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Structure and Tectonics of Deep-Water Kutch-Saurashtra area, Western India.

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Abstract

The Kutch-Saurashtra deep water area is a frontier for hydrocarbon exploration. This area is having a bathymetry range of 400m - 3000m and is located to the west of present day shelf break off Gujarat State of Western India. To the north lies the Indus region of Pakistan. Geologically, the area forms the northern extension of the Laxmi basin, which is situated to the east of Laxmi ridge which in turn separates the Laxmi basin from the Arabian basin. The ENE-WSW trending Saurashtra arch divides the area into two distinct geological entities viz., the northern Kutch and southern Saurashtra deepwater areas. The northern Kutch basin is contiguous with the south Indus region of Pakistan.

The study of recently acquired 2-D seismic data along with the geological data of deepwater and shelf has indicated that the age of the sediments in KutchSaurashtra Deepwater area may range from Mesozoic to Recent. These sediments are of considerable thickness, with basement lying at depths of more than 6000 meters.

The aim of the paper is to bring out, for the first time, the basic structure and tectonics of this area which may ultimately help to work out the possible petroleum system for this, otherwise frontier area. To begin with, structural / tectonic interpretation and modeling has been attempted to understand the genesis, time and process of different structural elements within the basin. This has led to identification of a number of distinct structural elements in the area viz., - 1] Saurashtra Arch 2] Girnar fracture zone 3] Dwarka Fault 4] Somnath hills (several clustered carbonate highs) 5] Kutch low 6] Chorwad low and 7] the present day continental slope. The initiation of these structural elements has been correlated with the three major tectonic events occurred during Late Cretaceous to Paleocene, Middle Eocene and Middle Miocene. All these are significant for geological evolution of this frontier area in their own way.

The immediate challenge in this deep water basin is to establish a working Petroleum System in general and source - kitchen areas in particular.

Introduction

The Kutch-Saurashtra deepwater area has a bathymetry range of 400m - 3000m and is located to the west of the present day shelf break, off Gujarat state of Western India (Figure:1). To the north of this area lies the Indus region of Pakistan. The ENE-WSW trending Saurashtra arch separates the area into two distinct geological entities viz., the northern Kutch and southern Saurashtra deepwater areas. The northern Kutch basin is contiguous with the south Indus region of Pakistan. The study of recent and earlier 2D seismic along with geological data acquired by ONGC and the well data of adjacent shelf has brought out the age of the sediments could range from Mesozoic to Recent. These sediments are of considerable thickness with basement occurring at more than 6000 m depth. Isopach maps indicate that clastic input for the Mesozoic to Lower Miocene is from the east while the Middle Miocene to present day clastics have been brought from the north by the Indus River from the Himalayan collision, which forms a large deep fan. The basin is characterized by several distinct structural elements. The aim of the paper is to discuss the structural elements of this area, their evolution in a broad framework.

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Broad Geological Frame

The Kutch-Saurashtra offshore basin forms the northern most part of the westrn continental margin of India which is classified as a passive margin. The Kutch-Saurashtra deepwater area is situated towards the northern part of Laxmi basin, northeast of the Laxmi ridge (Figure:1). The Laxmi ridge separates the Laxmi basin (Bhattacharya et. al., 1994) from the Arabian basin which is underlain by oceanic crust. To the west of the area lies the Owen fracture zone, and further northwards lies the Murray ridge, a prolongation of the Owen fracture zone.

A significant uplift of the Murray ridge commenced after Early Miocene, which has induced the southern movement of Indus sedimentation (Malod, J A. et al, 1997). The continental shelf of western India, made of prograding sediments, is generally wide (100-200 km) and the continental slope is smooth.

Tectonic Evolution

To understand this deep-water area, it is necessary to know the events that led to its formation. In the general framework of the Gondwana break-up, slow, dextral transtentional rifting along the line of contact between Madagascar and India had started by 118 Ma (Early Cretaceous). Extension of the pre-existing crust in the rift zone and the infilling of the rift with sediment led to creation of a thick but not truly continental crust over a period of 20 -40 Ma. This led to creation of a large area of extended "pericontinental crust" which contains remnants of stretched continental crust from the rift zone and also the products of crust creation at a ridge. The proximity of large continental areas indicates the availability of copious sediment supply (Reeves Colin and Leven Jim, 2001). Several geoscientists (Bhattacharya et. al., 1994, Malod J.A, et. al., 1997) have postulated the existence of oceanic spreading between Laxmi ridge and Kutch-Saurashtra deep-water area (Figure: 2).

