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Understanding of Volcanic Intrusives and Hydrocarbon Habitat Through Integrated Study in Gulf of Mannar Offshore, Cauvery Basin

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Summary

Mehsana tectonic block located in the western Indian state of Gujarat is a fairly well explored, productive block of North Cambay Basin. Exploitation in Mehsana block has attained a mature stage. Large sized pools are in Kalol Formation occurring at shallower depths in structural plays and operate under water drive while small sized pools are concentrated at deeper depths in Mehsana and Mandhali Members of Kadi Formation controlled by strati-structural entrapment operating under depletion drive. The problems in these reservoirs are of contrasting nature.

Introduction

Gulf of Mannar falling in the southern tip of India (Fig. 1) covers an area of over 60,000 Sq.Km in the Indian territorial waters. The basin fill in the deeper part of the basin is likely to be in excess of 12 km which might include pre-rift and early syn-rift sequences of Jurassic age. The regional aero gravity anomaly map (Fig.2) depicts the regional setting of Mannar basin vis-à-vis the Indian Craton to the west and Srilankan massif to the east.

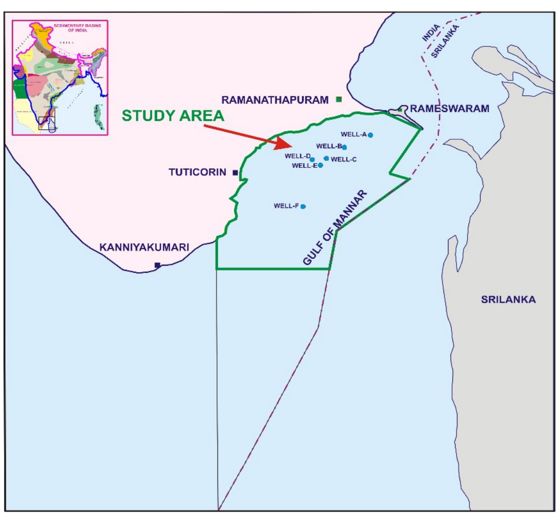

Fig.1 Index map showing study area

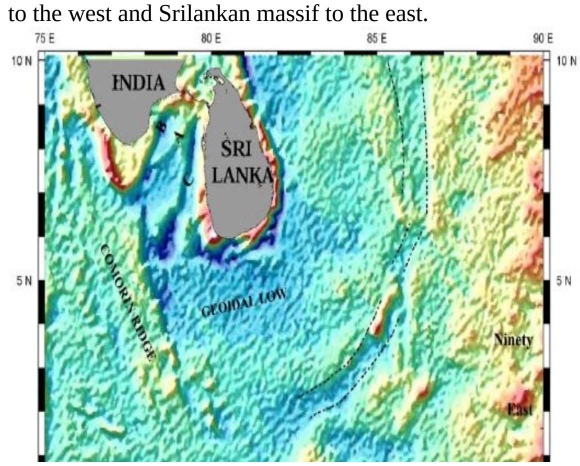

Fig 2 GEOSAT/ERS-1 derived free air gravity anomaly mosaic depicts high resolution imprints of several tectonic elements (after Sandwell and Smith, 1970) – Desa, 2006

Geologic and tectonic setting:

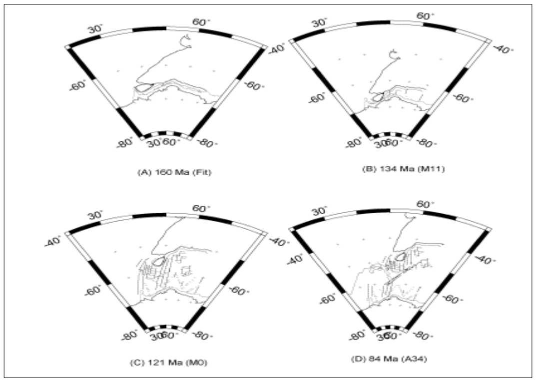

Fig 3 Plate reconstruction model depicting the paleo position magnetic anomaly lineaments – Desa, 2006

