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Source mechanism of earthquakes in Szechwan province, China

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सार — चीन के जेचवान प्रांत में भ्रंश की प्रकृति को समझने के लिए पूर्व शोधकर्ताओं द्वारा प्राप्त परिणामों और 1970-1976 की अवधि के सात भूकम्पों के नाभीय क्रियाविधि हलों का उपयोग किया गया है । ज्ञात हुआ है कि उस क्षेत्र में भ्रंश की प्रवृत्ति आमतौर पर सामान्य है । वहां दाब तेजी से नत हो जाते हैं और उनकी दिशा उत्तरपश्चिम से दक्षिणपूर्व हो जाती है जबकि तनाव सामान्यतः अगंभीर होते हैं ।

ABSTRACT. Focal mechanism solutions of seven earthquakes during 1970-1976 along with the results of the earlier workers have been used to understand the nature of faulting in the Szechwan Province, China. It has been found that the nature of faulting is predominantly normal in this region. Pressures are steeply dipping, trending northwest-southeast while the tensions are generally shallow.

1. Introduction

Szechwan province is one of the most seismically active regions in China. During the years 1963-1976, 116 earthquakes of magnitude more than 4 have been reported in the region. Fault plane solutions reported so far (Tapponnier and Molnar 1977 and Verma *et al.* 1980) however suggest that the tectonics of the region is complex and further studies are needed to understand the nature of faulting in the region.

The object of the present paper is to discuss the newly determined fault plane solutions in conjunction with the results of other workers with a view to understand the tectonics of this area based on the data during the years 1970-1976.

2. Tectonic setting

Szechwan province includes a wide alluvial plain towards southeast lying at about 500 metre above sea level and is considered to be stable since the tertiary. It is underlain by a thick section of mesozoic rocks. Towards west, lies the fracture zone called Lungmenshan, reaching heights of more than 5000 metre, which is believed to have formed during the tertiary. This fracture zone forms the boundary between the Szechwan basin and the central China fold system comprising of Kunlun fold belt of precambrian and palaeozoic age. It is a thrust fault dipping towards west. On the landsat photos, the Lungmenshan thrusts look similar to the Himalayan frontal thrusts, making a boundary between the rugged over-thrusting block and the flat quaternary alluvial deposits. Linear faults run parallel to the overall trend of the thrusts (N 40E) within Lungmenshan. In the adjoining Szechwan plain near Cheng Tu, elongated ridges run parallel to this thrust. Further west, lies Kang Ting fault extending throughout the whole of the western part of the Szechwan province from 33N in the upper Yangtze Kiang valley trending N 110 E for about 400 km, the system joining with Lungmenshan fracture zone at about 25N in the region of Kung Ming in Yunnan. It is a left lateral strike slip fault. In its northern section, the fault cuts through intensely deformed matamorphic rocks intruded by granite batholiths (Heim 1934). Near 32.5N, 99.5E, ridges and valleys oriented N 140 E to 160 E reflect a relatively homogeneous deformation resulting from left lateral motion. Tapponnier and Molnar (1977) have closely demarcated the fault system on the landsat images. Towards south of Kang Ting, north to northeast trending eroded anticlines and synclines outlined by the permian and triassic limestones are conspicuous on the landsat images. In the adjoining Yunnan region, large areas have experienced block faulting and as much as 2000 km of recent uplift at place in the late tertiary and quaternary. The dominant pattern of folding direction is north-south and northwest-southeast. Narrow elongated north-south depressions filled with quaternary sediments or in some places with lakes are bounded by normal faults; one of them being shown to the north of Hsia Kuan (26N, 100E). The fault abruptly ends along the *Red* river fault system which extends along a deep rupture reactivated in the Cenozoic. Strike slip motion along the fault is indicated.

