Structural and Economic Analysis of Meyal Oil Field in the Northern Potwar Deformed Zone, Upper Indus Basin, Pakistan

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Abstract: Potwar sub-basin is famous for its structural style, hydrocarbon exploration and production activities from Cambrian to Pliocene rocks. Foreland basin related subsurface structures, in the presence of source and seal rocks offer a variety of traps to host hydrocarbons. Meyal Oil field, situated in the NW Potwar sub-basin, is a hydrocarbon resource for the country. Subsurface structures of Meyal area were outlined by interpreting two strike and four dip lines in IHS Kingdom suite. Borehole data of MYL-10, MYL-12 and MYL-13 exploratory wells were incorporated to improve the subsurface understanding. A total five prominent reflectors of Permian, Triassic, Jurassic, Paleocene and Eocene rocks were marked on the seismic sections. The seismic interpretation shows a post Eocene pop-up structure flanked by a back thrust and a fore thrust. Moreover, the time structure maps for Meyal area display a doubly plunging and faulted anticline as a result of south directed compression. Four isochron maps show thickness variation in Permian to Eocene sediments in the study area. The results of interpretation show favorable structural trap for economic hydrocarbon exploration.

Keywords: Soil corrosion potential, electrical resistivity, vertical electrical sounding, cathodic protection.

Introduction

Present day investigations of sedimentary basins generally utilize modern software and technology to delineate subsurface structures, petroleum systems, plays and prospects. Potwar sub-basin, a region of oil and gas exploration and production (Kadri, 1995), is tectonically active part of foreland fold and thrust belt of the Pakistani Himalayas (Burbank and Raynolds, 1988; Pennock, 1988; Gee, 1989). It is delineated by Kala Chitta and Margalla faults to the west and Jhelum left lateral strike-slip fault and Hazara Kashmir syntaxis to the east (McDougall and Khan, 1990; Kazmi and Jan, 1997). This area indicates a complex interplay of north derived compression, basement ramp and salt tectonics that governed the evolution of the Salt Range and Potwar sub-basin (Lillie et al., 1984) reported deformation in this area as young as 0.4 m.y.

The Potwar sub-basin, a region of oil and gas exploration and production (Kadri, 1995), is tectonically active part of foreland fold and thrust belt of the Pakistani Himalayas (Burbank and Raynolds, 1988; Pennock, 1988; Gee, 1989). It is delineated by Kala Chitta and Margalla ranges (MBT) to the north, right lateral strike-slip Kalabagh fault to the west and Jhelum left lateral strike-slip fault and Hazara Kashmir syntaxis to the east (McDougall and Khan, 1990; Kazmi and Jan, 1997). This area indicates a complex interplay of north derived compression, basement ramp and salt tectonics that governed the evolution of the Salt Range and Potwar sub-basin (Lillie et al., 1987). In this context, many studies exist (Jaume and Lillie, 1988; Pennock et al., 1989; Jadoon et al., 1997; Jaswal et al., 1997; Jadoon et al., 2008; Lisa and Khawaja, 2004; Khawaja and Lisa, 2005; Moghal et al., 2007) to show two re-entrants; Jhelum and Kala Bagh re-entrant in the east and west, respectively, as well as the southward thrusting of the sub-Himalayas over Punjab plains generated plunging anticlines and synclines in compressional regimes.
Fig. 1 Generalized tectonic map of northern Pakistan showing the major divisions of Himalayas modified from Gansser (1981) and Kazmi (1982).

Structural styles of eastern, central and western Salt Range/ Potwar sub-basin are markedly diverse (Moghal et al., 2007). Furthermore, Moghal et al., (2007) indicate incongruity in surface and subsurface structures. Structurally, the Potwar sub-basin contains faulted anticlines, wide synclines and narrow imbricate thrusts. The fold and fault planes lie in the same direction of the major regional trend. A major syncline of Potwar sub-basin (the Soan syncline) trends east-northeast to west-southwest (Fig. 2). This structure (Soan syncline) divides the southern and northern deformed zones (SPPZ and NPDZ) of Potwar plateau (Lillie et al., 1987; Moghal et al., 2007).

Potwar sub-basin is famous for its structural style and hydrocarbon exploration and production activities (Raza et al., 1989; Kadri, 1995). The conversion of organic matter into hydrocarbons in the region is primarily caused by temperature fluctuations. It forms the top apex of the triangle of temperature of organic matter, which is used as one of the most important exploration tools for determining the hydrocarbon potential of any area (Telford et al., 1990; Gluyas and Swarbrick, 2009).

