CONTROL ID: 2011924

Hydrocarbon Prospectivity Analysis of Palaeozoic-Mesozoic Sequences along the Himalayan Fold Thrust Belt in India with other Prospective Analogous Provinces in Africa and Arabian Peninsula Based on Palaeogeographic Maps and Lithofacies Analysis

Tusar Dutta, Arun K. Arya, Manoj K. Baruah, Naresh K. Verma, Suryansh Suyash, Devendra N. Singh

Frontier Basin, Oil and Natural Gas Corporation Ltd., Dehradun, India
tusar.jugeology@gmail.com

Abstract

A very striking feature of the Himalayan tectonics is the continuation of structural elements and lithofacies in the form of longitudinal belts along strike. The tectonic elements have been recognized in the Indian subcontinent as well as in the neighboring countries. In Kohat-Potwar sub-Himalayan province of Pakistan, the main petroleum system is confined within the Palaeozoic and Mesozoic rocks having vast surface and subsurface exposures. In fact, contemporaneous stratigraphic units of Africa and Arabia contain some of the most prospective hydrocarbon provinces of the world. On the contrary, there are no surface evidences of Palaeozoic- Mesozoic units in the Indian sub-Himalaya. This paper discusses the documented Palaeozoic- Mesozoic of Lesser and Tethyan Himalaya and explores their hydrocarbon potentiality. Though these Palaeozoic- Mesozoic rocks have continuation with the petroliferous Peshawar basin, Pakistan and extend up to Nepal, they are comparatively less understood in the Indian parts. Obviously, for a clearer understanding about the possible petroleum systems in the NW margin of India, it is essential to understand the evolution of the northern Indian margin which is closely linked to its plate tectonic setting. Analysis of palaeogeographic maps show that the Indian, African and Arabian continents were in close juxtaposition at least up to Cretaceous. During Precambrian- Late Carboniferous, northern India was in an intra- cratonic setting and connected with Arabian peninsula in the West. The close proximity of Indian plate with its neighboring tectonic units/plates (Africa and Arabia) where the coeval lithounits are enriched in hydrocarbon and are locales of well- known petroliferous provinces draws the attention of geoscientists to similarly preserved rocks in India. Therefore a detailed analysis of the palaeomaps, paleo-environment and paleolithofacies from Early Palaeozoic to Late Cretaceous has been carried out resulting in valuable leads to develop future strategies for hydrocarbon exploration in northern Indian margin i.e. in Himalayan fold thrust belt. The study reveals that the Palaeozoic- Mesozoic units of the northern Indian margin is actually a part of the depositional regime that continued from Early Cambrian till the time of India's break-up from the main Gondwanaland. The systematic analysis carried out in this work suggests that the Palaeozoic-Mesozoic of Lesser and Tethyan Himalaya are highly prospective from hydrocarbon point of view.

Introduction

The Himalayan fold thrust belt, based on strati-structural units, has been sub-divided from South to North into Sub-Himalaya (Tertiary strata), Lesser Himalaya (non-fossiliferous low-grade metamorphic rocks), Higher/Greater Himalaya (crystalline complex) and Tethyan Himalaya (marine, fossiliferous strata). These tectonic units have been recognized along strike in Indian sub-continent as well as in the neighboring countries i.e. Pakistan and Afghanistan in the West, Kashmir, Punjab, Himachal Pradesh, Uttarakhand and Nepal in the central part and Darjeeling, Sikkim and Assam in the far East. The continuation of sub-Himalayan tectonic elements and lithofacies from eastern Pakistan (Kohat-Potwar provinces) into NW India and possible locales of hydrocarbon (*Dutta et al., 2013*) in Indian subcontinent has been already established. In Kohat-Potwar province, the main petroleum system is confined to the Palaeozoic and Mesozoic strata having widespread surface and subsurface exposures. On the contrary, there is limited knowledge of Palaeozoic-Mesozoic strata in Indian Sub-Himalaya both at surface as well as in the subsurface, with known exposures only at the northern parts of the Indian plate i.e. in Lesser and Tethyan Himalaya. Analysis of palaeogeographic maps shows that the northern Indian margin has a possibility to be coeval with the northern/ NE Africa and eastern Arabian plate, which are well known for preservation of prolific hydrocarbon. This paper presents the results of some work carried out to probe the possibility and nature of linkage between the Palaeozoic and Mesozoic strata of these different plates.

