

**MICROSTRUCTURAL ANALYSIS OF MAMMALIAN TEETH
ENAMEL FROM KUTCH AND SIWALIK BASIN**

Project Report Submitted to the Central University of Punjab

For the Award of

Master of Science

In

GEOLOGY

By

BIKASHIT GOGOI

(16mscegs10)

SUPERVISED BY

Dr. K.Milankumar Sharma



**Department of Geography and Geology
School of Environment and Earth Sciences
Central University of Punjab
May2018**

DECLARATION

I declare that the project report entitled **“Microstructural analysis of mammalian teeth of Kutch and siwalik basin for taxonomical identification”** has been prepared by me under the guidance of Dr. K.Milankumar Sharma, Centre for Geography and Geology of Punjab, Bathinda. No part of this project report has formed the basis for the award of any degree or fellowship previously.

BIKASHIT GOGOI

Reg.no-16mscegs10

MSc. Geology

Department of Geography & Geology

School of Environment and Earth sciences

CERTIFICATE

I certify that **Bikashit Gogoi** has prepared her project report entitled “**Microstructural analysis of mammalian teeth enamel from Kutch and siwalik basin.**” for the award of Master’s degree of the Central University of Punjab, under my guidance. She has carried out this work at the Department of Geography and Geology, School of Environment and Earth sciences, Central University of Punjab.

Dr. K MILANKUMAR SHARMA
Department of Geography and Geology
School of Environment and Earth sciences
Central University of Punjab
Bathinda -151001
Date:

ABSTRACT

Name of student: Bikashit Gogoi
Registration number: 16mscegs10
Degree of which submitted: Master of Science
Name of supervisor: Dr. K.Milankumar Sharma
Name of Department: Geography and Geology
Name of School: Environment and Earth Science

The studies area is lies along the western most part of the Indian sub-continent between, the latitude of 23.13°-24.68° N and longitude 68.10°-71.80° E, which is pre cratonic, is preserving almost a complete sequence of sedimentary deposits ranging in age from Triassic to Recent. This dissertation attempts to study the microstructural analysis of tooth's enamel of mammals of dinotherium, gompothorium, hipparion, rhino from Miocene deposit of Kutch basin Dental materials of deinotherium, gompothorium, hipparion, rhino of Kutch basin was collected and sampled for comprehensive analysis of the microstructure of the enamel. Microstructural features of the mammalian tooth enamel used for taxonomical identification of the analysed sample. I investigated the deinotheirum, Gompotheriidae, Rhinocerotidae, hipparion. Microstructures can be analysed by the stacking pattern of the prisms, different species belonging to different family shows different types of stacking pattern called HSB. The results obtained from study of the SEM images suggest that different species of different family show different enamel prism pattern. Apart from taxonomical identification of the studied sample one can also find out dietary habits, palaeo-environment and how substances with high hardness can be chewed and grinded by enamel which is of less hardness.

Key words- EDJ (Enamel dentine junction), Radial Enamel(RE), Inter Prismatic Matrix (IPM).

Bikashit Gogoi
Signature-

K. Milankumar Sharma
(Assistant professor)
Signature-

ACKNOWLEDGEMENT

At the very outset, I would like to thank Dr. R.K. Kohli, Vice Chancellor, Central University of Punjab, for giving us the opportunity to undergo dissertation work during the last semester of Post-graduation studies. The dissertation has helped us a lot to dig deeper into the branches of Geology

This dissertation was completed only with the support of my teachers, Ph.D. Students and my friends. I would like to express my sincere gratitude to all of them. First and foremost I am thankful to my guide Dr. K Milankumar sharma, for his valuable guidance, scholarly inputs and consistent encouragement that I have received throughout my dissertation. I would like to deepest gratitude to him for his continuous support, scientific advice, insightful suggestions and encouragement that he provided patiently to complete this dissertation. Further, I would also like to acknowledge a great appreciation and crucial role to the staff of Central University of Punjab, who gave me the permission to use all required equipment and the necessary material to complete the task Second my heartiest thanks to N. Amardas Singh, Priyananda Singh for their endless support and encouragement. These people helped me in my daily work, and I am specially giving great thanks to Amardas Singh who have explained me everything about experiment and thesis related difficulties very clearly. And my last thanks to all of my friends who always gave a great support to me in my any difficulty regarding dissertation.

BIKASHIT GOGOI

CONTENT

SERIAL NO.	NAME	PAGE NO
CHAPTER I	INTRODUCTION	1-14
CHAPTER II	LITERATURE REVIEW/PREVIOUS WORK	15-18
CHAPTER III	MATERIALS AND METHODS	19
CHAPTER IV	RESULTS AND DISCUSSION	20-27
CHAPTER V	CONCLUSION	28

LIST OF FIGURES

Figures	Description	Page Number
1	Geological map of Gujarat (Redrawn after Merh. 1995)	6
2	Geological map of Kutch (GSI 1990-2001)	7
3	Broad geological map of Kutch and Kathiawar (Gujarat). (Modified after Biswas 1992.)	14

LIST OF PLATES

Plates	Description	Page no
1	SEM images of Deinotherium	20
2	SEM images of Gompootherium	21
3	SEM images of Gompootherium	23
4	SEM images of Hipparion	24
5	SEM images of Rhinocetiidae.indet	26
6	SEM images of Rhinocetiidae.indet	26

LIST OF ABBREVIATIONS

SERIALNO	FULL FORM	ABBREVIATIONS
1	Enamel Dentine Junction	EDJ
2	Outer Enamel Surface	OES
3	Radial Enamel	RE
4	Hunter-Schreger Band	HSB
5	Inter Prismatic Matrix	IPM

CHAPTER-I

INTRODUCTION & GEOLOGY

CHAPTER II

REVIEW OF LITERATURE AND PREVIOUS WORK

CHAPTER III

MATERIALS AND METHODS

CHAPTER IV

RESULTS AND DISCUSSION

CHAPTER V

CONCLUSION

1. BRIEF IDEA OF THE AREA-

Kutch, lies between the latitude of 23.13°-24.68° N and longitude 68.10°-71.80° E, which is the largest district of Gujarat occupying an area of ~ 45,674 sq. km. It is located at the westernmost part of Indian Subcontinent is bounded by Gulf of Kutch in the south, the Arabian Sea on the west, Great Rann on the north and eastern parts are surrounded by Little Rann. Kutch basin is a pre-cratonic rift basin which is preserving almost a complete sequence from Triassic to Recent deposits (Biswas, 1992). Tertiary rock formations occurred in different parts of peninsular India, but their development is considered to be most extensive in the Kutch region (Kulkarni *et al.*, 2010). The Kutch region of peninsular India has a good expansion of Miocene rock ranging in age from Aquitanian to Messinian (Biswas, 1992). The Miocene Khari Nadi Formation of Kutch are well exposed at Khari Nadi section, Jangadia section, Pasuda section, Samda section, Tappar section, etc. and most of the collected fossils are also well preserved due to the less tectonic event in the area.

Kutch basin is well known for its rich assemblage of Miocene vertebrates including fish, reptiles and both marine and terrestrial mammals (Savage and Tewari, 1975; Sahni and Mishra, 1975; Bajpai and Doming, 1997; Thewissen and Bajpai, 2009; Bhandari *et al.*, 2010, 2015; Patnaik *et al.*, 2014). This deposit, well known for its rich fossil wealth of Miocene mammals, is considered to be co-relatable with the other Miocene formations of Indian sub-continent such as Siwalik, Baripada Beds, Miocene of Tripura and Mizoram, Miocene of Irrawaddy Formation of Burma, etc. The presence of ferruginous conglomerate bed found at the top of Khari Nadi Formation is significant for their extensive yield of both the marine and terrestrial vertebrate fauna including fish, reptiles and both marine and terrestrial mammals. Earlier workers on this basin mainly emphasised on the megavertebrate and invertebrate palaeontology from this area. Some of the previous works on the Miocene deposit of the Kutch reported the occurrence of certain micro and mega-vertebrate but detailed study of the micro mammals and Piscean remains has not been done yet. Data on the detailed study on marine and terrestrial microvertebrates from these are is still need to be synthesized as they serve a very important tool for reconstruction of biochronology, past climatic, palaeo-ecology, palaeo-environment and palaeogeography. The hypothesis on the records of global diversification of the terrestrial and marine

microvertebrates, including those of micro mammals and selachian, were synchronous with the changing in the climatic pattern in general and intensification of monsoon system during the Miocene time in particular need to be proved. Besides, earlier reports on the fossil records from Khari Nadi Formation of Kutch prefers Aquitanian (23-20 Ma) age or Aquitanian to Burdigalian age or 16.5 Ma to Basal Late Miocene age (~ 11 Ma) (Bhandari *et al.*, 2010). The age controversy in this area needs to sort out using more precise index fossils including that of micromammals biochronology from the terrestrial vertebrate bearing sections.

For fulfilling the above purposes, certain field and laboratory techniques will be used which may include surveys of the study area for establishing the spatial and temporal context of fossil-bearing localities/section and documenting the recovered fossil fauna and collection of rock samples for stable isotopic, clay mineralogical and petrographical study. In the laboratory, the palaeontological samples will be macerated using different maceration processes depending on the hardness of the samples and the macerated residue will be studied under stereozoom binocular microscope for picking the microfossil remains and subsequent taxonomic classification. SEM and EDX analysis of the fossil and sedimentological samples will be done in the SEM-EDX lab of Central University of Punjab, Bathinda.

2. PHYSIOGRAPHY, GEOLOGY, AND STRATIGRAPHY

2.1 Physiography of Gujarat

Gujarat is located in the westernmost part of the India and it covers an area of approximately 20,000 sq. km within the latitude from 20°10'N to 24°50'N and longitude from 68°40'E to 74°40'E. All type of important lithologies ranging in age from Mesozoic to Recent are found in this State. Physiographically, the state of Gujarat can be divided into three zones namely Mainland Gujarat, Saurashtra and Kutch. These physiographic zones are discussed as under.