3. Seismicity of the region

Fig. 1 shows the spatial distribution of epicentres taken from U.S.G.S. magnetic tape file for the period from 1628 upto 1976. The seismic activity is generally confined to the fracture zones Kang Ting, Lungmenshan and Annigho, forming a "Y" shaped fracture

TABLE 1

Epicentral parameters of earthquakes in Szechwan province, China

Event No.	Date	Epicentre		Origin time (GMT)			Depth (km)	Magnitude (mb)
		Lat. (°N)	Long. (°E)	*h*	*m*	*s*		
1	6-2-1973	31.33	100·49	10	37	07	05	5.9
2	7-2-1973	31.50	100.33	16	06	25	35	5.9
3	23-3-1973	31.83	100.05	19	14	51	19	5.3
4	02-8-1973	27.80	104.59	08	58	15	28	5.4
5	11-8-1973	32.94	104.02	07	15	38	20	5.5
6	15-1-1974	32.89	104.07	22	50	29	35	5.3
7	23-8-1976	32.49	104.18	03	30	07	33	6.2
8	14-4-1955	30.00	101.07	01	29	00	00	—
9	28-9-1966	27.50	100.07	14	00	22	27	6.2
10	30-8-1967	31.57	100.31	11	08	50	30	5.2
11	24-2-1970	30.06	103.00	02	07	36	33	5.9
12	31-7-1970	28.63	103.61	13	10	44	04	5.3
13	8-11-1970	32.12	101.31	09	15	00	34	5.0
14	16-8-1971	28.89	103.68	04	58	00	32	5.5
15	11-5-1974	28.20	104.00	19	25	17	17	5.8

TABLE 2

Orientation of nodal planes, pressure and tension axis

Event No.	Nodal plane I			Nodal plane II			*P*-axis		*T*-axis		Fault type	Reference
	Strike Dir. (°)	Dip Dir. (°)	Dip An. (°)	Strike Dir. (°)	Dip Dir. (°)	Dip An. (°)	Az. (°)	Pl. (°)	Az. (°)	Pl. (°)		
1 (i)	37	127	74	a 150	240	38	345	49	101	21	Normal, SS	Present study
				b 217	307	16	—	—	—	—	Normal, DS	
(ii)	36	126	82	306	36	84	261	9	301	0	Strike slip	Tapponnier and Molnar (1977)
2 (i)	60	330	60	240	150	30	150	76	330	14	Normal, DS	Present study
(ii)	208	298	62	28	118	28	119	73	299	17	Normal, DS	Tapponnier and Molnar (1977)
3	319	229	57	16	106	52	350	56	256	3	Normal, DS	Present study
4	346	256	60	156	66	30	66	75	246	15	Normal, DS	Do.
5	256	346	59	74	164	31	165	75	345	15	Normal, DS	Do.
6	124	34	70	a 304	214	20	214	65	34	25	Normal, DS	Do.
				b 48	138	56	—	—	—	—	Normal, SS	
7 (i)	310	220	74	130	40	16	220	30	40	60	Thrust, DS	Do.
(ii)	174	264	58	215	125	40	283	11	40	68	Thrust	Wallace and Teng (1980)
8	332	242	64	152	62	26	63	71	243	19	Normal	Verma *et al.* (1980)
9 (i)	138	48	43	328	238	48	125	84	232	4	Normal	Banghar (1974a)
(ii)	—	—	—	—	—	—	118	73	217	3	Normal	Tapponnier and Molnar (1977)
10	32	122	38	230	320	54	192	82	310	5	Normal	Tapponnier and Molnar (1977)
11	22	112	60	337	247	40	84	8	345	55	Thrust	Banghar (1974b)
12	—	—	—	—	—	—	338	53	193	9	Normal	Verma *et al.* (1980)
13	264	354	78	178	88	86	128	5	220	9	Strike slip	Verma *et al.* (1980)
14	80	170	60	190	280	60	312	2	45	44	Thrust, SS	Tapponnier and Molnar (1977)
	—	—	—	—	—	—	174	67	298	4	Normal, SS	Verma *et al.* (1980)
15	—	—	—	—	—	—	272	3	182	11	Strike slip	Chengtu Seismological Detachment (1975)

