[PS]Unfolding New Prospectivity in a Mature Rift Basin through Paradigm Shift in Basin Evolution Concepts: Barmer Basin Story*

Arpita Mandal[1], Shubhodip Konar[2], Priyabrata Chatterjee[2], Premanand Mishra[2], and Pinakadhar Mohapatra[2]

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Introduction

The Barmer Basin is a N-S oriented failed continental rift located in western India, extending from the Cambay Rift in the south to Devikot High in the north and with 6 km (20,000 ft.) of sedimentary fill. The exploration efforts in the last two decades has focused on releasing the potential of Tertiary syn-rift and post rift sequences. 38 discoveries have been made by Cairn India Limited in the basin, with 7.3 billion barrels of stock tank oil in place (STOIP), dominantly from the prolific Paleocene Fatehgarh Formation.

Data Availability

Jurassic sedimentary rocks are present just west and northwest in the Bikaner-Nagaur Basin and Jaisalmer Basin. The exploration campaign undertaken in Barmer Basin prior to 2014 did not penetrate these sediments and occurrences of older Jurassic rift and associated sequences were ruled out in earlier understandings. Further studies following the first exploration campaign helped in defining the tectono-stratigraphic evolution of the basin, which was, previously, poorly understood (Gombos et al., 1995; Compton, 2009).

Methodology

In 2014, an exploratory well was drilled in the deeper Mesozoic targets. The well encountered 18m potential source rock and 170m reservoir within the target interval, with significant gas shows. Detailed study of samples from this interval suggests presence of highly degraded woody debris, bisaccate pollen (undifferentiated), and simple fern spores (probably Deltoidaspora/Cyathidites spp.) of possible lacustrine origin, with a Thermal Alteration Index value of 3+/4.

Presence of an older rift system can also be inferred from gravity data. Gravity modeling concluded a deeper sedimentary unit underlying the earlier inferred crystalline basement, interpreted from seismic data, along specific profiles on the basis of variation between observed and modeled gravity. Though seismic acquisition was not designed for deeper targets, presence of Mesozoic basins can also be inferred in seismic lines in the profiles with gravity variations. An exhaustive geochemical analysis program established a distinct oil group atypical of the typed source rocks in the discovered fields and was subsequently attributed to deeper Mesozoic source rocks (Farrimond et al., 2015).

Result

Oldest sediments drilled in Barmer Basin in the well V&V Mesozic-1 is likely to be Permian-Triassic in age but the undrilled section could be equivalent of either Gondwana or Neo-Proterozoic age Bikaner-Nagaur Basin. It has proved presence of all the elements of petroleum system like matured swampy-lacustrine source rock, fluvial reservoirs, and thick Lower Cretaceous shale acting as a top seal. The same stratigraphy unit may be present in some other parts of the basin like Kaameshwari-West, Central Basin High, and Sanchor Basin to the south of Barmer Basin. Beyond the Tertiary basin trend in the North-East part of the Barmer Basin, current seismic data indicates possible extension of the older Mesozoic trend.

However, the coverage and quality of the seismic data is limited both in deeper intervals and outside of the current license acreage. Currently available data also suggests possibility of potential leads and prospects outside the current acreage and can be good candidates to explore the older Mesozoic plays in the matured basin.

Conclusion

Revised understanding of Barmer Basin envisages it to be a multi-cyclic rift basin, related to NW-SE India-Africa separation (185-165 Ma) followed by NE-SW India-Madagascar rifting (92-84 Ma) and subsequent separation of India-Seychelles (70-65 Ma). Present structural configuration of the basin is defined by two non-coaxial extensional events, with NW-SE extensional related structures incorporated in the NE-SW extensional event (Bladon, 2014), followed by structural inversion along the northern end related to India-Asia collision.

