

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 part of Upper Indus Basin located in sub-Himalayas of Pakistan, is famous worldwide for occurrence of large quantity of hydrocarbons. One of its entity Meyal Oil field, located in the NW Potwar sub-basin, is producing hydrocarbons from Jurassic and Tertiary sedimentary rocks. Geographically, Meyal is under the administration of Attock district and is about 107 km from Islamabad. Pakistan Oilfields Limited, was discovered by Meyal Oil field in 1968.

In the present study, IHS software kingdom suite 8.6 was utilized to outline the subsurface structures by interpreting two strike and four dip lines. In addition to this, borehole data pertaining three exploratory wells were used to refine the subsurface interpretation. The data regarding Meyal area was generated by Pakistan Oilfields Limited (POL) in 1997.

The Himalayas epitomize the youngest orogenic belt created by the continent to continent collision of Indian plate to the south and Eurasian plate to the north (Lefort, 1975; Powell, 1979; Yeats and Lawrence, 1984; Burbank and Reynolds, 1988; Jaumé and Lillie, 1988; Pennock et al., 1989; Ahsan and Chaudhry, 2008; Khan et al., 2012). The leading edge of Indian plate subducted beneath Eurasia to create Kohistan Island arc that collided with Eurasia with development of Shyok suture zone in Cretaceous time (Tahirkheli et al., 1979). Owing to this ongoing collision, thrusting migrated towards south creating Main Mantle Thrust (MMT), Main Boundary Thrust (MBT) and Salt Range Thrust (Molnar

and Tapponier, 1975; Gansser, 1981; Kazmi and Jan, 1997) (Fig. 1).

The Salt range thrust being the youngest marks the southern boundary of the Salt Range (Jaumé and Lillie, 1988). The Salt range fold and thrust belt is active tectonically with an average convergence rate of about 3.7-4.5 cm/yr (Lillie et al., 1987; Burbank and Reynolds, 1988; Jaumé and Lillie, 1988) and rises along the Salt Range Thrust exposing Eocambrian sediments against alluvial deposits of Punjab plains. In a study, Yeast 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 Reynolds, 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.

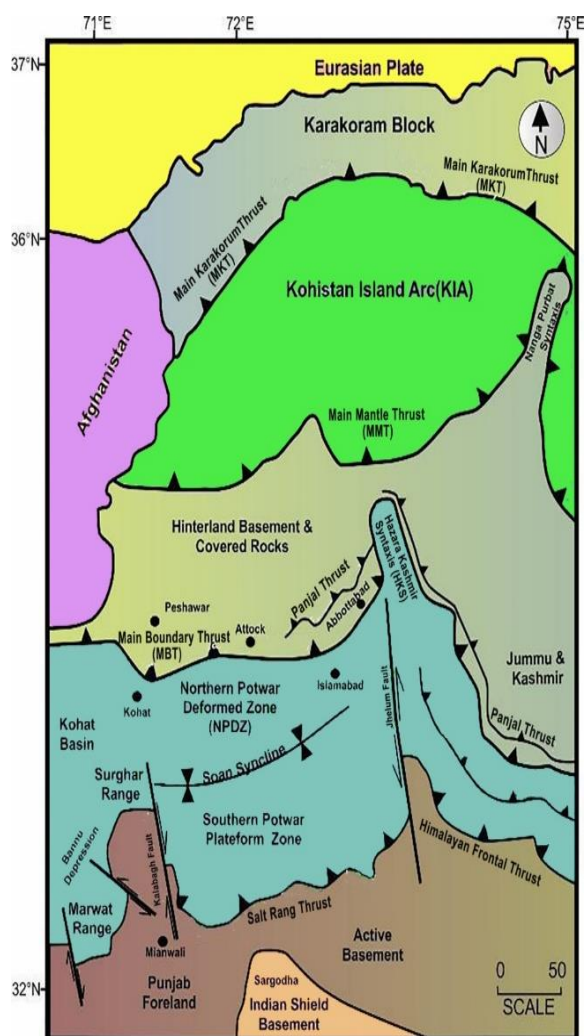


Fig. 1 Generalized tectonic map of northern Pakistan showing the major divisions of Himalayas modified from Gansser (1981) and Kazmi (1982).

