Focal mechanism studies of Kohat and northern Potwar deformed zone (NPDZ), Pakistan

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ABSTRACT: *Kohat Plateau and Northern Potwar Deformed Zone (NPDZ) are the parts of the foreland zone of NW Himalayan Fold-and-Thrust belt, which is seismically very active. Using the earthquake data of international as well local networks, seismicity maps of the area have been prepared. Focal mechanism solutions of nine events, for the period of 1970-1996 have been carried out. The dominance of strike slip faulting over the thrust faulting (i.e. 7 are left lateral strike slips while two are thrusts) supports the conclusion of previous workers that this area of convergence is undergoing a kinematic change. P-axes i.e. the axes of maximum compresses stress orientations are both in NW-SE and NE-SW directions indicating a complex pattern of deformation. Indications are that basement is most likely involved in the deformation.*

INTRODUCTION

Northern Pakistan is one of the seismically active regions of the world. Numerous studies have been undertaken to highlight and understand the ongoing collisional process of the Indo-Pakistan plate with the Kohistan Island Arc. Besides the N-S compression, as a result of this convergence, transpressional features have also been recognized. However, in the study area presence of evaporites (Eocambrian) has led to the development of duplex type models with the basal decollement in the evaporites above the Precambrian basement.

Indications are that deeper levels than the Eocambrian evaporites are also undergoing deformation. Thus, in the present study the nature of fault motions prevailing at depth within the tectonic subdivisions referred to as the Northern Potwar Deformed Zone (NPDZ) and Kohat Plateau are described. Such type of information, it is hoped would lead to incorporation of seismicity data in future models.

GENERAL GEOLOGY & TECTONICS OF THE AREA

The area comprising of the Kohat plateau and the northern portion of the Potwar plateau is bounded by Latitudes $33^0 - 33^0 37'$N and Longitudes $70^0 15' - 73^0 17'$ E (Fig.1). Besides the capital city of Islamabad, many other densely populated towns/ cities and industrial sites are located in the study area.

Geologically it forms part of the Himalayan zone of convergence in which deformation has shifted southwards through time. In the Salt Range, deformation as young as 0.4 Ma has been documented (Yeats and Lawrence, 1984). Kohat and Potwar plateaus along with the Salt Range represent a zone of foreland deformation south of the Main Boundary Thrust (Fig. 1).

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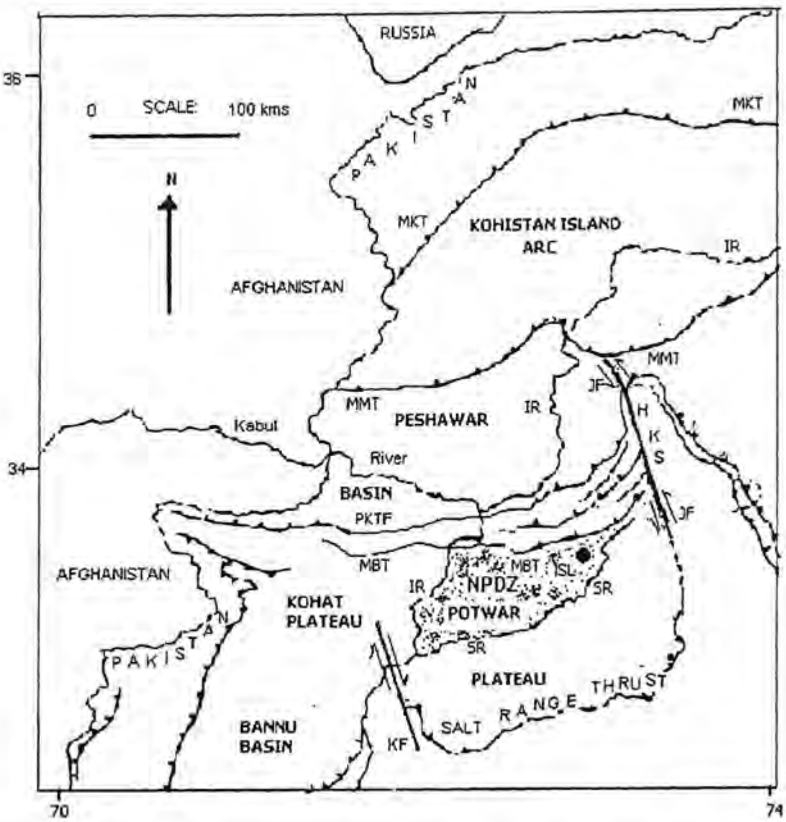

Fig. 1. Regional map showing the major tectonic divisions of northern Pakistan (After Kazmi and Rana, 1982). **MKT**= Main Karakoram Thrust. **MMT**= Main Mantle Thrust. **MBT**= Main Boundary thrust. **HKS**= Hazara Kashmir Syntaxis. **NPDZ**= Northern Potwar Deformed Zone (Study Area). **ISL**= Islamabad. **IR**= Indus River. **PKTF**= Panjal - Khairabad Thrust Fault. **KF**= Kalabagh Fault. **SR**= Soan River. **JF**= Jhelum Fault.

