Kutch-Offshore Basin: Mesozoic Hydrocarbon Exploration Opportunities and Challenges

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Abstract

In spite of being the major contributor to the worlds' oil and gas outputs, Mesozoic reservoirs contributes only around 3% of India's oil & gas production. Kutch basin, off Gujarat coast, however, has the potential to become the country's hotspot of Mesozoic exploration and production activities in near future. The basin has hydrocarbon discoveries at multiple stratigraphic levels- from Jurassic to Miocene. The Mesozoic sediments in the Kutch basin are affected by multiple phases of India-East Africa rifting; the latest extensional tectonic phase being India-Seychelles rifting in Paleocene. The area was also affected by Late Oligocene plate re-adjustment event and the Miocene compression owing to the Himalayan orogeny. The post-Miocene compression reactivated some of the favorably oriented rift faults as strike slip faults and has also created some inverted structure within the Mesozoic and Tertiary levels.

Till now, Mesozoic hydrocarbon exploration in the basin has been limited by poor vintage sub-basalt seismic imaging. Newly acquired 3D seismic data with optimized parameters has given new insight into sub-basalt geometries in conjunction with newly acquired full tensor gradiometry (FTG). In addition to the proven Mesozoic petroleum system, we propose a separate sub-Jurassic basin toward southern boundary of the Kutch basin, which could be a part of Late Triassic-Early Jurassic Gondwana basin and can hold significant upside for gas exploration in the area.

1. Introduction

Kutch basin is E-W oriented pericratonic rift basin at the westernmost periphery of the Indian craton (Biswas, S.K., 1987). It is initiated during the Late Triassic-Early Jurassic time (Figure 1) due to the rifting of Lhasa Block from NE Gondwana margin causing a reactivation of the steeply dipping E-W trending Permian rift faults (Aravalli Trend), resulting in an overall low net extension. After that the basin has gone through multiple stages of rifting during India-Africa separation, India-Madagascar Separation and India-Seychelles separation during Middle Jurassic, Late Cretaceous and Paleocene periods respectively. At the Cretaceous-Tertiary boundary the Mesozoic sediments got covered in most part of the basin by the widespread Deccan volcanism. Presently, the basin is going through a compression phase owing to the Himalayan orogeny, resultant uplift is seen in onland part of the Kutch mainland (Figure 2).

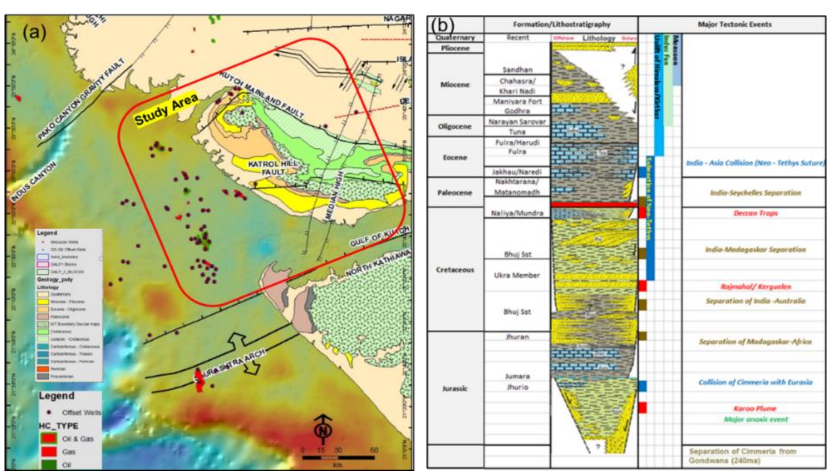

Figure 1. *(a) Geological map showing study area (b) Generalized stratigraphy of Kutch basin- showing major tectonic phases, extensional- compressional events and volcanic activities.*

