[PS]Lacustrine Turbidites in Rift Basins: Genesis, Morphology, and Petroleum Potential - A Case Study from Barmer Basin*

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Abstract

Sedimentary successions of lacustrine rift basins document variations in sediment supply through time, modified by structural controls. Typical continental rift sedimentation commences with fluvial and fluvio-lacustrine regime with progressive deepening of the grabens which have lacustrine turbidite deposits. Internal complexity, difficulties in defining reservoir continuity pose challenges to exploration and exploitation. Barmer Basin, situated in western Rajasthan, NW-SE trending failed continental rift containing mainly Tertiary sediments. Turbidite sands dominate the synrift basin centers during Late Paleocene to Early Eocene in the Barmer Hill and Dharvi Dungar Formations. Successful exploration of turbidites has established considerable inplace resource in strati-structural accumulations but challenges on production and optimal recoveries are yet to be resolved. Integrated geological model to explain the depositional architecture and reservoir facies distribution has been attempted using seismic attributes calibrated to cores and wireline logs. Surgical mapping of individual sand packages helped in defining the extent, morphologies, and inherent internal geometries. Sourced from the eastern margin, the Vijaya-Vandana turbidites show typical basal sheet sands, confined channel complexes, and mounded terminal lobe morphologies in the 3D seismic data. Penetrated in ten wells, the lithological association can broadly be classified into three categories: proximal turbidites along the basin bounding faults dominated by deep water channels, distal turbidites dominated by fan/lobe systems, and fluxoturbidites with varying thickness from thin laminations to 5mts thick massive beds. The porosity and permeability of reservoir sands vary widely, from 7% to 23% total porosity and 0.1 md to 20 md permeability in proximal fan and channels. Individual reservoir zones are highly heterogeneous, compartmentalized, and thinly laminated posing serious challenges in reservoir modelling. Three sand rich pulses in the Dharvi Dungar Formation have brought in coarser clastics in the deeper basin which are well demarcated by seismic attributes and well data indicating relatively thin basin margin deltas, slope channels, and deeper basin fans.

Thermal maturation modeling suggests Barmer Hill shales are thermally mature in the Vijaya-Vandana graben. Petroleum system analysis of these grabens, charge scenarios, and overall potential of the turbidite sequences are detailed in the poster.

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LACUSTRINE TURBIDITES IN RIFT BASINS: GENESIS, MORPHOLOGY AND PETROLEUM POTENTIAL - A CASE STUDY FROM BARMER BASIN

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ABSTRACT

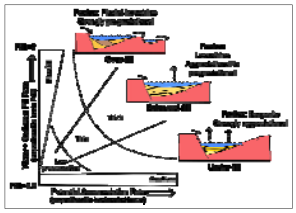
Sedimentary successions of lacustrine rift basins document variations in sediment supply through time, modified by structural controls. A typical continental rift sedimentation commences with fluvial and fluvio-lacustrine regime with progressive deepening of the grabens which have lacustrine turbidite deposits. Internal complexity, difficulties in defining reservoir continuity pose challenges to exploration and exploitation. The Barmer Basin, situated in western Rajasthan,India is NW-SE trending failed continental rift containing mainly Tertiary sediments. Turbidite sands dominate the deeper part of synrift basin centers during Late Paleocene to Early Eocene aged Barmer Hill and Dharvi Dungar Formations. Successful exploration of turbidites has established considerable inplace resource in strati-structural accumulations but challenges on production and optimal recoveries are yet to be resolved. Integrated geological model to explain the depositional architecture and reservoir facies distribution has been attempted using seismic attributes calibrated to cores and wireline logs. Surgical mapping of individual sand packages using high resolution 3D seismic data helped in defining the extent, morphologies and inherent internal geometries. Key seismic attributes have freely been used to capture the lateral heterogeneity.

