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Exploration Challenges in Tethyan Himalaya: Case Study of Sarchu Area in Lahaul-Spiti, Himachal Pradesh and Morey Plains in Ladakh, Jammu & Kashmir

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Abstract

Favourable analogies from producing fields in fold thrust belts elsewhere in the worldcontinues to allure the explorationist towards the complex Himalayan fold-thrust belt. Although many workershave acknowledged the hydrocarbon bearing potential of the Tethyan sector of the Himalaya, the region haslargely remained a major grey area as far as exploratory progress is concerned. It is the endeavour of the current paper to take one through the vast unexplored expanse of the Indian terrain within the TethyanHimalayan regime and current state of exploratory knowledge, with particular focus on Sarchu and MoreyPlain sectors.Beginning with integration of available geological knowledge of the area and its analysis vis-a-vis the inferred palaeogeographic set-up of the area, the results of available geochemical studies on selected samples asavailable on date are also discussed. Exploratory work done for hydrocarbon exploration till date (thoughsparse) is integrated into the study which culminates in the proposal of a possible Generation-Migration-Entrapment (GME) model through which the various petroleum system elements and processes as expectedare individually inspected.The study highlights that although the obvious hurdles of high altitude, remote location, poor infrastructure andnegligible exploratory inputs are major challenges at present, the favourable poly-phase evolutionary history ofthe basin, the presence of a highly lucrative and thick Palaeozoic-Mesozoic sedimentary column comprising of both siliciclastics and carbonates and the existence of relatively less deformed folded and thrusted structures make this sector quite interesting from the exploration viewpoint. Notwithstanding the exploratorychallenges, it is thus time for higher exploratory priority to be accorded to “high risk, high reward” areas, if at all a major breakthrough is to be achieved in this scenario of ever increasing demand-supply gap.

Introduction

Hydrocarbon exploration in the Himalaya has been restricted mainly to the foothills part while much less emphasis has been given to the Karewa and the Spiti-Zanskar basins which are known to have uncertain hydrocarbon potential. This can primarily be attributed to remote location, very high altitude, inadequate infrastructure and hostile weather conditions. All of these increase the financial risks manifold. However the increasing demand for hydrocarbons, increase in the global oil and gas prices, improved accessibility and decreasing security concerns has resulted into an augmented, though cautious need to move into the unexplored areas to identify new plays and fields to sustain the reserve accretion ratio.

The Tethyan Himalayan region, particularly Spiti-Zanskar basin is a reasonable target for the purpose, considering the fact that it has well preserved and complete succession of the Palaeozoic-Mesozoic sequences which are the major hydrocarbon producing formations elsewhere in the world, including neighbouring Kohat-Potwar Basin of Pakistan. Presence of thick sedimentary column of both siliciclastics and carbonates enhances the possibility of preservation of good source as well as reservoir rocks in this basin. Further observation that this region is less tectonically disturbed in comparison to the Sub-Himalaya and Lesser Himalaya enhances the possibility of better preservation of the hydrocarbons if generated. An attempt has therefore been taken up to analyze the hydrocarbon prospectivity of the area, with focus on the two topographically flat areas, Sarchu in Lahaul-Spiti and Morey Plains in Ladakh.

