Precise Seismic Substructural Model of the Eocene Chorgali Limestone in the Turkwal Oil Field, Central Potwar, Pakistan

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Abstract: The precise seismic substructural interpretation of the Turkwal oil field in the Central Potwar region of district Chakwal of Pakistan has been carried out. The research work was confined to the large fore-thrust that serves as an anticlinal structural trap through ten 2D seismic lines. A precise seismic substructural model of the Eocene Chorgali Limestone with precise orientation of thrust and oblique slip faults shows the presence of a huge fracture, which made this deposit a good reservoir. The abrupt surface changes in dip azimuth for the Eocene Chorgali Limestone verifies the structural trends and also the presence of structural traps in the Turkwal field. The logs of three wells (Turkwal deep X-2, Turkwal-01 and Fimkassar-01) were analyzed for petrophysical studies, well synthetic results and generation of an Amplitude Versus Offset (AVO) model for the area. The AVO model of Turkwal deep X-2 shows abrupt changes in amplitude, which depicts the presence of hydrocarbon content. Well correlation technique was used to define the overall stratigraphic setting and the thickness of the reservoir formation in two wells, Turkwal-01 and Turkwal deep X-2. The Eocene Chorgali Limestone in Turkwal-01 is an upward thrusted anticlinal structure and because of the close position of both wells to the faulted anticlinal structure, its lesser thickness differs compared to Turkwal deep X-2. The overall results confirm that the Turkwal field is comparable to several similar thrust-bound oil-bearing structures in the Potwar basin.

Key words: 2D seismic, well correlation, fore-thrust structural traps, AVO model, Eocene Chorgali Limestone and Basement, Potwar

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1 Introduction

Study of the 2D/3D seismic data is an opportunity to image effectively drained hydrocarbon reservoirs and provides key physical parameters of subterranean rock formations for geophysicists, geologists and engineers (Raza et al., 1989; Khan and Raza, 1986). Van der Pluijm and Marshak (1997) have developed seismic and structural imaging techniques and investigate their application to a spatial resolution scale (Khan et al., 2018). Seismic structural modeling is a science that precisely determines (Miller, 1996): 1) the shape and strength of reflectors; 2) geological information at target depth; and 3) the arrival time of seismic waves (through reflection or refraction survey) from the earth's surface.

Different geophysical methodologies (i.e., attributes analysis, petrophysical analysis, fluid substitution technique and AVO analysis) have been used for: 1) confirmation of subsurface structures; 2) lithologies and reservoir approximation; and 3) finding zones amenable to fractures that fall below seismic resolution, etc. (Rijks and Jaufred, 1991; Khan et al., 2018).

Several researchers have investigated the tectonically unstable Central Potwar basin of Pakistan and considered it as a highly active seismic region (Schoeppel, 1977; Ambrasseys and Bilham, 2003; George, 2006; Sercombe et al., 1998). The Turkwal oil field, within the Central Potwar basin, is very significant in all features, i.e., from geological, geophysical and seismological points of view. The Turkwal field (Fig. 1) is one of the most productive oil fields of the Central Potwar basin. It is adjacent to the Fimkassar, Mianwali and Adhi oil fields in the Potwar fold and thrust belt. The geological structures present in the study area are extremely fractured because the geology has been under the action of strong compression with an oblique convergence regime (Jadoon et al., 1999). The NE–SW oriented faults in the area are evidence of oblique fractures (Iqbal and Ali, 2001). Therefore, Turkwal is a thrust-bounded oil-bearing structure. This study focuses on the delineation of large structural features, generated in the strata due to tectonic forces, in the Turkwal oil field using 2D seismic data and well log interpretation results to correlate for a 3D

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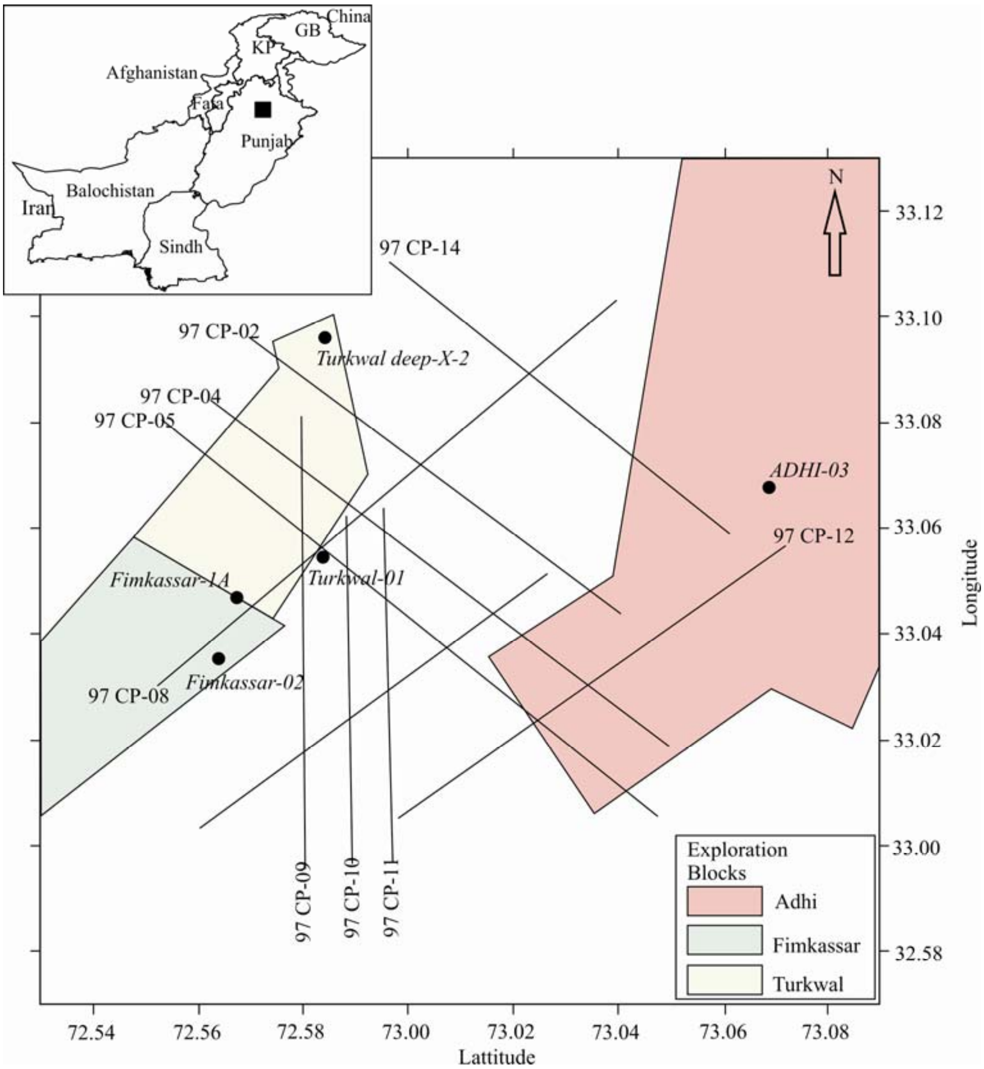

Fig. 1. Descriptive base map showing the exportation blocks in the studied area.

structural model. These structural features can act as a trap for hydrocarbons. Also, a 3D fault model and an AVO model (using well data) were developed to confirm the occurrence of a hydrocarbon (gas) zone.

