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SEISMICITY AND FAULT PLANE SOLUTIONS OF INTERMEDIATE DEPTH EARTHQUAKES IN THE PAMIR-HINDU KUSH REGION

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Abstract. Relocations of earthquakes, recorded by a local network of stations in Afghanistan and Tadjikistan in 1966 and 1967, indicate a narrow seismic zone (width $\lesssim$ 30 km) dipping steeply into the mantle to a depth of 300 km beneath the Pamir and Hindu Kush ranges. Very low seismicity was observed at depths less than about 70 km, the approximate depth of the Moho. Clear gaps in activity exist also within the zone of intermediate depth seismicity. One gap, about 50 km wide near 37°N and at depths greater than 100 km, separates a steeply northward dipping zone to the southwest from a steeply southeastward dipping zone to the northeast. This gap probably marks either a tear in the downgoing slab or a gap between two oppositely dipping slabs. Fault plane solutions, determined by Soboleva for events between 1960 and 1967, generally show steeply plunging T axes approximately within the planar seismic zone. They therefore are grossly similar to those at island arcs where no deep earthquakes occur and presumably result from gravitational body forces acting on a relatively dense slab of lithosphere. At the same time there is a very large variation in the fault plane solutions, much larger than is common at island arcs.

Introduction

Although it does not have an island arc structure, the Pamir-Hindu Kush region is the source of very high intermediate depth seismicity. This region is one of the most active sources of earthquakes felt within the USSR, even though most of it lies outside of the USSR, in Afghanistan. Accordingly, Soviet seismologists have devoted considerable attention to its study. An extensive network of stations has been operated in Tadjikistan for 20 years by the Tadjik Institute of Seismo-Resistant Construction and Seismology (TISSS) of the Academy of Sciences of the Tadjik SSR and by the Institute of Physics of the Earth (IFZ) of the Academy of Sciences of the USSR (in Moscow). Moreover, in 1966 and 1967 a special network was installed in Afghanistan and along the Soviet-Afghan boundary by the IFZ to study the seismicity and structure of this region. The data in 1966 and 1967 allowed the most precise determinations of hypocenter that were possible at that time [Lukk and Nersesov, 1970]. These hypocenters defined an approximately planar zone that dips steeply into upper mantle and extends in an east-west direction for nearly 700 km. With careful analytical and graphical techniques, but without the aid of high-speed computers, Lukk and Nersesov [1970] simultaneously determined a velocity structure for the crust and upper mantle and located the earthquakes. In the present paper we extend their study and present relocations of these same events using a computer.

The data obtained with this network were also used to infer a high-velocity zone surrounding the seismic zone [Vinnik and Lukk, 1973, 1974; Vinnik et al., 1977], and subsequent studies suggested a corresponding high Q zone [Khalturin et al., 1977; Molnar et al., 1976]. These studies and others [Billington et al., 1977, Chatelain et al., 1977, 1980; Malamud, 1973; Nowroozi, 1971, 1972] suggested a variety of possible configurations of slabs of oceanic or continental lithosphere that had been subducted in the region.

In addition, the longer-term recording in Tadjikistan has allowed the determination of numerous fault plane solutions of earthquakes with magnitudes ranging from about 4 3/4 to 7 [Soboleva, 1968a,b, 1972]. Because of the close proximity of many stations, much smaller events were studied than was ordinarily possible with data from the World-Wide Standardized Seismograph Network (WWSSN) alone. Soboleva [1968a] discussed the orientations of the P, T, and B axes and their relationships to the seismic zone, but her interpretation preceded the recognition of plate tectonics and more modern ideas about such relationships [Isacks et al., 1968, 1969; Isacks and Molnar, 1969, 1971]. Moreover, locations of these events which occurred between 1960 and 1967 were sufficiently imprecise to reveal systematic relationships between solution and location, such as those observed by Chatelain et al. [1980]. In the present paper we use either Nowroozi's 1971 relocations of the events or hypocentral determinations given by the International Seismological Center (ISC) to relate the solutions to the seismic zone defined by the well-located earthquakes determined here for smaller events in 1966 and 1967. We then discuss the results in light of the ideas given by Isacks et al. [1968, 1969] and Isacks and Molnar [1969, 1971]. (Nersesov and Lukk take no responsibility for the interpretation given in that discussion.)

