14th Biennial International Conference and Exposition
SPG 2023

Re-evaluation of prospectivity of Ganga Basin in the light of Neo-Proterozoic Cambrian plate tectonic reconstruction involving Arabian and Indian plate

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Keywords: Ganga Basin, Oman, tectonic reconstruction

Abstract

A GIS based plate tectonic reconstruction of the Indian and Arabian plate during Neo-Proterozoic-Cambrian suggests that the Najd Fault system of the Arabian Peninsula to be continuous from the Arabian Plate on to the northern part of Indian plate. These extension of Najd Fault systems can be spatially correlated with presently. E-W faults of Bikaner Nagaur and Ganga Basin. The Neo Proterozoic Cambrian Huqf supergroup of Oman which are prolific hydrocarbon producers are deposited in basins formed due to sinistral movement along these basins. Coeval formations in Bikaner Nagaur and Indus Basin have also been found to be hydrocarbon producing and are deposited in basins formed due to movement of faults considered to be extension of Najd Fault system. In Ganga basin, Hydrocarbon shows have been observed from Neo-Proterozoic-Cambrian sequences in Sarda and Gandak depressions. This paper attempts to delineate the extension of Najd Fault system on to Ganga basin and on that basis delineate prospective/ promising zones for exploration.

Introduction

During the end of Neo-Proterozoic and beginning of Cambrian, Indian Plate was contiguous with Madagascar, Africa and the Arabian plate in its west and the Antarctic and Australian plate in its east. This entire region was affected by a protracted cycle of tectonic, magmatic, and metamorphic activity of Neoproterozoic to earliest Palaeozoic age known as the Pan African Orogeny. The Neo-Proterozoic and Cambrian sequences in the Arabian plate especially Oman are found to be prolific producers of hydrocarbon. Similar coeval sequences are also observed in parts of Indus Basin and Bikaner Nagaur basin in western part of Indian plate. In this context, the present paper is an attempt to tectonically reconstruct the western part of India connecting it to Arabian plate during Neo-Proterozoic-Cambrian. Additionally, this paper attempts to visualize the implications of the reconstruction in terms of prospectivity in the present day Ganga Basin.

Neo-Proterozoic-Cambrian Facies Distribution and their Correlatives

Existing plate tectonic models pertaining to Cambrian suggests that the Neoproterozoic–Cambrian basins in western India, Pakistan and Oman were in close proximity. As a part of the study, the constituent Neo-Proterozoic-Cambrian facies for these respective basins have been studies, stratigraphically and spatially correlated and attempts made to connect them to prepare a geological model.

Oman: The Huqf Supergroup forms the earliest sedimentary formations in Oman resting unconformably on a Pan-African basement in south eastern margin of the Arabian peninsula that is considered part of the Arabian plate (Fig 1a).

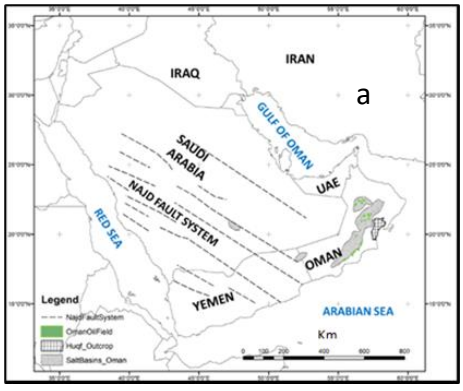


Fig 1a. Map depicting layout of Oman Salt basins and Huqf Supergroup outcrops as well as Najd Fault System

Re-evaluation of prospectivity of Ganga Basin in the light of Neo-Proterozoic Cambrian plate tectonic reconstruction

		Formations		Lithology	Environment
Huqf Super Group	Cambrian	Ara evaporite		Carbonate interlayered with evaporite	Supratidal
	Neo-Proterozoic	Nafun Group	Buah dolomite	Dolomite & Limestones	Shallow marine
			Shuram shale	Shale	
			Khufai dolomite	Dolomite	
			Hadash Fm.	Carbonartes	
		Abu Mahara Group		Extensive sst beds with thin limestones	Glacial-volcanogenic

b

Fig 1 b. Lithology and environment of Proterozoic Cambrian formations of Huqf basin, Oman (after Allen, 2007)

Of these, the Ara Group of the South Oman Salt Basin hosts some of the oldest known commercial hydrocarbon reservoirs (Fig 1b) within Ara dolomitized microbial carbonates and laminated organic-rich cherts (Sylvite) where source-reservoir-seal rocks are deposited in a single depositional sequence (Amthor, 2013). The Huqf Group is also considered stratigraphically correlatable to the Inda Ad Group (Greenwood, 1982) on the northern Somalia with an overall stratigraphy constituted of transgressive marine fan overlain with uppermost regressive facies.

