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Nature of Faults and Focal Mechanism Solutions of Part of Northern Pakistan

MONA LISA, AZAM A. KHAWAJA, GHULAM R. GHAZI, ISHTIAQ, A. K. JADOON & SARWAT HASHMI
Department of Earth Science, Quaid-i-Azam University, Islamabad, Pakistan.

ABSTRACT: *The area extending southwards from the MMT to Kohat/Potwar plateau in Northern Pakistan is considered to be one of the most seismically active region in the world. 13 earthquake events recorded during 1984-1995 from this area have been investigated for focal mechanism solution.*

Solution show strike-slip faulting with a majority (eight) indicating a left lateral sense of motion. They mostly confirm the trend and behavior of the exposed faults with exception of one which might be related with a blind fault.

Three right lateral strike-lip focal mechanism solution, one associated with the Thakot fault and other with the Kalabagh fault, support the active character of these faults or represent their buried offshoots. Two E-W trending right lateral focal mechanism solutions are considered to represent left lateral sheer at the western boundary of Indo-Pakistan Plate.

The P and T-axis orientation indicate NE-SW direction of compression for area located north of MBT, whereas in Kohat and Potwar area mixed trend of both NE-SW and NW-SE compressive directions are obtained suggesting more complexity. In this active zone of convergence i.e., thrusting dominated region, a kinematic change due to oblique collision is inferred.

INTRODUCTION

The destruction caused by earthquakes is a matter of great concern to mankind and different approaches are being implemented to understand the earthquake phenomena. One such approach, whereby an understanding of earthquakes is obtained, is focal mechanism solution.

In this study, focal mechanism solution of the earthquakes (Mb>4.5) have been carried out in parts of Northern Pakistan bounded by latitudes (33°-35°N) and longitudes (71°-73° 30 E) for the period 1984 to 1995.

As can be observed from fig 1, a large area of Northern Pakistan is covered in this study and it encompasses a wide range of geomorphic, lithologic and tectonic units like Swat Himalayas, Peshawar Basin, Nizampur Basin and Northern part of Kohat-Potwar plateau. Diverse lithologies ranging in age form Precambrian to Recent characterize the area. Structure and tectonics of the area is complex, important cities like Peshawar, Mardan, Nowshera, Abbottabad and Islamabad are located within the area.

A total of thirteen events have been selected for the determination of focal mechanism solution due to the fact that data of other earthquake events does not contain the requisite information for undertaking focal mechanism solution.

GEOLOGICAL SETTING

A number of workers (e.g., Yeats and Lawerence, 1984; Tahirkheli, 1980) have contributed towards an understanding of the various geological aspects of the area. According to these workers, Northern Pakistan is a part of Himalayan zone of convergence in which two prominent sutures are situated. The northern suture also known as the Main Karakoram Thrust (MKT) formed about 100 Million years ago (Treloar et al., 1989), whereas, the southern suture, also known as the Main Mantle Thrust (MMT) is believed to have originated about fifty million years ago (Treloar and Rex, 1990). Kohistan Island Arc lies between these two sutures. The deformation is believed to have shifted southwards with time to the Main Boundary Trust (MBT) in the Himalayan foreland where Lower Tertiary rocks are thrusted over Miocene molasse rocks. The Kohat plateau along with the Salt Range present a zone of foreland deformation South of MBT. The Salt Ranges is located above the Salt Range Thrust (SRT) where deformation as young as 0.4 million years has been documented (Years and Lawrence, 1984).