Seismicity

Three-component short-period seismograph stations, equipped with Soviet S5S seismometers,

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were operated at locations shown in Figure 1 (and at other sites not used in this study). These instruments have a flat frequency response for displacement between about 5 and 30 Hz. Recording speeds were typically 120 mm/min, and signals were usually impulsive. Consequently, P wave arrival times could be determined with uncertainties less than a few tenths of a second, and S waves arrival times could be identified with somewhat larger uncertainties, about 1 s. These times were measured by A. A. Lukk and I. L. Nersesov. When possible, the data were supplemented by published arrival times from stations at Warsak Dam, Pakistan (WRK), and Kabul, Afghanistan (KBL).

We relocated the earthquakes recorded by this network in 1966 and 1967 using the computer program HYPO71, written by Lee and Lahr [1975], assuming a modification of the velocity structure determined by Lukk and Nersesov [1970]. A more complete discussion of the velocity structure, of the location procedure, and of the various uncertainties is given in the companion paper [Chatelain et al., 1980]. Much of the analysis given in that study deals with networks with some stations in approximately the same places as Soviet stations were in 1966 and 1967. Therefore the precision of the locations is probably comparable. The Soviet network, however, is concentrated to the north of the seismic zone, and the temporary networks employed by Chatelain et al. [1980] in 1976 and 1977 were largely south of the zone. We found a systematic northward displacement (of about 10 km) of the seismic zone using the Soviet data compared with the data from 1976 and 1977, and we infer that pronounced lateral variation in velocity in the region may be the cause of systematic differences between the locations of events. Nevertheless, the uncertainties in the relative locations of events (their precision) are likely to be approximately the same for either