Indus Basin: Neoproterozoic–Early Cambrian outcrops in the Indus Basin are observed on the NW edge of Indian Plate are exposed along foothills of Salt Range and in wells drilled in Potwar Basin, on the Punjab Platform and further south on the Thar Platform. Stratigraphically they are represented as Salt range Formation and Jhelum Group constituting Khewra, Kussak, Jutana and Baghanwala Formations (Fig 2).

	Formations	Lithology	Environment
Mid Cambrian	Baghanwala Fm	red shale and clay, flaggy sst, salt pseudomorphs	lagoonal envtt and arid conditions
Early Mid Cambrian	Jutana Fm.	light green, massive, dolomite	Shallow Open Marine
	Kussak Fm.	glauconitic, micaceous sandstone	Marine Transgression
Early Cambrian	Khewra Fm.	purple to brown, fine grained sandstone.	Marginal marine
Neo-Proterozoic	Salt Range Fm	Red gypseous marl with rock salt & dolomite	Restricted marine

Fig 2. Lithology and environment of Proterozoic Cambrian formations of Indus Basin

In the Thar Platform of Lower Indus basin, in well Marvi-1, unmetamorphosed Cambrian-Late Neo-Proterozoic (about 550 ma) sedimentary sequence had been encountered believed to be equivalent to the formations of Jhelum Group.

Bikaner-Nagaur Basin: The Marwar Supergroup in the Bikaner-Nagaur region of Western Rajasthan is constituted of the Jodhpur Group, Bilara Group and Nagaur Group (Fig 3a) of an Edicaran-Early Cambrian age that rests directly over Malani Igneous Suite or Erinpura Granite of Delhi Supergroup.

	Formations	Lithology	Environment
Marwar Super Group	Nagaur Group	Reddish brown, sandstone	high energy shallow marine
	Hanseran Evaporite	7 evaporite cycles composed of dolomite, magnesite, anhydrite, halite & polyhalite	Restricted intertidal
	Bilara Group	dolomite and stromatolitic limestone with occasional clay beds	Transgressive marine
	Jodhpur Group	cross-bedded, reddish sandstone with maroon shale	fluvio-marine succession

a

Fig 3a. Lithology and environment of Proterozoic Cambrian formations of Bikaner-Nagaur basin

Hanseran Evaporite Group (HEG) is constituted of a maximum of seven evaporitic cycles each of which is composed of dolomite, magnesite, anhydrite, halite, polyhalite and clay bands in ascending order (with Sylvite being reported from some areas) that are considered to be deposited in a marine basin, restrictively connected with open sea. These cycles are envisaged to be similar to that of the Ara Group of Oman and are interpreted as transgressive–regressive cycles controlled by the ups and downs of relative sea-level within the Nagaur–Ganganagar Salt Basin (Cozzi et al, 2013).

In Wells Bagewala-1 and Nanuwala-1, hydrocarbon has been encountered in a number of intervals of Cambrian-Proterozoic sequences (Fig 3a). These are indicative of a Cambrian petroleum play in the Marwar Supergroup producing from Hanseran Evaporites within dolostones that are similar to the Ara Group intrasalt stringer play of Oman. Additionally, oil of well Karampur-1 in Indus Basin,

Re-evaluation of prospectivity of Ganga Basin in the light of Neo-Proterozoic Cambrian plate tectonic reconstruction

Pakistan from Salt Range Formation is geochemically similar to that of Baghewala oil. This suggests probability of continuation of Cambrian petroleum systems from Oman to Indus Basin to Bikaner-Nagaur.