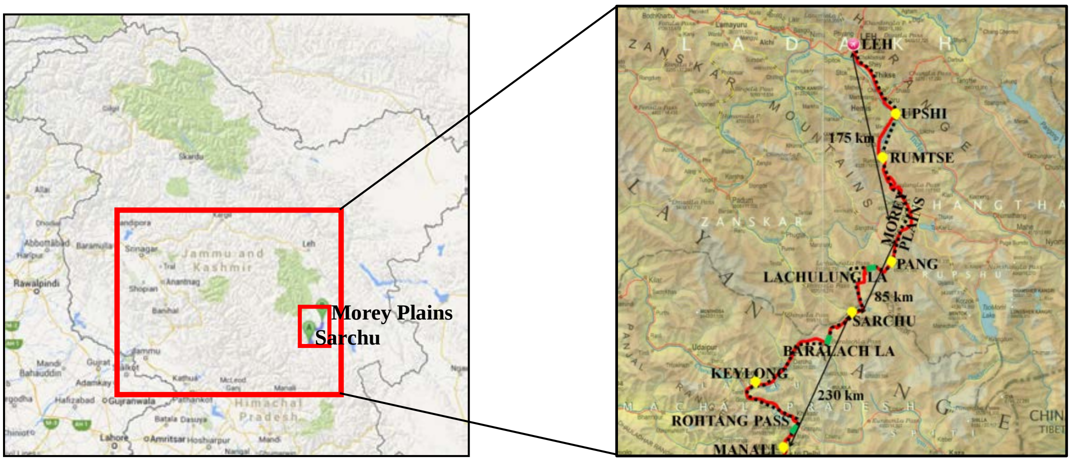

Fig. 1: Location map of the area showing Sarchu and Morey Plains along the Manali-Leh Highway

Geology of the Area

The Himalayas comprise a fascinating geological record of Precambrian to present. The zone of contact between the Indian and the Tibetian plate is known as the Indus-Tsangpo Suture Zone (ITSZ). South of the ITSZ, Himalayan tectonic framework comprises of four contrasted latitudinal litho-tectonic sub-provinces, each characterized by its own distinctive structural architecture, lithological composition and stratigraphic setting. All the units extend from east to west and are sharply separated from each other by major boundary thrusts. From north to south the litho-tectonic zones are Tethyan Himalayas, High Himalaya Crystalline Zone, Lesser Himalaya Zone and the Sub Himalaya Zone separated by the South Tibetian Detachment (STD), Main Central Thrust (MCT), Main Boundary Thrust (MBT) respectively from each other and ending up at the Himalayan Frontal Fault (HFT) on to alluvial plains (**Figs. 2 a & b**).

The Tethyan Himalayas comprises of a colossal pile of fossiliferous sediments ranging in age from late Precambrian through Cretaceous to Eocene laid down on the Precambrian high grade metamorphics and granites of the Higher or Great Himalaya which form the foundation. This sedimentary pile laid down in the basin of the Tethys and its precursor Palaeozoic sea, has been moulded into a huge synclinorium characterized by Jura type folding, with frequent back folded southern margins and isoclinal overturned or recumbent folds and imbricate thrust in the northern part (Report on Geological Field work in Lahaul-Spiti Valley, Himachal Pradesh and Zanskar, Leh-Nubra Valley, Jammu & Kashmir, Regional Interpretation Group, Frontier Basin, November, 2011). The Tethyan subprovinces have been delimited to the north along the upper Indus and Tsangpo valleys by the “Indus Suture Zone”. The study area has been affected by three major tectonic events, Pan-African Orogeny (Cambro-Ordovician), rifting of the Cimmerian micro-continents and opening of Neo-Tethys (Permian) and drifting and collision of the Indian Plate (Cretaceous). Several granitic intrusions have further resulted in formation of localized structures in the area.