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).

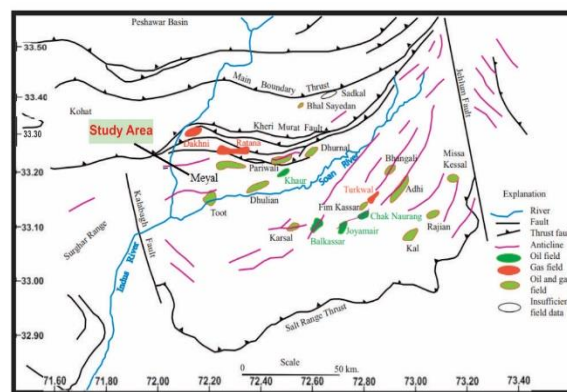


Fig. 2 Generalized oil and (or) gas field and structure map of Kohat-Potwar area including study area (modified after Wandrey et al., 2004 and Kazmi, 1982).

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 Mehal 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 Mehal 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 Mehal area, Chorgali and Datta formations are main oil producing reservoirs. Shami and Baig (2002) indicate that Himalayan orogyny related deformation has introduced fracture porosity, particularly along the fold axis of the anticlines. This fact is substantiated by high porosities in wells of north western Potwar. In Mehal 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 Mehal area, the shales of Kuldana, Namaml and Datta formations are proven seal horizons (Hasany and Saleem, 2021).

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 – Miocene	Chinji	Claystone and sandstone with stlstone			
Miocene	Kamlial	Sandstone and clay stone			
	Murree	Claystone, sandstone, conglomerates and shales			
Eocene	Kohat	Limestone			
	Kuldana	Shale			●
	Chorgali	Limestone and shale	●	●	
	Sakesar	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	●	●	

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.

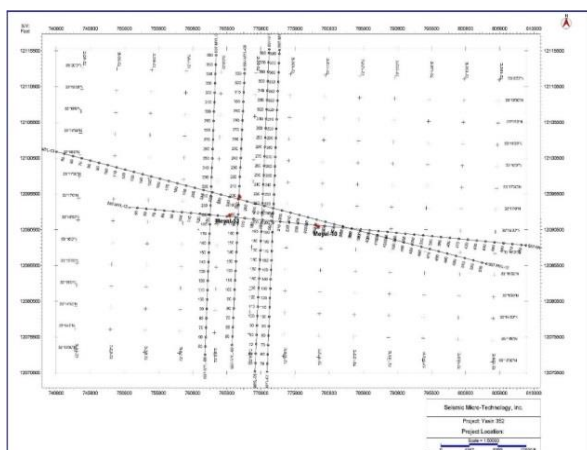


Fig. 3 Showing the orientation of seismic lines and well locations.

On seismic lines, five prominent reflecting surfaces were identified from the base to top to delineate various formations coupled with information of subsurface depths depicted by borehole logs. Velocity analysis and structural features were interpreted followed by time to

depth conversion of the seismic data. In order to refine the subsurface picture, geo-seismic cross-sections and structural contour maps for subsurface seismic analysis were prepared. In addition to this isochron maps were generated using two-way travel time (TWT) for base reflector and the reflector representing the top horizon. For seismic interpretation and isochrones, IHS Kingdom suite were utilized in the present study.

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.