A working Mesozoic Petroleum System has been established in the mature Barmer Basin and has opened vistas for maturing older rift prospects. Gravity along with reprocessed seismic data is being used to demarcate other probable Jurassic proto-rift basins. Based on palinspastic reconstructions, it appears that the vast expanse of Neoproterozoic-Cambrian Jodhpur and Nagaur Formation sandstones and Delhi-Aravalli Fold Belt were a significant source provenance for reservoir. However, the quality of this reservoir is observed to be greatly altered by cementation. These reservoirs require stimulation by hydraulic fracturing to assess the deliverability and performance. Recent discovery from a similar older rift in Alaman Basin, Egypt reaffirms our understanding of a huge potential in the untested Jurassic rifts within Barmer Basin.

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Abstract

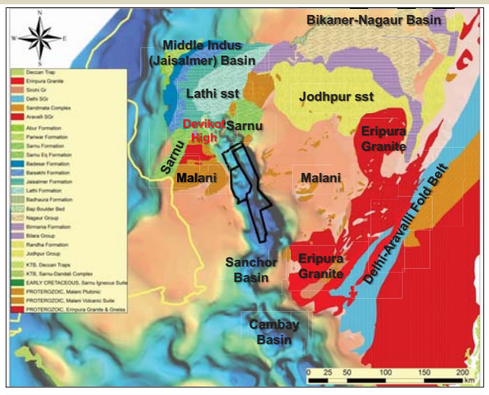
The Barmer Basin is a N-S oriented failed continental rift located in western India, extending from the Cambay rift in south till Devikot High in the north and with 6 km (20,000 ft.) of sedimentary fill. The exploration efforts in last two decades has focused on releasing the potential of Tertiary syn-rift and post rift sequences. 38 discoveries have been made by Cairn Oil & Gas in the basin, with 7.3 billion barrels of stock tank oil in place (STOIP), dominantly from the prolific Paleocene Fatehgarh Formation. Permo-Triassic sedimentary rocks are present just west and northwest in Bikaner-Nagaur Basin and Jaisalmer Basin. The exploration campaign undertaken in Barmer Basin prior to 2014 did not penetrate these sediments and occurrences of older Permo-Triassic rift and associated sequences were ruled out in earlier understandings. Further studies following the first exploration campaign helped in defining the tectono-stratigraphic evolution of the basin, which was, previously, poorly understood (Gombos et al., 1995; Compton, 2009).

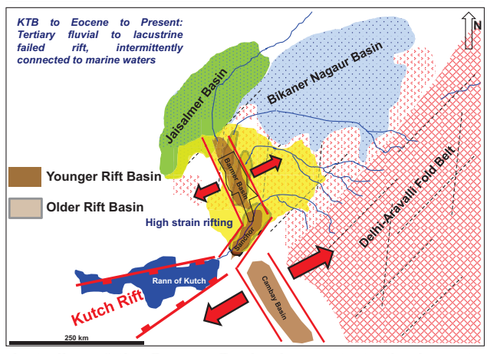
Based on the revised understanding, Barmer Basin is now considered to be a multi-cyclic rift basin, related to NW-SE India-Africa separation (185-165 Ma) followed by NE-SW India-Madagascar rifting (92-84 Ma) and subsequent separation of India-Seychelles (70-65 Ma). Present structural configuration of the basin is defined by two non-coaxial extensional events, with NW-SE extensional related structures incorporated in the NE-SW extensional event (Bladon, 2014), followed by structural inversion along the northern end related to India-Asia collision. Presence of an older rift system can also be inferred from gravity data. Gravity modeling concluded a deeper sedimentary unit underlying the earlier inferred crystalline basement, interpreted from seismic data, along specific profiles on the basis of variation between observed and modeled gravity. Though seismic acquisition was not designed for deeper targets, presence of Mesozoic basins can also be inferred in seismic lines in the profiles with gravity variations. An exhaustive geochemical analysis program established a distinct oil group atypical of the typed source rocks in the discovered fields and was subsequently attributed to deeper Mesozoic source rocks (Farrimond et al., 2015).

