i19 48	e22 21	Ze18 48 18 50	e29 29
Loyola . .	116·4								? e18 07			
Tucson . .	118·1								e 20 01			
Christ Church	121·0		15 27	[8]				[0]			18 56	

6—contd.

Comp.	SKS	SKKS	PS	PPS	SS	SSS	G	L	M		Other phases and remarks.
	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m.	s.		
	24 32						? 41 22	53·6			e 43m 09s.
	i 24 30		27 26					48·5			? 34m 14s.
	24 37		27 12	28 14	33 30			48·5			
					i 33 32			49·0			
		? 25 18			e 33 23		? 42 31	50·0			e 26m 52s.
	24 44			i 28 04	e 33 34			? 46·0			i 34 04, 41m 57s; e 17s. 36s, 36m 27s.
	24 46										
	24 42		27 37		33 22			48·3			Sc S Sc S 38m 18s; e 41m 06s; ? 44m 26s.
	24 44				e 34 06						
	e 24 57	?i 25 22	e 27 57	e 28 56		i 38 16		i 51·3	i 56·8		
	e 24 57	? 25 22	e 27 58		e 34 08	e 38 16		e 51·4	56·8		
	25 26		e 28 34	e 29 41				50·9			e 23m 14s, 31m 43s, 35 m 31s, 35m 44s.
	e 24 56		e 28 26	e 29 30				? 44·0	58·8		e PSPS 35m 09s; e 26m 15s, 38m 40s; i 30m 05s.
			i 29 06		34 26	e 39 01	45 15				e 22m 21s, 23m 27s.
			29 04		35 06						
		26 12									Assumed—4m 30s as time correction.
N, E	e 25 14	e26 07	e28 54	e 29 52	35 06			53·0	62·0		
N, E	e 25 17	e26 24		e 30 05	35 15			e 53·1	e 62·2		
			?e29 25		e 35 35			? 49·7			PSPS (?) 36m 05s; i 37m 41s, 37m 53s.
					35 41			49·9			
	e 25 46	27 19		e 30 18				? 49·0			e PSPS 36m 16s; i 43m 21s; e 20m 19s, 37m 01s. Assumed +1m as time correction.
								51·2			
	e 25 36		i 29 26	e 31 01				49·9			i 19m 34s.
							?i48 37		61·9		e 28m 37s, 37m 58s.
			29 19					59·1			? 41m 28s.
	25 53		30 11						65·8		Assumed—5m 45s as time correction.

TABLE

Station.	Δ	Comp.	P	P (O-C) J. B.	P. (O-C) J (1937.)	Comp.	S	S (O-C).	PP	PPP	PKP	PKKP
	°		m. s.	s.	s.		m. s.	s.	m. s.	m. s.	m. s.	m. s.
New Plymouth	121·0			[13]							19 01	
Arapuni .	121·95											
Wellington .	122·05											
Apia . .	124·2											
La Plata .	133·3			[15]					22 02		19 27	
Sucre . .	135·1			[23]				[—32]			19 38	
La Paz . .	136·55			[5]				[—18]	*i* 22 42	25 27	19 22	
Huancayo .	140·5			[31]							19 53	

6—*concld.*

Comp.	SKS	SKKS	PS	PPS	SS	SSS	Q	L	M		Other phases and remarks.
	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m.	s.		
				32 00				68·0			
			30 43	31 46	36 48			R60·0			SKP? 19m 50s±. Assumed—2m as time correction.
								q 52·0			
							50 19	61·8 LR 72·0m.			
	? 26 01							*q* 58·0			SKP 23m 04s.
								R 65·0			
	26 23	28 37	32 43					67·7	75·6		SKP 22m 59s.
					41 28	46 01		62·3			SKP 23m 13s; *i* 31m 29s; *e* 38m 01s, 39m 55s.

The Aftershocks of the Quetta Earthquake.

Within three days after the main shock, nearly twenty shocks were felt in the vicinity of Quetta. Of these, the one which occurred on June 2nd at 9h. 16m. 33s. G.M.T. was the most severe. In table 7 are given the times of arrival of the P and S waves from this shock at different observatories. The differences between the observed and calculated times of travel are also tabulated assuming the epicentre of the earthquake to have been the same as that of the Quetta earthquake and using Jeffreys-Bullen normal tables.

TABLE 7.—*Epc*: $29°{\cdot}6$ *N.*, $66°{\cdot}5$ *E.*; $t_0 : 9^h\ 16^m\ 33^s$.