In this zone of convergence, intense deformation has resulted in the formation of complex structures. The northern part of Potwar plateau, also referred to as the Northern Potwar Deformed Zone (NPDZ) lies between the Main Boundary Thrust and the Soan syncline (Fig. 2). It is more intensely deformed than the southern Potwar and the Salt Range. Mostly E-W trending tight and complex folds with the southern limbs overturned occur. Besides, the area contains a series of thrusts. General trend of these thrusts changes from E-W to northeast direction in the eastern part of the NPDZ. According to Lillie et al., 1987 the northern Potwar represents an imbricate stack of thrust faults with some present on the surface and the others occurring at depths as blind thrusts. Some of the thrusts are shown in Fig. 2. Soan Syncline, Soan (Dhurnal) back thrust and the Khair-i-Murat Imbricate Zone are considered to have played an important role in development of the present tectonic style (for details see Lillie et al., 1987; Jadoon et al., 1995; Jaswal et al., 1997).

According to Pennock et al. (1989), the basement along the Soan Syncline is at a depth of about 6 km. It increases towards the north and near the MBT is about 8 km (Jaswal et al., 1997). The NPDZ

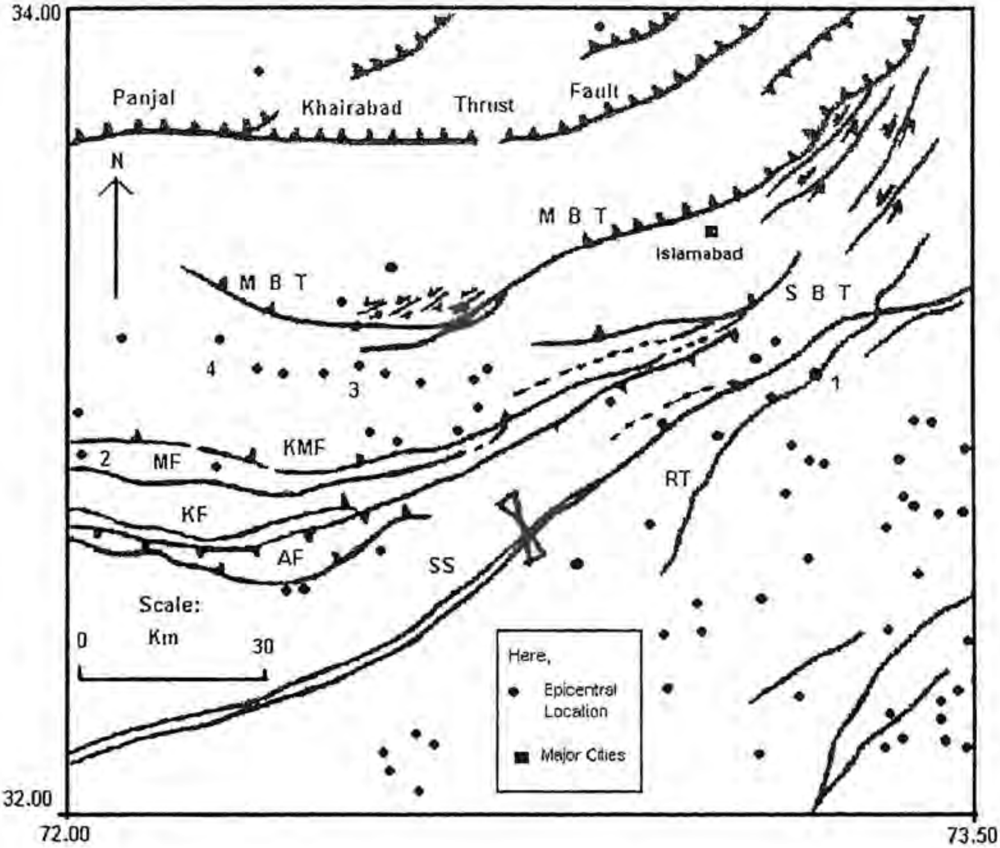

Fig. 2. Seismicity and structural map of NPDZ (compiled from many sources). The locations of events whose focal mechanism solutions have been determined are numbered 1-4. Here **MBT**= Main Boundary Thrust. **KMF**= Khair-i-Murat Fault. **MF**= Mianwala Fault. **KF**= Kanet Fault. **AF**= Ahmdal Fault. **SS**= Soan Syncline. **SBT**= Soan Backthrust. **RT**= Riwat Thrust.

is considered to be a thin-skinned tectonic feature by most workers in which the basal decollement is in the Eocambrian Salt Range Formation. In this interpretation the Dhurnal Fault is a passive back thrust and the area bounded by it and the Khair-i-Murat Fault (Fig. 2). A triangle zone of complex geology (e.g. Jadoon et al., 1999).