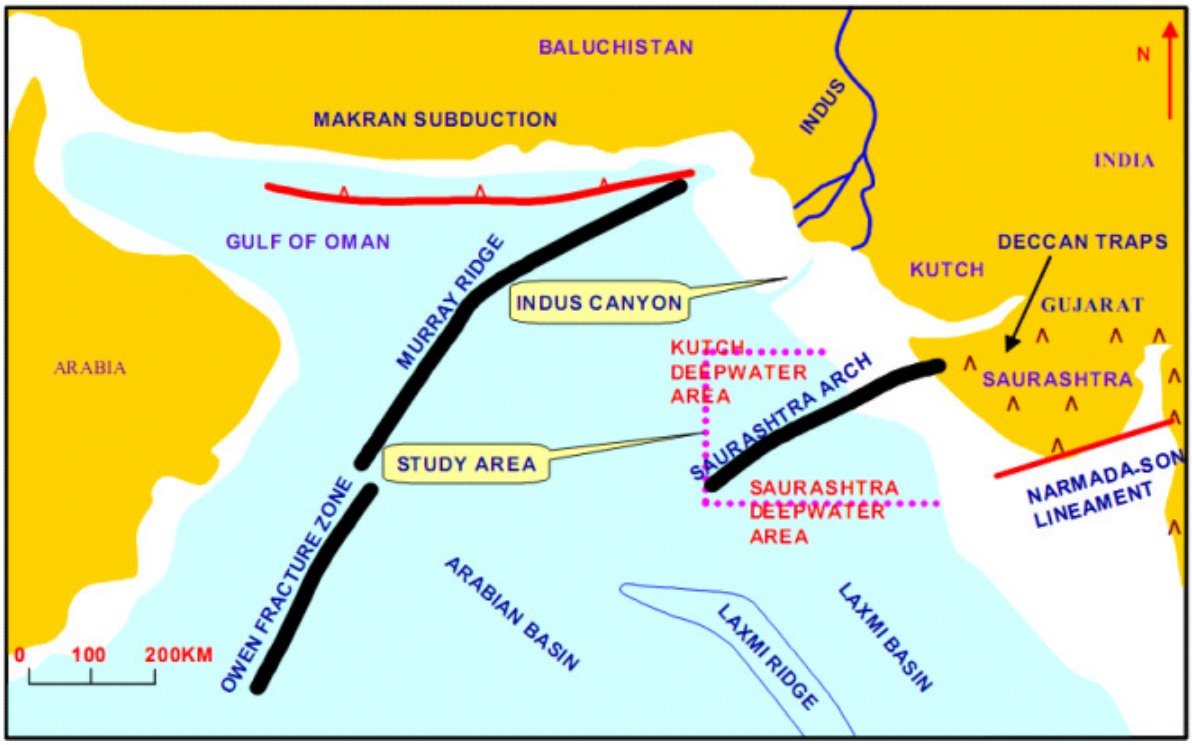

Figure-1: Location of the study area and regional framework (Modified after Malod, J.A. et.al., 1997). The present day continental areas are shown by brown. The area beyond shelf which corresponds to approximately 200m bathymetry contour is shown by light blue. The study area is shown by pink dotted lines.