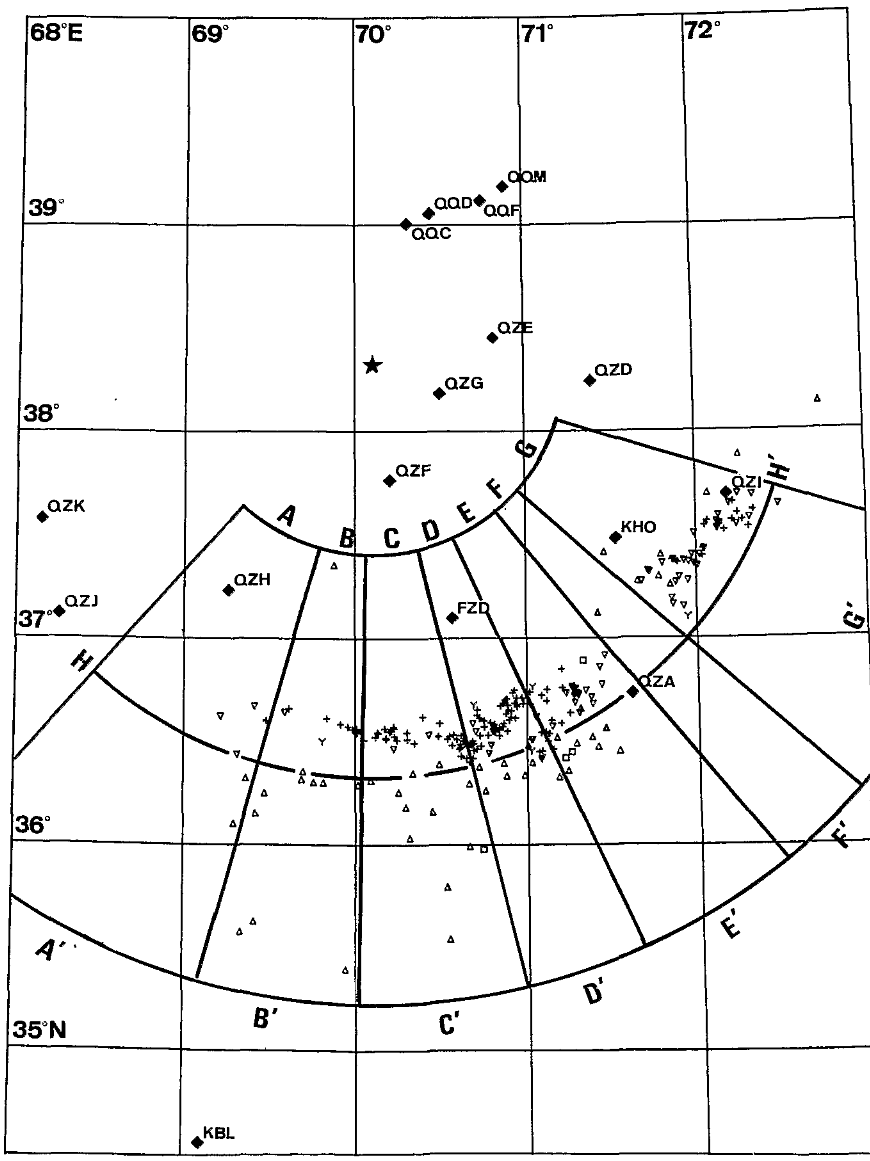

Fig. 1. Map of region showing position of stations (solid diamonds) and epicenter of earthquakes at various depths: solid triangles, 50-100 km; open triangles, 100-150 km; inverted triangles, 150-200 km; pluses, 200-250 km; and Y's, 250-300 km.

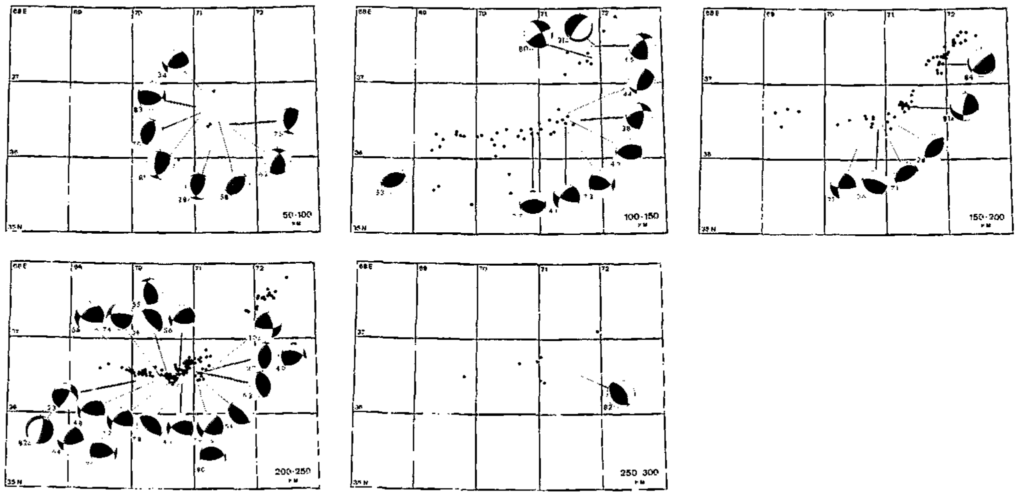

Fig. 2. Maps of 1966-1967 epicenters of events in different depth ranges and fault plane solutions in abbreviated balloon format. Lower hemisphere diagrams are shown with quadrants with compressional first motions in black, and locations of earthquakes with fault plane solutions are from Nowroozi [1971] or the ISC. Numbers correspond to events in Table 1 and Appendix A.

configuration of stations. For the majority of the events we estimate that uncertainties in the precision of the depths and hypocenters are about 10 km and that there could also be systematic errors of the same amount.

All locations with Rms residuals less than 0.7 sec [Chatelain et al., 1980] are plotted in Figure 1 and are listed in Table A1.[1] Maps for separate depth ranges are given in Figure 2, and cross sections are shown in Figure 3. This arrangement of plots is the same as in Chatelain et al. [1980], and the general features of the seismicity are similar. As noted in other studies, the seismic zone dips steeply (Figure 3) and is oriented approximately east-west (Figures 1 and 2) [Billington et al., 1977; Chatelain et al., 1977; Lukk and Nersesov, 1970; Malamud, 1973; Nowroozi, 1971]. West of approximately 71°E the zone trends east-west, but to the east it trends more nearly northeast-southwest. As the data from the studies referenced above show, at depths greater than about 150 km, the east-west zone dips steeply to the north, and the northeast-southwest zone dips steeply to the southeast (Figure 3).

Because of the greater number of more precisely determined hypocenters than for the previous studies, there are also some features that were less clearly resolved in most of these earlier studies. At shallower depths (70-150 km), both zones appear to dip at shallower angles than at greater depths (Figure 3), a result also obtained by Billington et al. [1977]. At the same time there is a very low level of seismicity at depths shallower than about 70 km (Figure 3). This is not a consequence of inaccurate locations but reflects much lower seismicity in the crust than in the underlying mantle.