In 2014, an exploratory well was drilled in the deeper Mesozoic targets. The well encountered 18m potential source rock and 170m reservoir within the target interval, with significant gas shows. Detailed study of samples from this interval suggests presence of highly degraded woody debris, bisaccate pollen (undifferentiated) and simple fern spores (probably Deltoidaspora/Cyathidites spp.) of possible lacustrine origin, with a Thermal Alteration Index value of 3+/4-. Presently the well is suspended for testing. This well successfully established a working Mesozoic Petroleum system and has opened up vistas for maturing older rift prospects. Gravity along with reprocessed seismic data is being used to demarcate other probable Permo-Triassic proto-rift basins. Based on palinspastic reconstructions, it appears that the vast expanse of Neoproterozoic-Cambrian Jodhpur and Nagaur formation sandstones and Delhi-Aravalli Fold Belt were a significant source provenance for reservoir, quality of which is observed to be greatly altered by cementation, and thus requires stimulation. Recent discovery from a similar older rift in Alaman Basin, Egypt reaffirms our understanding of a huge potential in the untested Permo-Triassic rifts within Barmer Basin.

Regional Database and Tectonic History

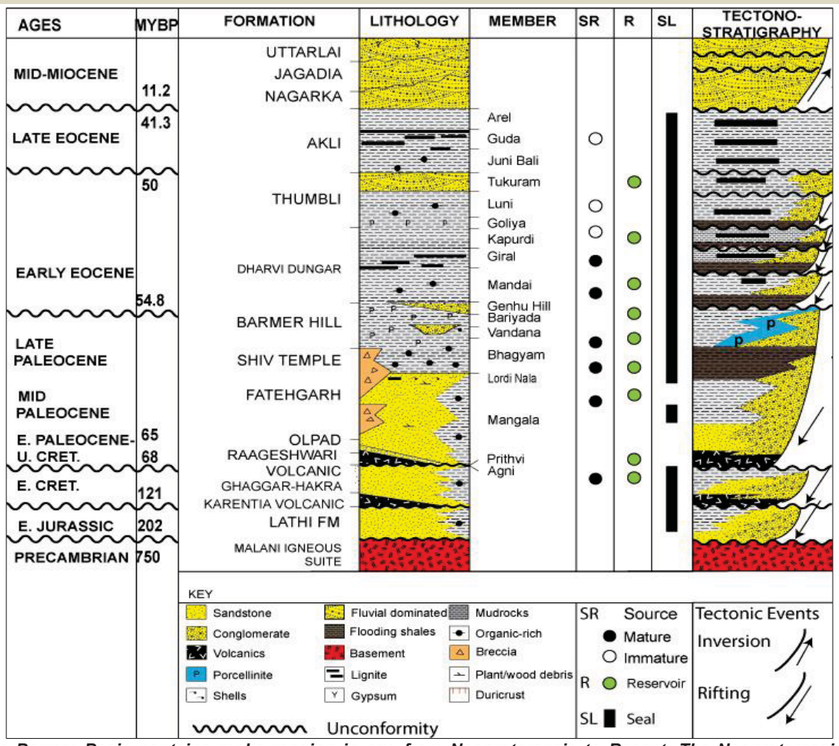
Regional Geology And Tectonics





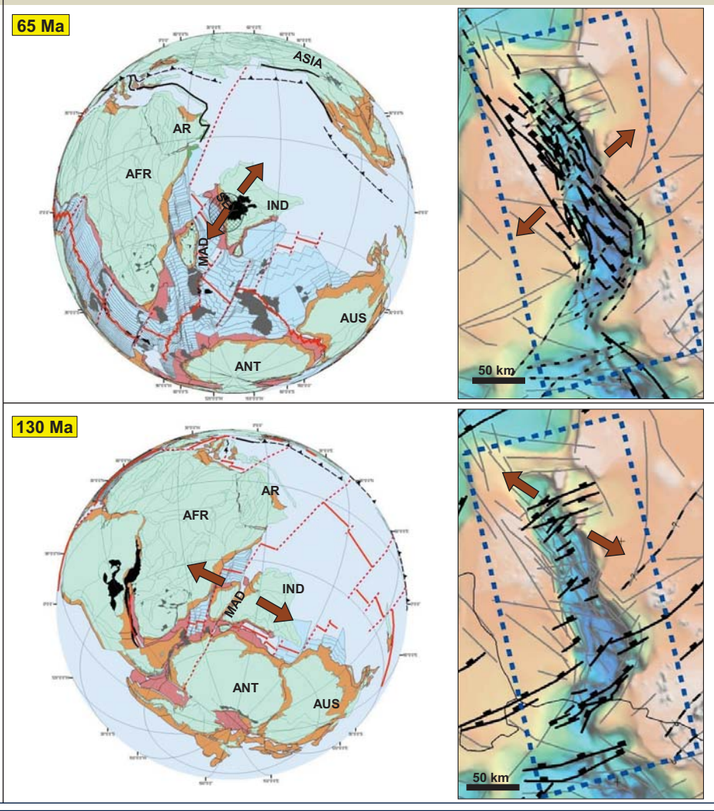