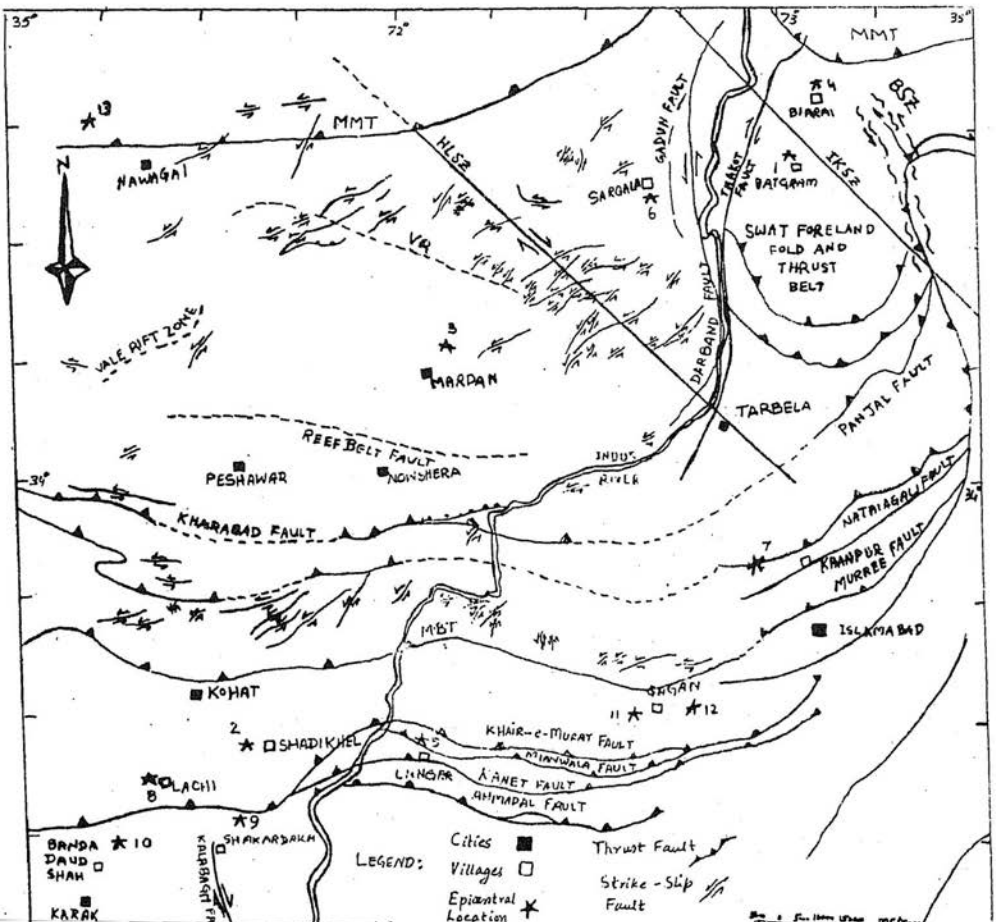

Fig. 1. Map showing the distribution of faults (compiled from many sources). Also shown are the epicentral locations of events used in focal mechanism solution.

STRUCTURE

A number of prominent faults occur within the area. Most of these faults have been described by various workers in the continuing attempt of deciphering the tectonic history of the area.

Fig. 1 shows the distribution of faults within the study area and also the epicentral distribution of the earthquakes in an attempt to determine the relationship between seismic activity and surface geology. Some major faults are the Main Mantle Thrust (MMT), Thakot Fault, Darband Fault, Balakot Shear zone, Panjal Thrust, Nathiagali Thrust, Main Boundary Thrust (MBT), Indus Kohistan Seismic Zone (IKSZ) and Hazara Lower Seismic Zone (HLSZ).

DATA SOURCES AND METHODOLOGY

All the thirteen events listed in Table 1 and shown in Fig. 1, have been analysed using the data complied by the United States Geological Survey (USGS) in their Preliminary Determination of Epicenters (PDE) reports. The other required parameters like epicentral distance, azimuthal angle and polarity for each event were obtained from the Earthquake Data Reports (EDR) of USGS.

With the help of above information, a set of orthogonal planes on the surface of a focal sphere were established in order to obtain the requisite information (such as nodal planes, P-Axis, T-axis, slip vector an their strikes and dips). From this set of data, fault planes have been identified by integrating the data with the available geological information.

