

Paleoclimatic and Environmental Interpretation using
Clay Mineralogy and Surface Textural Analysis of Quartz
Grains from Miocene deposits of Tapar, Kutch, Gujarat

Project submitted to the Central University of Punjab

For the award of

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In

Geology

BY

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May 2018

CERTIFICATE

I declare that the project entitled "PALEOCLIMATIC AND ENVIRONMENTAL INTERPRETATION USING CLAY MINERALOGY AND SURFACE TEXTURAL ANALYSIS OF QUARTZ GRAINS FROM MIOCENE DEPOSITS OF TAPAR, KUTCH, GUJARAT" has been prepared by me under the guidance of Dr. K. Milankumar Sharma, Assistant Professor, Department of Geography and Geology, School of Environmental and Earth Sciences, Central University of Punjab.

No part of this project has formed the basis for the award of any degree or fellowship previously.

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CERTIFICATE

I certify that MAHMUD HASSAN has prepared his project entitled “PALEOCLIMATIC AND ENVIRONMENTAL INTERPRETATION USING CLAY MINERALOGY AND SURFACE TEXTURAL ANALYSIS OF QUARTZ GRAINS FROM MIOCENE DEPOSITS OF TAPAR, KUTCH, GUJARAT”, for the award of M.Sc. degree of the Central University of Punjab, under my guidance. He has carried out this work at the Department of Geography and Geology, School of Environmental and Earth Sciences, Central University of Punjab.

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ABSTRACT

Paleoclimatic and Environmental Interpretation using Clay Mineralogy and Surface Textural Analysis of Quartz Grains from Miocene deposits of Tapar, Kutch, Gujarat

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The Tapar area situated in Kutch district of Gujarat is exposed of the miocene deposit. Extensive work has been done on Kutch basin on paleontological aspects but very less on sedimentological aspect. Clay assemblages is a great tool to understand the paleoclimate and environment of deposition. The study of the clay assemblages in the area show a higher amount of kaolinite and very less amount of dickite assemblages with negligible amount of Vermiculite and clinochlore indicating a tropical climate. Quartz being highly resistive mineral can withstand normal chemical weathering and physical weathering. Surface textural study of quartz grains indicates towards fluvial condition.

By: Mahmud Hassan

Supervisor: Dr. K. Milankumar Sharma

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CHAPTER-01

INTRODUCTION

Located between the latitude from 20°10'N to 24°50'N and longitude from 68°40'E to 74°40'E, covering an area of approximately 20,000 sq.km, Gujarat is situated in the Westernmost part of India. The state encompasses different types of important lithologies ranging from the Mesozoic epoch to the present. The Miocene deposits of Kutch are well known for its diverse vertebrate fossil assemblages. The deposition of this fossiliferous sediments is considered to be taken place as a result of the marine transgression and regression events taken place during the Cenozoic time. The present project aims to reconstruct Miocene paleoclimatic and environment using Clay Mineralogy and Surface Textural Analysis of Quartz Grains from Miocene deposits of Tapar, Kutch, Gujarat.

Clay minerals are a significant tool for understanding and establishment of paleoclimate conditions. Clay minerals help to elucidate the depositional process, weathering conditions and also the ocean current variations in marine deposits. The distribution of clay in the sediments contemplates the climate it has been subjected to during the course of the deposition. However, the mutation of the sediments has a great hold on the provenance it has been derived from (Sharma *et al.*, 2016). The limiting factor towards the deposition environment, constancy to a similar environment unless any major alteration of climate, aggregation constant throughout the process of weathering, post-burial stability and the undeviating sensitivity towards environmental changes bring clay into being as a significant means of paleoclimatic construe. Its sentiment towards changes in the environment is wavering. It has been used as a "marker mineral" in numerous paleoclimatic researchers (Singer, 1980). Various factors hinder the clay mineral content within a deposition viz. the provenance, weathering regimes, the environment of deposition and the diagenesis rate. These consequently results in the alteration of minerals which in turn aids in clay formation (Sharma *et al.*, 2016).