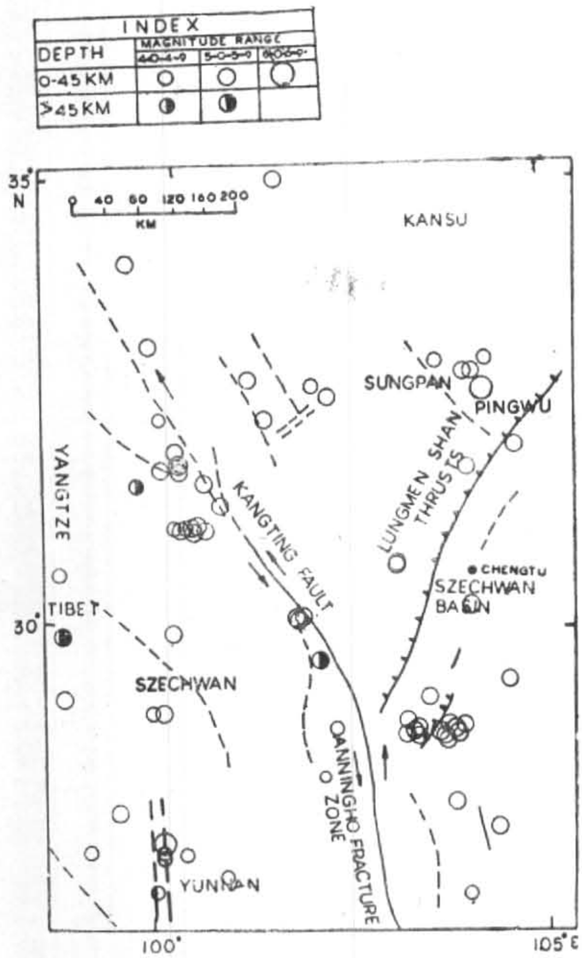


Fig. 1. The spatial distribution of epicentral locations of the earthquakes in the Szechwan province, China, for the period 1628-1976

pattern. Of these Lungmenshan fracture zone is seismically more active where 27 earthquakes of magnitude 4 or more have been recorded during the years 1958 to 1976 (July). Active seismicity is attributed to the renewed tertiary convergence resulting from eastward displacement of central China relative to southeast Asia along Lungmenshan and reactivation of these thrusts.

A few pockets of earthquake activity in the region may also be associated with fractures (shown dotted) running parallel to the main fault systems or inferred on the basis of landsat imagery. The seismic activity is also well marked in southwest region where north-south trending faults are predominant in Yunnan mountains. Shallow focus earthquakes are predominant throughout the region.

