Structure and Evolution of Saurashtra Arch in Kutch-Saurashtra Deepwater Area, Western India.

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Summary

The western offshore of India has been divided into five peri-cratonic basins viz., Kutch offshore, Saurashtra offshore, Bombay offshore, Konkan offshore and Kerala offshore basins from north to south. These basins extend beyond the shelf into the deepwaters and are separated from each other by east-west trending positive basement features viz., Saurashtra Arch, Son-Narmada Lineament, Vengurla Arch and Tellicherry Arch respectively. These features have had a crucial role in the evolution of these basins. Out of these basement features, the Saurashtra Arch is most prominent because of its size and tectonic intensity. It separates the northern Kutch basin from the southern Saurashtra basin and extends from the land across the shelf plunging into the deepwater realm.

The Kutch-Saurashtra deepwater is a frontier area for hydrocarbon exploration. This region is having a bathymetry range of 400m to 3000m and is located to the west of present day shelf break, off the coast of Gujarat State, Western India. To the north of this area lies the Indus region of Pakistan. Geologically, the area forms the northern part of the Laxmi basin, which is situated east of Laxmi ridge and separates it from the Arabian basin.

The application of structural/tectonic interpretation and modeling of recently acquired regional 2D seismic data across the Saurashtra Arch has been attempted to understand its origin in the deepwaters for the first time. The Arch has been envisaged to have undergone three stages of evolution viz., 1] Late Cretaceous Volcanic Ridge stage, 2] Early Paleocene crestal collapse and rifting stage and 3] Lower to Middle Miocene tilting stage. In deepwater, the Saurashtra Arch is more than 250 KM long and around 60 Km wide and is characterized by fascinating text book style horst and graben architecture. The Volcanic origin of the Saurashtra arch is supported by innumerable evidences of volcanicity in terms of dykes, sills and hydrothermal vents. The Arch has also played an important role in controlling the Indus fan sedimentation in Kutch and Saurashtra basins.

Introduction

Kutch offshore, Saurashtra offshore, Bombay offshore, Konkan offshore and Kerala offshore basins are sedimentary basins located on the north-south trending western continental shelf of India (Figure:1). These basins continue further into deep-waters beyond the shelf-slope break. These pericratonic basins, which initiated as intracratonic rifts at different times are separated from each other by East-West trending basement features. These features from north to south are the Saurashtra Arch, Son Narmada Lineament, Vengurla Arch and Tellicherry Arch (Figure:1).

Out of these east-west basement features, the Saurashtra Arch is the most conspicuous because of its size and tectonic intensity. The Saurashtra Arch separates the northern Kutch basin from the southern Saurashtra basin as two distinct geological entities (Figure: 1). The Arch which has been described on the shelf by many earlier workers as a broad anticlinal feature is seen to be plunging from the continental hinge into the deepwater area and continues further west for a considerable distance. The deepwater

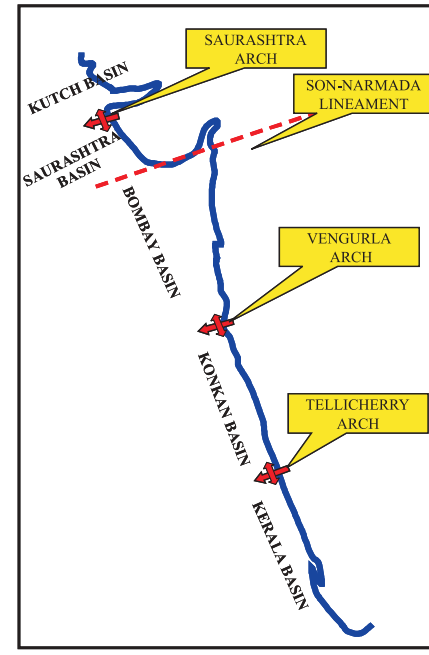

Fig. 1: Distribution of West coast offshore basins of India. The East – West trending Saurashtra Arch is a basement feature which separates the Kutch basin from Saurashtra Basin.

Kutch-Saurashtra area has a bathymetry range of 400m to 3000m and is located to the west of the present day shelf break, off the coast of Gujarat state, Western India. To the north of this area lies the Indus region of Pakistan.

The study of recently acquired 2D seismic and well data of ONGC in this frontier area of exploration has been attempted to bring out the structure and evolution of the Saurashtra Arch in deepwaters for the first time.