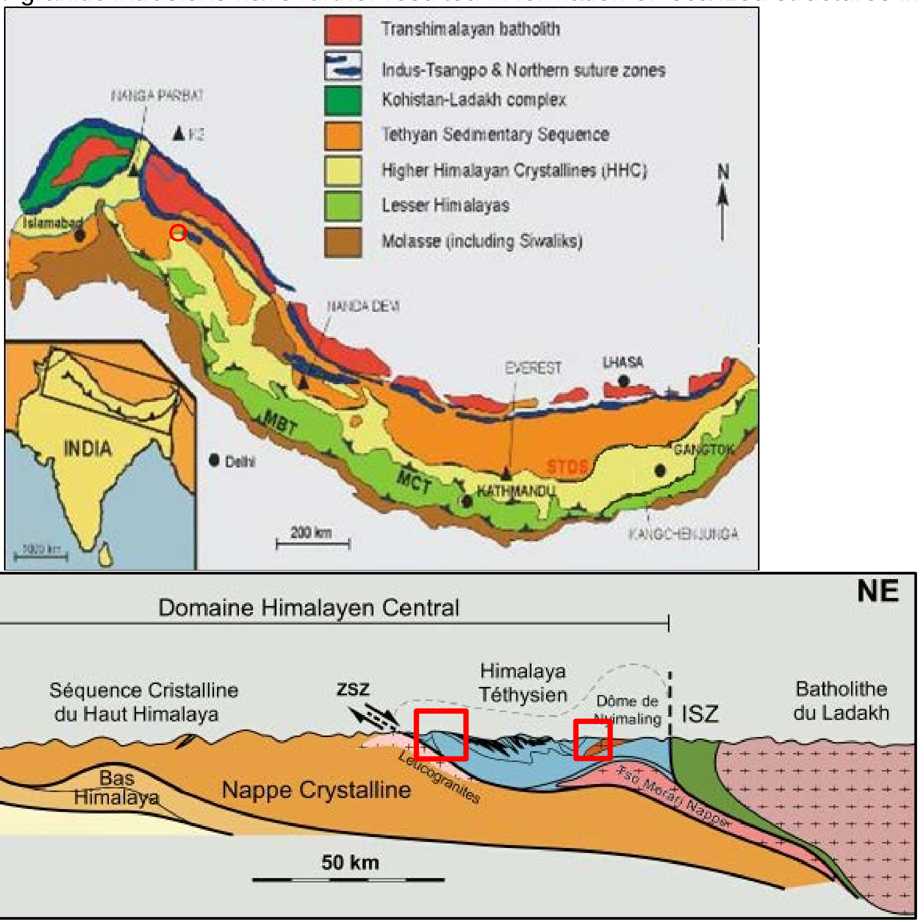

***Fig. 2 : a.** Regional geology of Himalaya with study area shown by red circle(top). **b.** Regional geological section of Himalaya with the study area highlighted (bottom).*

Stratigraphy of the area

The detailed stratigraphy of the area as compiled from available literature is given in Table-1.

AGE	GROUP	FORMATION	MEMBER	THICKNESS*	LITHOLOGY*
Cenozoic				N.A	Fluvio-glacial and lacustrine gravel, sand + minor shale
------------------------ Unconformity ------------------------					
Late Cretaceous	Lagudarsi Group	Chikkim Formation		30-80m (Zanskar) / 105m (Spiti)	grey, slightly nodular, well bedded limestone
Early Cretaceous		Giumal Formation		160-400m	Sandstone, interbedded black shale
Upper Jurassic		Spiti Shale		20-60m in Zanskar area, >900m in Spiti	dark shales, intercalated marl & calc. quartzite, very fine grained Sst
Late Middle Jurassic		Ferruginous Oolite Formation		5-10m	ferruginous carbonate, intraformational cong.& laminated

(Callovian)					shales
-- Unconformity --					
Late Lower – E. Mid. Jurassic	Lilang Group	Kioto Limestone		N.A	massive Lst with cherty dolomite
U. Triassic (Norian)		Quartzite Series	Third	N.A	-
			Second		micaceous siltstones, Lst and quartzose arenites
			First		bioturbated arkoses intercalated with Lst and micaceous pelites
Late Carnian		Zozar Formation	Upper	150m	dolomite, stromatolite, bioclastic lst.
			Lower		Bioclastic limestones
Ladinian-Carnian(?)		Hanse Formation	Third	400m	nodular or platy limestone
			Second		Lst with marl and shale content increasing upward
			First		Marl & ash-grey shales
Lower - Middle Triassic		Tamba Kurkur Formation	Third	50-60m	nodular limestones with upwards increasing shaly intercalations
			Second		nodular limestone
			First		nodular Lst, shaly on top
Upper Permian		Kuling Formation	Gungri	10-60m	black splintery shales and siltst., phosphatic nodules
			Gechang		sublitharenites, black shales & arenaceous bioclastic Lst
Permian		Panjal Traps		150-300m	effusive tholeiitic flood basalts
E. Permian (Sakmarian)		Chumik Formation	Second	20-80m	micro-conglomerates
			First		calcareous, shaly and glauconitic arenite
-- Unconformity --					
U. Carb. -Lower Permian		Ganmachidam Formation		<40m	diamictites, clasts of plutonic granitoid rocks
Middle Carboniferous		Po Formation		200m	Quartz-arenite, Sst, siltstone, volcanic rock clasts
Lower Carboniferous		Lipak Formation	L4	200m	dolomites, limestone and sandstones
			L3		gypsum, with rare dolomite interbeds, concordant dikes
			L2		dolomites, limestones, black shales, sandstones
			L1		Sst with gritty Lst overlain by beds of limestone and marl
Devonian		Muth Formation		0-50m	quarz-arenites
-- Unconformity --					
Lower Ordovician – Silurian		Thaple Formation	Takche (missing)	100-1200m	-
			Third		gritty dolomite with siltstone and shales
			Second		sandstone with siltstone and shale interbeds
			First		Sandstones, polygenetic conglomerates and siltstone
-- Unconformity --					
M. Cambrian – U. Cambrian		Kurgiakh Formation	Kuru	150m	detrital intercalated with dolomite
			Surichun	150m	black shales with rare dolomite
L. Cambrian – M. Cambrian		Karsha Formation	Teta	70-160m	Marly limestones and black shales
			Thidsi	200m	Massive dolomites
			Mauling	600-800m	Detrital sediments, Dolomite
U. Precambrian – L. Cambrian		Phe Formation	Doda	800-2000 m	siltstones, fine grained Sst and occasional slates
			Tsarap		
-- Unconformity --					
Precambrian	Vaikrita			-	Metamorphic Basement