Palaeozoic-Mesozoic through time in Africa, Arabia and northern Indian margin

Neo-Proterozoic: Close proximity of Indian plate with Africa and Arabia is tracked from the beginning of Neo-Proterozoic time (***Fig.1***). Similar basin evolution is also indicated from Oman, across the Middle East and the Indian Subcontinent to China, which hosts Neo-Proterozoic–Cambrian petroleum systems (*Bhat et al., 2012*). Hydrocarbon bearing Neo-Proterozoic to Palaeozoic succession of the Indus Basin on the NW edge of the Indian plate are exposed along the foothills of the Salt Range and in the Kirana Hills, and has been encountered in drilled wells in the Potwar basin, eastern Pakistan. Oil from Baghewala-1 (Bikaner – Nagaur Basin, India) is geochemically similar to the heavy oil from the Neo-Proterozoic Salt Range series, Pakistan and the carbonate evaporite facies of the Neo-Proterozoic Huqf Group, Oman (*Cozzi et al., 2004)* thus indicating close proximity with the Arabian plate. The Marwar Supergroup in the Bikaner–Nagaur Basin and the Krol Group in the Lesser Himalaya are chrono-stratigraphically coeval and represent marginal marine successions deposited along the same SW–NE trending continental margin having good indication of preservation of source facies and an indication of same depositional system. The Late Neo-Proterozoic to Early Cambrian evaporite deposits of the Hormuz Series in the Zagros Fold Belt in Oman (Ara Evaporites), in Central Iran (Kerman Evaporites), in Pakistan (the Salt Range) and in India (Hanseran evaporites) indicates a similar geological salt/evaporite province.

Lower Palaeozoic (Cambrian-Ordovician-Silurian): India was a part of Gonwanaland throughout the lower Palaeozoic (inter-cratonic setting) and closely attached to Africa and Arabia at its W-NW margin (*Rolle, 1991*). The main structural element controlling sedimentation was Najid fault system continuing from Arabia into the Indian shield (***Fig.2***), evidence of which is seen mainly in the Kutch and Son-Narmada lineament. Evaporites of Late Pre-Cambrian to Early Cambrian age is widespread in Arabia, Iran and NorthWest India due to restricted marine conditions and arid tropical climate. Salt range in Pakistan, their continuation in Oman, Iran and isolated salt occurrences in the Himalayan region (Guma, Badhla, Gwali salt deposits-a part of well known Mandi salt deposits) quite likely have formed under similar depositional environments. During Middle Cambrian to Middle Ordovician a transgression resulted in the development of a clastic shelf overlain by a widespread carbonate platform in northern India (Higher Himalaya). Isolated patches of carbonates are also evident in Arabian peninsula.

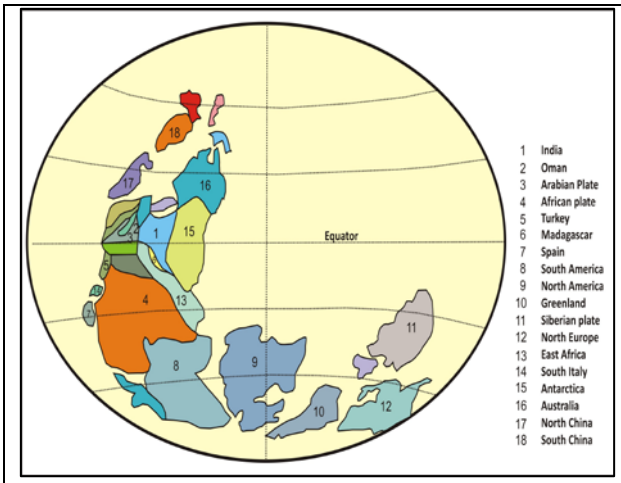

Fig 1. *Neoproterozoic; Pannotia supercontinent (600ma, after Scotese 2009) shows a close proximity of Indian plate with the Oman and Arabian plates.*

