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Research Article

Variation of Faunal Diversity Across Paleogene-Neogene Boundary Along Selected Transects, Kutch Basin, Gujarat, Western India

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Abstract

The Kutch Basin, of Gujarat, western India, is host to a diverse species of vertebrates and invertebrate faunas, which are both marine and terrestrial in origin. Kutch due its passive continental setting, has experienced multiple transgressive and regressive events on its carbonate platform, and was favourable for the growth and preservation of various living organisms in the Cenozoic. These organisms are mainly foraminifera, molluscs, bivalves, corals, echinoids, oyesters and vertebrates. Here in this work, we discuss, and compare the paleoecosystems of Paleogene with respect to the Neogene, of the Kutch Basin, and discuss how the ecosystem of Paleogene of the Kutch basin changes towards the Neogene. We have also tried to understand the genesis of the Middle Eocene Archaeocete fossil. In the Eocene, we have found large amounts of LBFs, such as *Assilina*, *N. obtusus, Nummulites;* mega-invertebrates; and vertebrate fossils such as (*Remingtonocetus harudiensis*, a middle Eocene Cetacea). In Oligocene formations, the dominant faunas are, Corals, echinoids such as *Clypeasteroids* and gastropods such as Physa, and very less diversity of LBFs, such as *Operculina*, *Lepidocyclina* and *Spiroclypeus*. The Miocene period is associated with newer taxa of microfossils such as *Miogypsina*, *Ammonia* sp, fossilized tree roots and land vertebrates of *Gomphotherium indet* and *Brachypotherium sp*. It is concluded, that the Paleogene was dominated by primitive vertebrates, in an isolated tropical forest ecosystem, and the marine faunas resided in shallow marine shelf or reef ecosystem, within a basic environment. Whereas the Neogene, was attributed by newer faunas, which migrated from North Africa and Afro-Arabia, as well as the Tibetan landmass, and resided in cooler drier, forest ecosystems and marsh environment, and the marine vertebrates resided in shallow creek environments and were resistant to terrigenous influx, and acidic environment. We hypothesized that the species of Paleogene of Kutch, morphologically and functionally habituated with a primitive ecosystem and endemic to the Indian sub-continent, whereas the species of Neogene are newer and complex and ancestors to the present day extant species.

Keywords

Morphological Species, Organisms in Cenozoic, Paleogene-Neogene Boundary

1. Introduction

The stratigraphic succession of the Cenozoic period, is well preserved in the Kutch basin of Western India. The Tertiary basin of Kutch is a result of shallow-marine carbonate platform sequence together with occasional siliciclastic deposits,

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developed over a passive continental margin. The micro-palaeontological significance of Kutch basin is described by [12-14]. The vertebrate Palaeontological significance is described by [3, 5, 10, 16, 18, 21, 23, 25, 26]. The mega-invertebrate faunal significance are described by [1, 4, 11, 18, 19, 22]. The aspects of change in palaeoclimatic and Palaeoeceanographic ecosystem in the transition of Paleogene-Neogene is given in [2, 6-10, 24, 27]. Few have found $Ce^{3}+$ anomaly in the Eocene-Oligocene transition [20]. But no such anomalies have been reported in the Oligocene-Miocene boundary as of yet. Palynofloral evidence suggests that Eocene is mainly composed of *Triorites triangulus* cenozone, in Fulra it is *Tricolporopilites*, and *Lygmodiumsporites* in Neogene [29-31]. In Eocene There are four foraminiferal bio-facies observed in Kutch, namely *Bulimina-Chiloguembilina* biofacies (SBZ5/6-SBZ10), *Asterigerina-Cibicides* biofacies, (SBZ11), *Jenkinsina-brizalina* biofacies (E12) and the *Cibicides-Nonion* biofacies [12]. The biofacies present in the Eocene Fulra Limestone are *Discocyclina* packstone biofacies and *Nummulites* grainstone biofacies, and Alveolina biofacies. In the Oligocene Coral member, the prominent biofacies are that of *Nummulites fitcheli* [32]. The Bermoti member on the other hand is associated with Miogypsina, and *Spiroclypeus ranjane* biofacies. The Miocene Khari Nadi formation is composed of Ferruginous beds. The chassra formation is known to be consisted of the *Miogypsina sp and Ammonia sp.* [33, 34]. Geologically the Miogypsinoides appeared in the Rupellian and disappeared in the Seravallian [35]. The platformal carbonate sequence, which initiated from about early Eocene, extends up to Neogene, although from Neogene onwards the sediments become more siliciclastic [19]. The sedimentation, in the Early Paleocene epoch, was mainly volcaniclastics, however from the late Paleocene to Early Eocene, the sedimentation becomes shallow marine in origin (as evidenced by occurrence of green shale and Carbonates at Naredi Formation) [12]. At Middle Eocene Harudi formation, Coquina beds and lignite beds are visible, marking various transgressive and regressive events. The Late Eocene Fulra Limestone consists of 50m succession of fossiliferous dense foraminiferal Limestone, mainly consists of orthophragmines and nummulitids, Oligocene Maniyara fort succession consists of mainly Glauconitic shale, Glauconitic sandstone, coral limestone and foraminiferal limestone. The Neogene, sediments are mainly dominated by sandstone, claystone and siltstone.

