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The faultplane technique and the mechanism in the focus of the Hindu Kush earthquakes

A. R. RITSEMA

Meteorological and Geophysical Service, Djakarta, Indonesia

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ABSTRACT. The mechanism in the focus of the Hindu Kush earthquakes centering at 36½°N, 70½°E and a depth of about 220 km is investigated. The faultplane technique developed by Byerly and Koning and extended by Hodgson is simplified by using the azimuth and the angle with the downward vertical in which the wave did leave the focus as variables and not the azimuth and epicentral distance or "extended epicentral distance". Compression and dilatation data of the *P* and *PKP* waves as reported to ISS and BCIS increased with some data as observed in original seismograms or copies of some seismographic stations in the NW-SE azimuth are the bases of this study. The use of reflected longitudinal waves and the *S* wave for the same purpose is briefly discussed.

It is found that the earthquakes are caused by a thrust fault movement in the focus. The principal stress component (greatest compression) acts about horizontal in the NW-SE azimuth the smallest stress component (greatest stretching) about vertical somewhat inclined towards SW. The derived stress system is not in contradiction with the about NE-SW trending Hindu Kush mountain system.

1. Introduction

Studying Hindu Kush earthquake seismograms as recorded in de Bilt (Holland) the author was struck by the strikingly similar registrations of all earthquakes of this famous centre at a depth of about 220 km (Ritsema 1953). All of the 21 earthquakes studied did show exactly the same characteristics. It did seem worth while to make an investigation of the type of movement in the focus, the similarity of the records suggesting that all earthquakes were caused by an essentially the same mechanism.

To this purpose all data of the direction of first motion of the *P* and *PKP* waves of Hindu Kush earthquakes as can be found in the ISS bulletins were gathered. For the years following 1946 the bulletins of the Central Bureau of Seismology (Strasbourg) were looked through. Of 30 earthquakes of the Hindu Kush centre such data could be found (Table 1). Examination of these data also point to a great conformity between all shocks of the Hindu Kush centre. Stations reporting a direction of first motion for more than one earthquake out of this series nearly always recorded the same sense of movement.

To check some of these data original seismograms or copies of some stations lying more or less in the same azimuth as seen from the Hindu Kush epicentre were studied. These readings only confirm the great similarity of the shocks. Moreover some dubious points could be solved in cases where a different first impulse for some shocks had been reported to ISS or BCIS.

All these investigations point to a same type of mechanism for all shocks of the Hindu Kush centre and it is clear that an investigation of the mechanism of the earthquakes should be tried by means of the faultplane technique as developed by Byerly (1926, 1928, 1930, 1934, 1938), Koning (1941, 1942) and modified and extended by Hodgson (1951, 1953, 1954). The compression and dilatation data of the *P* and *PKP* waves of all earthquakes of Table 1 were plotted in a single diagram as if they were from only one shock.

The data of earthquake shock of 21 November 1939 gathered by Mukherjee (1941) and those of 4 March 1949 shock gathered by Hodgson (1954a) were added to our list.

2. The faultplane technique

The method in plotting slightly differs from that used by the above authors and is definitely simpler in procedure. In a stereographic diagram with the earthquake centre in the origin the C and D data are plotted neither as a function of the azimuth and epicentral distance (Byerly, Koning), nor of the azimuth and extended epicentral distance (Hodgson) but of the azimuth and the angle with the downward vertical in which the seismic wave did leave the focus. This method has been described and used already by the author in 1952.