*Tectonic and Metamorphic Evolution of the Central Himalayan Domain in South-east Zanskar, Pierre Dèzes; Source Rock evaluation of key exploratory Wells/outcrop samples, KDMIPE, March 2013

Table 1: Stratigraphy of the area

Paleogeography and Basin fill

Upper Precambrian is characterized by deposition in an elongated and narrow intracontinental sea between the Indian continent and the Cimmerian Superterrane, documented by the Phe Formation. The sediments being 5000 to 10,000 metres thick (Fuchs and Linner, 1995; Wyss, 1999; Frank et al., 1997; Steck et al., 1998) indicate either a continuous sea level rise, or more likely a major subsidence in the basin. Lower to Middle Cambrian indicate a reduction in the rate of detrital input and subsidence, giving way to the formation of the dolomitic horizons, stromatolitic colonies and platform carbonates of the Karsha Formation. The presence of turbidites within the Kuru Member of the Kurgiakh Formation of Upper Cambrian indicates a return to a deeper sedimentation environment and of tectonic subsidence exceeding the sedimentation rate. The boundary between Cambrian and Ordovician is marked by an angular unconformity at the base of Thaple Formation. Moreover, the conglomeratic lithologies of the Thaple Formation testify for the uplift and erosion of parts of the underlying formations, as these conglomerates incorporate fragments of the Phe, Karsha and Kurgiakh Formations. This so-called late Pan-African tectono-magmatic event is marked by numerous~500 Ma old granitic intrusions forming a wide belt stretching from the Alps (Bussy et al. 1995) over the Arabic peninsula, Afghanistan, Africa, India, Australia and down to Antarctica (Le Fort, 1986 and references therein). The sedimentary environment after the Pan-African event essentially was littoral (Middle to Upper Ordovician members of the Thaple Formation) or coastal (Devonian Muth Formation). Most of the Silurian is missing, possibly as a consequence of erosion due to fall in sea level.