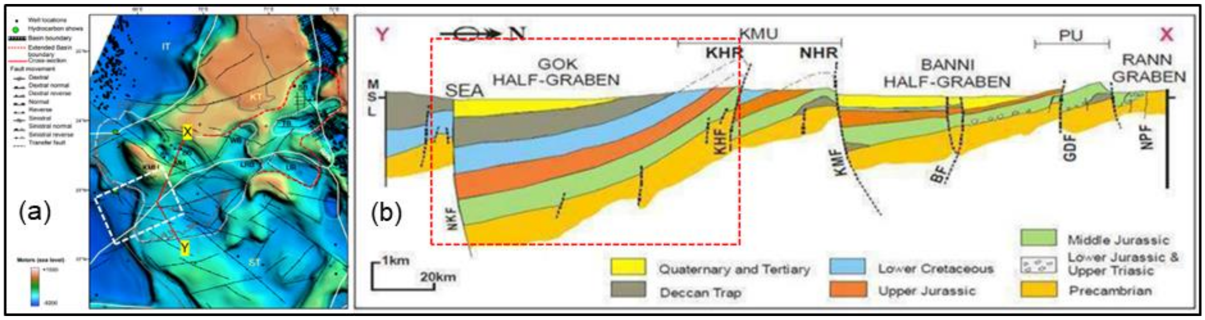

***Figure 2. Structural configuration of Kutch basin**. (a) Sea-base map showing basin geometry, major faults & depth to basement, (b) Geological section NE-SW (modified after Biswas, S.K, 2005) which shows key stratigraphic units and structural style. Towards the North Kathiawar fault (NKF) it shows half graben setup, which is believed to have thicker sedimentary cover. Rectangular polygon indicates area of interest.*

2. Mesozoic Hydrocarbon Exploration Opportunity

Around 70 wells have been drilled till date in Kutch basin and more than 20 hydrocarbon discoveries have been reported (Figure 3). In addition, there are numerous hydrocarbon shows (Figure 4) at different stratigraphic levels. While the shallowest oil discovery is at 733m, the deepest one is at depth of 4700m. However, most of the discovery sizes are small except 900 BCF inplace (IHS) Cretaceous discovery in Saurashtra basin. Inverted structural traps of Tertiary age have been the key focus areas. Exploration of Mesozoic traps are in initial stage, mainly due to poor sub-basalt seismic imaging. Integration of newly acquired data throws light on promising exploration opportunity in the area**.**