The various fossils species present across the Cenozoic of Kutch, are species of fishes, reptiles (such as tomistomid crocodiles), and mammals (such as Deinotherium sp. Gomphotheriidae indet., *Brachypotherium* sp., Cetaceans and Dugongidae), and huge number of micro-fossils and mega-invertebrates such as Larger Benthic Foraminifera (LBF), planktonic foraminifera, Gastropods, Bivalves, Echinoids, and corals [16]. Amongst these, Paleogene saw higher diversity of Larger benthic and Planktonic foraminifera [13], whereas Neogene saw higher diversity of gastropods, bivalves, echinoids and corals. Evidences of mid-Oligocene coral reef building, linked with mid-Oligocene warming, and paleo-biogeographic position of Indian Plate with respect to the Tethys Ocean have been noted by few authors [15]. From mid-Oligocene onwards, coral reef started narrowing, but on the other hand newer genera of LBFs appeared in the stratigraphic record, most of them resistant to terriginous input. In this work, we have tried to understand, the variation of morphology, and volumetric abundance of species across the Paleogene-Neogene boundary of Kutch, by relying on study of specific transects, from various locations of Kutch region. The transect locations, are shown in the map (Figure 1).

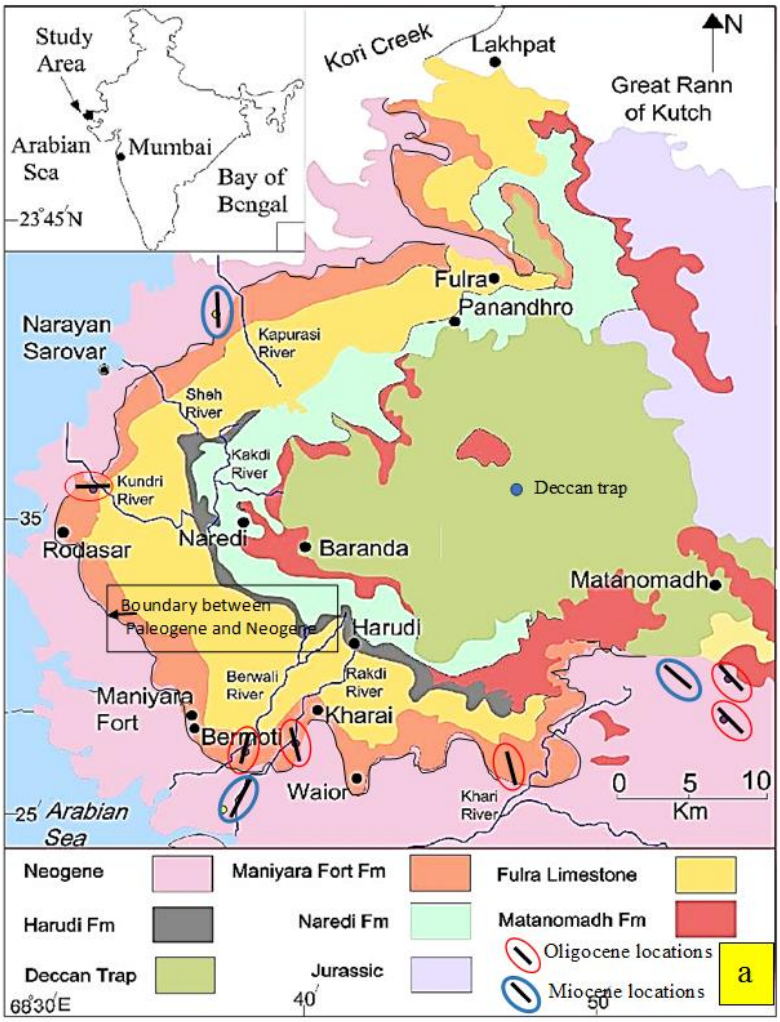
Cenozoic marks few significant transitional events, and the Paleogene to Neogene transitional period is one of the most important periods that occurred in the Cenozoic. It consists of the shift of both climate (from a warmer condition to a drier and cooler condition) and ecosystem (both marine and terrestrial), and is termed as the Paleogene-Neogene transitional event. It consisted of changeover of faunal elements in the marine realm, (i.e. new species of foraminifers appeared during and after this event), and emergence of newer species in the terrestrial realm as well. Importantly, the transition from Paleogene to Neogene was also marked by the Mid Oligocene extinction event which is significant for extinction of 30-50% of benthic foraminifers due to abrupt fall in temperature [17]. The Neogene marks a post Oligocene recovery in the marine realm. The Neogene is also associated with Himalayan uplift and initiation of the Indian monsoon. Neogene of Kutch is siliciclastic in nature and the nature of organism found are terrestrial. Though several works have addressed the Paleogene Neogene palaeontology and stratigraphy of the Kutch basin, but no comprehensive work has yet been done on the morphological-ecological significance of the faunal change over.

The Paleogene of Kutch (Naredi, Harudi, Fulra and Maniyara-Fort Formation) consisted of mainly LBFs and marine vertebrates. Marine vertebrates such as, various species of Cetaceans, Sirenian, Batoidea, Elasmobranchs were recorded. The Oligocene deposits, distinctive feature is that it consisted of diverse species of Corals, echinoids, gastropods and bivalves, and saw a decrease in LBFs population, in the early-Oligocene, which re-appeared in the Late-Oligocene. Neogene of Kutch, consists of siliciclastic sediments, which signifies a rapid weathering event. This rapid weathering may have initiated a global cooling phase [24] in the early-Miocene. Neogene hosts slightly less, but newer genera of foraminifera, it also hosts both terrestrial and marine vertebrate fossils, and much significantly terrestrial tree fossils. Evidences of terrestrial migration of mammals, and closure of Tethys Ocean was observed in Neogene only.

It is another mentionable fact, that the Tibetan ecosystem was also evolving during the major transition period from Paleogene to Neogene [8]. The Indian plate's collision with the Tibetan landmass, initiated upliftment of the Tibetan Plateau from lower Eocene. The upliftment of the Tibetan plateau resulted in changing of the original tropical ecosystem of Tibet to an alpine ecosystem. It also helped formation of the Himalayan Mountain range, the onset of the younger river systems in India during early Miocene (Neogene), followed by Northern Hemispheric glaciation [2] and higher sedimentation rates at the Indian subcontinent. Paleogene of Kutch saw marine mammalian fauna, that is observed in the carbonate platform deposits, and the relict terrestrial vertebrates, that were already existing in the Indian subcontinent. Neogene saw newer species of microfossils, and mostly terrestrial vertebrates in the Indian subcontinent, mainly terrestrial mammalian faunas, which mainly came to the Indian subcontinent by migration.