A succession of Eo-cambrian to Pleistocene (Shah, 1977, 2009) sedimentary deposits contain potential source, reservoir and cap rocks in Potwar sub-basin. A brief compilation (Hasany and Saleem, 2012) regarding source, reservoir cap rocks and geothermal gradient of the Meyal oil field (Table. 1).

In the Potwar sub-basin, Salt Range Formation contains oil shales with total organic carbon (TOC) of about 26% to 37% (Shami and Baig, 2002), a source rock in the eastern part. Moreover, Permian rocks have potential for both oil and condensate generation, whereas black/grey shales of Jurassic Datta Formation with fair to good maturity are the potential source rocks. In eastern Potwar sub-basin, horizons of Patala and Lockhart formations rich in organic matter are established high quality source rocks for oil. In eastern Potwar region, the Chorgali and Sakesar carbonates are confirmed source rocks because of containing fair to good amount of mature organic matter (Kadri, 1995). In Meyal oil field (Hasany and Saleem, 2012), variegated Jurassic shales are potential source rocks.

The rocks of Cambrian, Permian, Jurassic, Paleocene and Eocene are oil producing reservoirs in Potwar sub-basin. The main Eocene reservoirs are Sakesar Limestone and Chorgali Formation’s fractured carbonates. In Meyal area, Chorgali and Datta formations are main oil producing reservoirs. Shami and Baig (2002) indicate that Himalayan orogeny related deformation has introduced fracture porosity, particularly along the fold axis of the anticlines. This fact is substantiated by high porosities in wells of northwestern Potwar. In Meyal area (Hasany and Saleem, 2012), Chorgali, Sakesar and Lockhart formations are reservoir rocks.

In the Potwar sub-basin, Kuldana Formation lies on the top of Chorgali Formation and Sakesar Limestone and act as seal rock for the reservoirs of both formations. Whereas the argillaceous (clays and shales) content of Murree Formation also provide cap to Eocene reservoirs. In Meyal area, the shales of Kuldana, Namaml and Datta formations are proven seal horizons (Hasany and Saleem, 2021).
Materials and Methods

A number of geophysical surveys are carried out to know the subsurface geology of an area. The data obtained through borehole well logs and seismic lines were integrated to get the subsurface structure of Meyal area in the present study. 2D data in the form of six seismic lines were interpreted through geophysical software Kingdom Suite 8.6, Seismic Micro Technology (SMT). Amongst six seismic lines, two were strike lines (97-MYL-12, E-W and 97-MYL-13, NW-SE oriented) and four were N-S oriented dip lines, 97-MYL-06, 97-MYL-07, 97-MYL-08, 97-MYL-09 (Fig. 3). The geophysical data for the subsurface analysis of the Meyal area was acquired by the Pakistan Oil Field Limited in 1997. In addition to seismic lines, borehole data of three wells, Meyal 10, 12 and 13, were used to recognize the subsurface lithologies and to correlate these rocks with seismic data.

Table 1. Source, reservoir and seal rocks in the study area

| Age     | Formation | Lithology                                      | Hydrocarbon potential |
|---------|-----------|------------------------------------------------|-----------------------|
|         |           |                                                | Source | Reservoir | Seal |
| Pliocene| Nagri     | Sandstone and claystone                        |         |           |      |
| Pliocene| Chinji    | Claystone and sandstone with siltstone         |         |           |      |
| Miocene | Kamlal    | Sandstone and clay stone                       |         |           |      |
|         | Murree    | Claystone, sandstone, conglomerates and shales |         |           |      |
| Eocene  | Kohat     | Limestone                                      |         |           |      |
|         | Kuldana   | Shale                                          |         |           |      |
|         | Chorgali  | Limestone and shale                            |         |           |      |
|         | Sagesar   | Limestone                                      |         |           |      |
|         | Nammal    | Shale and limestone                            |         |           |      |
| Paleocene| Patala   | Shale with interbedded limestone                |         |           |      |
|         | Lockhart  | Limestone                                      |         |           |      |
|         | Hangu     | Sandstone                                      |         |           |      |
| Jurassic | Datta     | variegated sandstone and shale                 |         |           |      |
| Triassic| Mianwali  | Sandstone and shale                            |         |           |      |
| Precambrian | Salt Range | Evaporates and marls/shale                  |         |           |      |