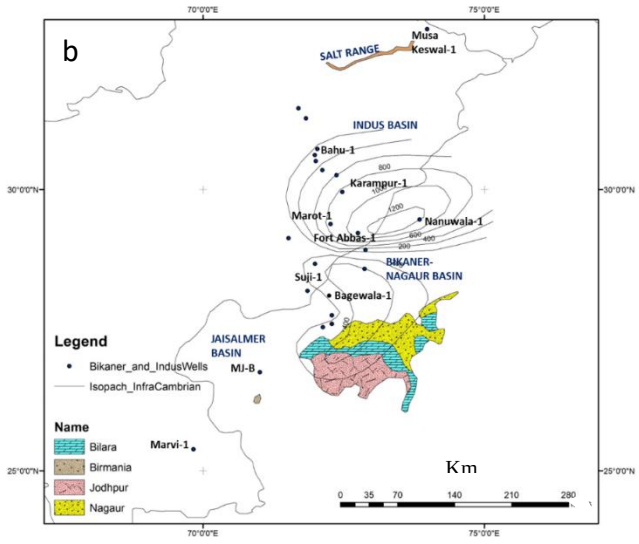


Fig 3b. Geological maps of outcrops for Cambrian-Neo-Proterozoic in Bikaner Nagaur basin, isopach and sub-crops suggesting their distribution in Indus Basin.

The Neo-Proterozoic-Cambrian is represented in between Jaisalmer-Barmer basins as outcrops of Birmania and Randha Formations (Fig 3d). The older Randha Formation is coarse grained calc. quartzose sandstone with shale intercalations deposited in an environment varying from continental to near shore. The overlying Birmania Formation are of cherty dolomitic limestone with phosporite indicative of a marine reducing environment with a restricted circulation. Additionally in the southern part of the Jaisalmer Basin, in well MJ-B, based on palynofloral assemblage, a Cambrian age has been assigned to deposits of quartz wacke.

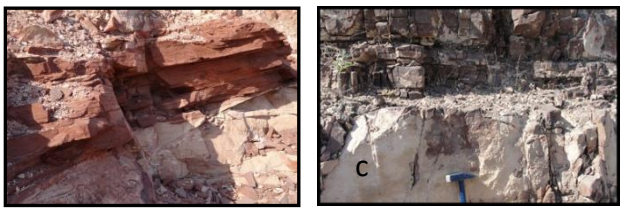
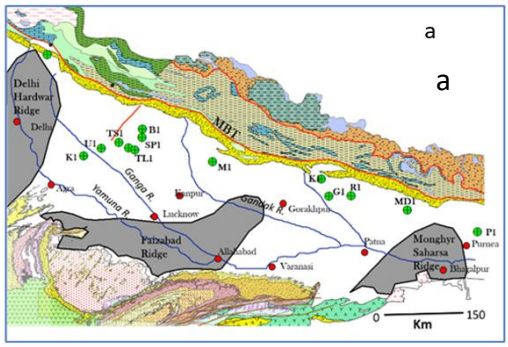


Fig 3c. Field photograph's of Jodhpur Sandstone and Randha Formation

Ganga Basin: Most of the above basins have been thoroughly explored and proved to be hydrocarbon bearing from Infra-Cambrian at least in parts. Ganga Basin further eastwards forms a large scale regional depression of a very vast expanse of about 3,00,000 sq. km with sediments ranging in age from Meso-Proterozoic to Recent (Fig 4a). Seismic campaigns and well data indicate a substantial thickness of Neo-Proterozoic to Cambrian sediments in Sarda and Gandak depressions of the basin represented by Ujhani, Tilhar and Karanpur Formations.