Similarly the Kohat plateau is intensely deformed. According to Coward et al., 1987 it is an imbricated area. Tight, overturned folds and many thrust sheets occur in the northern portion where as in the southern part, north and south dipping reverse faults are common. Structures like Mir Khewli Sar Thrust Belt, Main Boundary Thrust (MBT), Karak – Hukni Fault, Surghar Range Thrust and Kahi Fault characterize the area (Fig. 3). These and other important structures are described in Pivnik and Sercombe (1993), Kazmi and Jan (1997) and Sercombe et al. (1998).

Various workers like Abbasi and McElroy (1991) and McDougall and Khan (1990) prepared balanced cross-sections of the area whereas McDougall and Khan (1990) described the structure of the Kohat Plateau as a sequence of the fault –

propagating and fault – bend folds. Overall the geometry is in the form of the duplex structures with two detachment levels. Top detachment is within the Eocene salt and shale sequence, and lower detachment is in the Salt Range Formation of Eocambrian age. According to McDougall and Khan (1990), another detachment level occurs on top of the Eocene rocks.

The models invoking duplex structure have recently been questioned (Pivnik and Sercombe, 1993; Sercombe et al., 1998). These workers recognize the presence of strike-slip faults at the surface and even in the basement. They relate the structures (high angle strike-slip faults and associated flower structures) to transpressional deformation.

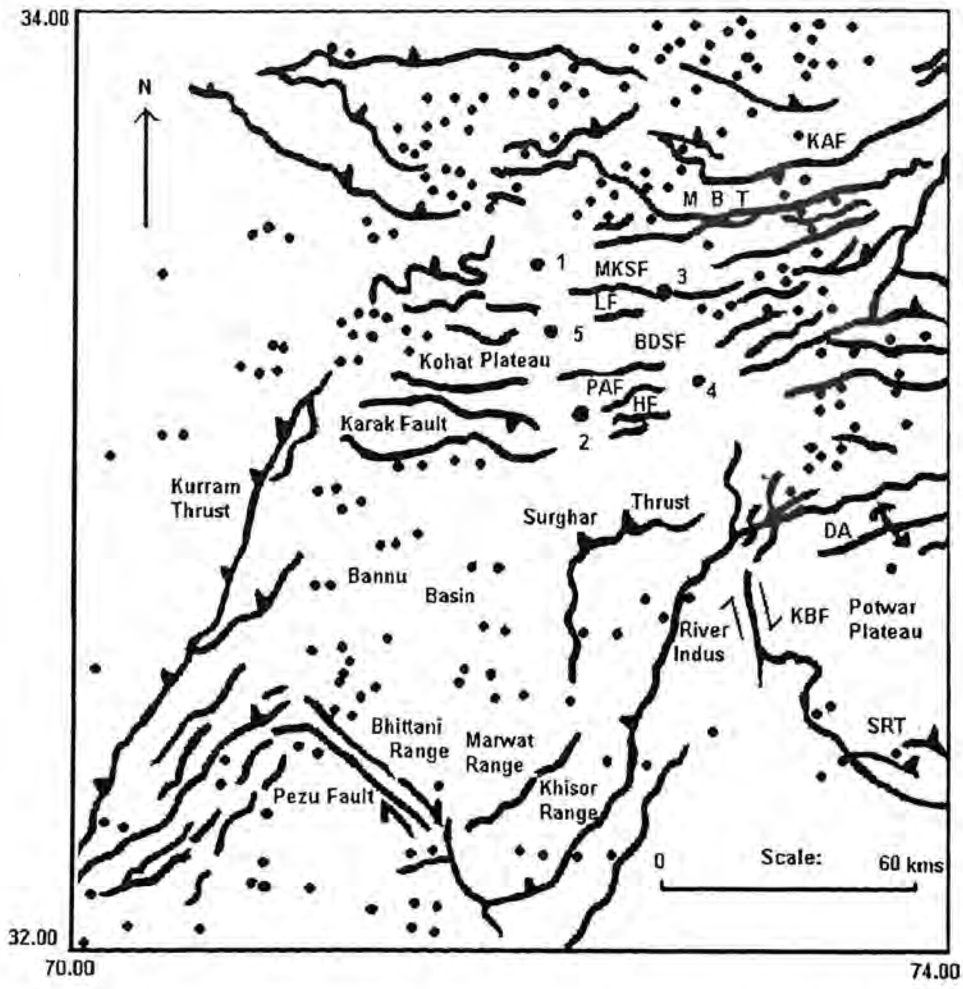

Fig. 3 Seismicity and structural map of the Kohat Plateau (compiled from many sources). The locations of events whose focal mechanism solutions have been determined are numbered 1-5. Here **KAF**= Khairabad Fault. **MKSF**= Mir Khewli Sar Fault. **LF**= Lachi Fault. **BDSF**= Banda Daud Shah Fault. **PAF**= Pathan Algad Fault. **HF**= Hukni Fault. **DA**= Dhermund Anticline. **KBF**= Kalabagh Fault. **SRT**= Salt Range Thrust.