Station.	Δ	P(obs).	P(O-C)	S(obs).	S(O-C)
	°	m. s.	Sec.	m. s.	Sec.
Agra	10·45	2 19	—8	4 07	—17
Bombay	12·1	2 53	3	5 08	3
Calcutta	20·85	4 37	—2	8 32	8
Kodaikanal	21·9	4 54	4	8 59	15
Colombo	26·0	5 25	—4	10 10	12
Budapest	40·4	7 36	—1	13 18	—24
Zagreb	42·3	7 51	0	14 17	6
Hongkong	43·2	7 57	—1	14 23	—1
Peichico	44·5	8 10	1	14 44	1
Stuttgart	47·1	8 28	—1	15 21	1
Manila	52·2	9 06	—2	16 29	—2
Batavia	52·7	e 9 52	40	17 51	73
Kew	51·15	i 9 14	—1	16 44	0
Amboina	67·7	e 10 00	—56	18 17	—96

Except for the large discrepancies between the observed and calculated values at Batavia and Amboina, the differences at the other stations are not sufficiently systematic to justify any change in the position of the epicentre.

In table 8 are given the phases of the main shock and aftershocks identifiable in the seismograms of the Agra Observatory.

TABLE 8.—*Phases of aftershocks from Agra seismograms.*

Date.	Times of phases in G.M.T.						Remarks.
	P	i-P	S-P	i-P	i-P	L-P	
	h. m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	
May 30	21 35 23	0 59	1 50				
,,	23 36 22		1 49				
May 31	2 5 51		1 51	2 22		3 06	
,,	i*8 26 25		1 55			3 10	Surface waves weak.
,,	17 14 36		1 52	2 20		3 08	
June 1	4 32 36	0 57	1 48	2 18	2 54	3 07	
,,	14 48 32		1 50				
June 2	*4 18 41		1 52				Surface waves weak.
,,	e 9 18 50	0 58	1 48		2 56	3 10	

The S-P interval corresponding to 10°·45, the distance between Agra and the epicentre of the Quetta Earthquake is, according to Jeffreys-Bullen normal table 1^m 57^s and according to Jeffreys' continental surface focus tables 2^m 02^s.* In all the shocks listed in table 8, the measured intervals are smaller, the mean value being only 1^m 50^s. In at least four of the shocks recorded, however, there is a second S phase 8^s to 12^s after the first. If the second S is taken as the normal S, the first one would perhaps correspond to the "curtsey" often observed a few seconds before the normal S; but it should be mentioned that the first S in most of the cases now considered was very clear and began with an impetus.

Other fairly clear phases are observed at 0^m 59^s, 2^m 20^s, 2^m 55^s and 3^m 08^s after P. The third of these probably corresponds to Sg the transverse wave whose path lies wholly above the lower

* According to Macelwane's tables, the corresponding interval is 2^m 09^s and according to Gutenberg and Richter 2^m 02^s.

boundary of the granitic layer and the last to L the long wave. In the seismograms of the aftershocks recorded at Bombay, the times of incidence of the phases are difficult to determine with any precision, both P and S being generally emergent. Except that all the shocks occurred at nearly the same distance, no detailed information about travel-times can be obtained with their aid.

SUMMARY.

A Seismological study of the Baluchistan (Quetta) earthquake of May 31, 1935.

The times of arrival of the P waves from the Quetta Earthquake at different observatories throughout the world have been analysed and the position of the epicentre has been determined to be 29°·6 N., 66°·5 E, and the epicentral time to be $30^d\ 21^h\ 32^m\ 58^s{\cdot}5$ G.M.T. Among the prominent features of the seismograms were the gradual increase of amplitude interrupted by larger and larger impulses and the large amplitudes of the long waves compared with those of the preliminary, suggesting block movement and a shallow depth of focus. An analysis of the S-P residuals using Jeffreys and Bullen's normal tables showed that its mean value was about +3 sec. suggesting a depth of focus definitely less than the normal depth (10km.) and possibly also a complex process at origin. The energy of the earthquake is estimated to be about 10^{21} ergs. The phases of the aftershocks as noted in the Agra seismograms have also been tabulated.

SEISMOGRAMS OF THE BALUCHISTAN (QUETTA) EARTHQUAKE OF MAY 31, 1935.

PLATE 25, FIG. 1.—Bombay (Milne-Shaw), N.-S. Component.
FIG. 2 „ „ E.-W. Component.

PLATE 26.—Agra (Omori), N.-S. Component.

PLATE 27.—Calcutta (Omori).

PLATE 28.—Kew, N.-S., E.-W. and Z Components.