Online **ISSN :** 3049-3455

Mineral Metal Energy Oil Gas and Aggregate

Contents available at: *www.informaticsjournals.co.in/index.php/2MEOGA*

Is There an Intracontinental Rift Basin between the Cambay and Saurashtra Basins in Western India?

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Abstract

The Cambay Basin is a Cenozoic petroleum-rich province that is understood geologically as a failed rift arm of a four-way mega fracture system that originated close to India's present-day west coast The Gujarat Alluvium tract covers the area between Cambay Basin and Saurashtra Uplift. Based on observed geomorphic features, lineament pattern, gravity anomaly, and sparse drill data, it is interpreted that a hidden rift basin to the west of the Cambay Rift lies beneath the alluvium cover, awaiting petroleum exploration. The work could be the foundation for more precise and detailed geological and tectonic models for the area.

Keywords: *Intracontinental Rift Basin, Cambay Basin, Mesozoic, Rifting, Geomorphic features, Gravity Anomaly, Lineament Pattern, Western India, Gujarat Alluvium*

1.0 Introduction

Plate tectonics drives continental extension, which results in rifting and the creation of many of the world's passive margins and ocean basins. Continental rifts are the net expression of regional horizontal stretching, and often intracontinental rifts have splays formed to adjust to the enormous stress. They are frequently associated with similar peripheral grabens of comparable intensity or as secondary rifts. Continental rift zones form in passive response to plate extensional forces or due to a thermal anomaly in the upper mantle. Continued extension may lead to the complete separation of the two sides of the rifted zone and the formation of an ocean basin. In other cases, a rift may stop extending further after the initial separation, i.e., it may become an inactive (failed) rift. The latter is the case with the Cambay Rift and the proposed rift, and the well-explored Cambay Basin forms a conjugate Cambay Rift System. This paper written based on newly available data in the public domain on the geology of the area, and on personal observations, it attempts to evaluate and put together a plausible viewpoint on the existence of an older rift west of the hydrocarbon-rich Cambay Basin, together constituting a conjugate rift system.

2.0 Geologic Framework

Cambay Basin is an elongate, arcuate petroliferous province containing Quaternary and Tertiary sediments deposited over the Deccan Trap basin floor. Mesozoic rocks are exposed primarily in the northwest part of the study area (Figure 1).

In the subsurface, Mesozoic rocks, other than Upper Cretaceous Deccan Trap rocks, are known from drilling data only in the Kutch area and the northern parts of the Cambay Basin and the Mumbai Offshore Basin. Well data reveal that the Tertiary rocks directly overlie the Mesozoics that rest above the Precambrian Basement. The Cambay Basin is a thriving Cenozoic petroleum-rich province widely interpreted by petroleum geologists as a failed rift arm of a four-way mega fracture system that originated close to India's present-day west coast.

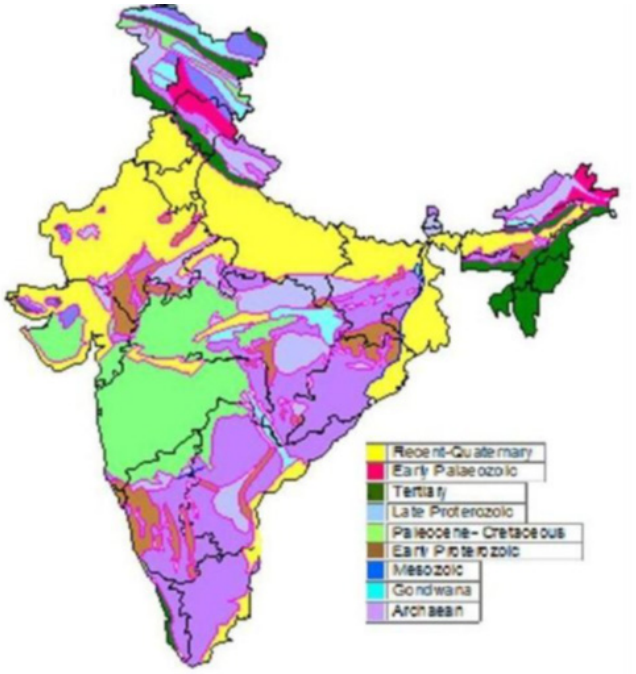


Figure 1. Distribution of exposed rocks in India[1].