2. Materials and Methods

The transect locations of the Paleogene-Neogene boundary of Kutch are marked in the field map of Kutch. Field work is done both from Paleogene successions and Neogene successions, along the selected transects. The transects are studied on the basis of their stratigraphic and palaeontologic significance. Fossil elements were identified in the field, and accordingly stratigraphic lithologs were created [28]. Samples of fossils are carried to the lab for further identification and analysis. Vertebrate bone fossil has been identified in the laboratory, on the basis of structure and anatomy. Mega-invertebrates are mostly identified in hand specimen. Micro-fossils are mostly identified on the basis of their micro-structural forms in the micro-scope. Simple paleontological concepts are used to understand the geometry and stratigraphy of the Kutch Basin. The fossils from the Formations of Naredi, Harudi, Fulra, Maniyara fort, Khari Nadi and Chassra are briefly studied, both in hand specimens and microscope. Attempts have been made for marine vertebrate CT scans in the Palaeontology Laboratory, of Geological studies unit. Our findings are correlated with the factors of evolution such as tectonics, environment of deposition, marine transgression and regression events, with that we have used heuristic algorithms to find the nature of organisms (especially marine or terrestrial vertebrates) that used to live in the Cenozoic of Kutch. The map of the Kutch Basin is utilised from [21]. Apart from that all the other tables and figures are prepared from field observations.



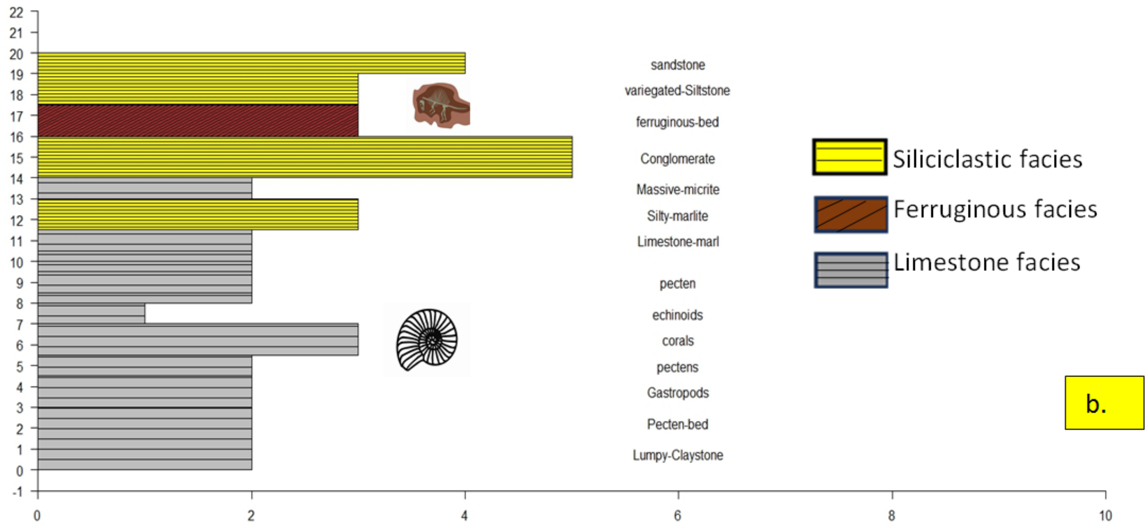


Figure 1. *a) Transects of Paleogene-Neogene Boundary in the Paleogene Map of Kutch [19]. b) Integrated Litholog of Maniyarafort, Khari Nadi Formation created in R.*

Table 1. *Stratigraphy of the Oligocene and Miocene formations of Kutch, formed through field observations.*

Formation	Epoch and (Age)	Lithology	Attributes
Sandhan	Messinian Tortonian Serravallian Langhian		Possible presence of terrestrial vertebrates
Chhasra	Burdigalian	Variegated Siltstone	Oyesters, *Ammonia sp*.
Khari Nadi Formation	Early Miocene (Aquitanian) (23-20 Mya)	Ferruginous beds, Sandstone and shale	fossilized tree roots present,
		Conglomerate, pebble clast	Probable start of Miocene
Maniyara Fort Formation	Upper Bermoti member (Chattian) (25-23 mya)	Massive impure, silty micritic limestone unit, foraminifera present.	Bed thickness higher than a meter. Less foraminifera present than previous one, may contain *Miogypsina*
		Foraminiferal Silty marlite unit, more than a meter thick, rich in foraminifera.	Foraminifera rich, contains small amounts of *Pecten*, may contain *Spiroclypeus*
	Lower Bermoti Member (Chattian) (26-25 mya)	Limestone marl bed, containing Gastropods and corals	Various forms of Gastropod present, along with corals.
		Echinoid rich limestone bed	Highly fossiliferous, mainly Echinoids, Oyesters and Forams. Possible presence of Marine Vertebrates
	Coralline member (28-26 Ma) (Chattian)	Coral beds	Calcareous Limestone, containing huge amounts of fossil corals of varied forms
		Pecten bed	Calcareous limestone, highly rich in fossils such as *Pecten*, *Chlamys*, and forams such as large sized *Discocyclina sp.*
	Lumpy Claystone Member (30-28 Mya)	Non Fossilliferous Carbonate Mud	Contains very less or no fossils

2.1. Transects Studied

The transects selected for this study, are situated mainly within the stratigraphic formations of age Early-Oligocene to Early Middle Miocene. The transects considered are present in the following sections; Lower Oligocene (Lumpy Claystone and coral member), Section near Kundri village, the Berwali river section near Bermoti village (Bermoti Member), Rakdi river section near Bernani village (Bermoti), Miocene Dam section near Bhadra, Oligocene-river section near Kotda (Shown in the map Figure 1). Apart from these transects, few other Oligocene and Miocene sections are also visited such as the Miocene ferruginous beds of Kapurashi, and Jangadia, Miocene sections near Naliya. The transect studied in various locations are given below in details.

