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Seismic Activity along the Main Boundary Thrust (MBT), Pakistan

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ABSTRACT: *Main Boundary Thrust (MBT) is the main frontal thrust of the Himalayan range, which runs about 1500 km from Assam in the east to Kashmir in the west. The MBT fault zone represents very high earthquake potential in this region, as it is the source of many earthquakes, which are amongst the greatest ever-recorded events. These include 1905 Kangra earthquake of M 8.6, 1934 Bihar-Nepal earthquake of M 8.4 and the great Assam earthquakes of 1897 and 1950. The rupture, which caused these earthquakes, is occurred in the detachment in the vicinity of the surface trace of MBT.*

Keeping the above fact in view, a seismicity map of the area within the 100 km of the MBT have been prepared using the seismological data from various sources for the period of 1904-2004. On the basis of the spatial distribution of the epicenters, the MBT is considered to be active. Focal mechanism studies (FMS) of three events for the period of 1989-1993 within the MBT forming the western portion of Hazara Kashmir Syntaxis (near Islamabad) have been carried out. Two of them are left lateral strike slip, whereas one is thrust with minor left lateral strike slip component. Dominance of strike slip over thrusting/reverse has been observed with the clear indication of the left lateral splays activation of MBT. However more data is required to confirm this interpretation.

INTRODUCTION

The ongoing collision of the Indo-Pak plate with the Eurasian plate makes the northern parts of Pakistan seismically very active. Several workers on the basis of geology, seismicity and focal mechanism solutions indicate this large-scale movement along the western boundary between the Indo-Pakistan and Eurasian Plates. The area between the MMT and SRT with its westward extensions (Surghar, Marwat, Bhittani and Manzai ranges) is referred to as the NW Himalayan Fold and Thrust Belt (Kazmi & Jan, 1997). According to Gee (1980) and later workers, the southern sides of these ranges are also marked by thrusts. The tectonic domains of Hazara-Kashmir Syntaxis and the Nanga Parbat Haramosh Massif comprise its eastern boundary. The western limit is not clearly defined. Besides the Kurram Fault in the southwestern portion, series of thrusts beyond the borders of Pakistan (like the Sarobi Fault in Afghanistan) are considered to be delineating this boundary.

In this nearly 250 km wide and 560 km long fold and thrust belt, the Panjal-Khairabad fault (Fig.1) divides it into a northern hinterland zone and the southern foreland zone. Main Boundary Thrust (MBT) is the main frontal thrust of the Himalayan range, which runs about 1500 km from Assam in the east to Kashmir in the west in the foreland zone. The MBT fault zone represents very high earthquake potential in this region, as it is the source of many earthquakes, which are amongst the greatest ever-recorded events. These include 1905 Kangra earthquake of M 8.6, 1934 Bihar-Nepal earthquake of M 8.4 and the great Assam earthquakes of 1897 and 1950. The rupture, which caused these earthquakes, is occurred in the detachment in the vicinity of the surface trace of MBT.