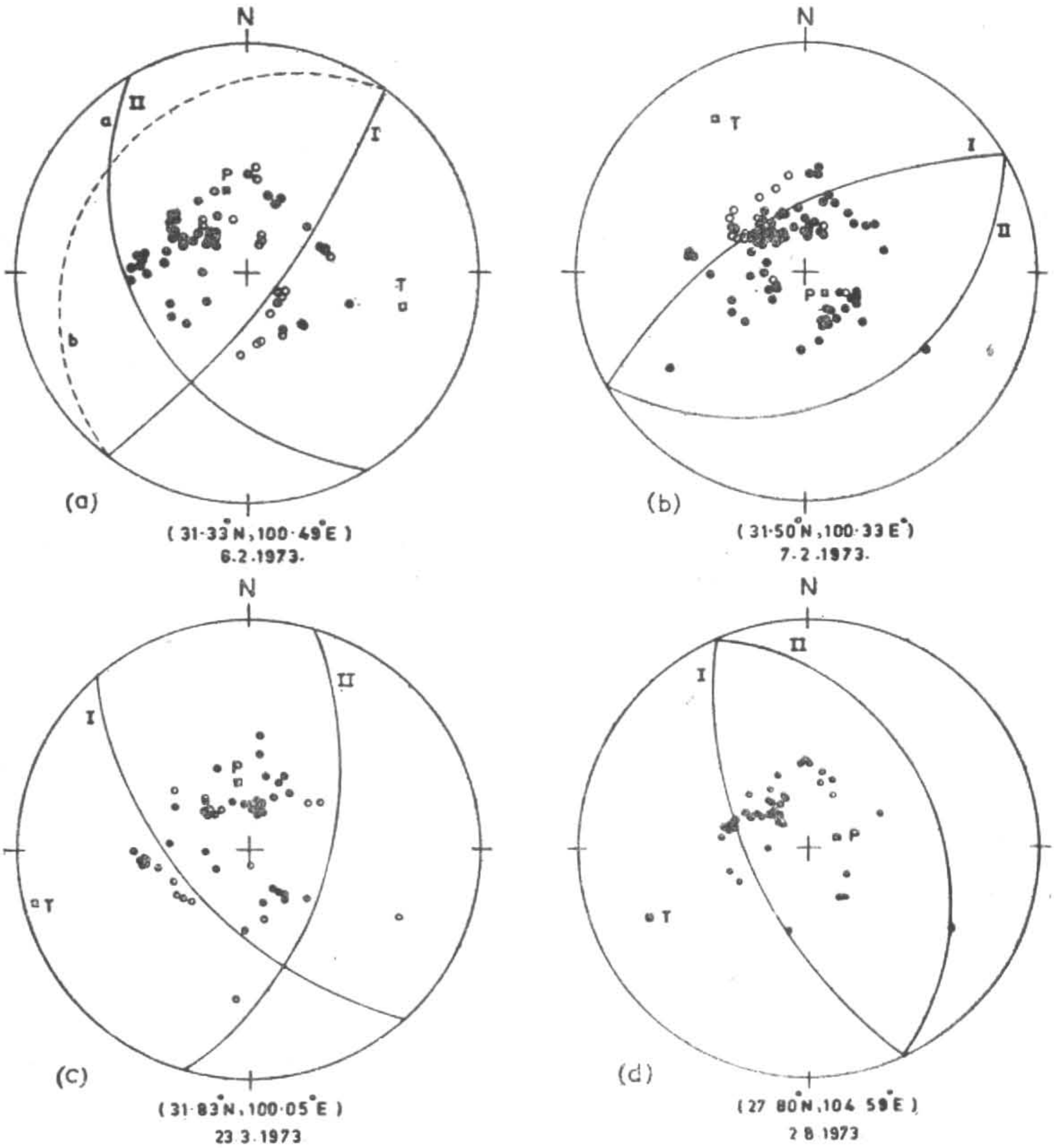
4. Results and discussion

Fig. 2 shows the newly determined focal mechanism solutions for seven earthquakes on Wulff's projection of the lower hemisphere. Table 1 gives the epicentral parameters of these earthquakes as well those reported earlier. The data for the new solutions have been taken from the Bulletins of the International Seismological Centre. First motions of *P* and *PKP* were used for fault plane analysis assuming a double couple source at the focus. The data were plotted on Wulff's projection of the lower hemisphere using using the Jeffreys-Bullen velocity model. The seismograms from all the Indian stations were carefully scrutinized and provided larger data base than that used by other workers. Greater weightage was assigned to the long period data for drawing the nodal planes separating the compressions from the dilatations. These solutions along with the orientations of pressures and tensions as well as those of earlier workers are given in Table 2. The orientations of the nodal planes for all the solutions (present and those reported earlier) are schematically illustrated in Fig. 3.

Of these solutions, the nodal planes for the events 2, 3, 4, 5 and 7 are unambiguously defined. However, for events 1 and 6 only one nodal plane could be uniquely drawn; the other nodal plane could vary within the limits marked as IIa and IIb on the focal sphere. Solutions for events 1 and 2 were also reported by Tapponnier and Molnar (1977) while that for event 7 has been reported by Wallace and Teng (1980).