2 Geology and Tectonics

The Turkwal oil field is located in the Central Potwar basin. The Kalachitta and Margala hills bound the basin to the north, the Indus River and the Kohat Plateau to the west, while the Jhelum River and the Hazara-Kashmir Syntaxis (HKS) cover the basin at its eastern side.

In the study area the Nagri and Chinji formations are exposed, with rocks of Miocene to Pliocene age (Coward and Buttler, 1985). The top upper layer is overlain by the Siwalik sequence, although in places Upper Eocene shale and limestone crop out locally in folded inliers (Kadri, 1995). The tectonic thrust plays an important role in the study area. The east–west trending faults were generated as a result of compressional forces and the internal pop-up was generated by the younger anticlockwise rotational movement of the Indian plate (Kadri, 1995; Moghal et al., 2007). The Turkwal area has structural variation from compartment to compartment due to its different nature and the direction of stresses (Fig. 2). Cambrian, Permian, Jurassic, Paleocene and Eocene reservoirs produce oil in the Turkwal area (Shami and Baig, 2002). The fractured carbonates of the Sakesar and Eocene Chorgali formations are the major producing reservoirs. The gray shales of the Mianwali, Datta and Patala formations are potential source rocks. The Kuldana Formation acts as a cap to the Turkwal oil field. The clay and shale of the Murree Formation also provides efficient vertical and lateral seals to the Eocene reservoirs in the area (Kadri, 1995).

3 Data Used

With the courtesy of the Directorate General of Petroleum Concession (DGPC), 2D post stack seismic data of lines 97-CP-01, 02, 04, 05, 09, 10, 14 trending to NW–SE and N–S are used. Well data comprise *Turkwal Deep X-2, Turkwal Deep 01, Fimkassar -1A, and Fimkassar -02.*

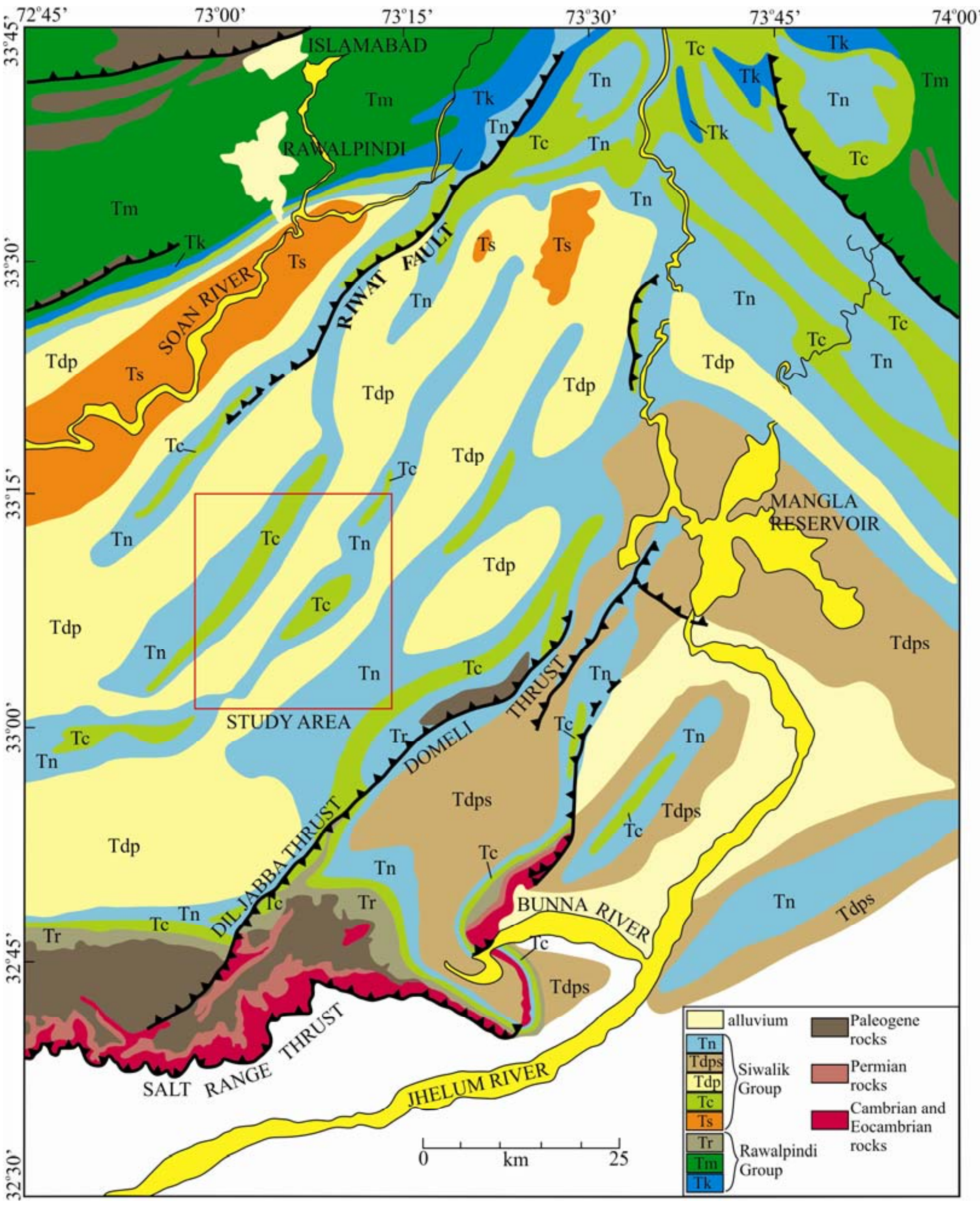

Fig. 2. Geological map of Potwar Turkwal Oilfield (modified from Gee,1980).