2.1.1. Lower Oligocene, Kundri Village (Figure 4)

Figure 2. *The Naredi formation of Kutch, village in Nareda a) Naredi shale, b) Naredi Laterites, c) Type section of Naredi formation.*

This section is located near the Kundri village near the Kakdi river, and is situated just beside the road connecting Naredi and Narayan Sarovar (shown in the map). This section is a typical lower Oligocene section, consisting of three -five calcareous beds, starting with a Lowermost Carbonate mud unit (fossils absent), above that a calcareous hard limestone bed containing huge number of *Pecten*, above it a limestone unit containing Gastropods and bivalves with bimodal distribution of Foraminifera, and the topmost bed is a Limestone unit containing large sized corals. Hence, in this section the Lowermost-carbonate mud unit is possibly the Lumpy Claystone unit, and the upper three layers belong to the Coralline member. Therefore, this section consisted of the upper part of SBZ 22a, Lumpy claystone member and above that, the lower part of the SBZ 22b Coralline member, of Maniyara Fort Formation. Unlike Naredi Fm. this section of lower Oligocene is typically rich with mega-invertebrates, and few of the upper beds contained echinoids and corals. Composition of the lower Coral member, mainly consists of larger bivalves such as *Chlamys* or *Pecten*, lesser Forams and fewer gastropods. Possible forams are *Discocyclina* sp., *Nummulites* sp. and *Heterostegina* sp. The reasons for the occurrence huge amounts of corals and echinoids are discussed in the later sections.

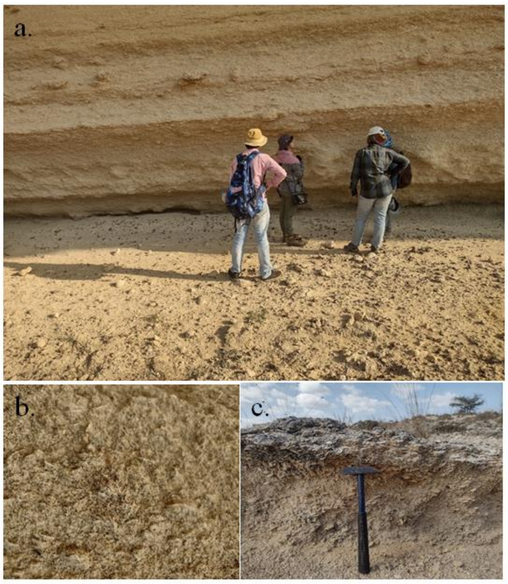


Figure 3. *Field photographs of Fulra formation of Kutch. a) Type section of Lower Fulra Formation of Kutch b) Desne foraminiferal limestone of Fulra Formation c) Nummulitic grainstone of fulra Formation.*

Figure 4. *Field Photographs of Lumpy Claystone Member a) Lumpy Claystone member, Maniyarafort Formation. The bed is composed of calcareous mud, but devoid of any fossils. Above this unit, consists of Pecten/Chlamys bed. Section near Kundri river, lower Oligocene. b) Pecten/ Chlamys bed, observed above the Lumpy Claystone Unit. Contains Pecten, Nummulites and Discocyclina. Possible start of the Coral Member. c) Corals (Possibly Scleractinians) of upper Coral member, Near Bermoti Village. (Corallites prismatic, sharing walls with mural pores).*

2.1.2. Berwali River Section, Upper Oligocene, (Bermoti Member Maniyara-Fort Formation)

The Bermoti member initiates where the Coral member ends, near Bermoti village. Before reaching the Bermoti river section large coral fossils were found, along with the bimodal distribution of foraminifera, the same observed near Kundri. This marks the end of the Coral member.

The Bermoti river-section consists of a clear stratigraphic zonation of the uppermost part of the Oligocene Bermoti Member of Maniyara Fort formation of Kutch, consisting of the SBZ 22b Coral Limestone member and SBZ 23 Bermoti Member (After [19]). In this section, a total of 8 beds of depositional history has been recorded, each bed about half a meter thick, starting from the Lowermost un-fossiliferous siltstone unit, to the uppermost Massive Limestone unit containing considerable amounts of authigenic alterations.

The 8 beds observed are as follows, a) the lowermost non-fossilliferous siltstone; b) echinoid rich calcareous limestone bed; c) calcareous bed containing *Pecten*, Forams, oyesters, *Discocyclina*; d) impure limestone bed containing small amounts of echinoids; e) impure limestone bed containing small amounts of *Pecten* and corals; f) impure limestone bed containing gastropods and corals, and dense concentrations of large sized *Pecten* at few places, the gastropods showed various morphological forms, this bed ends with a slightly erosional top; g) above that a silty marlite bed containing huge concentrations of foraminifera possibly *Spiroclypeus*; and h) uppermost massive micritic limestone unit more than a meter thick, which contains authigenic alterations.

Figure 5. *Field photographs of Bermoti Member a) Bermoti Member, Maniyara fort Formation. b) Silty Marlite Bed of Upper Bermoti Member, composed of Spiroclypeus packstone. c) Echinoid bed of Lower Bermoti Member. Clypeasteroids in Upper-Middle Oligocene. (Amal Dasgupta, An introduction to Palaeontology).*

The most significant part of this section is that, it hosts a typical upper Oligocene faunal section of Kutch. It consists of huge amounts of echinoids in the lower part, but very less foraminifera. But in the upper part, i.e. the silty marlite bed, the echinoids (and other mega-invertebrates such as gastropods) are absent, but foraminifera population is higher.