Events 1, 2, 3, 8 and 10 are close to the Kang Ting fault. Fissures observed from the earthquakes in 1923 (Lee 1948) and event 1 (Shu 1974) indicate primary left lateral strike slip motion but are consistent with some extensional component. This was supported by Shu (1974) who obtained predominantly left lateral motion on a plane striking N 50 W for earthquake of 6 February 1973. However, the solution for the event 2 which is an aftershock of event 1 showed normal faulting (Tapponnier and Molnar 1977). On comparison of these solutions with the present study, it may be noticed that except for the slight difference in the orientation of nodal plane by 10 to 15 deg. for the event 2 there is remarkable agreement. This type of normal faulting is expected in the regions where two segments of the Kang Ting fault are offset. The mechanism of this type of faulting within a predominantly strike slip fault with an offset could be understood if we look at mid oceanic ridges where its two segments get displaced relative to each other. These are connected by fracture zones and thus give rise to different nature of faulting along them. The solution for event 1 (present study) shows normal faulting with the motion ranging from pure dip slip to strike slip motion due to lesser control. However, pressures for both these events are oriented roughly along the fault strike. Events 3 and 10 which occurred close to Kang Ting fault also showed normal faulting with similar orientations of pressures as that obtained from the events 1 and 2. It may, therefore, be concluded that in the vicinity of the fault offset, the faulting is normal, with the pressures oriented almost along the strike of the fault. Further southwards near 26 N, 103 E, however, Molnar and Tapponnier have reported left lateral strike slip motion along N 170 E trending fault for events of 5 February 1966 and 13 February 1966.

Event 4 occurred in a region of minor fractures with a northnorthwesterly trend parallel to the Annigho feature zone and showed normal faulting. Pressures were steeply inclined but acting at right angle to the fault system. For earthquake of May 1974 (event 15) in its immediate vicinity almost similar orientation of