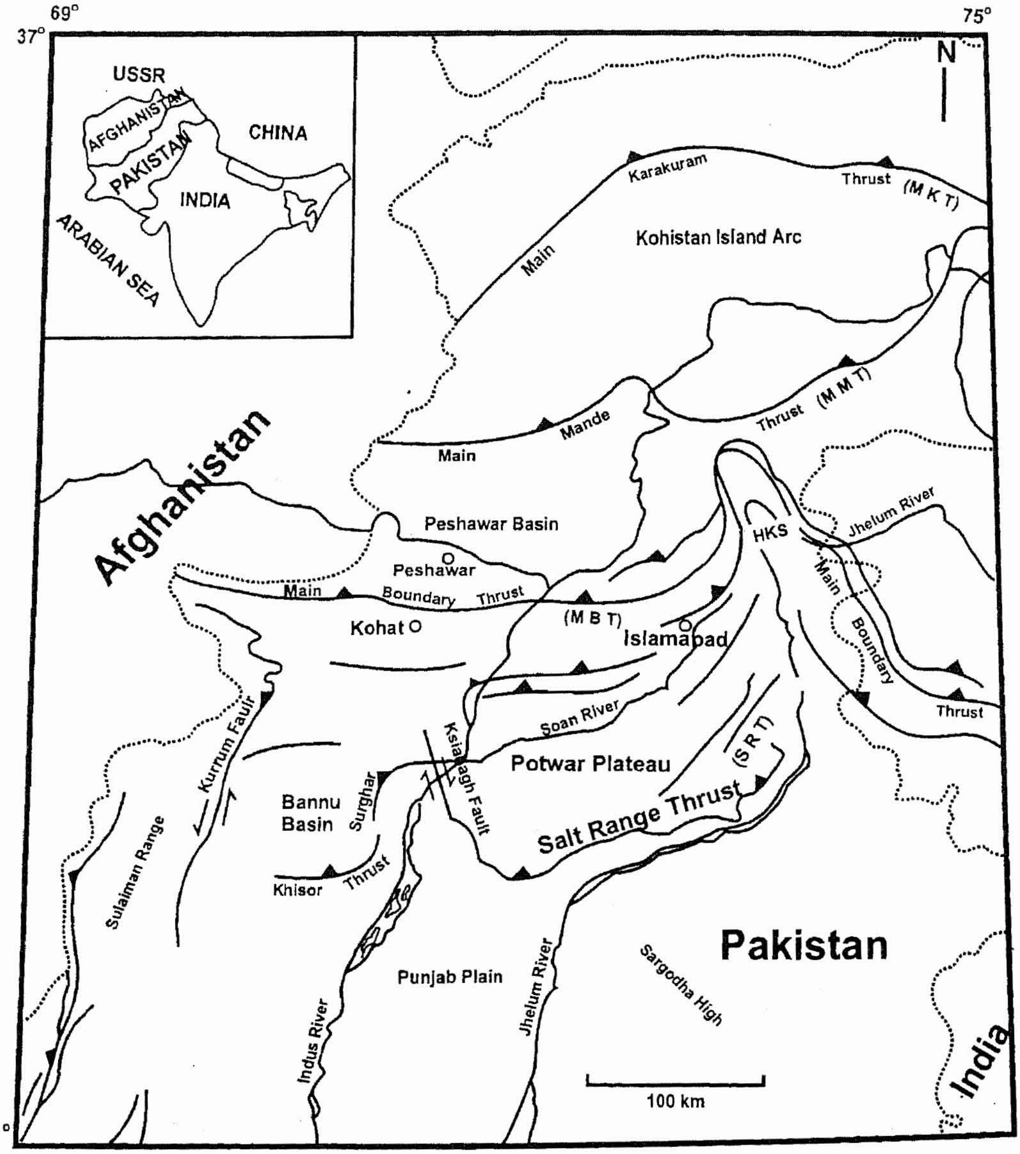

Fig. 1. Tectonic map of the study area (after Kazmi & Rana, 1982).

Keeping the above facts in view, an attempt has been made to discuss some seismological aspects of MBT using the seismicity data and focal mechanism solutions. In the sections to follow the geological/structural information of MBT has been provided followed by the focal mechanism solutions obtained from the western portion of Hazara Kashmir Syntaxis.

MAIN BOUNDARY THRUST (MBT)

Wadia (1957) recognized a series of nearly parallel faults in his division of Outer Himalayas (also known as Sub-Himalayas). All these were referred to as the Main Boundary Thrust (MBT). Nowadays the outermost of the fault named Murree Thrust by him (Hazara Fault of Seeber and Armbruster, 1979) is called the MBT. This distinct tectonic feature, in Pakistan, has thrusted the Eocene and older rocks over the Mid-Tertiary Murree Formation. Some parts of the capital city (Islamabad) contain splays of the fault that runs immediately north of it.

The fault dips are not constant varying from 50° to nearly vertical (Kazmi & Jan, 1997). In the east along the Hazara Kashmir Syntaxis, the fault loops around it. However, on the western side of the syntaxis, like the Panjal Fault, it is displaced by the left lateral Jhelum Fault. Seeber & Armbruster (1979) consider it to be a northward dipping reverse fault that in the lower crust is connected with the deeply buried faults referred to as the Hazara Lower Seismic Zone. On both sides of the MBT i.e. Hazara region in the North and Northern Potwar/ Kohat plateaux in the south, a number of mostly left lateral strike slip faults occur (e.g., Jadoon et al., 1995). Seismicity map (Fig. 2) indicates that a number of events (mostly on the western side of the HKS) occur along the surface trace of MBT confirming its seismically active nature.

PROCEDURE EMPLOYED AND FOCAL MECHANISM SOLUTIONS

In the present work, three Focal Mechanism Solutions (FMS) of earthquakes ($M_w \geq 4$) that occurred along the western portion of MBT during the period of 1989-1993 (Table. 1) have been carried out using the P-wave polarity data. The standard lower half hemisphere projections on an equal area net have been used. Two programs, namely AZMTAK and PMAN of Suetsugu (1997) in FORTRAN, using a PC have been employed. The former computes the epicentral distance and azimuth for each station, and obtains the take-off angle. The latter generates the focal mechanism diagrams based on input of geographic coordinates, magnitude, focal depth and P-wave polarity for each event. These FMS analysed in the present work are discussed below.

