Integrated tectono-sedimentary and petrophysical technique of mapping lithofacies heterogeneity within Olpad Formation in eastern margin of Ahmedabad Block, Cambay Basin, India

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Summary

The Olpad Formation marks the onset of sedimentation in Cambay basin over the Deccan basalt and was deposited as braided stream and lacustrine deposits in an overall alluvial fan complex during Paleocene. The sediments were essentially derived from the basalt terrain exposed all along the rifted eastern margin and thus comprise mostly basalt derivatives having variable thickness. Due to its proximity to the source rock facies in the overlying Cambay Shale Formation in the down dip lows, the hydrocarbon prospectivity of the Olpad Formation is quite encouraging and is one of the important objects of exploration. As the distribution of Olpad sediments was influenced by the basin architecture, there is large variation in its lithofacies characteristics in both time and space. Mapping of the facies heterogeneity and its petrophysical characteristic is thus a challenge in preparation of facies distribution map for the exploration of the Olpad Formation. The present paper provides details of application of an innovative non-seismic technique used for of calibration of the lithofacies heterogeneity with corresponding electrofacies in Olpad Formation which can act as guide for identification of lithofacies variations on the basis of logs over a large area and in preparation of the regional facies map.

Three distinct suits of lithofacies within the Olpad Formation were identified by detailed sedimentological studies of characteristic lithology, texture and mineralogy and grouped as proximal fan epiclastic trap conglomerate A-subfacies; moderately sorted sandstone rich mid fan B-subfacies and finer grained silty shale distal fan or overbank C-subfacies. The epiclastic conglomerate A- subfacies is the major rock type, followed by braided stream sandy B-subfacies and fluvial/ lacustrine shale with minor sandstone as C-subfacies. The facies distribution map depicting the lateral and down dip distribution of the subfacies are prepared and also extrapolated in both updip and down dip direction by considering the basin gradient. Due to occasional near similarity of facies with underlying weathered trap and overlying Cambay Shale of A-subfacies and C-subfacies respectively, the study has also identified the criteria for their demarcation at the site.

A new petrophysical technique of application of overlays of Resistivity-Sonic and Density-Neutron logs along with discriminant score function (D) obtained from Sonic and Resistivity logs has been applied for validating each of the subfacies and its distribution both in time and space and also precise demarcation of Olpad Formation boundaries from the overlying Cambay Shale and underlying Deccan basalt.

Introduction

The Cambay Basin is a pericratonic rift basin which evolved in three stages (Pandey et al. 1993). A number of regionally correlatable events resulted in deposition of thick sediments both as transgressive shale and regressive sandstone in the basin. The main source rock and reservoirs were formed within the Older Cambay shale (OCS) overlying the Olpad Formation and Eocene sandstone overlying the OCS. The sedimentation in Olpad Formation took place during early rift phase in Paleocene and mark the beginning of Cenozoic sedimentation over the Deccan Basalt. There have been sporadic occurrences and production of hydrocarbon from Olpad Formation in Limbodra, Halisa and Gamij fields along the eastern margin (Fig.1) and major accumulation in Nawagam field in the western part of Ahmedabad Block. The accumulation along the eastern margin is mainly attributed to the updip wedging of OCS against the older Olpad sediments. Disposition of the favourable facies in Olpad Formation having both reservoir as well as cap rock attributes has role to play in the hydrocarbon accumulation especially in area close to OCS. Due to near similarity of the facies both at the base and at the top of Olpad Formation, demarcation of Olpad – OCS boundary, especially towards the distal part of the fan as well as Olpad - Deccan Trap boundary in the proximal fan end remains subjective. Besides, there is considerable heterogeneity in facies distribution within Olpad Formation. The main objective of the present study is to identify various subfacies and its distribution both in time and space and also correlate them with distinct electrofacies, standardized by an innovative petrophysical technique.

Methodology

Detailed sedimentological studies of conventional cores and cuttings from a number of wells drilled along the eastern margin covering Limbodra, Halisa and Gamij fields were carried out for understanding the lithological variations. The vertical distribution of lithofacies were used for reconstruction of a number of alluvial fans and a coherent process response model of the area.