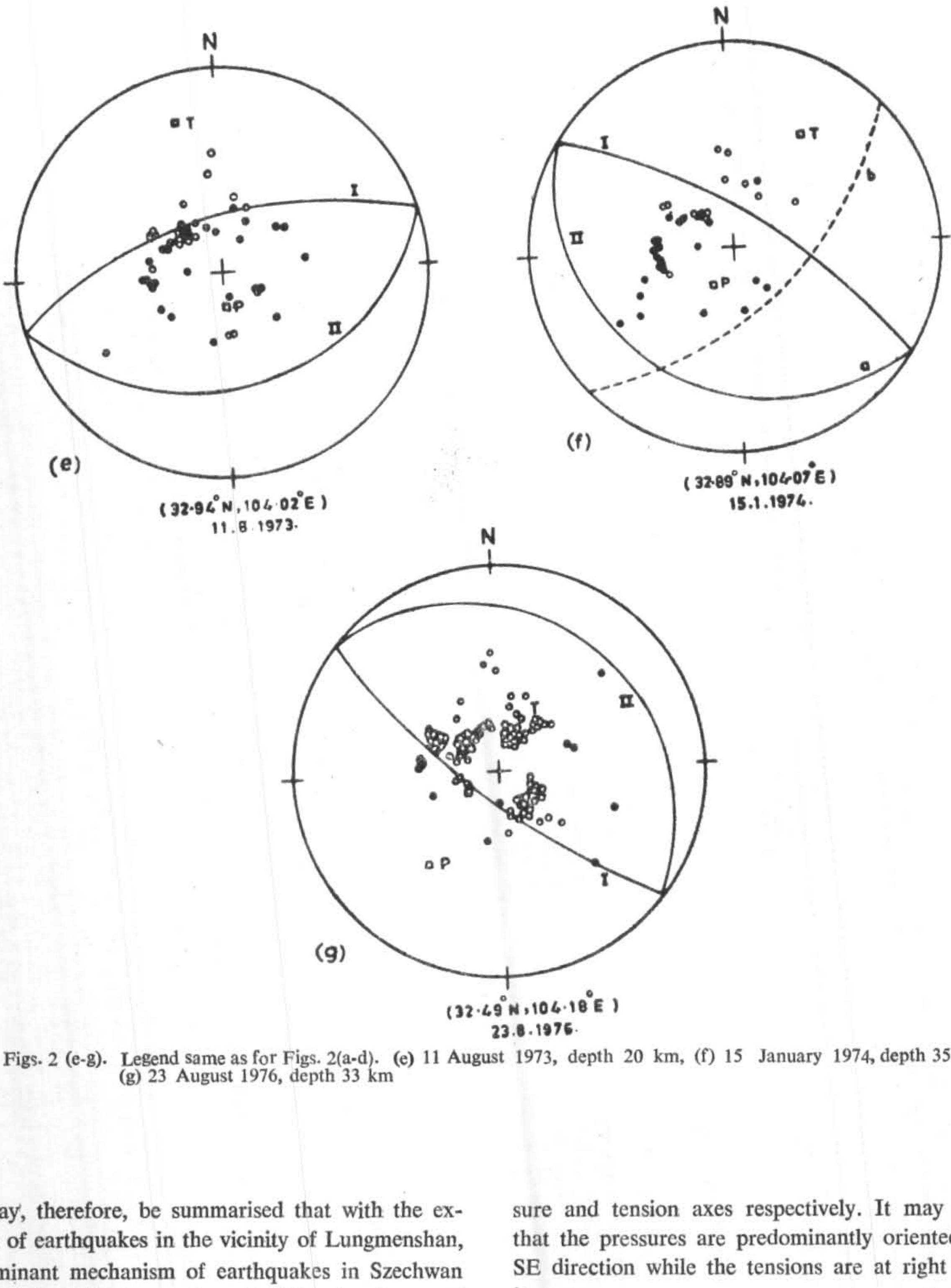
Figs. 2(a-d). Focal mechanism solution for seven earthquakes (events 1-7) on Wulff's projection of the lower hemisphere. Filled and open circles represent first-motion dilatations and compressions respectively. *P* is the pressure axis, *T* is the tension axis : (a) 6 February 1973, depth 5 km, (b) 7 February 1973, depth 35 km, (c) 23 March 1976, depth 19 km, (d) 2 August 1973, depth 28 km

pressures was reported although the motion was primarily strike slip.

Events 5, 6 and 7 are close to the northwest trending (shown dotted) fractures joining the Lungmenshan fault. While two of them have one plane in such a direction, event 5 is showing faulting almost at right angles to it. Further while two of them show normal faulting, event 7 shows thrusting. Some variations in the pressure directions are conspicuous for the events 5 and 6 which are closely located. For events 12 and 14 in the neighbouring region, Verma *et al.* (1980) and Molnar and Tapponnier (1977) have reported normal and thrust type of movements respectively showing complexity of the tectonics.

Event 11 occurred near Lungmenshan which showed predominant thrust faulting on a northeasterly trending fault. The solutions of two other earthquakes (events 12 and 14) close to the fault were reported as normal (Verma *et al.* 1980) and thrust (Tapponnier and Molnar 1977) respectively with the pressures acting at right angles to the faults running almost parallel to the Lungmenshan thrusts. The explanation about the nature of faulting in the vicinity of this fault must await the occurrence of more earthquakes in the region to solve the complexity of mechanism of earthquakes.

Event 9 located in Yunnan indicates normal faulting but on a northwest striking plane. The pressures are inclined at acute angle to the fault.



Figs. 2 (e-g). Legend same as for Figs. 2(a-d). (e) 11 August 1973, depth 20 km, (f) 15 January 1974, depth 35 km, (g) 23 August 1976, depth 33 km

It may, therefore, be summarised that with the exception of earthquakes in the vicinity of Lungmenshan, the dominant mechanism of earthquakes in Szechwan and adjoining Yunnan region of China is of normal type.