2.1.1 Mainland Gujarat: The Mainland Gujarat is divided into two sub-zone

i) The Eastern Rocky highlands: It shows an altitude ranging from 300 m to 1100 m and is considered to be the extension of the major mountains of western India viz. the Sahyadri, Satpura and the Aravalli mountains. The trappean highlands typically pointing as a strong structural control and the entire topography is characterized by E-W and NNE-SSW trending step faults, horsts and grabens.

ii) The Western Alluvial Plains: This zone comprises of thick unconsolidated sediments which were deposited as a combination of fluvial and Aeolian processes mainly during quaternary period. These form the western half of the Mainland Gujarat.

2.1.2 Saurashtra: This zone is formed by a rocky fringed of coastal plains and a major portion of it is occupied by the Deccan trap. The central part is made up of undulating plains broken by hills and dissected by various rivers from different directions. The Eastern fringe is low lying ground marking the site of the former sea connection between the Gulfs of Kutch and Cambay. Numerous linear dyke ridges protruding above the basaltic surfaces reached up to the height of 10 m. The coastal plains fringing the Trappean highlands show a maximum altitude of 50 m and comprise a Cenozoic cover consisting of Tertiary and Quaternary sediments.

2.1.3 Kutch: Kutch is also dividing into four geomorphic types (Merh, 1995)

i. The Rann: It forms a unique salt-encrusted wasteland rising only a few meters above sea level.

ii. The Low Lying Banni Plain: It lies between the great Rann and Rocky Mountain.

iii. The Hilly Regions: It is consisting of three units viz. the Island Belt, the Kutch mainland and the Wagad.

iv. The southern coastal plains: It borders the mainland against the Gulf of Kutch in the south and the Arabian Sea in the west.

The rocks of Gujarat comprise lithological formations ranging in age from the Precambrian to the recent. However, the major geological and tectonic events responsible for the formation of present day Gujarat were initiated during the Triassic with the breaking up of the Gondwanaland and completed during the Cenozoic to Quaternary time encompassing certain marine transgression/regression events during Mesozoic and Cenozoic, the Deccan volcanism and formation of quaternary deposits. The Mesozoic and Cenozoic tectonism related to the breaking up and drift have mainly controlled the geological evolution of Gujarat.

2.2 The drainage system of Gujarat

In Gujarat, there are many rivers which are flowing towards the Arabian Sea but some of them flow to Rann of Kutch. Most of the rivers in Gujarat are seasonal type river. Narmada River which is the largest river in Gujarat is originated from the Amarkantak plateau and flow to the Arabian Sea. The second largest river Tapi,

which is originated from Betul, Madhya Pradesh, is one of the major rivers flowing toward west in India. Sabarmati River originated from the Aravalli range along with Mahi and Aji Rivers are the main rivers in Gujarat.

2.3 Climate

Gujarat falls within the sub-tropical climatic zone and the tropic of cancer pass through this state. The weather of the state varies in different regions and due to its close proximity to the sea coast, the coastal regions experience a humid condition while the interior part of the state experiences a completely different climate. Summers season is extremely hot and the winter is extremely cold. However, on the coastal regions and the eastern belt of Gujarat have a slight pleasant climate with moderate rainfall during the monsoons. The monsoon season the area covers from mid-June to September. Before the monsoon, the temperatures are rising high with an increased humidity in the air. Most part of the state is under the isotherm between 35°C and 45°C (Merh, 1995). The approximate average temperature during day time is 29 °C and 12 °C in the night. Gujarat enjoys a moderate rainfall. Most of the rainfall is occurring between June and September from the southwest monsoon (Merh, 1995). Merh (1995) divided five regions in Gujarat on the basis of climate. They mention below.

i. Sub-Humid Region: - South Gujarat (South of Narmada)

ii. Moderately Humid Region: - Central Gujarat (between Narmada and Sabarmati)

iii. Humid and Sultry Region: - South facing coastal region of Saurashtra

iv. Dry Region: - Regions of Central Gujarat north of Ahmedabad and parts of central Saurashtra

v. Arid and Semi-arid Region: - North Gujarat and Kutch

. 2.4 Geology of Kutch

The first geological investigation of Kutch area was done by Grant (1837) and later on, Blanford (1869) presented proper ideas about the geological architecture of the region. The first report along with a map and the geology of Kutch was published by Wynne (1869 & 1872). Wynne (1872) classified the Tertiary sediment into six Groups viz. i) Sub-Nummulitic, ii) Gypseous shale, iii) Nummulitic Group, iv) Arenaceous Group, v) Argillaceous group; and vi) Recent tertiary. However, this classification lacks a definition of the units. Merh (1995) described the thick deposit of Mesozoic sequence which ranges up to 3000 m and ~1000 m thickness for Cenozoic sediments. There are several faults in the Kutch which are important for the

evolution of the geology of Kutch. The presence of these regional faults is inferred largely due to abrupt changes in lithology and topography. Karanth and Gadhavi (2007) described five main faults in this region namely Nagar Parkar Fault, Allah Bund Fault, Island Belt Fault, Kutch Mainland Fault, and Katrol Hill Fault and two minor faults Vigodi Fault and Naira River Fault. South Wagad Fault and Gedi Fault are found in eastern part of Kutch. These faults are reactivated from time to time (Biswas, 1971, 1980, 1982; Bodin and Horton, 2004; Chopra *et al.*, 2008).

Tertiary deposit of the Kutch region is mainly exposed in the narrow coastal plains of the Kutch mainland and in the peripheral plain (Fig. 1). The less deformed tertiary rock wrap around the Mesozoic structure and the most of the Tertiary sediment are deposit took place in the shallow marine peritidal environment (Biswas, 1992). Biswas (1965) proposed a new time-stratigraphic classification of the tertiary sediment of Kutch based on chronostratotype and detailed mapping of the time rock unit and it was again later on modified by himself (Biswas 1971, 1973). Biswas and Raja (1971, 1973) presented a lithostratigraphic classification of tertiary sediment of Kutch introducing a small change in previous nomenclatures. Biswas (1992) classified tertiary stratigraphic of Kutch as given below (Table 1): -

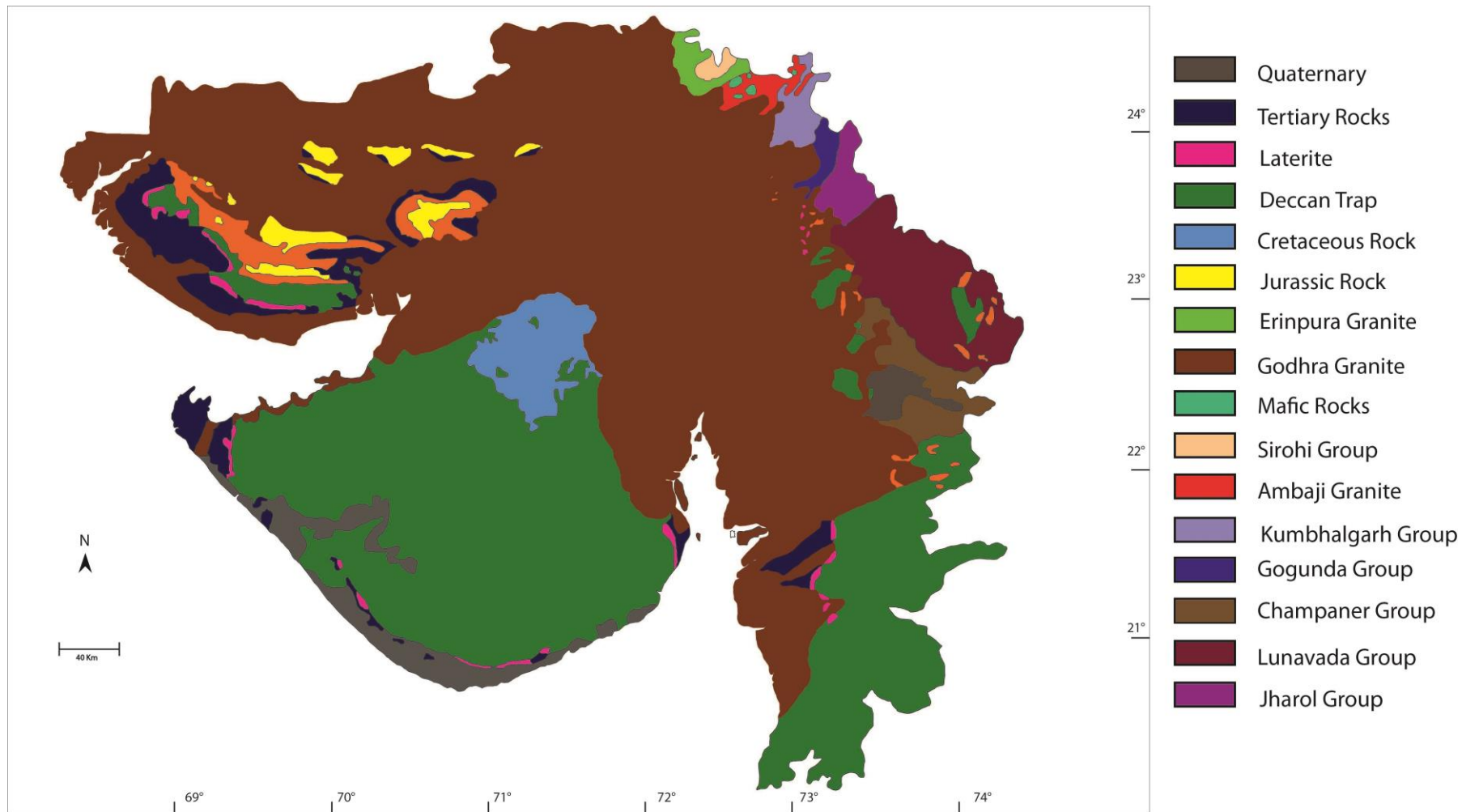


Figure 1 Geological map of Gujarat (Redrawn after Merh. 1995)