Structural studies of the Barmer Basin demonstrate the important effect that pre-existing faults can have on the geometries of evolving fault-systems at both the outcrop and basin-scale

Barmer Basin Stratigraphy And Petroleum System



The Barmer Basin contains rocks ranging in age from Neoproterozoic to Recent. The Neoproterozoic rocks primarily comprise acidic igneous extrusives and granite intrusions. Jurassic sandstones are recorded around the basin margin and the basin fill contains Cretaceous and Cenozoic siliciclastic and volcanic rocks

Plate Tectonic Reconstruction



Younger Rift

The passage of the Reunion Hotspot caused the outpouring of the Deccan traps volcanics between ~68 and 63Ma (Chandrasekhar et al., 2002). This time of LIP (Large Igneous Province) activity coincides with the final separation of the Seychelles micro-continent from India, causing an ~NNE-SSW direction of extension. The plume passed underneath the Barmer Basin during the Late Cretaceous causing significant changes in drainage patterns in western India.

Older Rift

The main event affecting the Indian Plate during the Early Cretaceous was the rifting of Australia and Antarctica from India between ~134 – 128Ma. According to plate reconstructions a small separation of the Indian Plate from Madagascar took place. This initial separation resulted from a clockwise rotation of the Indian Plate relative to Madagascar and subsequently followed by a more orthogonal separation between ~130 – 120Ma. The Older rift trend is probably the result of the differential movement between Indian and Madagascar