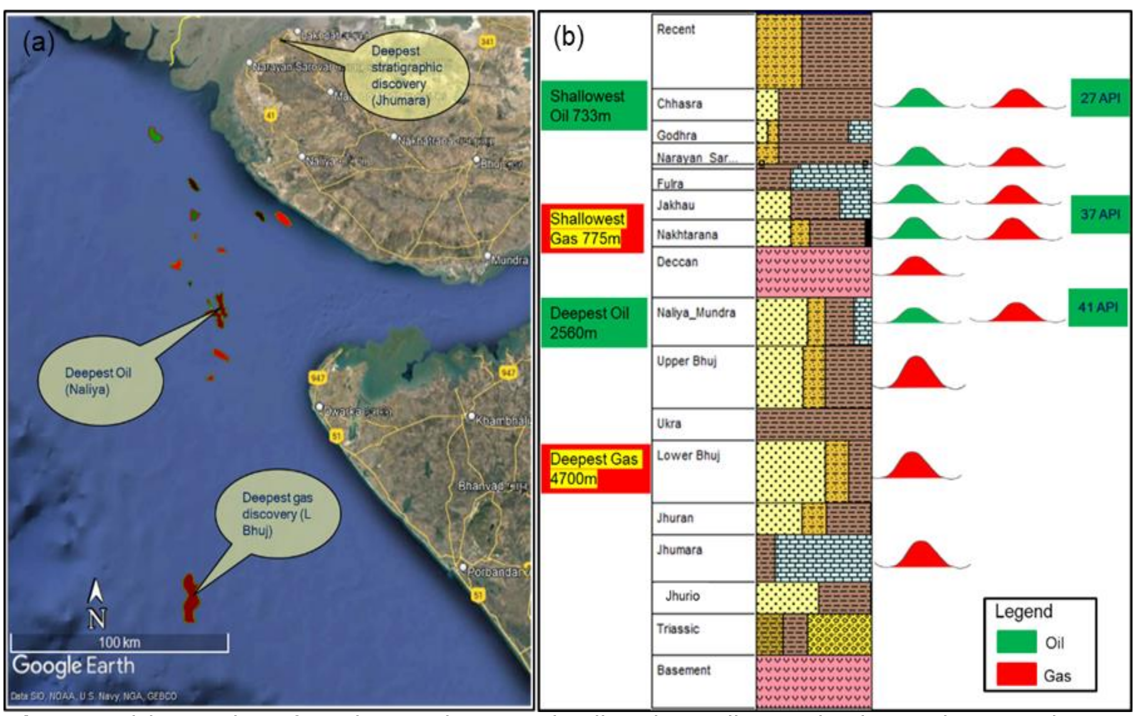

***Figure 3.** (a) Location of Tertiary and Mesozoic oil and gas discoveries in Kutch-Saurashtra Basin. (b) Hydrocarbon discoveries by stratigraphic levels, oil property and depth of hydrocarbon discoveries. Oil quality (API) also mentioned in the stratigraphic levels.*

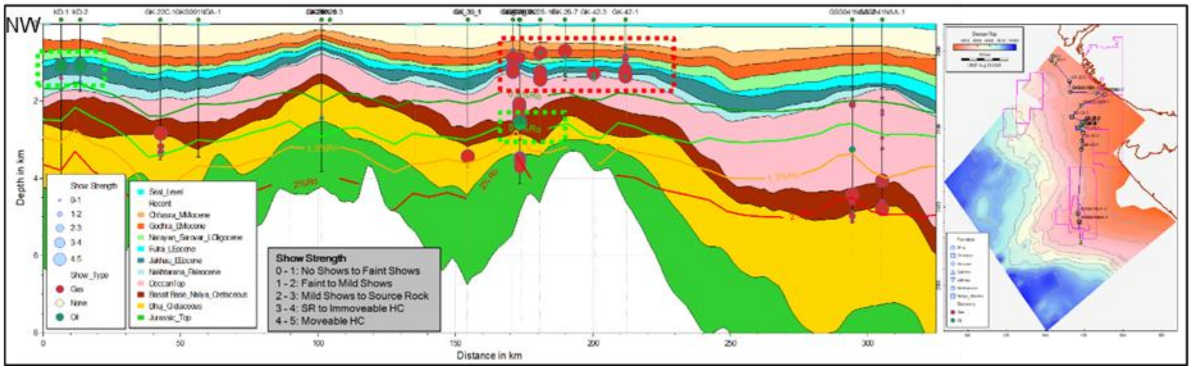

Figure 4. *N-S geological cross-section showing oil and gas shows encountered in drilled wells. In addition, the section shows Modelled Vro% levels corresponding to present day hydrocarbon maturity.*

2.1 Source Rock, Maturity and Migration

Geochemical data from drilled wells and outcrops indicate multiple source rock facies to be present in the basin at different stratigraphic levels. Mesozoic source rocks are broadly categorized into 3 zones- Jhuran, Bhuj/Kori and Naliya-Mundra shales (Figure 5a). The data suggest mixed type (II/III kerogen) source rock facies in the basin (Figure 5b shows van Krevelen diagram for four key source units). The primary source rocks, Jhuran shale has been modelled to be in mature gas window (Figure 6) in most part of offshore Kutch. Tertiary-Nakhtarana shales are oil mature towards deeper water area. In addition, we see substantial thickness in Triassic which might have good source potential especially at depocenters towards NKF. The latter could prove to be an upside for hydrocarbon generation in the basin and could open new deeper plays especially towards onland Kutch basin.

