Hydrocarbon Prospectivity and Depositional Model of Olpad Formation in Narmada Block, South Cambay Basin, India

Anima Saikia*, Kishori Lal, Satheesh Kumar and M. C. Kandpal

Summary

Olpad formation, the syn-rift sequence, comprises of volcanic conglomerate, sandstone, siltstone, ashy clay stone, exclusively derived from nearby volcanic terrains. Litho-facies within Olpad are highly variable from north to south Cambay basin depending upon the nature and distance of provenance. In the long exploration history of Cambay basin, it has been proved as commercial oil/gas producer in Ahmedabad-Tarapur tectonic block. Nawagam, Dholka, Gamij and Sanand are some of the major oil producing fields from Olpad reservoir. In the eastern margin of Broach depression oil entrapment has been reported from Padra field. Further south in Narmada block thick pile of volcanic derives sediments were deposited in graben and half-graben during first phase of rifting. Deposition of these basalt derived detritus took place in the form of cones, fans and gravel beds under sub aerial to fluvial conditions.

In present study Olpad Fm has been divided into three litho facies units namely, A, B & C from bottom to top based on their lithological variations. The topmost unit (Facies-C) in Ankleshwar field is trap conglomerate with fair to good porosity development and appears to be a sustainable oil producer. These conglomeratic facies was locally dumped from Ankleshwar High by feeder channels. Detailed G&G interpretation of 2D and 3D seismic data in Olpad-Dandi-Kim area has brought out coalescing fan morphology within a central graben towards SW of the study area. Wedge out and associated channel features are well preserved in vertical seismic profiles. Results of various attribute analysis corroborate this model. Taking analogy from Ankleshwar area and observing the presence of reservoir facies in nearby wells, this fan model has been envisaged as suitable target for future hydrocarbon exploration of deeper objects.

Keywords: Syn-rift, Trap Conglomerate, Coalescing fan, Amplitude slice

Introduction

Commercial accumulations of oil established from Olpad Fm in the central part of Cambay basin surrounding the Tarapur Depression that is Nawagam, Dholkha, Asmali, Gamij and Sanand fields. Presence of oil has also been reported from further south in Chaklasi, Manjipura, Nadia, Vadatal and Vasad area. In the eastern basin margin, east of Broach Depression, oil production from Olpad reservoir in Padra field is well established. In south Cambay basin, the topmost sand within Olpad Fm proved as oil producer in Ankleshwar area (Fig-1).

This is an unconventional reservoir derived from basalt and produced so far nearly 2MMt oil from this field. Being the lowest Tertiary unit, Olpad Fm has overlain by huge pile of sediments and underwent significant diagenesis. As a result primary inter granular porosity seems to be fair due to calcite cementation along with minor authigenic chlorite. But enhancement of
secondary porosity has been observed at places. Taking lead from these Paleocene oil/gas discoveries, 3D merged volume (PSTM) and some 2D lines of SIG-228 in Ankleshwar to Olpad-Dandi ML have been studied to bring out an integrated interpretation of Olpad Formation. This is one of the identified hydrocarbon play in south Cambay basin, merits attention for exploration of syn-rift sediments.

**Geological Setting**

The Cambay rift basin is a NNW-SSE trending narrow intra-cratonic graben. A number of discrete tectonic blocks generated later by reactivation of cross trends during anticlockwise rotation of Indian plate. The southernmost tectonic block i.e. „Narmada Block“ is an uplifted unit with two major depo-centers, viz. „Navsari Low“ and „Surat Depression“. The major tectonic lineament is the NarmadaSon trend, aligned ENE-WSW, which transects the Indian shield and divided it into a northern foreland and a southern peninsular block (Biswas, 1993).

It has been active since Proterozoic up to Late Cretaceous. Extensive uplift and erosion followed the end of Cretaceous, prior to the Deccan Trap volcanic episode. During this phase of rifting, graben or half-graben came into existence along marginal faults aligned NNW-SSE. The Bouger anomaly map of South Cambay basin depicts this tectonism at the end of Deccan Trap volcanic episode (Fig-2).

Thicker basaltic rocks in the graben as compared to its margins indicate downward movements along basin marginal faults. The first phase of rifting was followed by an intra-graben phase of tectonism resulting in the formation of intra-basinal horsts and grabens. During this phase reactivation along NNW-SSE trending basement faults produced considerable relief on the Deccan Trap floor during Paleocene. As a result, in parts of Cambay Basin, a thick sedimentary sequence consisting of volcanic conglomerate, sandstone, siltstone and claystone derived entirely from Deccan Trap basalts (Raju, 1968) deposited. This widespread deposition of basalt derived detritus took place in the form of cones, fans and gravel beds under subaerial to fluvial conditions.

