

Tectono-Sedimentary Evolution of Northern part of Cambay Basin*

Tusar Ranjan Sahoo¹ and Mainak Choudhuri²

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¹Petroleum Business (E&P), RCP, Reliance Industries Limited, India (tusar.sahoo@ril.com)

²Petroleum Business (E&P), RCP, Reliance Industries Limited, India

Abstract

The Cambay Basin is a Tertiary intra-cratonic graben in the western onshore part of India. The basin is divided into five tectonic blocks separated by major cross trends. The study area falls in the Sanchor-Patan tectonic block in the northern part of Cambay Basin. The present paper details the current understanding of tectonic evolution and sedimentation history within the study area. Many previous authors (Bhandari and Choudhary, 1975; Biswas et al., 1994; Kundu and Wani, 1992) have described the geology, tectonics, and stratigraphy of this basin in detail. Three stages of basin evolution are recognized; 1) Paleocene – Early Eocene rift stage (synrift; period of extension), 2) Middle Eocene – Early Miocene postrift stage (thermal subsidence), 3) Middle Miocene and younger stage of postrift structural inversion – period of compression. The Deccan Trap basalts erupted during the initiation of the Reunion Plume head close to KT boundary and form the basement to the overlying sediments in major part of the basin. Synrift phase in Paleocene is characterized by trap derivatives, trap conglomerate in form of alluvial fan deposits and lacustrine claystones in fault controlled half grabens. Later phase of synrift during Late Paleocene to Early Eocene is characterized by deposition of restricted marine and pro-delta shales. Postrift thermal subsidence phase is formed after synrift and is characterized by deltaic deposits and marginal marine deposits in Middle Eocene to Early Oligocene time. During Late Miocene to Recent times mainly fluvial sediments are deposited in this part of the basin.

Data and Methodology

Integration of seismic interpretation, well data, laboratory analysis results, and other geo-scientific data have been attempted to understand the tectonics, stratigraphic framework, and depositional environment of this part of the basin. Palinspastic modeling of a representative 2-D seismic line is done to study the tectonic evolution. Seismic megasequences are mapped and isopach maps are prepared to understand the sediment dispersal pattern.

Tectonic Framework

Three major Precambrian trends Dharwar (NNW-SSE), Aravali-Delhi (NE-SW), and Satpura (ENE-WSW) have strongly influenced the

overall tectonic framework of the Cambay Basin (Kundu and Wani, 1992). A simple tectonic map on top of basement is given in [Figure 1a](#) and [Figure 1b](#). The irregular shape of individual fault polygons probably indicates that some of these are composite faults that formed as smaller faults grew and joined during rifting. It raises the possibility that some faults actually may not be joined, but that fault ramps exist between the tips of the faults.

Most of the faults are NNW-SSE trending however few cross trends (almost ENE-WSW) are also observed. In the southern part of the study area most of the cross trends are associated with oblique-slip transfer faults. Transfer faults are caused by differential extension rates. Transfer zones in rifts are important because they subdivide rift basins and can strongly influence the entry of sediments into rifts and the subsequent movement of sediments within rifts. Transfer zone TZ-1 separates Tharad depression from Sanchor depression. Transfer zone TZ-2 separates the Tharad depression from Patan depression. The horst blocks in TZ-1 and TZ-2 appear to have affected Olpad and Cambay sedimentation and formed a barrier to longitudinal transport of sediments at that time. There is also ENE-WSW cross trends (TZ-3 and TZ-4) which may affect sedimentation within Patan depression.

Tectonic Evolution

The tectonic evolution of Cambay rift in the north-western part of Indian peninsula is closely related to the origin and evolution of Indian Plate (Biswas et al., 1994). Massive eruption of the Deccan Traps covering almost the whole of the Cambay Basin forms the tectonic basement over which rift sedimentation took place. The sequential restoration in [Figure 2](#) shows the tectonic evolution of a representative E-W section (AA' in [Figure 1a](#)) through the study area. However basin bounding master faults are not falling within the above representative section. At the end of Olpad Formation (Paleocene?) most of the fault systems were active during rifting and basin was in active extension phase. Sediment infill from rift shoulders continued during rift initiation and peak rift. Faults towards the basin margins (fault F2 and F6) developed early and played major role in providing maximum creation of accommodation. Subsequently other faults were developed and controlled the internal sedimentation in the basin. Synrift sedimentation continued during later part of Paleocene and Early Eocene during which Cambay Shale was deposited as late synrift sediments, overlying the Olpad Formation. Two phases of extension can be recognized due to the unconformable relation between the Cambay Shale and underlying Olpad Formation. Extension was arrested early in the eastern part as indicated by lesser accommodation there. Kadi Formation lies above it and is the part of synrift sequence. Kadi Formation top is marked by a regional unconformity which differentiates the synrift sequence from the postrift sequence. Rifting in most of the fault systems ceased towards the end of Lower Eocene. Thermal subsidence started during Mid Eocene and continued till Early Miocene. During Early Oligocene to Early Miocene, minor compressional events were noted in the Tarapur and Babaguru Formations. Major compression events, involving the basement in some parts of the study area occurred during Early-Late Miocene, during the deposition of Kand and Jhagadia Formations, which continues to the present times.