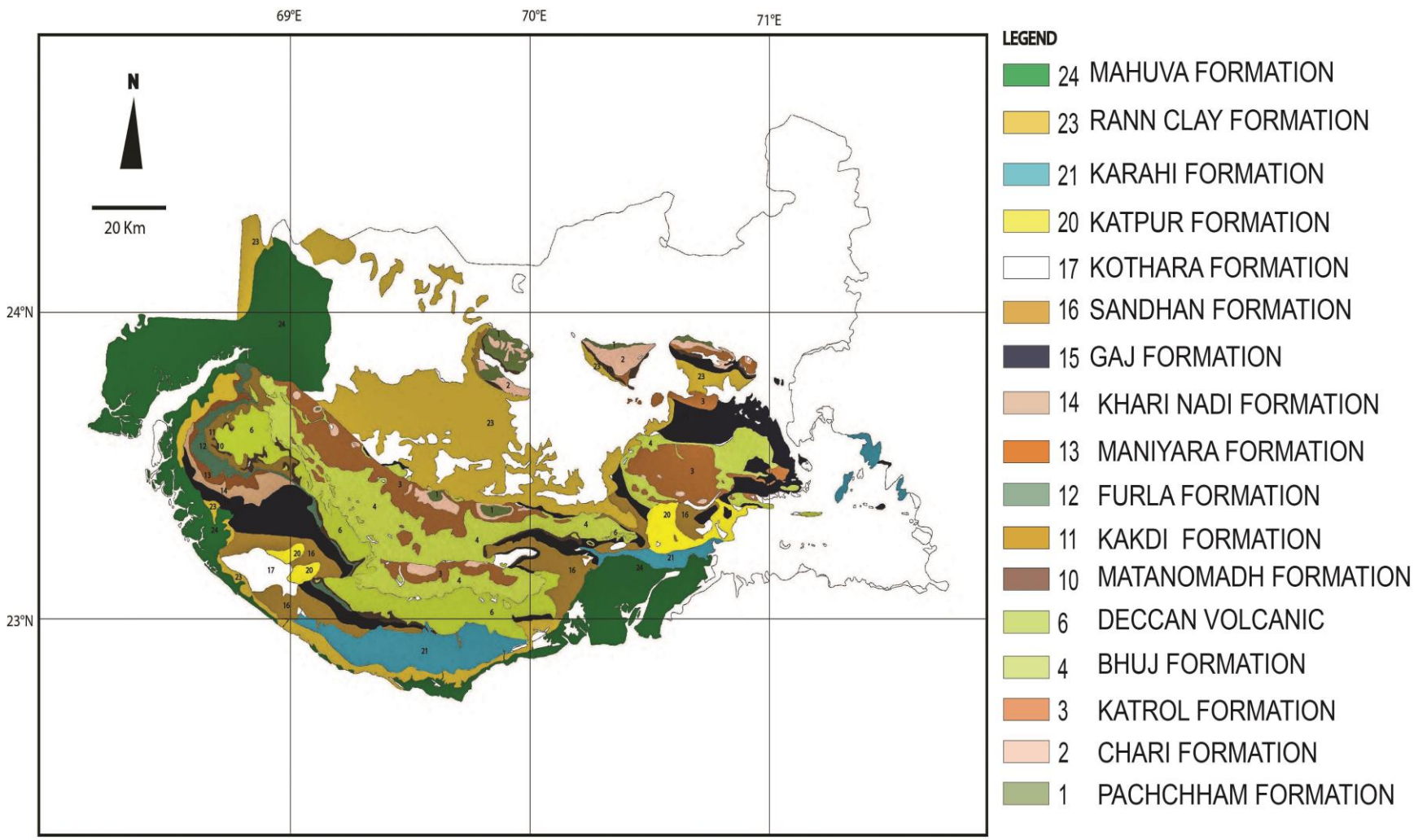


Figure 2 Geological map of Kutch (GSI 1990-2001)

Time in M.Y	Series	Stages	Lithostratigraphy Formation	Members	Kutch Stage
10	Miocene	Messinian	Sandhan		Kankawatian Super stage
		Tortonian			
20	Miocene	-----10.2----- Serravallian	Chhasra	Siltstone	Vinjhonian
		-----15.2--- Langhian		Claystone	
	-----16.2-- Burdigalian			Aidaian	
	-----20----- Aquitanian				
30	Oligocene	-----25.2-- Chattian	Maniyara Fort	Bermoti	Waiorian
		-----30----- Rupelian		Coral Limestone Lumpy Clay Basal Member	Ramanian
40	Oligocene	-----36----- Priabonian	Fulra Limestone		Babian
		-----39.4--- Bartonian			
	-----42----- Lutetian				
50	Eocene	-----49----- Ypresian	Hauridi	Ferr. Claystone Assilina Limestone Gypseous Shale	Kakdian
		-----54--- Thanetian	Naredi		Khasian
60	Paleocene	-----60.2--- Danian	Matanomadh		Madhian
			Deccan Trap		

Table 1-Classified Stratigraphy of Tertiary sediments of Kutch (after, Biswas 1992).

2.4.1 Matanomadh Formation:

This Formation is mainly exposed on the mainland Kutch, which is bordering the Tertiary rocks from the Mesozoic deposit and directly overlying the Deccan trap (Fig.2). It is named after the Matanomadh village, in western Kutch and is well exposed in Bhuj-Lakhpat road section, Madhwall Nadi section, etc. The lithologies of this Formation are red laterite, bauxite, conglomerate, clay, sandstone, etc. with a total thickness of about 49 m (Biswas, 1992). The formation is assigned as Palaeocene age by referring to pollen –spore assemblage (Mathur, 1966). The lithologies of this formation may be variegated in different sections with the presence of brightly colored rock types with different admixtures of clastic and volcanic material (Biwas, 1992). This Formation, mainly comprising of the volcanoclastic sediment, is considered to be deposited during the Deccan volcanic (Biwas and Deshpande, 1973). Matanomadh Formation is unproductive of fossils but locally rich in microflora dicot leaf impression, occasionally with fossil fruits and wood (Biwas, 1992).

2.4.2 Naredi Formation

Naredi Formation is well developed at the western part of Kutch and it overlies the Matanomadh Formation. The Formation is mainly exposed on the Kakdi Nadi and moderately along the Guvar stream section at the north western of Naredi village and it is having a total thickness of about 100 m (Biwas, 1992). Naredi Formation present huge thickness of lignite beds as developed in the Babia Syncline, Umarsar, Panandro area, etc.

Biwas (1992) described three distinct lithostratigraphic members as follows: -

i) Gypseous shale member: This member is about 24 m thick and comprises of grey, brown and olive green glauconitic claystone and splintery shale with a thin layer of gypsum, limonite, and bands of sideritic concretions which contain fossils –Veneri cardia and Nautilus.

ii) *Assilina* limestone member: This member is 6 m thick and contains a bedded, dirty white limestone and yellowish grey marlite studded with *Assilina*.

iii) Ferruginous claystone member: This member is about 15 m thick and comprises a grey and brown claystones with a layer of gypsum and red ferruginous laminae and a red laterite bed capping the sequence marks the unconformity with the above depositions.

The Lower member of the Formation is assigned as Palaeocene in age and the Middle member with *Assilina* is early Eocene in age. Naredi Formation overlies

above the Deccan trap Formation in the west of Naredi. The Naredi Formation is separated by disconformity from the Matanomadh Formation and also from the upper Haudi Formation. The deposition environment of this formation varies from lagoonal to marine inner shelf (Biwas, 1992).

2.4.3 Harudi Formation:

The Formation is well exposed in the western side of the Harudi village. The formation is well developed in the south of Lakhpat Fort and south-western flank of Narayan Sarovar. This formation is bordering the outcrop of the overlying nummulitic limestone. The Harudi Formation is thin (only 14 m thick) as compared to other formations. This Formation consists of claystone and siltstone and a layer of gypsum and carbonaceous shale. Harudi Formation is having a disconformable contact on top of the laterite bed of Naredi Formation. It is assigned as Middle Eocene age as indicated by Foraminifera assemblage. Biwas (1992) described the lithology of this Formation as comprising of variegated shale having green and greenish grey grey colour splintery shale with yellow limonitic separations in the lower part of calcareous claystone and siltstone with a layer of gypsum and carbonaceous shale in the upper part. The depositional environment of Harudi Formation is littoral to lagoonal in the lower part and inner shelf in the upper part as indicated by foraminiferal assemblage (Biwas, 1992).

2.4.4 Fulra Formation:

This Formation is well exposed only on the western part of the Kutch and best exposed on the southern flank of Babia hill, about 1.7 km south-west of Fulra village. The thickness of this Formation is about 60 m but some of the section of the formation has thinner exposure. The age of the Formation is given as late Middle Eocene (Biwas, 1992). The lithologies of this Formation is entirely made up by massive to thickly bedded, white, and buff-colored foraminiferal limestone. The limestone is fossiliferous micrites, biomicrites and bimicrosparite locally silty (Hardas and Biwas, 1973). The Formation is conformably contacted in the lower and the upper part is contacted with paraconformably. The deposition environment of this Formation as characterized by the foraminiferal assemblage indicated low energy, clear waters probably under middle shelf environment (Biwas, 1992). Fulra Formation is well fossiliferous and abundance of foraminiferal assemblages have been reported

(Mohan and Soodan, 1970) along with a record of nannoplankton form (Singh, 1986) and vertebrate fossils (Sahni and Mishra, 1975).

