Focal mechanism study of the Chakwal Earthquake of July 16, 2001 in the light of regional tectonics

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ABSTRACT: *On July 16, a body wave magnitude 5.2 (Ms = 4.7) earthquake occurred near Chakwal, about 75 km south of Islamabad. The earthquake was widely felt from Peshawar to Lahore. The fault-plane solution on the basis of p-wave polarity data of seismic stations of the PAEC's (Pakistan Atomic Energy Commission) Seismic Network has been found well-controlled and comparable with the Centroid Moment Tensor Solution given by Harvard University. The fault plane is oriented in the WNW direction with strike, dip and slip of 303°, 66° and 148° respectively which is in accordance with the local tectonics of the region. On the basis of Focal Mechanism Solution of this earthquake, along with two more solutions of earthquakes of the region, a possibility of another subsurface fault parallel to the Kallar Kahar fault is also derived.*

INTRODUCTION

A moderate earthquake of body wave magnitude 5.2, which occurred in the night of July 16, 2001, shook the city of Islamabad with intensity V on MM (Modified Mercalli) intensity scale. The earthquake was located at 32.93°N and 73.06°E at a focal depth of 32 km, in the southern part of Potwar Plateau near the city of Chakwal. It was felt widely from Peshawar to Lahore. Source Mechanism of this earthquake was determined on the basis of P-wave polarity data recorded on the PAEC's Seismic Network and its relation to the fault/lineaments in the vicinity of epicentral area was determined.

SOURCE PARAMETERS

Since the earthquake lies within the area covered by the Pakistan Atomic Energy Commission's Seismic network, it was possible to have quite accurate hypocenter location within acceptable limits. The analysis was carried out using the computer code HYPO71 PC (Lee and Lahr, 1975). The results of the analysis were good showing very small horizontal and vertical errors (1.7 km, 1.5km respectively) in location. The source parameters are given in Table 1 below:

TABLE 1

SOURCE PARAMETERS	MSSP
Origin Time	16:07:21.20
Latitude	32.93°
Longitude	73.06°
Depth	32 km
Magnitude	5.2

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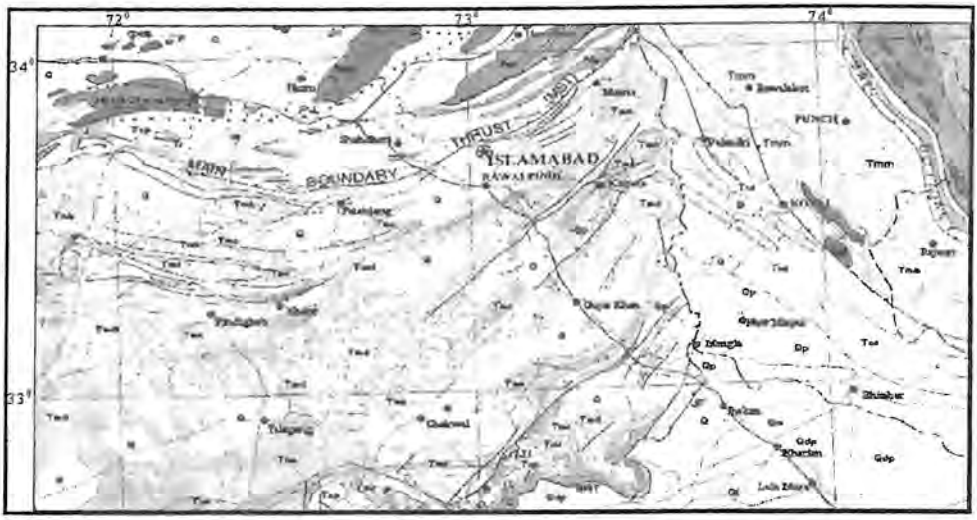

JF:	Jhelum fault	**Qp:**	Lei conglomerate	**Tmk:**	Kamlial Formation
PJ:	Panjal fault	**Qm:**	Stream bed deposits	**Tmm:**	Murree Formation
P:	Permian Rocks	**Tep:**	Eocene and Paleocene rocks	**Tmn:**	Nagri Formation
Q:	Unconsolidated surficial deposits	**Tmc:**	Chinji Formation	**Tmr:**	Rawalpindi Group
Qdp:	Piedmont deposits	**Tmd:**	Dhok Pathan Formation	**Tns:**	Siwalik group

Fig. 1. Map showing the geological distribution of rocks and main tectonic features of the Potwar Plateau and surrounding regions. Base map is taken from Geological Map of Pakistan published by Geological Survey of Pakistan 1993.