	Formations	Lithology	Environment
Cambr.	Karanpur Fm	Brown sandstone & non calcareous fissile shale	Shallow Marine
b	Tilhar Fm.	Grey to greenish grey limestone with fissile shale	Semi arid Mid to Outer shelf
Neo-Prot.	Ujhani Fm	Med to fine Sst, with dolomitic limestone & basaltic intrusions	Littoral to shallow marine

Fig 4a. Layout of Ganga Basin between Siwaliks & Vindhyans, divided into a number of segments by subsurface ridges b. Lithology and environment of Proterozoic Cambrian formations of Ganga Basin

Of these Ujhani and Tilhar Formations represent Cryogenian age whereas Karnapur Formation is of Ediacaran age making them equivalent to Huqf Supergroup. Of these Ujhani Formation is constituted of medium to fine grained sub-greywacke to arenite and shale with bands of dolomitic limestone indicating littoral to shallow marine deposition with Basaltic intrusions in parts of Gandak depression. This sequence indicates progressive transgression with a transition from inter tidal to inner shelf environment. The intervening Tilhar Formation lies

concordantly over Ujhani Formation with a biostratigraphic break of 27 Ma. Tilhar Formation occurs as greyish limestone interbedded with calcareous shale representing wide spread development of a semi-arid middle to outer shelf environment. The topmost unit Karnapur Formation conformably overlies Tilhar Formation and is dominantly arenaceous constituted of fine to medium grained sandstone and non-calcareous fissile shale deposited in a shallow marine environment (Fig 4b).

About 20 wells have been drilled throughout the basin with oil indications reported during drilling, production testing and DST samples in the Neo-Proterozoic -Cambrian sections of both the Gandak and Sarda depressions. This suggests the existence of a valid separate Neo-Proterozoic -Cambrian petroleum system limited to these depressions. Fault interpretations from seismic data sets indicate a distinct ENE-WSW fault trend mapped on top of Neo-Proterozoic-Cambrian horizons especially in the Sarda depression part of the Ganga Basin. Also based on drainage and DEM based analysis of the Ganga Basin, a number of E-W morphotectonic faults have been interpreted in the region that have been subsequently validated from field checks (Fig 4c) in the area. These can be considered as manifestations of the deeper trend. Additionally, residual gravity data in the basin indicates regional ENE-WSW trends in the area that broadly correlates with the Neo-Proterozoic-Cambrian seismic faults and surface geomorphic faults. An integrated analysis of all these trends suggests deep-seated E-W structural trends that control the structurisation of the area (Fig 4d). Correlation with geochemical adsorbed gas surveys shows a good degree of correlation of C2+ adsorbed gas concentrations and E-W fault/ structural trends in both Sarda and Gandak depressions (Figs 4e and f).

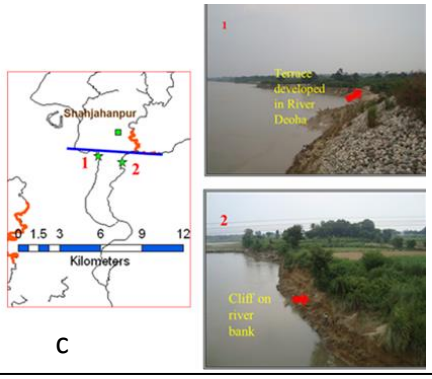


Fig 4c. Neotectonic evidences of E-W faulting in field

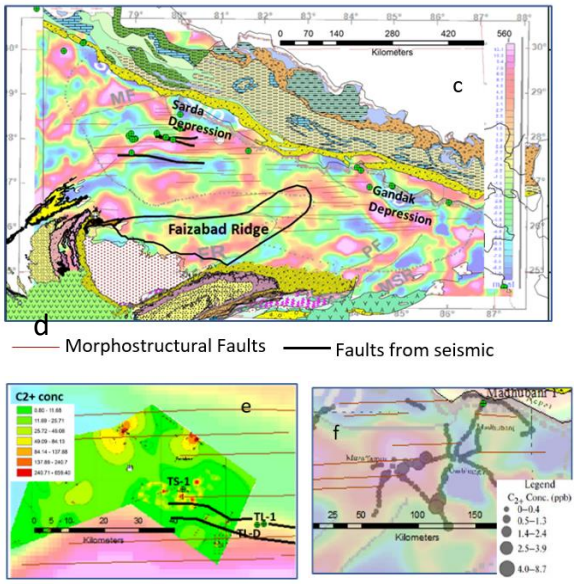


Fig **4d.** Overlay and spatial correlation of of E-W faults from seismic mapped on Ujhani Top, E-W morphostructural faults from drainage and DEM data and E-W regional trends in Residual gravity data suggest deep-seated E-W faults and their manifestations **e and f.** Correlation of E-W morphostructural faults with C2 adsorbed gas anomalies in Sarda and Gandak depression

Discussions.