Samanta (1989) recognised eight biofacies in Fulra Formation in Lakhpat area. They are given below, from bottom to top:-

- i. Large, thick *Discocyclina* Biofacies.
- ii. Large, *Discocyclina* radiate *Nummulites*- *Assilina* Biofacies.
- iii. Large compressed lenticular *Assilina* Biofacies.
- iv. *Asterocyclina*- *Discocyclina* Biofacies.
- v. *Discocyclina* – *Nummulites* Biofacies.
- vi. Large *Alveolina*-*Nummulite*-*Discocyclina* Biofacies.
- vii. Small *Nummulite*-*Discocyclina*- *Alveolina*.
- viii. Large ellipsoidal *Alveolina* Biofacies.

2.4.5 Maniyara Fort Formation

This Formation is mainly exposed in Ramani stream, Waior stream, Berwali Nadi, Bermoti stream and around the Lakhpat. The Formation is named after Maniyara Fort. It consists of yellow to ochre colored foraminiferal limestone with basal greyish green glauconite siltstone. Maniyara Fort Formation with a total thickness of about 35 m is considered to be of Oligocene age. Biswas (1992) divided the lithostratigraphy of this Formation into four members as described under: -

i. The basal member

This member is about 4.3 m thick and contains alternating beds of foraminiferal, glauconitic, brownish to yellowish siltstone and calcareous, gypseous claystone. The presence of green pellets of glauconite distinguishes this member from the underlying Fulra Limestone.

ii. The lumpy clay member

It is about 4.7 m thick and comprised of grey colored to brownish calcareous, lumpy claystone, occasionally containing thin limestone and marlite beds.

iii. The Coral limestone member

This member is about 9.14 m thick and contains dirty white nodular limestone and calcareous claystone in the lower part. The upper part comprises grey to dirty white massive limestone with a present of coral, small bioherms. And the

limestone is glauconitic, biomicrites and biosparite (Hardas and Biwas, 1973). This member is well exposed in the Ramania.

iv. The Bermoti member

The Bermoti member is about 11 m thick which is developed in the Bermoti and Waior. Also exposed in the Maniyara Fort Hill. This member consists rusty brown, friable glauconitic argillaceous sandstone with pseudo-oolites in the lower part and in the upper part thinly bedded, very hard, grey to yellowish foraminiferal limestones.

The formation is abundantly fossiliferous and vertebrate fossils are more common in this formation. The depositional environment of this formation is a marginal marine, littoral to shallow inner-shelf.

2.5 Geology of Miocene deposit of Kutch

Miocene deposit of the Kutch regions is covered about 30 percent, which are lying unconformably over on the Jurassic rock. The outcrops of Miocene rock are nearly east-west trending. The Miocene deposit of Kutch are classified into three formations by Biswas (1992)

2.5.1 Khari Nadi Formation

Khari Nadi Formation is known as Arenaceous Group (Wynne, 1872), Gaj bed (Poddar, 1959; Mohan and Bhatt, 1968). Khari Nadi Formation which infers as Lower Miocene (Aquitania) overlies the Maniyara Formation of Oligocene Epoch. The formation is a sequence of fine-grained to silty and sandstone. This formation is named after Kari Nadi exposed along cliffs and banks of Khari Nadi between its meetings with Sugandhi Nadi. The formation is mostly developed on the southern flank of the Narayan Sarovar. It extends to the north upto Lakhpat. Around the peripheries of the Rann Island and Wagad highland, the formation unconformably overlies above the Jurassic rocks. The thickness of the formation is 65 m which is reducing along the Kankawati river section which becomes 47 m and in the Rann Island the thickness is again lesser and varies from 15 to 35 m. The lithology of this formation comprised laminated to very thin bedded red and yellowish parti-colored to variegated siltstone and very fine-grained sandstone with random grey and brown gypseous claystone.

On the Eastern Kutch red lateritic conglomerate with agate pebbles, purple ferruginous sandstone, white-felspathic and tuffaceous sandstones with laminated claystone constitute the lithology of the formation. In the basal part of the formation,

bioturbation is common which is responsible for its mottled variegated appearance. And the vertical burrows are filled up with red hematite in contrast with the bright yellow color of the burrowed siltstone. The formation is contacted by conformable on the lower part and also on the upper part. The depositional environment of the formation is tidal flat, littoral to the shallow inner shelf, in slowly transgressive sea over a stable shelf (Biwas, 1992).

2.5.2 Chhasra Formation

The formation names after the Chhasra village. This formation is originally described as Vinjhan shale (Biwas and Raju, 1971, 1973) and Gaj bed (Tewari 1957, Podder, 1959; Chatterjee and Mathur, 1966). This formation exposes along the Khari Nadi and a 4.5 km stretch in the Kankawati River between Khirasra and Vinjhan is the best reference section. In broadly exposed Southern and Eastern Kutch part, it overlaps all the tertiary formations developed in western Kutch mainland, gradually toward the east where it lies over the Mesozoic rocks, the Deccan Trap or the Matanmadh Formation. Chhasra Formation which infers as lower Miocene (Burdigalian) conformably overlies the Khari Nadi Formation of lower Miocene (Aquitanian).

The lithology of this formation has divided into two distinct members as

i. A lower claystone member

This member is about 80 m thick which is best exposed in the formation and comprised of grey and khaki colored, laminated to splintery, gypseous shale and claystone with alternations of thin, yellowish, highly fossiliferous argillaceous limestone. And this member yields a mega fossil like *Turritella*, *Ostres*, and *Conus* (Biwas, 1992).

ii. An upper siltstone member It is about 35 m thick which is well exposed along the Kankawati River. This member comprised predominantly of alternating micaceous siltstone and laminated silty shales of dull khaki color. The upper part is reddish (Biwas, 1992).

2.5.3 Sandhan Formation

Sandhan Formation which infers as middle to upper Miocene disconformably overlies above the Chhasra Formation of Lower Miocene (Burdigalian). The formation is dominated by sandstone and is also the highest in the tertiary sequence of Kutch. The formation names after the Sandhan village. The formation is exposed in a wide continuous belt of outcrops all along the coastal plain of south-western, southern

and south-eastern Kutch mainland from Naliya in the west to Anjar in the east. In the plain lands of the eastern Kutch, it also exposes in patchy outcrops overlying the Chhasra Formation. The thickness of the formation is 294 m in south-western Kutch but thin continuously toward the east.

The lithology of the formation comprised well sorted, medium to coarse-grained, massive, micaceous, quartzose sandstones, overlain by clayey, laminated siltstones and topped by thin yellowish fossiliferous limestone beds on the lower part of the formation. In the middle part of the map conglomerates and coarse-grained sandstones with lenticular bodies of conglomerates are seen and in the upper part comprise mainly with hard, calcareous grits, overlain by pink and grey mottled silty sandstone with calcareous nodules.

The formation is disconformably overlies on the Chhasra Formation. The depositional environment of the formation is fluvial sedimentation and supra-littoral to deltaic or foreshore environment.

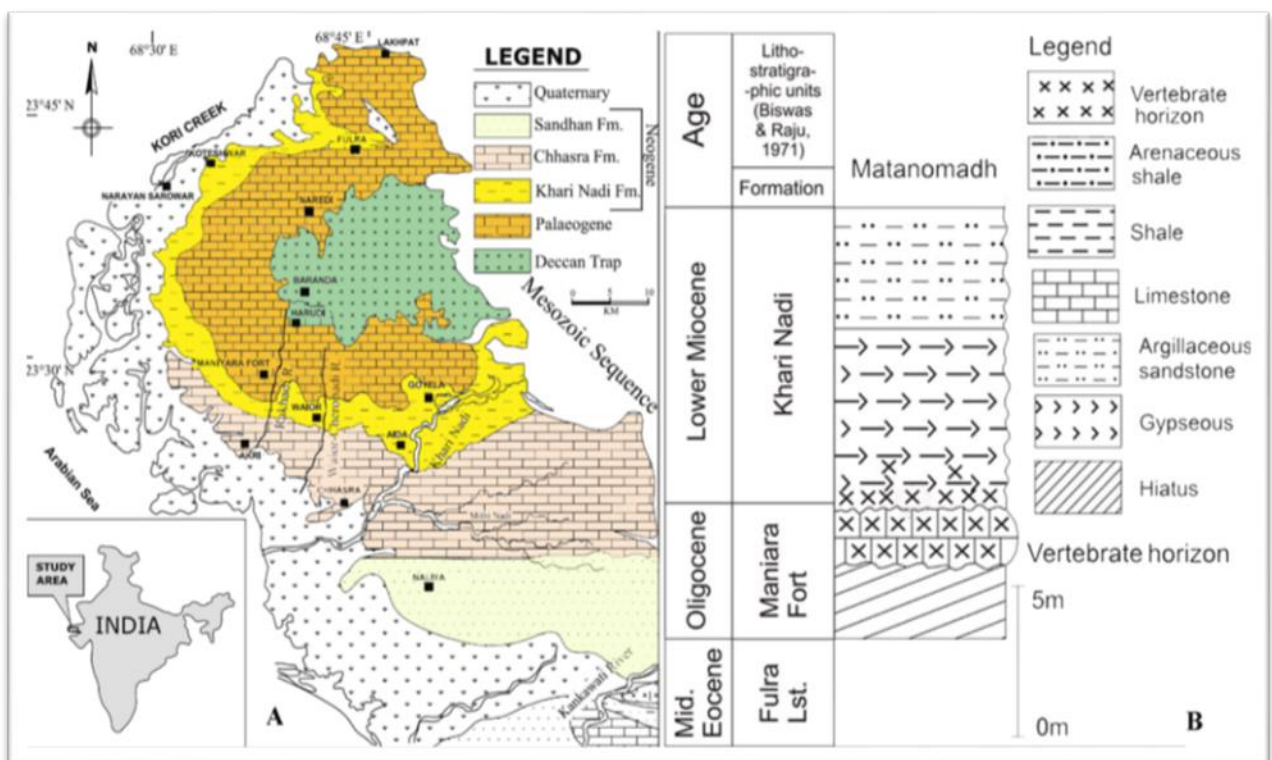


Figure 3 Broad geological map of Kutch and Kathiawar (Gujarat). (Modified after Biswas 1992.)