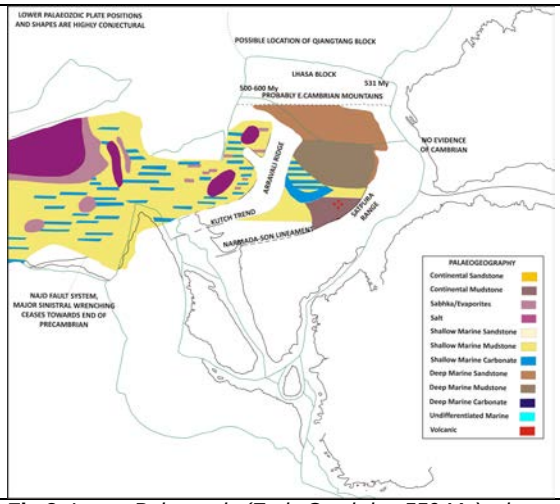

Fig 2. *Lower Palaeozoic (Early Cambrian 550 Ma); close association of Arabian plate and Indian plate is depicted during this phase (modified after ONGC-BP expl. report).*

Devonian : During Early Devonian, sedimentation in the Arabian shield was mainly continental and shallow marine whereas towards the East a vast carbonate platform, continued from the Silurian, appears to have covered northern India and erstwhile Lhasa (***Fig 3***). At the same time a carbonate-buildup trend occurred along the North Africa suggesting a basinal configuration deeper at the NE (present northern India) and SW (northern Africa) and shallower at the West (Arabian shield). Thus the development of a semi-closed basin, where carbonates and sandstones were accumulated, continued upto central Arabia (*Al-Laboun, 1986*). At Middle Devonian basins in the East and North-West of Iran became larger and allowed continuous deposition of shallow marine shelf deposits that includes sand, carbonates and shale (***Fig. 4***). A shallow sea persisted and 200–400 m thick argillaceous deposits accumulated at the northern margin of Africa, Arabia and India (***Fig. 4***). During Late Devonian the formation of shallow marine sandy-argillaceous deposits continued in Greater India, in the marginal basin of the Himalayas and southern Tibet, northern

Arabia and northern Africa (*Gupta & Brookfield 1991*). In the Late Devonian, organic-rich marine black shales were developed in low-latitude, restricted, intra-shelf basins, evident in North Africa and northern Himalaya (Kanawar group –Po & Lipak shale) and is coincident with a global oceanic anoxic event.

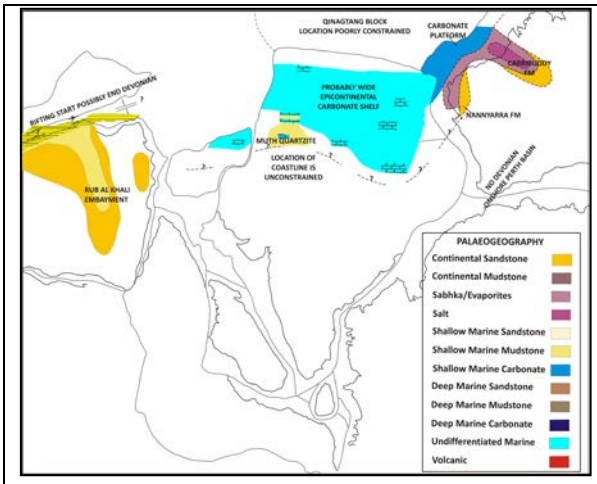

Fig 3. *Adjacent plates of India and Arabia during Early Devonian (400Ma) (modified after ONGC-BP expl. report)*

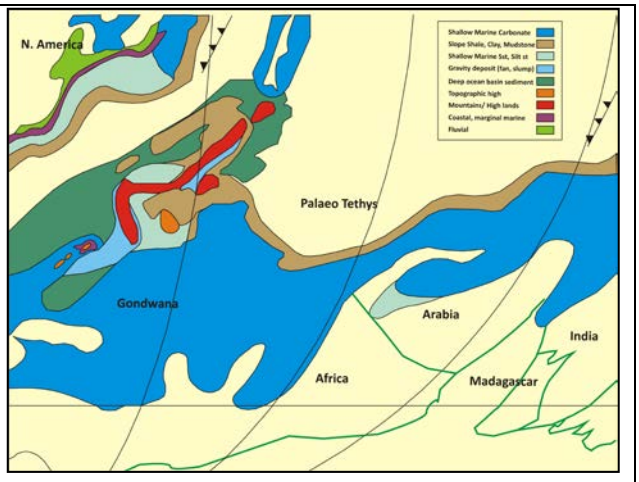

Fig 4. *Palaeoenvironment & lithofacies map of Africa, Madagascar, Arabia and India during Middle Devonian (after Golonka 2002)*