4 Materials and Methods

4.1 Seismic interpretation

Seismic interpretation is a geophysical and geological mean, mostly used for determining subsurface structures (Mitchum et al., 1977; Hardage and Remington, 1999; Pennington et al., 2004). The seismic interpretation technique was applied on processed post-stack 2D seismic data for structural modeling in this study. Two horizons, the Eocene Chorgali Limestone and the Top Basement were chosen and mapped throughout the study area, and these were the exploration objectives of this study. The Eocene Chorgali top horizon is marked by a very strong reflector beneath the Kohat Formation, i.e., the Eocene Top, which is correlated across the synthetic seismogram of three wells: Turkwal Deep X-2, Turkwal-01 and Fimkassar 1A. Turkwal-01 well is located at the seismic line 97-CP-08, and correlated through the loops across the entire area. Near the top, the Top Basement horizon was chosen as a strong to weak amplitude event with good to poor continuity, which is represented by the lowermost strong amplitude event.

The major fore-thrust in the area, marked as F1 (Fig. 3), plays a major role in the overall structural setting of the area, and other small faults, F2, F3 and F4, are marked in the Chorgali horizon. The Basement horizon also includes a major normal fault, termed as BF1 (Fig. 3); however, minor faults BF2 and BF3 are also marked.

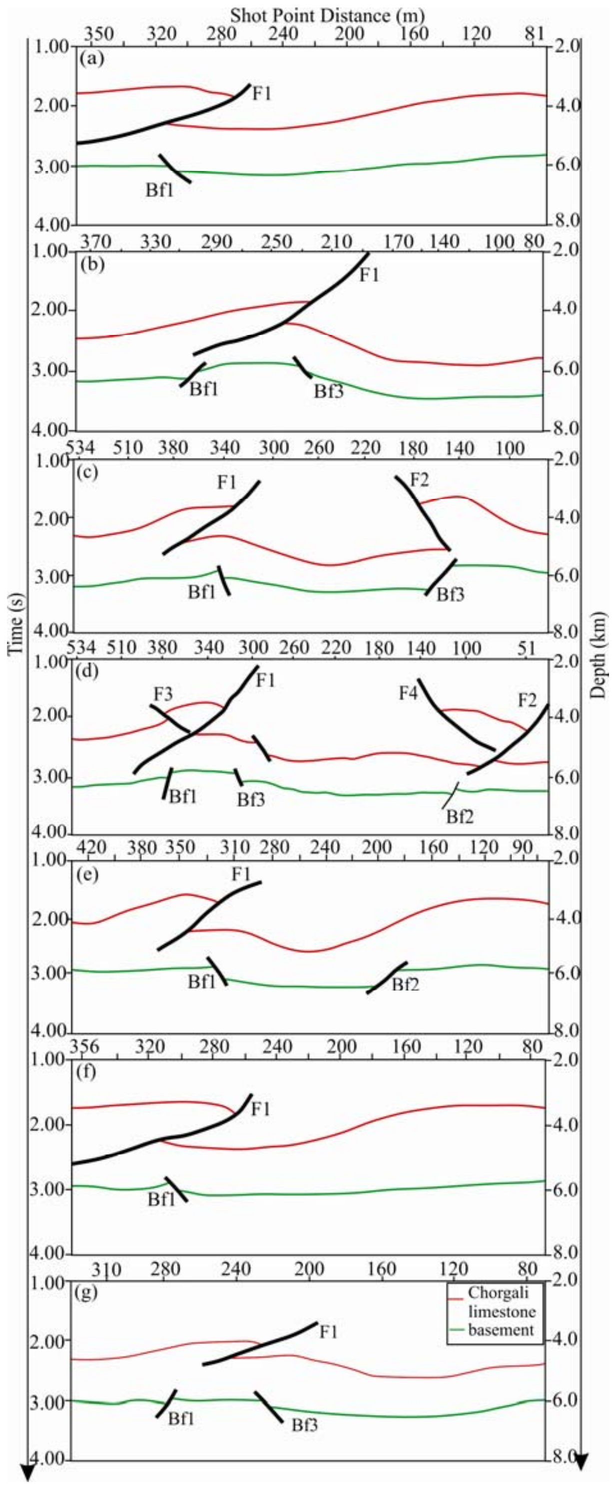

Fig. 3. Interpreted seismic lines with time and depth scale.
(a) 97-CP-01; (b) 97-CP-02; (c) 97-CP-04; (d) 97-CP-05; (e) 97-CP-09; (f) 97-CP-10; (g) 97-CP-14; F1, Major fault line; F2-F4, Minor fault line; BF1-BF3, Normal fault line.

4.2 Synthetic seismogram

A Ricker wavelet of 30Hz was used for the generation of the synthetic seismogram (Fig. 4). The velocity curve for Turkwal-01 well was generated by using sonic values of the log data using the inverse relationship (Fig. 4) where velocity =1/Sonic travel time.

The pseudo-density curve for Turkwal-01 was created following a built-in empirical relationship in the geophysical software Petrel. The constants were used as standard values for clastic environments. More representative values were required to be calibrated for local lithologies.

4.3 Three-dimensional time and depth contour map

Basic goals included contouring the time and depth structure maps and finding structural traps. In this respect, contour maps of time and depth ware prepared for Chorgali horizon at the scale of 1:41, 000 (Fig. 5). Time values are picked from time sections and plotted against every 20th shot point. Time contour map of Top Eocene Chorgali Limestone covering the whole Turkwal area and extending over to the eastern well-defined anomaly. Some prominent features were defined: 1) the highest closing contour for the main Turkwal structure is 2700 milli sec., which shows the structural trap; 2) in the west of the main Turkwal structure there could be a separate small structural high isolated by a die-out fault and more data is needed to clarify this feature.

Depth values were calculated using the relationship $S=V' t/2$, where V is the average velocity of the horizons obtained through well formation tops of the available three wells. The manual depth map for the Top Chorgali Limestone was prepared at the scale of 1:41,000 with respect to mean sea level (Fig. 5).

4.4 AVO well model and well correlation

Several studies (e.g., Ostrander, 1984; Rutherford and Williams, 1989; Castagna et al., 1998; Pramanik et al., 2000; Cambois, 2000; Goodway, 2001; Roden et al., 2005; Rizwan et al., 2018) have been carried out for oil and gas exploration using AVO techniques during the last three decades. All of them have witnessed the use of this technique as a powerful tool of P-wave reflection coefficient at the reflection interfaces of the reservoir and the surrounding sediments, as in the Aki and Richards (1980) equation (practically approximated to Zeoppritz's 1919 equation) for pore fluid type and reservoir lithology.

The AVO model for the Turkwal oil field was generated using sonic porosity and Poisson ratio value for the two wells, Turkwal-01 and Turkwal Deep X-2. The AVO well model (Fig. 6) indicates the top and base of the Eocene Chorgali Limestone with variation of amplitude with depth. The abrupt changes in amplitude were indicative of hydrocarbon content in reservoir formation i.e., differences in lithology and fluid content in the rocks above and below the Chorgali Horizon.