My work is to emphasize on the enamel microstructure of mammalian teeth belonging to the Kutch basin and to carry out taxonomical identification of the fossils. The fossils taken for study are mainly dinotherium, gompothorium, hipparion and rhino of Kutch basin, hence the review of literature section of the synopsis is mainly based on the microstructure analysis of mammalian teeth studied by various authors.

Lilian Paglarelli Bergqvist and Wighart von Koenigswald (2004) studied enamel development and structure in a number of placental and marsupial mammals by light microscopy, electron microscopy and scanning electron microscopy, and in particular, the relationship between the formative cells of the enamel and its structural organisations into prisms and inter prismatic matrix has been studied.

Post canine teeth of the Paleogene *Carodnia* from Brazil were studied in regard to the enamel microstructure analysis. The enamel is entirely prismatic, and the inter-prismatic matrix (IPM) is oriented parallel to the prisms, which consists of Boyde's patterns 1 and 2. The prominent vertical Hunter-Schreger-bands (HSB) are restricted to an outer zone, whereas the inner zone is formed by transverse but irregular HSB. Such a combination is very rare in mammalian teeth, but shows some similarities to the *schmelzmuster* of specific perissodactyls, where it evolved independently. Significant differences to Astrapotheria were found. The mastication pattern can be derived from the orientation of the wear facets on the transverse lophs. In stages of moderate tooth wear, the lophs have one-sided planar facets that are inclined in the upper and lower teeth antagonistically. Enamel crests on the leading sides cut like scissors. Subsequently, the antagonistic shear-cutting crests of the lophs pass each other and compress the food items until central occlusion. Thus, the jaw movement during phase I is predominantly mesial with a distinct inclination upwards. No traces indicate a phase II of the power stroke. Neither the enamel nor the widely-distributed mastication pattern offer convincing arguments to support any of proposed phylogenetic relationship of *Carodnia*.

Rodolphe Tabuce, Cyrille Delmer and Emmanuel Gheerbrant (2006) stated, in their paper that microstructural features of the mammalian tooth enamel are rarely used to

construct phylogenies, although macromorphological characters of the dentition figure are prominently used in phylogenetic analysis. In order to test the phylogenetic significance of the enamel microstructures, they investigated the earliest proboscideans recently found in the Early Palaeogene of Africa (e.g. *Phosphatherium*, *Daouitherium*, *Khamsaconus*, and *Numidotherium*). The results were discussed in light of the recent advances concerning the intra- and interordinal relationships of the Proboscidea, with the analysed microstructures suggesting that the enamel ancestral morphotype of paenungulates was primitive for eutherian mammals, consisting of radial enamel. More evolved proboscideans developed very complex enamel, the 3-D enamel, which represents an apomorphy for the group. The three-layered Schmelzmuster, typical of the elephantoids, is acquired during the late Eocene with the enigmatic '*Numidotherium savage*'. The peculiar enamel of elephantoids arose step by step. Although homoplasy and mosaic evolution occurred, but the enamel microstructures represent an important source of new dental characters for phylogenetic reconstructions. As macromorphological characters testified, the diversity of the enamel microstructures observed in the various basal proboscideans illustrates an unexpected early diversity of the order in Africa (2007).

Macro P Ferreti analysed the dental material of the South American elephantoid *Cuvieronius hyodon* from the Late Pleistocene of the Tarija Basin. The incisor and cheek teeth enamel is compared to that of other proboscideans in order to reveal phylogenetic and functional informative features useful to reconstruct the evolution of elephantoid enamel. The results obtained from this study demonstrate the generality, among elephantoids of the basic microstructural features of *Cuvieronius hyodon* enamel, allowing the characterization of the Elephantoid Enamel (EE).

Koenigswald et. al. (1999) studied on hypsodonty and concluded that the earliest mammals which developed hypsodont cheek-teeth were Gondwanatherium by Late Cretaceous. Hypsodonty occurred independently in Gondwanatheria, with the hypsodont molariform cheek-teeth of the early Paleocene. *Sudamerica ameghinoi*, the youngest member of the Gondwanatheria, has been described in the study. It had in the lower jaw a continuously growing incisor, separated by a large diastema, regarded as molariforms because of the four cheek-teeth that cannot be homologized with premolars or molars. They identified 8 different species while analyzing 1 fragmentary mandible and 30 isolated molariform, corresponding to four upper and four lower molariforms, which are characterized by transverse lophs. The enamel of

the molariforms of Sudamerica is one-layered and characterized by radial enamel, which is same as the enamel of Gondwanatherium. The evolution of hypsodonty in gondwanatherians during the Late Cretaceous and early Paleocene cannot be correlated with a grass diet, since grasses were not present during that time.

Remy and Benammi (2006) studied the Aït Kandoula basin, one of the richest Miocene micromammals having areas known in the South of the High-Atlas, with the large mammal being very rare. They studied a selected section in the center of the basin, and found it to be well calibrated with the Geomagnetic Polarities Time Scale (KC95) and shows a succession of six fossiliferous layers. Beside rodents, the Afoud AF6 layer yields among some large mammal remains a proboscidean, identified as a Gomphotheriidae indet from the enamel microstructure of a molar chip. However this determination is grounded on the thickness of the enamel, on the prisms type, on the thinness and characteristics of the 3D zone and outside on the preferential course of the prisms.

Rajiv Pattnaik & Milankumar Sharma et.al (2014) presented in their paper a list of the vertebrate fauna collected during fieldwork carried out in Kutch from several early Miocene localities in the Lower Miocene. They described and commented on fossil remains of fishes (Chondrichthyes and Osteichthyes), reptiles (tomistomid crocodiles) and mammals (*Deinotherium* sp., Gomphotheriidae indet. and *Brachypotherium* sp.) from an early Miocene ferruginous Khari Nadi formation exposed at localities Jangadia, Samda, Pasuda and Baadra. A shark, *Megaselachus chubutensis*, was reported for the first time from India and a batoid *Rhinoptera* from Kutch. A fossil latid fish has also been recorded for the first time from India. The fossils found belong to the sub-tropical regions. The present terrestrial and freshwater fauna has similar elements in North Africa and Europe and supports hypotheses of faunal exchange between these regions caused by the opening of land route between Afro-Arabian plate and Eurasia in the early Miocene time. These land connections have been disrupted irregularly by marine incursions as appeared by the presence of similar shark fauna in all of these areas.

A rich and diversified mammalian assemblage is known from the Miocene sediments of India. Though the major part of the Miocene mammals is reported from the Siwalik sediments, other localities and stratigraphic horizons have also been

recognised from where significant mammalian faunas of Miocene age have been reported. In India, the Lower and Middle Siwalik sediments of Jammu (J. & K.), Kangra and Bilaspur (H.P.) and Kalagarh (Uttarakhand) have yielded rich and diverse continental Miocene mammalian fossils. From the Himalayas, other than the Siwalik Group, the Miocene mammals have been on record from the Kargil Molasse Group of Ladakh Himalaya and from the Murree and Dharamsala Group of the Himalayan foreland basin. From the Indian shield region, while a very significant Miocene mammalian assemblage, both continental and marine, have been reported from Kutch, Gujarat (western India), while slow progress has been made very recently from Baripada Beds, Orissa (eastern India). In this contribution, the present status of the Miocene mammalian faunas from the above mentioned localities has been synthesized besides enumerating the future prospects of fossil mammal studies.

➤ FIELD INVESTIGATION

Detailed geological field work and mapping of the area is carried out selecting the n for paleontological and sedimentological studies. Thorough field work will also be done at the previously well-known fossil sites and its adjoining lithostratigraphic units. This survey will create the spatiotemporal context of fossil-bearing localities (including the collection of GPS coordinates for all localities) taking into consideration with the exposure of most complete and less tectonically undeformed section for documenting fossils.

For the paleontology bulk sampling from each horizon will be carried out during the section measurement. Approximately 2500kg of the sample will be taken for the analysis of mega vertebrate including Gomphotherium, Hipparion, Deinotherium and Rhino. The location and horizon from where the samples to be collected will be properly recorded in the diary and field photograph is taken. Each collected sample is properly labeled and each fauna collected will be properly labeled which will be stored in the laboratory of department of Geology and Geography.

➤ LABORATORY INVESTIGATIONS

SEM (Scanning Electron Microscope) ANALYSIS

Proper preparation for microfossil samples will be carried out before SEM-EDX analysis. The fossil sample that is collected from the field is first cleaned by using ultrasonic bath by 5-10 minute. After cleaning in the ultrasonic bath, the sample is put on the SEM plate by using double side tap and clean again with acetone. Thereafter, the fossil will be subjected to gold coating. For microstructure analysis of mammalian enamel and dentine, the cleaned samples will be first cut both in the longitudinal and transverse section by **Buehler Isomet 1000 Precision Saw** and the surface will be polished. Etching of the polished surface will be done using 0.2N HCL before gold coating. SEM-EDX analysis of the gold coated samples will be done including proper photography at the Carl Zeiss Merlin Compact 6073 Scanning Electron Microscope housed at Central Instrumentation Laboratory, Central University of Punjab, Bathinda.

5.1. Deinotherium

Description:

In the Fig A the OES is clearly visible, prisms are absent the whole enamel is comprised of IPM which are not well developed. In the Fig B the EDJ is clearly visible the enamel is comprised of prisms which are randomly oriented in various directions. Two types of HSB are present in one HSB the prisms are pointed upward which are less developed and other is pointed downward Fig C.