Plate reconstruction model (Fig-3) of India and Srilanka (Desa et. al. 2006) indicates that India and Srilanka were together up to Late Jurassic (Oxfordian, 160 Mabp). The oldest magnetic anomaly M 11 identified by them south of Srilanka has been dated as 134Mabp Hence it is assumed that earliest '**syn-rift'** sequence of Mannar depression should be in the window 134-160 Mabp as separation of India and Srilanka would have been initiated during this period. Deposition of thick '**early syn-rift'** and '**late syn-rift'** would have coincided with early Cretaceous period (134-100 Mabp). The Cretaceous basin in Gulf of Mannar area can be divided into two sub–basins, the Mannar sub-basin to the NW and Pamban depression to the SE. Towards the SE part of the basin adjoining Srilanka, maximum thickness of sediments is seen in Seismic section, probably indicating Rift initiation. Turonian is marked by widespread intrusive volcanics in the basin which draws support from the fact that Indian sub-continent was in close proximity to Kerguelen hot spot during that period. Deposition of sediments of '**post rift'** phase followed this (Nannilam and Portonovo Formations). Sediments of '**late drift'** phase and '**passive margin subsidence'** (Paleocene to Oligocene) followed this and during the last major tectonic activity of collision of India with Asia, the basin witnessed a '**compressional**' regime which is manifested as a gentle folding of Neogene sediments in seismic sections. The tectonic events and their stratigraphic occurrence are given in Fig.4

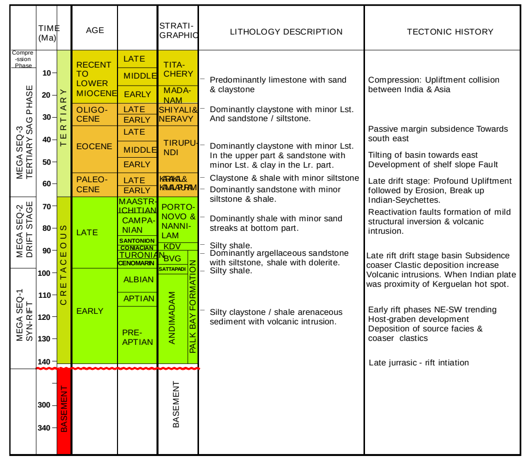

Fig 4 Stratigraphy and associated tectonic events of the study area

Careful scrutiny of the fault pattern in the Mannar basin indicates two major trends viz., NNE-SSW paralleling strike and in NNW-SSE direction. The older extensional faults have been reactivated indicating a multiphase tectonic activity.

Distribution of intrusives in wells:

Till date 6 wells have been drilled in the Mannar offshore in Indian Territory (wells `A' to `F'). Intrusives have been encountered in all the wells in Upper Cretaceous except in well 'B' which was drilled on the Mandapam Delft Ridge. An electro log correlation (Fig.5) through wells 'C', 'D', 'E' and 'F' clearly bring out the varying thickness of the intrusives. In wire line logs they are charecterised by low GR reading, high density, high resistivity and high interval velocity. They are encountered in sediments of Conician to Turonian age. Maximum thickness of about 300m is encountered in well `A'. The intrusive met in well `A' has been dated as 60.8 $\pm$ 3 ma while the intrusive encountered in Pearl-1 well in Srilankan offshore has been dated as 76 ma through k/Ar dating.

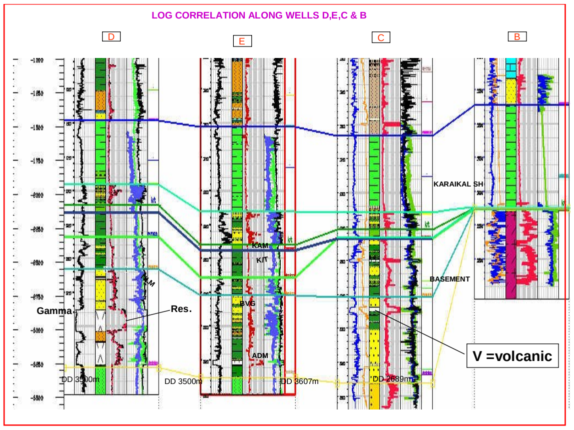

Fig.5 Electro log correlation through wells C, D, E & `F

Mineralogically, these intrusives are basically dolerite in nature. Megascopic analysis of the core samples in wells indicates they are very hard, compact and composed dominantly of feldspar (40-50%), ferro-magnesium minerals (40-50%) and quartz (<10%) and high angle slickenside is observed. Under thin section, (Fig.6) they

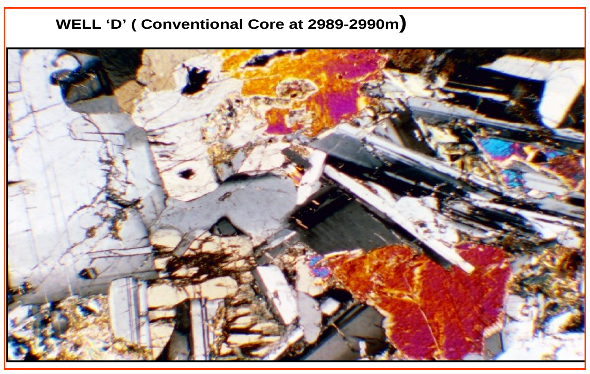

Fig.6 Microphotograph shows coarse laths of plagioclase feldspar partially enclosed in Augite showing ophitic texture

exhibit coarse laths of Plagioclase, feldspar partially enclosed in Augite showing sub ophilitic texture The close observation of cutting sample during drilling indicates the presence of low grade metamorphic mineral which probably developed due to contact thermal metamorphism.