SEISMICITY

Pakistan is considered to be a seismically active region. However, Kohat Plateau and Northern Potwar Deformed Zone (NPDZ) are comparatively less active. Epicentral distribution of events with magnitude > 4 that occurred during the period 1970 to 1996 are shown in Fig. 2 and 3. Sources of this data are United States Geological Survey (USGS), International Seismological Centre (ISC), International Seismological Summary (ISS) and local seismic networks. As focal depths reported are generally not reliable depth data has been obtained from the local Nilore (Rawalpindi) Observatory. Also included are historical earthquakes from Oldham (1893) and Quittmeyer and Jacob (1979). No distinct pattern is observed and the seismicity is scattered (Fig. 2 & 3).

FOCAL MECHANISM STUDIES

Procedure employed

In this study, nine focal mechanism solutions of earthquake events (Mb > 4) that occurred in the North Potwar Deformed Zone (NPDZ) and Kohat Plateau during the period of 1970 to 1996 have been carried out. The standard lower half hemisphere projections on an equal area net have been used. Visual interpretation of these focal mechanism diagrams generated with the help of a computer program (PMAN) that required input of geographic coordinates, magnitude, focal depth and P wave polarity were carried out for each event. The other two parameters azimuthal angle and take-off angle are determined by the software. The focal mechanism solutions of 4 events for Northern Potwar Deformed Zone (NPDZ) and 5 events for Kohat Plateau are discussed below.

Northern Potwar Deformed Zone (NPDZ)

Focal mechanism solutions undertaken by earlier workers (e.g. Verma et al., 1980; Verma and Chandra Sekhar, 1986) from immediately adjacent regions have shown the dominance of strike-slip faulting with some thrust faulting in this area of collisional tectonics. In the present case, four solutions have been undertaken (Fig. 2). One of these (event No. 1) had previously been analyzed by Verma and Chandra Sekhar (1986) and Seeber and Armbruster (1979) also.

Event No. 1. Commonly referred to as the Rawalpindi earthquake occurred at a shallow depth of 14.5 km. FMS obtained is of strike-slip faulting with a left-lateral sense of motion (Fig. 4). Seeber and Armbruster (1979) and Verma and Chandra Sekhar (1986) had earlier obtained similar solutions for this event. The relevant solution parameters are shown in Tables 1 and 2.

According to Seeber and Armbruster (1979), based on hypocentral distribution of aftershocks, the rupture plane had strike of N60^0 E and dip of 45^0 in the southeast direction. They discounted its relationship with the surface trace of the Hazara Fault (Main Boundary Thrust) and proposed the existence of a decoupling layer at a depth of about 10 kms along which the strike-slip movement occurred.

Our observation shows that the epicenter is located close to the surface trace of the Riwat Thrust in an area where another E-W trending thrust intersects it (Fig. 2). Also shown in the figure to the north of the epicenter are left-lateral strike slip faults that were plotted from Sercombe et al., (1998). According to Jadoon and Frisch (1997) the Riwat thrust dies out at a depth of 4 km, where it merges into a hinterland vergent blind thrust. This blind thrust propagates up section from the Eocambrian evaporites that cover the basement at depth of about 6 km. Earlier Johnson et al., 1986 had interpreted the Riwat Thrust as an emergent thrust propagating up section from the basement.

Sercombe et al., 1998 have pointed out the fact that focal mechanism solutions (mostly strike-slip) have so far not been integrated in the models proposed by different workers. The basement related

TABLE-1

Northern Potwar Deformed Zone (NPDZ)

Event Nos.	Date Y-M-D	Time H-M-S	Epicentral Location Latitude(N°)	Longitude (°E)	Depth (Kms)	Moment Magnitude (Mw)
1.	19770214	00 22 37	33.60	73.27	14.46	5.5
2.	19910217	07 00 35	33.45	72.2	41	4.8
3.	19930217	15 06 05	33.55	72.5	13.4	5.4
4.	19930608	14 30 37	33.58	72.26	33	5.1
KOHAT PLATEAU						
1.	19900821	18:27:03.37	33.58	71.21	10.0	4.7
2.	19920520	12:20:36.18	33.25	71.30	10.0	6.8
3.	19920531	11:12:52.00	33.30	71.33	10.0	5.4
4.	19920605	00:23:19.95	33.27	71.34	0.6	6.1
5.	19920609	09:14:24.60	33.30	71.28	0.4	5.4

Source parameters of the events whose Focal Mechanism Solutions have been determined.

TABLE-2

NORTHERN POTWAR DEFORMED ZONE (NPDZ)

Event Nos.	STRIKE1	DIP1	STRIKE2	DIP2	P-AXIS		T-AXIS		Fault Type
					Plunge	Azimuth	Plunge	Azimuth	
1.	285	74	27	53	14	-20	38	239	L.L.S.S
2.	51	20	229	70	25	320	65	138	Thrust
3.	50	83	319	56	22	179	25	280	L.L.S.S
4.	81	72	334	46	16	-158	45	308	L.L.S.S
KOHAT PLATEAU									
Event Nos.	STRIKE1	DIP1	STRIKE2	DIP2	P-AXIS		T-AXIS		Fault Type
					Plunge	Azimuth	Plunge	Azimuth	
1.	61	46	324	83	272	36	21	24	L.L.S.S
2.	88	68	333	43	-155	15	314	51	Thrust
3.	41	57	140	77	267	13	5	33	L.L.S.S
4.	232	87	141	79	97	10	6	6	L.L.S.S
5.	91	87	358	40	327	35	-147	30	L.L.S.S

List of the parameters obtained from focal mechanism studies.