[1]Appendix is available with entire article on microfiche. Order from the American Geophysical Union, 2000 Florida Ave., N. W., Washington, DC 20009. Document J80-003; $01.00. Payment must accompany order.

The seismic zone is not a continuous planar zone with uniformly distributed seismicity but instead contains pronounced gaps in activity and tight clusters of concentrated activity. One gap, near 37°N, is clear at all depths (Figure 2 and section FF' in Figure 3). This gap, approximately 50 km wide, seems to separate the zones that dip north and southeast (Figures 1 and 3), and it is tempting to suggest that the slab of lithosphere in which the earthquakes presumably occur is discontinuous there. This gap in activity is also clear in the data discussed by Chatelain et al. [1980].

A less well-defined gap in the western part of the zone between depths of about 150 and 180 km separates regions of shallower and deeper activity (profiles BB', CC', and HH' in Figure 3). Although there may not be enough events to convincingly demonstrate its existence here, this gap is particularly clear in the data described by Chatelain et al. [1980]. There is a suggestion also of a narrow gap in activity between 200 and 250 km at about 70.5°E (Figure 2 and profile HH' in Figure 3) which is very clear in the data from 1977 [Chatelain et al., 1980, Figure 5].

Along most of the zone and below about 150-km depth the width of the zone is about 30 km, a result similar to that of Billington et al. [1977] but much narrower than the data from most previous studies suggest [e.g., Lukk and Nersesov, 1970; Malamud, 1973; Nowroozi, 1971]. Given the uncertainties in the locations, the width could be narrower in most regions, except possibly near 71°E, and at depths greater than 200 km. There the zone seems to divide into two separate zones separated by a gap in activity about 20 km wide (Figure 2 and profile DD' in Figure 3). Events in both clusters were located with the same stations, and our estimation of the errors in locations suggests that this separation is real. Nevertheless, with a more favorable station distribution the southern branch is not apparent in the data of Chatelain et al. [1980].