Intrusive and seismic response:

Most of the intrusives images on seismic data are characterized by high acoustic impedance. These intrusions exhibit very high amplitudes within very low amplitudes and in time slices extracted through the Formation they can be seen as concentric rings or ellipsoidal geometries. The high amplitude roughly coincides with the top of sill complex inferred from well and seismic data in Well D. (Fig.7).

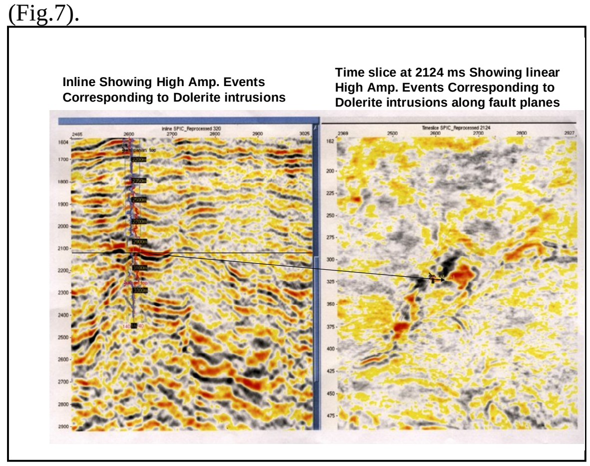

Fig 7 Seismic line showing well log response and seismic response corresponding to dolerite intrusions. The right side figure is a time slice showing the high amplitude events corresponding to dolerite intrusions along fault planes

This unusual geometry is unique in the volume for the referenced interval. These high amplitudes with tapering reflection strengths towards the tail are assumed to be caused by hydrothermal fluids that move across (Fig.8) the Formation and while passing through the country rock it heats not only the matrix but also the pore fluids. The pore fluids become super heated and due to their confined space, become severely over pressured. The high pressure fluid then rises along the track of the intrusion to the point at which the Formation pressure exceeds the fracture gradient of the rock matrix, it then rises vertically to the surface, which may be up to 500m above the over pressured zone. Time slices through these dolerites/basalts/intrusions (Fig.9) in a seismic volume sometimes appear as a channel feature and therby misleading the interpreters.

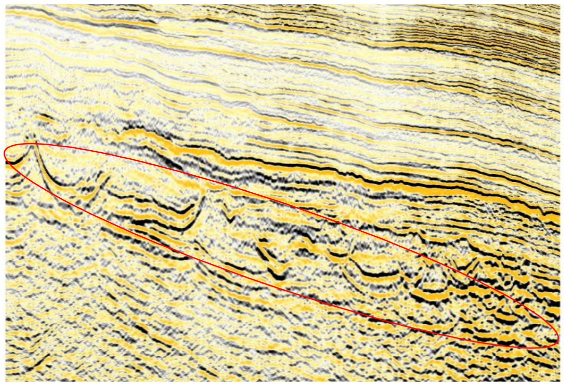

Fig 8 Intrusives corresponds to high amplitudes with tapering reflection towards the tail cut across the Formations.

The geometry of the event, reflection character (Fig.10), and the high interval velocities point towards igneous intrusive body and not sedimentary deposits. At the interface of shale and dolerite, AVO response was observed in seismic volume in the prospect "D". In 3D seismic opacity volume (Fig.11) the dispersion of intrusions are well visible.

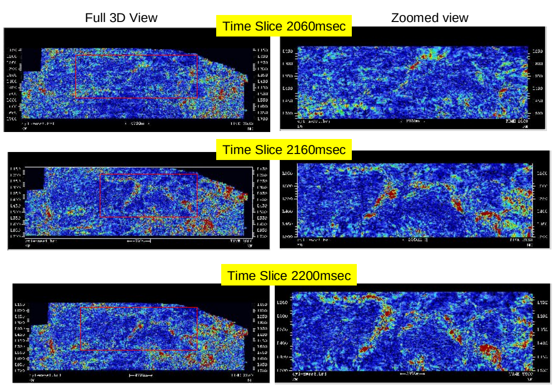

Fig 9 Time slices thro' the Dolerite section of Well 'D' showing channel like feature.