A variety of factors are responsible for the present shape of a mineral which includes the original shape of the mineral from the provenance; the spacing of fractures and the spacing in the bedrock which also influence in the present shape when underwent weathering and transportation; the nature and intensity of transportation of the materials; the burial process of the sediments such as

compaction which might also modify the grain shape (Samm Boggs, Jr, 2012). Quartz being one of the most abundant minerals found in nature and also being resistive enough to withstand normal weathering condition. Studying the surface texture of the quartz grain might also help in predicting the provenance, weathering condition and burial underwent process.

The drainage system of Gujarat: Gujarat is characterized by multiple intersections of rivers, some of which flow towards the Arabian Sea and others toward Rann of Kutch. Most of the rivers in Gujarat are of a seasonal type. The Narmada River, which is the largest river in Gujarat originates from the Amarkantak plateau and falls in the Arabian sea. The second largest river Tapi, which is originated from Betul, Madhya Pradesh, is one of the major rivers flowing toward western India. Sabarmati River originated from the Aravalli range along with Mahi and Aji rivers which are some of the main rivers in Gujarat.

Climate: As the tropic of cancer passes through this state, Gujarat falls within the sub-tropical climatic zone. There are perceptible weather variations within the state due to its close proximity to the sea coast, the coastal regions experience a humid condition while the remote areas of the state experience a wholly different climatic condition. The State experiences climatic variations in extremities. However, as compared to other parts of the state, the coastal regions and the eastern belt of Gujarat have a slightly pleasant climate with moderate rainfall during the monsoons. The monsoon season commences from mid-June to September. Before its onset, there is a rise in temperature and high humidity. Most parts of the state are under the isotherm between 35°C and 45°C (Merh, 1995). The approximate average temperature recorded during the day is 29°C and 12°C at night. Gujarat enjoys a moderate rainfall. Most of the rainfall occurs between June and September during the Southwest monsoon (Merh, 1995). Merh (1995) divided five regions in Gujarat on the basis of its climatic variations. They are mentioned below.

- i. **Sub-Humid Region:** - South Gujarat (South of Narmada).
- ii. **Moderately Humid Region:** - Central Gujarat (between Narmada and Sabarmati).

iii. **Humid and SultryRegion:** - South facing coastal region of Saurashtra.

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

iv. **Arid and Semi-aridRegion:** - North Gujarat and Kutch.

Flora and Fauna:The Gulf of Kutch is well known for its marine wealth which includes corals, mangroves, algae, sponges, mollusks, prawns, fishes, reptiles, birds and mammals(Nair, 2002). Khadir one of the largest island of Great Rann of Kutch includes rare and endangered plant species viz. *Citulluscolocynthis*, *Commiphora wightii*, *Convolvulus stoksii*, *Dactyliandra welwitschii*, *Dipcadi erythraeum*, *Ephedra foliata*, *Helichrysum cutchicum*, *Heliotropium bacciferum*, *Heliotropium rariflorum*, *Ipomoea kotschyana*, *Indigofera caerulea*, *Limonium stocksii*, *Pavonia certatocarpa*, *Sida tiagi* and *Trilumbs rajasthanisis*. The area is one of the largest gathering of Greater Flamingo within the entire country. The area also support many water birds. Among mammalian species, Long-eared Hedgehog (*Hemiechinus auritus*), Indian wolf (*Canis lupus pallipses*), desert fox (*Vulpes vulpes pusilla*), Chinkara (*Gazelle gazelle*), desert cat (*Felis silvestris*), India porcupine (*Hystrix indica*), Indian ratle (*Mellivora capensis*), caracal (*Felis caracal*) and striped hyena (*Hyena hyena*) have been recorded from different areas of Great Rann of Kutch.

About 253 species of flowering plants have been reported from the Kutch area. A total 93 species of invertebrates includes 25 species of zooplanktons, one species of Annelid, 4 crustacean, 24 insects, 12 molluscans, 27 spiders have been recorded from Nanda and Shedwa bayets(Gajera *et al.*, 2010).