TABLE 1. LOCATION, DEPTH AND MAGNITUDE OF EARTHQUAKES USED IN THE STUDY (FROM PDE REPORTS OF USGS)

Event No.	Date	Origin Time h-mi-s	Epicentral Location		Focal Depth (km)	Body Wave Magnitude M_b
			Latitude (°N)	Longitude (°E)		
1	Jan 18, 1984	20-24-14.29+/-0.21	34°41'6"	73°1'8.4"	33	5.3
2	Feb 11, 1984	08-37-06.63+/-0.14	33°27'18"	71°33'57.6"	33	4.9
3	Feb 18, 1984	07-04-57.67+/-0.28	34°17'6"	72°7'37.2"	33	4.8
4	Jun 04, 1984	05-03-47.83+/-0.19	34°49'37.2"	73°6'0"	33	4.9
5	Feb 17, 1991	07-00-36.54+/-0.52	33°27'36"	72°1'48"	33	4.6
6	Mar 16, 1991	03-57-41.26+/-0.41	34°35'24"	72°39'0"	33	4.5
7	Mar 24, 1992	21-01-47.57+/-0.19	33°49'48"	72°54'0"	14.2	5.0
8	May 20, 1992	12-20-32.85+/-0.12	33°22'48"	71°19'12"	16.3	6.0
9	May 31, 1992	11-12-52.04+/-0.69	33°17'24"	71°32'24"	33	4.6
10	Jun 05, 1992	00-23-43.79+/-0.26	33°14'24"	71°13'48"	33	4.9
11	Feb 17, 1993	15-06-05.44+/-0.20	33°31'37.2"	72°30'28.8"	13.4	5.0
12	Jun 08, 1993	14-30-37.32+/-0.29	33°35'6"	72°44'45.6"	33	4.8
13	Jan 07, 1994	09-25-46.57+/-1.08	34°45'36"	71°12'36"	37.4	4.7

INTERPRETATION

A description of the focal mechanism solutions of all the events considered in the present study are given below:

Event No: 1

The earthquake epicenter is located 2 kms NW of Batgram district (fig.1). The two significant tectonic features present in this area are Thakot Fault and the Indus Kohistan Seismic Zone (IKSZ). The latter is related to decollement tectonics and thrust wedging at the leading edge of the subthrusted Indo-Pakistan plate (Seeber et al, 1981). From fig. 2.1 it can be observed that the focal mechanism solution is of a strike-slip fault. As such the nodal plane NW-SE following the trend of IKSZ which is a