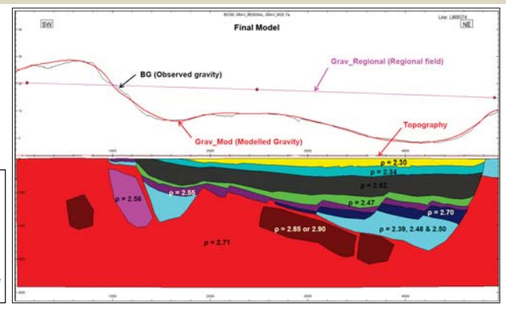
Methodology

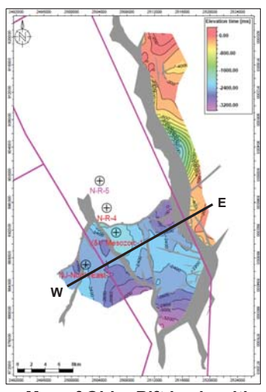
Gravity Model

Gravity Model of Depth to Basement

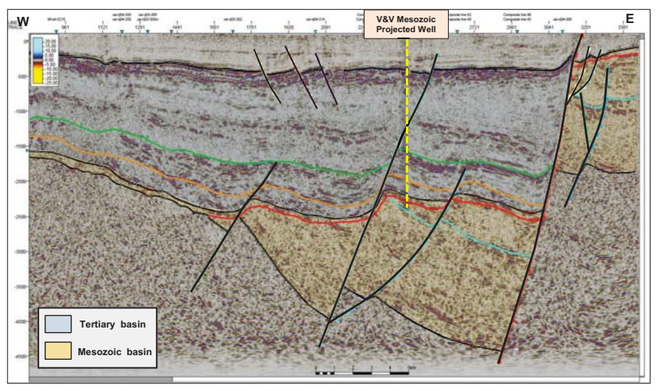
The mafic (dark red) and granitic (pink) bodies represent compositional variations within the basement. In reality these bodies are unlikely to have the modelled shape, or in the position shown. However they reflect compositional variations within the basement to match the models while still honoring the constraints that are available for the shallower section (derived from seismic and wells).

Final model results for gravity profile in the Barmer Basin showing the match between modelled gravity and the gravity signal, and the gravity bodies with a modified Basement interpretation.





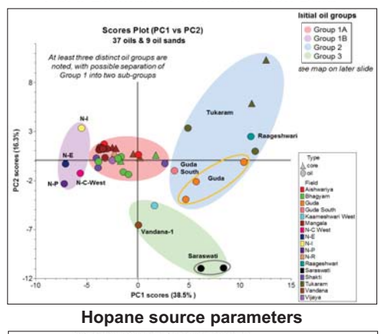
Map of Older Rift basin with Older Mesozoic depocentres



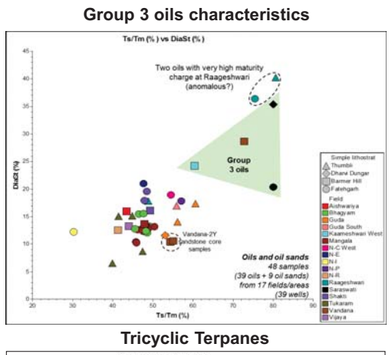
Seismic section across Older Rift basin showing Mesozoic depocentres and faults along with overlying Tertiary Rift basin

