

Igneous Intrusion in Mesozoic, Kutch Offshore: Contact Metasomatism in Host Rock and Impact on Hydrocarbon Prospectivity

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Keywords

Deccan, metasomatism, contact metamorphism, metamorphic aureole, intrusive, hydrocarbon.

Abstract

Deccan volcanism in Western part of India has been a unique phenomenon. It has modified the entire landscape of the western India. Most of the Mesozoic sedimentary basins of western India have been capped by the Deccan continental flood basalt. Which pose unique challenges for natural resource exploration in Mesozoic sedimentary basins in the region. In addition to effusive basalt on the surface multiple intrusive bodies throughout host rock are expected. The intrusive volcanism tends to alter the host rocks.

This paper will discuss key findings on interaction between igneous rock and sedimentary rock; and resultant host rock alteration due to contact metasomatism; especially on reservoir quality. Such intrusive bodies in Mesozoic could be identified and reasonably mapped 3D seismic data, which has some unique seismic character. Wireline logs also show some unique log characters at the intrusive. The altered zones at intrusive volcanics show higher resistivity in wireline logs, which could sometimes be interpreted as pay zone. Detailed studies need to be conducted integrating mud log data, side wall core (SWC), advanced wireline data to identify any hydrocarbon prospectivity in such zones. The understanding of the phenomenon and subsequent interpretation of well logs and seismic data are helpful to de-risk such hydrocarbon prospects/zones in the region. This understanding has great implication on hydrocarbon exploration in sub-basalt sedimentary basins.

Introduction

The term contact metasomatism, generally attributed in the first instance to Barrell (1907), refers to a process of chemical change in the composition of rocks adjacent to igneous intrusions, the change being brought about by migration of elements originating from the magma or the host. Migration

may take place either by solid diffusion or through the agency of pore fluids, vapors, or gases. Contact metamorphism takes place where a body of magma intrudes into the upper part of the crust. Any type of magma body can lead to contact metamorphism, from a thin dyke to a large stock. The type and intensity of the metamorphism, and width of the metamorphic aureole will depend on a number of factors, including the type of country rock, the temperature of the intruding body and the size of the body. A large intrusion will contain more thermal energy and will cool much more slowly than a small one, and therefore will provide a longer time and more heat for metamorphism. That will allow the heat to extend farther into the country rock, creating a larger aureole.

In Kutch region (figure -1a), igneous intrusion in Mesozoic is expected to be related to Deccan volcanism. Deccan volcanism is known to be related to Hot-spot volcanism of Late Cretaceous age. Largely it is effusive viscous continental flood basalt and covers most of the Mesozoic sedimentary basin in western part of India (Figure-1a). The deccan volcanism extended toward the western offshore region. Multiple drilled wells have encountered Deccan layer below Tertiary sedimentary cover. In addition, multiple evidence of intrusive magmatism reported in different outcrop bodies in the region and some intrusive encountered in the well targeted for Mesozoic prospects.

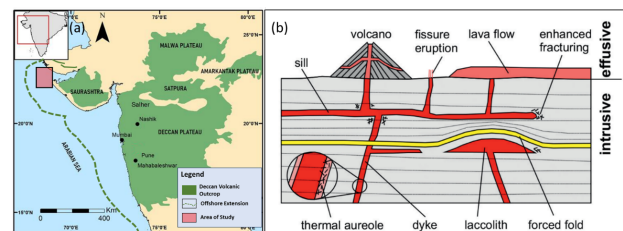


Figure-1. (a) Extended Deccan province and area of study. (b) volcanic processes and related intrusive and effusive geomorphologies (Kim Senger, 2017)

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Igneous and Sedimentary Rock Interaction

The contact metamorphic aureole is typically quite small (Figure-2), from just a few centimeters to 10s of meters depending on small intrusion- dike& sill to large flood basalt. Metamorphisms refer to one mineral replacing another mineral phenomenon. Its essence is that the dissolution of minerals and metasomatic minerals deposition occurs at the same time, leading to metasomatism occurrence. The effect often occurs along vesicles, intergranular pores, and cracks and has typically metasomatic stripes characters. One characteristic feature of the contact metamorphism is that mineral assemblages in the aureole show a concentric zonation around the intrusion with the grade of metamorphism and intensity of metamorphic recrystallization decreasing radially outward. The width and the max temperature reached in the thermal aureole are a function of the size, composition and the intrusion depth of the magmatic body and the temperature difference between the intrusion and the country rock (Spear, 1993).