Following the formative phase, a second phase of rifting took place along the pre-existing NNW-SSE aligned marginal faults during Lower Eocene. With continued subsidence the sea transgressed and immersed the entire Cambay basin with thick cover of Cambay Shale, which acts as regional cap for Olpad reservoirs.

**Depositional Environment**

Olpad formation, the oldest tertiary sedimentary unit, and its equivalent in outcrops designated as Wagadkhol Fm by various workers. This formation comprises volcanic conglomerate, sandstone, siltstone, ashy claystone and at places clays exclusively derived from nearby volcanic terrains. In present study Olpad Fm has been divided into three litho-units based on log signatures and lithological variations. These are facies-A, B & C from bottom to top.

Pandey et al. (1993) also described three distinct lithofacies within Olpad Fm. These are weathered Trap wash, Clay stone and Trap conglomerate/Trap wacke from bottom to top. These facies are well preserved in fault grabens as a result of weathering of Trap/Basalt rocks from nearby highs. Over the paleo-highs mainly weathered trap is preserved. Presence of pyrite and Dinoflagellate Cyst in claystone and oolites within Trapwacke facies indicates brackish water coastal environment along with the continental deposits. Detailead analysis of a number of conventional cores taken from wells drilled in central and south Cambay basin confirms the vertical and areal distribution of these litho-facies (FIG-3). RHOB vs NPHI crossplot of Olpad Fm in well ANK-J clearly demonstrate the differences among the three facies in terms of porosity development.
The bottommost litho-facies (Facies-A) is comprising of light to dark greenish gray, hard & compact, with mostly subrounded, occasionally subangular, moderately sorted basalt derived fragments set in chloritic matrix. Carbonate enriched zones are common and are designated as calcareous lithicwacke.

The dominant facies present within Olpad Fm is claystone, the middle unit (Facies-B) comprising of brown to chocolate brown, highly mottled, hard & compact clay sized particles with iron-rich chloritic matrix along with close admixtures of dark grey to slaty grey shale and weathered trap materials. Pyrite also occurs in the form of specks and segregated patches. Crisscross calcite inclusions or veins are also occasionally seen.

The topmost unit of Olpad Fm (Facies-C) in Ankleshwar field (LS-1 reservoir) is Trap conglomerate comprising of grey to brownish grey, moderately hard to friable, trap fragments of varying size from granule to pebble, bounded by highly altered trap derived material of silt size (FIG-4). Primary inter granular porosity seems to be fair due to calcite cementation along with minor authigenic chlorite. But enhancement of secondary porosity has been observed because of dissolution or leaching of cavities. Deposition of trap conglomerate at the top of Olpad Fm followed by sub-areal unconformity may lead to the activity of abandoned channel. These trap conglomerates were locally dumped from Ankleshwar High by feeder channels.

Seismo-geological profile-XX” along the wells OLP-E, OLP-I, ANK-C, ANK-G, ANK-K and ANK-H highlights prominent thickness as well as facies variation within the drilled section of Olpad Fm (Fig-5). The proven reservoir trap conglomerate facies is present in wells ANKC and ANK-G of Ankleshwar area. This facies seems to be absent in wells drilled in the eastern part. In these area only the older sequences of Olpad Fm, comprising of clay to silt sized derivatives of basalt, are present. Similar reservoir facies have been developed in lower part of Olpad Fm in some of the wells drilled in Ankleshwar area, which on testing produced noncommercial hydrocarbon.

Correlation profile-YY” along the wells BH-A, OLP-A and OLP-B (Fig-6) in NW-SE trend shows the thickest section of Olpad Fm in the deepest well OLP-A and in the central graben. The Olpad and other younger sequences appear to be much thicker as compared to that shown in profile-XX”. All the three facies within Olpad Fm, as mentioned above, seem to be well developed.

Presence of reservoir facies has been envisaged within the graben in the form of wedge out features and encountered in wells OLP-A & B drilled in the vicinity of N-S oriented volcanic paleo-high. Presence of gas along with water has been reported in one of these wells. Wells located away from this volcanic terrain that is OLP-D, BHA and OLP-E, reveal complete absence of Facies-C.

In Olpad area (wells OLP-A & B) cyclic deposition of A & C and B & C facies are observed with increase in thickness of C-facies towards top. It indicates that deposition might have taken place during major flood events on the proximal part of a fan by the braided channel. Whereas, dominance of facies-B and absence of facies-C in wells OLP-D & OLP-G reveal deposition in distal fan under fluvial plain environment (Fig-7).
Thickness map of each facies highlights alluvial fan morphology in Olpad-Dandi as well as Ankleshwar area. In Olpad-Dandi area alluvial fans might have originated from the nearby N-S high.