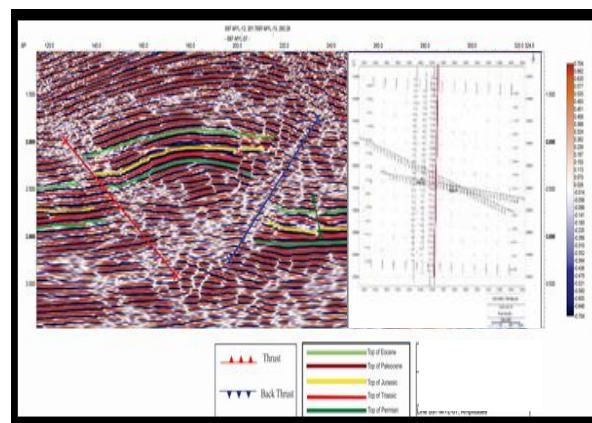


Fig. 4 NS oriented seismic cross section (97-MYL-07) showing pop up structure.

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.

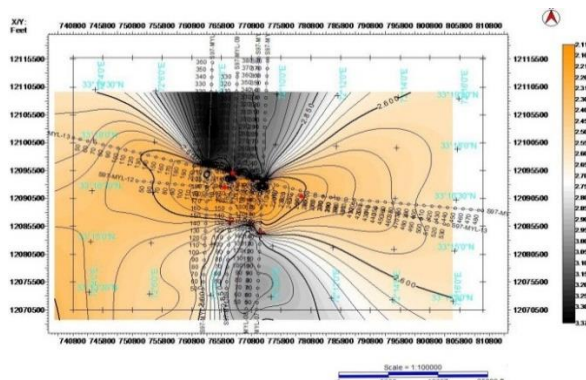


Fig. 5 Time structure map of the top of Permian.

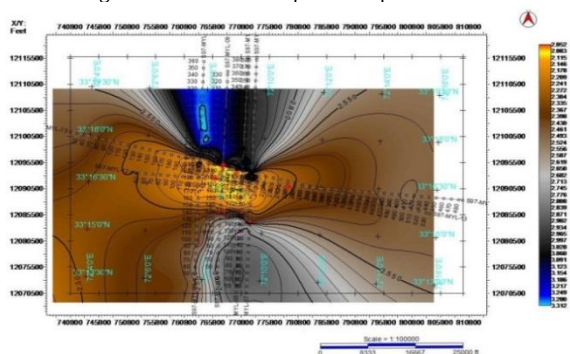


Fig. 6 Time structure map of the top of Triassic.

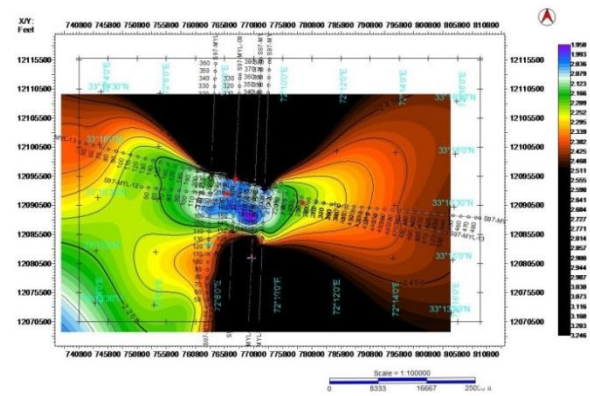


Fig. 7 Time structure map of the top of Jurassic.

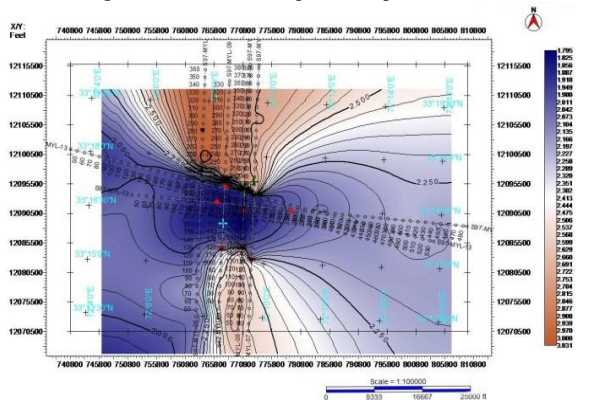


Fig. 8 Time structure map of the top of Paleocene.