Sourced from the eastern margin, the Vijaya-Vandana turbidites show typical basal sheet sands, confined channel complexes and mounded terminal lobe morphologies in the 3D seismic data. Penetrated in twelve wells, the lithological association can broadly be classified into three categories: (i) proximal turbidites along the basin bounding faults dominated by deep water channels, (ii) distal turbidites dominated by fan/lobe systems and (iii) fluxoturbidites with varying thickness from thin laminations to 5mts thick massive beds. The porosity and permeability of reservoir sands vary widely, from 7% to 23% total porosity and 0.1md to 20md permeability in proximal fan and channels. Individual reservoir zones are highly heterogeneous, often compartmentalized and thinly laminated, posing serious challenges in reservoir modelling. Three sand rich pulses in shallower Dharvi Dungar Formation brought in coarser clastics in the deeper basin which are well demarcated by seismic signatures (high amplitude anomalies). Regional seismic attribute maps clearly indicate presence of relatively thin basin margin deltas, slope channels and deeper basin fans. Thermal maturation modeling suggests Lower Barmer Hill shales are thermally mature in most part of the basin including the Vijaya-Vandana graben.

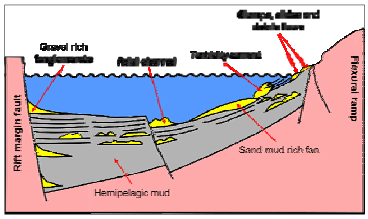
Key Words: Lacustrine turbidite, rift basin, proximal turbidite, distal turbidite, compartmentalization, Barmer basin.

Introduction

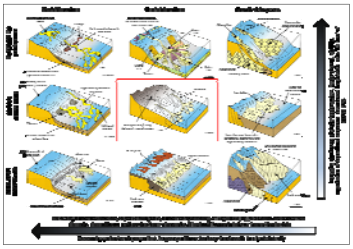
Turbidite systems in non-marine, tectonically active lacustrine rift basins, are underexplored and less understood, though they comprise hydrocarbon reservoirs in East Brazil (Bruhn et al, 1998; Carozzi and Fonseca, 1989), West Africa (Teisserenc and Villemin, 1990) and China (Wagner et al, 1988; Xi-Jiang, 1988). Modern day lakes associated with rifts exhibit presence of fluxo-turbidites (Dzulynski et al., 1959) on one end and normal turbidites on the other, developed at the frontal part of channels entering the basins through relay ramps or flexural margins. Single or multiple feeder gravel rich, mixed sand-mud and mud rich turbidite systems are more common in rift associated lacustrine basins. Tectonic activity generally is the main factor controlling the occurrence of primary sequences, whereas climate, which in turn controls sediment influx, provides dominant control on the development of 4th and 5th order sequences. (Arienti, L. M. 1998).



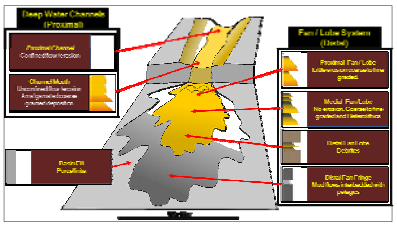
Lacustrine sequences with associated facies. Turbities in true sense can be observed in balance-fill situation (modified after Carroll and Bohacs, 1999)



Different types of deep water deposits observed in balanced-fill lacustrine systems (modified after Nelson. C.H, 2009)



Depositional model for turbidite systems (modified after Reading and Richards, 1994)

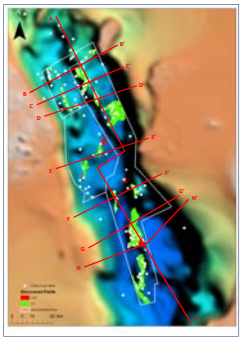


Architectural elements in lacustrine turbidites and associated lithologies (modified after Ben Kneller, 2012)

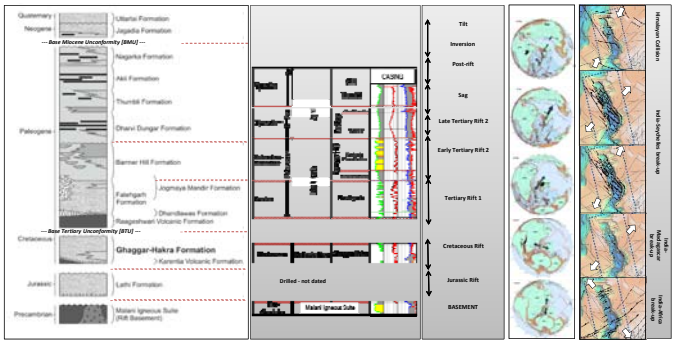
Barmer Basin

Barmer Basin, situated in western Rajasthan, is a low strain, NW-SE trending, 200 km long and 25 km wide, failed continental rift and is a northward extension of the Kutch or Cambay basin. The basin contains Jurassic to Recent sediments overlying Proterozoic basement. The basin suffered multiple phases of rifting and later inversion and tilting during the Himalayan orogeny.