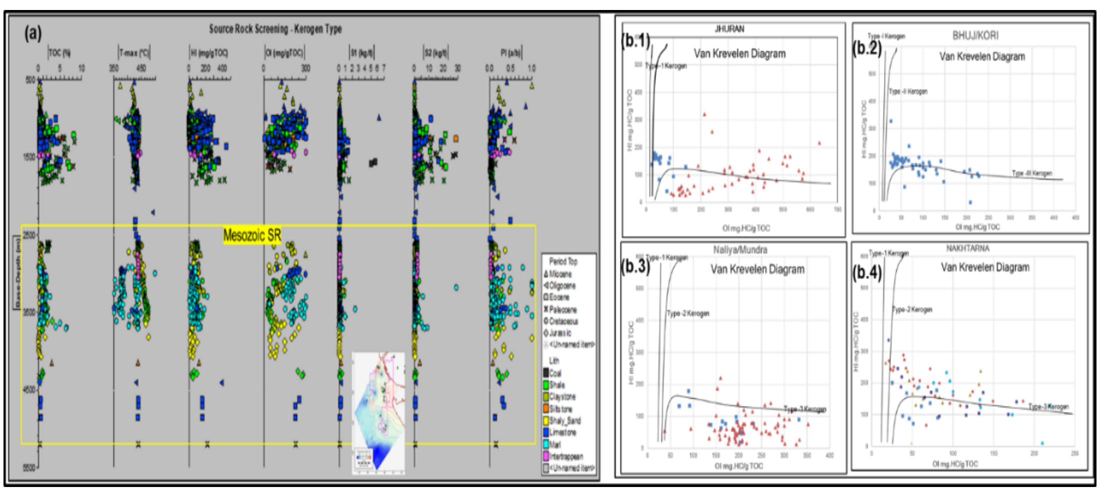

Figure 5. Source rock characterization*; (a) Depth vs, pyrolysis data indicating Mesozoic has moderate to good source rock quality, especially, Jurassic and Later part of Cretaceous shales (b) Van Krevelen diagram for kerogen affinity (b.1) Jurassic-Jhuran Shale (b.2) Cetaceous- Bhuj shale (b.3) Naliya shale (b.4) Paleocene- Nakhtarana shale*

Hydrocarbon discoveries at multiple stratigraphic levels in Tertiary indicate vertical migration through faults from deeper Mesozoic kitchens. The shallower accumulations may be primary migration but more likely this is due to remigration from deeper trap breach during compressional tectonic phase (Figure 6). Oil API distribution in discovery zones indicate early matured oil is migrated to shallower reservoirs.

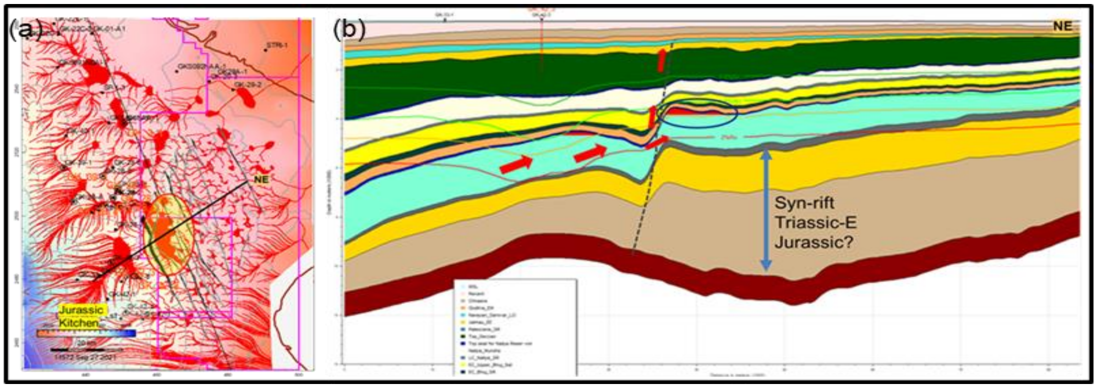

Figure 6. Hydrocarbon Maturation and Migration Model *(a) Jurassic gas kitchen fetch area showing migration route/spider map; (b) a NE-SW dip section shows lateral migration and possible vertical migration through faults to shallower reservoirs. Under-burden proposed Syn-rift Triassic-E Jurassic clastic could have additional upside for source/reservoir.*

2.2 Reservoir Understanding

Kutch basin formed as a failed rift and is of Late Triassic-Early Jurassic age. There is evidence of Triassic conglomerate beds in onland Kutch; which is believed to be thickening towards NKF- a half graben depocenter- for early continental sediments.