Fig-5. Seismo-geological Cross Section along a NE-SW Profile

Fig-6. Seismo-geological Cross Section along a NW-SE Profile

**G&G Interpretation**

Integrated study of 3D seismic and available well data has brought out a detailed fault pattern, which includes original rifting faults, generated during first rifting and reactivated normal listric faults during second rifting (Fig-8). These faults are oriented in NW-SE and NE-SW trend. At the end of Paleocene huge subsidence of sediments derived from Deccan Trap volcanic observed along the half-graben. Along the re-activated faults a number of en-echelon reverse anticlines are seen; particularly in the younger sequences of eastern part of Narmada block.

Fig-7. Conceptualised Depositional Model of Olpad Fm

Fig-8. Time Slice at 1620 ms Depicts Interpreted Faults

The seismic event at Olpad top seems to be a good marker and shows angular events terminated against it at many places. However, in few places conformable nature of this event with the underlying sequence is also observed (Fig-9). This reflector, corresponds to Paleocene top unconformity, has been mapped in present study which has brought out a major structural low in the southern part of the study area (Fig-10). This is a northward extension of Navsari Low which has been proved to have very good hydrocarbon source potential and contributed to a good number of offshore oil/gas fields.
The overlying Cambay Shale (parallel reflections) may be clearly distinguished from the unconformable Olpad top event.

Seismic facies variation is observed both inline and cross line. The seismic event corresponding to Low frequency and medium amplitudes appears to have reservoir facies. The high amplitudes may correspond to tight facies, while low amplitude transparent zone within Olpad formation may be related to claystone facies.

RMS amplitude and Instantaneous phase slices, extracted along Olpad top from 3D data (PSTM volume: window: 20ms-60ms) indicate low to medium amplitudes correspond to reservoir facies. Amplitude slices at 4msec interval from the picked horizon demonstrate fan morphology with associated channel system within the central graben (Fig-13).

This attribute generated fan morphology is substantiated by detailed geological analysis of subsurface samples (cores & cuttings). Preservation of reservoir facies within the coalescing fans could be a suitable locale for hydrocarbon entrapment as well as future exploratory target.

It has been envisaged that hydrocarbon, migrated from the potential source kitchen Low², and will be accumulated.
in the first available structure as highlighted in the present study (Fig-14).

Fig-13. RMS Amplitude Slide (0-60ms from Olpad Top) Demonstrates coalescing fan Morphology

Fig-14. Envisaged Petroleum System of the Study Area

Conclusions

Following conclusions may be drawn from the present study:

- Olpad formation comprises exclusively volcanic derived fine sand to pebble sizes sediments These syn-rift sediments deposited in the form of cones, fans and gravel beds under sub aerial to fluvial conditions during the first phase of rifting.
- The litho facies are highly variable from north to south Cambay basin depending upon the nature and distance of provenance.
- In present study Olpad Fm has been divided into three litho facies- A, B & C from bottom to top based on their lithological variations.
- Facies-C comprises the major reservoir units with fair to good porosity development in Narmada block.

- The thickest section of Olpad Fm penetrated in the deepest well OLP-A with cyclic nature of facies distribution Thickness map of each facies highlights alluvial fan morphology in OlpadDandi as well as Ankleshwar area.
- Two sets of faults have been identified from integrated 2D and 3D seismic interpretation
- A major structural low has been identified in the southern part of the study area within which wedge out and channel cut and fill features are seen to be developed.
- Horizon slices demonstrate coalescing fan morphology with associated channel system.
- Preservation of reservoir facies within the coalescing fans has been envisaged as suitable locale for hydrocarbon entrapment.

Acknowledgement

Authors are grateful to Director (Exploration), ONGC Ltd for according permission to present this paper in SPG, 2013. Authors express their deep gratitude to Shri S. K. Das, ED-Basin Manager, Western Onshore Basin, for his guidance and encouragement. Sincere thanks are due to Shri G. L. Hansa, DGM (Geology), Shri K. K. Das, GM (Geology); Shri M. J. Panchal, Drawing officers for their valuable suggestions and co-operation during the course of study.

References

Biswa, S. K., 1993, Tectonic Framework and Evaluation of Graben Basins of India: Rifted Basins and Aulacogens,

Pandey, J. et al, 1993, Lithofacies, Depositional Environments and Reservoir Characteristics of Middle Eocene sands in Nada Area, Cambay Basin; Proceedings Second Seminar on Petroliferous Basins of India,


Views expressed in this paper are that of the authors and not of the organization they belong.