Carboniferous : Major rifting affected Gondwanaland during Carboniferous to Early Permian accompanied by volcanism in many regions (Panjal Traps in Kashmir and Late Carboniferous dolerite intrusion in Spiti). Similar volcanic sequence is present in the Mozambique basin and in northeastern South Africa (Karoo Basin) where an occurrence of bimodal volcanic activity of Rhyolitic/Dacitic and Basaltic/Andesitic tuff sequence (Drakensberg - Lebombo - Letaba basalts and rhyolites) is widespread. The Early Carboniferous was the time of Hercynian Orogeny, which is evident in Europe, Africa and Arabia (*Golonka 2002*). Evidence of this orogenic episode is also reported in Lesser Himalaya where a marked unconformity is recorded between Mid Cambrian Sincha, Bimdasa (in Jammu & Kashmir (J&K)), Baliana-Krol-Tal group (in Himachal Pradesh (HP) and Uttrakhand (UK)) and Panjal Volcanics, Agglomeratic Slate (in J&K) and Boulder Slate (in HP and UK). Restricted, low-latitude carbonates and sandy-argillaceous lagoonal facies were extensively developed at shelf margins covering northern parts of Africa, Arabia and India containing skeletal and oolitic sand bodies (***Fig.5***).

Permian : During Early Permian the Palaeo-Tethys Ocean transgressed over the northern margin of Gondwanaland. An outer shelf mudstone basin developed on the northern margin of the Lhasa plate, while coarser shallow shelf sediments were deposited further South at the northeastern Indian plate and it continued through the Arabian Peninsula (***Fig.6***). During this time Panjal volcanism in Kashmir reached its peak. Similar volcanic activity is found in Karoo volcanic sediments in Mozambique and Tanzania. During the Middle - Late Permian the transgression continued while the northern margin of Gondwanaland moved into the warmer climatic zones facilitating development of a wide carbonate shelf. Thus carbonate facies and clastic sediments dominated and extended from the Arabian plate across Lhasa and the northern Indian plate (*Leeder et al., 1988*) (***Fig.7***). During Late Permian marginal-marine and shallow marine deposits like carbonate-shale, carbonate-evaporite and sandy-shale persisted in northern India, eastern Africa (Kenya, Tanzania and Mozambique coasts) and eastern Arabia.

Triassic : This was a period of regression over most of northern Gondwanaland. In Arabia, continental to shallow marine clastic sediments eventually covered the widespread Permian carbonate shelf. Sabkha sedimentation continued only in relatively small areas. In the Baluchistan-Indus basin sedimentation probably continued uninterrupted from the Permian with the marine mudstones and limestones of the Wulgai formations (*Williams, 1959*) while the sea retreated from the Rajasthan margin, leaving only thin, local shallow marine to parallic clastics. In northern India, during early to mid Triassic, mostly condensed deep-water carbonates like Mikin and Chomula Formation in the Spiti valley were deposited (Bhargava and Gadhoke, 1988), while in Lhasa, development of a generally regressive carbonate ramp to shallow platform environment is recorded (*Leeder et al., 1988*). This indicates that the basin was relatively deeper in the East towards Indian plate (***Fig.8***). After this period, a major clastic sequence started prograding over the shelf. In Spiti Valley this late Triassic regressive sequence is represented by Nunuluka Fm consisting of basin margin limestone and shales over the platform shale and reefs, topped by a beach sandstone sequence.

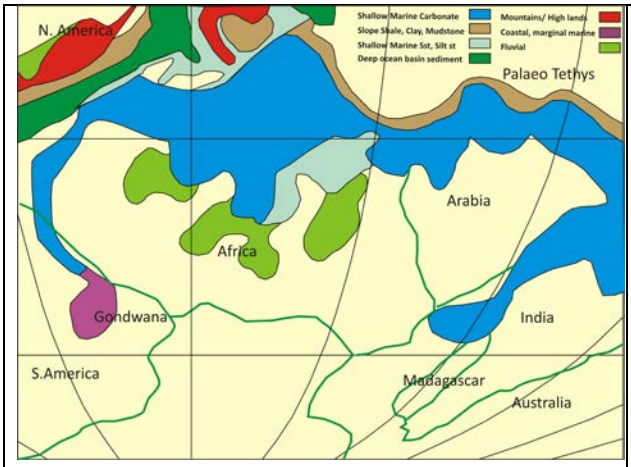

Fig 5. *Plate tectonic, palaeoenvironment and lithofacies map of Africa, Arabia and India during Early Carboniferous (after Golonka 2002)*