In this study, the well to well correlation technique was applied to define the overall stratigraphic setting of the area as well as the thicknesses of the reservoir formation in Turkwal-01 and Turkwal deep X-2 wells (Fig. 7). The Eocene Chorgali Limestone in Turkwal-01 was thrusted upward due to the thrusted anticlinal structure of the area. The thickness of the Eocene Chorgali Limestone in both wells did not differ with distance because of the close position of the wells around the faulted anticlinal structure.

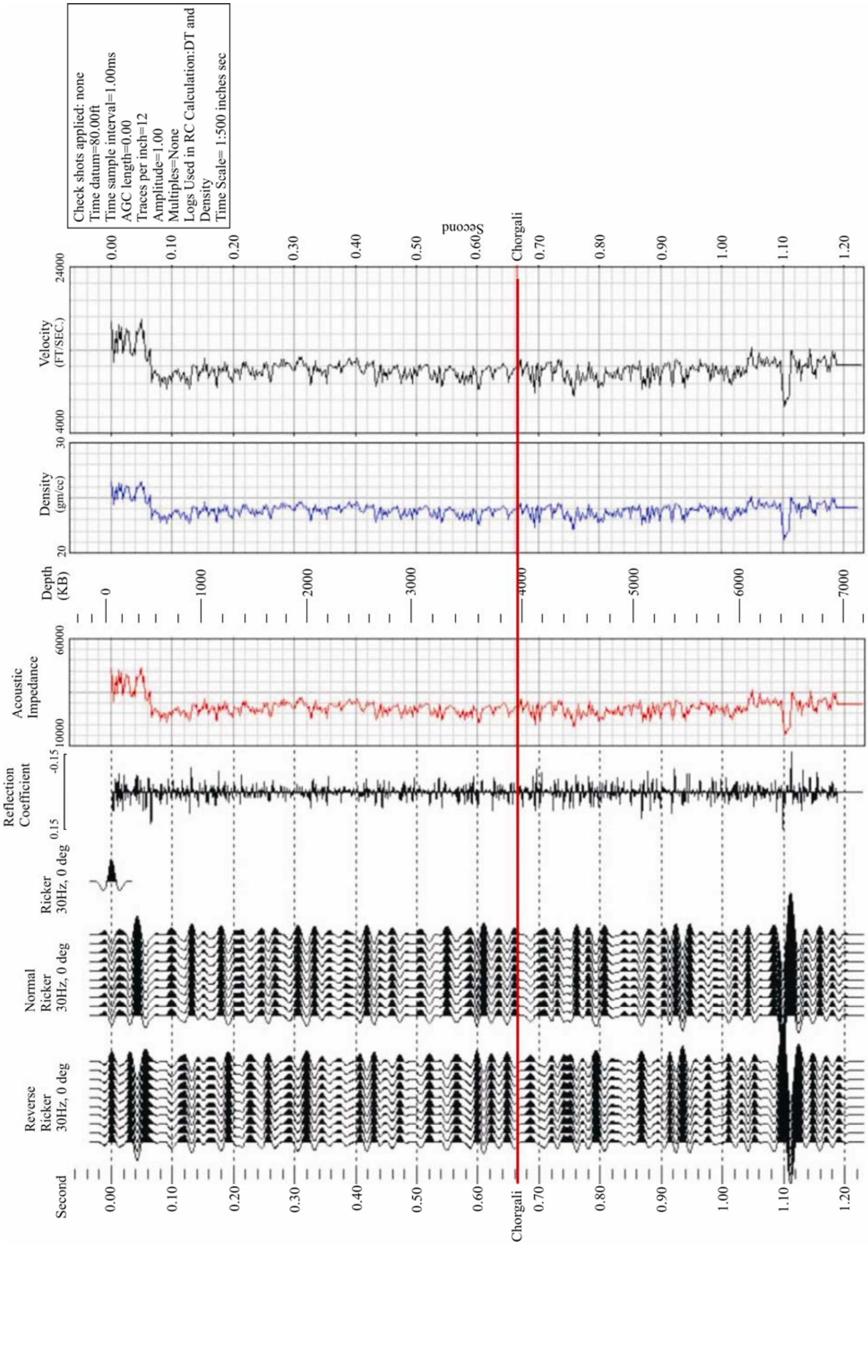

Fig. 4. Synthetic seismogram for Turkwal-01 well. Eocene Chorgali Limestone was located at 0.67 sec.

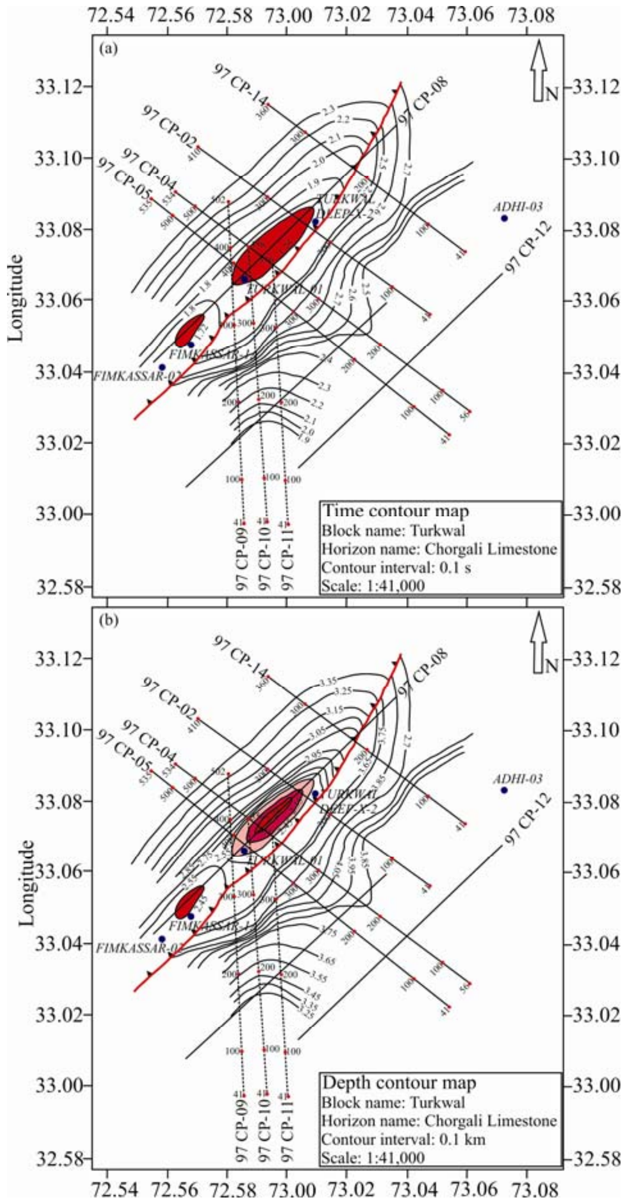

Fig. 5. Contour map of the Top Chorgali Limestone. (a) Time Contour map and (b) depth contour map. The red portion shows the popup structure acts as hydrocarbon accumulation trap zone, Turkwal Deep X-02 well is also placed on this structure.