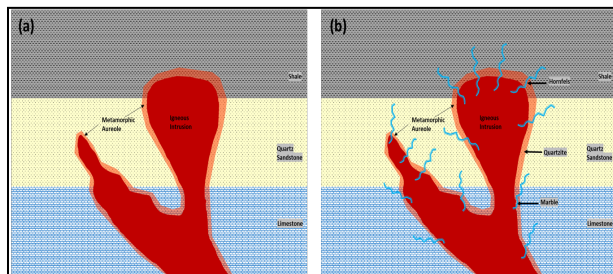


Figure-2: Igneous intrusive in sedimentary rock and resultant deformation caused by contact metamorphism. (a) Metamorphic aureole around intrusive igneous body. (b) Contact metamorphism of country rock and resultant metamorphic equivalent rocks. In addition, due to release of fluid during cooling of intrusive body alter the pore fluid in the country rocks.

Evidence of Igneous Intrusion in Mesozoic, Kutch Offshore

While Deccan layer and intrusive bodies are well explored in onshore outcrops of Kutch region. The Kutch mainland has various outcrops of intrusive

volcanics in Mesozoic of various shapes and sizes. There is little work published on Offshore area where Mesozoic rocks are buried deep under thick Deccan basalt layer. There are few wells penetrated in the area sub-basalt and fewer wells penetrated igneous intrusive in the region. There are basic wireline logs and cutting samples available in drilled wells. Seismic data acquisition under thick basalt is generally a challenge and seismic resolution is not suitable to identify small intrusion. Intrusive bodies >50m can be identified in moderate quality 3D data.

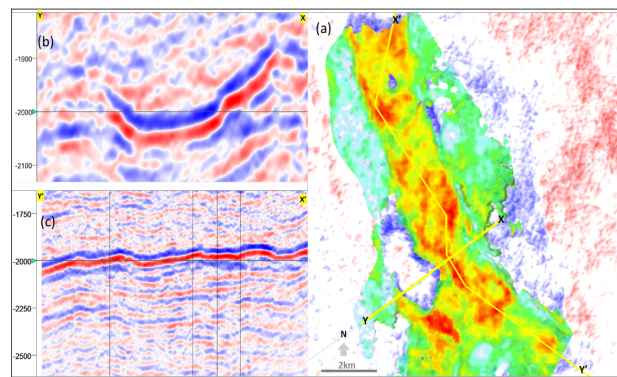
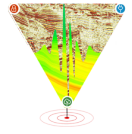


Figure-3. A bed parallel intrusive body mapped in seismic. (a) high impedance (red) spread over large area. (b) & (c) showing a dip and strike section.

Thicker volcanic bodies are well identified in the seismic data (figure-3 & 4). Intrusive bodies- bed parallel (sill) and oblique/sub-vertical(dike) are sometime mappable. A careful interpretation approach is required while evaluating sub-basalt hydrocarbon traps. Sometime oblique intrusive bodies give the impression of tilted fault block (Figure 2c) which could be misinterpreted as structural traps. Sill bodies parallel to bed are unlikely to be mappable unless it has contrasting impedance. Basic amplitude extraction at the identified intrusive bodies could help to identify the extent and shape of the intrusive. Igneous intrusive near to top of the sedimentary bed could create some dome like feature- Laccolith structure. Which could be an interesting trap for hydrocarbon if mappable!



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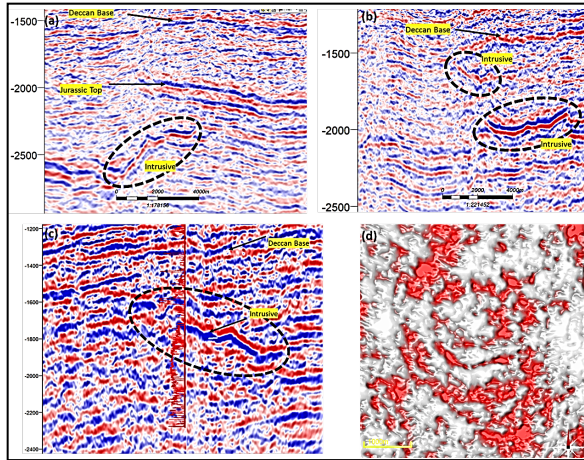


Figure-4. Seismic evidence of intrusive bodies in the Mesozoic. (a) intrusive Identified in Jurassic (b) Intrusive in Cretaceous clastic (c) intrusive in Cretaceous, well also encountered 80-meter intrusive (d) amplitude map at Cretaceous- A large high impedance (red) circular feature at top of the intrusive.