CHAPTER-02

REVIEW OF LITERATURES

The tertiary of Kutch and Saurashtra have yielded a diverse assemblage of mammalian fauna, invertebrates, fish, and reptiles (Wynn, 1872; Lydekker, 1876; Venkatappaya, 1955; Prasad, 1964a; Sahni and Mishra, 1975; Sahni and Mehrotra, 1980; Mehrotra, 1981; Bajpai and Domning, 1997; Bajpai *et al.* 2006; Thewissen and Bajpai, 2008; 2009; Bhandari *et al.*, 2009). Previous records of Miocene mammalian fossils remains from Kutch comprises of deinotheres, mastodont, rhinocerotids, anthracotheres, tetraconodont suid, giraffid and a small tragulid, etc. (Wynn, 1872; Prasad, 1964 and 1967; Mishra, 1976; Sahni and Mishra, 1975; Pickford, 1988; Bhandari *et al.*, 2009; Patnaik, *et al.* 2014). Miocene deposits of Kutch are also well known to yield different foraminifers and molluscs species (Jauri, 1981; Jauhri and Khare, 1990; Harzhauser, 2007; Kulkarni *et al.* 2009; Chattopadhyaya and Dutta, 2013). Bhandari *et al.* (2016) report a review of the mammalian faunas of Miocene of Kutch from Tapar and Pasuda locality and additional records of Rodentia including the family Muridae, Cricetidae, Sciuridae and Rhizomyidae; associated Late Miocene, with taxa such as *Hipparion*, *Kachchhchoerus salinus* and *Tetraconodon indicus* and thereby assigning a Basal Late Miocene age to these deposits.

(Bhandari *et al.*, 2015) in “Basal Late Miocene Mammal Fauna from Tapar and Pasuda, Kachchh”: The Kutch peninsula on India mainly consists of the Neogene sediments of terrestrial and marine deposits which overlays the Jurassic, Cretaceous and Paleogene rocks. Bhandari discovered equid *Hipparion*, *Kachchhchoerus salinus*, *Tetraconodon indicus*, a small giraffid, a tragulid, an anithere and murid rodents too. These fossils are an indication towards the deposition of Tapar and Pasuda towards a late Miocene epoch, which was earlier considered as of middle Miocene. “Pellet rocks, comprising intra-formational conglomerate (crevasse splay deposits) indicate accumulation in both overbank and channel setting within a floodplain.” The sediments of the Tapar and Pasuda generally represent fluvial sediment. The resemblance of Calcareous nodules present in the Pasuda and Tapar conglomerate with the kunkar nodules is an indication of sub-humid to semi-arid environment. “Most of the vertebrate fossils at

Tapar and Pasuda occur in the crevasse splay deposits, but some specimens undoubtedly occur in overbank silts and clays". Based on the sedimentary features like kunkar nodules and cast of the tree boles of the area and the vertebrate fossils mentioned above, the area may be slightly more humid woodland to Savannah than today's semi-arid bushland.

Biswas, (1992) in "Tertiary Stratigraphy of Kutch": Kutch basin is situated at the marginal boundary of Kutch. It preserved almost the entire sequence from Triassic to recent, punctured by some transgressive cycles. The major divisions by Wynne (1872) suggest six groups viz. from younger to older (1) Recent-upper Tertiary (2) Argillaceous Group (3) Arenaceous Group (4) Nummulitic Group (5) Gypseous Shales (6) Sub-Nummulitic. The Chhasra Formation named by Biswas was earlier known as Gaj Formation. Within Chhasra Formation "The rich biota and lithology clearly indicate deposition in the sublittoral environment during the highest stand of the sea. Foraminifera suggests a fluctuating marginal marine to shallow inner-shelf conditions of deposition. Miogypsinidae assemblage suggests Burdigalian age"; which indicates that Chhasra Formation was of early to middle Miocene Epoch. Sandhan Formation overlying the Chhasra Formation is highest of the Kutch Tertiary sequence. Sandhan Formation is exposed along Kankawati river which is overlying by Quaternary and recent deposits.

