A Step towards Understanding Olpad Prospectivity in Charada-Mansa area, North Cambay Basin, India

P.K.Sinha[1], Anil Kumar[1], Arun[2] and K.Viswanath[1]*
1 WON Basin, ONGC Vadodara, 2 WOFF Basin, ONGC, Mumbai
*E-mail: SINHA_PRAMOD@ONGC.CO.IN

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Summary

The eastern margin of Cambay Basin is known for many oil occurrences. Commercial discovery of oil within the Olpad Formation in a well in Mansa area has added a new dimension to oil exploration in the area. The success prompted intensified exploration activities to chase the lead. A number of studies have been carried out in the recent past to understand the Olpad play in Charada-Mansa area. The present work brought out Olpad depositional model along with reservoir model by integrating results of various studies. The study also demonstrates heavy oil distribution pattern within the formation.

The syn-rift Olpad of Paleocene age is mostly derived from the Deccan Trap. The formation is divisible into two informal litho-units: Lower Olpad and Upper Olpad. The lower unit which is argillaceous in nature is envisaged to have been deposited by N-S axial drainage set in the basin during initial rifting. It occupies a major part of the half-grabens formed during rifting process. The upper unit was deposited by younger transverse drainage close to the basin margin in the form of alluvial fans. The alluvial fan part of the Olpad is important from hydrocarbon point of view as it accounts for all the discoveries made so far. Reservoir distribution within a fan is not uniform because it comprises of highly immature sediments of complex lithology. Only the upper and middle fan areas show reservoir development where conglomerates predominate while the facies deteriorate in the distal fan areas.

Reservoir characterization of upper Olpad carried out with the help of cores, cuttings, image logs and electro-facies (Cluster Analysis) of drilled wells confirms alluvial fan model. The perceived reservoir model also explains dry and wet wells in the area. The Charada-Mansa field is also known for heavy oil. There are three distinct oil zones (east to west) in the area parallel to the basin margin fault – fully biodegraded oil zone, partially biodegraded oil zone and light oil zone. The area west of 80°C isotherm is characterized by light oil only.

Introduction

Commercial discovery of oil within Olpad Formation in a well drilled in Mansa area led to intensive exploration activity in the area and as many as seven wells were drilled in a short span of time to chase the lead. However, the results of subsequent wells were not as encouraging as the discovery well; as a matter of fact some wells went dry. This prompted a serious review of the Olpad play and a need was felt to understand the play in totality. Consequently, a number of projects were undertaken at various work centers of ONGC to comprehend the depositional model and reservoir property development in Olpad. The present work is a part of this endeavor wherein an attempt has been made to bring out a comprehensive geological model of Olpad play in Charada-Mansa area (Fig.1) by integrating geo-scientific data available in the area.

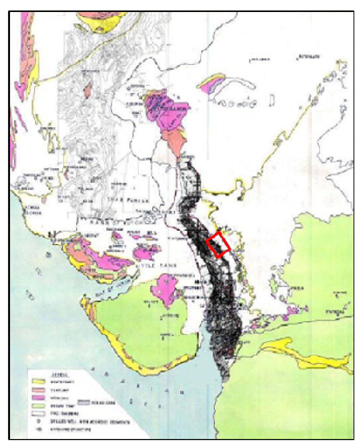

Figure-1: Charada-Mansa area (in red), Cambay Basin

Regional Geology and Petroleum System

Cambay Basin is a rich Petroleum Province of India, located in the western Indian state of Gujarat. It is a