A new log based overlay technique both in normal and reverse scale along with discriminant score function (D) obtained by using various combination of logs parameters mainly Sonic and Resistivity logs have been used to demarcate the Olpad Formation boundaries and also differentiate the different subfacies within Olpad Formation which can later act as ready reference for their identification in the field and also in preparation of facies distribution map in time and space. In the overlay, the Resistivity and Sonic logs in reverse scale are plotted by normalizing the two curves at the bottom of Cambay shale. At the bottom of Cambay shale, both the curves almost matches each other and bulges out as soon it enters the Olpad Formation. To supplement and corroborate the demarcation of the boundary between the two, Sonic log on normal scale is also plotted with Resistivity log by keeping same range of scale. The two overlys are then correlated with Neutron-Density separation as a supporting evidence of a facies change. The discriminant score function is a method developed by Kendall (1961), mainly used to demarcate the source rock and non-source rock facies for shale gas prospect evaluation and is also found to be useful here to demarcate the Cambay shale and Olpad boundary because of sudden change in D factor in Olpad Formation from the overlying OCS. The lower part of Cambay shale normally show a positive D, whereas, the Olpad Formation shows a negative D. All the available facies are cross plotted on a combined Density-Neutron and Sonic-Resistivity plot with shale background obtained from overall shale behavior to characterize each subfacies and a N-S lateral correlation profile of the subfacies / electrofacies prepared.

Sedimentary facies and alluvial fan model

The sediments of Olpad Formation were grouped under three broad alluvial fan subfacies on the basis of relative percentage of epiclastic conglomerate, trapwacke and claystone-sandstone facies in the subsurface. The A-subfacies consists of dominant matrix supported conglomerate with minor alternations of trapwacke and claystone / shale / sandstone and indicate debris flow component at the proximal end of an alluvial fan. The B-subfacies consists of dominant trapwacke with minor alternations of trap conglomerate, sandstone and shale and forms braided stream flow complex at the mid fan. The C-subfacies consists mainly of claystone and shale with minor siltstone and sandstone alternations and forms the sheet flood complex deposited at the distal end of the alluvial fan (Fig.2).

A number of profiles were selected along the eastern margin of Ahmedabad block, covering the Limbodra, Halisa and Gamij fields (Fig.3) and the distribution of the subfacies in the subsurface were mapped both along and across the probable fans and two conceptualized fan model in Gamij field have been presented for reference (Fig.4). From North Limbodra to South Gamij, it is observed that parallel west hading basin margin longitudinal faults have triggered the fans and it is envisaged that the NW-SE trending transverse faults delimit the lateral extent of each of the fan mapped which apparently also coincide with field limit. While plotting the limit of a fan on the basis of the disposition of facies, it has been observed that some faults triggering a fan probably lie further east to the known basin margin thereby, suggesting an extended eastward limit of the basin margin. In the deeper part to the west in the Nadipur low (Fig.3), the Olpad sediments represent a progradational system of alluvial fans having intertidal C-subfacies and are the probable prospective area.

No preferential accumulation of hydrocarbon is so far observed in any particular subfacies of Olpad Formation. Reservoir facies is developed in all the three subfacies. The hydrocarbon occurrence has been reported in one well each in A-subfacies in Gamij, B-subfacies in Limbodra and C-subfacies in Halisa fields. The conglomeratic A-subfacies is mostly matrix supported and has moderate primary matrix porosity. The porosity at places is affected by overburden pressure at deeper level. Very often the basalt clasts get weathered and the matrix gets enriched with secondary chlorite which reduces the effective porosity. The B-subfacies is mostly deposited by the braided streams and has relatively better development of reservoir facies in the form of primary inter-granular porosity. This subfacies is best suited for the hydrocarbon as it is mostly overlain by impervious C-subfacies at deeper level. Source rock studies in some wells in Nadipur low has indicated adequate source to charge the Olpad sediments in the deeper part. A facies influenced alluvial fan model in the Gamij field has been conceptualized (Fig.4) having multiple stacking of subfacies, originating from eastern margin and prograding towards Nadipur low in the west.

Electrofacies characteristics

A new log based technique has been applied to validate the subfacies identified above. This technique is also used in demarcation of formation boundaries. As observed, there is very low contrast in petrophysical properties of C subfacies with the overlying Cambay shale and also the conglomeratic A-subfacies with Deccan basalt. Hence, demarcation of Olpad-OCS and Olpad-underlying Deccan basalt boundaries remains subjective, even in the conventional logs. The new log based overlay technique both in normal and reverse scale along with discriminant score function (D) have been used in the present study for the above objectives. The standard subfacies established on the basis of lithological attributes in the Olpad Formation along the eastern margin are standardized through their typical log responses (Fig.5) The petrophysical attributes are further validated by cross plots of Density-Neutron and Sonic-Resistivity (Fig.6) and used on regional scale to establish a lateral correlation (Fig.7).