Sedimentation and Magasequences

Paleocene (Synrift Sequence: early rift and rift climax)

Olpad Formation is deposited during this period and it lies above Deccan Trap Formation. Olpad Formation is mainly composed of trap conglomerates, weathered trap, and claystone. Few siltstone bands are also observed in the upper part of this formation. Poor degree of textural and compositional maturity is indicative of proximity to provenance. This sequence is a wedge shaped synrift sequence characterized by chaotic reflection pattern, high amplitude, and dominated in the fault controlled half grabens. During the initial phase of intense rifting trap derivatives, trap conglomerates are formed as alluvial fan deposits. During later stages lacustrine claystones are deposited in the deeper axial parts of half grabens. Depositional environment is continental; alluvial fans, lakes, or probable flood plains. Isopach map of Olpad Formation showing major depositional trends and depocenters is given in [Figure 3](#). Major deposition trends run parallel to the NW-SE fault trends. Transfer zones which separate the major depressions act as a barrier to the longitudinal transport of sediments and indicate major influx of sediments from rift margins.

Paleocene –Early Eocene (Late Synrift Sequence)

Marine dark grey shales dominate the lithologic assemblage in the lower part, while deltaic succession and prodelta shales comprise the upper part of the sequence. Cambay Shale and Kadi Formation are deposited during this period. There is a remarkable episode of marine transgression during which Cambay Shale was deposited. Cambay Shale Group contains major petroleum source beds in the basin. In the study area major depocenters are observed in the southern part and thickness gradually decreases towards northern part suggesting marine transgression from south ([Figure 4](#)). Sedimentation and depositional trends are largely controlled by the NW-SE trending rift faults. Significant activity of the transfer zones separating Sanchar, Tharad, and Patan depressions are indicated by low thickness areas.

In the southern part of the study area within this period it is observed that, Lower part of the unit consists of claystone, shale, and few siltstones and deposited in shallow marine to marginal marine; overbank/swamp environment. Middle part consists of mainly shale and claystone and deposited in marine to marginal marine environment. Upper part (Kadi Formation) consists of mainly alternation claystone, sand, and sandstone and is mainly fluvio-deltaic deposits. Towards Northern part of the study area during this period Tharad Formation is deposited. It is mainly composed of nonmarine sandstone with interbeds of claystone and thin coal seams. Laboratory study (medium to coarse grained sediments, frequently fining and coarsening up sequence, palynofossil study) shows that sediments of Tharad Formation may be of lower delta plain to delta front deposits. Presence of phytoplanktons and brownish grey claystone are suggestive of periodic fluctuation of water condition.

Mid Eocene – Early Oligocene (Postrift Sequence)

This period started with a major regression where sediments of undifferentiated Kalol Formation are deposited in deltaic facies. Kalol

Formation is separated from the lower unit by a regional erosional unconformity. Kalol Formation is overlain by Tarapur Formation. Isopach map within this time interval shows that there is a differential in thickness at different depressions which may be due to differential thermal subsidence rate ([Figure 5](#)). Transfer zones controls the sediment dispersal pattern as indicated by thickness variation across it. More sediments are deposited in Sanchor and Patan depression as compared to Tharad Formation.

Kalol Formation is characterized by presence of sandstone with interbeds of claystone. Towards the upper part interbeds of coals are observed. Eastern part of the study area is sand dominated whereas towards west it is more clay rich indicating sediment influx from eastern side of the basin. Kalol contains majority of the hydrocarbon trapping reservoirs in the Cambay Basin. Fining upward sandstone sequence with carbonaceous shale, siltstones, thick coal along with abundance terrestrial elements suggest that deposition of Kalol Formation took place in upper delta plain environment.

Tarapur Formation is deposited during period of marine transgression. It is characterized by intercalation of shale, claystone, clay, and few sandstone beds. Thin sand intervals are observed in upper and middle part of this formation. In southern part of study area palynofossil study indicate deposition environment to be in shallow marine condition. In the northern part towards Tharad depression the faunal assemblage is dominated by larger benthic foraminifera. The palynotaxa are mainly represented by coastal elements along with scanty occurrence of mangrove elements. These data reveal that Tarapur Formation was deposited in marginal marine to shallow inner neritic environment.