This rather uneventful period is followed by rifting between the Indian continent and the Cimmerian micro-continents, followed by the opening of the Neo-Tethys. An early transtensive stage of rifting is observed since the Early Carboniferous in the Lipak Formation, where syn-sedimentary extension faults are noted (Vannay, 1993). In the Lower Permian, an episode of thermal uplift of rift shoulders is suggested by the absence, to various degrees, of the Palaeozoic formations, whilst in adjacent graben areas the stratigraphic record is complete. A magmatic event also occurred at the boundary between the Carboniferous and the Permian, as documented by the granitic intrusion of the Yunam, in the Sarchu region (Spring et al. 1993). The opening of the neo-Tethys starts in the Middle Permian with the formation of oceanic crust. This event is marked in many regions of the Himalaya by the outpouring of the Panjal Traps. Following the rifting of the neo-Tethys, the transgressive Upper Permian Kuling Formation testifies the progressive subsidence of the passive Indian margin. The Triassic Lilang Group then corresponds to the formation of a carbonate platform on this flexural margin. Middle to Late Jurassic is characterized by submergence to shelf/mud-slope environment due to sea level rise with the deposition of Spiti Shales. The dark grey sandstones in Giumal Formation show a short lived shallowing due to tilt of the basin with deposition of proximal turbidites. This period is then succeeded by the deepening of the basin, coinciding with the commencement of drift of Indian Plate. Folding and granite emplacement is noted with the gradual collision of the Indian Plate into the Eurasian Plate and the basin then transformed into an area of positive relief, subsequently dominated by fluvio-glacial deposition and formation of lakes due to damming of the rivers (**Fig. 3**).