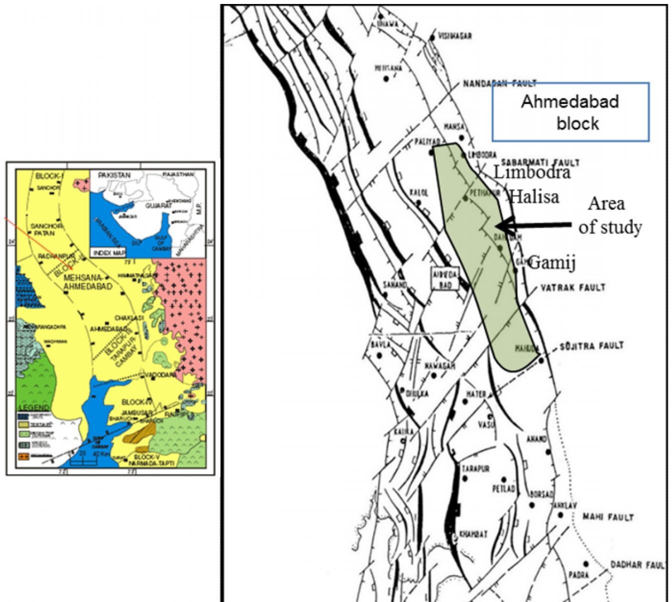


Fig.1: Area of study in eastern margin of Ahmedabad Block

Fig.2:Core Photographs showing various subfacies

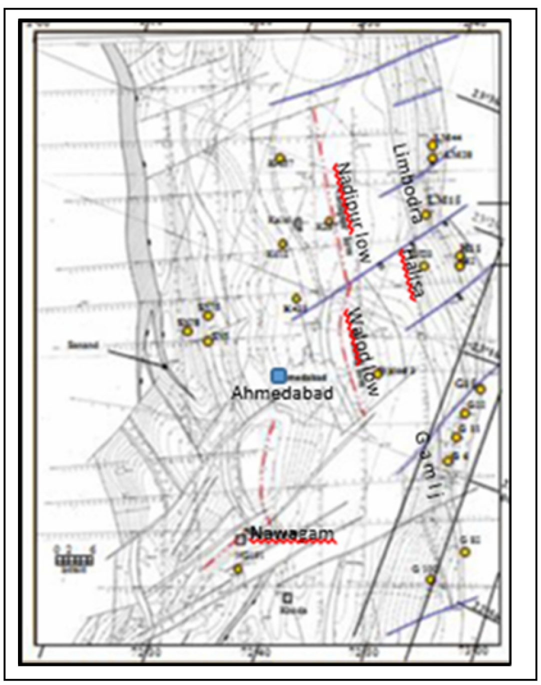


Fig.3: Tectonic map showing longitudinal and transverse faults and Nadipur low After Kundu et al 1992).

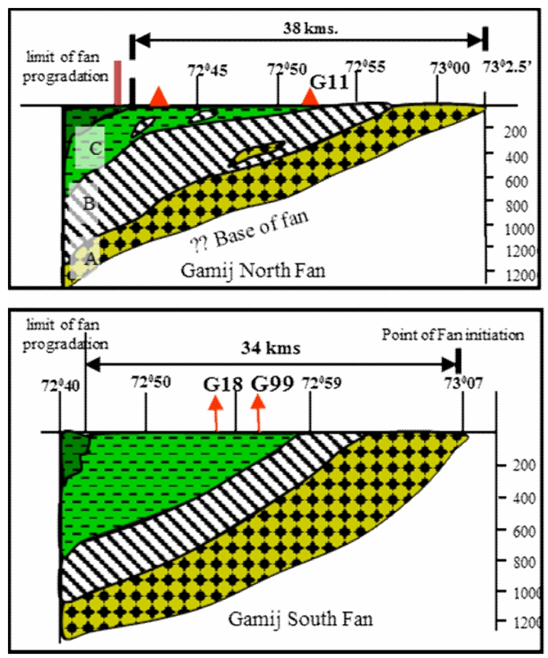


Fig.4: Reconstruction of two fans in Gamij field and disposition of various subfacies