Early Miocene to Middle Miocene (Postrift Sequence)

During this period thermal subsidence continues and entire area is covered by terrestrial sediments. Babaguru and Kand Formations are deposited during this period. Isopach map ([Figure 6](#)) indicate differential subsidence rate within this basin. During this period transfer zones also controlled the sediment dispersal pattern within the basin. Babaguru Formation is mainly arenaceous section with alternation of claystone and shale. Sandstones are sometimes coated with pyrite indicating reducing environment of deposition. Absence of fauna, paucity of flora, and the litho association suggest sedimentation in continental environment with swampy conditions developing locally. Kand Formation conformably lies above Babaguru Formation. This is clay and claystone dominated with alternation of few sand beds. Claystones are pyritic at places. This was deposited in shallow marine environment and had euxinic condition favourable for deposition of shales and pyrite.

Middle Miocene to Recent (Postrift Sequence)

Postrift structural inversion started during this period. This section is mainly arenaceous section with alternation of clay and claystone. Sands are yellow to brown in color; medium to coarse grained, sub-rounded, and fairly sorted. Clays are yellow, light brown, soft, and sticky. From the nature of lithological association this section appears to be deposited in continental environment. Clays and claystones were deposited in continental environment and mainly flood plain deposits.

Conclusion

This part of the basin developed in three phases. Synrift phase is characterized by alluvial fan and lacustrine claystone deposits in the bottom and restricted marine deposits in the upper part. During postrift thermal subsidence phase deltaic and marginal marine deposits covers the entire study area. Postrift structural inversion phase started during Middle Miocene and continues to younger stage. Differential subsidence rates are observed in postrift sequence as seen in isopach maps. Rift faults as well as cross trends control sedimentation in this part of the basin.

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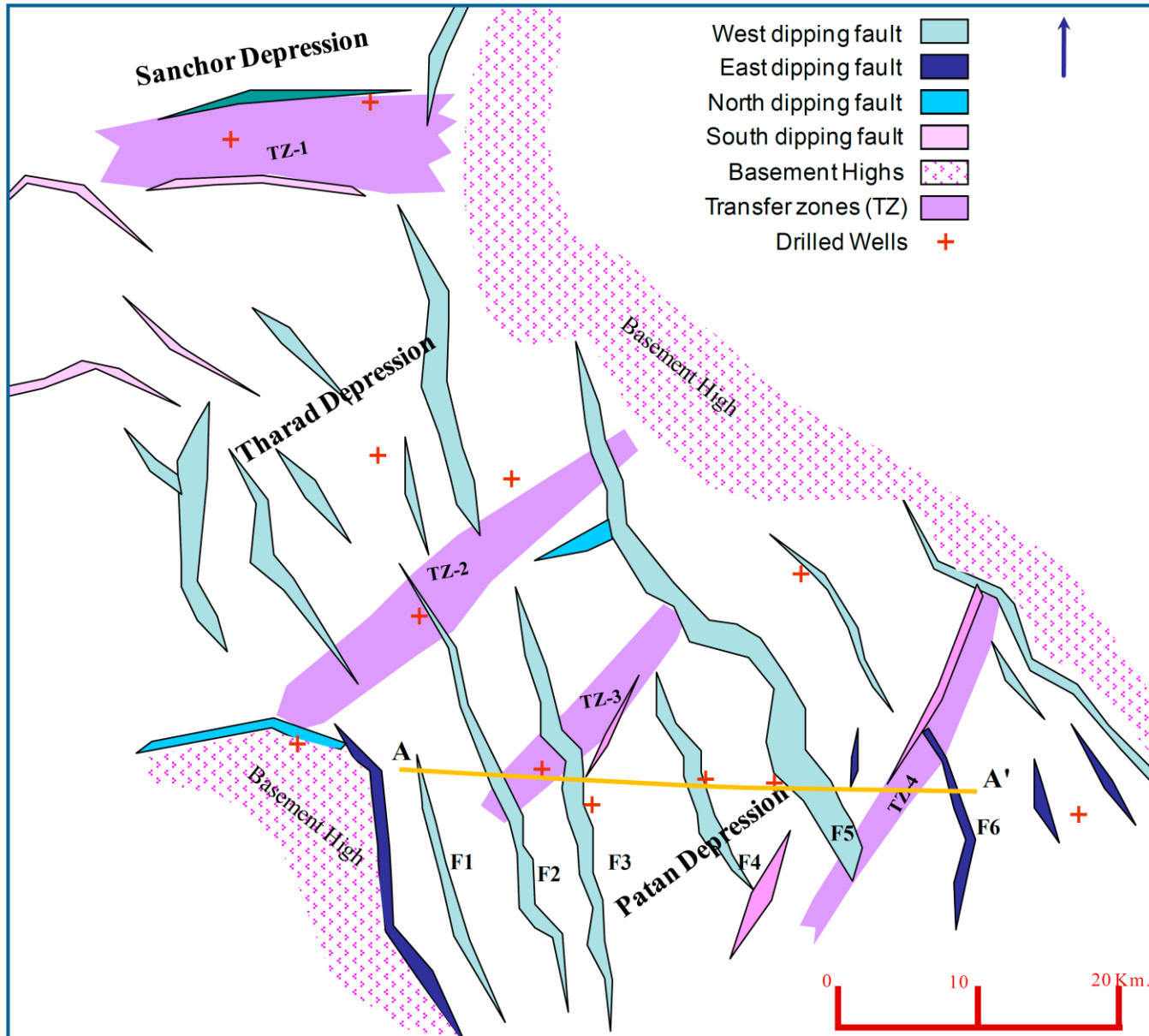


Figure 1a. Tectonic map on top of basement in the study area.