Regional Frame

The Kutch-Saurashtra deep-water area is situated towards the northern part of Laxmi basin (Figure: 2). It is located northeast of the Laxmi ridge which separates the Laxmi basin (Bhattacharya et. al., 1994) from the Arabian basin. To the west lies the Owen fracture zone, and further northwards lies the Murray ridge. The Indus canyon which lies to the north of the area is the only canyon that cuts the western continental margin. The other important structural elements in the vicinity of the Arch are the NE-SW trending Dwarka Fault, ENE-WSW trending Girnar fracture zone and Chorwad low, the Kutch low and a cluster of isolated volcanic hills called the Somnath hills (Figure: 3 and 4).

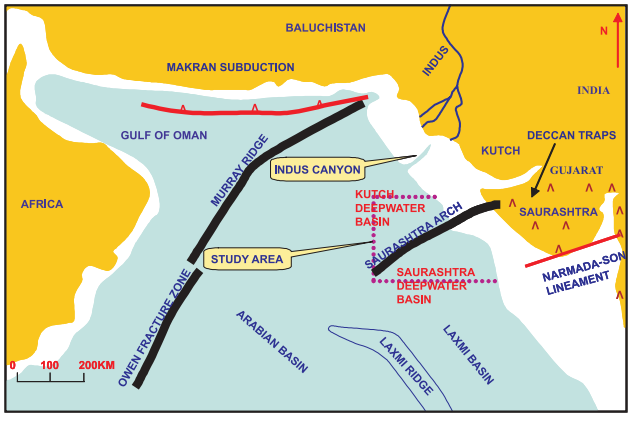

Fig.2 : Location of the study area and regional framework (Modified after Malod, J.A. et.al., 1997). The present day continental areas are shown by brown. The area beyond shelf which corresponds to approximately 200m bathymetry contour is shown by light blue. The study area is shown by pink dotted lines.

Initiation of the Laxmi Basin

To understand the evolution of Saurashtra Arch it is important to understand the events which have led to the evolution of this part of Western Continental Margin of India. 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 188

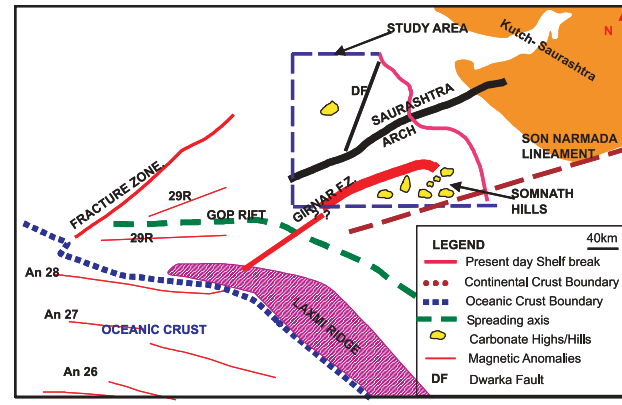

Fig.3: Showing probable extinct spreading axis in the vicinity of the Kutch-Saurashtra deep water area (Modified after Malod et al 1997).The structural elements of Kutch-Saurashtra deep water area have been placed along with Malod's geodynamic sketch.

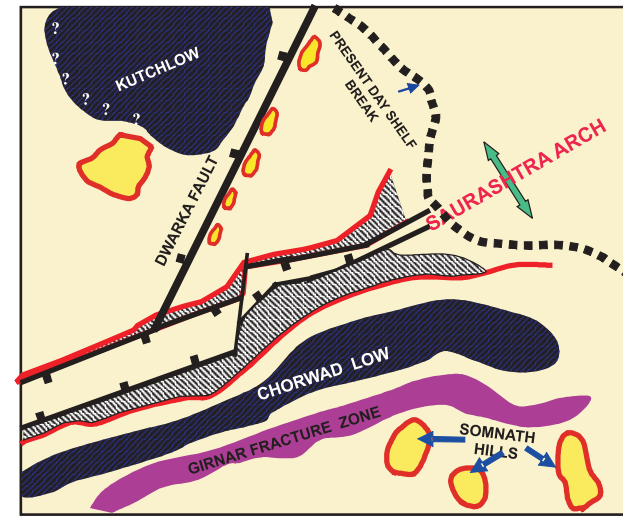

Fig.4: Sketch showing major structural elements of Kutch Saurashtra deep water area.