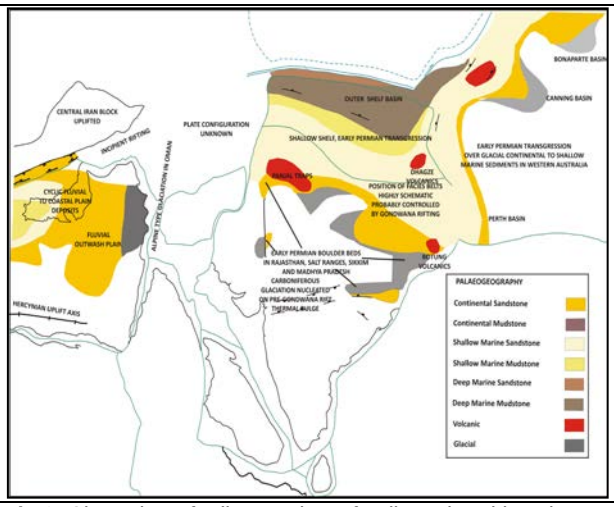

Fig 6. *Close view of adjacent plate of India and Arabian plate at the* Base of Permian (290 Ma) *(after ONGC-BP expl. report)*

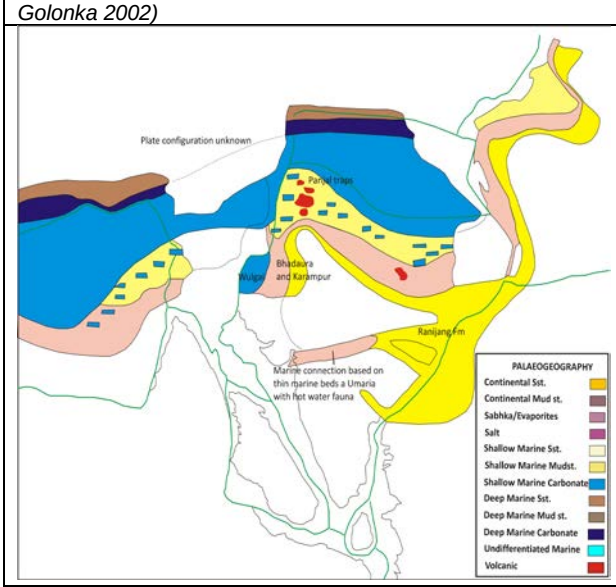

Fig 7. *A close view of adjacent plate of India and Arabian plate at the* Late Permian (250 Ma) *(modified after ONGC-BP expl. report)*

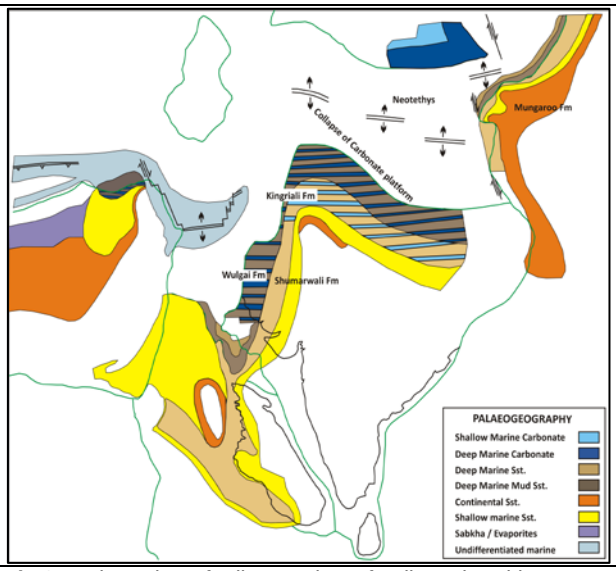

Fig 8. *A close view of adjacent plate of India and Arabian plate at* Late Triassic (225 Ma) *(modified after ONGC-BP expl. report)*

Jurassic : Rifting between Africa and India/Madagascar in the Early to Middle Jurassic (175-160 Ma) separated East Gondwanaland from West Gondwanaland (***Fig.9***). Middle Jurassic was a period of transgression all around the Indian craton. Northern India remained a passive margin to the widening Tethys Ocean, dominated by oolitic carbonate shelf sedimentation. Large carbonate deposits are also reported in Seychelles, Ethiopia, Somalia, Madagascar, Kenya, and Tanzania. Marine shales are widespread but subordinate, and reflect a regional flooding event in the Late Jurassic. As a whole, the sequence indicates the onset of a relatively stable marine shelf system with a link to the Tethyan Ocean. Limestones are of oolitic nature in Seychelles, Madagascar, Tanzania, Kenya, Somalia and Ethiopia.