In Fig D the enamel comprises of IPM but as we go further up we get well developed prisms. HSB's are oblique to the EDJ, they seem to be parallel to another Fig E. In the Fig F near the OES the enamel is dominated by IPM, few HSB are seen but are not distinct which are in form of striation marks parallel to each other.

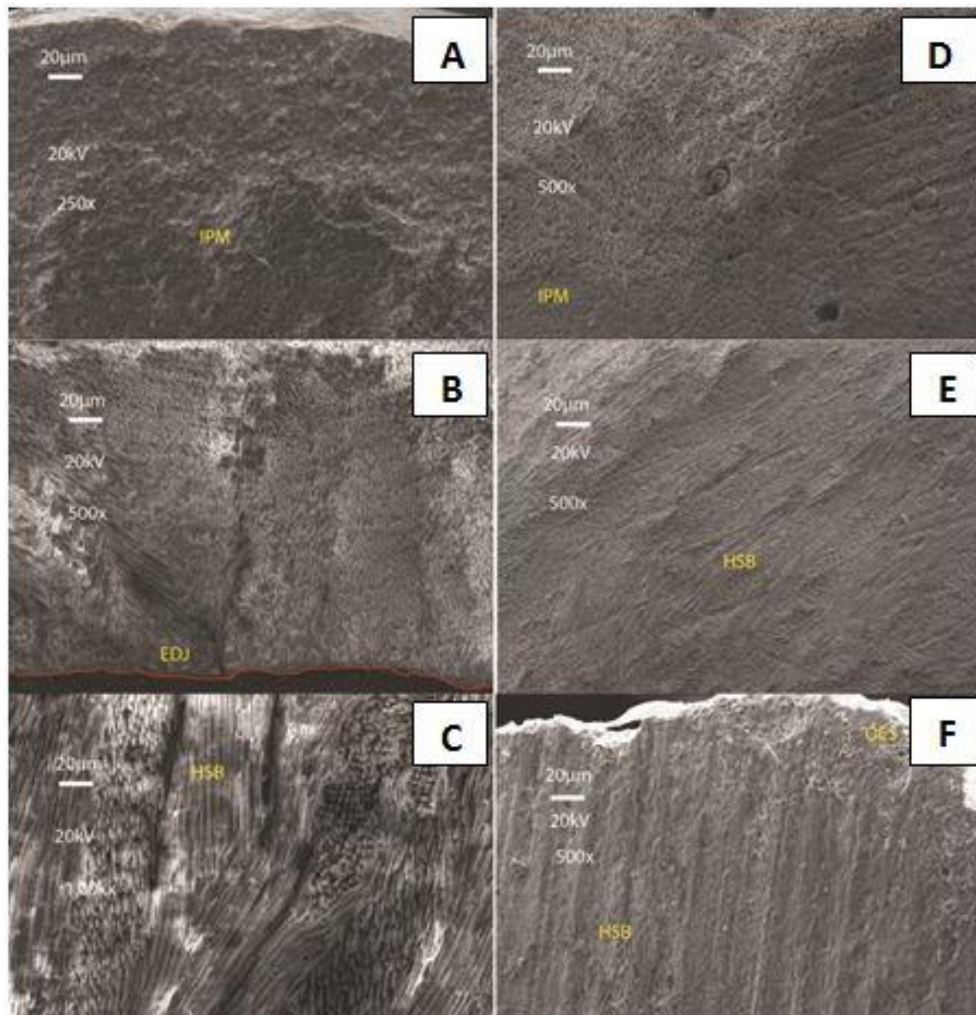


PLATE 1 SEM images of Deinotherium

Remarks-

Macro P Ferreti studied and analysed the enamel microstructure of dinotherium and observed their stacking pattern. As the present specimen is only a part of the fossil teeth so it is difficult to identify it in species level, however the prism pattern a their orientation shows resemblance to dinotherium.

5.2 Gomphotherium

Description of Gomphotherium teeth enamel

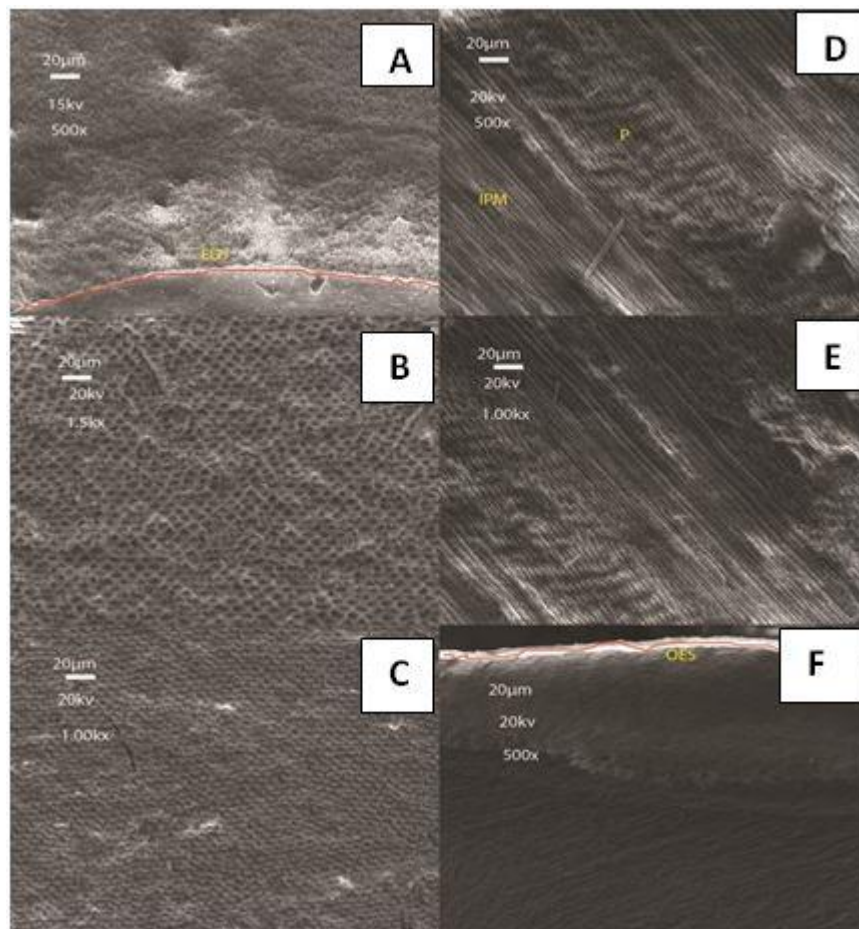


PLATE 2 SEM images of Gomphotherium

This is the longitudinal view of gomphotherium teeth the EDJ is clearly visible in which are prims are well developed and randomly arranged Fig A. In the Fig B prisms are present which are typical key-hole pattern. In the Fig C the prisms are seen to be grown in ginkgo leaf pattern.

In the transverse view of the teeth the HSB are oblique to the enamel, between two HSB, IPM is fully developed and are seen in tabular patterns Fig D. Two different types of IPM are seen one is fully developed and near the OES they are not developed Fig E. In the Fig F thick HSB is seen surrounded by well-developed IPM on both sides which are diagonal to the enamel surface.

Remarks-

Jean A Renny and Mouloud Benammi studied the complexity and stacking pattern of the gomphotheriidae indet (Proboscidea, Mammalia), their results and my results have little similarity because it's a part of the teeth. . However the microstructural features observed in the SEM image suggest that the tooth is having closer affinity to the Family Gomphotheriidae but difficult to identify in the species level.

5.3 Gomphotherium

Description –

The EDJ and OES are clearly visible, major portion of enamel is covered by IPM which are high developed in the middle portion but are not so well developed near OES Fig A. In Fig B major portion of the enamel is covered by the IPM which are well developed into crystallites which are arranged in bundles which are parallel to one another and are diagonal to EDJ. In Fig C prisms are arranged in between linear crystallites which are surrounded by bundle of prism both on top and bottom.

This is the transverse view of the tooth enamel where tooth seem to grow almost vertically with a little bit of tilt with long linear crystallites surrounding them from both slides. The prisms grow vertically upward and then orient randomly Fig D. It is the same SEM image as of D with less magnification, where the EDJ is visible in the corner the prims are seen to be growing in between the IPM crystallites Fig E. Two types of HSB are seen, prisms are seen to be intercalated in the IPM linear crystallites