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 Figure-4: Sketch showing major structural elements of Kutch Saurashtra deep water area. 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 deepwater area (Figure: 3). Based on the magnetic anomaly studies, Malod et al, 1997, favored the hypothesis of oceanic spreading between Laxmi ridge and

India, at the Gop rift. The Gop rift is situated immediate southwest of Saurashtra Arch. 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: 3).

Extension of Saurashtra Arch in deepwaters

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: 4). In deepwater area the arch is seen to be having a length of around 250-km and width of around 60 km. The Arch is an area of broad uplift on a regional scale resultant of basement upheaval which seems to have been formed contemporaneous to the Deccan trap activity. The crestal part of the arch is marked by a striking presence of text book type graben and horst complex all along its axis (Figures: 5 & 6). This kind of faulting is not seen in the adjacent shelfal part, where it is manifested as a simple anticline.

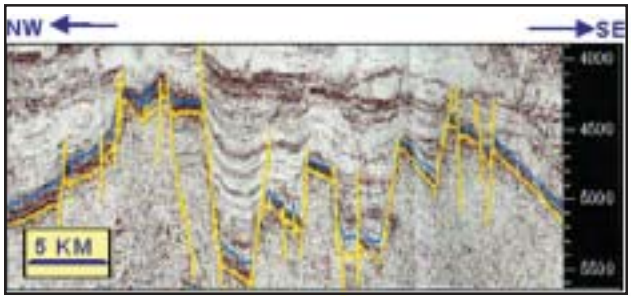

Fig.5: Seismic line across Saurashtra arch depicting the striking presence of horst and graben complex on crest of the arch in the deepwater area. The horst and graben complex is present all along the axis of the arch.

It is observed that the arch has steeper limb on the southern side. In general, in the central graben complex, the southern binding fault has steeper and larger throws than the northern binding fault (Figure: 6). Thus, the low axis within the graben complex remains towards the south. The elevation of the arch and the fault intensity becomes gentler towards the west (Figure: 7). On the seismic sections the limbs of the Arch comprise of volcanic base which is very clearly manifested by their sharp contrast in the attributes.

The present day shelf bordering the deepwater

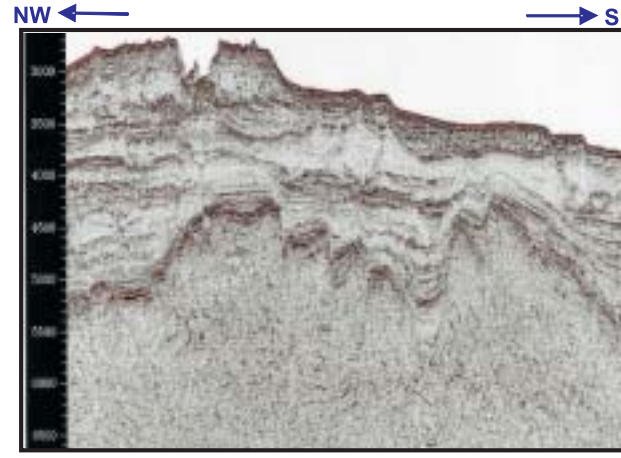

Fig.6: Seismic section across the Saurashtra arch in the central part of the study area. It is observed that the arch has steeper limb on the southern side. In general, the low axis within the graben complex remains towards the south.

regime to the east has a general NW-SE trend and is smooth. An offset in its trend is observed at the Saurashtra Arch. The change in the trend of the shelf edge reflects tectonic movements associated with the formation of this arch (Figure: 4).

Evolution of the Saurashtra Arch

The study of regional seismic and geological data has indicated that there is evidence of enormous volcanic activity in the region during the Cretaceous –Tertiary transition. During this period Deccan Trap basalt volcanism erupted near the developing plate boundary. The area is endowed with ridges, numerous large to small intrusive bodies (Figure:7), isolated large volcanic plateaus and

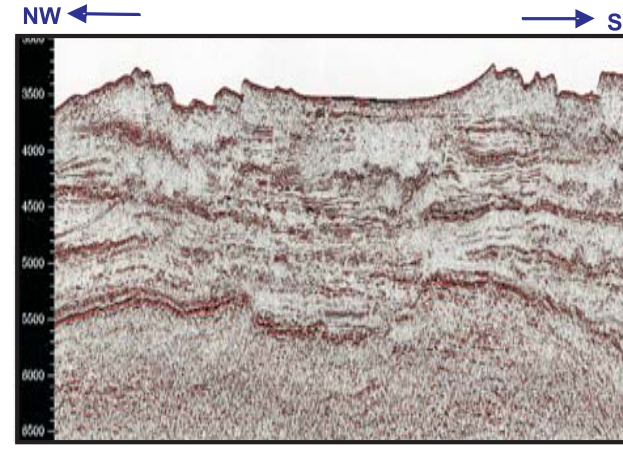

Fig.7: Seismic section across the Saurashtra arch in the western most part of the study area. The elevation of the arch and the fault intensity become gentler towards the west.