Because most of the gaps and clusters in the

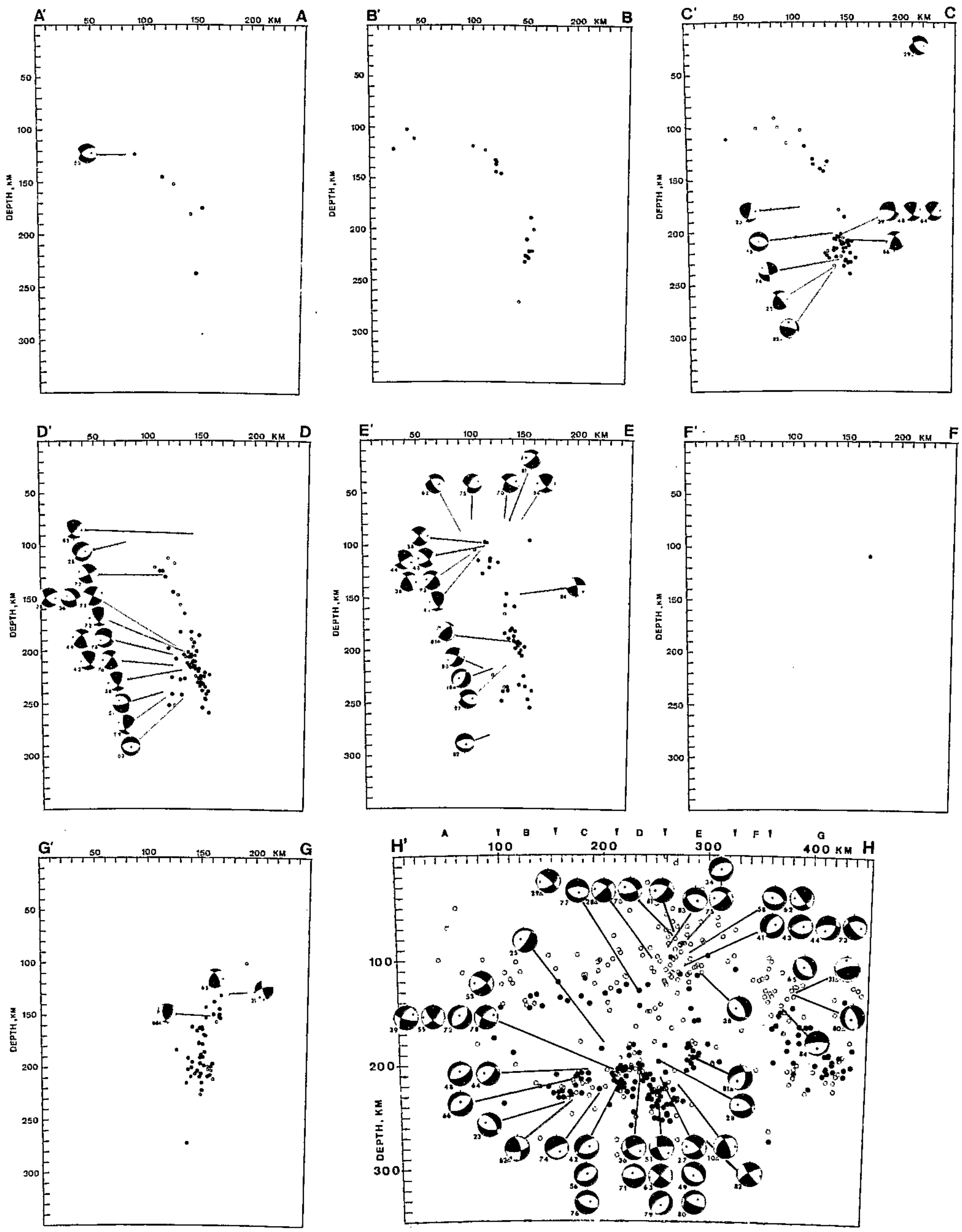

Fig. 3. Cross section of seismicity perpendicular to seismic zone (A'A to G'G) and parallel to zone (H'H) and fault plane solutions (see Figure 1). Back hemisphere of fault plane solutions shown. Solid symbols for earthquakes which met the quality constraint in Chatelain et al. [1980], and open symbols for those with most mean square residuals less than 0.7 s.

seismicity in 1966 and 1967 are evident in the data obtained in 1976 and 1977 [Chatelain et al., 1980], we do not consider them to be artifacts of short time periods of recording. At the same time the data are clearly inadequate to show that these features are representative of much longer periods of time. A close correlation of peculiarities in fault plane solutions with hypocentral positions [Chatelain et al., 1980], however, suggests that these clusters and gaps reflect variations in the state of stress and therefore may be representative of the seismicity for longer time periods than considered here.

Fault Plane Solutions

Since most of the data used to determine the fault plane solutions were radiated into the upper hemisphere of the focal sphere, upper hemisphere diagrams for all of the solutions are given in Appendix A. Pertinent parameters are listed in Table 1. To facilitate comparison with data in other studies, however, lower hemispheres given in abbreviated balloon format in Figure 2 for earthquakes at different depths, and back hemispheres are given in Figure 3 in the cross sections. These solutions were determined by Soboleva [1968a,b, 1972, new unpublished data, 1979], and among those discussed in her papers, these include only the ones to which she assigned the highest quality factor. They include essentially all events between 1960 and 1967 for which it was possible to determine a solution with Soviet data. The locations of these earthquakes were taken from Nowroozi's [1971] tabulation for events occurring in 1960-1963 and from the ISC listings for the more recent events. We assume that the uncertainty in the locations of some of these may be 10 km, but for most it is probably 20 km.

Probably the most obvious generality reflected in these data is that the T axes are nearly vertical in most cases, a result noted by Soboleva [1968a, 1972] and observed with solutions determined with other data [e.g., Billington et al., 1977; Chatelain et al., 1980; Isacks and Molnar, 1971; Nowroozi, 1972]. Among Soboleva's better constrained solutions, those used here, the T axis is in all but two cases more nearly vertical than the P axis.

Perhaps the most notable feature in Figure 2 is the wide variety of fault plane solutions. This contrasts markedly with island arc structures, where fault plane solutions of intermediate and of deep earthquakes are usually very similar to one another within the arc and in the same depth range [Isacks and Molnar, 1971]. Solutions for events 71, 78, 80, and 82 were obtained both from Soviet recordings, most of which were radiated into the upper hemisphere of the focal sphere (Appendix A), and from data of the WWSSN, which were radiated into the lower hemisphere [Chatelain et al., 1980, Table 1, Appendix A]. In general, the parameters differ by less than 10° and always less than 15°, their approximate uncertainty. This suggests that locally heterogeneous velocity structures do not cause the large observed variation in the solutions and that there is a real variation in the orientation of the fault planes.