Facies correlatives of the above discussed basins when plotted on the plate tectonic fit shows that the sedimentary deposits are very much related in alignment as well as in succession. These regional tectonic reconstructions (Fig 5a) indicate a genetic link between the oil producing Infracambrian salt basins of Oman with that of Pakistan and India (Johnson, 2008) suggesting similar depositional agents might have covered all the areas of Bikaner-Nagaur, Barmer, Salt Range, Somalia and Oman continuing upto Ganga basin.

The Najd Fault System (Fig 1a) forms a set of braided complex set of parallel and curved, en echelon sinistral strike-slip faults and ductile shear zones that strike NW-SE across the Precambrian shield of Arabian Plate that developed during 540-620 Ma. The salt basins of Oman and adjacent areas have been interpreted to be rift basins associated with

Re-evaluation of prospectivity of Ganga Basin in the light of Neo-Proterozoic Cambrian plate tectonic reconstruction

movements of the Najd fault systems as well as other Najd-parallel faults. These faults prior to break-up of Gondwana continued further eastwards upto parts of Indus Basin and India. Bikaner–Nagaur basin is also envisaged to be formed as a result of extension due to sinistral movement along this Najd fault system associated with the latest phase of Pan-African orogeny.

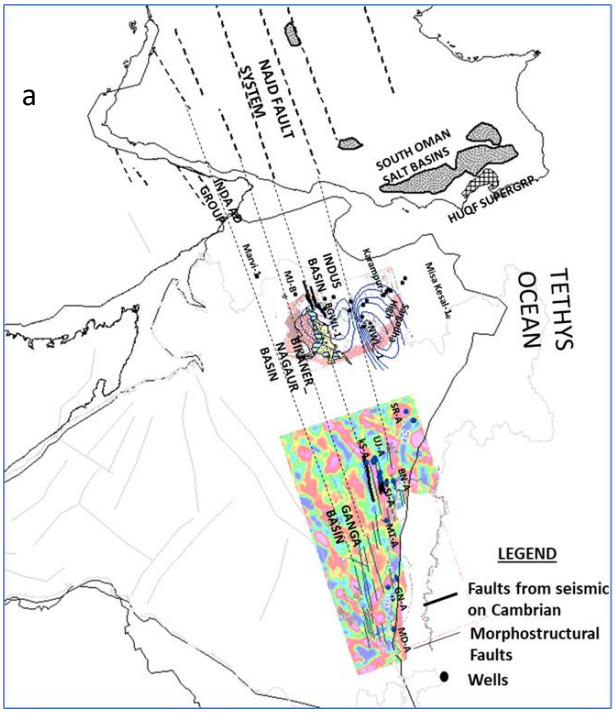


Fig **5a.** Overlay and spatial correlation of of E-W faults from seismic mapped on Ujhani Top, E-W morphostructural faults from drainage and DEM data and E-W regional trends in Residual gravity data suggest deep-seated E-W faults and their manifestations **e and f.** Correlation of E-W morphostructural faults with C2 adsorbed gas anomalies in Sarda and Gandak depression

This movement is considered to form a series of grabens in both the Bikaner-Nagaur Basin in Western Rajasthan and Punjab rift in Pakistan hosting Neo-Proterozoic- Cambrian sediments. These movements probably resulted in grabens of 100 km in southern Oman to about 200 km in Pakistan. Fault bounded anticlinal structures resulting from Cambrian transpression form the main entrapment for hydrocarbon accumulation in the Bikaner Nagaur area. On a GIS based Cambrian tectonic reconstruction, the Najd Faults of the Arabian Plate can be correlated with the E-W faults in Bikaner Nagaur and those in Ganga basin indicating their continuity.