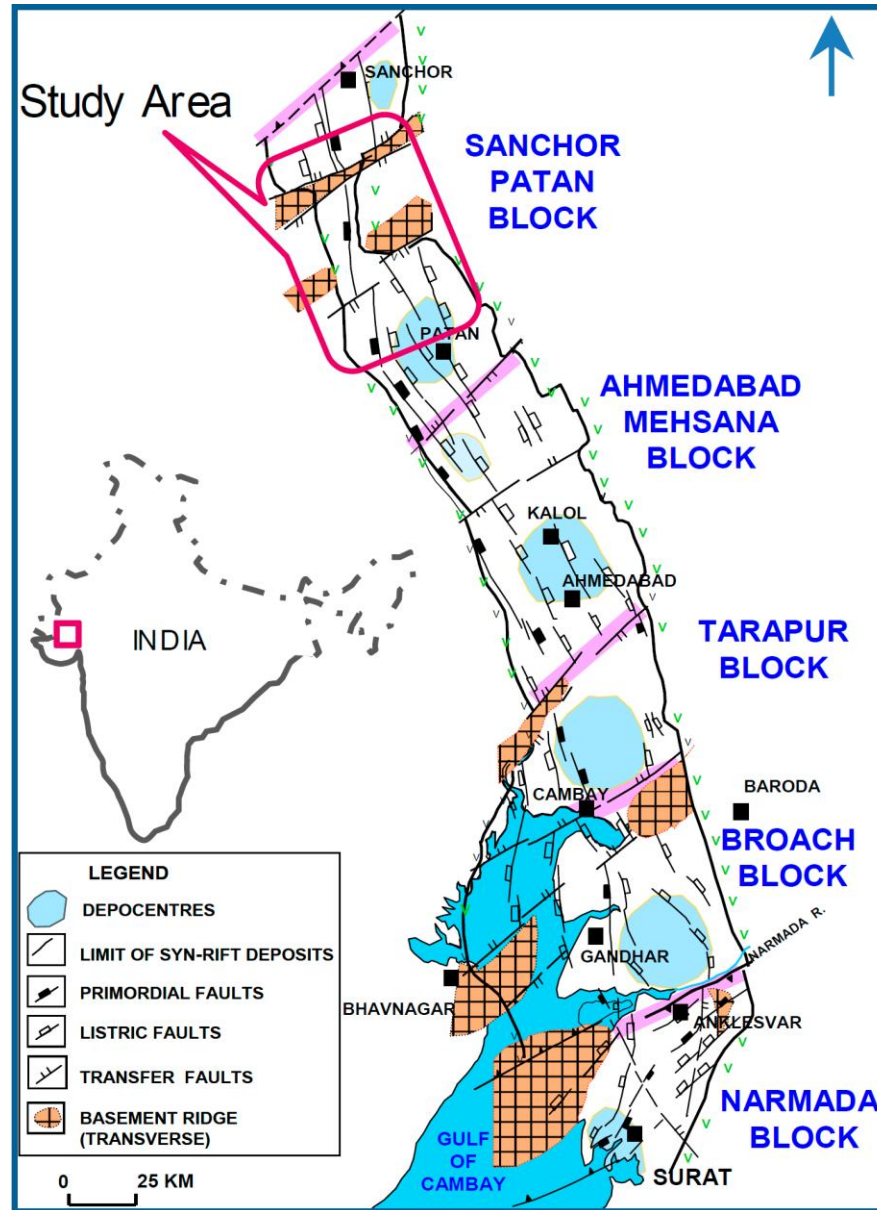


Figure 1b. Generalized tectonic map of Cambay Basin showing study area (modified from DGH Information Docket).

