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Integration of Seismic and Seismological Data Interpretation for Subsurface Structure Identification

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***Abstract*—**The structural interpretation of a part of eastern Potwar (Missa Keswal) has been carried out with available seismological, seismic and well data. Seismological data contains both the source parameters and fault plane solution (FPS) parameters and seismic data contains ten seismic lines that were re-interpreted by using well data. Structural interpretation depicts two broad types of fault sets namely, thrust and back thrust faults. These faults together give rise to pop up structures in the study area and also responsible for many structural traps and seismicity. Seismic interpretation includes time and depth contour maps of Chorgali Formation while seismological interpretation includes focal mechanism solution (FMS), depth, frequency, magnitude bar graphs and renewal of Seismotectonic map. The Focal Mechanism Solutions (FMS) that surrounds the study area are correlated with the different geological and structural maps of the area for the determination of the nature of subsurface faults. Results of structural interpretation from both seismic and seismological data show good correlation. It is hoped that the present work will help in better understanding of the variations in the subsurface structure and can be a useful tool for earthquake prediction, planning of oil field and reservoir monitoring.

***Keywords*—**Focal mechanism solution (FMS), Fault plane solution (FPS), Reservoir monitoring, earthquake prediction.

I. INTRODUCTION

THE Missa Keswal oil field (study area) is located in the eastern part of Potwar Plateau. Pakistan is considered as a seismically very active region, North Potwar deformed zone (NPDZ) and other parts of Potwar appear to be relatively less active as compared to adjacent areas [4]. Three Focal mechanism solutions (FMS) are present near the study area as shown in Fig. 1. Eastern Potwar Plateau is characterized by north-east, south-west trending tight, faulted anticlines separated by broad synclines [3]. Anticline represents folding phenomenon while synclines are not true folds and represents un-deformed area between anticlines. The tectonic framework of the eastern Potwar region is largely controlled by the Salt Range and Domeli forward thrust systems along with DilJabba and Domeli backthrusts. Chorgali Formation of Eocene age is the main reservoir rock in the study area. The shale and clays of Murree Formation act as cap rocks [1].

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II. INTERPRETATION

The focal mechanism solution (FMS) is important tool for the identification/correlation of the major subsurface structures. This technique has been used in various parts of the world for the structural interpretation as well as for the hazard mitigation. In the present study this technique is employed along with seismic reflection and well data.

Seismological data interpretation gives information about the nature of earthquake, nature of stresses and also helps in understanding the kinematic behavior of the seismic zones. Seismicity map of the Potwar area is generated for the period 1973-2007 as shown in Fig. 2. Bar graphs and 3D models are prepared to find the magnitude, depth and frequency of earthquakes in the Potwar area Fig. 3, 4 and 5. FMS map of Potwar area shows the dominance of strike slip faults, followed by some thrust/reverse mechanism Fig. 6.

Seismotectonic map of the NW Himalayan fold and thrust belt [4] is modified by using international data from USGS. All the earthquakes that have occurred in NW Himalayan fold and thrust belt from 2006-2008 having magnitude > 4mb are added in the map as the events till 2005 has already been added. From the map it is clear that tectonic activity has increased in the North Western side Fig. 7.

Results obtained from the structural interpretation of seismological data are correlated with structural map of Kohat-Potwar area. The position of FMS also marked on the two way time map of the Potwar area Fig. 8. Depth of these three FMS is from 5-33 km and their dip is towards NW. The orientation of the surface structure present in the area is also from NE-SW and is dipping towards NW.

The epicenter of focal mechanism Solution1 (FMS1) is located about 3-5 km north of Dil-Jabba thrust. Hypocentral depth given by the local network is 31.9 Km. Structural trend is NE-SW direction is quite prominent in this area and it correlates with DilJabba thrust as they have similar trends NE-SW and shows left-lateral strike-slip faulting.

The magnitude of FMS2 is 5.1 Mw and it is one of the few strongest events (Mw>5.0) to have occurred in the area for which the required parameters were available. The Hypocentral depth of this event as given by local network is 33 km. Prominent structural trend of the area where the event occurred is in the NE-SW direction. This event can be correlated with Jhelum Fault surrounding the area and have same NW-SE.