This also indicates that similar grabens might be formed due to movements along E-W faults in the Ganga Basin with fault bounded anticlinal structures acting as structural entrapments. Geomorphic highs that act as surface manifestations of subsurface structural highs are found to be associated with E-W morphostructural faults used suggesting Fault bounded anticlinal structures. These geomorphic highs are associated with structural highs in Neo-Proterozoic and the E-W faults are found to be associated with faults rooted in basement (Fig 5b). Structural restoration was carried out on selected lines in the Ganga Basin. For the restoration of Neo-Proterozoic along a NW-SE section, erosion at Neo-Proterozoic sequences was reconstructed above each of the inversion structure that formed earlier in Pre Tertiary. The reconstructed structures emerge as asymmetric anticlines generated by reactivation of basement associated sub-vertical faults primarily in transpressive stress regime similar to Bikaner Nagaur. A total amount of shortening is estimated to be 10% Post Neo-Proterozoic. The restored section indicates uniform sedimentation occurred in passive margin condition.

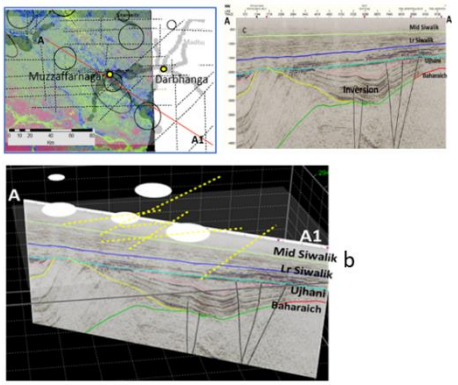


Fig 5b. . Geomorphic highs delineated from morphostructural analysis associated with E-W morphostructural faults used to identify Fault bounded anticlinal structures resulting from Cambrian transpression. Seismic line marked in red in first figure

Re-evaluation of prospectivity of Ganga Basin in the light of Neo-Proterozoic Cambrian plate tectonic reconstruction

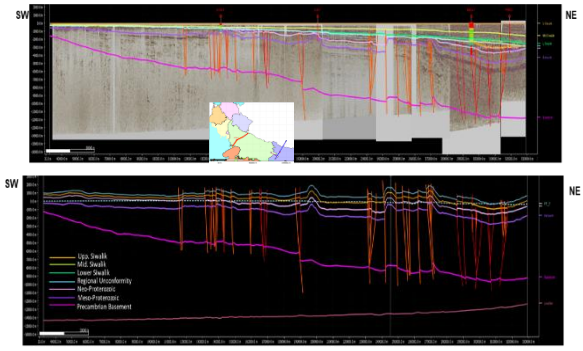


Fig **5c.** Present day structural configuration of oriented in NE-SW direction covering the Sarda depression. The major inversion structures in Pre-Tertiary associated with sub-vertical basement related faults are distinctly present. The Tertiary sequence shows a gradual increase to the north **5d.** Erosion reconstructed above Neo-Proterozoic shows that the reconstructed structures emerge as asymmetric anticlines generated by reactivation of basement associated sub-vertical faults primarily in transpressive stress regime

The association of the E-W faults with adsorbed gas data indicate these faults can also be considered as conduits for migration that might feed these structures.

1-D modelling of Ganga basin indicates onset of oil generation for Ujhani Formation similar to that of Huqf Supergroup of Oman, Proterozoic-Cambrian of Indus Basin and Bikaner-Nagaur basin. This suggests all these petroleum systems to be equivalent with probable continuation of source facies to Ganga Basin. Since a large area is to be evaluated for prospectivity in Ganga Basin, geomorphic highs delineated from drainage data may be used as an alias for anticlinal structures. Such geomorphic highs in Gandak and Sarda areas associated with E-W trending faults can be targeted for anticlinal structures in Cambrian-NeoProterozoic sequence associated with E-W faults.

Conclusions

1. Najd Fault systems may continue from the Arabian Peninsula on to the Bikaner Nagaur and Ganga Basin. E-W faults in Ganga basin may be representative of these faults.

2. A similar stratigraphic sequence to Huqf Supergroup in Oman, Bikaner Nagaur Basin in Western Rajasthan exists in Ganga Basin and its possible that all these basins are connected with aforestated fault systems indicative of equivalent petroleum systems.

3. Fault bounded anticlinal structures in Ujhani, Tilhar and Karnapur sequences may be targeted as entrapments. Geomorphic highs associated with E-W faults may serve as an alias for exploration.

Acknowledgements

The authors express their sincere thanks to the management of ONGC for their kind permission to present and publish this paper.

The views represented in the paper are solely those of the author and not necessarily that of the organization he represents.

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