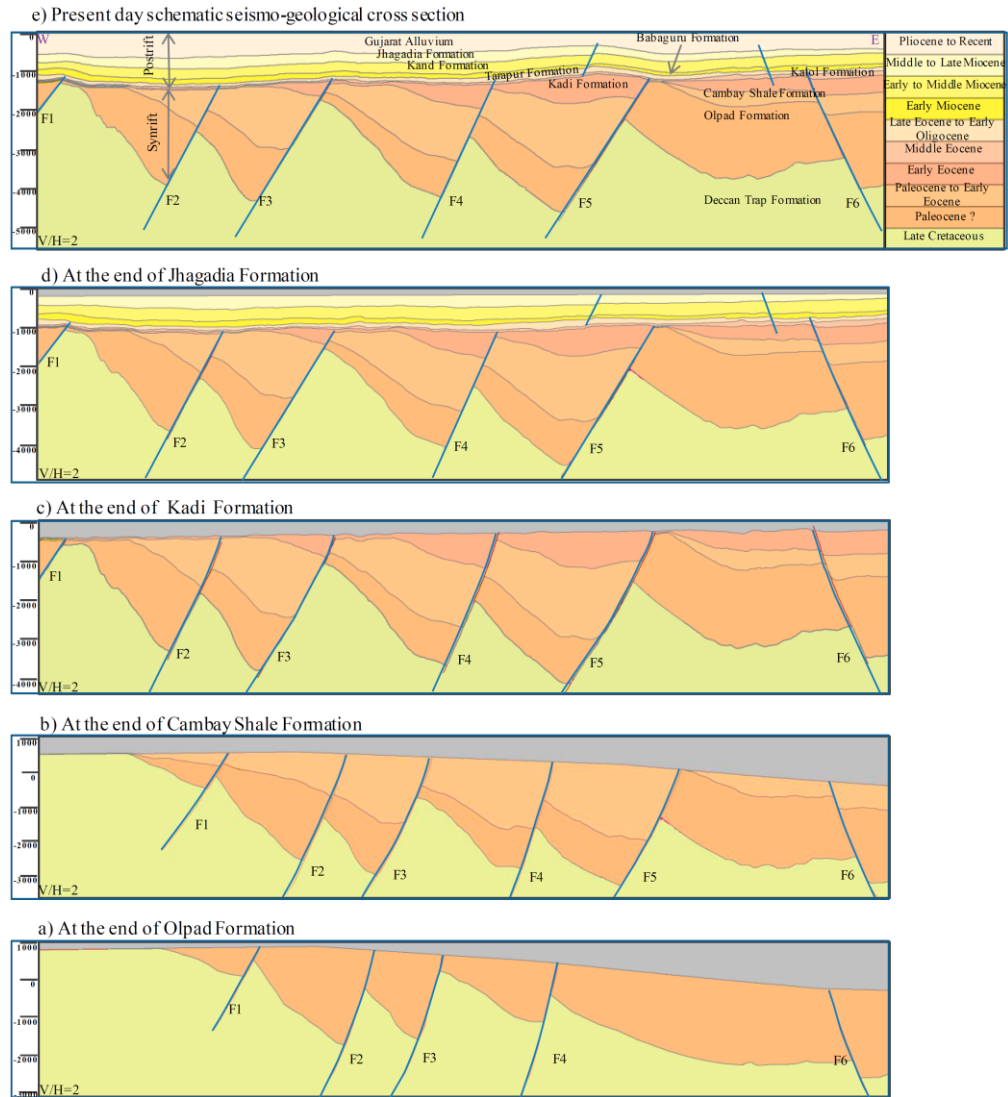


Figure 2. Tectonic evolution along an E-W section through the study area (AA').

- At the end of Olpad Formation.
- At the end of Cambay Shale Formation.
- At the end of Kadi Formation.
- At the end of Jhagadia Formation.
- Present day schematic seismo-geological cross section.