Impact of Intrusive bodies in country rock

A unique phenomenon is observed in wireline logs at the boundary around intrusive body. Elevated resistivity is seen just above and below the intrusive body and seems to be prospective in terms of hydrocarbon accumulation. Therefore, detailed studies need to be conducted integrating all mud log data, side wall core (SWC), advanced wireline data etc. The density is also higher (lower porosity) compared to similar reservoirs farther from intrusive body (Figure 5). The formation pressure tester run against these zones show the reservoir adjacent to intrusive body were tight and reservoir farther from intrusive body could get stabilized pressure data as well as taken samples (Figure 5 (a)).

The various wireline log overlay methodology could be investigated for hydrocarbon prospectivity. The overlay methodology only with resistivity shows positivity but compressive and shear sonic did not indicate any light fluid response in the well. Again, shallower resistivity logs were higher than deeper resistivity values in oil base mud (OBM) system

(Figure 5 (b)) which indicates wet reservoir. The SWCs indicate poor porosity and no fluorescence/ no cut (NF/NC) as well as no elevated gas in mud logs. By integrating all the above observations, such zones nearby intrusive body is a clear indication of contact metasomatism (recrystallisation) by high temperature intrusive body.

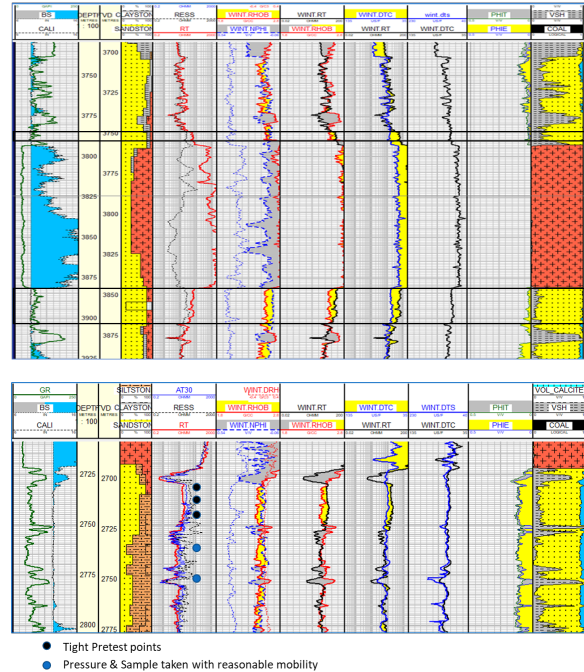


Figure 4. Wire-line log interpretation (a) Elevated resistivity just below intrusive; (b) Another example of elevated resistivity at top and bottom of intrusive.

Conclusion

Kutch region or any other basalt impacted sedimentary basins, the elevated resistivity just below and above of intrusive body could be interpreted as hydrocarbon pay zone. Resistivity logs are very crucial to understand the hydrocarbon saturation in any exploration well. Elevated resistivity along other wireline logs used by Petrophysicist to calculate oil and gas saturation in a particular well. A careful interpretation with understanding of contact metasomatism and related deformation is helpful for meaning-full interpretation of such zones.



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Further analysis will be needed to determine the metamorphic/metasomatic processes leading to occlusion of porosity and elevation of resistivity profiles above and below the intrusions. Many igneous intrusions in sedimentary rock have been reported in Kutch mainland Mesozoic outcrops (Chauhan G. et al, 2021). Detailed sampling and lab study in such outcrops will give better estimate of degree/depth of host rock deformation. The results of petrographic study should be integrated with seismic data and well log observations to assess impact of igneous intrusion on hydrocarbon prospectivity/reservoir quality in the region.

Acknowledgement

Authors are thankful to Cairn Oil & Gas, Vedanta Limited for giving this opportunity to present the technical work. The authors also thank their co-workers at Cairn Oil & Gas, Vedanta Ltd. for their support and technical input in completion of this paper.

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