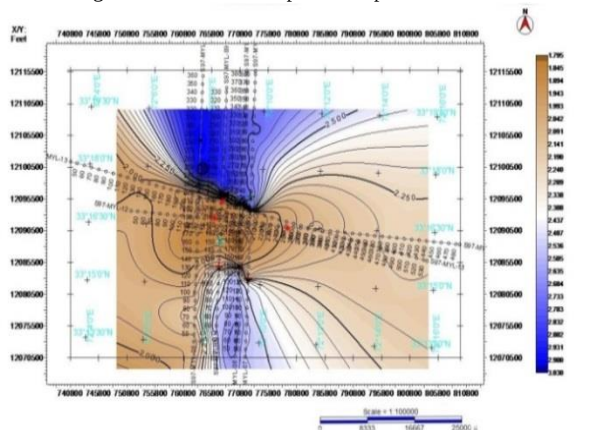


Fig. 9 Time structure map of the top of Eocene.

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.

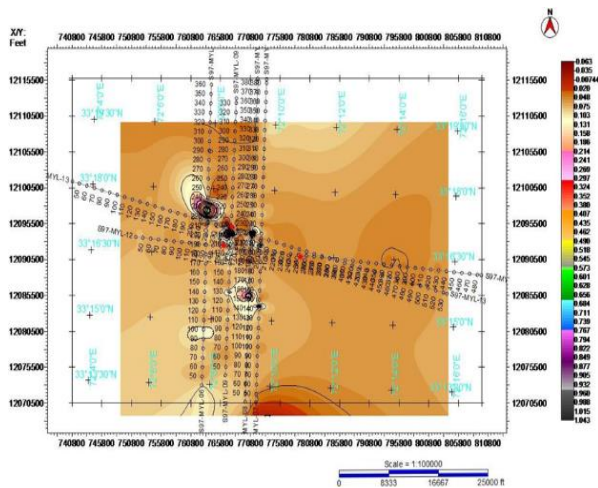


Fig. 10 Isochron map of Triassic.

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.

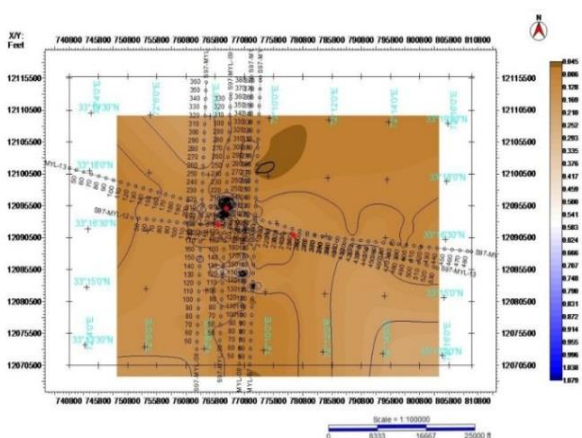


Fig. 11 Isochron map of Jurassic

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.

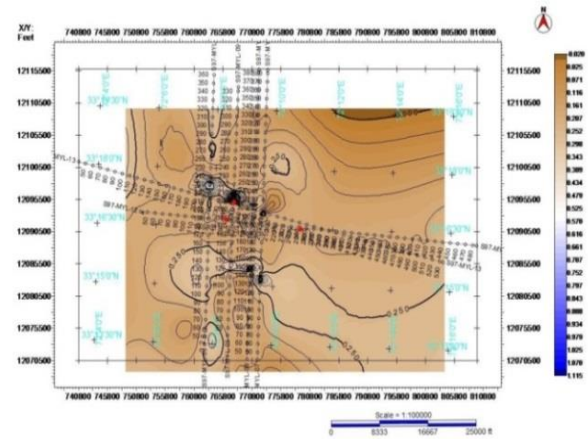


Fig. 12 Isochron map of Paleocene.

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).