FMS 1 and 2

Both these events are located in an area bounded by the MBT in the north and Khair-i-Murat Fault (KMF) in the south (Fig. 2). The area is commonly referred to as the Northern Potwar Deformed Zone (e.g. Kazmi & Jan, 1997). E-W trending tight and complex folds characterize this area. The southern limbs of the folds are overturned and cut by steep angle faults.

According to Lillie et al., (1987) the area contains an imbricate stack of thrust faults (mostly E-W trending, but NE-SW trend in eastern part) with some being on the surface and others occurring as blind thrusts. Seismic sections indicate that several subsurface faults merge into the basement between the MBT and the KMF. They also reveal that MBT has a dip of about 65°-70° and KMF has steeper dip of 80^0. Both dip towards the north. Further a number of left lateral strike slip faults with small displacement and lateral extent occur on both sides of the MBT (e.g. Sercombe et al., 1998; Jadoon et al., 1995). These are considered to be splays of the MBT.

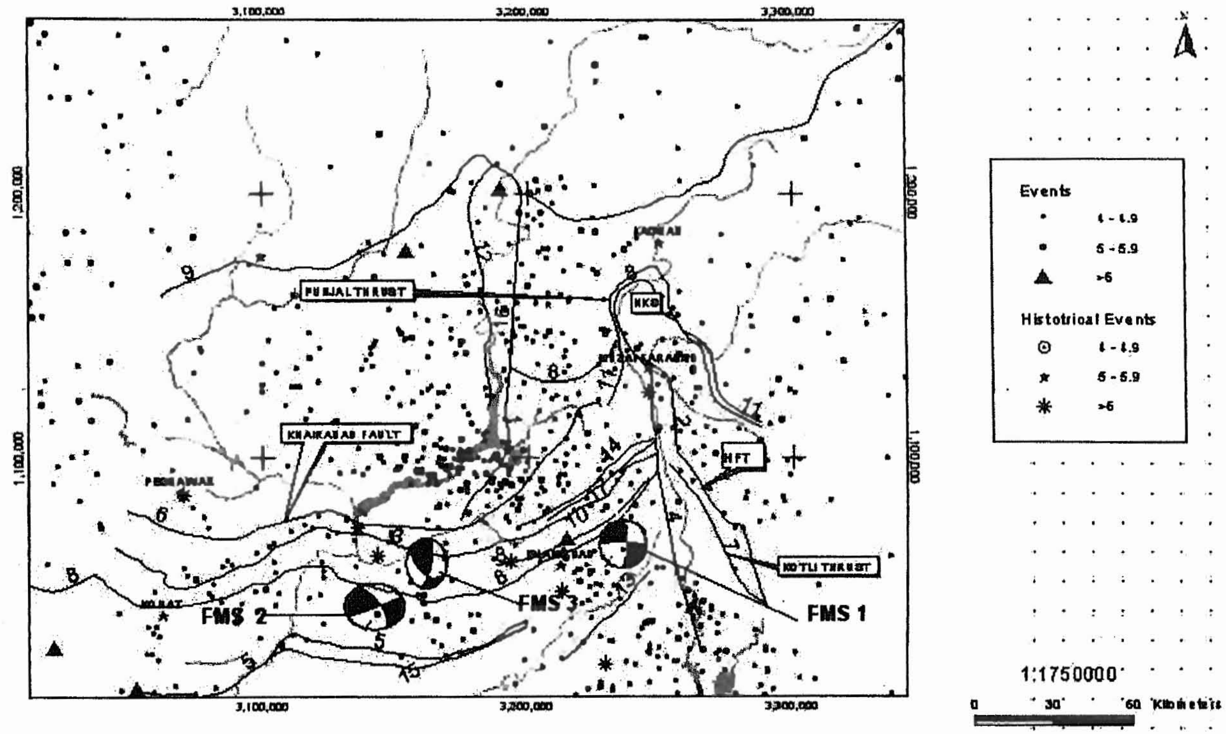

Fig. 2. Seismicity, structural and FMS map of the area.
1. Darband Fault: 2. Himalayan Frontal Thrust: 3. Hissartang Fault 4. Jhelum Fault: 5. Khair-i-Murat Fault: 6. Khairabad Fault: 7. Kotli Thrust: 8. MBT: 9. MMT: 10. Nathiagali Thrust: 11. Punjal Thrust: 12. Puran Fault: 13. Riwat Thrust: 14. Sangargali Thrust: 15. Soan (Dhurnal) Backthrust: 16. Thakot Fault: 17. Thandiani Thrust.