This rift system is considered to have originated due to the impingement of the Reunion Mantle Plume during the Late Cretaceous on the Indian lithosphere, which was moving northwards after the breakup of Gondwanaland[2].

Critical geological and geophysical observations particularly, the recently published developments related to oil and gas exploration in Barmer Basin further north show that several geologic issues concerning the evolution of the basin require a revisit. The distribution of exposed rocks around Cambay Basin and to its west indicate Quaternary sedimentary cover (Figure 2). The alluvial tract known as Gujarat plains that cover Cambay Basin extends further to the west up to the elevated terrain of Saurashtra and further to the north, it ends up in the Little Rann of Kutch. Though the Cambay Basin is well explored, only two wells, Dhandhuka-1 and Viramgam-1 have been drilled in the area to the west of the western margin of the Cambay Basin and penetrated beneath the Deccan Trap.

3.0 Geomorphic Expression

Geomorphological anomalies aid in the unravelling of buried features in the alluvium-covered areas. The geomorphic expression of topographic depressions characterized by swamps and shallow dry lakes like Nal Sarovar, without obvious uplifted shoulders, probably reflects the subsurface structural features of the proposed rift.

Mishra's map of peninsular India that depicts the attitude of satellite lineaments reveals lineaments to be predominantly parallel to the major tectonic features which is suggestive of their tectonic origin (Figure 3). The imprints of the primordial tectonic trend keeping parallelism to Cambay Basin could be seen to the west of Cambay Basin. Lineaments continue from the Archaean basement to the region covered by the Deccan Trap volcanics. Lineaments allow the enhancement of the comprehension of structural geology, besides tectonics. Mostly they parallel subsurface faults and thus aid the unravelling of tectonic highs and lows in the alluvial-

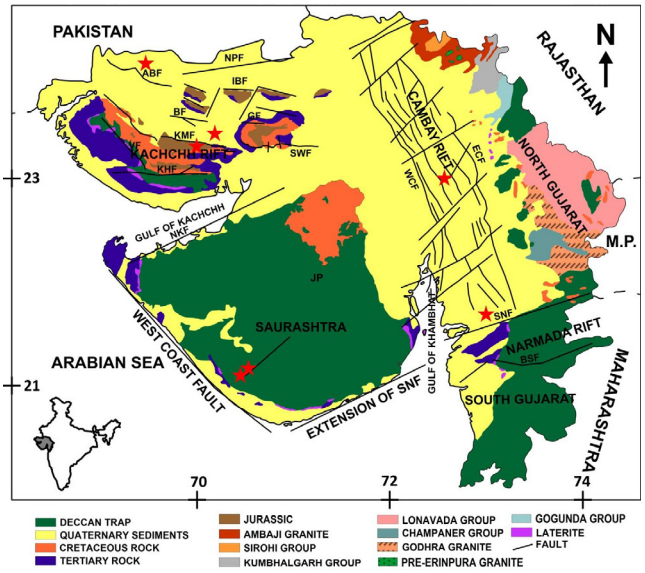


Figure 2. Geological and tectonic map of Gujarat[3].

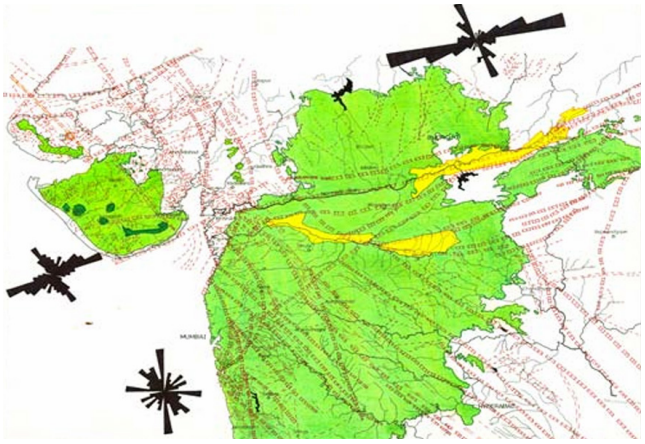


Figure 3. Lineament Map of peninsular India[4].

covered areas. Lineaments transect from the exposed Archean region and continue below the Deccan Trap volcanics in the western Indian state of Gujarat. The higher density of lineaments could be related to the margins of sedimentary basins[5]. The rift margin has been interpreted in the area west of the proposed rift from the higher density of lineaments.