Geochemical Analysis

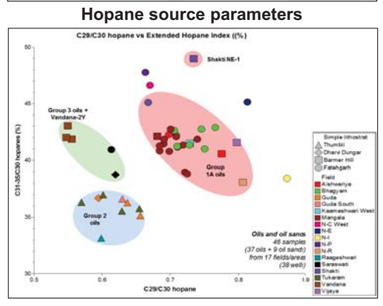
PCA: Biomarker concentration Data



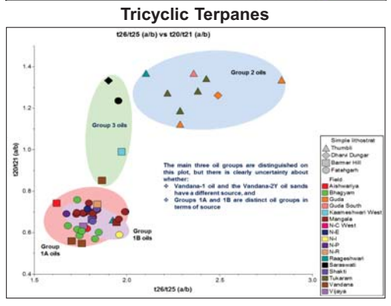
Group 3 oils characteristics



Hopane source parameters



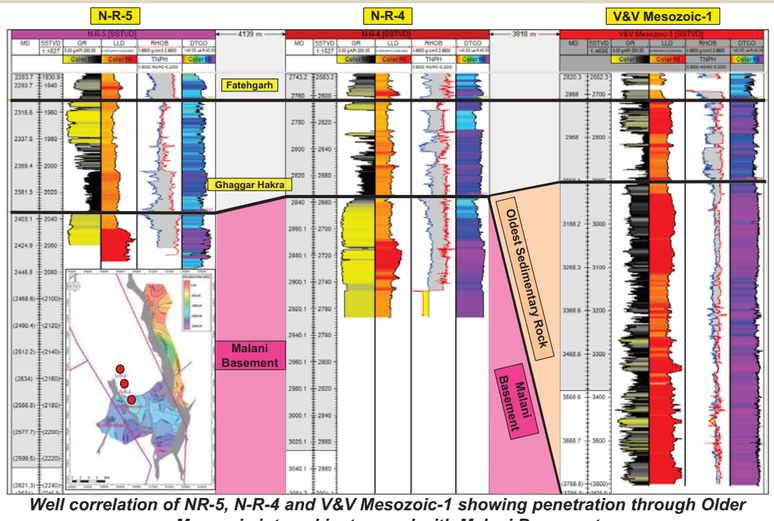
Tricyclic Terpanes



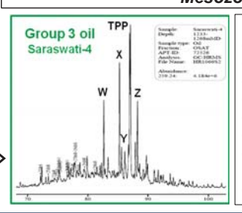
3 distinct oil groups are noted, with possible separation of Group 1 into two sub-groups. The high values of both Ts/Tm (%) and diasteranes (%) could be a function of source facies. Indication of higher maturity of oils, consistent with lower βα/αβ hopane ratio

Group 3 oils have a high ratio of unknown peak X / C30 ab hopane

Well Correlation



Well correlation of NR-5, N-R-4 and V&V Mesozoic-1 showing penetration through Older Mesozoic interval juxtaposed with Malani Basement

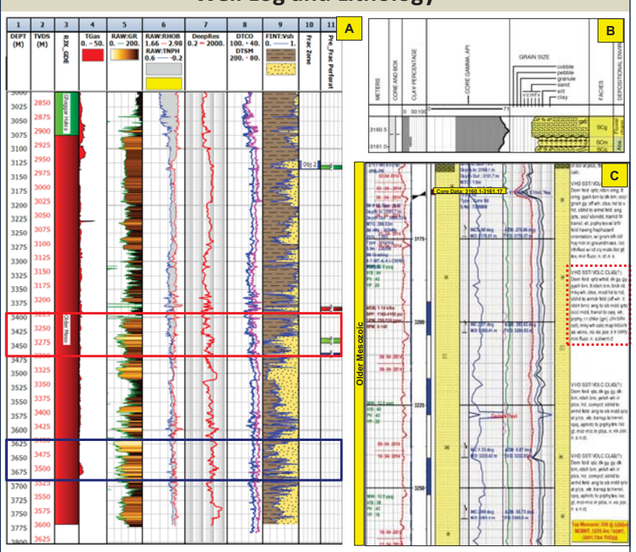


Source Rock Potential in Older Mesozoic Sediment

- **Palynology:** Highly degraded woody debris, palynomorphs
- **Micropaleontology:** Bisaccate pollen, simple fern spores
- **Kerogen Type:** bleached plant cuticle, woody debris
- **Depositional Environment:** Swamp-Lacustrine; No marine Indication
- **Thermal Alteration Index:** 3+/4- (visual)
- **Lithology:** Not Coal, dominantly claystone (iron mineralized)
- **Paler Fragments:** Chert and tightly chert- and calcite-cemented arkosic and lithic sandstones (both partially replaced by calcite)
- **Porosity:** Sandstone-no macroporosity in thin section