FMS 3 has magnitude 4.7 Mw and its epicenter is also located in the eastern part of Potwar. Hypocentral depth as given by the local network is 5.0 km. Majority of the surface structures in this part of Potwar trend in the NE-SW direction. The focal mechanism solution indicates the presence of strike-slip fault. From the earlier description of geology, it is known that blind faults are present underneath the Qazian anticline and one of them even extends into the basement. Seismic data shows the these two thrust faults originate at a depth of about 1.5 km and extend up to the depth of 4 km in the subsurface Fig. 9. FMS3 correlates with these thrust faults underneath the Qazian anticlines.

The value of stress has been calculated at the shot point interval of 20 on the seismic dip lines (Shown on the base map) with the help of rock physical properties (Moduli, VS, VP etc.)

By using these data points (at every 20th SP) stress contour map has been prepared at the interval of .25 N/M2 (Pascal).

Maximum stress value lies on the NW –SE side and diminishes toward the central portion of map. This helps to understand the possible force orientation on the basis of which pop up structure has been formed as shown in Fig. 10.

To understand the nature of thrust system, 3D geological model of interpreted horizons and fault surfaces was constructed. The construction of the 3D model is based on the interpretation of a dense 2D seismic grid and borehole data. The primary aim of the three-dimensional model is to further understand the structural styles present within thrust settings through detailed analysis of two exceptionally well exposed thrust faults in the eastern Potwar. All major fault planes and time surfaces are shown on the fault model Fig. 11.

FMS1 and FMS 2 are also correlated with seismic transect and cross section of eastern Potwar Plateau Fig. 12 and 13. Rheological model of the study area is prepared by using stereonet, shows the thrust dominant strike slip stresses which correlates with the seismological models (FMS) surrounding the study area and it also shows that faults are changing their nature from thrust to strike slip Fig. 14.

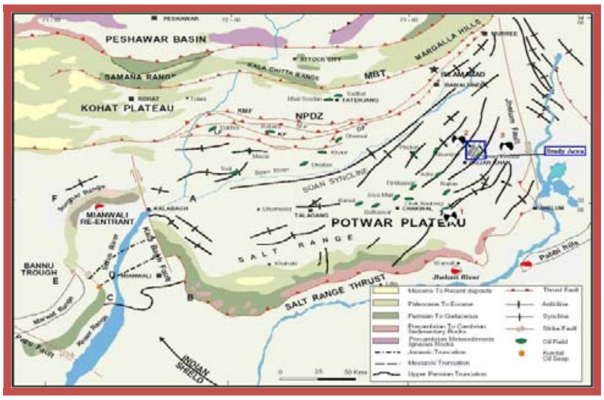

Fig. 1 Structure map of the Kohat-Potwar area with location of study area and FMS updated from [5]

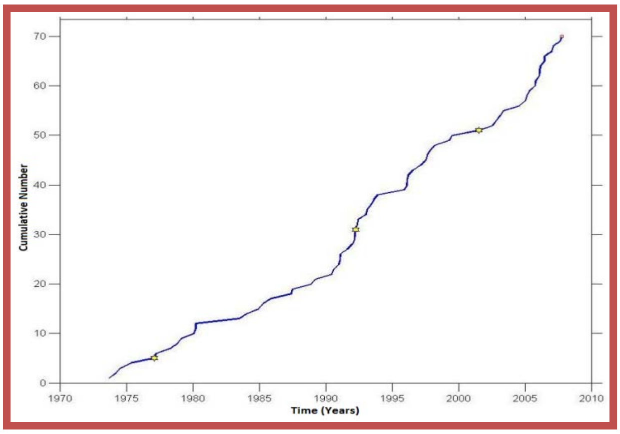

Fig. 2 Seismicity map of Potwar area (1973-2008) shows that the continuity of seismicity in the Potwar area, the number of earthquakes increased with the time

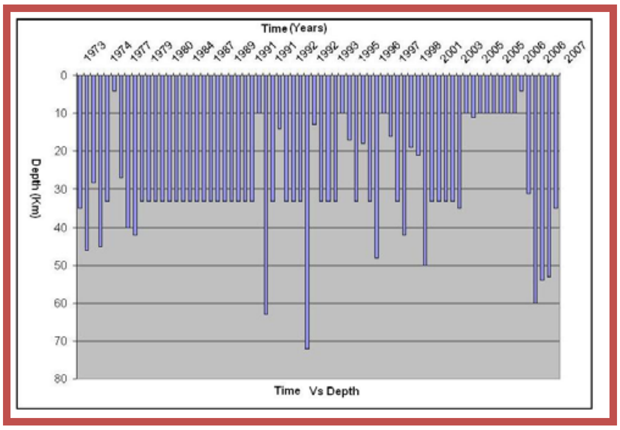

Fig. 3 Time- Depth bar graph shows that almost 60-70% earthquakes originated at the depth of 33 km (Shallow focused)

