Sub-Unconformity Hydrocarbon Exploration in North-West Himalaya

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Keywords
Himalayan, Thrust and Subathu

Abstract

Himalayan Fold Thrust Belt and Foreland in short Himalayan Basin comprising of tectonic units between Indus Tsangpo Suture Zone (ITSZ)/ Main Karakoram Thrust (MKT) and Himalayan Frontal Thrust (HFT)/ Main Frontal Thrust (MFT) along with the Punjab plains and the Ganga plains as foreland is spread in northern part of Indian plate bounded by southern part of Eurasian plate. This enables the division of sub-Himalaya into three tectonic belts, namely, Outer tectonic belt, Median tectonic belt and Inner tectonic belt from South to North. Numerous oil/ gas shows have been observed in the Median and Inner tectonic belts in Siwaliks, Dharamsalas and Subathu rocks exposed in sub-Himalaya and in Siwaliks in Ganga basin. These occurrences give ample evidence of the fact that hydrocarbon generation had indeed taken place within or around the vicinity of the sub-Himalaya and foreland. The authors have focused their studies in Eocene-Cambrian (E-C) package of sub-Himalaya in analogy with hydrocarbon producing province of Potwar plateau.

Introduction

Himalayan Fold Thrust Belt and Foreland in short Himalayan Basin comprising of tectonic units between Indus Tsangpo Suture Zone (ITSZ)/ Main Karakoram Thrust (MKT) and Himalayan Frontal Thrust (HFT)/ Main Frontal Thrust (MFT) along with the Punjab plains and the Ganga plains as foreland is spread in northern part of Indian plate bounded by southern part of Eurasian plate. Further Heim and Gansser (1939) geologically divided Himalaya into four East-West trending geographic belts that correspond exactly to four geologic domains. These geographic and geologic zones are

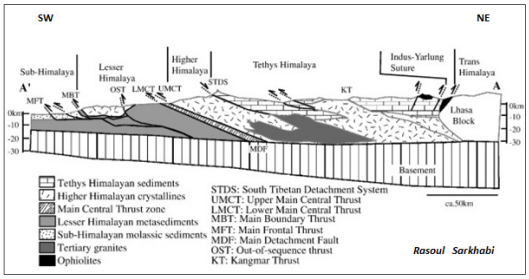

Figure 1 Geological cross section across NW Himalaya

assumed continuous along the entire Himalayan orogen and separated by well-defined thrusts (*Sarkhabi, R. 2010,* Figure 1 and *Thakur, V.C.* and *Rawat, B.S.1992,* Figure 2) from South to North i.e. (i) sub-Himalaya (Tertiary strata, tectonically bounded by Himalayan Frontal Thrust (HFT) to Main Boundary Thrust (MBT), (ii) Lower Himalaya (non-fossiliferous low-grade metamorphic rocks; also known as the Lesser Himalaya, tectonically bounded by Main Boundary Thrust (MBT) to Main Central Thrust (MCT)), (iii) Higher Himalaya (crystalline complex consisting of gneisses and aplitic granites; also known as the Greater Himalaya, tectonically bounded by Main Central Thrust (MCT) to South Tibetan Detachment (STD) and (iv) Tethyan Himalaya (marine, fossiliferous strata, tectonically bounded by South Tebetian Detachment (STD) to Indus Tsangpo Suture Zone (ITSZ). The northern margin of the Tethys Himalaya is sharply defined by ITSZ,