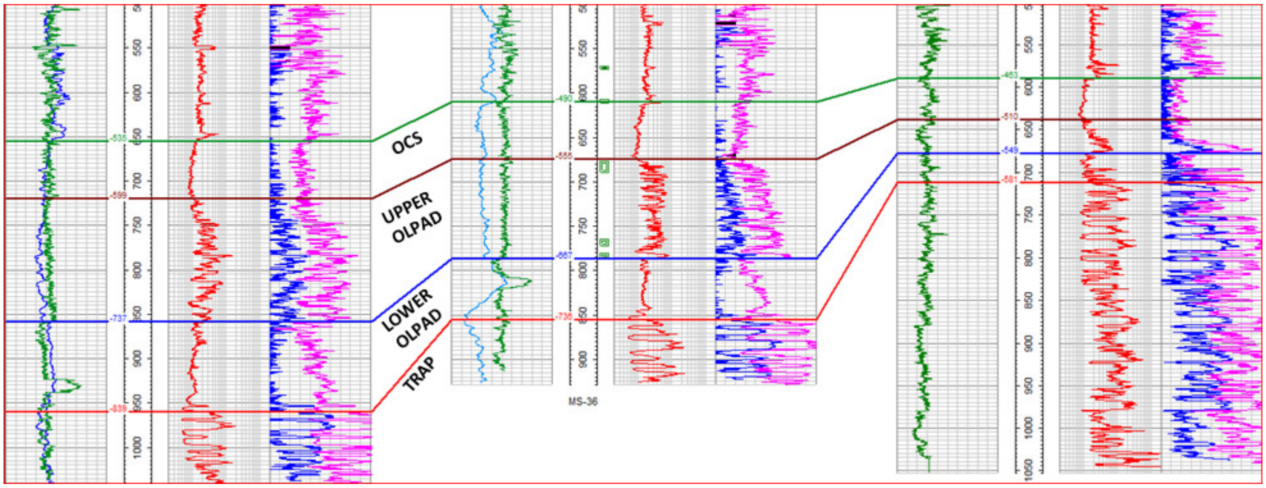

Figure-2: NE-SW well log correlation in north Mansa.

narrow, elongated, NNW-SSE trending intra-cratonic rift graben which came into existence at the close of Cretaceous following extensive outpour of Deccan Basalts. The Deccan Trap forms the technical basement over which about 8km of Tertiary sediments were deposited during syn-rift and post-rift phases of basin development.

In Cambay Basin, three stages of basin evolution are recognized: 1) Late Cretaceous – Early Eocene ***rift stage*** (syn-rift; period of extension); 2) Middle Eocene – Early Miocene ***post-rift stage*** (thermal sag with subsidence); and Middle Miocene and younger ***structural inversion stage*** (period of compression). Syn-rift phase in Paleocene is characterized by lacustrine claystones in fault controlled half grabens and overlain by trap derivatives, trap conglomerates in the form of alluvial fan deposits. Late syn-rift is characterized by deposition of restricted marine and pro-delta shales. Post-rift thermal subsidence phase is characterized by deltaic deposits and marginally marine deposits. Oligocene marks the last marine transgression in the basin in the form of Tarapur shale. During Late Miocene to Recent times mainly fluvial sediments were deposited in this part of the basin.

Cambay-Kalol (!) and Cambay-Kadi (!) are the two prominent petroleum systems in the northern part of Cambay Basin. Sometimes, Olpad and Tarapur Formations also form a part of petroleum system, especially along the basin margins. In general, Cambay Shale acts as regional source rock, Kadi and Kalol as reservoir and Tarapur Shale as regional cap rock in the North Cambay Basin. As per petroleum system modelling, the peak of oil generation and migration in the basin is understood to have taken place during Early to Middle Miocene.

Olpad Depositional Model

The depositional model of Olpad Formation has been brought out by integrating the analyses of cuttings, cores and well logs. Olpad in Charada-Mansa area can be divided into two informal litho-units: Lower Olpad and Upper Olpad (Fig.2). The lower Olpad is argillaceous and consists of shale, laminated siltstone/claystone with thin interlayered volcanic wacke. Density and resistivity values are generally lower in this unit but neutron porosity is relatively higher due to presence of higher clay content. The lower Olpad occupies a major part of the half-grabens formed during the rifting process (Fig.3). The upper Olpad is characterized by trap conglomerate interlayered with trapwacke and thin claystone bands. Resistivity and density values are higher in upper Olpad but neutron shows relatively lower value as compared to lower Olpad.

The lower unit is envisaged to have been deposited by N-S axial drainage that came into existence along the major longitudinal faults during initial phase of rifting. This unit is dominantly argillaceous and, in general, does not have any reservoir characteristics.