Results and Discussion

Five reflectors from top of Permian to top Eocene (Permian, Triassic, Jurassic, Paleocene and Eocene) were marked on all seismic sections. A compression related pop-up structure bounded by two thrusts is identified in the study area (Fig. 4). On the southern flank of the structure, a north dipping fore thrust is present whereas a south dipping back thrust marks the northern limb of the anticline. Moreover, throw of the strata in back thrust is greater as compared to the displacement occurred in fore thrust thereby demonstrating that intensity of compressional forces was much higher from northern side of the structure. In the north of the pop-up structure, a reverse fault is displacing the Triassic to Eocene strata.
**Time Structure Maps**

Five-time structure maps for Permian, Triassic, Jurassic, Paleocene and Eocene horizons were generated to interpret the subsurface configuration like faults, folds and other geological subsurface structures of the Meyal area. The time structure maps generated for Permian to Eocene horizons show the pop-up structure with two major thrust running in NW-SE direction (Figs. 5, 6, 7, 8 and 9). In these maps, like seismic cross section (Fig. 4), the thrust on northern side is present in all the dip lines and its throw is greater as compared to the back thrust. Presence of compressional forces is also confirmed by greater thickness of strata in the center of the structure. Furthermore, the identification of shortage in post Eocene strata in the subsurface is suggest ongoing compression in NPDZ.

TWT decreases in the center of the anticline substantiating the fact that area was uplifted due to India-Asia collision. Moreover, TWT time points to a closure in the center of the structure, therefore all the wells, MYL-10, MYL-12 and MYL-13, were drilled at the crest of up thrown block in Meyal anticline. The shape of the time structure maps generated for five horizons (Permian to Eocene, Figs. 5, 6, 7, 8 and 9) indicate an up thrown structure bounded by the two major thrusts. Moreover, perusal of Permian to Eocene time structure maps show that depth is much greater at eastern side as compared to western side of the anticline. This difference in TWT indicates that the pop-up structure is a plunging anticline. The contours should be deleted to remove the mixing or very close spacing of these or change color and put surface instead of contours.

**Isochron Maps**

Thickness maps depict basin geometry, tectonics and dimensions of sediments at particular level. Such maps help to elucidate models for basin evolution. In present work, four isochron maps were generated for Triassic, Jurassic, Paleocene and Eocene reflectors. Furthermore, the maps were correlated with time and well tops to find the thickness of strata.

**Triassic Isochron Map**

TWT of the seismic waves vary from the 1.043 to -0.063 seconds in the sediments deposited in Triassic time (Fig. 10). The calculated thickness of the Triassic in MYL-13
well is 516ft and TWT is 0.048 seconds. Isochron map generated for this horizon indicates that the thickness of the Triassic rocks varies in core (increases) as well as on limbs (decreases). Moreover, the western axis of the anticline is comparatively thicker than the eastern side. Moreover, three small depressions are also present in Triassic isochron map almost in the center. The depression with maximum thickness of sediments is present in the south of the MYL-12. Rest of the two depressions with less thickness are located in the NW and West of MYL-12, respectively. The probable reason for the depression is that in Triassic times due to some tectonic forces depression like structures were formed and most of the sediments were accumulated in the deeper part.

**Jurassic Isochron Map**

Isochron map generated for Jurassic sediments depicts that thickness of the Jurassic rocks decreases away from the axis of the anticline towards its limbs (Fig. 11). The map also shows that the thickest sediments accumulation is in anticline as compared to all other isochron maps. Moreover, thick northern limb of the anticline is observed. Ongoing tectonic forces resulted in the formation of two depressions located in the west and southwest of the MYL-12 well.

**Paleocene Isochron Map**

In the isochron map of the Paleocene, maximum variations in the thickness of the Paleocene rocks can be seen (Fig. 12). The range of two ways travel time is from 0.020 to 1.115 seconds. The well MYL-12 has also attained more thickness as compared to other wells. Tectonic forces also resulted in the formation of smaller depressions in the study area during Paleocene times.

**Eocene Isochron Map**

The isochron map for the Eocene rocks, a reservoir in Meyal, in terms of TWT (0.045 to 1.079 seconds) indicate that the Eocene rocks are thick in the center of the map, whereas in the northern part compressional forces formed a structure having less thickness as compared to other parts of the study area (Fig. 13).

**Conclusion**

A pop-up structure is identified on the dip lines bounded by a back thrust to the north and fore thrust to the south. Time structure maps display a doubly plunging and faulted anticline. The throw of the back thrust on the northern limb is greater than that of the southern limb of fore thrust substantiating that major forces are from the north due to Himalayan orogeny. Increased thickness
of strata in the center of the anticline indicates Himalayan compressional regime in NPDZ. Shortening in post Eocene strata in the subsurface is indicative of ongoing compression in NPDZ. The results of interpretation show favorable structural trap for economic hydrocarbon exploration in Meyal area.

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