4.5 Structural mapping of Eocene Chorgali Limestone

Evaluation of the structural setting was carried out through software using 2D seismic SEG-Y data along with '.las' extension files of wells for reservoir modeling of the Eocene Chorgali Limestone (Fig. 8). A better horizon marking resulted from the presence of manual seismic section works as well as formation tops of the Turkwal wells in the area. Horizons were marked in all seven seismic lines for the Eocene Chorgali Limestone as well as the Top Basement.

The next step was the marking of faults in the area from known geology and manual interpretation. The area had highly compressional forces so all major fore-thrust with minor thrusts were marked. The major fore-thrust F1 with minor faults F2 and F3 (Fig. 8) were marked with precise accuracy due to the high reflection nature of the Chorgali horizon in the seismic lines.

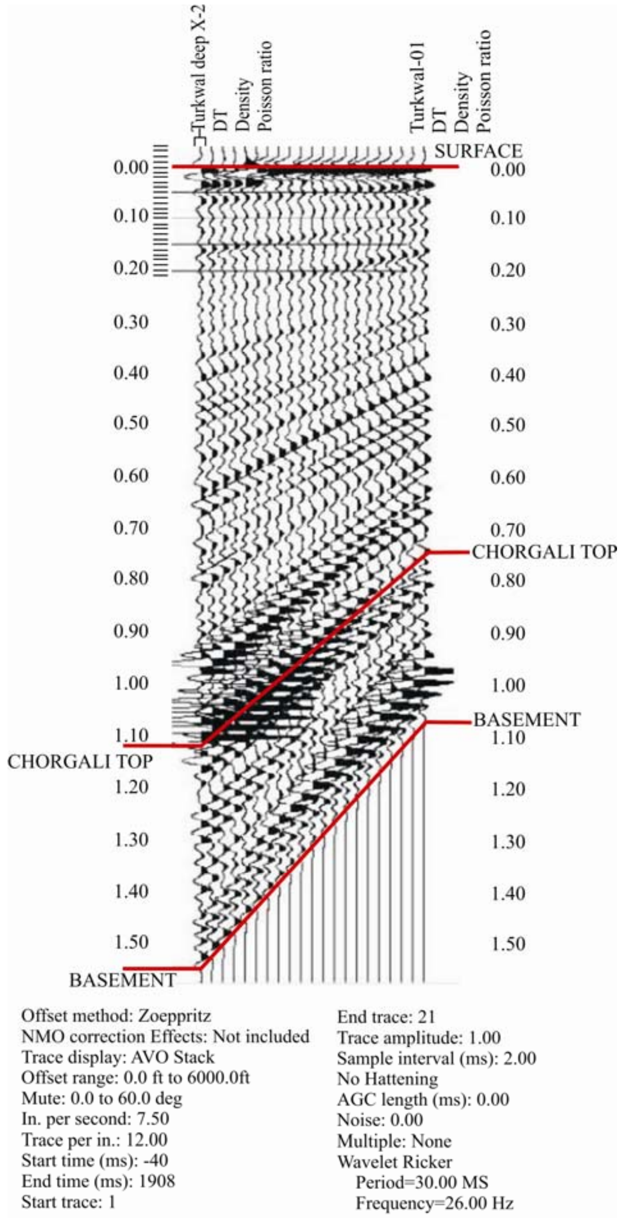

Fig. 6. Turkwal AVO Well Model in Turkwal Deep X-02 and Turkwal-01 wells.

5 Results and Discussion

5.1 Time and depth contouring

The time contoured Chorgali horizon surface map (Fig. 5) indicates the presence of a major fore-thrust fault on eastern flank of the anticlinal structure. Note that, the orientation of the fore-thrust is trending NE–SW. The time contour Chorgali surface was converted to depth units for better visualization of structural features of the Eocene Chorgali Limestone, as all measurements were made in depth units.