2.1.3. Rakdi River Section, Bernani

The Rakdi river section near Bernani village has litholog similar to the Bermoti River Section. The rivers of Bermoti and Bernani have almost the similar trends in flow direction and also very near to each other, rendering similar stratigraphy, consisting of all the strata that is observed in Bermoti, starting from the lower most un-fossiliferous siltstone bed to the uppermost massive limestone bed just like the Bermoti river section. But, the speciality, of the Bernani river is the detrital fossils that are present in the bed. It consisted of huge number of detrital coral fossils, detrital gastropods and bivalves, of the coral member present right on the river bed, giving us a vivid idea about the kind of morpho-species of invertebrates that was present during the middle-Oligocene times.

2.1.4. Outcrop Near Goyla (Figure 8c)

A section in Goyla was found to be having a lower most shale unit and uppermost Hard calcareous limestone unit. This limestone contained very fossilized remains of bivalves and gastropods, along with some oyesters. Bivalves such as *Pecten*, *Venus*; and gastropods such as *Turritella* were found.

2.1.5. River section in Bhadra: (Figure 8a)

This is a river section situated just beside the road connecting Kotda to Bhadra, it is about 15m in thickness. The section consisted of a lowermost extremely hard impure calcareous limestone unit, which itself is about 10m in thickness, and is capped by a thin marl-sandstone bed. The calcareous limestone unit is fossiliferous and contains large number of Bivalve, and Corals, whereas the upper marl sandstone unit contain Gastropods. Although not a very distinct section for stratigraphic analysis, but it was quite observable that the lower layer was carbonate dominated, while the above one is clastic dominated, denoting probably an upper Oligocene age of the formation.

2.1.6. Miocene Beds, Jangadia (Figure 7a)

Ferruginous bed near Jangadia village (23 25’ 21.8”, 68 47’ 52.7”) is found. The age of this bed is possibly Late early -Miocene, and belongs to the Khari Nadi Formation. This is a ferruginous reworked bed, composed of mainly fossilized fecal-pellets, burrows, reworked gastropods, and rare wood fossils, in clastic facies of rock. Terrestrial Vertebrate fossils are likely to be found in this kind of beds. This bed is highly reworked diagenetically and is perfect for the preservation of vertebrate fossils of Kutch. Although we did not find vertebrate fossils, but we did find quite a good number of fossilized tree trunks, some of them are shown in the pictures below. These are mainly fossils of terrestrial trees that were present during the Miocene. The speciality of this bed, is that it is highly reworked and carbonate depleted and composed of diagenetically altered siliciclastic deposits.

Figure 6. Field photographs of Detrital fossils, Middle Oligocene, Rakdi river. Detrital gastropods, bivalves and corals at the Rakdi river near Bernani. a) Physa (Pulmonata) b) Brain corals Diploria strigosa c) Brachiopod, possibly Atrypa and Bivalve shells.[1]

Figure 7. Field photographs of Miocene members of Kutch a) Ferruginous Beds of Miocene, Jangadia, mainly consisting of fossilized, burrows, and reworked gastropods. b) Miocene terrestrial tree fossils of the Khari Nadi Formation. c) Lower Miocene plane laminated variegated siltstone unit from Khari Nadi formation.

2.1.7. Chhasra river section: (Figure 7c)

A laminated siltstone unit is observed near Chhasra village. It is present beside a river section just beside the road connecting Aida-Vayor. It is a thinly laminated variegated siltstone unit. The bed is relatively younger. Our inference is, it is probably a part of the Chhasra formation.

2.1.8. Kankawati river section, Naliya (Figure 8b)

This river section (possibly Kankawati river section) near Naliya is also visited and studied. This section consisted of a laminated siltstone unit, and above that a bedded course sandstone unit. The lower siltstone unit is red in colour, whereas the upper sandstone unit is slightly yellowish. It is possibly a part of the Sandhan Formation and it did not contain any fossils.

Figure 8. Field photographs of lower Miocene Chassra formations of Kutch a) Dam section near Bhadra, containing hard calcareous limestone beneath and turritellid sandstone above. b) Miocene Sandstone in Naliya. c) Hard calcareous limestone near Goyla, containing Turritella, Bivalves and Oyesters.

Table 2. Showing schematic view of species diversity of Foraminifera, mega-invertebrates, vertebrates and tree-root diversity across Early-Eocene to Early Miocene.

Period	Formations (Epoch)		Foraminifera (LBF)	Mega-invertebrates	Vertebrates	Fossilized Tree roots	Comment
NEOGENE	Khari Nadi Formation (Miocene)		*Miogypsina sp.* (quartz influx) *Spiroclypeus sp.*	Oyesters, *Turritellid* gastropods	Reworked vertebrate bones, Crustaceans (Terrestrial vertebrate)	Reworked tree roots and tree-trunks (terrestrial)	N.A.
PALEOGENE	Maniyara	Upper	*Spiroclypeus sp.,*	Lesser amounts of	Sirenians		Foramini-feral

Period	Formations (Epoch)	Foraminifera (LBF)	Mega-invertebrates	Vertebrates	Fossilized Tree roots	Comment
	Fort Formation (Oligocene)	*Heterostegina sp.*, *Miogypsinoides*	corals and gastropods.			Packstone Foramini-feral wackestone
	Middle	*Operculina sp.*, *Lepidocyclina sp.*, *Eulepidina (*Very less forams*)*	higher amounts of Corals and Echinoids. Bivalves (*Pecten*), large quantities of Gastropods.			
	Lower	Large quantities of Forams, mainly *Reticulate Nummulites*	Fewer Gastropods			
	Fulra Limestone (Upper Eocene)	*Alveolina elliptica*, *Assilina Exponens*		Small bone fossils of vertebrate (marine)		Packstone and Grain-stone
	Harudi Formation (Middle Eocene)	*Nummulites obtusus*, *Pellatispira*, *Discocyclina sp*	Bivalve, molluscs (Eocene coquina bed)	Whale skull (marine vertebrate)		Grainstone and packstone
	Naredi Formation (Lower Eocene)	*Nummulites burdigalensis*				n.a.