L.L.S.S= Left Lateral Strike Slip

NORTHERN POTWAR DEFORMED ZONE (NPDZ)

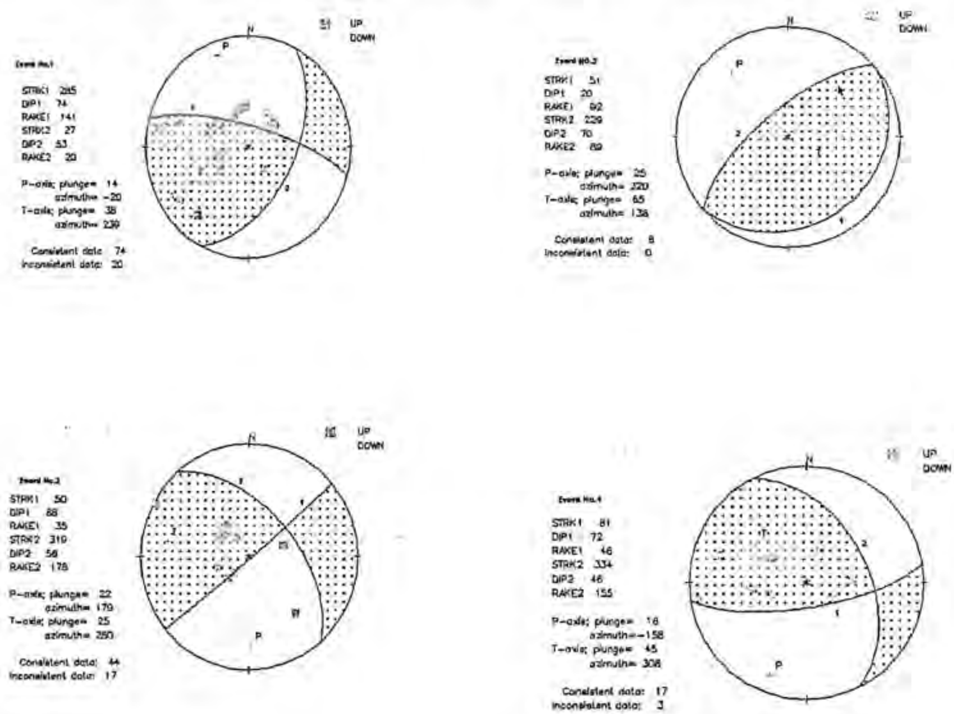

Fig. 4. Focal Mechanism Solutions obtained from NPDZ using the P wave polarities in lower hemisphere projections.

strike slip solution of this event indicates that at least in this area of the foreland, compressional tectonics is not the only factor prevailing. Study of more events may perhaps be able to unravel the complexity.

Event No. 2 is located between the Khair-i-Murat and the Mianwala Faults (Fig. 2). The area between the northward dipping Khair-i-Murat Thrust and the southward dipping Dhurnal Fault (back thrust) is interpreted to be a triangle zone underlain by evaporites that acts as a decollement (e.g. Jadoon et al., 1999). They interpret the basement to be lying at a depth of 6 to 7 km. At this depth, they infer the presence of a basement normal fault with hanging wall down to the north displacement and a throw of about 600m. Alternatively they consider it to be a basement warp.

FMS obtained for this event is of thrusting (Fig. 4). Thrusting could be either in the NW or SE direction. As most of the surface thrusts mapped in the area dip towards the north, the plane with strike of N 51°E and dip of 20° NW is considered to be the thrust plane. Hypocenter of this event is at a depth of 14 km. It is believed that the basement warp mentioned by Jadoon et al, 1999 probably extends to this depth.

Event No. 3 is located about 14 km west of Fatehjang in an area lying between the Khair-i-Murat Fault and the MBT (Fig. 2). Jaswal et al., 1997 in their map show the presence of an E-W trending syncline (Seri Syncline) with no surface trace of a fault and the epicenter is located along the axis of the syncline.

A left-lateral strike slip solution is obtained for this event. The nodal plane with strike of N50°E is considered to be the fault plane (Fig. 4). The near vertical dip indicates that it is a wrench fault. Focus is at a depth of 14 km thereby indicating involvement of the basement. According to Pivnik and Sercombe (1993), the Potwar Plateau is a hybrid terrain consisting of thrust faults and a series of short lateral-displacement, high vertical displacement pressure ridges associated with offsets in the basement. Thus, the inferred strike-slip fault may be a part of one such pressure ridge.

Event No. 4 is located in the same area as the previous one, but further west of it (Fig. 2). The focal mechanism solution obtained is of strike-slip faulting. The nodal plane trending in the E-W direction and with steeper dip (Fig. 4) is considered to be the rupture plane.