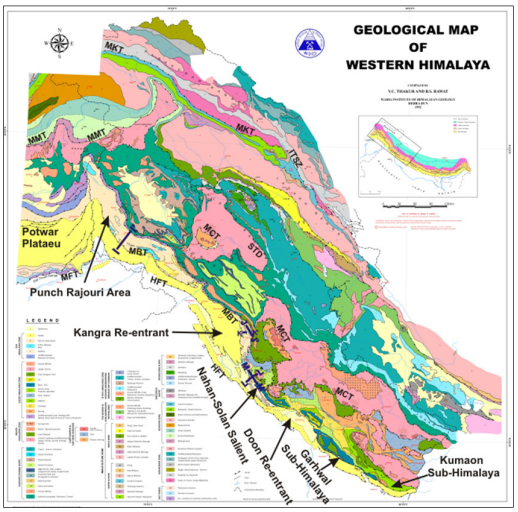

Figure 2 Tectonic setup of North-West Himalaya

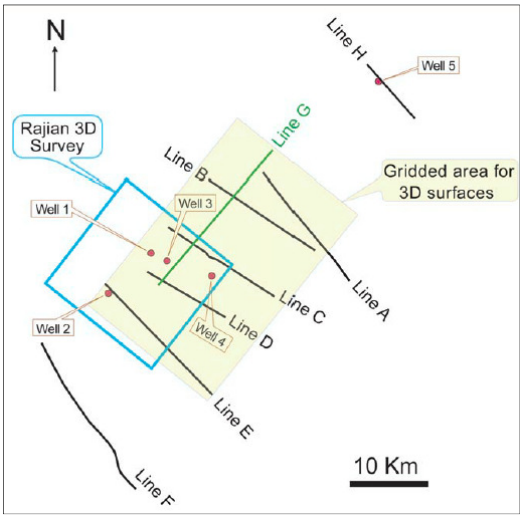

Figure 3 Seismic base map showing location of 2D seismic lines, gridded area and Rajian 3D seismic survey with key wells

against which lies the rocks associated with the Indus Suture or the Trans Himalaya zone. The tectonic unit between MBT in North and HFT in South known as sub-Himalaya encompasses Potwar plateau, Punchh- Rajouri area, Kangra re-entrant, Nahan-Solan salient, Doon re-entrant, Garhwal-Kumaon area (Figure 2). Aamir, M. and Siddiqui, M.M. (2006) studied Eocene-Cambrian (E-C) undifferentiated package of Potwar plateau along with prevailing petroleum systems in the area. Throughout the eastern Potwar, oil production has been established from Eocene, Permian and Cambrian age rocks. Hydrocarbon exploration in the Potwar began by drilling simple surface structures. With the advent of improvement of seismic acquisition , processing and interpretation, the search for additional petroleum reserves has entered an active phase of hydrocarbon exploration. Two exploratory wells were drilled in Rajian field to test sub-thrust sheets. These wells proved the existence of a second E-C package. Drilling of wells in Rajian field improved the understanding of the deformation styles and gave direction to new entrapment possibilities. The success of Rajian well 4 proved the existence of the deeper plays (sub-thrust structures are drilling targets) (Figure 3). The discovery of oil at Rajian field was the first of its kind in the area producing hydrocarbons from the sub-thrust structure which opened new play concepts possibly present in similar types of plays in adjoining areas.

Authors of this paper established the similarity of sediments in the thrust belt setup of sub-Himalaya tectonic unit. Instant paper deals with the nature of sediments' manifestation in seismic data and some of their age related issues as per laboratory studies.

Methodology

The E-C package of sediments manifested with typical 4 cycles of seismic signature was noticed in Punchh-Rajouri area in immediate vicinity of Potwar plateau (*cf.* Figure 4 and Figure 5). Presence of these sediments were established in the East of Potwar plateau in sub-Himalaya (*Datta, T. et.al. 2013*). Lateral facies variation leads to amplitude variation so minor variation of cycles and discontinuities may be attributed to this phenomenon. Similarly E-C package seismic character may also vary in regional perspective, but it stands out distinct in the background of seismic events.

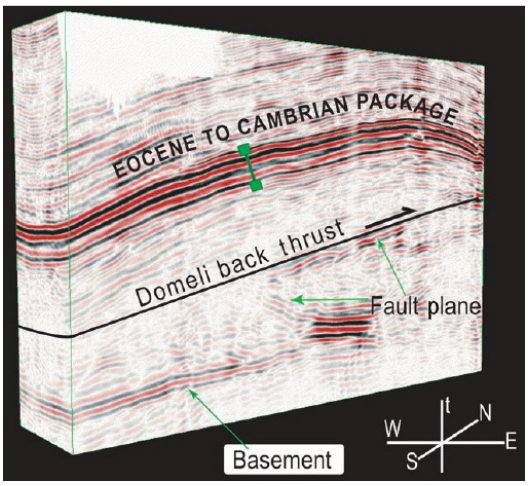

Figure 4 A selected portion of Rajian 3D cube to show Domeli backthrust along the strike direction. The Domeli backthrust runs at a low angle for at least 45 km. Note the increased resolution of E-C package in Potwar plateau.