Study of A middle Eocene Archaeocete.

Figure 9. *Side view of Skull of cetacean, specimen of Remingtonocetus harudiensis, Middle Eocene Harudi Formation, Kutch. (Pic courtesy: [5]).*

A complete skull of a marine vertebrate is found from the Middle Eocene Harudi Formation. The skull specimen is about half a meter in length and about 20cms in breadth. It has long snout and its lower mandible has teeth. It is identified as a member of the cetacean family and named *Remingtonocetus harudiensis*. [5]. Most of the cetacean fossils are found in places like Pakistan and Afghanistan, along with few other localities in Kutch. Appearance of marine fossils in continental lithosphere suggests that during the Eocene the land-bridge between Afro-Asia and Indian Plate already started to build, suggesting the initial collision between the Indian plate and the Dras arc volcanic arc happened in Eocene itself. Contrary to their report [5], this species specimen does not seem to be showing significant variation in morphology within the species than other reported specimens of Cetacea from Kutch.

2.2. Thin Section Analysis

Rock samples from few of the specific strata of Oligocene and Miocene were collected for hand specimen and thin section analysis. The juncture of the Paleogene and Neogene is considered to be of prime focus. As the Bermoti river section had distinct zonation of the beds, starting from Early-Middle Oligocene to Upper Oligocene age, thin section study of this section was considered more over the others. Samples from all the 8 layers of the upper Bermoti member has been considered for thin section analysis. The results are shown below. Thin sections of Lower Oligocene Coral Member, Maniyara Fort formation is also shown.

Some of the samples were also collected from the Bernani river section, few samples from the Khadi Nadi section near Jangadia village, few from the Miocene section of Kapurasi and few from the Navavas section of Kutch near Navavas area.

2.2.1. Thin Section Analysis of Lower Oligocene Maniyara Fort Formation

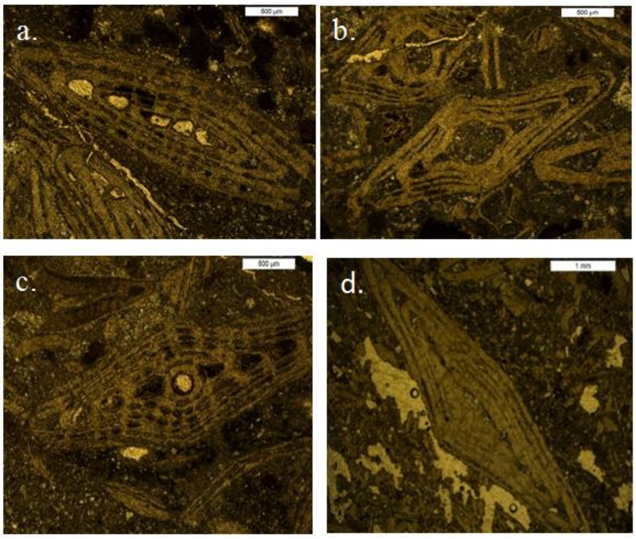


Figure 10. *Various species of Nummulites, in axial section, lenticular shaped, from lower Oligocene, Coral Member, Maniayara Fort Formation. a) Nummulites with growing nucleus b) Nummulites with single nucleus. c) Nummulites with single nucleus and cubicula. d) Reticulate Nummulites.*

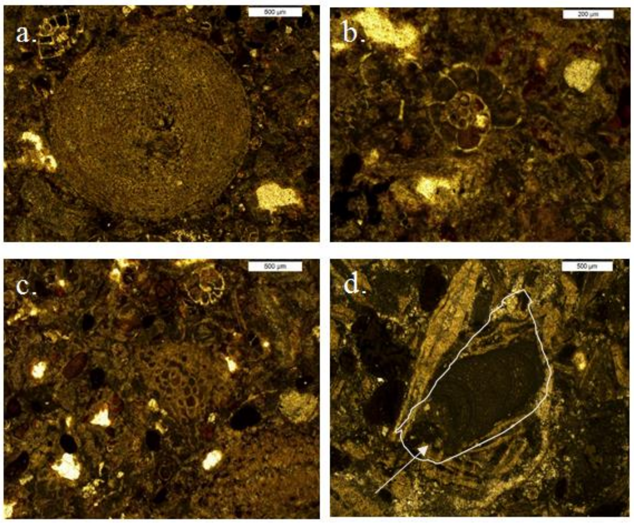


Figure 11. *Lower Middle Oligocene, Maniyara fort formation. a) Heterostegina sp., b) Planktonic Forams. c) Miogypsinoides. d) Coralline Algae, marked by white arrow and lines. e) Lower Oligocene. Discocyclina sp. and Nummulites sp. from Lower Oligocene, coralline member. f) Heterostegina sp., and planktonic foraminifera from Early-Middle- Oligocene in a foraminiferal Grainstone (Dunham classification).*