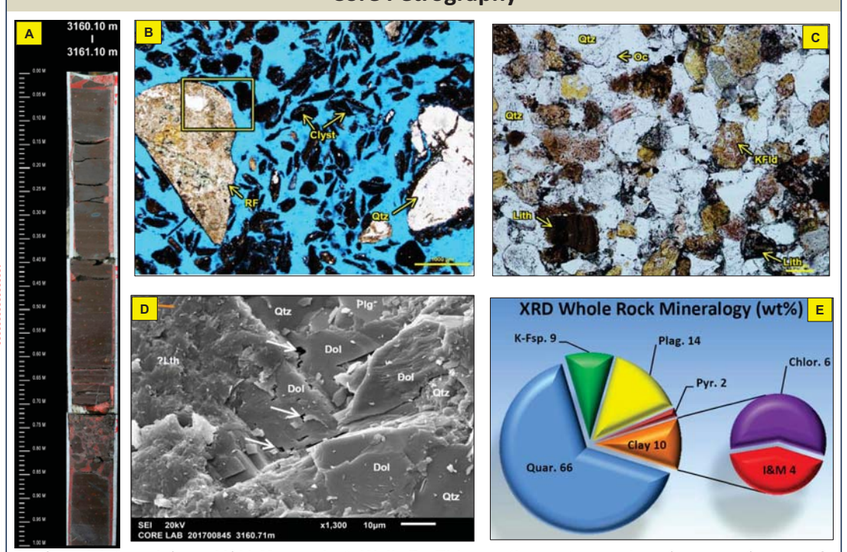
Results

Well Log and Lithology



A: V&V Mesozoic-1 Well with basic and interpreted logs; B: *Grain-size and Facies from Core; C: Mudlog description*

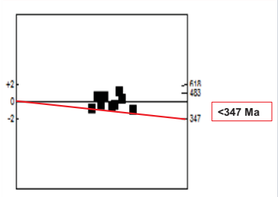
Core Petrography



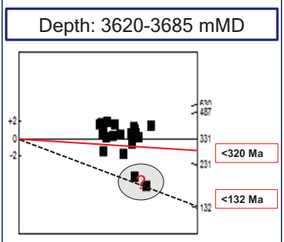
A: *Cored interval from V&V Mesozoic-1 Well;* B: *Thin section petrography of source facies ;* C: *Photomicrograph of Arkosic sandstone;* D: *SEM showing microporosity and pore connectivity that is restricted to tight microporous networks;* E: *Typical Whole Rock Mineralogy of reservoir sandstone*

Age Dating

Depth: 3380-3470 mMD

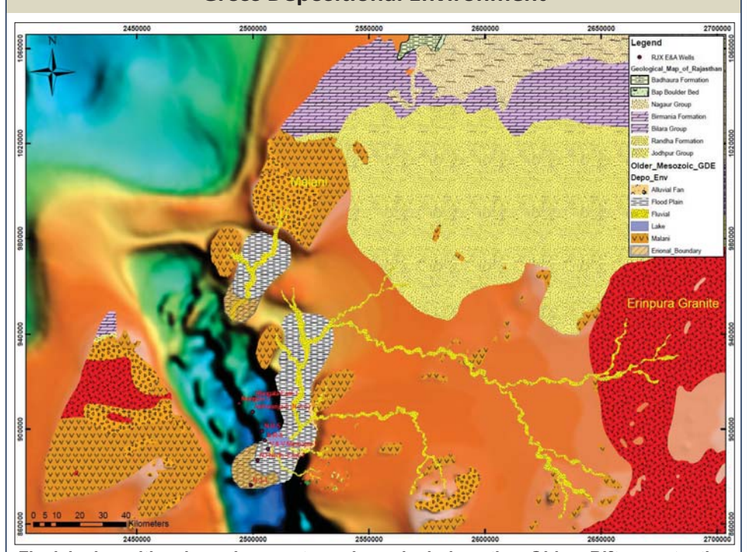


Depth: 3620-3685 mMD



Zircon Fission Track Analysis suggest age of the Sediment to be younger than Carboniferous

Gross Depositional Environment



Fluvial depositional environment envisaged during the Older Rift event; the provenance has a strong control over mineralogical composition derived by the feeder systems from exposed basement complex and older matured sandstones

Conclusion

Oldest sediments drilled in Barmer Basin is likely to be Permian-Triassic in age. There is proven presence of petroleum system elements like matured swampy-lacustrine source rock, fluvial reservoirs and thick Lower Cretaceous shale as a top seal. An older petroleum system is established in the mature Barmer basin.

Acknowledgement

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