TABLE 1

No.	Date	Origin time	Source of information
1	21 Apr 1917	$00^h49^m49^s$	deB
2	20 May 1921	00 43 20	deB
3	15 Nov 1921	20 36 38	deB, Djak, DDun, Riv, Ham
4	17 Dec 1922	00 51 20	deB
5	13 Oct 1924	16 17 45	deB
6	20 Jun 1925	13 04 15	deB
7	10 Aug 1928	15 33 48	deB
8	1 Feb 1929	17 14 26	deB Djak, Ham, DDun, Riv, Per, Mel
9	5 Oct 1931	22 31 27	deB
10	9 Jan 1933	02 01 43	deB Djak, Amb (ISS)
11	22 Jul 1934	19 56 57	deB (ISS)
12	18 Nov 1934	03 21 24	deB, Djak, Med (ISS)
13	3 Apr 1935	11 11 59	deB (ISS)
14	29 Jun 1936	14 30 10	deB, Med (ISS)
15	29 Oct 1937	07 26 30	deB (ISS)
16	14 Nov 1937	10 58 12	deB, Djak, Amb, Med, DDun, Cal, Pas, Hu, SJu, Ham, Kew, Riv, Mel, Chr, Wel (ISS)
17	21 Nov 1939	11 01 50	deB, Djak, Med, DDun, Cal, Pas, Hu, SJu, Ham, Kew, Mel, Per, Riv, Chr, Wel, (ISS) (Mukherjee)
18	27 May 1940	$04^h10^m38^s$	deB (ISS)
19	21 Sep 1940	13 49 03	deB (ISS)
20	11 Mar 1941	21 48 53	(ISS)
21	14 Apr 1941	19 32 44	(ISS)
22	28 Nov 1941	12 23 29	(ISS)
23	22 Mar 1942	02 08 29	(ISS)
24	15 May 1942	16 55 29	(ISS)
25	28 Feb 1943	12 54 33	deB (ISS)
26	20 Apr 1943	15 19 33	(ISS)
27	9 Sep 1943	04 06 09	deB (ISS)
28	5 Dec 1943	03 16 17	(ISS)
29	12 Dec 1943	15 54 17	(ISS)
30	28 Dec 1943	14 56 30	(ISS)
31	7 Sep 1948	08 15 20	(BCIS)
32	4 Mar 1949	10 19 26	Djak (BCIS) (Hodgson)
33	9 Jul 1950	16 10 25	(BCIS)
34	6 Jan 1951	05 17 19	(BCIS)
35	13 Jun 1951	22 40 36	(BCIS)
36	28 May 1952	07 47 40	(BCIS)
37	5 Jul 1952	17 19 50	(BCIS)
38	18 Oct 1952	21 26 17	(BCIS)
39	27 Nov 1952	07 20 34	(BCIS)

Abbreviations used for seismograms of :

de Bilt, Djakarta, Dehra Dun, Riverview, Hamburg, Perth, Amboina, Medan, Calcutta, Pasadena, Huancayo, San Juan, Kew, Christchurch, Wellington, Melbourne

Note—All earthquakes originated in the Hindu Kush centre at about 36½°N, 70½°E and at a depth of about 220 km

In fact a diagram like this does show directly the distribution of compressions and dilatations in the focus. The planes separating the C and D quadrants in the stereographic diagram must follow the course of a meridian line. If the position of one of these planes (lines in the diagram) is known, the simple fact that the two planes separating the C and D quadrants are perpendicular to one another implies that the other plane must pass through the pole of the first one. Also the other line in the diagram must follow the course of one of the meridian lines. With these two limitations it is easy to determine the possible variation in the position of the second plane.

3. The mechanism in the focus of the Hindu Kush earthquakes

To illustrate the method the construction of the diagram of the Hindu Kush earthquakes will follow now (Fig. 1).