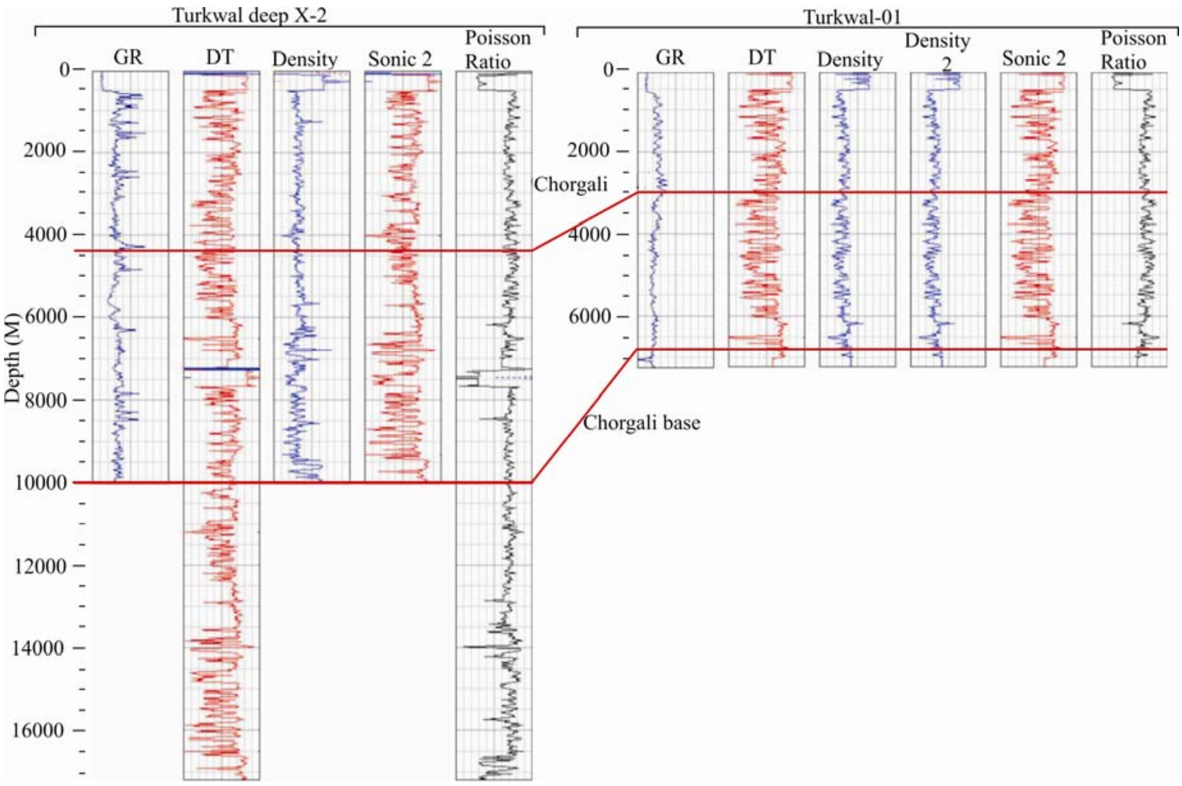

Fig. 7. Well correlation between Turkwal Deep X-2 and Turkwal-01. Eocene Chorgali Limestone is identified at depth of 4100 m in Turkwal Deep X-02 and at 2200 m in Turkwal-01 well.

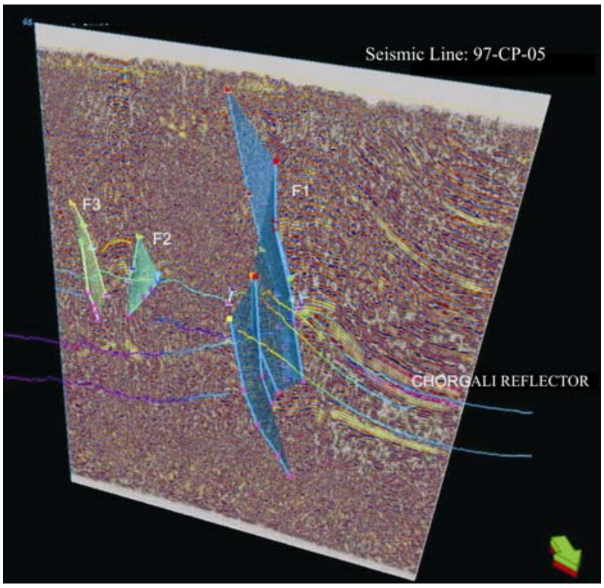

Fig. 8. Reflectors are marked on seismic line 97-CP-05 in Petrel software with major fore-thrust (F1) and minor thrust fault (F2, F3) in Eocene Chorgali Limestone.

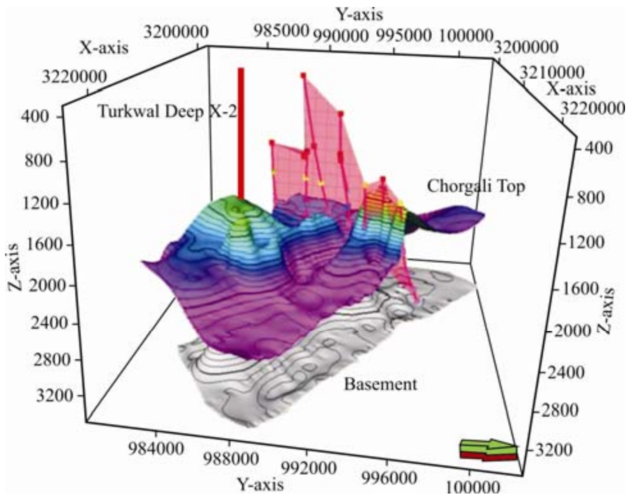

Fig. 9. The 3D depth contour map of Eocene Chorgali Limestone indicates the overall setting of the reservoir and presence of fore-thrust fault. Figure also represents the location of Turkwal Deep X-02 well at popup structure at highest closing contour interval of 2.7 second.

The depth contour map of the Eocene Chorgali Limestone indicates the overall setting of the reservoir and its structural complexities due to the presence of a fore-thrust fault. The highest closing contour interval of 2500 milli sec. (Fig. 5) is present in the area and abrupt changes in contour interval on its central to northwestern part in the map are clear indications of a major fault, which can be verified in the depth contoured surface map (Fig. 9).

5.2 Dip Azimuth surface map for Eocene Chorgali Limestone

The dip azimuth surface for Eocene Chorgali Limestone verifies the structural trends as indicated by depth surface

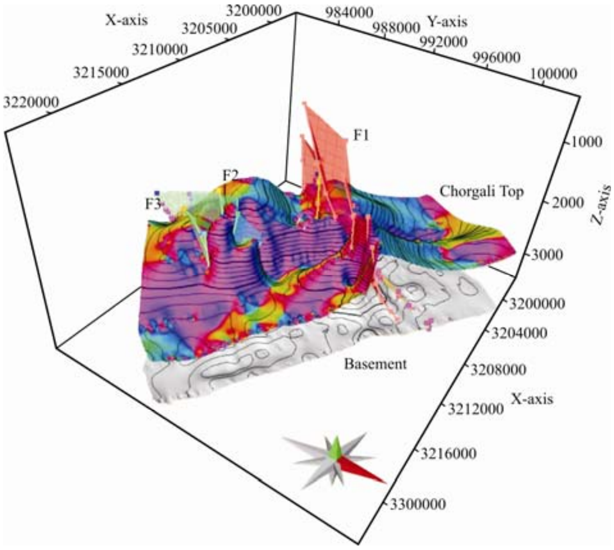

Fig. 10. Dip Azimuth contour map for Eocene Chorgali surface. The contour map indicates high dipping values around the fore-thrust fault F1 and minor faults F2 and F3.

and also verifies the presence of structural traps in the area by showing rapid changes in dip azimuth value in the Turkwal oil field. It is noted that, the contoured map for dip azimuth of the reservoir indicates high dipping values around the fore-thrust fault F1 and minor faults F2 and F3 (Fig. 10) which also verifies the fault exact orientation in the area.

5.3 Structural model for Eocene Chorgali Limestone

The time and depth contoured surface and the fore-thrust model helped in determining the exact structural interpretation of the Eocene Chorgali Limestone. The structural model was first generated for the top middle and bottom layers of the Eocene Chorgali Limestone to provide the basic platform for the structural model (Fig. 11). It is noted that due to the fore-thrust fault the northwestern portion of the Eocene Chorgali Limestone has been uplifted, which indicates that the main source for the structural trend of the Chorgali Limestone in the Turkwal field is a NE–SW trending fore-thrust. The anticlinal traps produced due to the counter-clockwise movement are the main source for accumulation of hydrocarbons in the area (Fig. 11). The minor faults also help in the formation of structural traps such as popup structures where accumulation of hydrocarbons is well suited. The Turkwal Deep X-2 well is situated at one of these popup structures (Pennock et al., 1989) bounded by minor thrust faults F2 and F3 (Fig. 11).