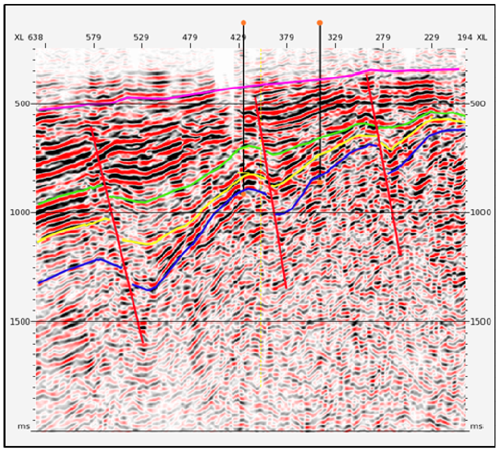

Figure-3: NE-SW seismic section in north Mansa area. Blue: Trap Top, Yellow: Lower Olpad Top, Green: Upper Olpad Top, Pink: Kalol Top.

The upper unit is interpreted as the alluvial fan deposited by E-W transverse drainage which deeply incised the steeper foot wall. In the present work, focus is mainly on upper Olpad because this litho-unit is important from hydrocarbon point of view and accounts for all the discoveries made so far in the formation.

Isopach map of upper Olpad (Fig.4) in Charada-Mansa area shows five NE-SW trending coalescing alluvial fans of different size. The areal extent of the fans diminishes southward where throw of the basin margin fault increases substantially. Presence of hydrocarbon is established in the two fans in the northern part.

Reservoir Facies Modelling

Reservoir facies prediction is challenging in alluvial fan deposits as it comprises of immature sediments of complex lithology where the grain size varies from boulder to silt. As a result, reservoir facies distribution is not uniform in a fan complex. However, a well sorted conglomerate within the fan is considered as the best lithology for development of reservoir facies. Possibly, because of this reason conglomerates account for more than ninety percent of production from the alluvial fans. In view of this, identification of conglomerate prone areas in an alluvial fan is key to reservoir facies prediction. In a

Figure-4: Isopach map of Upper Olpad.

typical fan geometry, proximal fan and bottom part of mid fan are places of conglomerate deposition (Fig.5). Therefore, these areas are important from hydrocarbon point of view. In distal fan, reservoir properties deteriorate due to decrease in grain size.

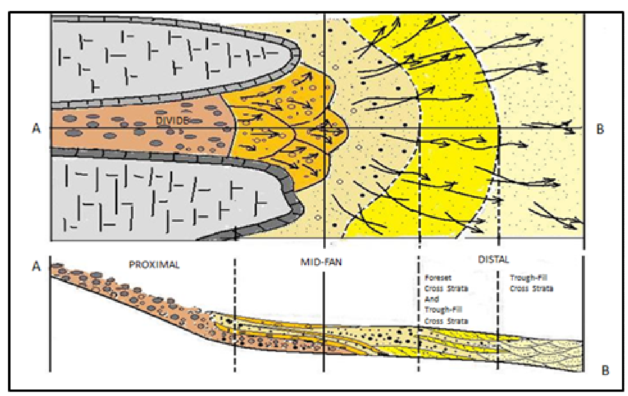

Figure-5: Schematic diagram showing cross section of a single canyon and fan (modified after McGowen and Groat, 1974).

The ***electric micro-imager*** log (FMI) has been found to be very useful in deciphering different volcanoclastic facies within Olpad Formation.

Figure-6 depicts various reservoir types identified by image logs. Figure-7 is the image log of Olpad Formation of Well-A in Mansa area, which produced 25 m3/d of oil during initial testing. The image log clearly depicts the conglomeritic nature of the formation. It mainly consists of pebble to cobble size conglomerate, rounded to sub-rounded, supported by sand size grains.

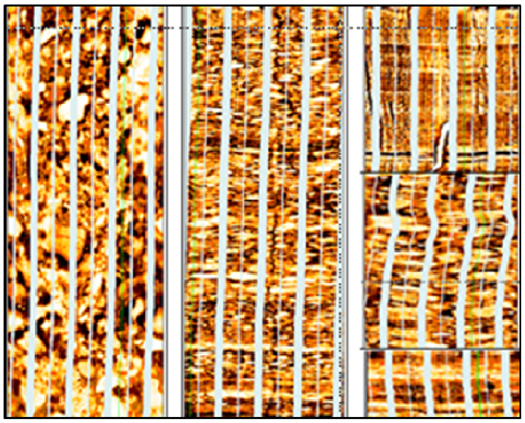

Figure-6: Various facies identified by image logs. Left to right: Conglomerates-good reservoir, Trapwacke-moderate to poor reservoir, Shale/Trapwash- poor reservoir