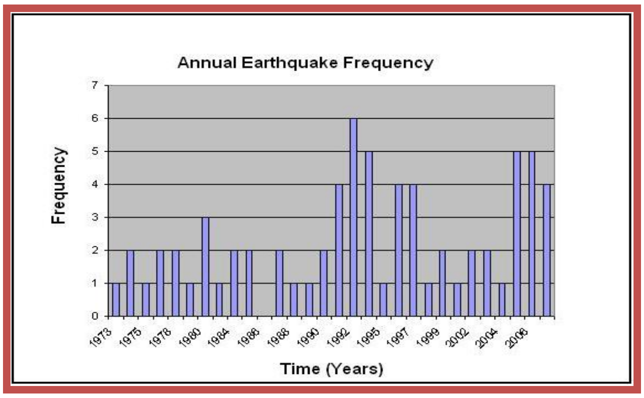

Fig. 4 Time- Frequency bar graph shows that maximum numbers of earthquakes have occurred in the years of 1992(6), 1993(5) and 2005-06 (5)

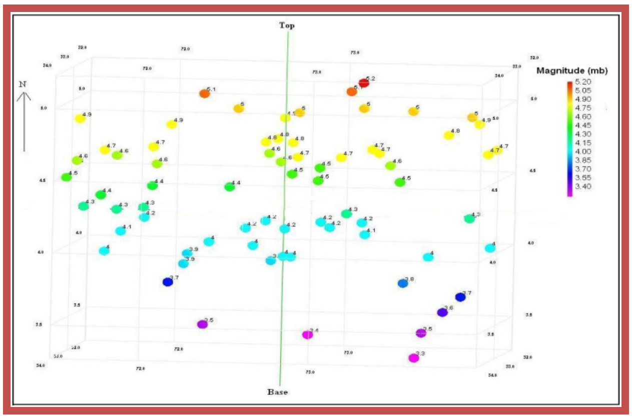

Fig. 5 Seismicity model of the Potwar area with respect to magnitude

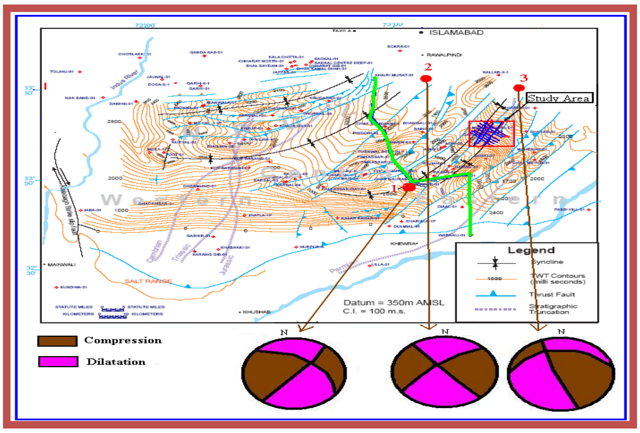

Fig. 8 Two-way time map at base Miocene updated from [3]. Green line shows the locations of the points where eastern Potwar cross section is taken. Mark 1- 3 shows location of FMS