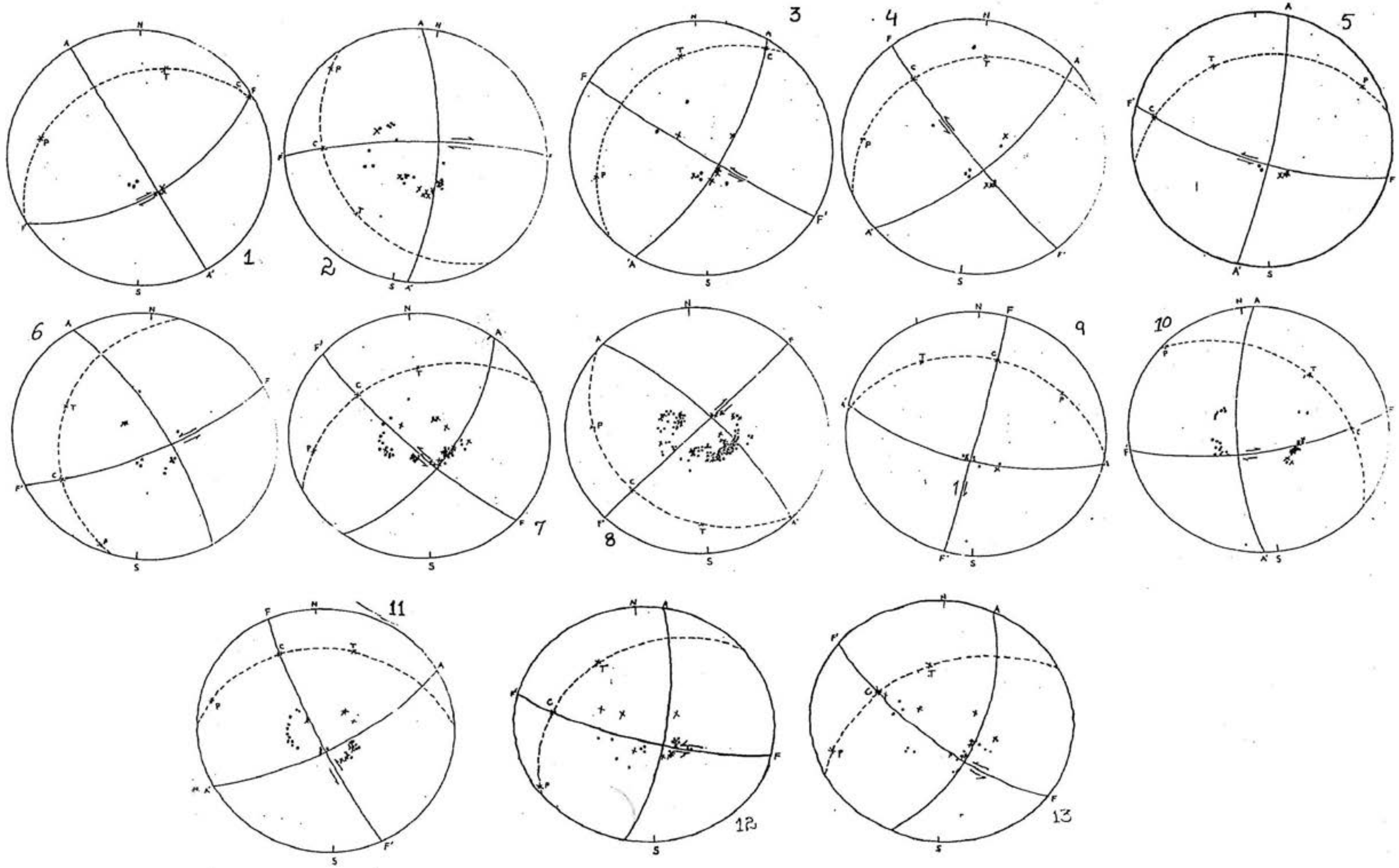

Fig. 2. Focal mechanism solutions of the events (cross denotes compression, dot denotes dilatation, P=Compressional stress, T=Tensional stress, FF'=Fault plane, AA'=Auxiliary plane, C=Slip Vector).

thrust is ignored. The nodal plane trending in the NE-SE direction with a right-lateral sense of slip is believed to be the rupture plane as it corresponds more closely with the Thakot Fault. This solution confirms the active nature of the Thakot Fault.

Event No: 2

The earthquake epicenter is located about 5km west of Shadikhel in Kohat district (fig.1). This is a strike-slip focal mechanism solution. The nodal plane which trends in E-W direction with right-lateral sense of slip has been preferred as the rupture plane (fig.2.2). If the rupture is taken to be an extension of the Kalabagh Fault, then change in strike of the fault at this particular location is suggested. However, from this region and the adjoining Sulaiman fold belt, E-W trending right-lateral strike-slip faults have been recognized (Pivink and Sercombe, 1993; Jadoon and Helmcke, 1996). Their presence has been related to the block rotation at the western end of Indo-Pakistan subcontinent and the above solution fits in a similar scheme of classification.

Event No: 3

This is a strike-slip focal mechanism solution. Location of the epicenter is about 8 km NE of Mardan in Peshawar Basin (fig.1). The two nodal planes in this strike-slip focal mechanism solution trend in the NW-SE and NE-SW directions. As the first one with a left-lateral sense of slip has more steeper dip, it is considered to be the rupture plane. A left-lateral fault occurs to the east of the epicenter (Rafiq et al., 1984). This is a nearly E-W trending fault, whereas in our solution the trend observed is NW-SE. Thus if the rupture is a continuation of the surface fault, then change in strike of fault is suggested. Alternatively, the rupture plane is denoting the presence of some previously unknown fault.