The seismic activity within the Cambay Rift Basin indicates its current tectonic sensitivity. A network of faults trending NNW-SSE, NW-SE, and NE-SW influences the channel morphology in certain basin areas. The drainage systems indicate ongoing faulting[6].

The watershed map, in conjunction with the earthquake data provided by Surabhi et al. (2024), suggests that the proposed rift zone exhibits seismic activity[6]. Their map reveals a linear basin beneath the alluvial region west of the Cambay Basin's western boundary (Figure 4).

A linear arrangement of water bodies in an NW-SE alignment from the Gulf of Cambay to the Rann of Kutch characterizes the geomorphic manifestation (Figure 5). The Little Rann of Kutch, Nal Sarovar, Lothal, and the northwestern arm of the Gulf of Khambat form an elongated NW-SE trending depression which had active subsidence till the Quaternary or Recent. An arm of the sea of the Gulf of Khambat might have reached Lothal at that time and entered the low-lying area that continues to be low-lying to this day. Sedimentary succession which was deposited before the Cambay Basin rift event lies exposed in the fringe areas. This prompted the examination of the available gravity and related relevant geological data.

4.0 Geophysical Evidence from Gravity Field

Most recently in their quest for oil and gas in Barmer Basin, J. Dolson et al have published an excellent, robust three-dimensional relief map of the basement structure from well, gravity, and magnetic data of Cambay-Barmer Basins and surrounding areas (Figure 6). The significance in the context of the onshore sedimentary basins in northwestern India is displayed on a map of depth to the top basement with red depicting shallow, blue is for deep; and the colour scales are generalized to reflect the deep versus shallow depths to the top of basement derived from gravity, magnetic, and well data[7]. The depth-to-basement thickness map thus generated based on gravity and magnetic data reveals the presence of a rift

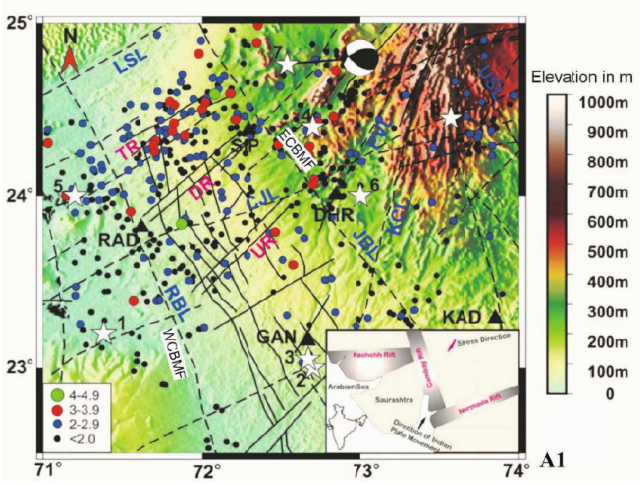


Figure 4. Watershed map along with seismicity in Cambay Basin and adjoining areas[6].



Figure 5. Satellite map of Gujarat (internet).

basin to the west of the Cambay Basin. The basin seems to extend to Radhanpur in the north in Little Rann of Kutch and merges with the Cambay Basin in the south with intervening cross faults that separate the basin into sub-basins.

This map strengthens the concept behind the interpretation based on other geoscientific data. An elongated basement low sub-parallel to the main Cambay graben is conspicuous. It could be a rift graben aligned in a NW-SE direction, about 250 km in length and 40-50 km in width that merges with the main Cambay graben in the southeast close to the Gulf of Khambat. Thus, the presence