2.2.2. Thin Section Analysis of the Bermoti Member

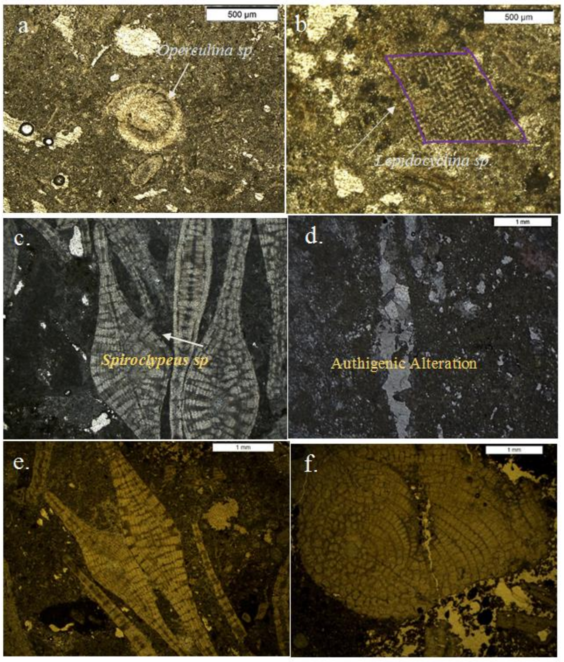


Figure 12. *Lower-middle -Oligocene, Bermoti member a) Operculina sp. (Foraminiferal wackestone). b) Lepidocyclina sp. (Rhombic shape), from middle Oligocene of Kutch, Sparite crystal. c) Spiroclypeus sp. packstone, (characterized by fully grown umbonal region), from upper Oligocene silty-marlite bed, Bermoti Member, Kutch. (Foraminiferal grainstone, Dunham Classification). d) Authigenic alterations in calcic bioclasts of late-Oligocene to Early-Miocene, Upper Bermoti Micritic- limestone of Kutch. e) Upper Bermoti member Spiroclypeus and Heterostegina. f) Miogypsinoides complanatus (Ogival shape).*

3. Discussion

3.1 Change in Faunal Ecosystem Observed Across Paleogene and Neogene

It is observed, that the Paleogene deposits of Naredi, Harudi, and Fulra are rich in microfossils, such as diverse species of Larger Benthic Foraminifera (LBFs), and occasionally Planktonic Foraminifera. Apart from that Eocene consists of, marine mammalian fossils of *Remingtocetus* (An Archeocete). This archeocete are the remnants of the oldest know whales of Eocene. LBFs such as various species of *Nummulites*, *Discocyclina*, *Alveolina* are abundant, and few coquina beds are also visible at Eocene. At Oligocene of Kutch, the LBF population was reduced significantly but the mega-invertebrate fauna such as various species of gastropods, bivalves, corals and echinoids are found hugely in the Mid-Oligocene and is also characterized by huge population of corals. The LBFs found are *Heterostegina*, *Operculina* and *Lepidocyclina* in the lower to middle Oligocene. Skeletal remains of Sirenians are also reported [3]. This suggests that in Oligocene of Kutch, there was definitely a reef ecosystem. At the Miocene, the most common types of foraminifera are *Spiroclypeus* and *Miogypsinoides*, and the most common type of mammalian fossils are that of *Gomphotheridae* (A terrestrial Mammoth), depicts that the paleo-ecosystem was terrestrial during this time period.

Table 3. List of Paleogene and Neogene species of Kutch.

Faunas	Paleogene Species	Neogene Species
Archeocete	*Remingtocetus harudiensis*	-
Sirenians	*Bhartisiren indica*	-
Gomphotheridae	-	Gomphotheridae indet
Tree Trunks	-	Present
Tree Roots	-	Present
Molluscs	*Physa, Conus*	*Turritella sp*
Bivalves	*Pecten*	-
Echinoids	*Clypeaster*	-
Corals	Favosites	-
Crustaceans		Present
LBFs	*Nummulites* sp, *Discocyclina* sp, *Pellatispira* sp, *Alveolina* sp; *Heterostegina* sp, *Operculina* sp, *Lepidocyclina* sp, *Spiroclypeus* sp.	*Spiroclypeus* sp, *Miogypsina* sp, *Ammonia* sp.
Planktonic		

In the Eocene age, of Naredi, Harudi and Fulra, which are chiefly Paleogene formations, the relative abundance of LBFs were quite large than Neogene. The most common explanation for this, is the occurrence of multiple transgressive events in Eocene. Whereas in the Lower Oligocene Basal Member, (Maniyara fort formation), the most common foraminifera are *Nummulites*, the Lumpy Claystone unit is devoid of any foraminifera (un-fossiliferous). In the Middle Oligocene, coral member, the most common foraminifera found are *Heterostegina*, *Operculina* and *Lepidocyclina*, with the relative abundance of LBFs quite low as compared to the Basal member. In the Late Oligocene, Bermoti Member which is approaching towards Neogene Formations, the foraminifera population regained its diversity, and the common genera of Foraminifera found are *Spiroclypeus* and *Miogypsinoides*.

At Miocene (Neogene times), LBFs population recovered again in the marine realm, but their morphology suggests that they are resistant to terrigenous input, and is very different in morphology from their Paleogene ancestors. Evidenced by presence of *Spiroclypeus* beds in the upper Oligocene, Bermoti Member. In these beds various species *Miogypsinoides* and planktonic foraminifera were also found. At Miocene, beds have become mainly siliciclastic dominated, and are diagenetically reworked. Common Faunal elements observed at Miocene formations are mega-invertebrates such as *Turritellid* Gastropods, Oyesters, crustaceans [9]. Apart from that, the Neogene rocks are also rich in fossilized tree-roots and tree-trunks, burrows, terrestrial-vertebrate fossils and at a few places iron rich concretions.