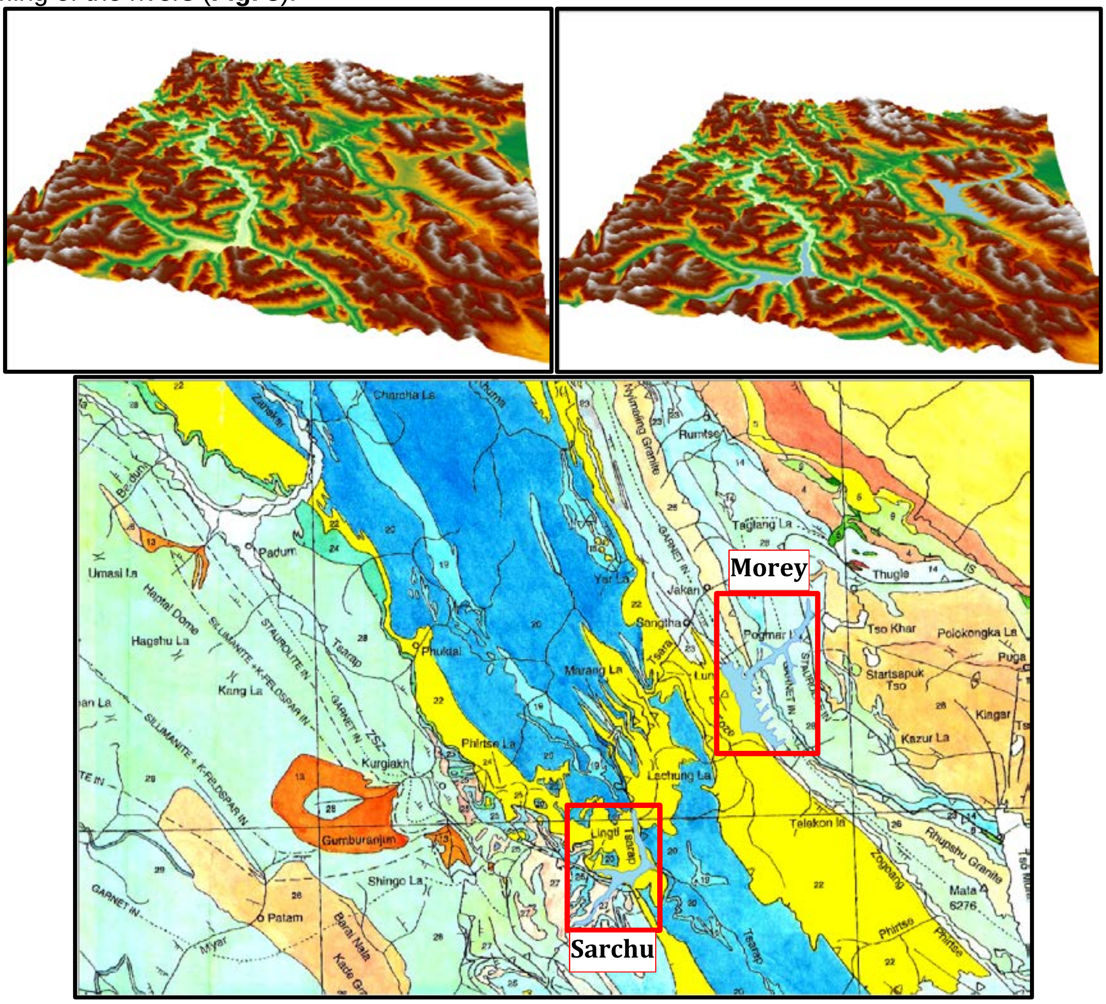

Fig. 3: Palaeo-lake and its overlay on the geology of the area

Hydrocarbon Potential

The area has a continuous sequence of Palaeozoic to Mesozoic sedimentary succession of clastics as well as carbonates deposited mainly in marine environment which enhances the possibility of presence of good source and reservoir rocks. The potential of the region is further increased by the fact that analogous basin in similar tectono-sedimentary setup have yielded good quantity of hydrocarbons elsewhere in the world. Geological mapping has indicated presence of thick carbonaceous shales in the area in both Palaeozoic and Mesozoic units. No surface hydrocarbon signature has been reported till date but this may also be due to rare human movement in the area due to difficult logistics and harsh climatic conditions. Sarchu Plain has exposures of both Palaeozoic and Mesozoic units including Thaple, Muth, Lilang and Kioto group of rocks as can be seen in the geological map and thus the Palaeozoic-Mesozoic succession is envisaged to be preserved in the area making it prospective for hydrocarbons. Morey Plain has exposures of the Early Paleozoic rocks of Karsha, Kugiakh and Thaple Formations, indicating lesser sedimentary thickness. The close proximity of the Nymaling Granite towards the north and east of the Morey plains suggests that the basin may be confined to the west and south of the Morey plains only. The hydrocarbon potential of the area thus appears to be good, and to objectively assess this, a systematic exploration strategy with physical inputs and interventions is needed.

Envisaged Petroleum System

Source Rock

Theoretically organic-rich potential source rocks are developed at several stratigraphic levels in the area. The uppermost Teta Member of Karsha Formation and the lowermost Surichun member of the Kurgiakh Formation are dominated by black shale layers which indicate presence of good TOC. The combined gross thickness of the two layers being 220-300m makes and its deposition in shallow marine environment makes it an attractive proposition. The black shale layers of L2 member of Lipak Formation and the Gechang and Gungri members of Kuling Formation also appear likely to have good source rock potential. Apart from these Palaeozoic formations, the thick carbonaceous Mesozoic shales of Spiti and Giumal Formations also have good source potential. The black colour of conodonts and spores from Permian and Triassic sequences is indicative of the maturity of source rocks for hydrocarbon generation (Personal communication with Shri O.N. Bhargava, Ex-Director, GSI). Geochemical evaluation of surface samples (Regional Interpretation Group, Frontier Basin, 2011) has revealed TOC values of 0.12-0.64 for Phe Formation, 0.16-0.86 for Lipak/Po Formations and 0.35-0.08 for Kioto Formation (KDMIPE, 2013). However these values for subsurface samples may be quite different as the surface samples may have been influenced by weathering processes. Good quantity of carbonate rocks exist in the entire Palaeozoic-Mesozoic sequence of this area, but their source potential is yet to be objectively assessed.

Reservoir Rock

Siliciclastic and carbonate rocks that occur at several stratigraphic levels could form suitable reservoirs. However, due to diagenesis, cementation and cavity-filling, porosity is observed to be rather poor in outcrop samples. Faults, fractures and joints can provide passage for oil migration. Hydrocarbons possibly generated in Teta and Surichun members can be preserved in the overlying fluvial to shallow marine sandstones of Thaple Formation and Muth Quartzite. Similarly for source rocks of of Lipak Formation, reservoir units exist within the deltaic sands of Po Formation. The upper stratigraphic units of the Lilang Group contain stromatolites and sands which may act as reservoirs for hydrocarbons generated from Kuling Formation and thus suggests the possible existence of an exciting Palaeozoic-Mesozoic Petroleum System. Hydrocarbons from Upper Mesozoic Spiti and Giumal shales could be stored in the overlying sandstones of Giumal Formation or the carbonates of Chikkim Formation and together these may form a younger Petroleum System.