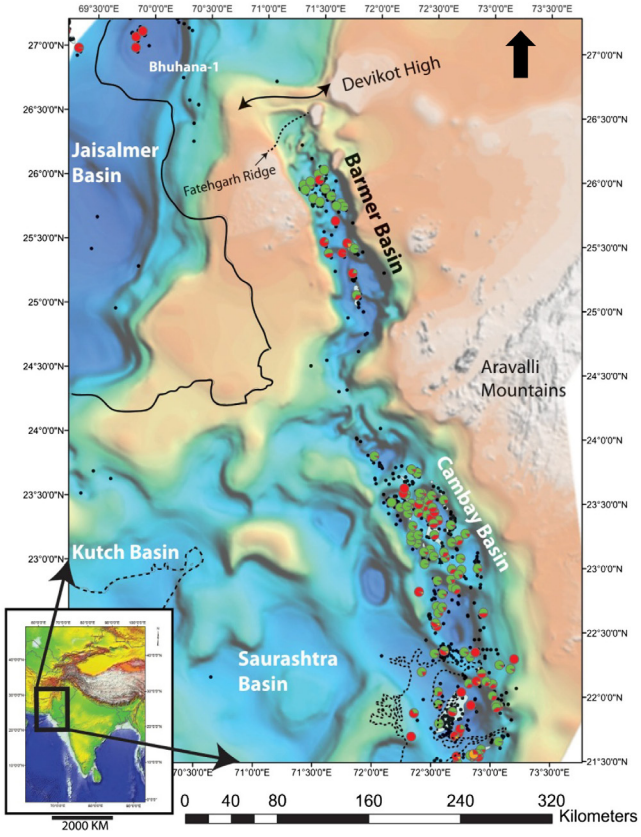


Figure 6. 3D relief map of Basement architecture from wells, gravity, and magnetics[7].

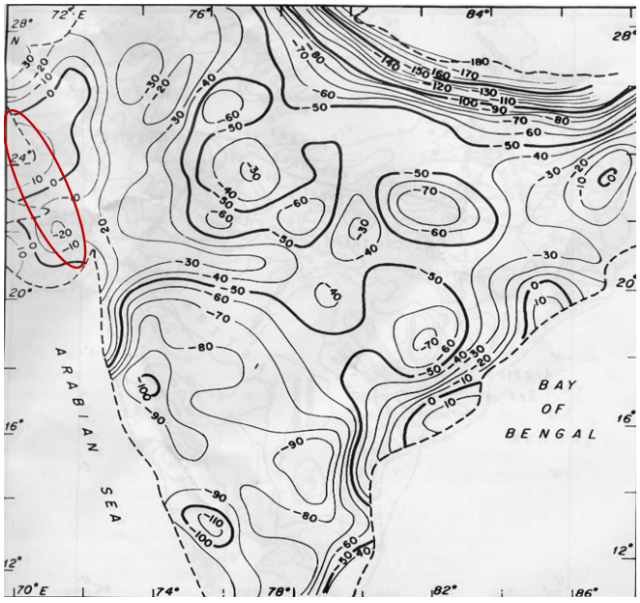


Figure 7. Derived regional gravity anomaly map of India, keeping all anomalies > 200km wavelength[9].

of a second conjugate rift graben, west of Cambay Basin is entirely a likelihood. Globally, these trans-tensional rift grabens, most often do not occur as isolated, single grabens. They are often associated with similar parallel grabens of equal intensity or as secondary rifts. Rift basins of the Central African Rift system in Sudan and the well-known rift grabens of the North Sea are good examples.

Bouguer anomalies are overly sensitive to the mass distributions and hence are influenced by the nature of underlying geological formations[8]. Geology and tectonics are responsible for the gravity field reflected by the major trends (highs and lows) on the gravity anomaly map. The gravity fields in the Aravalli and adjoining Cambay and Saurashtra areas maintain positivity consistent with a contrasting deep crustal structure and distinctive geological history (Figure 7). The causal factors that result in the higher Bouguer anomalies are a combination of both the Basement and sediment evolution in the rift system. They collectively may have made the lithosphere denser in the area, resulting in positive Bouguer anomalies.

The stand-out feature of the basin is its broadly smooth arcuate outline which is clear in the Bouguer anomaly map[2]. Cambay Basin exhibits continuous and concentric margins, barring the slight broadening, south of Narmada River. This is seen on the Bouguer anomaly map, not only in the Cambay Basin but continues westward beyond the western margin of the Cambay Basin into the Kutch-Rajasthan area. However, both its western and northern ends are unclear. The effect of the primordial Dharwarian trend on the Cambay Basin continues to the west where the conjugate rift has been proposed.

Bouguer Gravity maps of NGRI (1978) support the latest complete Bouguer map (2020) confirming the positive anomaly in the areas to the west of the Cambay Basin that borders the Saurashtra Basin. The Cambay Basin in the northwest shows higher Bouguer gravity anomaly values in comparison to the surrounding areas[10]. Similar high Bouguer gravity anomaly values persist in the area to the west between Cambay Basin and Saurashtra Uplift covered by alluvium fill. The area seems associated with rift tectonics. The existence of a rift graben, west of the Cambay Basin and east of Saurashtra Uplift could be interpreted from the gravity data and maps (Figures 8 and 9).