Catuneanu, (2017.) in "Cenozoic sequence stratigraphy of the Kachchh Basin, India" stated, "The Cenozoic sedimentation began in Kachchh in a stable shelf environment. Thus, the strata have remarkable lateral continuity from inland to offshore." Several unconformities have been identified which extends even to offshore. The environments of the Kutch and Saurashtra basin have been considered as shelf, slope and basin floor. "The first occurrence of marine sediments of Bathonian age indicates that the basin became fully marine during the Middle Jurassic. The basin formed the site for a westerly deepening epicontinental sea, probably an extension of the Tethys, in which a thick pile of sediments, ranging in age from Middle Jurassic to Early Cretaceous, was deposited in shallow marine to deltaic environments.

Khari Nadi Formation of Early Miocene (Aquitania) is of fine-grained to silty nature. Its deposition infers towards a tidal flat, littoral to the shallow marine

environment. Chhasra Formation which overlays the Khari Nadi formation belongs to the Burdigalian age, of Miocene epoch. The faunal assemblage suggests towards a fluctuating marginal marine to shallow inner shelf environment for deposition. Sandhan formation of Middle Miocene to Pliocene is overlain by Quaternary and recent deposits overlay the Chhasra Formation. This formation consists of large Calcareous nodules. Sandstone appears of coastal sand of advancing sea hence post regression

(Shukla, Mehrotra, Mandal, & Thakkar, 2014) in “**Two new fossil woods from the early Miocene of Kutch, Gujarat, India and their significance**” mention about two fossil woods, viz. *Bauhinium palaeomalabaricum* Prakash and Prasad (Fabaceae) and *Ebenoxylon indicum* Ghosh and Kazmi (Ebenaceae) discovered from Kutch which helps to infer the palaeovegetation and palaeoclimate. The taxa from the early Miocene deposits are thermophilic in nature and generally tends to grow in evergreen to deciduous forest, thus these taxa indicate towards a warm and humid climate. Moreover, some mangrove taxa assemblage from the same horizon is indicative of lagoonal to the intertidal environment.

“Wood anatomical characters play an important role in predicting climate. Vessels are more or less uniform in size and evenly distributed in diffuse-porous woods showing little seasonality in temperature, whereas they are larger and more in number in early wood and fewer and smaller in late wood in ring porous woods showing marked seasonality in temperature.”; thus we can see that the paleoclimatic condition of the early Miocene of Kutch indicates towards an extensive climate change which results in more and large rings within the fossil woods.

(Biswas, 2016) in “**Mesozoic and Tertiary Stratigraphy of Kutch* (Kachchh) – A Review**”: The Kutch basin is basically a rift basin from which is overlaid by sediments from Jurassic to Quaternary Era. The sediments were of both synrift and of post-rift basin formation. “The Late Cretaceous-Early Paleocene break in sedimentation is marked by post-rift inversion-related uplift and Deccan Trap volcanism. The Trap flows separate the two groups Mesozoic and Tertiary.” Ammonite rich highly fossiliferous strata represent the deposition is of marine origin of the Kutch basin in the studied area.

(Patnaik et al., 2014) in “Additional vertebrate remains from the early Miocene of Kutch, Gujarat”: The various marine fossils of the Khari Nadi formation from Jangadia, Samda, Pasuda, and Baadraindicate a marine environment. “We describe and comment 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. We report for the first time a shark, *Megaselachus chubutensis* from India and a batoid *Rhinoptera* from Kutch. A fossil latid fish has also been recorded for the first time from India”; indicates a marine environment and the presence of these fossils were from tropical-subtropical conditions.