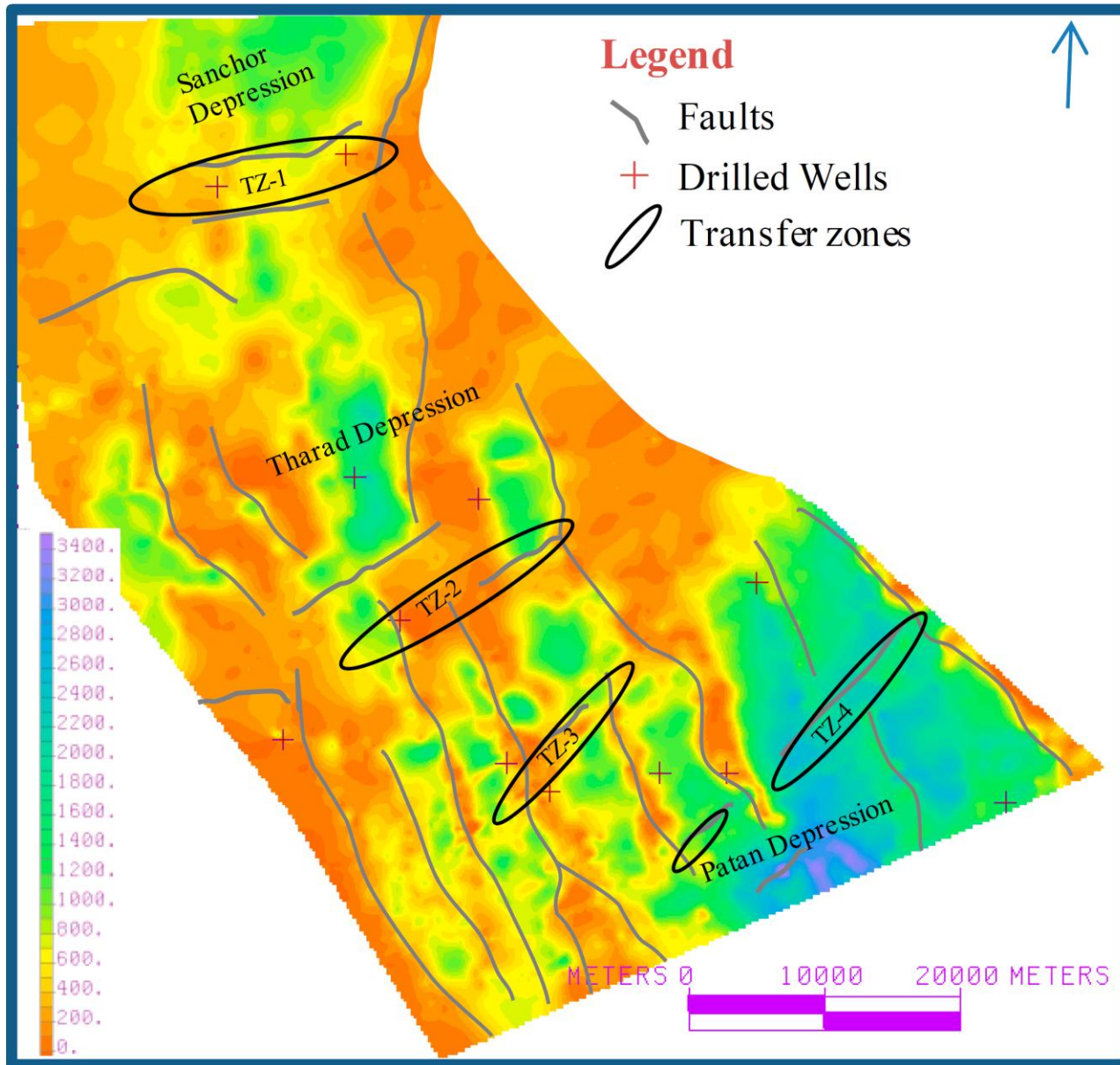


Figure 3. Isopach map of Paleocene section (Olpad Formation) showing faults and depocenters.