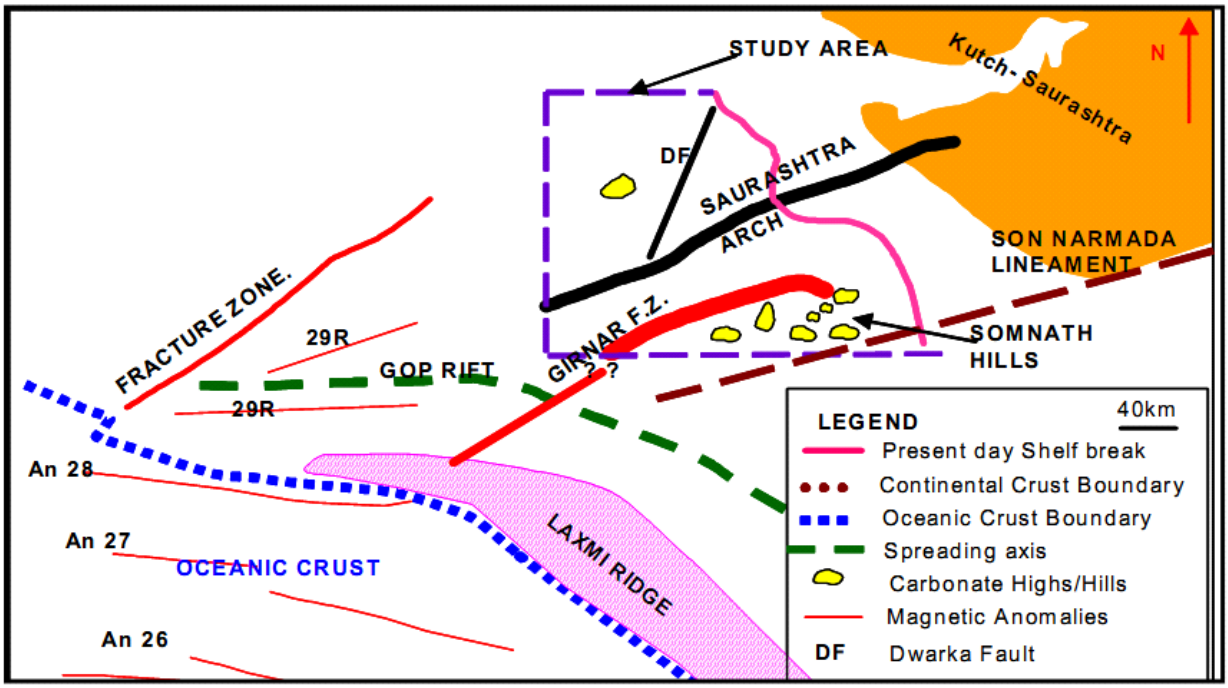

Figure:2: Showing probable extinct spreading axis in the vicinity of the Kutch-Saurashtra deep water area (Modified after Malod et al 1997).The structural elements of Kutch-Saurashtra deep water area have been placed alongwith Malod's geodynamic sketch.

Based on the magnetic anomaly studies, Malod et al favored the hypothesis of oceanic spreading between Laxmi ridge and India, at the Gop rift. The Gop rift is situated immediate to the southwest of the Saurashtra deep waters. The chronologies of events postulated are: - 1) Post -chron 32-29 R (73 Ma to 65 Ma) spreading between Seychelles-Laxmi ridge and India. 2) Emplacement of the Deccan Traps at chron 29 R that covered the stretched continental crust as well as the newly formed oceanic crust. 3) End of spreading between Laxmi Ridge and India at anomaly 29 (66 Ma). 4) Ridge jump at chron 28 (64 Ma) to south west of Laxmi ridge and 5) Further spreading in the Arabian basin, separating the Seychelles from the Laxmi ridge and India (Figure: 2).

Major structural elements of Kutch -Saurashtra Deep Water Area

The Kutch Saurashtra deep-water area has a large aerial extent (> 60,000 sq. km). The detailed study of 15,000 LKM of 2D seismic data has brought out the morphology and origin of the major structural elements present (Figure: 3). These structural elements include: - 1. Saurashtra Arch 2. Dwarka Fault 3. Girnar Fracture Zone 4. Somnath Hills (several clustered carbonate highs) 5. Kutch Low 6. Chorwad Low 7. Continental Slope.

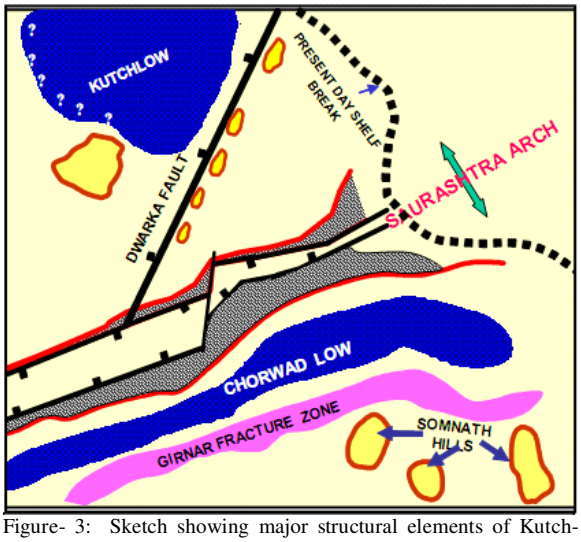

Figure- 3: Sketch showing major structural elements of Kutch-Saurashtra deep water area.