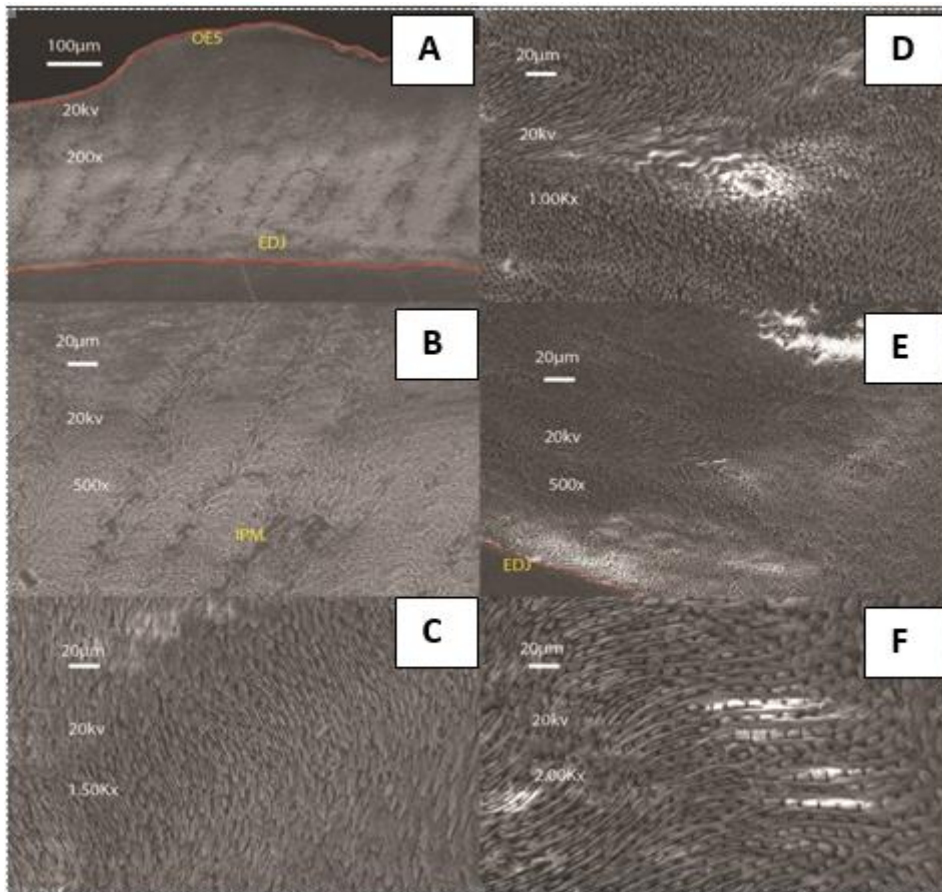


PLATE 3 SEM images of Gompothorium

Remarks-

Macro P Ferreti and Jean A Renny studied the enamel microstructure of gompothoridae and observed the stacking pattern of the prisms and inter-prismatic matrix, since the present fossil is a part of the bigger fossil teeth so species level identification is difficult but prisms pattern is very much similar to gompothoridae.

5.4 Hipparion

Description-

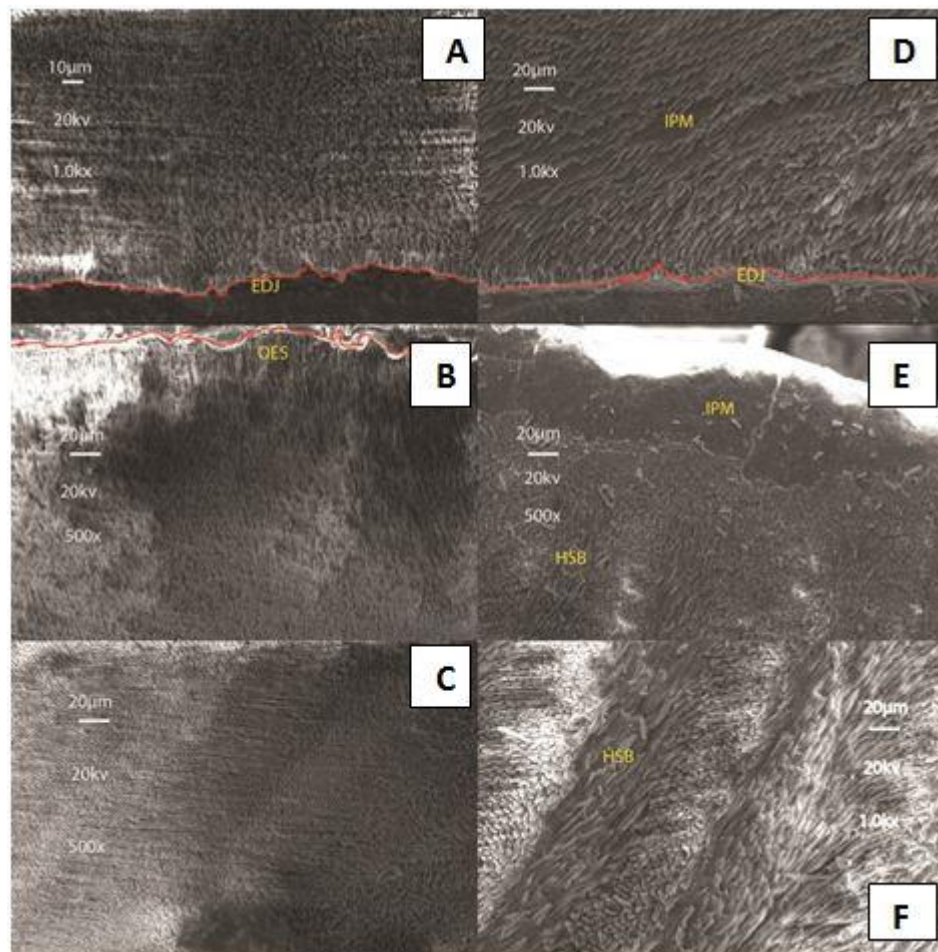


PLATE 4 SEM images of Hipparion

The EDJ is clearly visible, near the EDJ the prisms are irregularly arranged in any direction but as we go up we can see that IPM are growing linearly parallel to one another in which prism are encased Fig A. OES is clearly visible as seen illuminated by light from that direction, the prisms are growing vertically upward, they are of unequal depth Fig B. Prisms are developed in sinusoidal wavy pattern, some IPM are also visible Fig C.

The EDJ is visible clearly, the IPM is well developed and are intersecting the prisms at an acute angle diagonally Fig D. Here there are 3 types of HSB. They are parallel to one another and are diagonal to the enamel surface Fig E. In Fig E the OES is visible; IPM dominates the enamel surface near the OES. Down the IPM there are HSB's which are diagonal to the enamel surface and in between them are the prisms which are randomly oriented.

Remarks-

The Nicolas A Famoso studied and analyzed the enamel microstructure and enamel complexity where he identified hipparion equidae (perissodactyla), however from the present specimen and its SEM image one can identify it as hipparion but since it is a part of the fossil teeth so we cannot identify it to species level. We can only tell it belongs to the family of hipparion.

5.5 Rhinocerotidae.indet

Description-

These are the longitudinal view of tooth enamel of rhinoceros (Fig A to C), where HSB (Hunter-Schreger Bands) are clearly visible which can be characterized by alternating layers of prism which are seem to be growing from EDJ (Enamel Dentine Junction) towards the occlusal surface of the teeth and are more or less parallel to each other.(fig A) In between the HSB's the prisms are seen to be randomly arranged. The Fig B is just a magnified image of Fig A with a magnification of 1000x.the prisms are seen to be randomly arranged, a small portion of key-hole type prism pattern. (Fig D to E) are the transverse view of the enamel in which the prisms are in sinusoidal pattern (Fig A) ,the prisms are elongated and are more oblique near the OES(Outer Enamel Surface). Fig B is the magnified image of Fig A with a magnification of 1000x.Oblique orientation of prism. The prisms are slightly oblique to the OES but changes its direction as it moves towards the EDJ.

Remarks-

Rensberger and Koenigswald (1980) studied the rhinoceros teeth and discussed about the complexity of the microstructure of the enamel, these microstructure images reveal a quite similarity with the family rhinocerotidae. But identification of genus and species is difficult as it is a portion of the teeth