5.0 Hydrocarbon Prospectivity

The few wells drilled beyond the western boundary limits of the Cambay Basin revealed Mesozoic stratigraphy. However, except for a tube well that indicated inflammable gas, no hydrocarbon shows were recorded. The outcrops of Mesozoic rocks show a palaeoslope toward the southwest and sediments were laid under fluvial/deltaic to shallow marine conditions. However, after the Deccan volcanic activity, the eastern rift shoulder of the new basin acted as an embayment hindering further sedimentation into the basin. The creation of topography is an integral part of localized deformation at continental rifta (Brune et al, 2022).[13]. Cenozoic sediments would be much thinner than in the Cambay Basin in the proposed rift. Since the Deccan Trap and Intertrappean sediments are not expected to be much at the uplifted rift shoulders due to erosion for 30-40 million years, the Mesozoic sediments of the rift could be in contact with source rocks of Tertiary sediments of Cambay Basin and migration of Cenozoic oil into Mesozoics of the new basin is within the realms of plausible geological possibility. The results have not been encouraging for Mesozoic sections from a hydrocarbon point of view as of date due to the paucity of data in the area west of Cambay Basin. With this sparse drill data, it is just in an incipient stage of frontier exploration and the prospects now stay indeterminate due to lack of concerted efforts.

6.0 Postulation of Evolution

The main theme of this paper is to emphasize and discuss the existence of a second rift parallel to the Cambay Basin as a conjugate rift. However, it has been attempted to postulate the evolution of the conjugate rift system. Geologists agree that the Cambay Basin formed during the Early Cretaceous period, when India began to migrate northward following its unlocking from Gondwanaland in the Late Triassic to Early Jurassic times. The Cambay Rift System resulted from a prolonged succession of regional tectonic events. Major primordial Precambrian structural grains partly influenced the orientation and configuration of rifts. The conjugate Cambay Rift system of the Western Indian craton results from a complex interaction of the two rift segments, namely the proposed rift and the known Cambay Basin. The proposed rift dates earlier to the known Cambay Basin. It is postulated that the rifting of the West Indian craton initiated in the Late Triassic-Jurassic times created space for Mesozoic sedimentation from the Aravalli hinterland. In addition to having broader implications for the evolution of the rift basin, the resulting rift margin accommodation structures have significant effects on early sediment routing and depocentre evolution. However, after the Deccan volcanic activity, the eastern rift shoulder of the proposed rift acted as an embankment impeding further sediment input into the basin. This created a rift migration to the Cambay Basin area. Conjugate margins usually have distinct histories after separation from one another. Thus, an appreciation of the margins as separate entities post-breakup is required, and the significance of the western margin fault of Cambay Basin cannot be underestimated.

Mesozoic fluvial rocks of a pre-Palaeocene rift sequence could be present in the proposed rift. Closer to

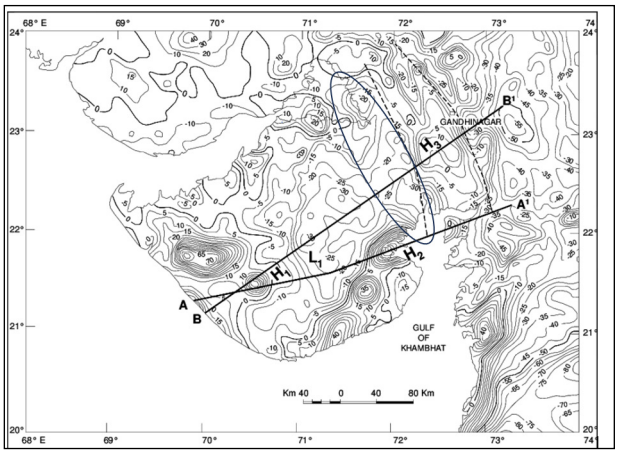


Figure 8. Bouguer anomaly map[10].