Location of Barmer basin



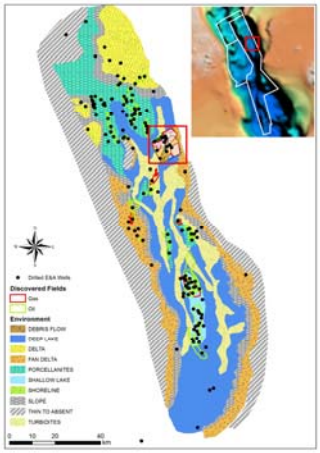
Representative west–east structural cross sections illustrating the major structural features of the Barmer basin.



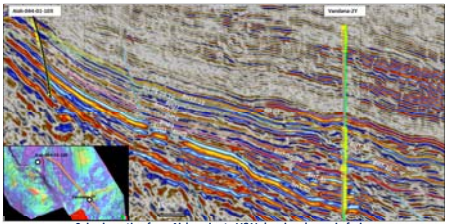
Stratigraphy of the Barmer basin, linked to principal steps in tectonic evolution

Vijaya-Vandana Area

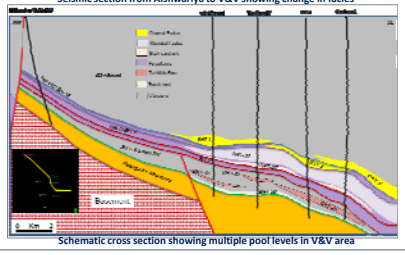
The Vijaya & Vandana (V&V) area lies SE of the producing Aishwarya field along Eastern Margin. Total twelve wells have been drilled in V&V graben, which shows good reservoir development in the lacustrine Barmer Hill Formation. Reservoir lithology of this interval is predominantly laminated siltstone, coarser beds of siltstone, argillaceous sandstone and conglomerates of turbidite origin, deposited against the background canvas of shales and porcellanites. It exhibits distinctly different channel and mounds morphology in seismic data as compared to the layered Porcellanites of Aishwariya field.



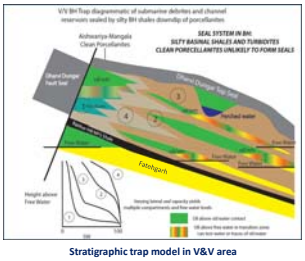
Barmer Hill GDE with Vijaya and Vandana (V&V) location in RJ-ON-90/1 block



Seismic section from Aishwariya to V&V showing change in facies



Schematic cross section showing multiple pool levels in V&V area



Stratigraphic trap model in V&V area

Turbidite fairway:

- Combination traps, dominantly stratigraphic
- Multiple pool levels, all within the BH complex
- Reservoir quality decreases with depth
- Perched water (?) in some sands, overpressured
- Free water levels unknown
- Laminated reservoirs, often compartmentalized

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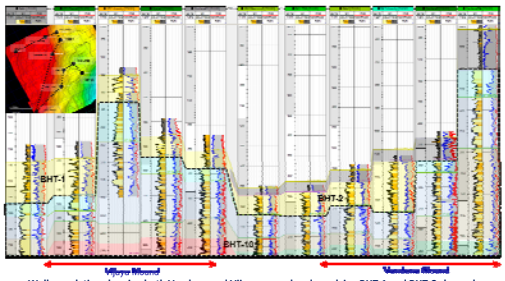
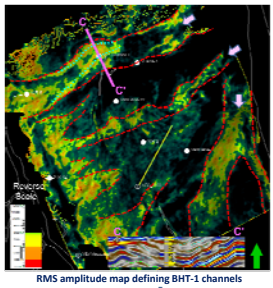
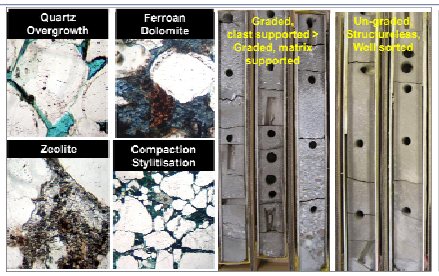