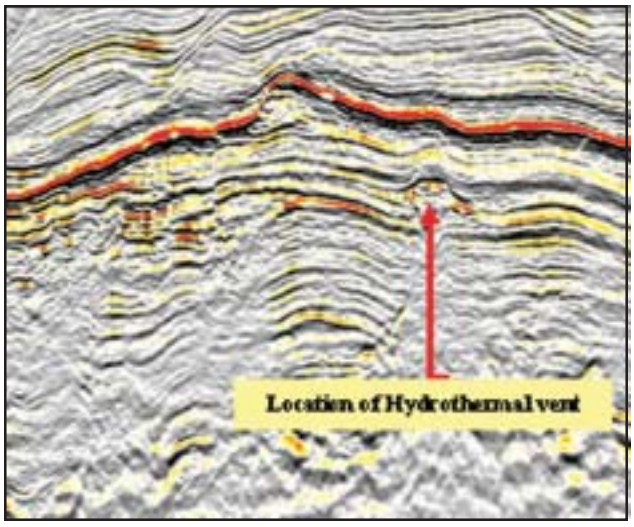

Fig.8. Seismic section showing example of hydrothermal vent near Saurashtra Arch

indications of hydrothermal vents (Figure:8). Geological data from one of the drilled wells have indicated the age of the volcanics to be equivalent of Deccan traps. The present study has led the authors to postulate the origin of Saurashtra Arch in the deepwaters in three stages:-

STAGE –I: Late Cretaceous Volcanic stage: 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 between Late Cretaceous to Early Paleocene. The ridge narrows and dies towards the west (away from the continent).

STAGE-II: Early Paleocene collapse and rifting: The already attenuated crust at the Saurashtra Arch experienced crestal collapse 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 has led to the development of horst-graben complex (Figures: 5, 6 and 7). The uplifted horst blocks witnessed carbonate growth activity at least till end of Middle Eocene, while grabens remained starved and received pelagic sediments from the Indian side. The period also witnessed gradual subsidence of the Kutch-Saurashtra basin. By the end of Middle Eocene the Arch had subsided below the photic zone which completely arrested the carbonate sedimentation activity. Subsequently the area witnessed starved conditions till Lower part of Miocene.

STAGE-III- Lower to Middle Miocene tilting stage: 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. Post Lower Miocene Murray Ridge uplift witnessed the major sediment input from of Indus fan (Malod, J A. et al, 1997) and minor input continued by smaller rivers from the Indian side. It has been seen on the seismic data that the successive younger sequences of Mio-Pliocene to Recent onlap on the southern limb of the arch as the basin subsided episodically (Figure:9).

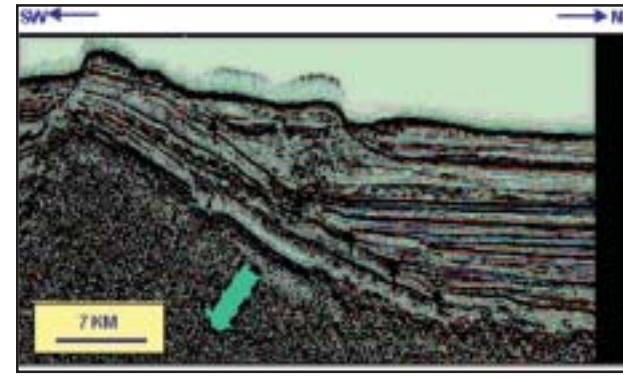

Fig.9: Seismic section depicting the eastern limb of Saurashtra Arch which has tilted (shown by green arrow) during the Early or Middle Miocene. The younger packages are seen to onlap onto the limb progressively as the basin subsided (shown by black arrows).