GEOLOGY OF AREA

The Potwar Plateau, in which lies the study area (Fig. 1) is bounded by Margala Hills in the north and Salt Range in the south. The boundaries extend up to River Jhelum in the east and River Indus in the west. The Potwar is highly dissected plateau, which covers an area of about 18130 square kilometers with an average elevation of about 457 meters above mean sea level. The plateau slopes concordant with the flow of the River Soan from east-northeast to west-southwest. Generally, the northern part of the Potwar plateau has higher relief as compared with its southern part.

The rocks exposed in the Potwar area belong to the Rawalpindi Group of Miocene age and the Siwalik Group of Miocene Pliocene age (Kazmi & Jan, 1997). The rock formations in the region surrounding the epicenter include Dhok Pathan, Nagri and Chinji. The Dhok Pathan Formation consists of grey sandstone and red-brown silt interbeded with minor conglomerate lenses. The Nagri Formation comprises of grey, massive, thick sandstone forming laterally extensive ridges with subordinate silt and conglomerate whereas Chinji Formation contain red-brown mudstone and sandstone (Hussain, 1993).

In the south lie the Cambrian rocks of Jhelum Group and Eocambrian rocks of the Salt Range Formation. Exposures are restricted to the Salt and Trans Indus Ranges. The Cambrian Jhelum Group includes Baghanwala Formation with shales and sandstone having salt pseudomorphs, Jutan Dolomite, Kussak Formation and Khewra Formation with purple sandstone and subordinate shale. The Eocambrian Salt Range Formation comprises of thick salt deposits with red gypseous mixture of clay and particles of calcite and dolomite, with occasional oil shale and volcanic 'Khewra Trap' in the eastern Salt Range (Wadia, 1978).

SEISMOTECTONICS AND SEISMICITY OF THE REGION

The Potwar Plateau which belongs to the Himalayan Foreland has a number of faults active in the region (Wadia, 1978). On the basis of seismic activity (Fig. 2), the Potwar Plateau may be subdivided into two parts–northern and southern. The northern part is north of the Soan Syncline up to the Margala Hills of the MBT and the southern part is south of the Soan Syncline up to the Salt Range. In the east, the area is terminated by almost N-S trending left-lateral Jhelum fault.

The seismic activity in the northern part of the plateau in the vicinity of Islamabad and Attock is