Cretaceous: In the Earliest Cretaceous, due to equatorial setting, carbonate sedimentation was largely restricted to the Arabian Shield and clastic sedimentation dominated along the West and North Indian margins (away from equator). The clastic input is likely to have been localized, condensed and the depositional facies were isolated and not very extensive. Deposition of deeper water pelagic limestones and black shales in the lower Indus basin, Sember Formation and Belemnite beds (*Williams, 1959*) are reported in Nepal. During Late Cretaceous (83 Ma) India started to break away from Madagascar as evident from the volcanism in the area. Volcanics are common in the Cretaceous sequence in Seychelles, Madagascar, Ethiopia and Somalia and similar effects of volcanism is also seen in India as Deccan Traps. The effect of breakup of the Indian-African plate is also evident in the similar extensional phases (rifting) within the Arabian plate. Late Cretaceous carbonate shelf sedimentation dominated most of Northern India and Arabia, partly as a function of diminished relief on the cratons and partly because of the more equatorial setting. In the active rifts, mixed clastic/volcano-clastic sedimentation continued, and on the

northernmost margin of India, carbonate flysch type deposits and radiolarites were deposited. Thus a good continuity between Indian and Arabian plate can be observed at least upto the Late Cretaceous (***Fig.10***).

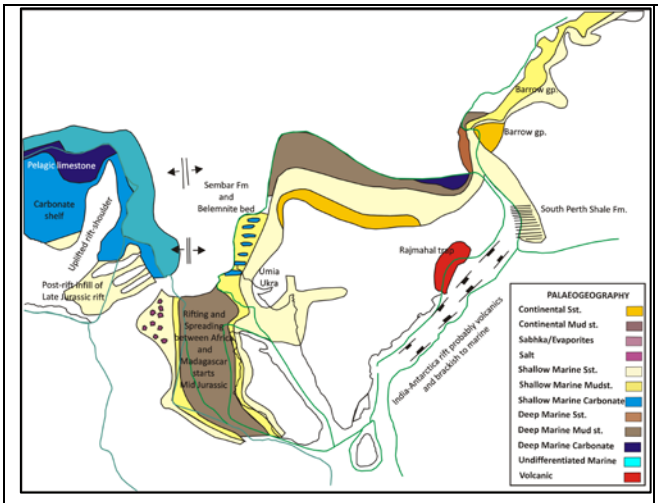

Fig 9. *Paleogeography map during Late Jurassic (152 Ma) showing initiation of breakup of continents of Indian, African and plate (Modified after Golonka,2002)*

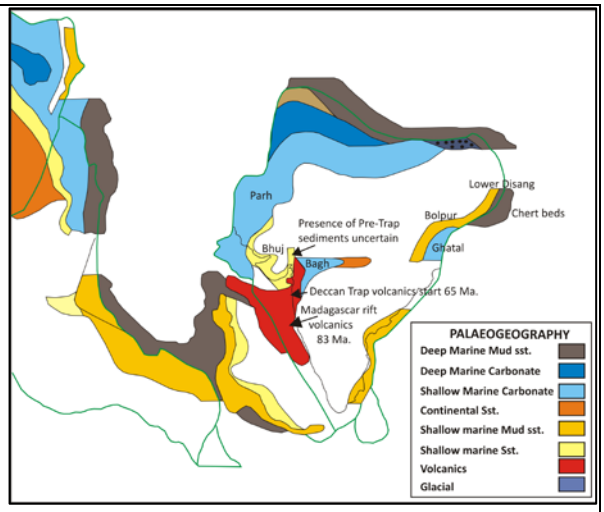

Fig 10. *A close view of adjacent plate of India and Arabian plate* during Late Cretaceous (90 Ma) *(modified after ONGC-BP expl. report)*

Prospectivity of Palaeozoic-Mesozoics in India and Nepal

There are mainly three sectors where the Palaeozoic-Mesozoic rocks are exposed on the surface in the Indian part of the subcontinent viz. Zewan beds in the Lesser Himalaya, Karewa basin in Kashmir valley and in the Tethyan basin.