The conglomeratic A-subfacies developed in the proximal end of the fan has good Sonic-Resistivity overlay separation and also a cross over on its reverse overlay. The D-factor curve shows constant negative value through out. It has moderately thick Density-Neutron separation. The mid fan B-subfacies has D-factor curve more or less in the zero base line region and swings both ways and the Sonic-Resistivity reverse overlay shows a uniform and wide separation, whereas the overlay separation shows increase in separation towards bottom and reverse overlay showsuniform and thick separation. In the C-subfacies at distal end of a fan, D-factor curve mostly shows low positive and mixture of positive and negative values negative values (Fig. 5). Development of various subfacies were further validated through Density-Neutron and Resistivity-Sonic cross plots depicting distinct spread of each subfacies with respect to average value of Cambay shale(Fig.6) Figure 5 depicts the facies heterogeneity along a N-S profile from Limbodra-Gamij fields.

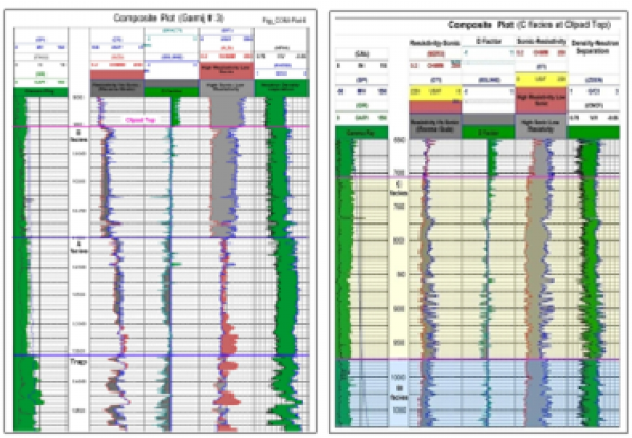
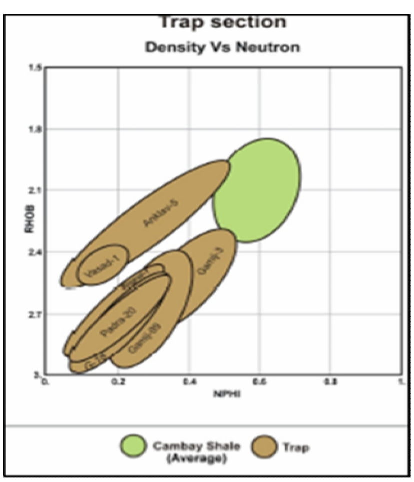


Fig.5: Composite plot which is the combination of logs, different log overlays and D factor in demarcation of various lithofacies in Olpad Formation