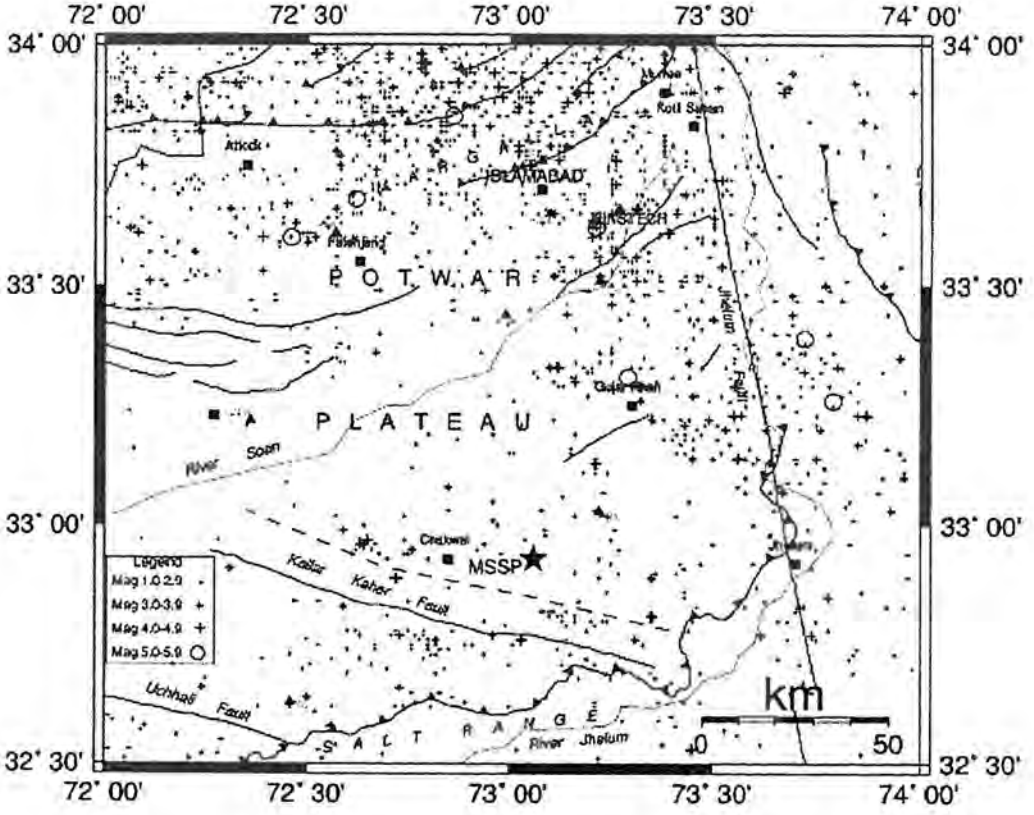

Fig. 2. Seismicity of the Chakwal Region since 1976, in the light of local Tectonic Setting. Filled star is the event under study and filled triangles are the seismic stations of MSSP network.

concentrated mainly around the Hazara Thrust system, which is regarded as the westward extension of Main Boundary Thrust, extending up to Parachinar (Kazmi & Jan, 1997). Since the establishment of PAEC's Seismic Network in the region in 1976, about 24 earthquakes of body wave magnitude $\geq$ 4.0 were recorded in the area, with 4 having magnitude $\geq$ 5.0. The largest is the Rawalpindi Earthquake of Feb. 14, 1977 of body wave magnitude 5.8 (Mubarak et al., 1977). In the southern part, the activity is mainly concentrated along the Jhelum fault in the vicinity of Gujar Khan and Jhelum in the east and along the major Kallar Kahar fault. Total of sixteen earthquakes of body wave magnitude $\geq$ 4.0 are recorded in this area by MSSP in the last 25 years including 4 of magnitude $\geq$ 5.0.

As mentioned earlier, the earthquake under study belongs to the southern part of the Potwar Plateau. It occurred about 20 km north of the Kallar Kahar fault, which cuts across the Salt Range in WNW direction close to the Kallar Kahar Lake, south of Chakwal city. The Kallar Kahar Lake is straddled by many smaller faults. A right-lateral movement is apparent along most of these faults (Kazmi, 1979). A view of the local seismicity, recorded through the microseismic network of MSSP since 1976 and the