Traps

The very nature of the tectono-stratigraphic setup suggests a huge scope for existence of both structural and stratigraphic traps. Being part of a fold thrust regime, structural traps genetically related to folding and/or faulting should exist in plenty. This inference is also supported by the innumerable structures that have been mapped in the field. The stratigraphic traps envisaged may be associated with features such as fluvial/tidal channel deposits in Thaple, Muth and Chumik sands, unconformity associated traps of Cambro-Ordovician Boundary, Silurian or Middle Jurassic between Lilang Supergroup and the overlying Spiti shales, etc.

Seal/Cap Rock

The multiple shale and limestone layers developed at various horizons within both Palaeozoic and Mesozoic successions can also double up as effective seals for the migrating hydrocarbons, if impervious, and induce commercial accumulations. Reported presence of a gypsum horizon in the Lipak Formation further increases the possibility of a suitable seal being present in the study area.

GME Model

Based on the understanding of the study area from the preliminary geological information as discussed above, a GME model has been conceptualised and summarized in tabular form (**Fig. 4**) which lucidly places the various aspects of present understanding of the different aspects of the Petroleum System elements vis-à-vis their characteristics through geological time.

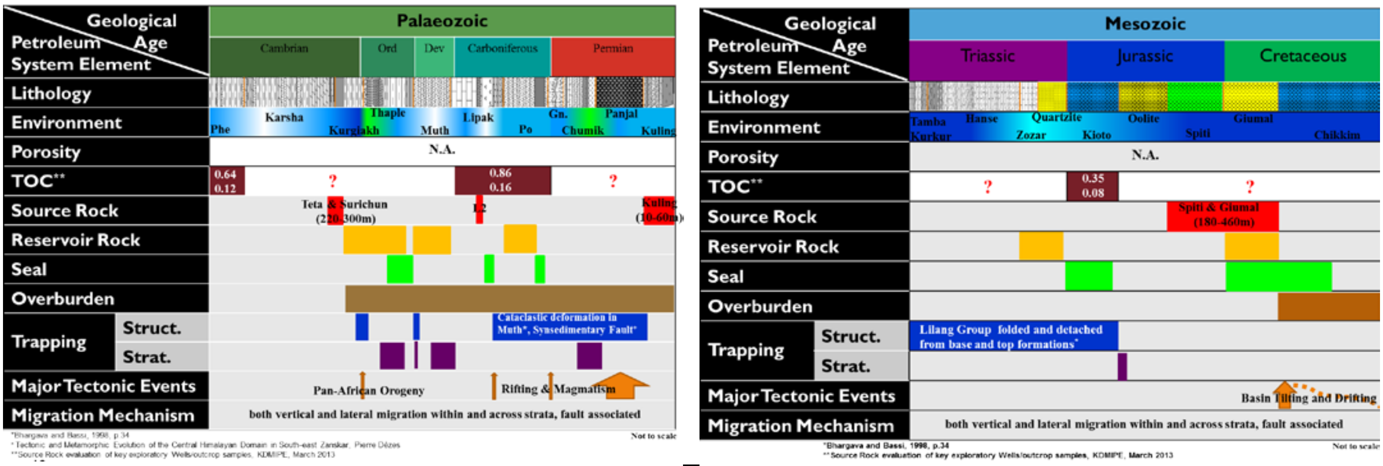

Fig.4: Palaezoic- Mesozoic GME model

Conclusion

The Tethyan Himalayas contain a thick sedimentary sequence comprising of primarily marine Palaeozoic-Mesozoic to fluvio-glacial and lacustrine recent sediments. The stratigraphic column shows abundant presence of lithofacies assemblages that appear to have all requisite characteristics for viable petroleum systems to exist. Tectonic episodes have presumably given rise to favourable stratigraphic and structural entrapment conditions in these areas. The envisaged GME model makes the area look attractive for physical exploratory inputs. All the above coupled with a good number of global analogies of similarly located tectono-sedimentary packages vis-à-vis the expected benefits strongly suggest that the area is worth exploring in terms of their hydrocarbon content for which a well calked out exploration strategy is required.

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