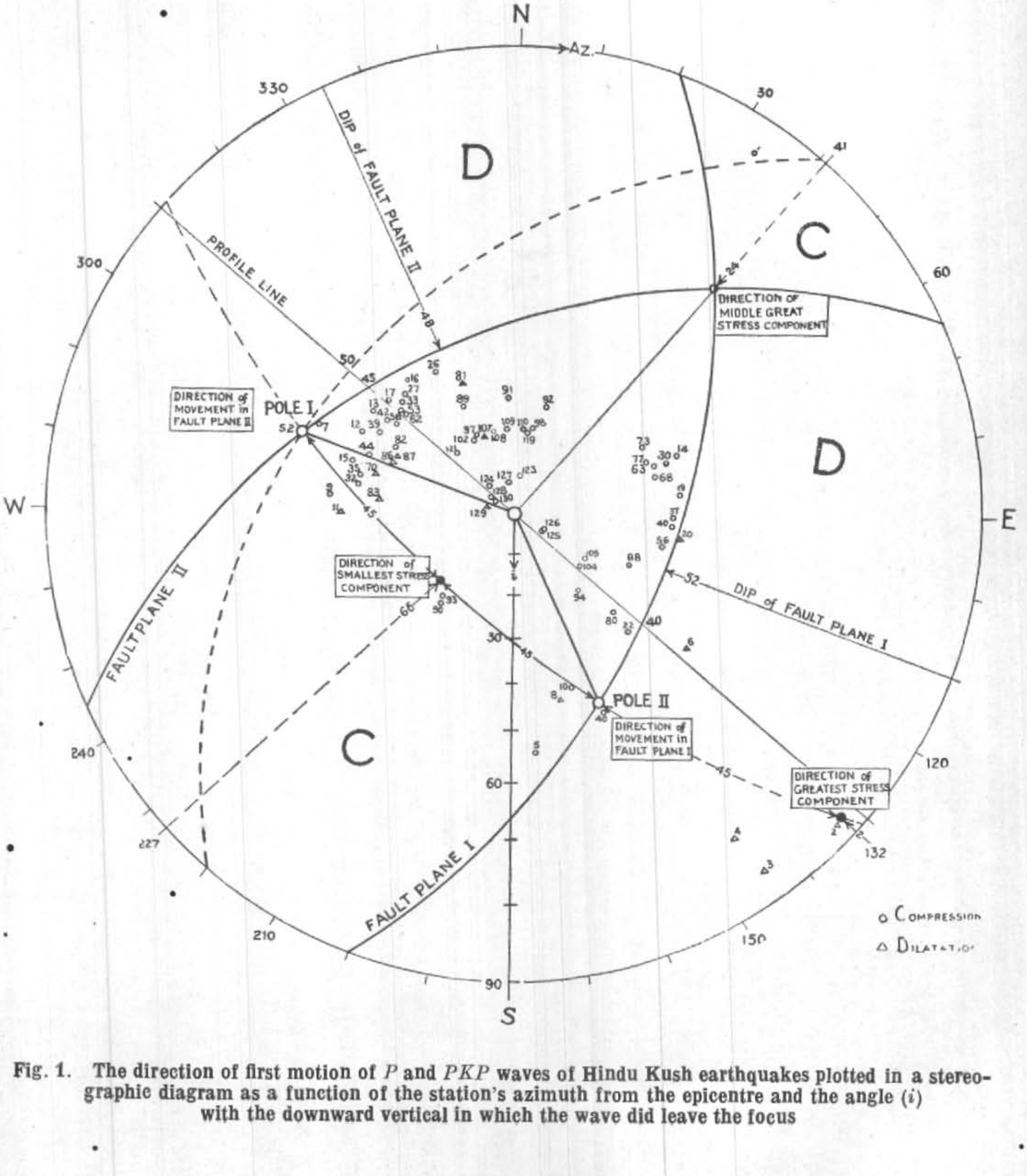

Fig. 1. The direction of first motion of *P* and *PKP* waves of Hindu Kush earthquakes plotted in a stereographic diagram as a function of the station's azimuth from the epicentre and the angle (*i*) with the downward vertical in which the wave did leave the focus

There are 130 stations of which C or D data of P and PKP waves of Hindu Kush shocks are known (Table 2). Epicentral distances and azimuths of the stations from the Hindu Kush epicentre are taken from the ISS bulletins or are measured on a globe. The corresponding angles i in the focus are calculated by means of the apparent velocity of the P and PKP wave fronts along the earth's surface and an assumed velocity distribution of longitudinal waves in the earth. For a detailed description hereof the reader may be referred to the publications of Byerly, Koning, Hodgson and Ritsema. The values of i appearing in Table 2 are extracted from the $(\triangle, i)$—function for a depth of 0·03 R (=223 km) as calculated by the author (1952).

The C and D data are plotted in the proper azimuth and at a radial distance from the centre of the diagram equal to the value of i in the focus. The station of Quetta (1) is an exception to this rule, the P wave in this case leaving the focus in an upward direction. The C observation of this station has been plotted in a direction opposite to that in which the wave did leave the focus, *i.e.*, $Az=33°$ and $i=86°$. In this direction the P wave must be of exactly the same kind.

C observations are plotted as small open circles, D observations as small open triangles. In some areas with many data of the same kind a number of these observations are omitted not to overcrowd the figure.

In most of the recording stations the P wave did arrive as a compression. In the SE quadrant, however, some clear dilatations appear, some of them having been checked by the author with the help of original or copies of seismograms (see also Mukherjee 1941). The line in the diagram (in reality the plane) separating these D observations from the adjacent C data must have a course as indicated in the figure. The data fixing this course are the C observations of Quetta (1), Nangking (19), Karenko (37), Kosyun (40), Manila (56), Medan (22) and Bombay (5) and the D observation of Hongkong (20). Moreover the seismograms of Medan do show a compressive P motion but the amplitude is so small that it suggests that the line must be located very near to this station.