Event No: 4

The epicenter is located in the Mansehra district about 4 km N of Biarai village. Gelogically this area is traversed by the Indus Kohistan Seismic Zone (IKSZ) at depth and the Balakot Shear Zone (BSZ) at the surface (Fig.1). According to Seeber and Armbruster, 1979 and Seeber at al., 1981, the IKSZ is a wedge-shaped structure related to thrusting and decollement tectonics at the leading edge of the subthrusted Indo-Pakistan plate. Baig and Lawrence (1987) consider the BSZ to be a 1/2 to 2 km wide brittle zone in which deformed sedimentary rocks occur and sometimes represent a sedimentary melange. The sense of shear is believed by them to be of left-lateral strike-slip fault.

The focal mechanism solution obtained for this event is of a strike-slip fault (Fig. 2.4) that is, it shows relationship with the BSZ. The nodal plane trending in the NW-SE direction with a left-lateral sense of slip is considered to be the rupture plane due to its similarity to the trend and slip of the BSZ. Based on this solution it is inferred that the seismicity supports the active nature of the BSZ.

Event No: 5

This earthquake occurred in the Attock district about 5 km north of Langar village . In this area, a number of E-W trending thrust faults are known to be present and the epicenter is located most probably in the hanging wall of the Mianwala Fault and immediately south of the Khaire-e-Murat Fault (Fig. 1).

Inspite of the location of this event in a thrusting dominated region, the focal mechanism solution is of a left-lateral strike-slip fault (Fig. 2.5). This inferred rupture plane trends in a nearly "E-W direction. It believed that the dominance of transpression over compression indicated by the focal mechanism solution is due to the ongoing deformation process which are related to the evolution of the Hazara Kashmir Syntaxis.

Event No: 6

Epicenter of this event is located 4 km south of the Sar Village in Buner area of Swat. A large number of small faults have been mapped by Rafiq et al., 1984 from Buner and adjoining areas (see Fig. 1). In addition, a large nearly N-

S trending left-later Darband Fault occurs to the east of the epicenter.

The focal mechanism solution is of a strike-strip fault (Fig. 2.6). From amongst the two nodal planes, the one trending in the NE-SW direction with a left-lateral sense of slip is considered to be the rupture plane. This inference is consistent with the nearby located Darband Fault and other small mapped faults.

Event No: 7

The epicenter of this earthquake is located about 5 km NW of Khanpur in Hazara area. From Islamabad the distance of the epicenter is only 20 km towards the north west along the Nathiagali Thrust (Fig. 1).

A strike-slip focal mechanism solution is obtained for this event (Fig. 2.7). The more steeper nodal plane trending in NW-SE direction is considered to be the rupture plane and has a left-lateral sense of slip.

The presence of strike-slip motion within an overall thrust regime is considered to be indicating a change in the kinematic behavior of NGT at this particular location. Such types of kinematic changes are known to occur in thrusted areas (Treloar et al., 1989).

Event No: 8

The strongest (Mb = 6) of the studied events is located about 1 km SW of Lachi in Kohat district. Structurally, the location is in a thrusted region as well as north of the surface trace of the N-S trending right-lateral Kalabagh Fault (Fig. 1).

A strike slip focal mechanism solution is obtained for this event (Fig. 2.8). The nodal plane with nearly vertical dip, and trending in the NW-SW direction, is considered to be the rupture plane. It has a right lateral sense of slip similar to that of the Kalabagh Fault. This leads to the conclusion that the Kalabagh Fault most likely extends further north than its surface trace. In such a situation, based on the direction of the rupture plane (NE-SW), a change in strike direction of this fault is also suggested at this particular location.

Event No: 9

This event occured about 9 km NW of Shakardarra on the border between Kohat and Karak district of NWFP. In close proximity of the epicenter are situated a nearly E-W trending thrust fault and the N-S trending right-lateral Kalabagh Fault (Fig.1).The two nodal planes trend in the NNW-SSW and ESE-WNW direction of this focal mechanism solution (Fig. 2.9). The second plane is considered to be the rupure plane as it corresponds to the trend of the Kalabagh fault and also indicates a similar sense of slip i.e., right-lateral. Thus the rupture is interpreted to have taken place along the N-S trending right-lateral strike-slip Kalabagh Fault or one of its concealed offshoots.

Event No: 10

This earthquake of magnitude (Mb = 4.9) had its epicenter in the vicinity of Banda Daud Shah in Karak district of NWFP.