Effect of Saurashtra Arch on Indus Fan

The Saurashtra Arch has in a way affected distribution of Indus fan sediments in the area causing marked thickness variation across the Arch. After Early Miocene, the southern migration of Indus fan commenced. However, these sediments were dammed at the Saurashtra Arch which resulted in minor diversion towards west. This is clearly brought out in the isopach map of the Indus Fan sediments. The area immediately towards south and south east of the Saurashtra arch remained starved as far as earlier Indus fan activity is concerned. The area south of the arch started receiving the sediments only after overflowing the Arch.

Nature of sediments at the Arch

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, doubtful seismic events corresponding to Mesozoic age are observed (Figure: 10). 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

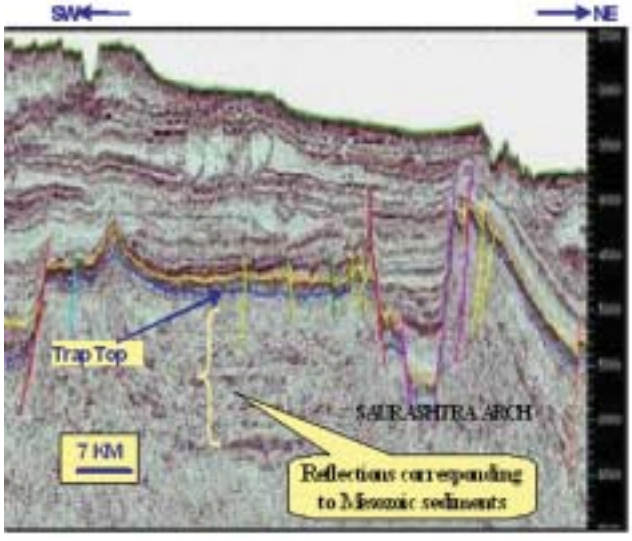

Fig.10. Seismic section across Saurashtra Arch , indicating reflections corresponding to Mesozoics.

Miocene time the basin remained more or less starved, after which Indus sediment started filling the basin (Figure: 11) and subsequently covered the highs.

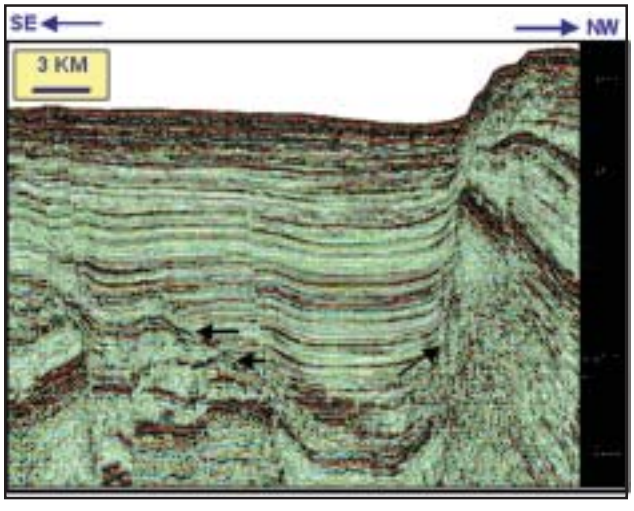

Fig.11: Seismic section clearly demonstrating the passive infill of the tectonised underlying Eocene and Palaeocene section within the horst-graben complex of the Saurashtra Arch (contact shown by black arrows).

Challenges for Hydrocarbon exploration

The deep-water Kutch- Saurashtra basin is a frontier area of exploration where a petroleum system is yet to be established. Geological situation for presence of both structural and stratigraphic entrapments exist at the Saurashtra Arch. The immediate challenge probably lies in understand the Mesozoic geology by induction of new technologies to image below the basalt cover at the KT boundary.

Conclusions

The Saurashtra Arch is an ENE-WSW trending basement feature which plunges from the shelf to the Kutch-Saurashtra deep-water area. The Kutch-Saurashtra deepwater is a frontier area for oil exploration. The Arch which divides the northern Kutch basin from the southern Saurashtra basin is characterized by text book style horst and graben complex all along its axis. The study has brought out that the Arch has gone through a three stage evolution process, viz., Late Cretaceous Volcanic stage, Early Paleocene collapse and rifting stage and Lower to Middle Miocene tilting stage. The Arch has also a major influence on the deposition of Indus fan sediments in this area. Even though the Arch is marked by the presence of a host of hydrocarbon entrapment situations, the foremost challenge is to establish working petroleum system and to understanding the Mesozoic geology by induction of new technologies to image below the basalt cover at the KT boundary.

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Views expressed in this paper are that of the author only and may not necessarily be of ONGC.

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