The so determined nodal plane has a strike of N20°E and dips 52° towards ESE. The possible variation in the strike is not more than a few degrees to either side.

The second plane must run through the pole of the former indicated in the figure by a greater open circle. The points limiting the course of the second plane are the C observations of Quetta (1) and Tiflis (7). The second plane may have a position ranging between a strike of N40°E dipping 40° towards NW and a strike of N65°E dipping 48°NNW.

It is not possible to determine which of the two nodal planes acted as the faultplane. In either case, however, the movement along the shear plane is of the thrust fault type which is clearly indicated by the concentration of C data all around the centre of the diagram.

4. Inconsistent observations

There are 19 stations not in accordance with this picture. This seems to be a rather normal percentage (about one in seven) after the publications of Hodgson. Of these inconsistent data a group of stations in S. Europe and N. Africa, *i.e.*, Helwan (11), Beograd (18), Algeria (70), Tammanrasset (83), Cartuya (84), Malaga (86) and Lisbon (87) were rather unexplainable. Mostly the P waves of Hindu Kush earthquakes seem to record as a dilatation in these stations, where it should be as a compression. There can be found some other instances of discrepancies of some of these stations in literature (Ritsema 1952, 1954 ; Hodgson 1954a) suggesting that the faults are systematic rather than haphazard.

Another rather serious discrepancy is the station of La Paz (129). Of at least two of the D observations, however, the O-C difference is rather great. The third D observation could not be checked but has been used by Hodgson (1954a).

The other inconsistencies are of a less serious kind, the D observations being surrounded on all sides by consistent C observations.

Hodgson and Storey (1954a) made a special study of the 4 March 1949 earthquake. They

TABLE 2

No.	Station	△	*Az.*	*i*	Number of		Assumed character	Remarks
					compr.	dilat.		
	P							
1	Quetta	6°.7	213	94°	2		C	
2	**Dehra Dun**	8·4	133	88		5	D	(Mukherjee)
3	New Delhi	9·3	144	86	1	2	D	
4	Agra	10·9	145	80		3	D	
5	**Bombay**	17·4	174	54·8	3	1	C	(M)
6	**Calcutta**	20·4	127	50·5	1	6	D	(Hodgson)
7	Tiflis	20·8	293	50·1	2		C	
8	Kodaikanal	27·4	165	44·6		2	(D)	(H)
9	Ksara	28·8	275	43·6	6		C	
10	**Colombo**	30·4	161	42·9	1		C	(M)
11	Helwan	33·7	270	41·5	1	5	(D)	(H)
12	Bucharest	34·8	297	41·2	2	1	C	
13	Cernauti	34·9	305	41·2	1		C	
14	Chiufeng	35·6	70	40·9	2	2	C	
15	Athene	36·9	287	40·4	3		C	(H)
16	Helsinki	37·3	320	40·3	2		C	(H)
17	Warsaw	37·6	311	40·2	3		C	
18	Beograd	38·6	299	39·9	3	7	(D)	(H)
19	Nangking	39·7	83	39·6	2		C	(H)
20	Hongkong	39·8	98	39·6		2	D	
21	Upsala	40·8	318	39·3	6		C	(H)
22	**Medan**	41·4	135	38·9	2		C	
23	Zagreb	41·5	301	38·9	1		C	
24	Zi-Ka-Wei	41·9	81	38·8		2	(D)	
25	Praha	42·5	308	38·6	5	1	C	(H)
26	Kiruna	42·6	330	38·5	3		C	
27	Kobenhavn	42·8	316	38·4	8	1	C	(H)
28	Potsdam	43·2	311	38·3	1		C	
29	Trieste	43·3	301	38·3	7	1	C	(H)
30	Zinsen	44·0	71	38·1	2		C	
31	Jena	44·2	308	38·0	1	1	C	(H)
32	Messina	44·8	280	37·8	2	1	C	(H)
33	**Hamburg**	44·8	314	37·8	9	1	C	
34	Göttingen	44·9	310	37·8	3		C	(H)
35	Catania	44·9	283	37·8	1		C	(H)
36	Cheb	45·0	305	37·8	1		C	(H)
37	Karenko	45·0	91	37·8	1		C	
38	Roma	45·0	296	37·8	9		C	(H)
39	Firenze	45·2	300	37·7	6	1	C	(H)
40	Kosyun	45·3	94	37·6	1		C	
41	Chur	45·4	304	37·6	5		C	(H)
42	Stuttgart	45·5	305	37·5	18	1	C	(H)
43	Taikyu	45·9	72	37·3	1		C	
44	Bologna	45·9	290	37·3	2		C	(H)
45	Salo	46·0	300	37·3	3		C	(H)
46	Piacenze	46·0	302	37·3		1	(D)	
47	Zürich	46·4	305	37·2	11		C	(H)
48	Husan	46·5	73	37·1	1		C	
49	Strasbourg	46·7	307	37·1	11		C	(H)
50	Witteveen	46·8	313	37·0		1	(D)	
51	Ravensburg	46·8	306	37·0	1		C	(H)
52	Basel	47·3	304	36·9	4		C	(H)
53	**de Bilt**	47·8	311	36·8	25		C	(H)