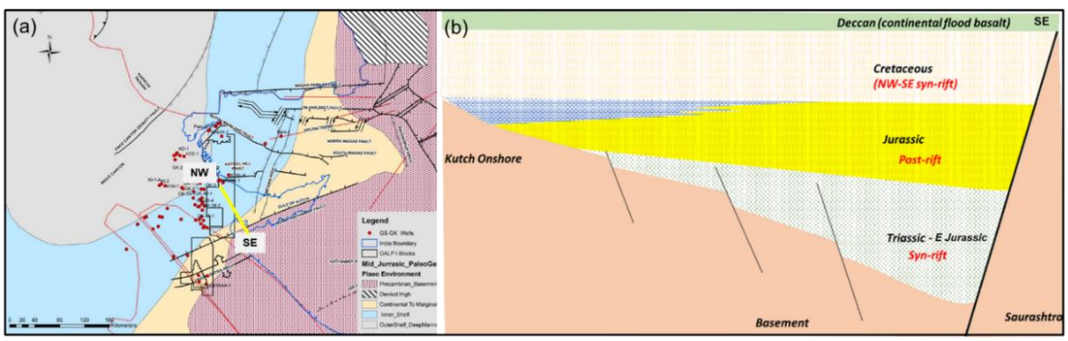

Figure 7. Triassic and Jurassic Reservoir Understanding *(a) Mid Jurassic Paleogeography - towards southern basin bounding fault (NKF); clastic facies grades into carbonate towards Jurassic shelf region and shale in deeper water toward NW direction; (b) NE-SW geological cross section at U Cretaceous age, showing Triassic-E. Jurassic synrift fill and post rift Jurassic carbonate*

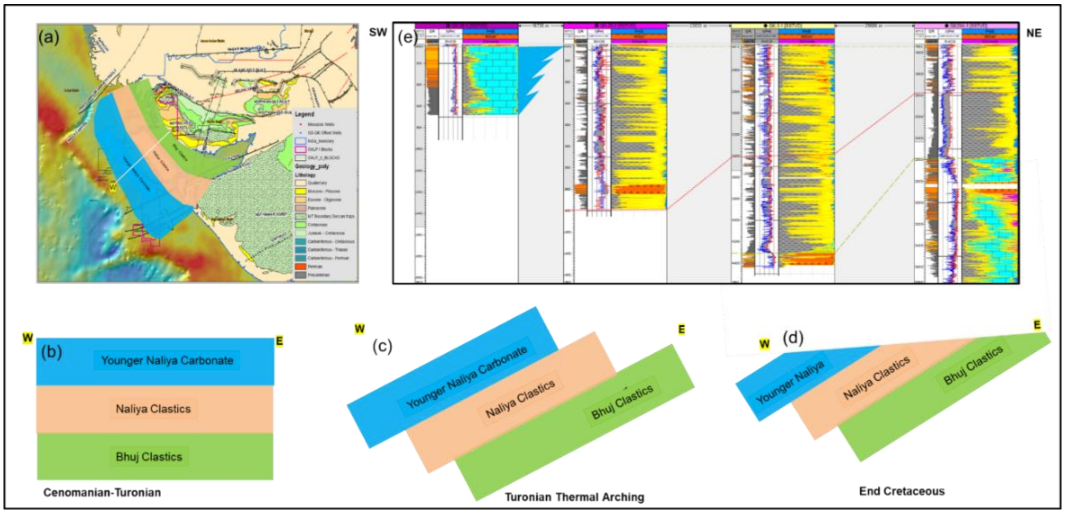

Figure 8. Cretaceous Reservoir Understanding: *(a) Cretaceous lateral facies distribution in Kutch offshore; (b) Deposition phase (c) Thermal arching (d) Hiatus phase and Deccan flood basalt (e) NE-SW (Cretaceous depositional dip) well correlation complements lateral facies variation.*

2.3 Seal

Deccan Basalt provides the ultimate seal for sub-basalt traps; in addition, intraformational shales within Mesozoic provide top and lateral seal for Bhuj and Jurassic reservoirs.