1. **Saurashtra Arch:** - The Saurashtra Arch is the most important and conspicuous positive structural feature trending ENE-WSW and is seen plunging from the shelf, across the slope to the deep-sea area (Figure: 3). The arch is seen to be having a length of around 250-km and width of around 60 km in the deep water area. Huge amount of intrusion of volcanic material had taken place along an already existing ENE-WSW Precambrian weak zone to form a linear zone of broad uplift in form of a volcanic ridge with a flat top. This event been envisaged to have happened contemporaneous to the Deccan Trap episode during Late Cretaceous to Early Paleocene. The crestal part of the arch, in the deepwater area, is marked by a striking presence of graben and horst complex all along its axis (Figures: 3 & 4). This kind of faulting is not seen in the adjacent shelfal part. The graben-horst complex presumably has formed due to crestal collapse of the attenuated crust due to thermal cooling and simultaneous rifting due to north –south extension caused by India's northerly movement after its separation from Seychelles. The rifting/faulting continued till Middle Eocene. The southern limb of the Saurashtra Arch witnessed tilting at a dramatic scale which caused it to rotate at high angle. The cause of this massive scale tilting coincides either to the Lower Miocene Murray ridge uplift event or it is isochronous with the most violent Middle Miocene Himalayan collision event of India with Eurasia. This has caused the southern limb of the Arch steeper and also more often in the central graben complex, the southern binding fault is steeper and has larger throws than the northern binding fault (Figure: 5). Thus, the low axis within the graben complex remains towards the south.

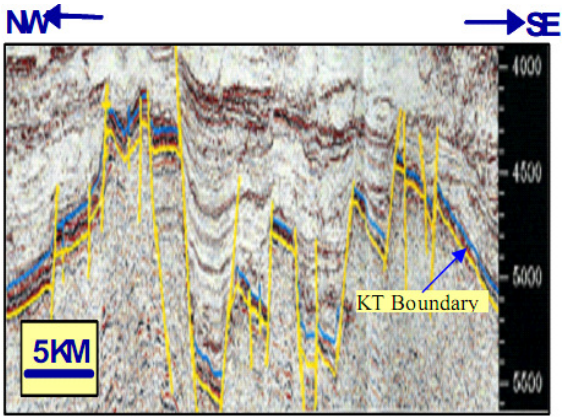

Figure-4: Seismic line across Saurashtra arch depicting the striking presence of horst and graben complex on crest of the arch in the deepwater area. The horst and graben complex is present all along the axis of the arch.

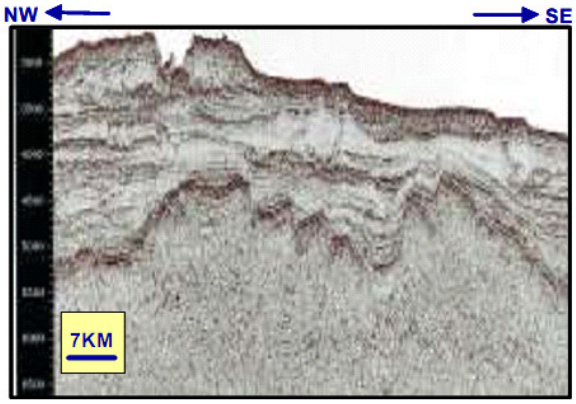

Figure-5: Seismic section across the Saurashtra arch in the central part of the study area. It is observed that the arch has steeper limb on the southern side. In general, the low axis within the graben complex remains towards the south.

The elevation of the arch and the fault intensity become gentler towards the west (Figure: 6). From the study of the seismic data it is observed that the

episodic movement of the Saurashtra arch has resulted in triggering of slope fans/debris flows in the vicinity of the continental slope (Figure: 7). This arch has also affected distribution of Indus fan sediments in the area causing marked thickness variation of Indus sediments across the Arch.