Like the event No. 3, this left-lateral strike slip solution may be a part of the same or different pressure ridge that may be present in the area. Depth control is not reliable for this event. However keeping in mind the basement offsets proposed by Pivnik and Sercombe (1993) and inferred in the other two solutions, it seems likely that it too represents basement deformation.

Kohat Plateau

A total of five events have been selected for the determination of focal mechanism studies for the period of (1970 – 1996) in the area of Kohat Plateau in NW Himalayan Fold – and – Thrust Belt, Pakistan. Brief discussion of each event is given below.

Event No. 1 is located nearly 12 km ENE of Hangu. Hypocentral depth is 10 km. Structurally, the event is located north of Mir Khweli Sar Thrust Belt on the northern limb of the E-W trending Tanda lake syncline. Immediately north (about 3 km) of the epicenter, Ahmad et al. (2001) have shown the presence of a backthrust (Sher Kot Fault). No surface exposure of rocks exists at the epicentral location, but immediately north to it are rocks representing the Murree Formation that have steep dips and is overturned.

Focal mechanism solution is shown in Fig. 5. Considering the steepness of the nodal planes, the one trending in the NW-SE direction may be the rupture plane. This implies that it is a steeply dipping (83°) left-lateral fault. This would be in agreement with the work of Pivnik and Sercombe (1993) who have shown steeply dipping (near vertical) blind fault in their cross section of the area. Alternatively if the Sher Kot Fault was extended to the site as a blind fault, the solution obtained should have at least been a thrust fault with a strike-slip component, which is not the case.

Event No. 2 of magnitude 6.8 Mw is the strongest of nine events to be studied in this study. Its epicenter is located about 1 km SW of Lachi in the Kohat district. Structurally E-W trending folds characterize the area. The epicenter is located at the eastward termination of one such syncline shown in the published maps of Pivnik and Sercombe (1993) and Ahmad et al. (2001). According to the above named authors a number of thrust faults is also present in the immediate surroundings of the area.

Rocks of Chinji Formation represent the surface lithology. If a thrust fault shown to be present in the maps is extended eastwards, it would pass through the epicentral location. However, there is confusion regarding its name. According to Pivnik and Sercombe (1993) the fault is named the Pathan Algad Fault where as Ahmad et al. (2001) refer to it as the Braghdi Algad Fault which the former have shown to be another fault located NE of the Pathan Algad.