The focal depths of both the events are 10 and 6.5 km respectively (Table. 1). Basement (for FMS 1) and cover rocks (for FMS 2) seem to have been affected. Strike slip solutions are obtained for them (Fig. 3). The E-W trending nodal plane in solution number 1 and the NE trending nodal plane for solution number 2 with left lateral slip (Table. 2) are considered to be the rupture planes. These trends are in agreement with the observed trend of major structures. Also the nearly vertical dips of these inferred rupture planes support this view.

Probably the uplift of Hazara-Kashmir Syntaxis located to the east of these events is responsible for left lateral slip in the area. The influence of the N-S trending left lateral Jhelum Fault, a major structure of the area that also separates this area from the HKS could also be the reason for this type of displacement. In this same area i.e. eastern Potwar, Iqbal & Ali (2001) have interpreted the NE oriented thrusts to be a result of deformation along the left lateral Jhelum Fault.

FMS 3

This event is from an area situated immediately north of the MBT (Fig. 2). As already described that MBT is a major thrust of the area and has variable dips ranging from 50° to nearly vertical (Kazmi & Jan, 1997). A number of left lateral strike slip faults with minor displacement and small lateral extent occur on both sides of the MBT (e.g. Sercombe et al., 1998; Jadoon et al., 1995). These are considered to be splays of the northward dipping MBT and in the vicinity of the epicentre have a nearly NE-SW trend.

The depth of basement near the MBT is about 8km (Jaswal et al., 1997). On the basis of gravity data, it has been inferred that the MBT is a thick-skinned fault penetrating upto the depth of the upper crystalline basement (Khan & Ali, 1994).

TABLE 1. SOURCE PARAMETERS OF EARTHQUAKES WHOSE FMS HAS BEEN DETERMINED IN THE PRESENT STUDY

FMS Nos.	Date D/M/Y	Time H: M: S	Latitude (N)	Longitude (E)	Depth (Km)	Magnitude (M_w)
1	7/4/89	43:24.0	33.75	73.2	10	5.1
2	17/2/93	16:06:07	33.55	72.5	6.5	5.4
3	8/6/93	14:30:37	33.68	72.62	7.6	5.3

TABLE 2. PARAMETERS OBTAINED FROM THE FOCAL MECHANISM SOLUTIONS (FMS)

FMS No.	Nature of FMS	Fault Plane (FP)		Auxiliary Plane (AP)		P-Axis		T-Axis	
		Strike	Dip	Strike	Dip	Strike	Plunge	Strike	Plunge
1	LLSS	271°	86° N	2°	76° W	-43°	7°	225°	13°
2	LLSS	64°	82°NW	332°	75° NE	5°	-162°	16°	289°
3	THRUST	126°	51°SW	16°	66°SW	74°	9°	334°	47°