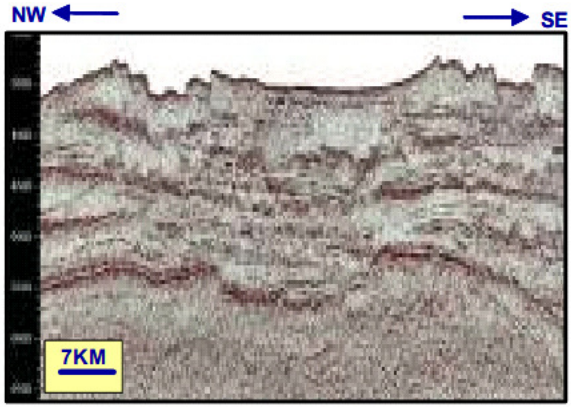

Figure-6: Seismic section across the Saurashtra arch in the western most part of the study area. The elevation of the arch and the fault intensity become gentler towards the west.

2. **Dwarka Fault: -** The Dwarka fault is a major linear tectonic feature trending NNE-SSW towards the north of the Saurashtra Arch (Figure: 3). The Dwarka fault is having a length of around 190-km. It is a normal fault with down thrown to the west and is basement controlled. The up- thrown block of the fault is characterized by presence of a number of carbonate buildups all along the fault trend (Figure: 8). The study of the seismic data indicates that this fault was active from Paleocene time. Subsidence along the fault resulted in cessation of carbonate deposition activity on the downthrown western side, while favorable condition lead to formation of a chain of carbonate buildups all along the crestal part of the upthrown eastern block. The continued subsidence of the entire deepwater basin along the hinge resulted in complete cessation of carbonate depositional activity towards the end of Middle Eocene. The southern end of the fault terminates at the Saurashtra arch.

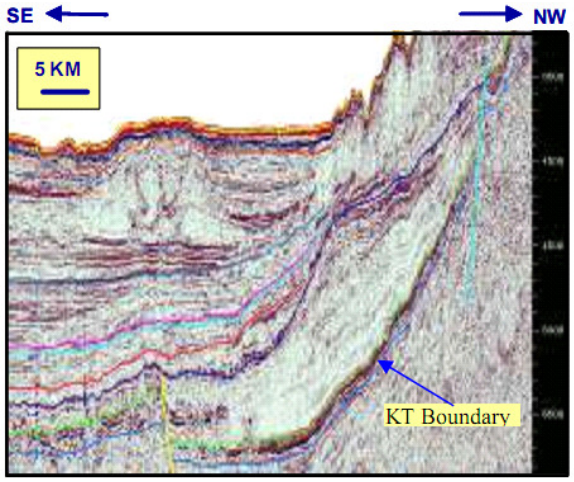

Figure-7.Seismic section depicting gravity driven slope deposits resulted due to episodic movement of the Saurashtra arch.

3. Girnar Fracture Zone (GFZ): - The Girnar fracture zone has been mapped by Malod et al as a possible strike slip zone in the area north of the Laxmi ridge which is seen extending eastward in the Saurashtra deep water area (Figure: 2). South of the Saurashtra Arch this is the most prominent linear feature trending ENE-WSW and having a width of around 20-30 km. During the Deccan Trap activity volcanic rocks have erupted all along the fracture forming a chain of basaltic hills. This facilitated carbonate growth activity along the Girnar fracture zone over the highs till at least Middle Eocene times (Figure: 9).

4. **Somnath Hills**: - A number of clustered carbonate highs are located to the south of Girnar fracture zone. (Figure:3). These carbonate highs look like buried subsurface hills in the seismic sections. The substratum of the carbonate buildups is obviously volcanic in origin related to the Deccan trap activity. Some of these carbonate highs protrude above the mud line (Figure: 10). These carbonate highs mark the junction between two major tectonic features viz., ENE-WSW trending Girnar Fracture Zone and NW-SE trending West Margin Basement arch (Kori Comorin ridge) south of the study area.

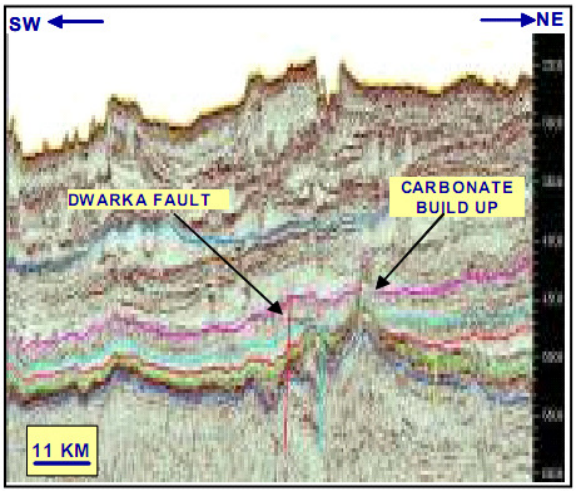

Figure-8: Seismic section across Dwarka fault. The upthrown block of the fault is characterized by a number of carbonate buildups all along the length of 190 km.