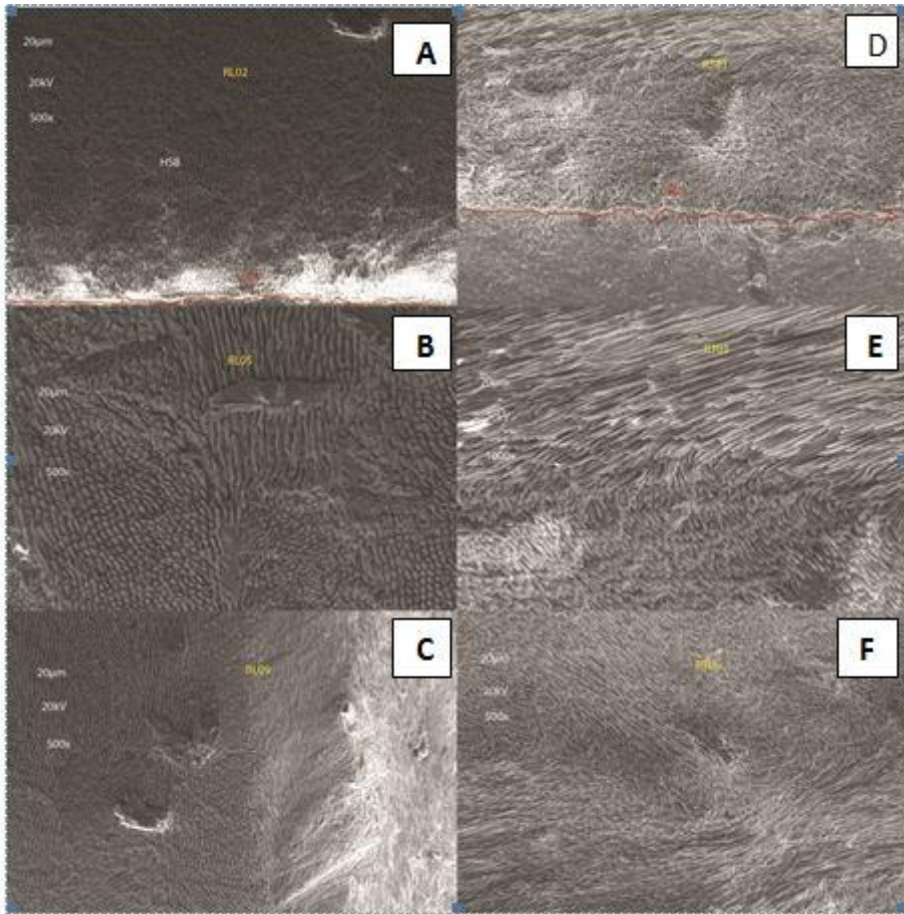


PLATE 5 SEM images of Rhinocetidae.Indet

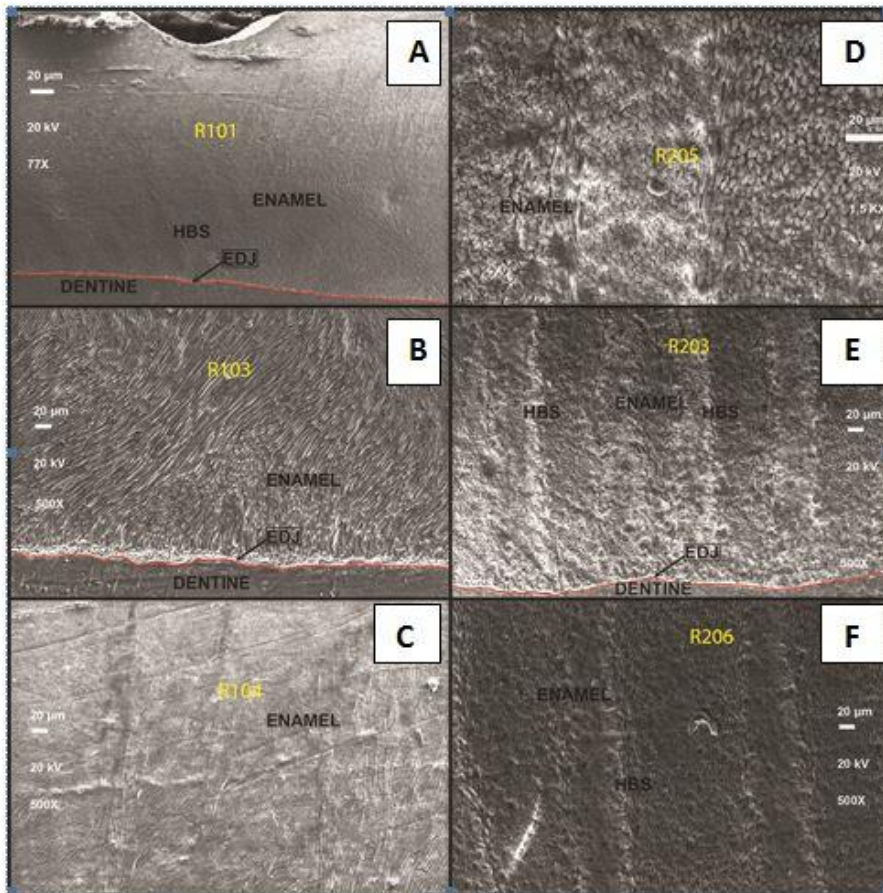


PLATE 6 SEM images of Rhinocetidae.Indet

Description-

FigA The EDJ and OES is clearly visible, HSB are visible near the OES but are not distinct. The EDJ is visible and crystal seem to have grown from the EDJ itself, the prisms are irregularly arranged Fig B.the HSB are oblique in nature which tend to orient roughly parallel to one another but most part of the enamel is IPM Fig C. In the Fig D Two types of prism patterns are seen, one in is typical type 3 pattern and ginko leaf pattern. EDJ is visible, HSB is visible in the form of ridge or elevated surface and in between the HSBs prisms are seen to be irregularly oriented Fig E. Same as in FigE in Fig F HSB are parallel to each other which are ridge type.

Remarks-The microstructure of enamel in the SEM image have little bit of similarity with - Rensberger and Koenigswald (1980) microstructural analysis but not as much to identify it in genus species level but the microstructures suggest it belongs to the family rhinocerotidae.

The analysis of various fossils that have been discussed in this report shows us the variability in the enamel microstructure irrespective of fossil species, here four genus namely dinotherium, gompothorium, hipparion and rhinocetidae has been analysed and for each genus we I have found a different pattern of enamel prisms and different stacking pattern.

- a) In Dinotherium the prisms are seen to be randomly oriented and the enamel surface is mostly dominated by HSB formed by clusters of prisms. HSB's are more or less inclined to EDJ.
- b) In Gompothorium the prisms developed in the enamel surface are of key-hole and ginko-leaf pattern. In transverse view it also showed diagonal HSBs and IPM encasing prisms. There it was also seen that linear IPM crystallites encase enamel prisms.
- c) In Hipparion the prism are randomly arranged in longitudinal view and in transverse view we can see HSBs growing diagonal to the enamel. In Hipparion both IPM crystallites and enamel prisms are well developed.
- d) In Rhinocetidae indet, the enamel prisms are elongated tubular form, which are randomly arranged. Enamel prisms are oblique to the OES but the HSB's are parallel to one another and perpendicular EDJ.

Thus after detailed analysis of these specimen's SEM images we are able to conclude the enamel prisms are of different shapes and size and are arranged in different 3D pattern which helps organisms to chew food which has higher hardness than that of the enamel. With the help of the microstructural analysis we can do taxonomical identification and can identify the paleo-biogeography and dietary pattern.

REFERENCE-

- Ferretti, M. P. (2008).** Enamel structure of *Cuvieronius hyodon* (Proboscidea, Gomphotheriidae) with a discussion on enamel evolution in elephantoids. *Journal of Mammalian Evolution*, **15(1)**, 37-58.
- Koenigswald, W. V., Kalthoff, D. C., & Semprebon, G. M. (2010).** The microstructure of enamel, dentine and cementum in advanced Taeniodonta (Mammalia) with comments on their dietary adaptations. *Journal of Vertebrate Paleontology*, **30(6)**, 1797-1804.
- Tabuce, R., Delmer, C., & Gheerbrant, E. (2007).** Evolution of the tooth enamel microstructure in the earliest proboscideans (Mammalia). *Zoological Journal of the Linnean Society*, **149(4)**, 611-628.
- Koenigswald, W. V. Goin, F., & Pascual, R. (1999).** Hypsodonty and enamel microstructure in the Paleocene gondwanatherian mammal *Sudamerica ameghinoi*. *Acta Palaeontologica Polonica*, **44(3)**, 263-300.
- Remy, J. A., & Benammi, M. (2006).** Presence of a Gomphotheriidae indet.(Proboscidea, Mammalia) in the Vallesian fauna of Afoud AF6 (Ait Kandoula Basin, Morocco), inferred from the enamel microstructure of a molar chip. *Geobios*, **39(4)**, 555-562.
- Dumont, E. R. (1995).** Mammalian enamel prism patterns and enamel deposition rates. *Scanning microscopy*, **9(2)**, 429-442.
- Koenigswald, W. V., Holbrook, L. T., & Rose, K. D. (2011).** Diversity and evolution of Hunter-Schreger band configuration in tooth enamel of perissodactyl mammals. *Acta Palaeontologica Polonica*, **56(1)**, 11-32.
- Pfretzschner, H. U. (1993).** Enamel microstructure in the phylogeny of the Equidae. *Journal of vertebrate paleontology*, **13(3)**, 342-349.
- Boyde, A. (1976).** Amelogenesis and the structure of enamel. *Scientific foundations of dentistry*.
- Carlson SJ & Krause OW (1985)** Enamel Ultrastructure of Multituberculate mammal 1 s. An Investigation of *Variabilis* ty. Contrib. Mus. Palaeontol. Univ. Michigan. **27(1)**: 1-50.

Boyde, A. (1984). A non-destructive survey of prism packing patterns in primate enamel. *Tooth enamel*, 417-421.

Bond, M., Carlini, A. A., Goin, F. J., Legarreta, L., Ortiz-Jaureguizar, E., Pascual, R., & Uliana, M. A. (1995). Episodes in South American land mammal evolution and sedimentation: testing their apparent concurrence in a Paleocene succession from central Patagonia. In *Actas del VI Congreso Argentino de Paleontología y Bioestratigrafía, Trelew* (pp. 47-58).

Carlson, S. J., & Krause, D. W. (1985). Enamel ultrastructure of multituberculate mammals: an investigation of variability.

Janis, C. M. (1988). An estimation of tooth volume and hypsodonty indices in ungulate mammals, and the correlation of these factors with dietary preferences. *Mémoires du Muséum National d'Histoire Naturelle*, 53, 367-387.

Koenigswald, W. V. (1988). Enamel modification in enlarged front teeth among mammals and the various possible reinforcements of the enamel. In *Teeth revisited: Proceedings of the VIIth International Symposium on Dental Morphology: Mémoires du Muséum national d'Histoire Naturelle, Paris, série C* (Vol. 53, pp. 147-167).

Sudre, J., & Hartenberger, J. L. (1992). Oued Mya 1, nouveau gisement de mammifères du Miocène supérieur dans le sud Algérien. *Geobios*, 25(4), 553-565.

Krijgsman, W., Blanc-Valleron, M. M., Flecker, R., Hilgen, F. J., Kouwenhoven, T. J., Merle, D., ... & Rouchy, J. M. (2002). The onset of the Messinian salinity crisis in the Eastern Mediterranean (Pissouri Basin, Cyprus). *Earth and Planetary Science Letters*, 194(3-4), 299-310.

Dumont ER (1995) The effects of sectioning angle on measurements of enamel prism size and spacing. *Arch Oral Biol* 40(10):959–966

Kamiya H, Taruno H (1988) Tooth structure in *Stegolophodon*, *Eostegodon* and *Stegodon* (Proboscidea, Mammalia): their phylogenetic relation. In: Russell DE, Santoro J-P, Sigogneau-Russell D (eds) *Teeth revisited: Proceedings of the 7th International Symposium on Dental Morphology*. *Mém Mus natl Hist Nat Sci de la Terre (C)* 53:233–240

Hoffstetter R (1952) Les mammifères Pléistocènes de la République de l'Équateur. *Mém Soc Géol Fr* 66:1–391

Koenigswald Wv, Martin T, Pfretzschner HU (1993) Phylogenetic interpretation of enamel structures in Mammalian teeth: possibilities and problems. In: Szalay FS, Novacek MJ, McKenna MC (eds) *Mammal phylogeny: placentals*. New York, Springer, pp 303–314.