Seismograms of the stations given in bold types have been checked by the author

D in brackets not in accordance with the assumed position of the faultplane

TABLE 2 *(contd)*

No.	Station	△	*Az.*	*i*	Number of compr.	Number of dilat.	Assumed character	Remarks
	P							
54	Uccle	48·0	309	36·7	7		C	
55	Kumamoto	48·6	76	36·5	1		C	
56	Manila	49·6	102	36·1	6		C	
57	Clermont	50·2	304	35·5	1	1	C	(H)
58	Paris	50·4	307	35·3	3	1	C	(H)
59	Fukuoko	50·9	75	35·2	1		C	(H)
60	Muroto	51·2	74	35·1	1		C	
61	Sumoto	51·3	72	35·1	1		C	
62	**Kew**	51·3	311	35·1	10		C	(H)
63	Osaka	51·6	71	35·0	3		C	(H)
64	Wakayama	51·6	72	35·0	1		C	
65	Kyoto	51·7	70	35·0	1		C	
66	Oxford	52·1	312	34·9	3		C	
67	Gihu	52·4	70	34·8	1		C	
68	Kobe	52·8	75	34·8	1		C	(H)
69	Nagano	53·0	68	34·7	1		C	
70	Algeria	53·1	285	34·6	1	2	(D)	
71	Akiba	53·3	64	34·5	1		C	
72	Oiwaka	53·4	68	34·5	1		C	
73	Hatinola	54·1	62	34·1	1		C	
74	Kumagaya	54·1	68	34·2	1		C	
75	Morioka	54·1	63	34·2	1		C	
76	Yokohama	54·5	69	33·9	1		C	
77	Tokyo	54·5	68	33·9	2		C	(H)
78	Sapporo	54·5	70	33·9	1		C	(H)
79	Mito	54·8	67	33·8	1		C	
80	**Djakarta**	55·0	134	33·6	7		C	(H)
81	Scoresby Sund	56·4	337	33·2	1	2	(D)	(H)
82	Toledo	57·5	298	32·7	3		C	(H)
83	Tamanrasset	57·9	275	32·5	2	5	(D)	(H)
84	Cartuya	58·0	297	32·5		4	(D)	(H)
85	Granada	58·3	295	32·3	3	3	C	
86	Malaga	60·0	290	31·6		1	(D)	(H)
87	Lisbon	61·6	295	31·0		2	(D)	
88	**Amboina**	66·5	113	30·1	2		C	
89	Ivigtut	70·7	334	28·2	2		C	(H)
90	Pretoria	71·3	219	27·9	1		C	
91	Resolute Bay	72·4	356	27·4	1		C	
92	College	74·7	16	26·3	2		C	(H)
93	Kimberley	74·8	220	26·3	1		C	
94	**Perth**	81·2	140	24·1	2		C	
95	Oak Ridge	94·4	333	20·9	2		C	
96	Weston	94·5	333	20·9	3		C	(H)
97	Harvard	94·5	333	20·9	1		C	
98	Seattle	95·6	10	20·8	1		C	
99	Fordham	96·7	333	20·7		1	(D)	
100	Cleveland	98·8	330	20·5	2	1	C	(H)
101	Brisbane	99·0	120	20·5		1	(D)	(H)
102	New York cc	99·0	330	20·5	1		C	(H)
103	Jersey	99·1	330	20·5		1	(D)	(H)
104	**Melbourne**	100·6	129	20·4	2		C	
105	**Riverview**	102·2	122	20·3	2		C	(H)
106	Seven Falls	102·5	330	20·3	1		C	(H)
107	Cincinnati	103·5	338	20·2		1	(D)	(H)