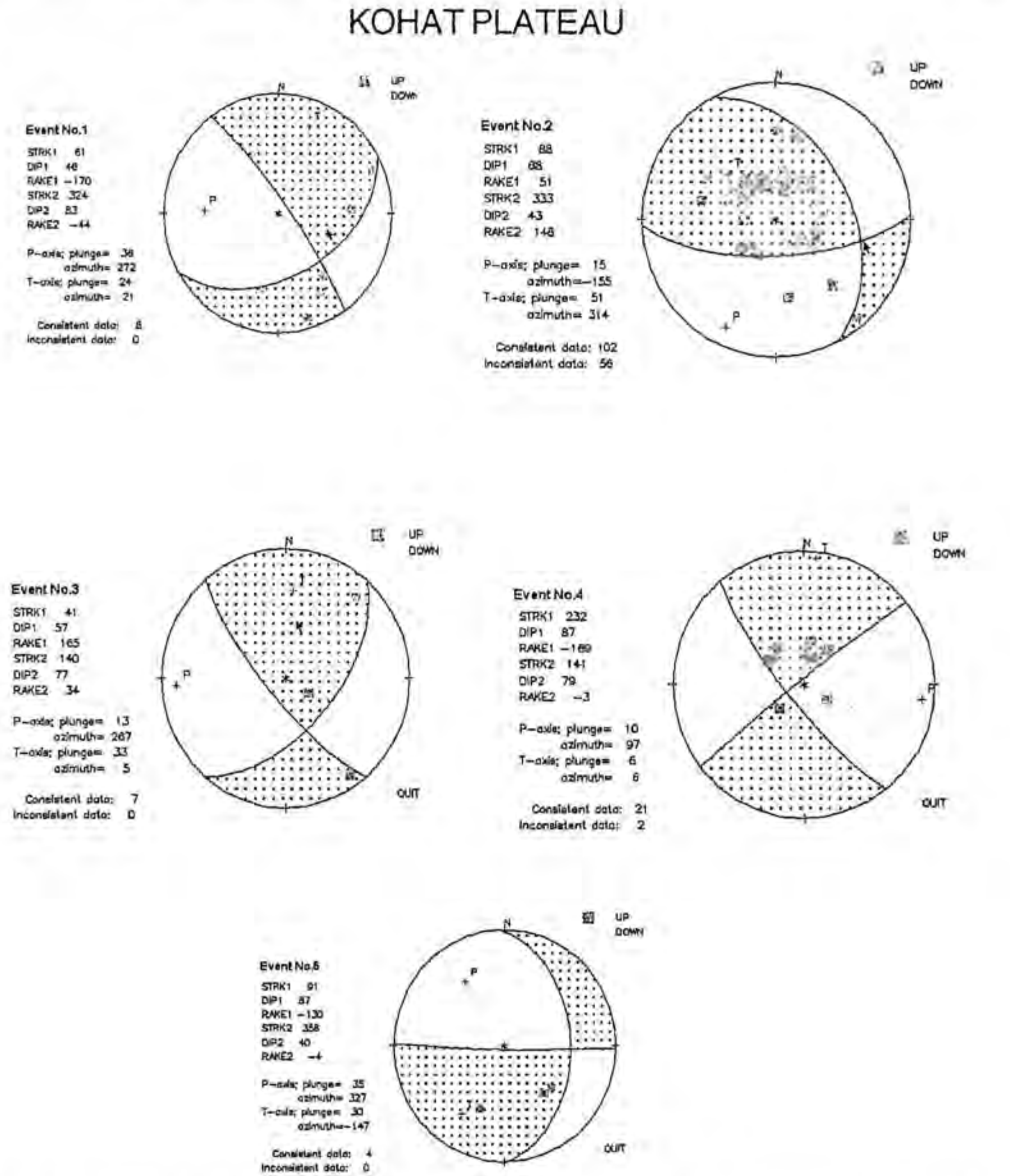

Fig. 5. Focal Mechanism Solutions obtained from Kohat Plateau using the P wave polarities in lower hemisphere projections.

In any case the solution obtained for the event shows a thrust fault with a strike- slip com-ponent (Fig. 5). If it is assumed that the thrust fault men-tioned above extend eastwards into the Chinji For-mation, then the nodal plane (E-W) conforming to the trend of this fault can be considered to be the thrust plane and strike-slip component indicates a left-lateral sense of motion. This solu-tion again is in agreement with observations of Pivnik and Sercombe (1993) and Sercombe et al. (1998).

Event No. 3 is about 7 km NW of Shakardarra on the border between Kohat and Karak districts of

NWFP. An E- W trending anticline is shown to be present here in the maps of Pivnik and Sercombe (1993) and Ahmad et al. (2001). The epicenter is located on the steeply dipping southern limb (60°) of this anticline. Contact of Kohat Formation with the alluvium is shown in the map of Ahmad et al. (2001).

Inspite of the location of this event in a thrusting dominated region, the focal mechanism solution is of left-lateral strike – slip fault (Fig. 5). The inferred rupture plane trends in NW-SE direction. 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.

Event No. 4 has its epicenter about 6 km SE of Banda Daud Shah in Karak district of NWFP. It is situated about 2.5 kms NE of the event no. 2. Structurally the area is characterized by E-W trending folds. The epicenter is located at the eastward termination of one such anticline shown in the published maps of Pivnik and Sercombe (1993) and Ahmad et al. (2001).

In any case the solution obtained for the event shows a strike-slip fault and the NE-SW trending nodal plane with the left-lateral sense of motion is taken as the rupture plane (Fig. 5) following the previous works of Pivnik and Sercombe (1993) and Sercombe et al. (1998).

Event No. 5 is nearly 6 km west of Lachi. It is situated about 1 km in the west of the event no. 3 and like event no. 3 it too has a left-lateral strike – slip solution. Nearly E-W trending nodal plane is taken as the rupture plane (Fig. 5), which is in close agreement with the E-W trending structures in the area. However a left-lateral strike – slip solution indicates that the same blind fault has been activated which caused the occurrence of earthquake of 31 May 1992 (i.e. event no. 3). Thus most probably the rupture is extended from the location of event no. 3 to the place of this event.

SUMMARY AND CONCLUSIONS

As mentioned earlier focal mechanism solutions undertaken by earlier workers (e.g. Verma et al., 1980; Verma and Chandra Sekhar, 1986) from Kohat/Potwar Plateau have shown the dominance of strike-slip faulting with some thrust faulting in this area of collisional tectonics. P and T axes orientations are shown in Table 2. A mixed P axes trend of NW and NE orientation is obtained. Earlier workers had also shown a similar mixed trend and relate it to be a result of oblique convergence.

In the area of Kohat Plateau, Pivnik and Sercombe (1993) and Sercombe et al. (1998) have shown that duplex structures interpreted by some workers are not present. Instead, wrench faulting and flower structures occur. According to Pivnik and Sercombe (1993) the first episode of deformation included south verging, compression related thrusting followed by transpression related wrench faulting. Ali et al. (2000) also documented the transpressional deformation in the Kohat plateau. The strike-slip faults inferred in the present study are believed to be a result of such overprinting of transpressional features. Thus the thin-skinned tectonic models proposed by different workers for Potwar may not be valid without considering the deformation that is affecting the basement in the area. Further work is needed to confirm the presence of a decoupling layer in the basement.

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REFERENCES

Abbasi, I. A. and McElroy, R., 1991. Thrust kinematics of the Kohat Plateau, Trans Indus Salt Range, and Pakistan. J. Struc. Geol., 13, 319-327.

Ahmad, S., Ali A., Ahmad, A. & Hamidullah, S., 2001. Geological Map of Kohat Plateau, North - West Himalayas, NWFP, Pakistan. Geol. Bull. Univ. Peshawar., 34 (in pocket).