The Turkwal structural features are integrally related to the regional structural development of the area. Therefore, fractures are controlled by the tectonic/structural style of an area and this structural model would have a major impact on future exploration and development of the Turkwal field.

5.4 Volumetric model for Eocene Chorgali Limestone

The top middle and basal layers for the Eocene Chorgali Limestone (Fig. 11) were used to construct the volumetric model (Fig. 12). This model displays the volumetric extent of the Chorgali reservoir in the area covering all the vertical and horizontal thicknesses.

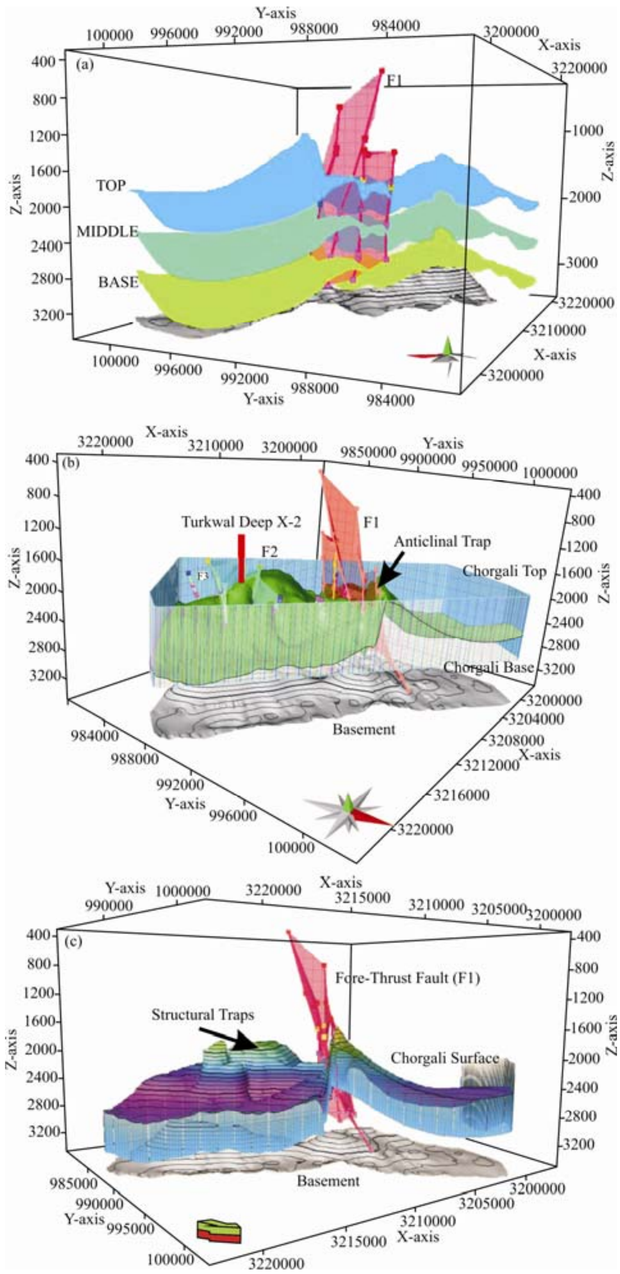

Fig. 11. Structural model for Eocene Chorgali Limestone with. (a) The top, middle and base layer used to construct the volumetric model; (b) Reservoir structural setting, the anticlinal traps are the main source for accumulation of hydrocarbons in the area; and (c) The complete structural model.

5.5 Well correlation

The Chorgali base well model showed an inclined nature, which is due to the thrusted anticlinal structure in the area. The Turkwal Well model not only indicates the amplitude variation for hydrocarbon content but also reflects the overall structural setting of the reservoir. The

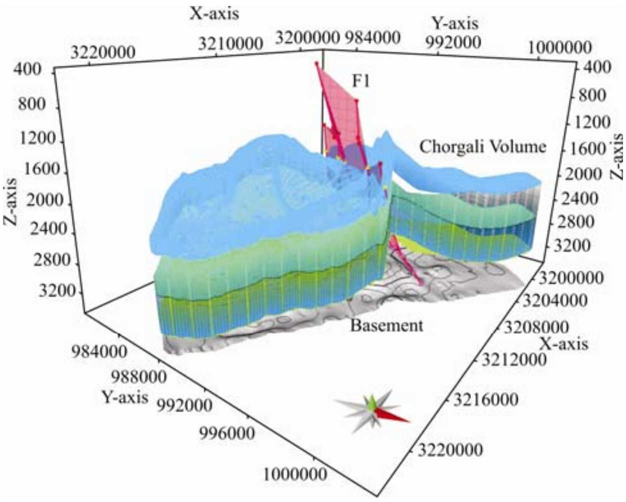

Fig. 12. Volumetric model for Eocene Chorgali Limestone, the model displays the volumetric extent of the reservoir and covers the vertical and horizontal thickness.

abrupt change in amplitude (Fig. 7) is present in Turkwal Deep X-2, which indicates its more productive nature than any other well.

6 Conclusions

The following conclusions were made for the Turkwal oil field:

(1) The results confirmed that the field is one of a number of similar thrust-bounded oil-bearing structures in the Potwar basin.

(2) Turkwal Deep X-2 and Turkwal-01 showed varying thrusting and uplifting of strata. Turkwal-01 is more thrusted and uplifted than Turkwal Deep X-2.

(3) The thickness of the Eocene Chorgali Limestone did not show varying range.

(4) The Chorgali top was recorded around 2500–3000 meter.

(5) The Turkwal AVO model indicates the top and base of the Eocene Chorgali Limestone with variation of amplitude with depth. The abrupt changes in amplitude, differences in lithology and fluid content in the rocks above and below the Eocene Chorgali Limestone are indicative of hydrocarbon content in reservoir formation.

(6) Turkwal Deep X-2 showed abrupt change in amplitude which depicted the presence of hydrocarbon content.

(7) Normal faulting at basement can be related with early extension and plate drifting.

(8) The fore-thrust fault F1 is the major fault in the area and it plays a vital role in overall structural setting of the reservoir. The fore-thrust fault cuts the anticlinal portion of the reservoir trending NE–SW and serves as a structural trap for the accumulation of hydrocarbons.

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References

Aki, K., and Richards, P.G., 1980. Quantitative Seismology: Theory and Methods. San Francisco: W. H. Freeman and Co., 932 pp.

Ambrasseys, N., and Bilham, R., 2003. Earthquakes and Associated Deformation in North Baluchistan 1892-2001. Bull. Seismol. Soc. Am., 93(4): 1573–1605.