Seismograms of the stations given in bold types have been checked by the author
D in brackets not in accordance with the assumed position of the faultplane

TABLE 2 (*contd*)

No.	Station	△	Az.	*i*	Number of compr.	Number of dilat.	Assumed character	Remarks
	P							
108	St. Louis	104·5	345	20·2	1		C	(H)
109	Lincoln	105·2	354	20·2	1		C	(H)
110	Berkeley	105·3	6	20·2	2		C	(H)
111	Reno	106·0	7	20·2	1		C	(H)
112	Shawinigan Falls	106·2	337	20·2		1	(D)	(H)
113	Skalnate	106·8	7	20·2	1		C	(H)
114	Tinemaha	107·1	5	20·2	1		C	(H)
115	Arcata	107·2	10	20·2	1		C	(H)
116	Mineral	108·0	6	20·2	1		C	(H)
117	Palo Alto	108·2	6	20·2	1		C	(H)
118	Mt. Hamilton	108·9	7	20·2		1	(D)	(H)
119	**Pasadena**	109·3	7	20·2	4		C	(H)
120	Fresno	109·4	16	20·2	1		C	(H)
121	**San Juan**	112·2	315	20·2	2		C	
122	**Christchurch**	121·5	123	20·2	1		C	
	PKP							
123	**Pasadena**	109·3	7	9	2		C	
124	**San Juan**	112·2	315	9	2		C	
125	**Christchurch**	121·5	123	8	2		C	
126	**Wellington**	122·2	120	8	1		C	
127	Tacubaya	125·0	350	8	1		C	(H)
128	Bogota	134·8	305	7	1		C	(H)
129	La Paz	138·6	287	7	1	3	(D)	(H)
130	**Huancayo**	141·3	300	6	3		C	(H)

Seismograms of the stations given in bold types have been checked by the author

D in brackets not in accordance with the assumed position of the faultplane

TABLE 3

Station	*P*	*i*	*pP*	*i*	*PP*	*i*	*pPP*	*i*	*PPP*	*i*	*PKP*	*i*	*pPKP*	*i*	*S*
Dehra Dun	4D	88°													
Calcutta	(1C) 1D	53·5													–?
Medan	2C	38·9	2D	140°·1	1C (1D)	51°·0			(1C)	86°					–?
Hamburg	4C	37·8	4D	141·1	4C	49·4	1D	127°·9	1D	80					–
de Bilt	19C	36·8	(2C) 9D	142·2	11C (2D)	48·3	10D	130·2	14D	76·2					–
Kew	2C	35·1	(1C) 1D	143·6	1C	46·4			1D	73·5					–
Djakarta	7C	33·6	5D	145·2	4C	45·0	(1C) 1D	133·8	(2C) 1D	70·1					–
Amboina	2C	30·1													–?
Perth	2C	24·1	1D	155·5	1C	39·5	2C	140·1							–?
Melbourne	2C	20·4	2D	159·6	(3C)	36·0	3C	143·4							
Riverview	1C	20·3			2D	35·0	2C	143·8							
San Juan	2C	20·2			(1C)	33·6	1C	145·9			2C	9°			
Christchurch	1C	20·2	(1C)	159·8	2D	31·7	1C	147·9	(1D)	39·7	2C	8	1D	172°	
Wellington			1D	159·8	2D	31·5	2C	148·0	1C (1D)	39·6	1C	8	1D	172	
Huancayo					(2C)	27·8	1C	151·7	1C	37·5	2C	6	1D	174	

derived a position of the shear plane that is different from our solution. Seismograms of Djakarta station were looked through to see if a clear difference between this shock and the other Hindu Kush earthquakes could be found. There appears to be no evidence hereof. In fact the seismograms do show exactly the same characteristics as those of the other shocks.

Assuming the position of the faultplane derived by Hodgson to be true, *i.e.*, strike N86½°E, dip 87°N with the auxiliary plane, strike N7½°W dip 48°W, there are 30 stations out of Table 2 inconsistent. Serious discrepancies following Hodgson's concept are the C observations of Bombay, Indonesia, Manila, some of the Chinese stations, Australia (except Brisbane), New Zealand and S. Africa. Hodgson, however, did not dispose of the greater number of these inconsistent data at the time.