2.4 Sedimentation vs Structural Evolution Understanding

There are multiple untested sub-basalt plays in Kutch offshore region. Three-way synrift plays are the key targets as they could hold significant hydrocarbon volumes. Figure 9 shows sedimentation vs structural configuration for Mesozoic structural play which can be broadly divided into- 1. extensional phase (Jurassic to Paleocene) and 2. compression phase- post Miocene. Figure 9 shows stepwise sedimentation vs structural understanding in the area of study. Understanding of hydrocarbon trap filling history vs structural evolution is key to de-risking of the sub-basalt structural plays.

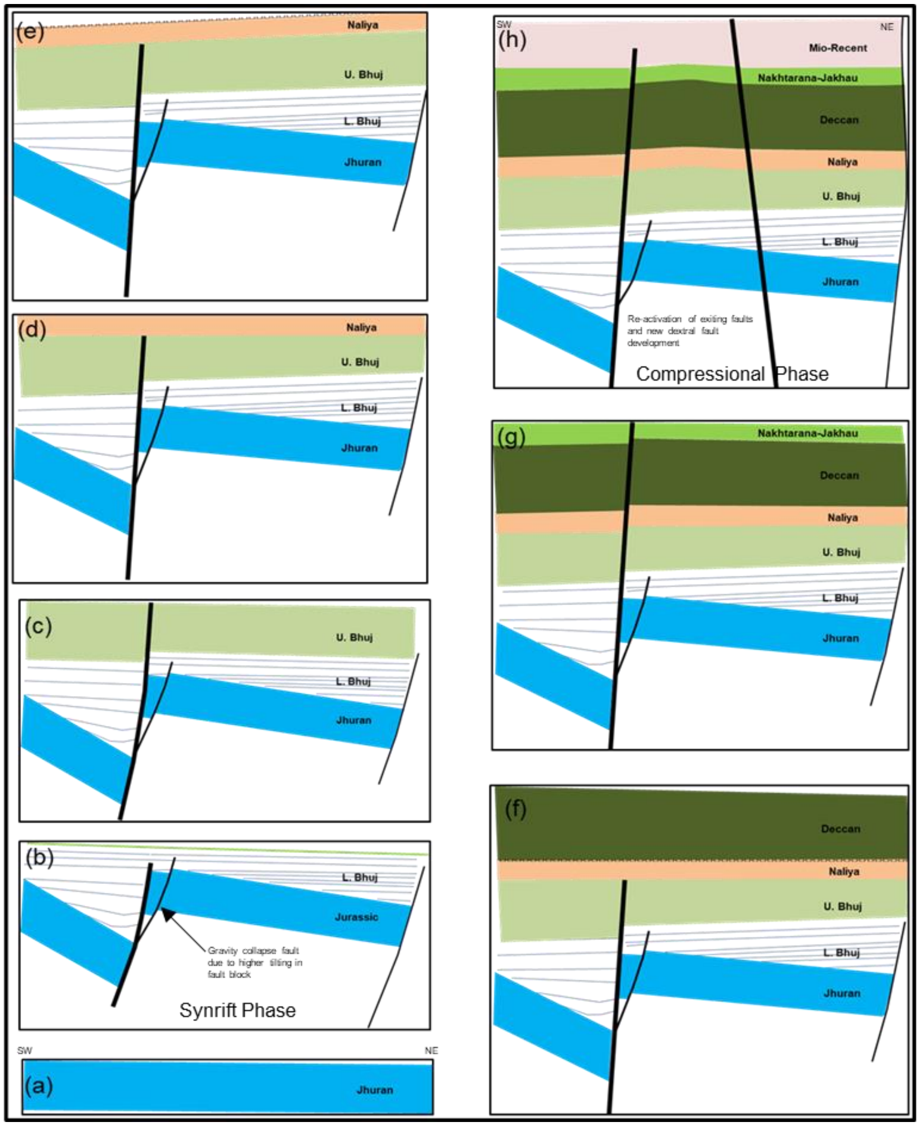

***Figure 9. Sedimentation vs Structural evolution**- (a) Jurassic deposition (b) synrift fluvio-deltaic fill of Lower Bhuj, (c) & (d) Post rift fill- some faults are expected to be active (e) Thermal uplift due to Reunion hotspot-hiatus period, which caused Cretaceous deposit erosion during Late Cretaceous- Erosion is expected to be more toward mainland topographic higher part (f) Deccan continental flood basalt, (g) Seychelles-India separation- last phase of extensional trap formation time, (h) Post Miocene compressional tectonics due to Himalayan orogeny*

3. Key Subsurface Risk

Due to post-Miocene continued compression, the favorably orientated faults have been reactivated; especially, NW-SE trending faults show dextral slip movement (Figure 10). Which are key subsurface risk and de-risking such faults are critical for successful exploration.

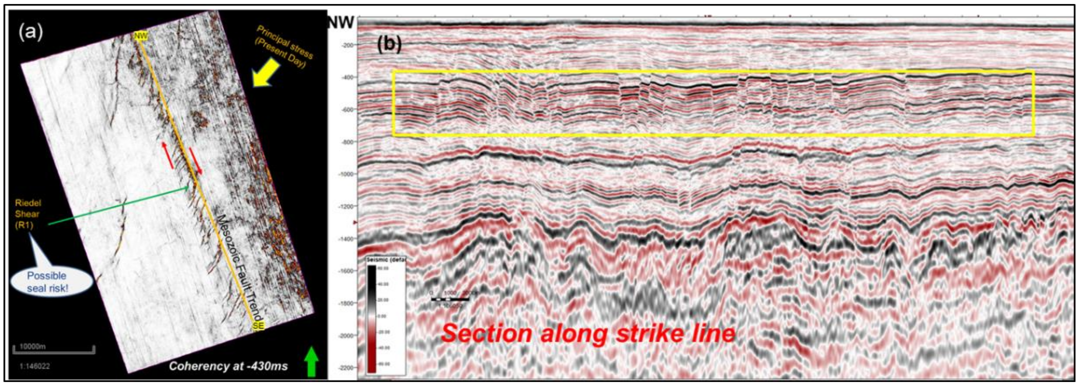