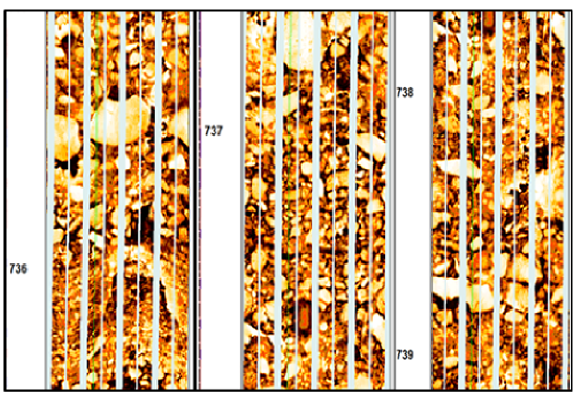

Figure-7: Image log of discovery well in Mansa area showing conglomerates.

Cluster Analysis based ***electro-facies*** is an invaluable tool in identifying various volcanoclastic facies of alluvial fan. The electro-facies is generated from basic conventional logs like resistivity, density, neutron, sonic and then correlated with high resolution image data to assign a litho-facies to each electro-facies. For upper Olpad, five clusters (i.e. five electro-facies) were used for facies description (Fig.8), they are: 1-Green Facies (Good Reservoir – Conglomerate well sorted and connected), 2-Yellow Facies (Moderate Reservoir – Conglomerate poorly sorted and less connected), 3-Brown Facies (Tight Reservoir – Conglomerate cemented and very less connected), 4-Orange Facies (Silty Reservoir – Trapwacke Facies) and 5-Grey Facies (Shale Facies). Cluster analysis of Olpad in Charada – Mansa wells brings out that green facies with higher resistivity produces hydrocarbons.

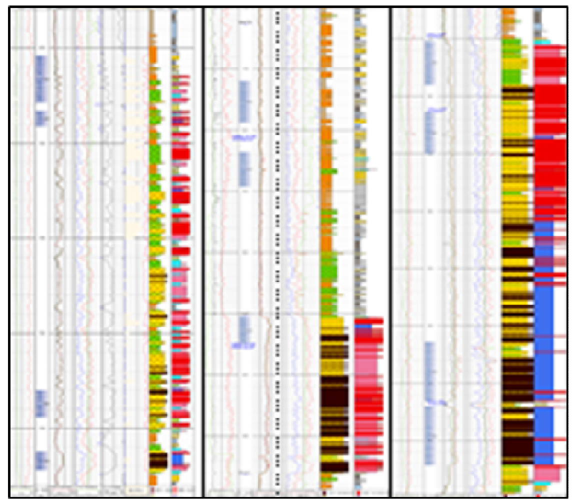

Figure-8: Wells showing predominance of Green, Orange and Yellow facies within upper Olpad.

For facies modelling, dominant facies well wise was plotted and contoured. The facies map also confirms alluvial fan model for upper Olpad as it shows good reservoir development in the upper and mid fan areas of each fan while the distal fan area is usually devoid of reservoir facies (Fig.9). The alluvial fan model is also able to explain dry and wet wells in terms of reservoir properties in Charada-Mansa area.

Heavy Oil Zone

The Charada-Mansa area is a known heavy oil belt in the North Cambay Basin. Heavy oil is mostly restricted to the basin margins and is thought to be the residue of formerly light oil that has lost its light-molecular-weight components through degradation by bacteria, water-washing, and evaporation. As per the available literature, degradation begins when oil migrates toward the surface and encounters descending meteoric water containing oxygen and

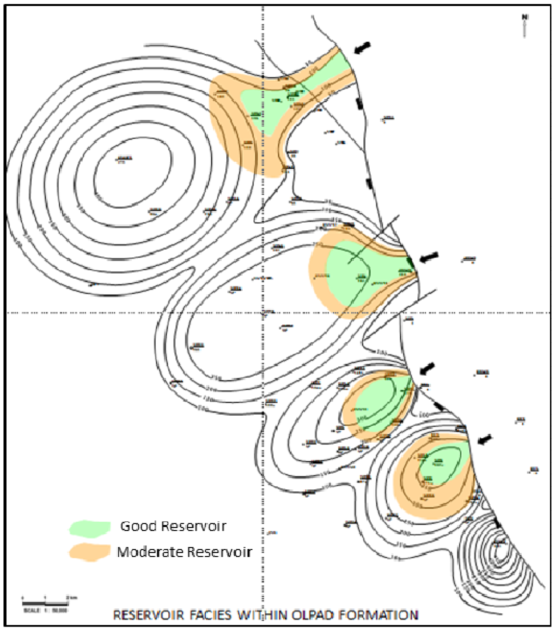

Figure-9: Reservoir facies within various fans.