5. Reflected longitudinal waves

As has been mentioned before some seismograms of Hindu Kush earthquakes of stations in azimuths N130°E and N310°E were studied. The results of the *P* and *PKP* waves were entered in Table 2. Table 3 shows the observed directions of first motion in the reflected longitudinal waves.

Fig. 2 shows the N130°E—N310°E vertical section through the Hindu Kush centre with the character of the longitudinal waves leaving the focus. Assuming that at the reflection point at the earth's surface the phase of the longitudinal wave changes 180° an observed compression *PP* wave is indicated in the figure as leaving the focus as a dilatational wave. In the case of two times reflected waves such as *PPP* and *pPP* the direction of first movement as observed in the station is assumed to be the same as that of the same wave leaving the focus. Also the nodal lines, the possible positions of the shear plane as derived from Fig. 1 are indicated, dipping respectively 50°SE and between 40° and 45°NW.

It is seen that all *P* and *PKP* data in the section are concordant with the position of the nodal lines. The *PP* observations are somewhat out of line, especially the clear C registrations of Huancayo, San Juan and Melbourne, *pP* and *pPP* data again are remarkably good in accordance with the assumed position of the shearplane.

As the clear C registrations of the *PP* wave in de Bilt, Hamburg and Kew must leave the focus in the D quadrangle it is more likely that in the N310°E azimuth the nodal line dips 45° and not 40°.

The comparatively badly developed *pP* wave in the same stations points to a position very near to that of one of the nodal lines. This is in accordance with the position of the faultplane as derived here.

Seeing, however, that the clear compressional *PP* wave recorded in Huancayo, San Juan and Melbourne are not in accordance with the general lines it seems to be doubtful if we can attach much importance to the reflected waves at all. The author is inclined to believe that the position of the shearplane derived from *P*, *PKP* and eventually *pP* and *pPKP* waves is the more reliable.

6. Transversal waves

In Fig. 1 it is seen that the azimuth of the stations of which seismograms have been studied differs only little from the azimuth in which the fault movement took place. This is strongly confirmed by the fact that in all seismograms studied the transversal waves are mainly *SV* waves with only a very small or even negligible *SH* wave.

In the seismograms of the stations—Calcutta, Medan, Hamburg, de Bilt, Kew, Djakarta, Amboina and Perth a clear *SV* wave could be observed. In all of these stations the first motion in the *SV* wave in the horizontal seismograms is directed away from the epicentre. This means that the first motion of the *SV* wave when leaving the focus is directed downwards and backwards (Fig. 3). This is in good accordance with the type of movement in the focus as derived from the direction of first motion in the longitudinal waves (see Fig. 2.).

In fact the direction of first motion in the *S* waves can be used equally well for the determination of the type of movement in the

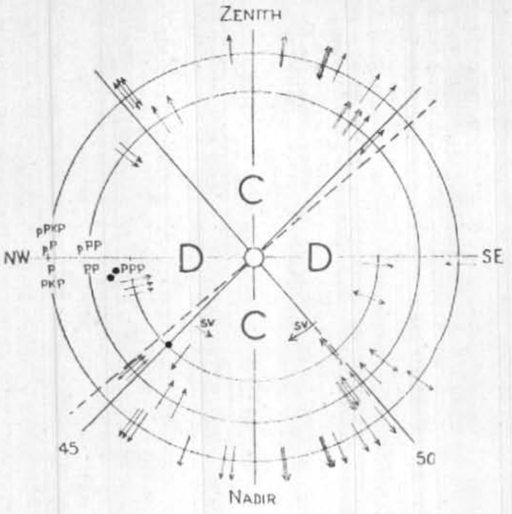

Fig. 2. Vertical section through the Hindu Kush earthquake centre in the NW-SE azimuth

(The arrows indicating the direction of first motion in the longitudinal waves and the *SV* wave as observed in seismograms of the stations given in Table 3)