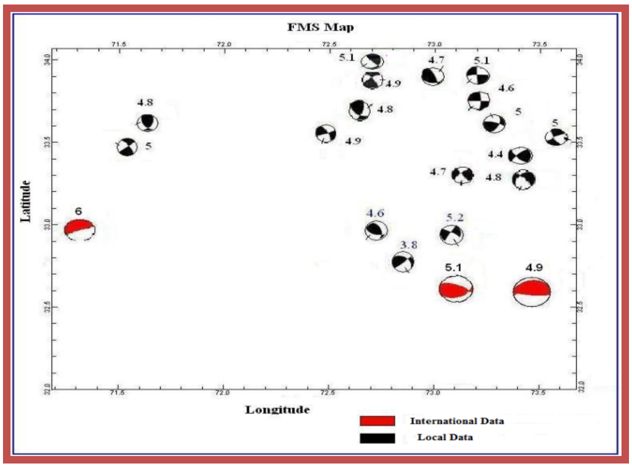

Fig. 6 FMS map of the Potwar area shows the dominance of strike slip faults

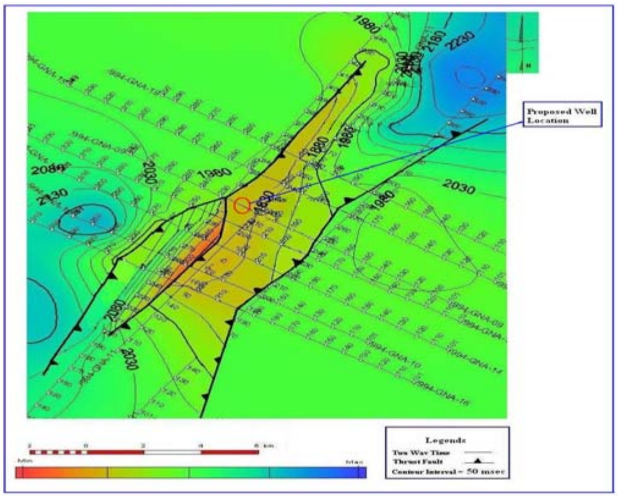

Fig. 9 Time contour map of top of seismic data shows the pop up structure bounded by the two thrust faults dipping NW and SE and the orientation of the structure is NE-SW

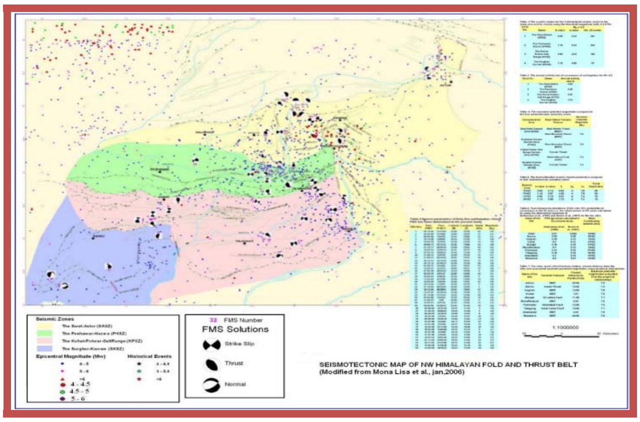

Fig. 7 Renewed Seismotectonic map of the NW Himalayan Fold and Thrust Belt shows that tectonic activity increased in the NW side updated from [4]

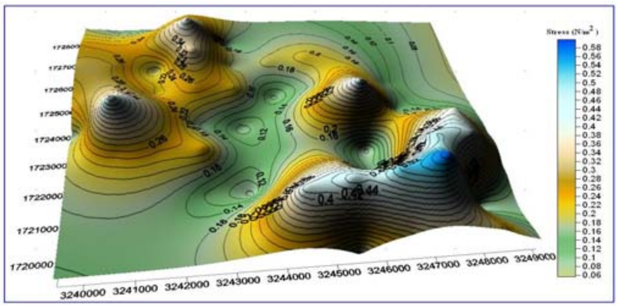

Fig. 10 3-D model of stress shows that the maximum stress values lies on the NW-SE portion

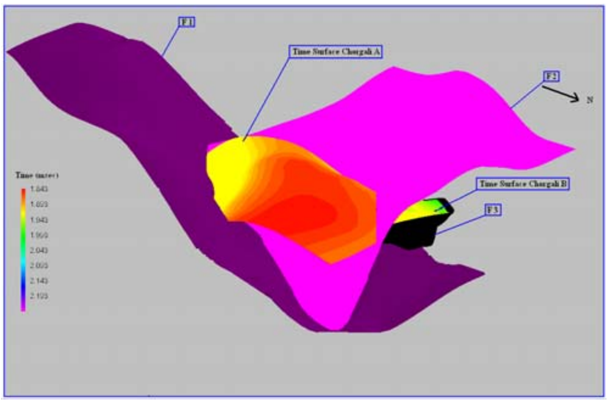

Fig. 11 3D fault model shows the all the major thrust and back thrust faults present in the study area. F1 is dipping towards NW. F2 and F3 are dipping towards SE