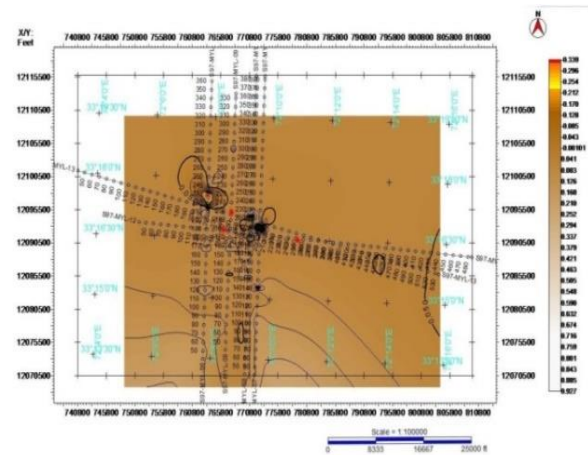


Fig. 13 Isochron map of Eocene

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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References

- Ahsan, N., M. N. Chaudhry, (2008). Geology of Hettangian to Middle Eocene Rocks of Hazara and Kashmir Basins, Northwest Lesser Himalayas, Pakistan. *Geological Bulletin Punjab University*, **43**, 131-152.
- Burbank, D.W., Raynolds, R.G.H. (1988). Stratigraphic keys to the timing of deformation: An example from the northwestern Himalayan foredeep. In C. Paola and K. Kleinspater, (eds.). *New perspectives in basin analysis* Springer-Verlag, New York, 331-351.
- Gansser, A. (1981). The geodynamic history of the Himalaya, in Zagros, Hindu Kush. In Gupta, H. K. and Delany, F. M. (Eds.) *Himalaya-Geodynamik Evolution*. Geodynamik Series 3. *American Geophysical Union*, 111-121.
- Gee, E. R. (1989). Overview of the Geology and structure of the Salt Range, with observations on related areas of northern Pakistan. *Geological Society of America*, Special Paper, **232**, 95-112.
- Gluyas, J., Swarbrick, R. (2009). *Petroleum Geoscience*, Wiley, London, 1-376.
- Hasany, S. T., Saleem, U. (2012). An integrated subsurface geological and engineering study of Meyal field, Potwar Plateau, *Annual Technical Conference* Pakistan Association of Petroleum Geoscientists, Islamabad.
- Jadoon, I. A.K., Frisch, Kemal, W. A., Jaswal, T. M. 1997. Thrust geometries and kinematics in the Himalayan foreland (north Potwar deformed zone), north Pakistan. *Geologische Rundschau*, **86**, 120-31.
- Jadoon, I.A.K., Frisch, W., Jadoon, S.K. (2008). Structural traps and hydrocarbon exploration in the Salt Range/Potwar Plateau, North Pakistan. *Annual Technical Conference* Pakistan Association of Petroleum Geoscientists, Islamabad.
- Jaswal, T., Lillie, R.J., Lawrence, R.D. (1997). Structure and evolution of northern Potwar deformed zone, Pakistan. *AAPG Bulletin*, **81**(2), 308-328.
- Jaumé, S.C., Lillie, R.J. (1988). Mechanics of the Salt Range- Potwar Plateau, Pakistan: A fold-and-thrust belt underlain by evaporates. *Tectonics*, **7**, 57-71.
- Kadri, I.B. (1995). *Petroleum geology of Pakistan*. Pakistan Petroleum Limited, Karachi, Pakistan, 275 pages.
- Kazmi, A.H., Rana, R.A. (1982). Tectonic map of Pakistan. Geological Survey of Pakistan, scale: 1:2,000,000.
- Kazmi, A.H., Jan, M.Q. (1997). *Geology and tectonics of Pakistan*; Graphic Publishers, Karachi, 545 pages.
- Khan, M.A., Rehman, S.U., Ahsan, N. (2012). Geology and geochemistry of Sumalampibolites, Kamila amphibolite unit, southeast Kohistan, *Pakistan. Int. J. Agric. App. Sci.*, **4**(2), 299-111.
- Khawaja, A.A., Lisa, M. (2005). Seismic activity in the western extension of Salt Range. *Pakistan Journal of Meteorology*, **2**(3), 35-39.
- LeFort, P. (1975). Himalayas collided range present knowledge of continental arc. *American Journal of Science*, **75**(A2), 1-44.
- Lillie, R.J., Johnson, G.D., Yousaf, M., Zamin, A.S.H., Yeats, R.S. (1987). Structural development within the Himalayan foreland fold-and-thrust belt of Pakistan. In: *Sedimentary basins and basins forming mechanisms* Beaumont and Tankard, (eds.). *Canadian Society of Petroleum Geologists*, **12**, 379-392.
- McDougall, J.W., Khan, S.H. (1990). Strike slip faulting in a foreland foldthrust belt: the Kalabagh fault and western Salt Range, Pakistan. *Tectonics*, **9**, 1061-1075.
- Moghal, M.A., Hameed, A., Saqi, M.I., Bugti, M.N. (2007). Subsurface geometry of Potwar Sub-basin in relation to structuration and entrapment. *Annual Technical Conference* Pakistan Association of Petroleum Geoscientists, Islamabad.
- Molnar, P., Tapponier, P. (1975). Cenozoic Tectonics of Asia: Effects of a continental collision: *Science*, **189**, 419-426.