From amongst the two nodal planes shown in the focal mechanism solution (Fig. 2.10), the one trending in the E-W direction is considered to be the rupture plane. It depicts a right-lateral strike-slip fault. This observation is in agreement with the contributions of Pivnik and Sercombe (1993) and Jadoon and Helmcke (1996). They have recognized right-lateral strike-slip fault from this area and the adjacent Sulaiman Range. Such faults have been interpreted by these workers to be a result of the oblique collision at the western margin of the Indo-Pakistan plate. As such, the right-lateral strike-slip focal mechanism solution is believed to be of similar origin.

Event No: 11

The epicenter is located 14 kms westward of Fatehjang in Northern Potwar. This is the most shallow of the thirteen studied events with the focus being only about thirteen kms (see Table 1) Geologically, nearly E-W trending thrust sheets characterize the area; the prominent ones being the Main Boundary Thrust (MBT) and the Khair-e-Murat Fault (Fig. 1). Jadoon et al., 1997 (in press) consider it to be an imbricated zone.

A strike-slip focal mechanism solution is obtained for this event. It can be observed from Fig. 2.11 that the two nodal planes trend in ENE-WSW and NNW-SSE directions. The former indicates a right-lateral slip. both right-later and left-lateral shear have been recognized from this region (e.g., Jadoon and Helmcke, 1996; Verma and Chandra Sekhar, 1986; Kazmi, 1979). However at the location of epicenter no strike-slip or thrust fault is known to occur and probably rupture took place along a blind basement fault.

On the basis of the steepness of the nodal plane, the one trending in NWN-SES direction with left-lateral sense of slip is inferred to be the rupture plane. Similar types of the solutions have been obtained by Verma and Chandrasekhar (1986) from this region.

Events No: 12

The epicentre is located about 13 kms cast of Fatehjang in district Attock. the location of this event is situated south of the MBT. this area is considered by Jadoon et al., 1997 (in press) to be an imbricated zone.

This is a strike-slip focal mechanism solution (Fig. 2.12) in which tow nodal planes trend in the NNE-SSW and WNW-ESE directions. The WNW-ESE trending nodal plane has a slightly steeper dip and as this trend is similar to the strike of the known thrusts from this region, it is considered to be the rupture plane. Also the left-later sense of slip of the rupture plane is in agreement with the observations of Rafiq et al.,. 1984. He has shown prevalence of strike-slip displacement along thrusts in his mapped area on the western side of the Hazara Kashmir Syntaxis. Such type of strike-slip displacement is believed to be due to the ongoing collision of the western margins of the Indo-Pakistan plate (e.g. Pivnik and Sercombe, 1993; Jadoon and Helmcke, 1996).

Events No: 13

The location of this event given in the EDR reports of USGS mentions it to be in Pakistan, whereas on plotting the geographic coordinates the location indicated is slightly west of Bajaur Agency in Afghanistan. But as the epicentre is located in the vicinity of MMT, it has been included in this study At this particular epicentral location, MMT trends in nearly E-W direction. thus the nodal plane trending in the WNW-ESE direction is believed to be the rupture plane (Fig. 2.13). This figure also indicates the presence of a left-lateral strike-slip fault in contrast to the thrust behavior of the MMT, Lawrence and Ghouri (1983) have also observed strike-slip motion elsewhere along the MMT and considered it to be a result of the oblique collision taking place at the north-western boundary of the Indo-Pakistan plate. Thus, following these workers the dominance of strike-slip motion in the focal mechanism solution is believed to be due to the present kinematics.

DISCUSSION, SUMMARY AND CONCLUSIONS

Pakistan is considered to be one of the most seismically active regions in the world. Based on the level of seismicity, the country has been divided into different seismotectonic provinces (e.g., Kazmi, 1979; Quittmeyer et al., 1979; Verma and chandra Sekhar, 1986). The area covered in this study forms part of the Hazara thrust region with some portions in the Gardez-Kunar fault region according to Vedrma and chandra Sekhar (1986). If seismotectonic provinces also lies in the study area besides the Hazara region and the Gardez, Kunar and Safed-Koh Fault Zones.