Zewan Beds: Upper Permian to Triassic *Zewan beds,* occur as part of an autochthonous folded belt between the Main Boundary Thrust (~MBT or Murree Fault or) and Main Crystalline Thrust (~MCT or Panjal Thrust) in Poonch area (J&K). The width ranges from a few meters to 7 km and is restricted in SE upto Mandi-Daraba area only. A complete stratigraphy from Precambrian (Gamir, Baila, Ramban, Bhimdasa and Sincha formations), through Palaeozoic to Lower Tertiary (agglomeratic slate, Panjal volcanics, Zewan beds, Poonch-Mandi and Rajpur formations) are exposed in this area. At the basal part it contains dark grey ferruginous shale, slate, limestone, coral limestone, quartzite and semi crystalline limestones while at the top it has grey sandy limestone and quartzite. Presence of recumbent folds and distribution of good potential source rocks throughout the overall area from Lower Permian to Tertiary makes the area structurally and stratigraphically prospective.

Karewa Basin: It is developed as a piggyback basin on top of the uplifted Paleozoic-Mesozoic sequences floored by the Kashmir Napee. Presence of numerous surface gas shows and carbonaceous matter in the form of peat & lignite of Pakharpur Formation enhances the chances of a suitable source rock in the sub-surface. The Paleozoic-Mesozoic rocks surrounding it have Tethyan affinity and therefore have greater prospectivity from hydrocarbon exploration point of view. The stratigraphy has good faunal control like presence of Marine fossils in agglomeratic shales *and* Fenestella shales (*Rhacopteris fauna*)-possible source facies, various species of corals in Syringothyris Limestone. Sandstones of Muth quartzite (Devonian), carbonates in Syringothyris Limestone (Lr. carboniferous) & sandstones within Fenestella Shales (Mid. carboniferous) can be good reservoir rocks. Paleozoic and Mesozoic rocks contain many thick, aerially extensive argillaceous rocks, which can act as effective seals for this area.

Tethyan Basin: It comprises a thickness ~12 km of clastics & carbonates ranging in age from Proterozoic to Eocene. The basal Haimanta Formation made up of low-grade metamorphic rocks of Proterozoic age is overlain by a huge pile of fossiliferous sedimentary rocks such as sandstone, shale and (dolomitic) limestone. The Permian Gungri Formation and Jurassic Spiti Shale (TOC 1-1.24%, V_{RO} = 1.85 to 2.22%) have source potential, Triassic-Jurassic clastics (Giumal sandstones) and carbonates have good reservoir properties to form viable petroleum systems. Being part of a fold thrust belt, anticlines and fault related plays, pinchouts and stratigraphic plays might be readily available entrapment conditions.

Nepal: In Nepal Himalaya there is a fair continuation of Triassic limestone (marl) belt from NW-Kashmir, SE-Kashmir, Chamba, Zanskar, Spiti, Kathmandu Nappe (South Nepal) to Thakkhola (North Nepal). The

sequence mainly follows the Tethyan sequence, which is very characteristics among the belt of Peshwar basin Pakistan, SE Zanskar, India and northern Nepal. In Nepal, the sequence Muth Quartzite (Devonian), Kioto Limestone (Early Jurassic), Spiti Shale (Late Jurassic to Early Cretaceous) and Kangi La Formation (Late Cretaceous-Paleocene) are of similar character with the Tethyan sequence in Indian territory.