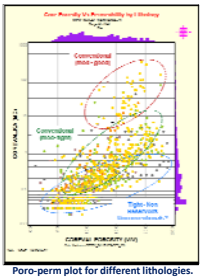
Well correlation showing both Vandana and Vijaya mound and overlying BHT-1 and BHT-2 channels



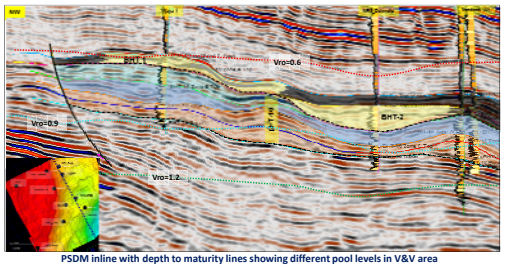
RMS amplitude map defining BHT-1 channels



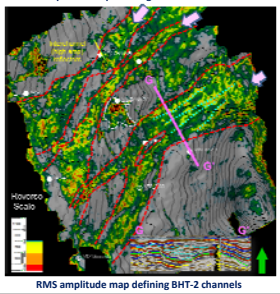
BHT-10 cores with thin sections showing heavy diagenetic alteration



Poro-perm plot for different lithologies. Reservoir quality variation within each litho-facies is mainly due to diagenesis.



PSDM inline with depth to maturity lines showing different pool levels in V&V area



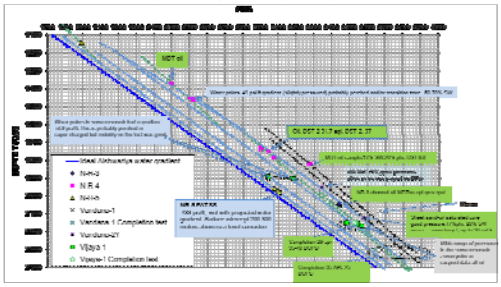
RMS amplitude map defining BHT-2 channels

Depositional Setting	Lithology						RQ					RQ Range
	S	H	C	X	M	P	vg	g	m	p	n	
Distal Channel												good-v good
												mod good- poor
												poor -non res
Turbidite Sheet Sand												v good & mod good
												poor - non res
Proximal Channel												mod good
												poor
Proximal Fan												mod good to poor
												poor - non res
												occ mod good-good
Medial Lobe/Levee												poor - non res
												mod good -poor
												rare mod good -good
Distal Area												poor - non res
Non Axial												occ mod good
												poor - non res
												occ mod good
Distal Fan Fringe												non reservoir
Fan Adjacent												poor - non res

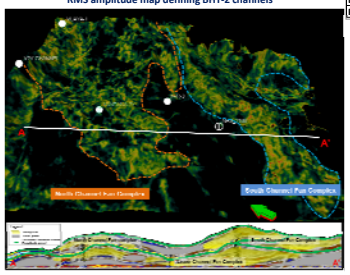
Major lithologies observable in different depositional settings

Lithology
S Sst
H Heterolithics
C Conglomerates
X Chaotics
M Mudstones
P Porcellanite

Abundance
occassional-rare
common-v common



Pressure data in V&V area showing highly compartmentalized reservoirs with perched water



RMS amplitude map defining BHT-10 channel-fan complexes

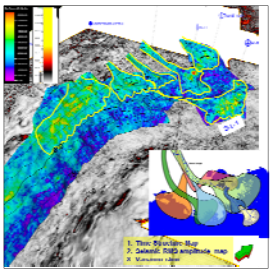
Core Porosity and Peremability Statistics

Lithotype	samples	Porosity (%)					Permeability (md)						
	n	min	max	mean	mode	median	min	max	mean (geom)	mean (arith)	mean (harm)	mode	median
Sandstones (all)	412	2.5	23	13.1	13.9	13.1	0.02	295	0.29	7.23	0.14	0.04	0.29
Clean Sandstones	259	2.5	23	15.6	16.2	16.4	0.03	295	1.3	11.6	0.32	0.7	1.04
Argillaceous Sandstones	216	1.9	23	9.3	0.27	8.4	1.9	24	0.13	0.6	0.08	0.04	0.1
Heterolithics	204	2.2	23	11.4	5.5	10.5	0.02	70	0.22	1.3	0.1	0.04	0.17
Conglomerates	46	4	18.7	11.5	13.3	11.8	0.04	23	0.05	1.74	0.24	0.33	0.41
Chaotics	124	2.1	19.2	8.4	6.8	8.1	0.02	83	0.01	0.9	0.07	0.04	0.09
Mudstones (Porcellanite)	97	1.3	25	12.2	9.2	11.3	0.03	39	0.21	0.95	0.1	0.04	0.18