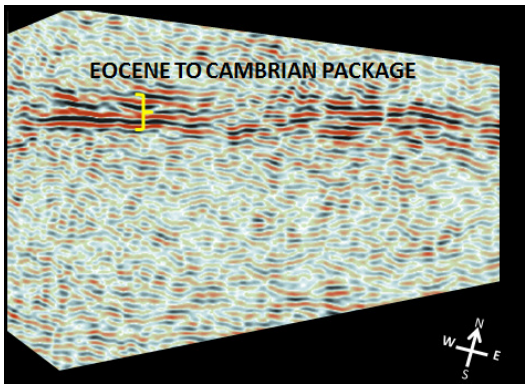

Figure 5 A selected portion of 2D seismic section I-I' to show increased resolution of E-C package in Punchh-Rajouri area.

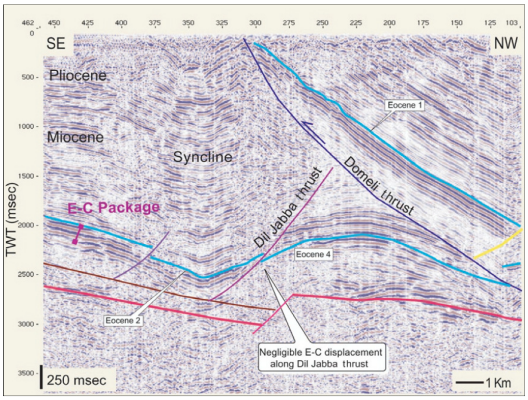

Figure 6 A selected seismic section A in increased resolution of E-C package in hanging wall of Domeli Thrust in Potwar plateau.

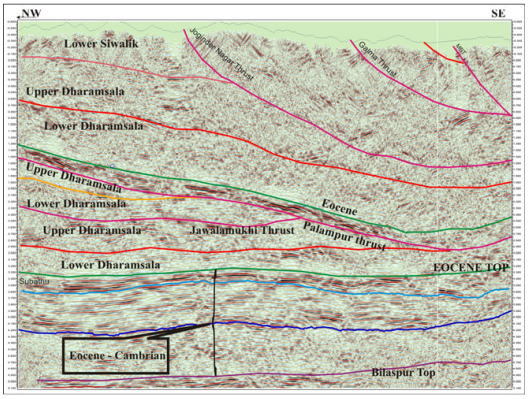

Figure 7 A selected portion of 2D seismic section J-J' to show E-C package in Kangra re-entrant.

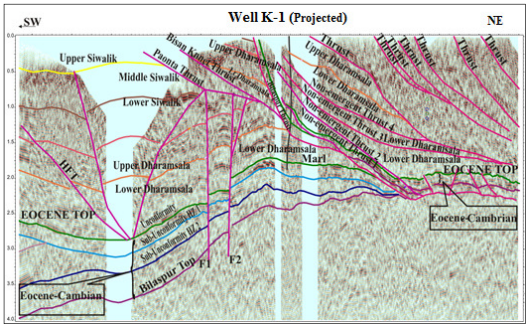

Figure 8 A selected portion of 2D seismic section L-L' in dip direction to show E-C package in Nahan-Solan salient

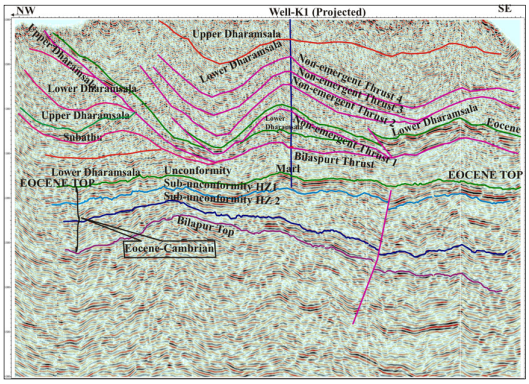

Figure 9 A selected portion of 2D seismic section M-M' in strike direction to show E-C package in Nahan-Solan salient

E-C package present in footwall has been transported to shallower depths by thrusting identified by 3-4 cycles of seismic signature (Figures 6-9). All above analogy of E-C package among Potwar plateau, Punchh-Rajouri area, Kangra re-entrant and Nahan-Solan salient implies that this package needs focus in entire sub-Himalaya.