bacteria at temperatures below 80 °C (about 176 °F). A tarlike material is formed at the oil-water contact, and it eventually invades the entire oil accumulation laterally and vertically. Biodegradation cannot take place above 80 °C as the bacteria responsible for it cannot survive above this temperature.

Biodegradation can also take place at depth in subsurface reservoirs if it has a water leg and has not attained a temperature more than 176° F. Nearly all the deposits of heavy hydrocarbons are degraded remnants of accumulations of conventional oils. But it may represent as little as 10 percent of the original conventional oil. Some of the heavy oils, however, appear thermally immature and therefore may be unaltered. But, there is general agreement that immature oils account for a small percentage of the heavy oil (Larter and others, 2006).

In the present work, oil types derived from well testing were plotted on the isotherm map on top of Olpad in Charada-Mansa area. It suggests three zones parallel to the basin margin fault (Fig.10). The zone adjacent to the basin margin fault comprises of fully biodegraded oil wherein the entire reservoir is degraded. Zone west of it consists of partially degraded oil where only lower portion of the reservoir is degraded. The third zone is beyond 80°C and contains light oil where no degradation whatsoever has taken place. Fully degraded oil zone is wider in the north Mansa area due to prevalent low thermal gradient.

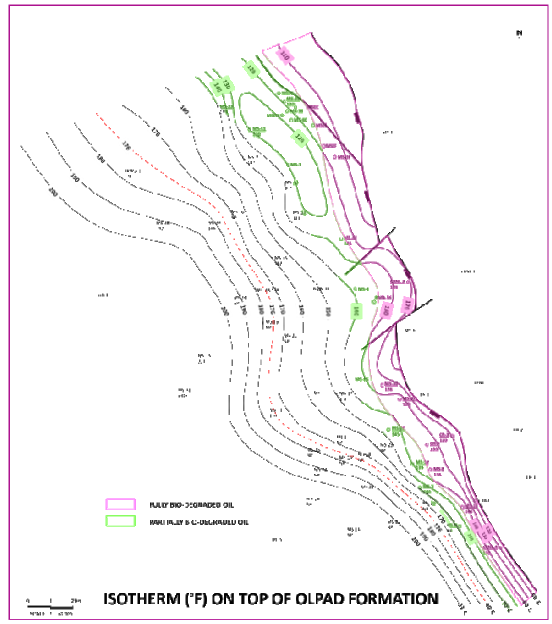

Figure-10: Heavy oil belt in Charada-Mansa area. Pink- fully bio-degraded oil, Green- partially bio-degraded, White- light oil

Conclusions

Olpad Formation in Charada-Mansa area is divisible into two litho-units. The lower unit, deposited by N-S drainage, is argillaceous in nature and is devoid of any reservoir properties. The upper Olpad is deposited as alluvial fan along the basin margin by transverse drainage. Alluvial fan part of Olpad is important from hydrocarbon point of view as it accounts for all the discoveries made in the formation. Reservoir characterization of alluvial fan suggests better reservoir development in the proximal and mid fan areas due to the presence of conglomerates. Distal fan area, in general, is characterized by poor reservoir properties. The results of reservoir characterization are in full agreement with the alluvial fan model. Testing results of wells also support fan model as wells drilled in the proximal and mid fan areas are oil producers whereas well drilled in the distal part show poor reservoir properties. The Charada-Mansa area is also known for heavy oil. There are three distinct oil zones (east to west) in the area parallel to the basin margin fault – fully biodegraded oil zone, partially biodegraded oil zone and light oil zone. The area west of 80°C isotherm is characterized by light oil only.

The work brought out that only the proximal and mid fan areas of the upper Olpad (alluvial fan) need to be targeted for future exploration and that if the prospect lies beyond the 80°C isotherm, chances of getting light oil is very high.

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