Variation in fault plane solutions was noted for the larger events ($M \gtrsim 5.5$) in the Hindu Kush region, but much of this variation is systematic [Chatelain et al., 1980]. Near 70.6°E most of the P axes trend northeast-southwest, becoming more nearly north-south near 70.8°E and approximately northwest-southeast farther east near 71.0°E (Figure 2). Although many of the solutions presented here fit this general pattern, particularly the larger events, there is still a very large scatter. Although the solutions presented here are not as well constrained as those determined with the WWSSN, the variation in the observed first motions of the P waves requires large differences among the solutions (see Appendix A). We think that the variability within localized regions may not be real but is simply a consequence of large errors in the locations of the events. Chatelain et al. [1980] found very large differences in fault plane solutions of earthquakes only 20-30 km apart. Therefore errors in locations of this amount, which are difficult to eliminate, could introduce an apparently random scatter of solutions, whereas in fact there is a simple regional variation.

The fault plane solutions for the shallower events (70-150 km) include large components of

Table 1. FAULT PLANE SOLUTIONS

#	DATE	Origin Time	LAT (°N)	LONG (°E)	DEPTH (KM)	P AXIS		T AXIS		B AXIS		POLE OF FIRST NODAL PLANE		POLE OF SECOND NODAL PLANE	
						AZ	PL	AZ	PL	AZ	PL	AZ	PL	AZ	PL
23	60/01/9	07:24	36.43°	70.10°	234	150	15	260	50	49	36	300	20	190	40
25	60/02/8	18:54	36.19°	70.55°	175	143	10	46	33	247	55	100	30	0	15
27	60/02/19	10:36	36.56°	71.11°	211	95	5	195	80	4	10	260	40	105	45
28	60/02/23	02:09	36.51°	71.11°	194	310	5	135	80	40	1	130	40	320	50
34	61/03/20	03:30	36.78°	71.26°	75	335	0	65	60	245	30	130	35	0	40
10Δ	61/04/26	05:23	36.56°	71.30°	218	40	0	310	40	130	50	0	25	260	30
36	61/06/19	17:04	36.47°	70.88°	197	30	20	170	70	296	12	200	25	50	60
30Δ	61/07/20	00:40	38.40°	72.40°	120	15	62	126	12	223	24	98	50	326	31
31Δ	61/08/17	13:46	37.50°	71.70°	113	105	60	315	26	220	15	344	68	134	18
32Δ	61/08/18	07:56	38.70°	72.70°	110	142	2	234	79	52	10	154	46	311	42
38	61/08/21	07:00	36.49°	71.68°	108	130	0	220	45	40	45	275	30	165	30
39	61/09/6	13:35	36.52°	70.61°	204	225	30	45	60	135	0	45	15	225	75
41	62/01/5	04:27	36.46°	71.39°	104	166	9	67	40	266	48	125	35	20	20
42	62/01/8	22:25	36.41°	70.77°	212	182	6	84	54	276	35	150	40	30	30
43	62/02/27	05:40	36.53°	71.45°	101	355	0	90	75	265	15	160	40	10	40
44	62/03/28	00:51	36.58°	71.47°	102	307	22	78	59	208	21	110	20	340	60
48	62/07/6	23:05	36.46°	70.35°	208	172	14	39	58	270	29	140	50	15	25
49	62/08/3	18:02	36.52°	71.10°	203	340	5	245	60	73	30	315	40	185	35
51	62/10/9	15:59	36.41°	71.19°	238	40	25	235	65	133	6	25	65	225	20
53	63/01/12	06:20	36.09°	69.09°	122	155	0	345	85	245	1	330	45	160	50
55	63/02/17	05:38	36.46°	70.55°	201	255	0	160	65	345	25	100	40	230	40
56	63/02/18	14:25	36.46°	70.78°	218	165	5	70	55	258	35	140	40	15	35
58	63/03/7	21:49	36.47°	71.41°	96	135	0	235	80	45	10	300	40	145	45
28Δ	63/06/1	10:49	36.12°	71.24°	96	100	3	355	63	193	26	300	35	70	45
29Δ	63/06/11	03:25	37.11°	70.07°	24	295	5	185	70	27	19	280	50	130	35
62	63/07/10	02:12	36.37°	71.60°	87	275	5	180	55	9	35	125	30	240	40
63	63/08/13	07:03	36.55°	71.04°	245	255	10	80	85	344	1	75	40	255	60
64	63/09/29	10:39	36.46°	70.33°	205	145	0	55	54	235	36	115	35	355	35
65	63/10/14	21:12	37.46°	71.68°	113	107	0	197	43	17	47	145	30	250	30
66	63/12/28	01:40	36.55°	70.12°	209	170	9	68	53	266	35	136	42	19	27
70	64/01/23	15:19	36.58°	71.18°	76	110	15	270	75	19	5	280	30	120	60
71	64/01/28	14:09	36.48°	70.95°	197	150	20	335	70	241	2	150	65	330	25
72	64/02/18	17:08	36.47°	70.70°	202	162	9	69	40	264	44	130	40	15	25
72Δ	64/03/23	08:38	38.25°	73.63°	125	355	41	345	18	138	44	290	43	36	15
73	64/05/16	08:28	36.36°	71.43°	110	9	6	271	56	103	33	340	40	215	30
74	64/05/17	11:45	36.49°	70.47°	226	22	26	149	51	278	27	180	15	70	60
75	64/09/28	06:51	36.42°	71.51°	77	105	10	0	65	200	24	305	35	80	45
76	64/11/27	11:03	36.40°	70.73°	211	181	5	283	65	92	24	340	35	205	45
77	64/12/24	01:08	36.35°	70.89°	127	350	15	180	75	81	2	350	60	170	30
78	65/03/14	15:53	36.42°	70.73°	205	220	15	40	75	130	0	220	60	40	30
80Δ	65/04/10	21:21	37.33°	71.87°	129	290	16	195	18	58	65	244	23	152	2
81Δ	65/07/20	07:43	36.72°	71.32°	131	308	30	62	35	188	40	1	48	94	4
79	65/11/16	01:03	36.41°	71.11°	242	341	19	89	43	233	41	130	15	25	45
82Δ	65/05/30	11:28	36.42°	70.09°	234	268	58	116	28	20	14	149	68	286	15
80	66/06/6	07:46	36.43°	71.12°	214	178	18	322	68	86	13	350	25	200	60
81	66/07/07	19:00	36.53°	71.14°	79	286	8	30	59	192	34	80	31	318	43
82	67/01/25	01:50	36.71°	71.60°	281	43	11	265	76	138	7	36	55	234	33
83	67/02/11	08:05	36.65°	71.05°	88	2	9	249	62	96	25	202	30	334	48
84	67/12/28	20:15	37.28°	71.92°	147	330	35	123	54	230	12	138	11	13	76