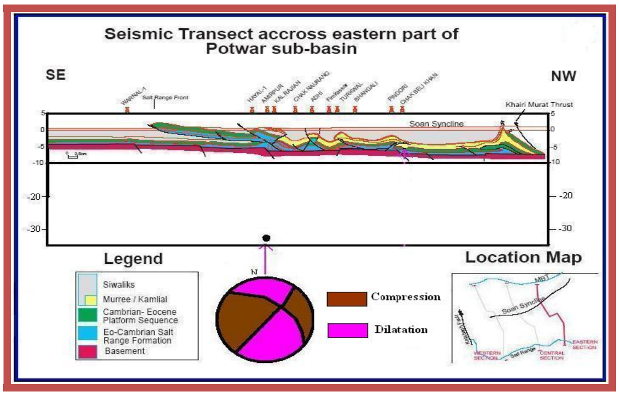

Fig. 12 Correlation of FMS1 with the Seismic Transect across Eastern part of Potwar sub-basin Updated from [3]

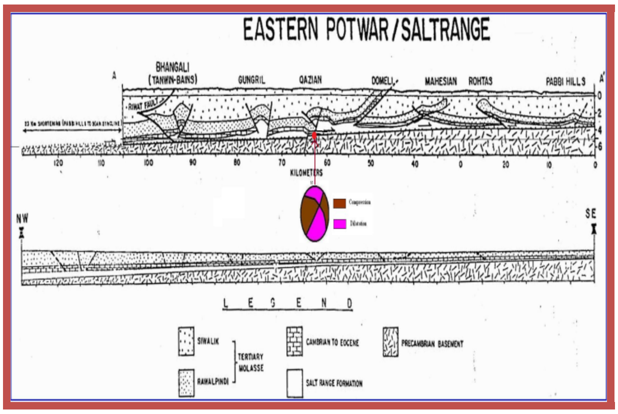

Fig. 13 Correlation of FMS 2 with cross section of eastern part of Potwar sub-basin updated from [2]

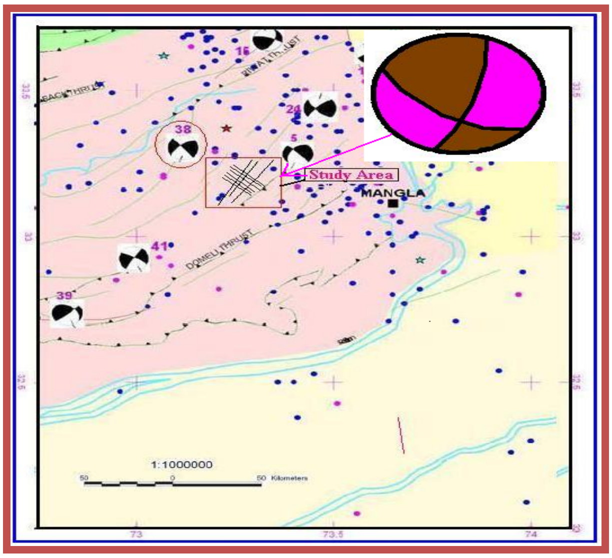

Fig. 14 Seismotectonic map of NW Himalayan Fold and Thrust Belt updated from [4] shows the shows the seismological models (FMS) while the map at the top right corner shows the rheological model of study area

III. CONCLUSION

Potwar area was highly tectonically active during 1992-93 and 2005-07, maximum magnitude earthquake was originated in the eastern Potwar. Strike slip faults are dominant in the Potwar area followed by some thrust/reverse mechanism. Magnitude, depth and frequency of the earthquake increased during 2005-2008. Percentage of shallow focus earthquake is high in the region and maximum earthquakes occurred at the depth of 33 Km. FMS1, FMS2 and FMS3 are prepared through seismological data interpretation, shows the correlation with the surface structure and the structure interpreted from seismic data. With the depth faults are changing their nature from thrust to strike slip. Stress contour map shows the presence of compressional forces with the strike slip component which are the possible cause of earthquakes in the study area. The rheological modeling can be used to integrate the seismically and seismologically interpreted subsurface structures. Present work will help in better understanding of the variations in the subsurface structure and can be a useful tool for earthquake prediction.

In future, this integrated technique can be applied for reservoir engineering. Focal mechanism solution technique can be used to determine the direction and spatial extent of fracture induced by fluid injection/extraction for oil production. Seismological studies define the rate and direction of stress in the area which can be helpful in planning of oil field and reservoir monitoring.

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