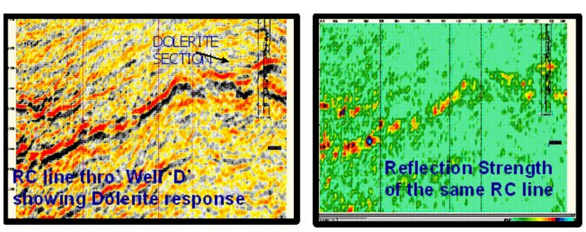

Fig. 10 RC line showing high amplitude events corresponding to Dolerite intrusions.

In regions of extensive igneous intrusions a number of common features are observed. In competent strata sills are seen which often follow a weak lithological boundary bedding planes and upon reaching structural boundary, a pre existing fault step up through strata in a staircase manner. In less consolidated formations the intrusive magma tends to rise in an inverted conical manner. (described as saucer or rose petal shaped)

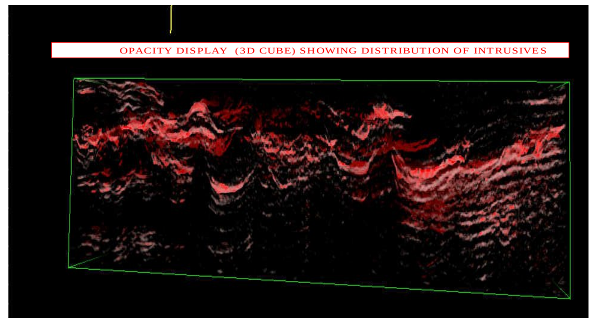

Fig 11 Opacity volume: Dispersion of intrusion is well visible

Igneous intrusives and Petroleum System:

The effect of intrusive on various components of petroleum system is described below:

Source:

It has been found that in well 'D', **Vro** value was abnormally high in vicinity of intrusive (Table I). As it is only a local phenomenon, it does not change significant geothermal gradient in the area. During Dolerite intrusion, the heat is transmitted to adjacent surrounding sediments, where Vro abnormally increases. This may create mature local source rock pods with limited extended area. In nearby well 'E', minor gas show with higher hydrocarbons(C-5 and above) was observed within Kamalapuram (Paleocene) reservoirs.

Sample no.	Depth(m)	Vro	Remarks
1	2110	0.40	Dolerite interval
2	2684	0.78*	2631-2656m
3	2990	0.41**	2875-3033m
4	3000	0.46**	3116-3281m
5	3150	0.40**	
6	3318	1.46*	

Table-I: Vro values observed in well 'D'

Reservoir:

Hydrothermal solutions in form of steam/vapor might have affected Paleocene reservoir in wells 'D' and 'E'. Sedimentological study indicates the destruction of primary porosity due to pore filling of calcite cementation .This might have developed due to dissolution of organic shells in contact with hydrothermally heated fluids coming from sub-seismic micro-hydrothermal vents generated by the intersections of sill intrusion and sediments pore fluids.

Charge:

The intrusion of dolerite might lead to formation of low grade meta-sediments due to contact thermal metamorphism (ditch sample description of well 'D') which could have choked migratory path along the deep seated fault planes thereby restricting hydrocarbon migration. However, triggering of Tertiary migration from an earlier charged reservoir below during the process of intrusion can not be ruled out. There are examples of such 'injectites' housing hydrocarbons.

Intrusive-induced traps:

Sill intrusion can generate subtle anticlinal traps. The jack up (forced folds) structure is clear in seismic sections in well 'D'. Such type of structures has been documented by many authors. The seismic data shows forced fold structure (pseudo inversion) to form hanging wall anticlines and fault closures along the pre existing fault blocks which got rotated.

Discussion and conclusions:

Volcanic intrusive are commonly encountered in Gulf of Mannar. Their thickness however varies from well to well. They are mainly Dolerites. The expression of such intrusives in seismic sections/time slices is very typical and easy to distinguish.

Such intrusives are commonly met in the Upper Cretaceous section in the drilled wells. It is thought that the occurrence of Indian plate close to Kerguelen hotspot during this period could be the cause for this. A number of eruptions in multiple episodes of magamatism are observed which is supported by different age dating. The maximum intensity of magamatism occurred in the Turonian sediments during the deep subsidence along reactivated normal faults.

An understanding of the dynamic processes of volcanic emplacement is most important to assess the petroleum potential of this part of the basin as volcanic intrusions may influence trap formation, hydrocarbon migration and reservoir.

In Gulf of Mannar, presence of huge thickness of syn-rift sequence may prompt early expulsion of hydrocarbon from deeper source. These hydrocarbons may accumulate in the reservoirs below intrusives (Zhenyan Chen) which can be prime exploration focus in such volcanic basins.

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