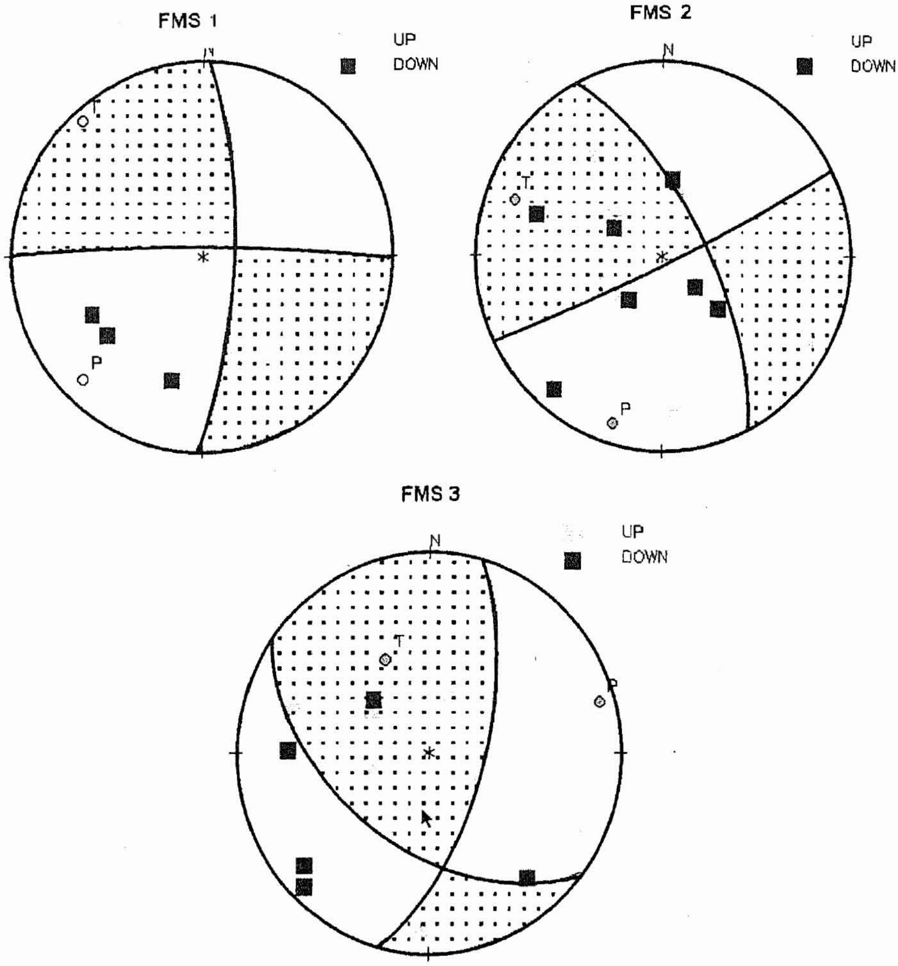

Fig. 3. Focal Mechanism Solutions (FMS).

Seeber and Jacob (1977) had suggested that MBT is directly connected to the earlier described HLSZ forming a north dipping reverse fault. According to Seeber and Armbruster (1979) this seismic structure (decoupling layer) is well recognized below a depth of 20 km. The focal depth of the event of about 8 km (Table. 1) coincides to the depth of basement thereby indicating that the event is probably not related to this seismic structure, but occurs above it.

FMS obtained is of thrusting with a strike slip component (Fig. 3). Considering the above information, the nodal plane trending in the NW direction (Table. 2) is considered to be the rupture plane. This indicates left lateral sense of motion that is in accord with the observed motion on the mapped strike slip faults occurring in the area. Thus the event indicates shallow activity on one of the many splays of the MBT. Influence of the left lateral Jhelum Fault (western boundary of HKS) or uplift of the Hazara Kashmir Syntaxis is considered to be playing an important role in the development of left lateral slip.

DISCUSSION

Looking at the study area in the regional perspective, a number of interpretations by different workers are available to explain the collisional tectonics between the northward moving Indo-Pakistan and the Eurasian plates. It is beyond the scope of this study to describe them, however earlier contributions are summarized in Molnar and Tapponnier (1975), Molnar et al. (1977), Tapponnier and Molnar (1976, 1977), Farah and DeJong (1979), whereas later contributions are available in Kazmi and Jan (1997). All agree that the Indo-Pakistan plate is being underthrusted at the suture referred to in this study as the MMT.

Regional shortening due to convergence is probably absorbed by thickening of the crust, folding and accommodation along strike slip faults both to the north and south of the Himalayas (e.g., Royden & Burchfiel, 1997). One of these faults along the western boundary of the study area is nearly 1000 km long, sinistral Chaman Fault. This fault is also the western plate boundary of the Indo-Pakistan plate.

Another type of deformation (transpression and transtensile) occurs in a wide range of geodynamical settings like at oceanic and continental transforms, convergent plate boundaries such as orogenic belts, and regions of continental extension undergoing rifting (e.g., Allen & Allen, 1993). Transpressional features have been recognized from parts of the northern area of Pakistan (e.g., Sercombe et al., 1998). Some focal mechanism studies (e.g. Verma et al., 1980; Verma, 1991; Khan et al., 2002; MonaLisa et al., 1997, 2002) undertaken in parts of the northern Pakistan indicate the strike slip solutions. This fact has also been observed in this study (2 out of 3) show the dominance of strike slip deformation.

It is believed that the sinistral Chaman Fault is responsible for the convergent (transpressive) strike slip deformation in the area. Recent work of Iqbal and Ali (2001) in the Potwar area includes a stress model to explain the formation of structures between the Jhelum and Kalabagh Faults. Earlier Sercombe et al., (1998) in their work on the Kohat area emphasized the importance of Chaman Fault and Domeli Tear (in Potwar area) to explain strike slip deformation.

MBT forms the northern boundary of Kohat and Potwar fold belt. The solutions obtained near MBT indicate a left lateral sense of motion. In our opinion the importance of the Hazara Kashmir Syntaxis and the Jhelum Fault (western margin of the syntaxis) in the present case seems to be quite prominent. Uplift rates within the syntaxis are not known, but Baig and Lawrence (1987) have observed uplifted and tilted Quaternary terraces in the area. Stresses being generated here could explain the left lateral slip inferred presently near MBT.

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