Cambois, G., 2000. Can P-wave AVO be quantitative? The Leading Edge, 20(11): 1246–1251.

Castagna, J.P., Swan, H.W., and Foster, D.J., 1998. Frame work for AVO gradient and intercept interpretation. Geophysics, 63: 948–956.

Coward, M.P., and Buttler, R.W.H., 1985. Thrust tectonic and the deep structure of the Pakistan Himalaya. Geology, 13: 417–420.

Gee, E.R., 1980. Pakistan geological Salt Range series: Directorate of Overseas Survey (DOS), United Kingdom, for the Government of Pakistan and Geological survey of Pakistan, 6 sheet, scale 1:50,000.

George, P.-C., 2006. The potential of tsunami generation along the Makran subduction zone in the northern Arabian Sea. Case study: the earthquake and tsunami of November 28, 1945. Science of Tsunami Hazards, 24(5): 358–359.

Goodway, B., 2001. AVO and Lamé Constants for rock parameterization and fluid detection. CSEG recorder, 26(6): 39–60.

Hardage, B.A., and Remington, R.L., 1999. 3-D Seismic Stratal Surface Concepts Applied to the Interpretation of a Fluvial Channel System Deposited in a High-Accommodation Environment. Geophysics, 64(2): 609–620. http://dx.doi.org/10.1190/1.1444568.

Iqbal, M., and Ali, S.M., 2001. Correlation of structural lineaments with oil discoveries in Potwar sub-basin, Pakistan. Pakistan J. Hydrocarbon Res., 12: 73–80.

Jadoon, I.A.K., Frisch, W., Jaswal, T.M., and Kemal, A., 1999. Triangle zone in the Himalayan Foreland, north Pakistan. In: A. Macfarelane, R.B. Sorkhabi and J. Quade, (eds), Himalayas and Tibet: Mountain Roots to Mountain Traps: Boulder, Colorado: Geological Society of America, GSA Special Papers, vol 328. https://doi.org/10.1130/0-8137-2328-0.275

Kadri, I.B., 1995. Petroleum Geology of Pakistan. Karachi: Pakistan Petroleum Limited (PPL) and Ferozsons (Pvt.) Ltd., 275 pp.

Khan, M.A., and Raza, H.A., 1986. The role of geothermal gradients in hydrocarbon exploration in Pakistan. Journal of Petroleum Geology, 9: 245–258.

Khan, S., Umair, B.N., Ahmed, K.A., Waseem, M., and Ahmed, W., 2018. Is Ziarat a Potential Site for Conventional or Unconventional Energy Resource? Acta Geologica Sinica (English Edition), 92(4): 1544–1557. Doi.org/10.1111/1755-6724.13642.

Miller, S., 1996. Multicomponent seismic data interpretation. Unpublished M.Sc. Thesis, University of Calgary: Calgary, Alberta, pp 85.

Mitchum, R.M. Jr., Vail, P.R., and Thompson, S.I., 1977. Seismic stratigraphy and global changes in sea level, Part 2, The depositional sequence as a basic unit for stratigraphic analysis. In: Payton, C.E., (ed.), American Association of Petroleum Geologists Memoir. AAPG Special Volumes. Seismic Stratigraphy: Applications to Hydrocarbon Exploration, M26: 53–62.

Moghal, M.A., Saqi, M.I., Hameed, A., and Bugti, M.N., 2007. Subsurface Geometry of Potwar Sub-basin in relation to Structuration and Entrapment. Pakistan J. Hydrocarbon Res.,

17: 61–72.
Ostrander, W.J., 1984. Plane-wave reflection coefficients for gas sands at non-normal angles of incidence. Geophysics, 49: 1637–1648.
Pennington, W.D., Minaeva, A., and Len, S., 2004. Uses and abuses of “phantom” seismic horizons. The Leading Edge, 23 (5): 454–456.
Pennock, E.S., Lillie, R.J., Zaman, A.S.H., and Yousaf, M., 1989. Structural interpretation of seismic reflection data from eastern Salt Range and Potwar Plateau, Pakistan. American Association of Petroleum Geologist Bulletin, 73: 841–857.
Pramanik, A.G., Singh, V, Srivastava, A.K., and Painuly, P.K., 2000. AVO attributes Inversion as an additional tool for Reservoir delineation. Improved Recovery Symposium-2000 (IRS-2K), Proceedings of ONGC Conference July 27–28, Ahmedabad, India, 1–9.
Raza, H.A., Ahmed, R., Alam, S., and Ali, S.M., 1989. Petroleum prospects: Sulaiman Sub-Basin, Pakistan. Pakistan Journal of Hydrocarbon Research, 1(2): 21–56.
Rijks, E.J.H., and Jauffred, C.E.M., 1991. Attribute extraction: An important application in any detailed 3-D interpretation studies. The Leading Edge, 10: 11–19.
Rizwan, M., Gulraiz A., Mustafa, A., Umair, B.N., and Ahmed, K.A., 2018. Amplitude versus offset (AVO) modelling and analysis for quantitative interpretation of porosity and saturation: A case study for Sawan gas field, middle Indus basin, Pakistan. Geofísica Internacional, 57(2): 151–160.
Roden, R., Castagna, J.P., and Jones, G., 2005. The impact of prestack data phase on the AVO interpretation-A case study. The Leading Edge, 25: 890–895.
Rutherford, R.H., and Williams, R.H., 1989. Amplitude-versus offset variations in gas sands. Geophysics, 54: 680– 688.
Schoeppel, R.J., 1977. Prospects of Geothermal power in Saindak area, Baluchistan province, Pakistan. Final report for Oil and Gas Development Company, 15p.
Sercombe, W.J., Pivnik, D.A., Wilson, W.P., Albertin, M.L., Beck, R.A., and Stratton, M.A., 1998. Wrench faulting in the northern Pakistan foreland. American Association of Petroleum Geologist Bulletin, 82(11): 2003–2030.
Shami, B.A., and Baig, M.S., 2002. Geomodelling for the enhancement of hydrocarbon potential of Joya Mair oil field, Potwar, Pakistan. PAPG-SPE Annual Technical Conference, 125–146.
Van der Pluijm, B.A., and Marshak, S., 1997. Earth Structure: An Introduction to Structural Geology and Tectonics. Dubuque, IA, United States: WCB/McGraw-Hill, 544 pp.
Zoeppritz, K., 1919. Erdbebenwellen VII b: über Reflexion und Durchgang seismischer ellen durch Unstetigkeitsflächen. Nachrichten von der Gesellschaft der Wissenschaften zu Göttingen, Mathematisch-Physikalische Klasse, 1: 66–84.

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