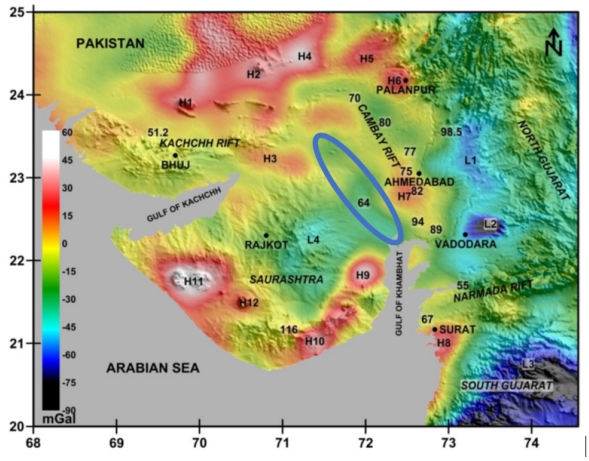


Figure 9. Complete Bouguer anomaly map[11].

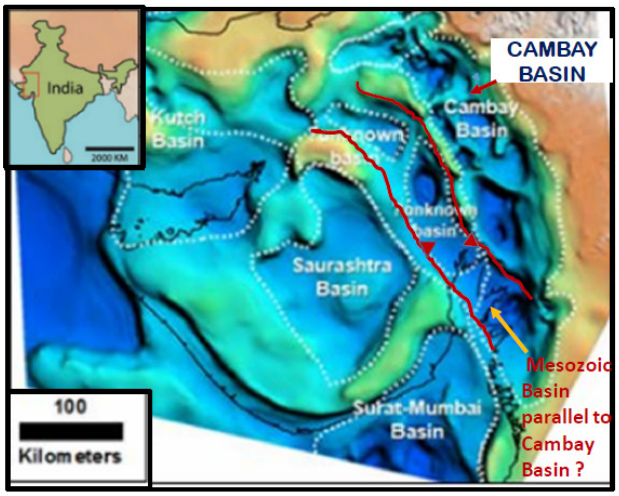


Figure 10. An unrecognized sedimentary basin to the west of Cambay Basin, India, depth to top basement map SEEBASE ™ based on J. Dolson et al., 2015[7].

the rift margins the sediments may be of an earlier Jurassic to Cretaceous rift system. Sediment deposition would be controlled by the structural geometry and fault evolution, both within the basin and along the basin margins analogous to other known rift basins elsewhere. This stratigraphically deeper Mesozoic basin stays unexplored with just two wells drilled and is a typical intracontinental failed conjugate rift, bounded by normal extensional faults that display both north-northwest–south-southeast and north-northeast–south-southwest orientations as seen from gravity and lineaments.

Continental extension along an NNW–SSE trend led to the formation of the Cambay Basin during the Mesozoic period as rift migration post the proposed rift when the eastern margin of the proposed rift acted as an embankment to arrest the flow of sediments westward. Deccan volcanism dates near the Cretaceous-Tertiary boundary and restrained early rifting by erupting thick Deccan basalts over the Cretaceous sediments, shaping the basin basement[12]. Tertiary and Quaternary sediments comprising clastics inclusive of sandstone, siltstone, claystone, and shales, then filled the basin.

The sequence of rifting in the western Indian craton can be summarised as:

- The three rift systems along the primordial Precambrian tectonic trend created the grabens.
- Rifting around the Saurashtra horst occurred from the north to south.
- In the Jurassic to Early Cretaceous period, the hypothesized arm of the older rift of the Cambay Basin with Mesozoic sedimentation was followed by the formation of the Kutch basin in the Early Jurassic.
- In the Early Cretaceous, the eastern arm of the Cambay Basin originated, and in the Late Cretaceous, the Narmada rift was formed.
- The Cambay Rift system is a conjugate rift with two arms with the eastern arm being a major Tertiary petroleum province.
- Following the Indian plate's parting from Gondwanaland in the Late Triassic to Early Jurassic, several rifting events took place at different points during the plate's northward movement.
- These rift basins are predicted to have opened gradually owing of the counter clockwise drift of the Indian craton.

A few well-thought-out regional lines covering the proposed rift area will be the key to unravelling this envisaged rift basin and understanding the geological history.

7.0 Concluding Remarks

This analysis describes how remote sensing, gravity, geomorphology, and well data sets have been integrated to evolve a plausible geological story. An elongated basement low sub-parallel to the Cambay Basin observed on the depth to basement thickness map marked unknown basin is a geological certainty (Figure 10). It will open a new avenue for petroleum exploration once an adequate quantum of seismic data becomes available. It is appropriate for petroleum companies to probe this area, understand the subsurface architecture, and prognosticate the reserves it may hold and categorize them in the basin classification documents of the country. In conclusion, the work establishes a basis for more precise and comprehensive geological and tectonic models for the area.

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