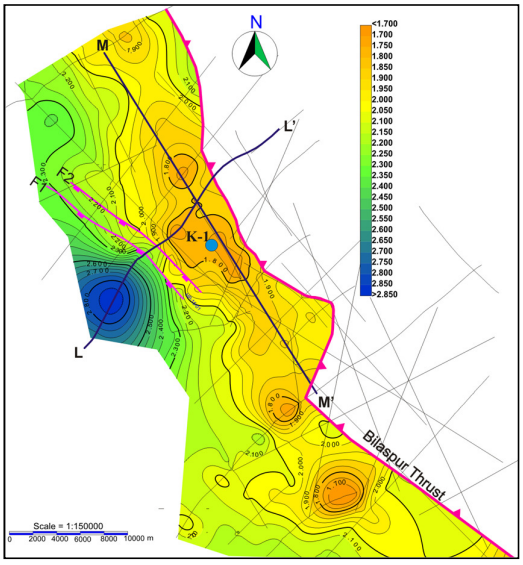

Figure 10 Time Structure Map of Eocene Top in Nahan-Solan salient area.

So search for E-C package gains importance in sub-Himalaya to target these sediments. Eocene Top of E-C package was calibrated in well-seismic data with the help of well K-1 in Nahan-Solan salient (Figures 8-9). The Eocene Top was correlated in seismic data of sub-Himalaya. It being the regional unconformity its event picking became easy. A Time Structure map of Eocene Top is reproduced above as Figure 10. The map reveals that there is a low in South-West which corroborates with southern extension of Una-Kalka low.

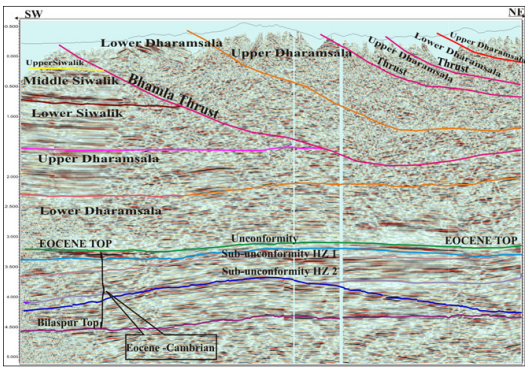

Figure 11 A selected portion of 2D seismic section K-K' to show E-C package in Kangra re-entrant.

The thickness of E-C package is also sizeable here. (Figures 8-9) So is the case in South of Lambagraon Syncline of Kangra re-entrant (Figure 11).

Discussion

Eocene Top is situated relatively very shallow in Nahan-Solan salient, so it was penetrated in footwall and hanging walls of Bilaspur Thrust and a few non-emergent thrusts in well K-1 (Figures 8-10). Marl was also encountered within Eocene giving rise to increase in amplitude. The Marl sample was subjected to Carbon- Oxygen isotopic laboratory studies in KDMIPE, ONGC, Dehradun (*Raina, A. et.al. 2013)*. The isotopic ratios are expressed in the usual delta (δ) notation as follows:

$$\delta \text{ in per mil } (‰) = \left(\frac{R_{sample}}{R_{standard}} - 1\right) \times 1000$$

Where R represents the measured isotope ratios, namely, $^{13}C/^{12}C$ and $^{18}O/^{16}O$. The results of carbon and oxygen isotopic analyses carried out on the

Table 1 Carbon-Oxygen isotope values

Sl. No.	Sample Name	Average $\delta^{13}C$(‰)	Average $\delta^{18}O$(‰)
1	Marl	-5.72	-14.66
2	Subathu Limestone	-5.85	-11.85
3	Bilaspur Limestone	1.0	-13.98

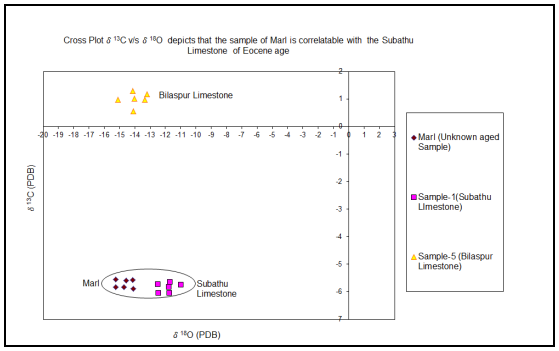

Figure 12 Cross plot of Carbon-Oxygen isotope values

samples and standard are placed in Table 1. Each sample was repeated 6 times and average value of data is provided in Figure 12. The Carbon and Oxygen isotopic analyses of Marl and the surface samples of known ages indicate that the isotopic values of Marl are correlatable with surface sample -1 of Subathu limestone of Eocene age.