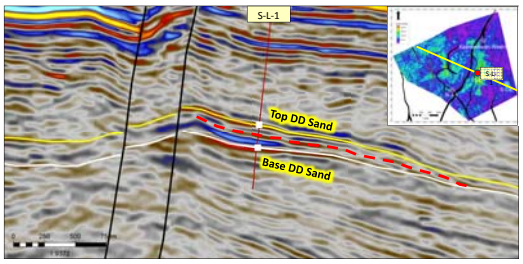
Statistics of core permeability and porosity observable in different lithologies

Stratigraphic Lead (SL)

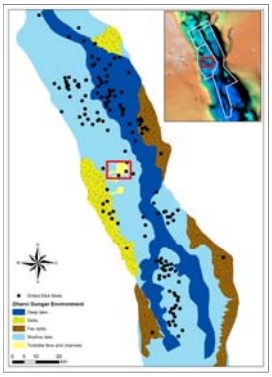
Stratigraphic Lead (SL) is situated in the western flank of the central part of Barmer basin. The reservoir facies is syn-rift Dharvi Dungar Formation of Eocene age. The Dharvi Dungar Formation initially considered as having been deposited during a major transgressive cycle, subsequent integrated studies with seismic and well indicated presence of at least three regressive cycles bringing in coarser clastics in the basin during Late Paleocene-Early Eocene. Spectral decomposition exhibits channel-fan shaped geomorphology.



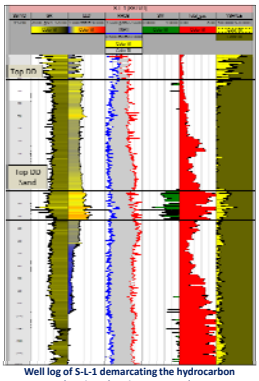
Geological Model showing sediment input from Western Margin to form fan and fan delta which is shown in high amplitudes



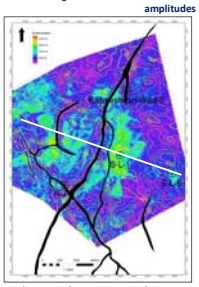
Depth Structure Map of Top Dharvi Dungar Sand in Kaameshwari-West area (left inset); Window for average RMS amplitude in seismic section; RMS amplitude map overlain on depth structure contours (right inset)



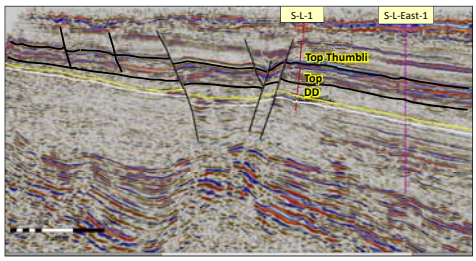
Dharvi Dungar GDE with SL location in RJ-ON-90/1 block layout



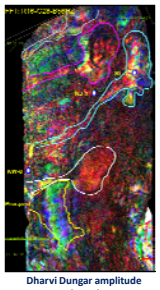
Well log of S-L-1 demarcating the hydrocarbon bearing Dharvi Dungar sands



Isopach contour between Top and Base DD sand overlain on average RMS amplitude map



3D Seismic PSTM through S-L-1 and updip extension of the amplitude anomaly of Dharvi Dungar formation



Dharvi Dungar amplitude prospects along the Western Margin

Conclusion:

Application of regional tectonics and sequence stratigraphy is required to identify to turbidites in rift settings as exploration targets. The turbidite occurences are periodic in nature and depending upon the provenance, may develop thick vertically connected reasonable good reservoirs especially during rift initiation. Though stratigraphic sequences are correlatable in well logs as gross packages, detailing of individual sands units within these sequences may not feasible with limited well data but high resolution seismic and calibrated attributes can provide valuable guidance for lateral thickness variations and also facies changes. The lake turbidites tend to be laterally heterogeneous and often compartmentalized with reservoir property variation is mainly controlled by diagenetic alteration, hence multi-disciplinary approach is required for appraisal and development of sweet spots.

Acknowledgement:

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