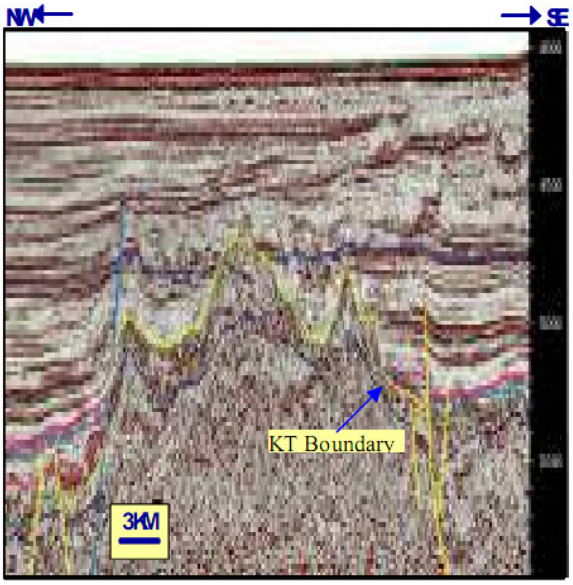

Figure-9: Seismic section across Girnar fracture zone.

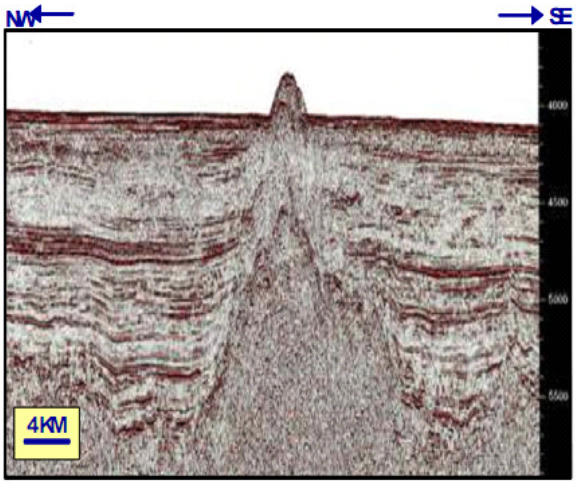

Figure-10. One of the Somnath Hills (carbonate highs) seen protruding above the mudline. These highs are situated towards the south-eastern part of the area.

5. **Kutch Low:** - A low is situated towards north of the Saurashtra arch and northwest of the Dwarka fault in the Kutch deep-water area (Figure: 3). Only a part of this low is observed on the available seismic data. It is believed that this low extends further towards north in the Pakistan territory. The basement in this low is at least 6.5 -7 seconds (twt) deep.

6. **Chorwad Low**: - Between the Saurashtra Arch and the Girnar fracture zone a ENE-WSW trending low has been mapped which has been named as the Chorwad low (Figure: 3). This low is a linear feature extending parallel to saurashtra arch in its south. The basement in this low is at least 6.5 seconds (twt) deep.

7. **The Continental Slope**: - The present day continental slope bordering the deepwater regime to the east (Figure: 11), has a general NW-SE trend and is smooth. An offset in its trend is observed to the west at the Saurashtra Arch (Figure: 3). The change in the trend of the shelf edge reflects tectonic movements associated with the formation of this arch.

Age of Tectonics and Nature of sedimentary cover

The study has led to the understanding of the evolution of these prominent structural elements. The events that have led to their initiation can be related to the following three major tectonic episodes

1) Late Cretaceous to Paleocene faulting associated with the rifting of western Indian margin was followed by emplacement of Deccan Trap volcanism. This event has initiated formation of the Girnar fracture zone, Dwarka fault, Somnath hills and upliftment of the Saurashtra arch and subsequent faulting along its central axis.
2) Middle Eocene tectonic episode, corresponding to the first collision of India and Eurasia, resulted in rapid subsidence along the hinge line marking the advent of present deep water basin as a separate entity. This led to the cessation of Carbonate build up activity in the entire area as it subsided below the photic zone.
3) Middle Miocene tectonic episode in all probability related to the last and most violent collision between India and Tibet, led to the huge influx of Indus sediments in the area.