Marl within Eocene Top (~4965 m) is considered a noticeable seismic marker (Figures 8-9). This marker is known as regional unconformity. Before above Carbon and Oxygen isotopic analyses, the marker was termed as Tertiary/ Neo-proterozoic boundary. After crossing the Marl (Unconformity) sediments of Eocene age continued in well K-1 till drilled depth 5320 m. As per geological section (Figure 1), the average basement depth is ~13 kms. in sub-Himalaya. So Eocene-Mesozoic-Paleozoic-Proterozoic sediments thickness estimates come around ~ 8035 m, which opens up sizeable thickness of sediments for exploration. A petroleum system analysis points towards requirement of exploratory efforts in exploration of E-C package.

Source

A number of source layers are present in Potwar plateau which includes Precambrian shales and carbonates, shales of Permian, Jurassic, Paleocene and carbonates of Eocene. All of these units possess fair-good quality source rocks and fall within appropriate maturity levels. The well K-1 could not be deepened to completely know above section of E-C package and Proterozoics. Focus on exploratory drilling of this package will reveal details of these sub-unconformity sediments.

Reservoir

Eocene (Chorgali and Sakesar), Paleocene (Lockhart and Patala limestone), Jurassic (Datta sandstone), Triassic (Kingriali) and Paleozoic sandstones are the established reservoirs in the Kohat-Potwar area. These reservoirs though deep need deliberate search in sub-Himalaya tectonic unit. As sediments in footwall are the least disturbed ones in thrust fold belt, so reservoirs of E-C package may prove to be primary reservoirs. Sediments corresponding to horizons below unconformity viz. sub-unconformity HZ 1 and sub-unconformity HZ 2 in E-C package may help explore hydrocarbons in sub-Himalaya.

Seal

Clays and shales of Eocene-Miocene formations (Kuldana and Murree) are the known seals for Eocene reservoir (Sakessar and Chorgali), while intra-formation tight limestone and shale provide the seal to Paleocene reservoirs (Lockhart and Patala). Intra-formation shales may act as effective seal for Jurassic reservoirs (Datta Formation) and Paleozoic reservoirs. Presence of clays in Dharamsalas and envisaged intervening clays/shales of Mesozoic and Paleozoic sediments may provide seals in this tectonic unit.

Trapping Mechanism

The potential trapping styles in the area are buckle anticline, pop-up, faulted anticline, wedge outs and stratigraphic traps.

Migration

Vertical migration from deep sources along fault planes are established in sub-Himalayas (*Arya, A.K. et.al.* , 2015). It may also hold good in deep reservoirs.

Conclusion and Recommendation

- Seismic signatures in North-West Himalaya indicate disposition of E-C package in sub-Himalaya tectonic unit.
- Unconformity is identified within Eocene sediments as per laboratory studies.
- Sediments below unconformity appear to be interesting from hydrocarbon exploration point of view in analogy with Potwar hydrocarbon province.
- Large spread lengths (> 10 kms.) with 12 sec. record length may address imaging issues of deep sediments and basement.
- Stratigraphic traps' delineation may require 3D/ Multi-component seismic data.
- Drilling capacity requires enhancement to penetrate sub-unconformity targets.

Acknowledgements

The authors are indebted to Shri A.K. Dwivedi, Director (Exploration) for granting permission to publish this paper. The authors would like to express deep sense of gratitude to Shri N.K. Punjrath, GM-Basin Manager, Frontier Basin for constant support and encouragement. The authors are also thankful to Shri S. Gogia, D.G.M.-I/C-

Database and his team for providing work station support. The views expressed in this paper are of authors only not of the organization.

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