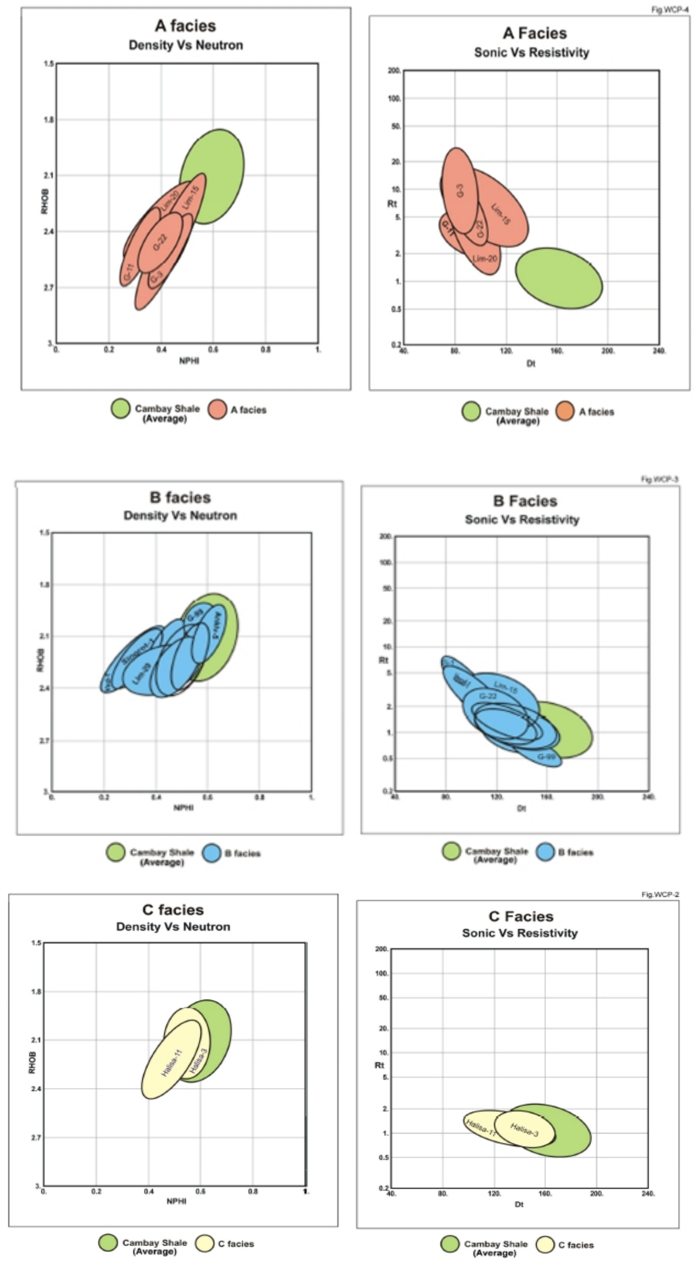


Fig.6: Density-Neutron and Sonic-Resistivity cross plots showing distinct cluster of each subfacies as compared to average cambay shale plots.

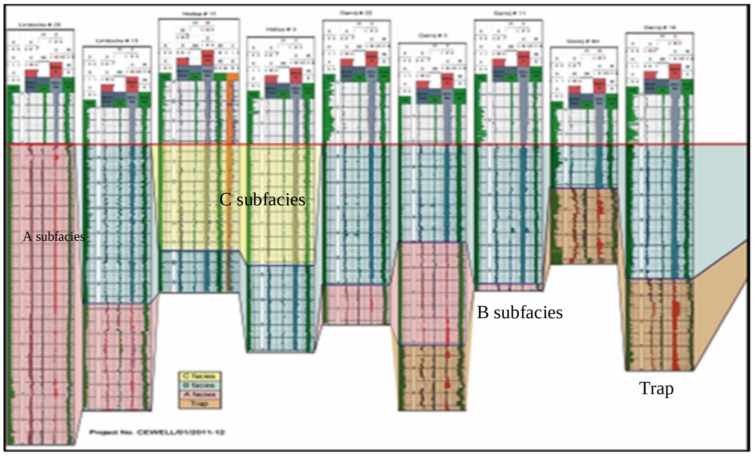


Fig.7: Log correlation showing distribution of the subfacies along a N-S profile from Limbodra to Gamij fields

Conclusion

1) The Olpad Formation in Limbodra, Halisa and Gamij fields situated along the eastern margin of Ahmedabad Block comprises three major lithological subfacies of alluvial fan complex namely, debris flow A-subfacies at proximal end of fan, stream flow B-subfacies at mid fan and sheet flood C-subfacies as part of distal fan.
2) A number of prograding fans could be reconstructed on the basis of distribution of the subfacies and the basin slope.
3) No preferential accumulation of hydrocarbon is observed in particular subfacies, however, the B and C-subfacies have better reservoir development and the area where there is multiple overriding of A and B-subfacies having C-subfacies shale on top are prospective.
4) Adequate source rock facies in Olpad Formation has been observed in some of the wells in the deeper part of Nadipur Low which can act as source for hydrocarbon.
5) The new log based interpretation technique using different log overlays of Sonic & Resistivity and Density-Neutron separation along with Discriminant score function (D) has helped in exact demarcation of Olpad and overlying Cambay shale formations and Olpad-Deccan Basalt boundaries and evolving a standard criteria for accurate demarcation of the three subfacies.
6) The conglomeratic A-subfacies has good Sonic-Resistivity separation and also a cross over on its reverse overlay. The D-factor curve shows constant negative value through out.
7) The B-subfacies has D-factor curve more or less in zero base and swings both ways and the Sonic-Resistivity reverse overlay shows a uniform and wide separation.
8) The accurate calibration of lithofacies with electrofacies by the innovative technique is a new approach in exploration of reservoir facies in the similar geological setting and can be a substitute to the sample examination especially in development wells.

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