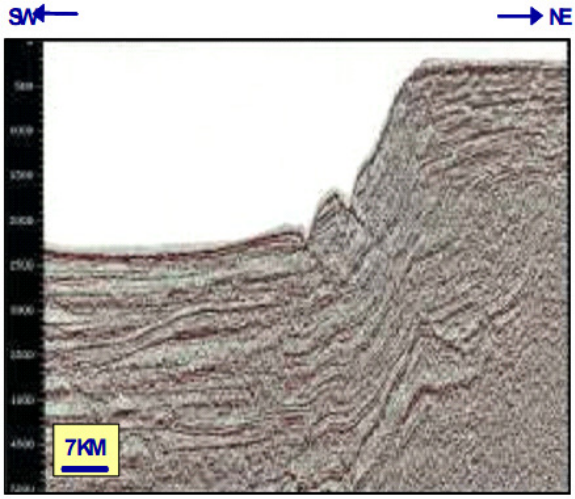

Figure-11: Seismic section depicting the present day continental slope.

The Deccan Traps represent the K-T boundary and thus divide the stratigraphic succession in two: the older Mesozoic succession and the younger Tertiary. Below the trap seismic events corresponding to Mesozoic age are observed in some seismic sections (Figure: 12). The correlation of seismic markers from the shelf to the deep indicates that the Middle Eocene- Paleocene sequence continues to the deep and consists of limestone sequences. From Eocene to Middle Miocene time the basin remained more or less akin to starved basin till at least Middle Miocene times, after which Indus sediment started filling the basin and subsequently covered the highs. On the seismic sections the highs comprised of carbonate and volcanic base are very clearly manifested by their sharp contrast in the attributes. The isopach maps of different sequences have brought out that during the lower part of Tertiary period the provenance of these clastics was from Indian part of the continent in the east, while post Lower Miocene sequences indicate a northerly clastic input by the Indus fan.

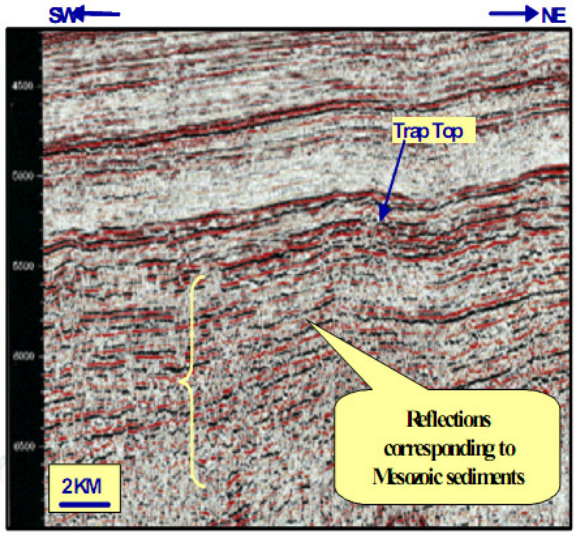

Figure 12: Seismic section showing reflections corresponding to Mesozoic sediments.

Challenges for Hydrocarbon exploration

The deep-water Kutch- Saurashtra basin is a huge area where a petroleum system is yet to be established. Geological situation for presence of both structural and

stratigraphic entrapments exist at the carbonate highs of the Dwarka fault, Somnath hills, the Saurashtra Arch and also within the Indus –Channel Levee complex itself. The immediate challenge probably lies in establishing kitchen areas for Tertiary charging within the adjacent south Indus region of Pakistan and to understand the Mesozoic geology by induction of new technologies to image below the basalt cover at the KT boundary.

Conclusions

The Kutch-Saurashtra deep-water area situated towards the northern part of Laxmi basin, contains several distinct varied structural elements viz., Saurashtra Arch, Girnar fracture zone, Dwarka Fault, Somnath hills (several clustered carbonate highs), Kutch low, Chorwad low and the present day continental slope. In this paper the evolution of this deep-water basin and the geneses of these structural elements have been brought out for the first time. The origin of these structural elements has been related to three major tectonic events of Late Cretaceous- Paleocene, Middle Eocene and Middle Miocene. Even though the area is marked by the presence of a host of hydrocarbon entrapment situations because of the existence of these varied types of structural elements, the establishment of a working petroleum system remains elusive. The immediate challenge is in terms of establishing potential Kitchen areas and understanding Mesozoic Geology.

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