5. Regional trend of the stresses

In Figs. 4 (a & b) are shown the depth-wise distributions of the pressure and tension axes of the fault planes. The majority of events are noted to be of normal fault type in which the pressures are steeply dipping while the tensions dipping shallow. Figs. 5 (a & b) show the azimuthal distribution of the pressure and tension axes respectively. It may be noted that the pressures are predominantly oriented in NW-SE direction while the tensions are at right angles to it.

6. Conclusions

The present study demonstrates that the nature of faulting in Szechwan province of China is predominantly of normal fault type except in the vicinity of Lungmenshan thrust. Pressures are steeply inclined to the fault zones while tensions are rather shallow. Further studies are needed to resolve the differences in the individual fault plane solutions *vis-a-vis* the principal faults in the region, namely, Lungmenshan, Kang Ting and other fractures.

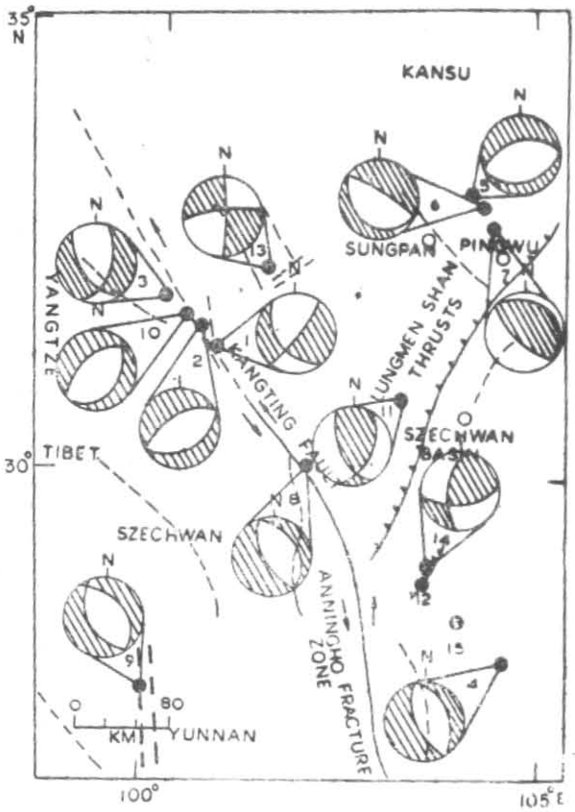
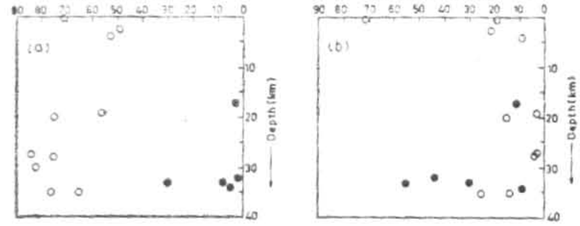
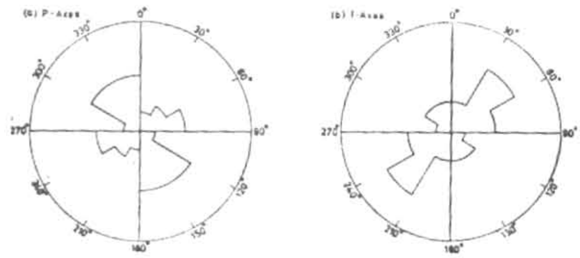


Fig. 3. Schematic orientation of the nodal planes for the present and past focal mechanism solutions considered in this work. The numbers refer to the earthquake events for which solution parameters are listed in Table 2. Nodal plane orientations for the events 12 and 15 are not shown due to discrepant data. Shaded—Compressions, Blank—Dilatations



Figs. 4 (a&b). A plot of plunge of P axis (a) and T axis (b) with focal depth respectively for the focal mechanism solutions considered here. Open, solid and open with cross mark circles represent normal, thrust and strike slip type mechanism



Figs. 5 (a&b). The azimuthal distribution (direction) of (a) pressure and (b) Tension axes respectively

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