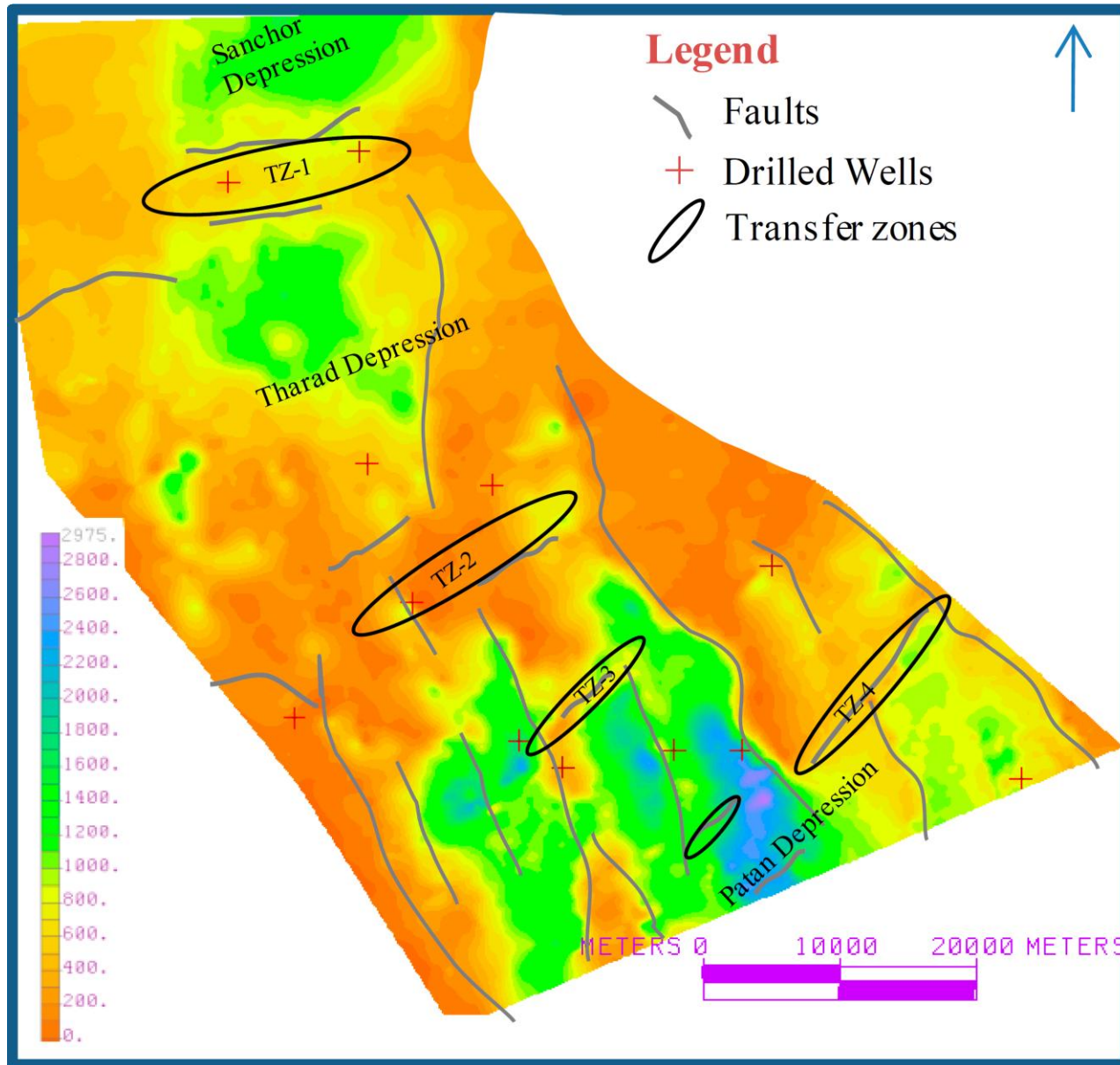


Figure 4. Isopach map of Paleocene to Early Eocene section (Cambay Shale and Kadi Formation) showing faults and depocenters.