Figure 10. Critical sub-surface risk *(a) Coherency attribute showing reactivation of Mesozoic faults- dextral-slip fault and associated Riedel shear (R1), which are critical risk for hydrocarbon prospectivity, (b) seismic line along strike-slip fault shows shallow fault zone.*

4. Summary and Discussion

As per DGH estimates, Kutch basin holds around 5Bboe hydrocarbon (year 2005 estimate). Out of which only around 5% has been discovered till date. Kutch basin has active and proven petroleum system; good quality multiple Mesozoic source rocks are mature in potential kitchen areas and hydrocarbon has migrated to both Mesozoic and Tertiary reservoirs. There is good understanding on the structure formation vs expulsion in the basin; however, latest Himalayan orogeny has modified most of the structural traps. As present, major structural elements/faults are dominated by strike slip movement. De-risking fault vs hydrocarbon preservation is key to success. In addition, good quality sub-basalt imaging with integration of other geophysical data such as Gravity-Magnetic, low frequency velocity survey could help to mature/de-risk the prospects further. The area has relatively fewer sub-basalt well penetrations; more drilling will add value to understand full basin potential. Efficient drilling through basalt, especially with higher ROP and lesser bit trips also considered a key success factor for overall project execution. Joint offshore and onshore infrastructure development agreement among operators could speed up hydrocarbon exploitation from the basin.

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