thrust faulting, therefore with steeply dipping T axes, and with P axes oriented approximately northwest-southeast (Figure 2). The dip of the seismic zone is not well defined in this depth range (Figure 3) but seems to increase with depth. It is possible that for some of these events one of the nodal planes is parallel to the seismic zone (event 53 in AA'; event 77 in DD'; events 38, 41, 43, 44, 58, and 73 in EE'; and event 65 in GG' of Figure 3). In such a case the slip during earthquake might represent displacement along a fault parallel to the seismic zone [Vinnik and Lukk, 1973, 1974; Vinnik et al., 1977]. Such a phenomenon is unusual for earthquakes at these depths, but perhaps in Asia the plates are thicker than at island arcs [e.g., Vinnik et al., 1977]. These earthquakes would then result from relative plate motion, not internal deformation of the downgoing slab as at island arcs [Isacks and Molnar, 1971].

The approximately horizontal northwest-southeast P axes for these events (Figures 2 and 3) are similar to those of shallower, crustal events further south [Prevot et al., 1980]. At the same time the solutions in Figure 2 are sufficiently different that the slip vectors definitely differ from one another. Therefore only some, if any, of these events between 70 and 150 km could reflect slip of one plate past another. They might reflect more diffuse deformation resulting from northwest-southeast compressive stress due to the India-Eurasia collision.

Alternatively, the nearly vertical T axes for the deeper of these events (near 150-km depth) could indicate internal deformation of the downgoing slab, as is typical of intermediate depth events at island arcs. The uncertainties in the locations of these events and in the configuration of the seismic zone do not allow this to be resolved.