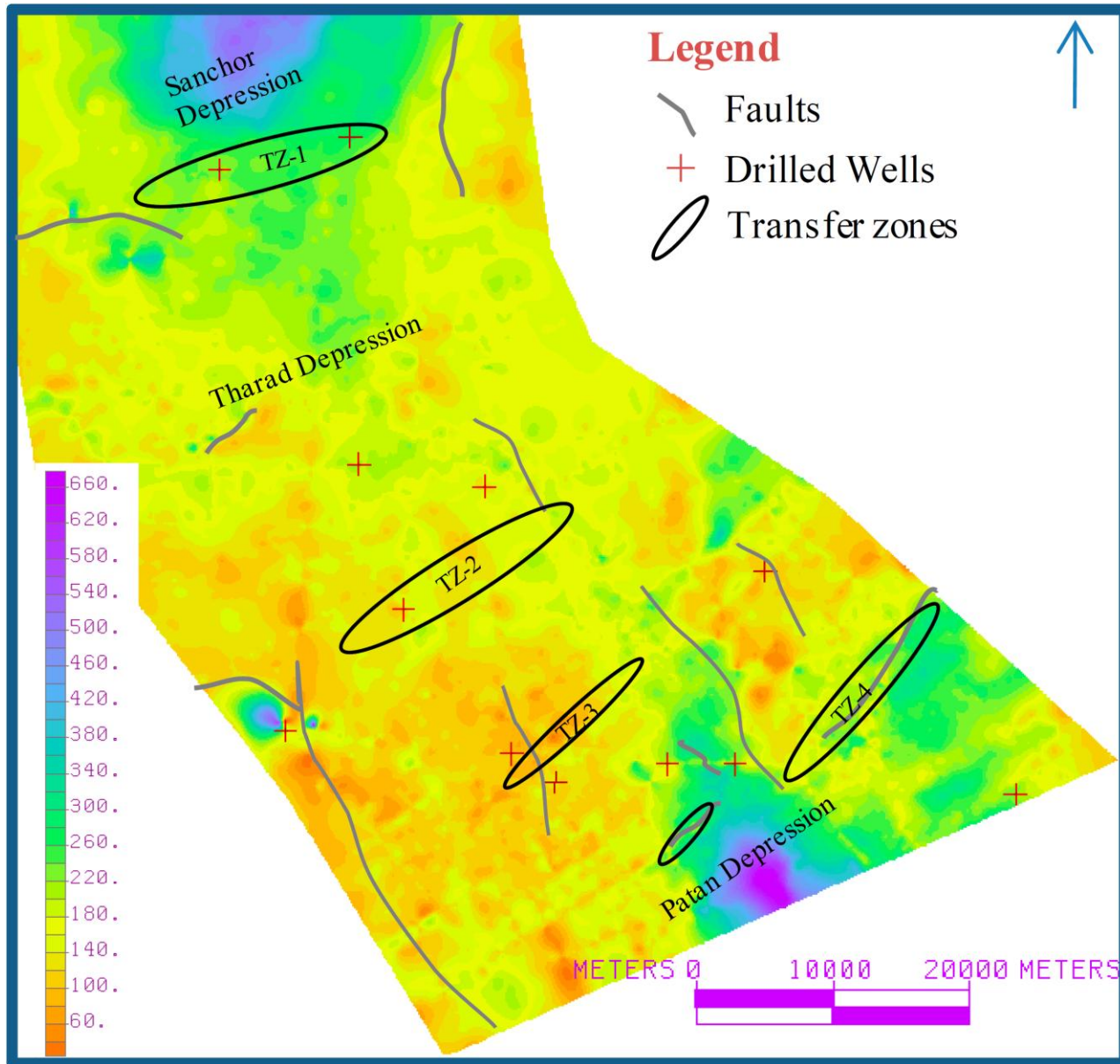


Figure 5. Isopach map of Mid Eocene to Early Oligocene section (Kalol and Tarapur Formations) showing faults and depocenters.

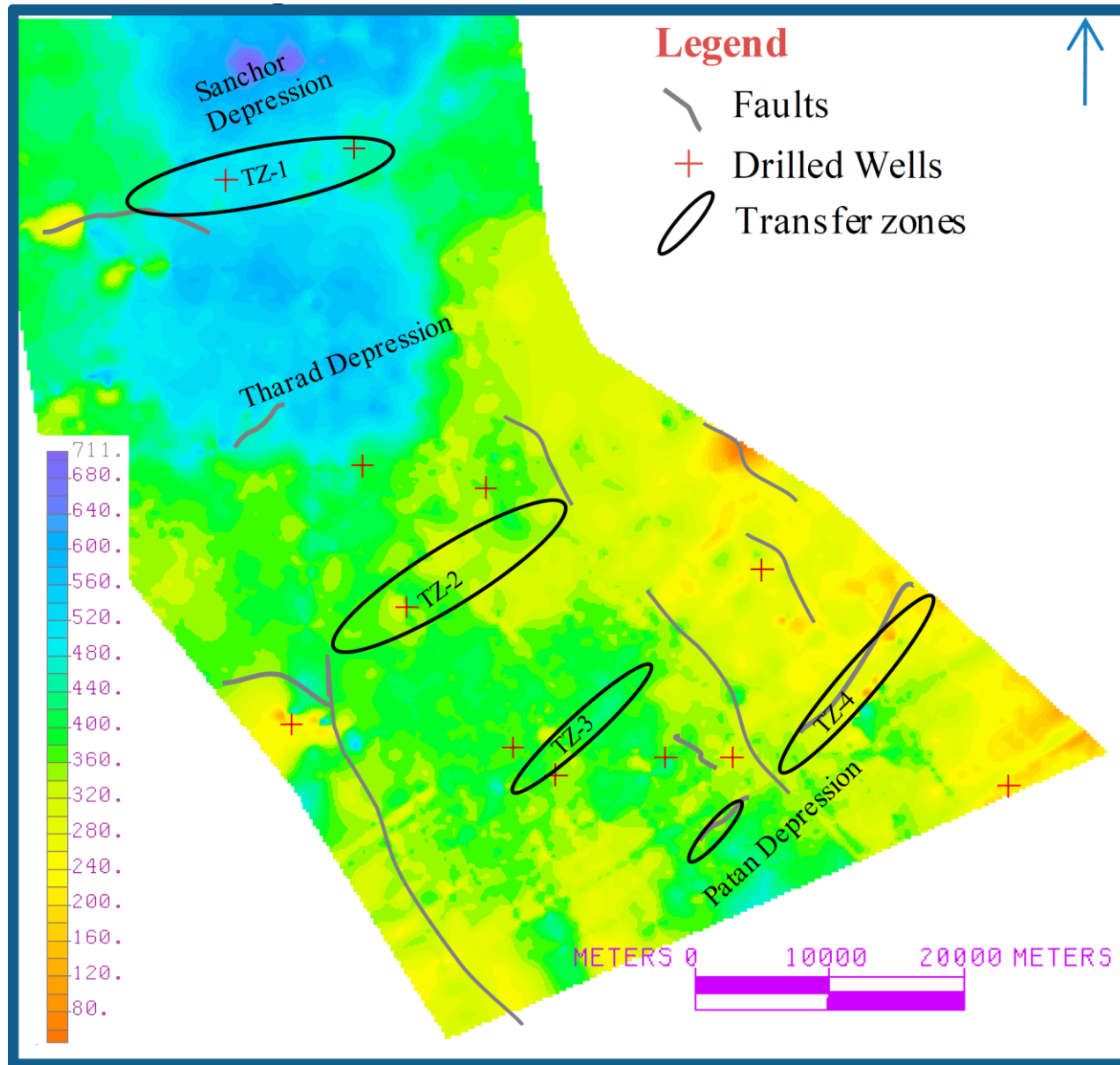


Figure 6. Isopach map of Early to Middle Miocene section (Babaguru and Kand Formations) showing faults and depocenters.