Ali, F., Ahmad, S., Ahmad, I. and Hamidullah S. 2000. Imprints of transpressional deformation on the Southern Kohat Plateau, Karak area, NW Himalayas, NWFP, Pakistan. Geol. Bull. Univ. Peshawar., 33. 87-95.

Coward, M.P., Butler, R.W.H., Khan, M.A. and Knipe, R. J., 1987. The tectonic history of Kohistan and its implication for Himalayan structure, J. Geol. Soc. Lond., 144, 381.

Jadoon, I.A.K., Khawaja, A.A., and Jamshed, S.Q., 1995. Thrust Geometries and Evolution of the Eastern North Potwar Deformed Zone, Pakistan. Geol. Bull. Univ. Peshawar., 28, 79-96.

Jadoon, I.A.K and Frisch, W., 1997. Hinterland – Vergent Tectonic Wedge Below the Riwat Thrust, Himalayan Foreland, Pakistan: Implications for Hydrocarbon Exploration. AAPG Bulletin., 81, 438-448.

Jadoon, I.A.K., Frisch, W., Jaswal, T. M., and Kemal, A., 1999. Triangle Zone in the Himalayan foreland, north Pakistan. In. Macfarelane, A., Sorkhabi. R.B., and Quade, J., (eds.). Himalayas and Tibet: Mountain Roots to Mountain Traps: Boulder, Colorado, Geological Society of America. Special paper 328.

Jaswal, T. M., Lillie, R.J. and Lawrence, R.D., 1997. Structure and Evolution of the Northern Potwar Deformed Zone, Pakistan. AAPG Bulletin., 81,2,308-328.

Johnson, G.D., Raynolds, R. G., Burbank, D.W., 1986. Late Cenozoic Tectonic and Sedimentation in the Northwestern Himalayan Foredeep: I. Thrust Ramping and Associated Deformation in the Potwar Region, In P. Allen and P. Homewood, (eds.). Foreland Basins: International Association of Sedimentologists Spec. Publ., 273-291.

Kazmi, A. H., and Jan. M. Q., 1997. Geology and Tectonics of Pakistan. Graphic Publishers Karachi – Pakistan.1-554.

Lillie, R.J., Johnson, G.D., Yousuf, M., Zaman, A.S.H., Yeats, R.S., 1987. Structural Development within the Himalayan Foreland Fold – and Thrust Belt of Pakistan. In. C. Beaumont and A.J. Tankard (eds.) Sedimentary Bsins and Basin- Forming Mechanisms: Canadian Society of Petroleum Geol. Mem., 12, 379-392.

McDougall, J. W. and Khan, S.H., 1990. Strike -slip faulting in a foreland fold-and- thrust belt: the Kalabagh and western Salt Range, Pakistan. Tectonics., 9, 1061-1075.

Oldham, T. 1882. A Catalogue of Indian Earthquakes from the Earliest Time to A.D. 1869. Mem. Geol. Sur. India. 19. part. 3.

Pennock, E.S., Lillie, R.J., Zaman, A.S., and Yousuf, M., 1989. Structural Interpretation of Seismic Reflection Data from Eastern Salt Range and Potwar Plateau, Pakistan. AAPG Bulletin., 73, 841-857.

Pivnik, D.A. and Sercombe, W.T., 1993. Compression and Transpression – related Deformation in the Kohat Plateau, NW Pakistan. In: Treloar, P.T. and Searle, M.P. (eds.), Himalayan Tectonics. Geol. Soc. Spec. Publ., 74, 559-580.

Quittmeyer, R. L., Farah, A. and Jacob, K .H., 1979. The Seismicity of Pakistan and its relation to surface faults. In Farah, A. and DeJong, K. A. (eds.), Geodynamics of Pakistan. Geol. Sur. Pak., Quetta., 271 – 284

Seeber, L. and Armbruster, J. 1979. Seismicity of Hazara Arc in Northern Pakistan: Decollement vs. Basement Faulting. In: Farah, A. and Dejong, K.A. (eds.), Geodynamics of Pakistan. Geol. Surv. Pak. 131-142.

Sercombe, W.J., Pivnik, D.A., Wilson, W.P., Albertin, M.L., Beck, R.A., & Stratton, M.A., 1998. Wrench Faulting in the northern Pakistan foreland. AAPG Bulletin., 82, 11, 2003 –2030.

Verma, R. K. and Chandra Sekhar, Ch., 1986. Focal Mechanism Solutions and Nature of Plate movements in Pakistan. Jour. Geodyn., 5, 331 – 351.

Verma, R. k., Mukhopadhyay, M. and Bhanja, A. K., 1980. Seismotectonics of the Hindukush and Baluchistan Arc. Tectonophysics., 66, 301 – 322.

Yeats, R.S. and Lawrence, R.D. (1984). Tectonics of the Himalayan thrust belt in northern Pakistan. In Haq, B. and Milliman, J.D. (eds.), Marine Geology and Oceanography of Arabian Sea and Coastal Pakistan. Van Nostrand Reinhold Co., New York, 177-200.