- Lisa, Mona., Khwaja, A.A. (2004). Structural trends and focal mechanism studies in the Potwar area with special emphasis on hydrocarbon exploration. *Pakistan Journal of Hydrocarbon Research*, **14**, 49-60.
- Pennock, E.S. (1988). Structural interpretation of seismic reflection data from the eastern Salt Range and Potwar Plateau, Pakistan. Corvallis Oregon State University, M.S. Thesis, 55 pages.
- Pennock, E.S., Lillie, R.J., Zaman, A.S.H., Yousaf, M. (1989). Structural interpretation of seismic reflection data from eastern Salt Range and Potwar Plateau, Pakistan. *AAPG Bulletin*, **73**, 841-857.
- Powell, C. McA, (1979). A Speculative tectonic history of Pakistan and surroundings: Some constraints from the Indian Ocean in Geodynamics of Pakistan. Farah, A., DeJong, K.A. (eds.), Geological Survey of Pakistan, Quetta, Pakistan, 5-24 pages.
- Raza, H.A., Ahmed, R., Alam, S., Ali, S.M. (1989). Petroleum zones of Pakistan. *Pakistan Journal of Hydrocarbon Research*, **1** (2), 1-19.
- Shah, S.M.I. (1977). Stratigraphy of Pakistan. *Geological Survey of Pakistan*, **12**, 122 pages.
- Shah, S.M.I. (2009). Stratigraphy of Pakistan. *Geological Survey of Pakistan*, **22**, 1-381.
- Shami, B.A., Baig, M.S. (2002). Geomodeling for the enhancement of hydrocarbon potential of Joya Mair field (Potwar), Pakistan. PAPG-SPE Annual Technical Conference, 124-145 pages.
- Tahirkheli, R.A.K., Mattauer, M., Proust, F., Tapponier, P. (1979). The India–Eurasia suture zone in northern Pakistan: Some new data for interpretation at plate scale. In Geodynamics of Pakistan. Farah, A., DeJong, K.A. (eds.), *Geological Survey of Pakistan*, Quetta, 251 pages.
- Telford, W.M., Geldort, L.P., Sheriff, R.E. (1990). Applied Geophysics (second edition). *Cambridge University Press*, 1-759 pages.
- Wandrey, C.J., Law, B.E., Shah, H.A. (2004). Patala-Nammal composite total petroleum system, Kohat-Potwar Geologic province, Pakistan. *U.S. Geological Survey Bulletin*, 2208-B
- Yeats, R.S., Lawrence, R.D. (1984), Tectonics of the Himalayan thrust belt in northern Pakistan, in Haq, B.U., Milliman, J.D. (eds.), Marine geology and oceanography of the Arabian Sea and coastal Pakistan, New York, Van Nostrand Reinhold.