The most common LBF species found across Eocene to Lower Miocene are as follows. At Naredi, *Nummulites burdigalensis*; at Harudi *Nummulites obtusus*, *Pellatispira*, *Discocyclina sp.*; At Fulra, *Alveolina elliptica*, *Assilina exponens*, larger *Discocyclina sp.;* At Maniyara Fort *Reticulate Nummulites*, *Heterostegina sp.*, *Spiroclypeus sp.*; At early Miocene Khari Nadi *Miogypsina sp.* is found. However, the first occurrence of *Miogypsinoides* is recorded at Middle-Oligocene by few authors.

Table 4. Schematic view of vertebrate occurrence throughout the Cenozoic period.

Age	Vertebrate fossils	Remarks
Miocene	Gomphotherid, Sanitheriid, Deinotherid, Elasmobranch	Higher diversity of terrestrial species, Terrestrial ecosystem.
Oligocene	Sirenians	Marine species, Reef Ecosystem
Eocene	Cetaceans	Marine species,

Age	Vertebrate fossils	Remarks
		Shelf ecosystem
Paleocene	No vertebrate fossils	-

3.2. Reasons for This Faunal Changeover

There can be a number of significant factors that have played role in the faunal changeover from Paleogene to Neogene. Tectonic position of the Indian plate with respect to Gondwanaland and Laurasia is one factor. Role of climate, global temperature is the second factor, third is the species ability to adapt to its own habitat is the third factor.

During Paleogene, the global temperatures were high, the Indian plate's position was definitely South of the Equator. During this time the faunas prevailed in the Indian subcontinent are the relict terrestrial faunas, which were already residing in the landmass, and along the western passive margin setting (Like Kutch basin), mainly marine vertebrate mammalians prevailed.

During Oligocene, the temperature became cooler than Eocene. The Indian plate's position was possibly near and about the equator. This was when, the occurrence of huge amounts of Corals and Echinoids along with, lesser population of LBFs, compared to Eocene (Figure 12), was observed. The occurrence of huge amounts of Corals of diverse morphology, indicates the presence of a reef environment, which prevailed during the Mid- Oligocene of Kutch. This may be related to a mid-Oligocene warming event, Paleo-tectonic position (Latitude) and stability of the Indian Plate. The foraminifera present during this period are very less, but very few number of *Discocyclina sp* and *Nummulites sp*. are observed, along with species of *Operculina*, *Lepidocyclina*, *Heterostegina* in the middle-Oligocene times.

During Neogene, the global temperature was in a declining stage [27]. But more significantly India's land connection with the western Tethyan continents, had increased significantly, which favoured migration of African mammals to the Indian subcontinent [16]. Terrestrial mammalian vertebrates in the Neogene of Kutch.

The reason for the existence of higher diversity of marine vertebrates in Paleogene compared to higher diversity of terrestrial fossils in Neogene can be explained by the time of closure of the Paleo-Tethys Ocean. The Paleo-Tethys Ocean during the Paleogene, separated the two continental landmasses of the Indian plate and Tibetan Plate. The Indian Plate was an isolated landmass, bounded on all sides by the ocean. So, Kutch being a passive continental margin consisting of only carbonate platform sequence was likely to host mainly marine vertebrate faunas during this time period. But when, the Paleo-Tethys Ocean closed during the Miocene, the Indian plate did not remain as an isolated landmass, it got in connection with the Tibetan landmass [2], and the Eurasian landmass. This phenomenon paved way for migration of terrestrial mammals from the Western Tethyan continents such as Africa, Arabia and Europe to the Indian subcontinent, and hence saw the higher diversity, of terrestrial vertebrate fossils, in the Neogene period of Kutch.

4. Conclusion

As stated earlier the Paleogene faunas of Kutch basin are chiefly marine in origin. It is because the faunas, resided in a carbonate platform setting. The shallow marine environment, hosted mainly marine vertebrates, and invertebrates. Although terrestrial vertebrates are reported from Eocene by. The Oligocene beds of Kutch is host to ample amounts of corals and echinoids apart from marine vertebrates such as *Dugongidae*, indicating a brief period of reef building. It is also in this time period, foraminifera population decreased. The Neogene faunas of Kutch basin were both terrestrial and marine in origin. In Miocene beds of Kutch, both *Chondrichthyes* and *Deinotheriid* fossils are found. But, an overall change in ecosystem of faunas from a marine to terrestrial realm has been observed in Neogene of Kutch. This is also testified, by the occurrence of terrestrial tree fossils in many Miocene beds of Kutch.

The Mid-Oligocene was the exact time when the reef building took place. The reason for the formation of reef environment in Kutch, can be explained by a minor climatic optimum in the lower to middle Oligocene. It can be also explained, by the position of the Indian plate. From middle Oligocene onwards, temperature gradually cooled, as coral reef started diminishing. During the end of Oligocene, coral reef in Kutch disappeared completely, but foraminifera population re-appeared in the marine realm. Temperature in the early Miocene was cooler, and evidence of rapid weathering in the Indian sub-continents were recorded, giving rise to major river systems and terrigenous input in the early Miocene.

Therefore, Paleogene of the Kutch basin consisted of a carbonate platform setting, coral reefs marine vertebrates and invertebrates in a shallow marine shelf environment, along with occasional terrestrial vertebrates in a tropical humid forest. Whereas, Neogene of Kutch basin is characterized by shallow creek environments, and cooler drier forests. Neogene is also marked by Morphologically newer genera of foraminifera such as Miogypsinade and *Ammonia*, and terrestrial tree fossils of Rhizhophora and Ebenaceae, implies a period of rapid terrestrial weathering and sedimentation, and connection with the mainland. Morphologically, the Neogene faunas (especially foraminifera) are different from their Palaeogene ancestors, and were ancestors of the present-day species diversity.

Abbreviations

LBF	Larger Benthic Foraminifera

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Author Contributions

Ujan Karmakar is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

The author declares no conflicts of interest.

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