Summary

A study of earthquakes occurring in 1966 and 1967 in the Pamir-Hindu Kush region and recorded by a relatively dense network of local stations reveals several unusual patterns in the seismicity. Seismicity in the crust is very low so that the intermediate depth zone does not continue to the earth's surface along any clear zone. Two possible explanations are either that convergence between India and Eurasia continues, with deformation in the crust occurring aseismically, or that convergence is absorbed farther north (or south), with the intermediate depth earthquakes occurring in a slab of lithosphere hanging in the mantle. These two explanations are not mutually exclusive.

To a first approximation the seismicity is confined to a narrow (width <30 km) planar zone that dips steeply into the mantle. The data suggest a pronounced gap near 37°N that separates a steeply north dipping zone in the west from a steeply southeast dipping zone in the northeast. This gap in activity could represent a discontinuity in the downgoing slab of lithosphere or even a gap between two lithospheric slabs [see Chatelain et al., 1980]. There is a suggestion of a decrease in the dip of the zones at shallower depths (~100 km), but because of the lack of continuity of seismicity to the surface, it is difficult to trace either inferred zone to a place at the earth's surface, where subduction of the slab would have occurred. The dips of the seismic zone suggest a southerly source of the western zone and a northerly source for the eastern zone, an idea expressed by others from the faulting and geologic structure along the northern margin of the Pamir [Khalturin et al., 1977; Malamud, 1973; Molnar et al., 1973; Ulomov, 1974; Vinnik and Lukk, 1973, 1974; Vinnik et al., 1977]. This interpretation is certainly not required by the data, and Billington et al. [1977] give other possible scenarios.

The gap in activity at 37° is not the only gap, and clusters of activity also occur. Since these gaps and clusters are evident in data obtained during short periods of recording 10 years later, we think that they are representative of the seismicity for at least tens of years. Perhaps they have persisted hundreds or thousands of years [Chatelain et al., 1980].

We used fault plane solutions of earthquakes in 1960-1967, determined by Soboleva [1968a, 1972], but assumed the locations given in Nowroozi [1971] and ISC. The T axes, in general, plunge at steep angles and lie approximately within the plane of the seismic zone. Thus they conform to the gross pattern for intermediate depth events at island arcs where there are no deep events or where there is a gap in seismicity between intermediate and deep events [Isacks and Molnar, 1969, 1971]. Therefore most of them presumably result from stress in a downgoing (or hanging) slab of lithosphere. The important parameters would be the orientation of the P, T, and B axes, not the nodal planes or slip vectors. The downdipping T axes imply that gravitational body forces tend to pull the slab down [Isacks and Molnar, 1969, 1971].

The only exception to this pattern might be for events at shallower depths (70-150 km), where the seismic zones seem to dip less steeply. Solutions for some but not all of these events show that one plane could be parallel to the seismic zone. If the plane of seismicity marks a fault, then the displacement might represent slip of one plate with respect to another. The data do not require this interpretation, however.

Fault plane solutions of deeper events (180-230 km) also show considerable variability. Although the regional variation in solutions discussed by Chatelain et al. [1980] describes much of the variation in the data presented here, the scatter is still very large. We suspect that the scatter is only apparent and is due to errors in the locations.

Acknowledgments. I. Nersesov and A. Lukk carried out the analysis of the travel times and determined preliminary locations. O. Soboleva determined the fault plane solutions. S. Roecker, D. Hatzfeld, and J. Chatelain redetermined the locations and carried out the analysis of the fault plane solutions in light of the seismicity. S. Roecker, D. Hatzfeld, and P. Molnar assembled the manuscript; they, O. Soboleva, and J. Chatelain made the interpretations in terms of subduction of oceanic lithosphere. Much of the work was done at Applied Seismology Group in Lincoln Laboratories. We thank them for making their facilities available and for their help. We also thank V. I. Khalturin, R. North, G. Perrier, T. G. Rautian, and B. E. Tucker for help at various stages in this work and two anonymous referees for constructive criticism of the manuscript. This work was supported by NSF grants EAR76-13367 and EAR78-13673, by contract ATP No. 35-06, 35-25, and 35-58 of INAG from the Centre National de la Recherches de France, by an H. O. Wood Award, and by an Alfred P. Sloan Fellowship.

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