Conclusions

- Analysis of palaeo-geographic maps suggest that the Palaeozoic-Mesozoic units of the northern Indian margin are actually a part of a same depositional regime that continued from Early Cambrian till the time of India's break-up from the main Gondwanaland. Correlation of lithofacies i.e. carbonates as well as clastics among the various parts of the Arabian-African continents and northern Indian margin strongly suggest the similar co-evolution.
- Presence of contemporaneous salt-evaporite, various igneous activities within the adjacent plates is a good indicator of the co-existence of these plates.
- Presence of Palaeozoic-Mesozoic rocks in few of the drilled wells strengthens the analysis. In the Well M-1, drilled in the Mohand area, Dehradun (near Himalayan Frontal Thrust), in C-1 within Kashmir Valley, around 1000m Triassic/Jurassic limestones have been drilled and in the well S-1, North of the MBT, pre-Tertiary (Palaeozoic) limestones have been recorded.
- Detailed analysis of available palaeogeographic maps, paleo-environment and paleo-lithofacies from Early Palaeozoic to Late Cretaceous has been carried out for filtering out valuable leads to develop future strategies for hydrocarbon exploration in northern Indian margin i.e. in the Himalayan fold thrust belt and thus it suggests the Palaeozoic- Mesozoic of Lesser and Tethyan Himalaya are highly prospective for hydrocarbon exploration.

Recommendation

- ✓ Intensive exploration is required to prove homotaxial formations within Palaeozoic and Mesozoic in this part of Indian subcontinent.
- ✓ Concerted efforts are warranted with the help of deep drilling to convincingly and conclusively prove the existence of these Palaeozoic –Mesozoic sequences in Poonch-Rajauri (J&K) area and in Tethyan area.
- ✓ In analogy to producing basins (Palaeozoic and Mesozoic) in neighboring plates, commercial finds in this part of Indian subcontinent necessitates above efforts.

References

Al-Laboun A.A., 1986. Stratigraphy and hydrocarbon poterntial of the Paleozoic succe- ssion in both Tabuk and Widyan basins, Arabia. In: Halbouty M.T. (ed.), Future petro- leum provinces of the world, American Association of Petroleum Geologists, Memoir, 40, 373–397.

Bhargava, O.N and Gadhoke, S.K., 1988: Triassic microfauna of the Lilang group with special reference to Scythian-AnisianConodonds, Spiti valley, Himachal Himalaya. J. Geol.Soc. India,v.32,p.494-505

Bhat, G.M et al., 2012, Geology and hydrocarbon potential of Neoproterozoic gCElam brian Basins Society, London, Special Publications 2012, v.366; p1-17. doi:10.1144/SP366.15

Cozzi, A. & Al- Siyabi, 2004. Sedimentology and play potential of the Late Proterozoic Buah Carbonates of Oman. GeoArabia, 9, 11–36.

Dutta, T et al., 2013, Analysis of continuity of sub-himalayan tectonic elements and lithofacies from eastern Pakistan into India based on some geological and geophysical leads: insights into the hydrocarbon prospectivity of Jammu and Kashmir sector, article no 377, 10th Biennial International Conference & Exposition, SPG, Kochi.

Leeder, M.R., Smith, A.B and Yin Jixiang.,1988: Sedimentology, palaeontology and palaeoenvironment and evolution of the 1985 Lhasa to Golmud geotraverse. Phil.Trans.R.soc.Lond.A 327,p.107-143

Golonka J., 2002. Plate-tectonic maps of the Phanerozoic. In: Kiessling W., Flügel E. & Golonka J. (eds), Phanerozoic reef patterns, SEPM (Society for Sedimentary Geology) Special Publication, 72, 21–75.

Gupta J. & Brookfield M.E., 1991. India. In: Moullade M. & Nairn A.E.M. (eds), The Pa- laeozoic, A, The Phanerozoic geology of the world I, 71–110, Elsevier, Amsterdam

Peters, K. E., Clark, M. E., Das Gupta, U. & Lee, C. Y. 223 1995. Recognition of an Infracambrian source rock, based on biomarkers in the Baghewala-1 oil, India. American Association of Petroleum Geologists Bulle- tin, 79, 1481–1494.

Rolle, F, 1991, The Hydrocarbon prospects of the Himalayan margins in India (The plate tectonic setting of northern India). ONGC-BP joint study report.

Scotese, C. R. 2009. Late Proterozoic plate tectonics and palaeogeography: a tale of two supercontinents, Rodinia and Pannotia. In: Craig, J., Thurow, J., Thusu, B., Whitham, A. & Abutarruma, Y. (eds) Global Neoproterozoic Petroleum Systems: The Emer- ging Potential in North Africa. Geological Society, London, Special Publications, 326, 67–83.

Williams.M.D., 1959: Stratigraphy of the lower Indus basin, West Pakistan. Proc. Fifth world petroleum congress, section 1, paper 19, p 1-15