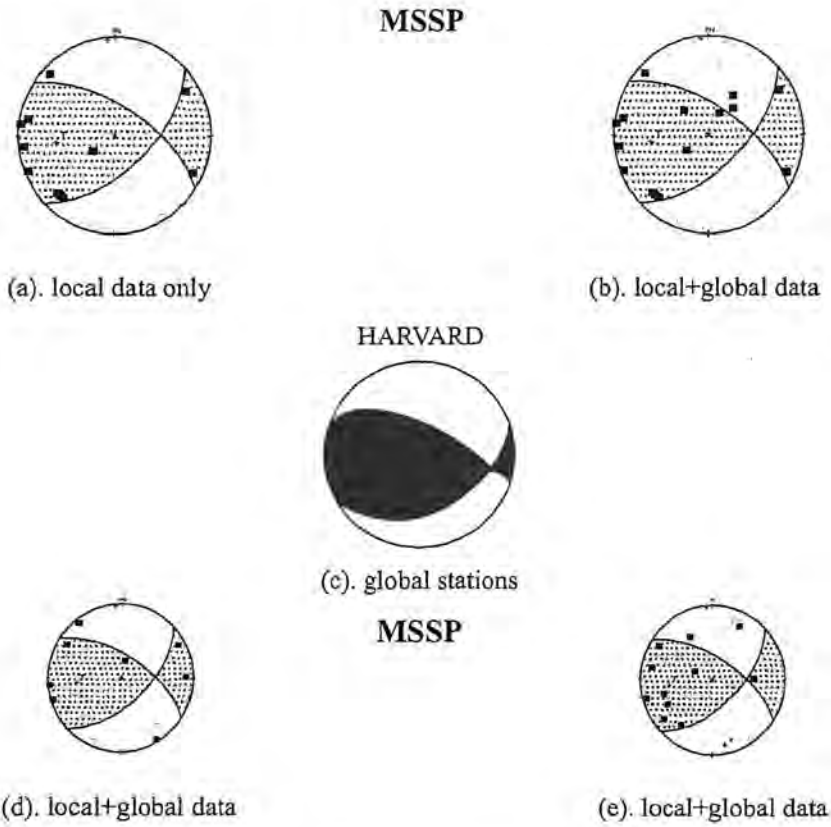

Fig. 3. Fault Plane Solution of the earthquake under study. a) is the solution obtained by MSSP local stations, b is the solution by local and global stations and c is the Harvard (CMT) solution. Figures (d) and (e) are the solutions of two supporting earthquakes.

location of the recent earthquake under study shows that there is a reasonable concentration of earthquakes spreading in the vicinity of the event, parallel to the Kallar Kahar fault.

FAULT PLANE SOLUTION

An attempt is made to determine the Source Mechanism of this earthquake on the basis of P-wave polarity data of PAEC's network. For this purpose, fault plane solution is derived using computer codes AZMTAK and PMAN (Suetsugu, 1997). The solution on the basis of local network data is shown in Figure 3a, whereas Figure 3b shows the solution obtained by adding the global seismic stations. Out of 29 seismic stations, only 4 show inconsistency. The Centroid Moment Tensor Solution (CMT) given by the Harvard University (Fig. 3c) shows similar trend. Results of both the solutions are given Table 2.

TABLE 2

MSSP		HARVARD (CMT)
(Local Sts. only)	(Local Sts. + Global Sts.)	Global
Strike = 303°	Strike = 303°	Strike = 292°
Dip = 66°	Dip = 66°	Dip = 64°
Slip = 148°	Slip = 149°	Slip = 116°

The fault plane solution clearly shows that the nature of the source is right-lateral strike slip with dominant component of thrusting.

To look into the possibility of another fault parallel to the Kalar Kahar fault and passing through the concentration of the seismicity observed there, Focal Mechanism study of two more earthquakes occurring in the vicinity is also carried out. The solution of these earthquakes occurring on November 18, 1978 (32.89° N, 72.72° E, $m_b = 4.9$) and July 15, 1999 (location 32.72° N, 72.75° E, $m_b = 4.5$), are shown in Figure 3d and 3e respectively and summarized below in Table 3.

TABLE 3

November 11, 1978	July 15, 1999
Strike = 301°	Strike = 302°
Dip = 56°	Dip = 60°
Slip = 147°	Slip = 158°

The solutions of these earthquakes show the trend similar to the one shown by the event under study.

CONCLUSIONS

The study of the earthquake leads to the following conclusions.

1. Since the event is located in the region surrounded by the seismic stations of the PAEC's network, with one station, PDA lying only 15 km from the source, it can safely be said that the location is quite accurate within the acceptable limits.
2. Location of the earthquake along with the spread of the seismicity (Fig. 2) shows that there is a reasonable concentration of earthquakes in the vicinity of the location of the event. The concentration is parallel to the Kallar Kahar fault and contains 4 events of body wave magnitude ≥ 4.0, apart from the magnitude 5.2 earthquake under study.
3. The well-controlled Fault Plane Solution of the earthquake and recorded seismicity are in accordance with the structural trend in the area.
4. Since the large earthquakes, like the one under study are always associated with some fault, and also the concentration of the earthquakes is in well aligned manner, the presence of a subsurface fault parallel to the Kallar Kahar fault

with almost same orientation is quite possible over here. To substantiate this conclusion, solutions of two earlier earthquakes are also carried out (Table 3).

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