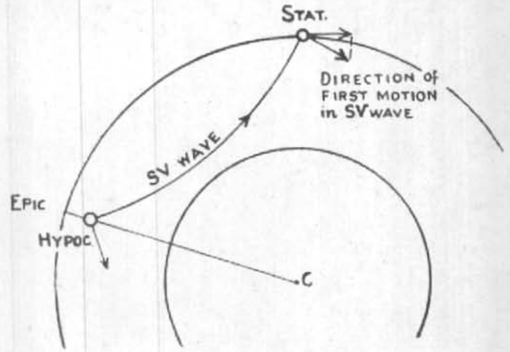

Fig. 3. The relation between the direction of first motion of the *SV* wave in the recording station and in the earthquake focus

focus as that of the *P* and *PKP* waves. Maximal amplitudes in the *S* wave can be expected in directions where the first motion of the longitudinal waves changes 180° (nodal lines of Figs. 1 and 2). For *S* waves the nodal planes have the same line of intersection as that of the nodal planes of the longitudinal waves but the planes are turned 45° along this line.

7. Conclusion

We are lead to the conclusion that the movement in the focus of the Hindu Kush earthquakes is of the thrust fault type with only a small component of movement in the strike direction. The faultplane either strikes about N20°E, dipping 52°E or strikes about N65°E, dipping 48°NW. The intersecting line of the two possible faultplanes dips 24° in the N41° E azimuth. The intersecting line of the plane perpendicular to this direction and the faultplane gives the direction of movement in the faultplane (see Fig. 1). In the case of a N20°E striking faultplane the movement in the plane is directed in the N155°E azimuth dipping 42°. In the other case of a N65°E striking faultplane the movement in the plane is directed in the N290°E azimuth dipping 38°.

The intersecting line of the two possible faultplanes (azimuth N41°E, dip 24°) gives the direction in which the middle great stress component acted. Assuming that the faultplane makes an angle of 45° with the two principal stress components this means that the greatest stress component must be directed in a N132° E azimuth dipping only 2° SE and the smallest stress component dipping 66°SW in the N227°E azimuth (see Fig. 1).

All these figures are given with an accuracy of one degree only to illustrate that in favourable cases such a measure of accuracy is possible with the method used. It is understood, however, that in the case of the Hindu Kush earthquakes described here, it is not probable that such an accuracy is reached because data of many different shocks have been used in a single diagram. Still the author is inclined to believe that the above mentioned figures give a good approximation of the mechanism in the focus of these quakes and that investigations of single Hindu Kush shocks out of this series will not result in serious discrepancies with the figures derived here.

It is understood that the earthquakes of the Hindu Kush centre are caused by a tangentially directed (horizontal) compressive force acting in the NW-SE (SE-NW) azimuth and a more or less radial (vertical) stretching force. This is the same type of stress condition that must have been acted more near to the earth's surface during the orogenesis of the more or less SW-NE trending Hindu Kush mountain system. The processes resulting in the upbuilding of mountain systems at the earth's surface are not restricted to the upper crust but are also acting at greater depths (in the case of the Hindu Kush system at least to a depth of 0·03 R) and with a considerable intensity.

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REFERENCES

Byerly, P.	1926	*Bull. seism. Soc. Amer.*, **16**, pp. 209-265.
	1928	*J. Sci., Amer.*, Fifth Series, **16**, pp. 232-236.
	1930	*ibid*, **19**, pp. 274-282.
	1934	*Bull. seism. Soc. Amer.*, **24** , pp. 81-99.
	1938	*ibid*, **28**, pp. 1-13.
	1949	*ibid*, **39**, 269-284.
Hodgson, J.H. *et al*	1951	*Bull. seism. Soc. Amer.*, **41**, pp. 221-242.
	1953	*ibid*, **43**, pp. 49-61; **43**, pp.121-125; **44**, pp. 57-83.
	1954	Publication Dominion Observatory, Ottawa, **16**.10.
	1954a	*ibid*, **16**, 11.
Koning, L.P.G.	1941	*Beitr. Geophys.*, **58**, pp. 159-197.
	1942	*Proc. Acad. Sci., Amst.*, **45**, pp. 636-642.
Mukherjee, S.M. *et al*	1941	*India met. Dep. Sci. Notes*, **8**, 91, pp. 85-90.
Ritsema, A.R.	1952	Thesis Utrecht Univ. N.V. Wed. J. Ahrend and Zn., Rotterdam, Holland.
	1953	*J. sci. Res.*, Indonesia, **2**, pp. 10-12.
	1954	*Proc, U.G.G.I. Congr*, Rome.