In this active area of thrusting dominated collisional tectonics mostly strike-slip and thrust faulting with few normal faulting solutions have been obtained by previous workers. All the 13 solutions of this study are of strike-slip faulting and the calculated parameters are shown in Table.2. The 8 left-lateral strike-slip solutions are situated on or in close vicinity of known mapped faults/lineaments. In all cases, except one (event no.10) the trend of the inferred rupture planes corresponds to the trends of the known faults. In the case of event no.10, a changes in the trend of the known fault or alternatively presence of another blind fault is inferred.

Out of 5 right-lateral strike-slip solutions one solution (no.1) is similar in trend and sense of motion to the Thakot Fault. The other 4 are concentrated around the Kalabagh Fault but only two (events 8 and 9) are believed to be representing the northward extensions of this fault. The remaining two (events 2 and 10) show E-W trends which are different from the trend of the fault. Such similar trending faults do occur elsewhere in the area and have been related to the block rotation at the western margin of the Indo-Pakistan plate (Pivnik and Sercombe, 1993; Jadoon and Helmcke, 1996).

The P-axis (compressional stresses) and T-axis (tensional stresses) are also determined in this study (Table. 2). Their study provides information about the active character of ongoing deformation in an area.

All events located north of the MBT (event nos. 1,3,4,6,7, & 13) have P-Axis oriented in the NE-SW direction, thereby indicating that this large area is under compression from this direction. On the other hand, P-axes orientation from south of the MBT (Northern Potwar and Kohat plateaus) show both NE-SW and NW-SE (event nos. 2,5,8,9,10,11, & 12) directions. This complex picture of energy accumulation and release is not fully understood, although similar directions were obtained by Verma and ChandraSekhar (1986) from this active continent collision zone. They related the energy release to thrust and strike-slip.

In our case no thrust mechanisms were obtained i.e., all solutions as mentioned previously are strike-slip faults. Most probably, the mixed thrust and strike-slip domain interpreted by Verma and ChandraSekhar (1986) for events recorded during 1965-1978 has given way to a strike-slip region based on events (1984-1995) used in the present study. Thus, the final conclusion that can be drawn based on the predominance of strike-slip focal mechanism solutions is the suggested change in the kinematic from thrusting (due to direct collision) to transpression (due to oblique collision).

TABLE 2. LIST OF PARAMETERS OBTAINED FROM THE FOCAL MECHANISM SOLUTIONS

	Fault Plane		Fault Type	Auxiliary Plane		T-axix		P-axis		C-axis	
	Strike	Dip	Strike-Slip	Strike	Dip	Strike	Plunge	Strike	Plunge	Strike	Plug
1	N58°E	56°ES		N32°W	91°NE	N58°E	1°	N23°E	17°	N81°W	15°
2	N78°E	70°E		S42°W	76°N	N6°W	24°	N54°W	4°	S84°W	20°
3	N56°W	88°SW		N32°E	70°SE	N20°E	17°	N44°E	11°	N60°W	20°
4	N44°W	97°SW		N43°E	69°SE	N19°E	19°	S87°W	10°	N50°E	20°
5	N72°W	70°S		N15°E	80°E	N36°W	22°	N63°E	7°	N72°W	10°
6	N61°E	72°SE		N35°W	72°NE	N73°W	25°	S17°W	3°	N34°W	17°
7	N43°W	78°SW		N40°E	60°ES	N30°E	30°	S85°W	11°	N48°E	13°
8	N48°E	89°NW		N42°W	72°NE	S6°W	15°	N86°W	13°	N52°W	20°
9	N79°W	64°S		N13°E	89°E	N40°W	19°	N62°E	17°	N29°E	26°
10	N88°E	70°S		N5°E	70W	N53°E	29°	N42°W	1°	E5°S	20°
11	N22°W	80°SW		N63°E	70°ES	N30°E	22°	N71°W	7°	N67°E	10°
12	N71°W	74S°W		N13°E	70°ES	N38°W	26°	S60°W	2°	N78°W	20°
13	N54°W	70S°W		N22°E	56°ES	N541°W	40	S71°W	8	N41E	20

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