(Chaudhri & Singh, 2012) in “Clay Minerals as Climate Change Indicators- A Case Study” examines the assemblages of clay minerals in the Pinjor Formation of Late Pliocene- Early Pleistocene age. “The presence of illite and kaolinite suggests their derivation from crystalline rocks containing felspar and mica as also from pre-existing soils and sedimentary rocks. Further, the paleoclimatic conditions were moderate. Presence of chlorite suggests the weathering of intermediate and basic crystalline rocks and low-grade metamorphic rocks in the positive areas. The presence of kaolinite in the Pinjor Formation is mainly attributed to the weathering and subsequent leaching of the mineral from granitic and basic rocks in the hinterland. Vermiculite has been mainly formed by weathering and transformation of biotite”. Thus the clay minerals help us to understand the environment of deposition analyzing the clay content on various samples and thus helps to reconstruct the paleoclimatic condition of the studied area. Kaolinite is generally formed by weathering of granite and basic rocks. Chlorite is resultant of weathering of intermediate and basic crystalline rocks. The main elements needed for kaolinite formation are generally silicon and aluminium. Vermiculite result from diagenesis of potassium and as a consequence of the alteration of fluorite and illite. “A temperate environment and moderate weathering conditions have been recorded for the formation of Illite. Illite is formed as a consequence of absorption of potassium from seawater by montmorillonite”

Sharma *et al.* (2016) in “**Clay mineralogy of the Late Miocene Baripada Beds (Mayurbhanj District, Orissa): Palaeoclimatic implications**” take an attempt to correlate the fossil and clay mineral assemblage of the Baripada Bed. Clay minerals are a strong indicator towards the interpretation of marine depositional processes and also has a great influence to understand the paleoclimatic condition. “The abundance of smectite may indicate the presence of Monsoon type of climate and deposition under relatively low energy condition”. Presence of Kaolinite also suggests that the area must have an annual precipitation rate of about 50-150cm in the Late Miocene Epoch. “Late Miocene represents the time period when marine transgression took place at a global scale” and thus fossils are widely present in the Baripada Bed. Clay mineral can also help in the interpretation of ocean currents variations. Illite and chlorite may be the result of chemical weathering, moderate leaching yields smectite and that of intense weathering results in kaolinite formation. The Miocene Epoch was the peak time for Himalaya Exhumation. Reconstruction of the paleoclimate model suggests that the Asian monsoon has a direct link to the upliftment of the Himalaya. The Miocene deposit of Kutch and Eastern coast of Baripada Bed infer towards a warm tropical climate somewhat similar to the present-day climate

CHAPTER 03

GEOLOGY AND STRATIGRAPHY OF THE STUDIED AREA

Tapar located in Gujrat having GPS coordinates 23°15'12.93"N and 70°8'52.17"E lies on the Kutch district. The studied area may lie in the Sandham formation



Figure 1: Google Earth imagery of the Studied area, Tapar and Showing Gujarat In India Map

which is the thickest formation with 294m of the Kutch Basin. The Sandham formation is thickest towards SW and generally thin continuously towards East. Lithology here generally consists of well sorted, medium to coarse-grained, massive, micaceous, quartzose sandstone, overlain by clay. Fossiliferous beds are also observed in few segments.

Geology of Kutch

Grant (1837) carried out the first geological investigation of Kutch area followed by Blanford (1869) who presented proper ideas about the geological architecture of the region. Later on, Wynne (1872) published the first report along with a map and the geology of Kutch. 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 upto 3000 m and ~1000 m thickness for Cenozoic sediments. The perceptibility of several faults in the Kutch is important for the evolution of the geology of Kutch. The presence of these regional faults can be 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. 2). The less deformed tertiary rock wrap around the Mesozoic structure and most of the Tertiary sediment deposition took place in the shallow marine peritidal environment (Biswas, 1992).

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): -

1. Matanomadh Formation:

This Formation is mainly exposed on the mainland Kutch, which borders the Tertiary rocks from the Mesozoic deposit and directly overlying the Deccan trap (Fig.3). Its etymology can be traced back to Matanomadh village, in western Kutch and is well exposed in Bhuj-Lakhpat road section, Madhwall Nadi section, etc. This Formation is comprised of lithologies like red laterite, bauxite, conglomerate, clay, sandstone, etc. with a total thickness of about 49 m (Biswas, 1992). By referring to pollen–spore assemblage (Mathur, 1966), this Formation is assigned as Palaeocene age. 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 (Biswas, 1992). This Formation, mainly comprising the volcanoclastic sediment, is considered to be deposited during the Deccan volcanic (Biswas and Deshpande, 1973).

Field Photographs correlating the Litholog:

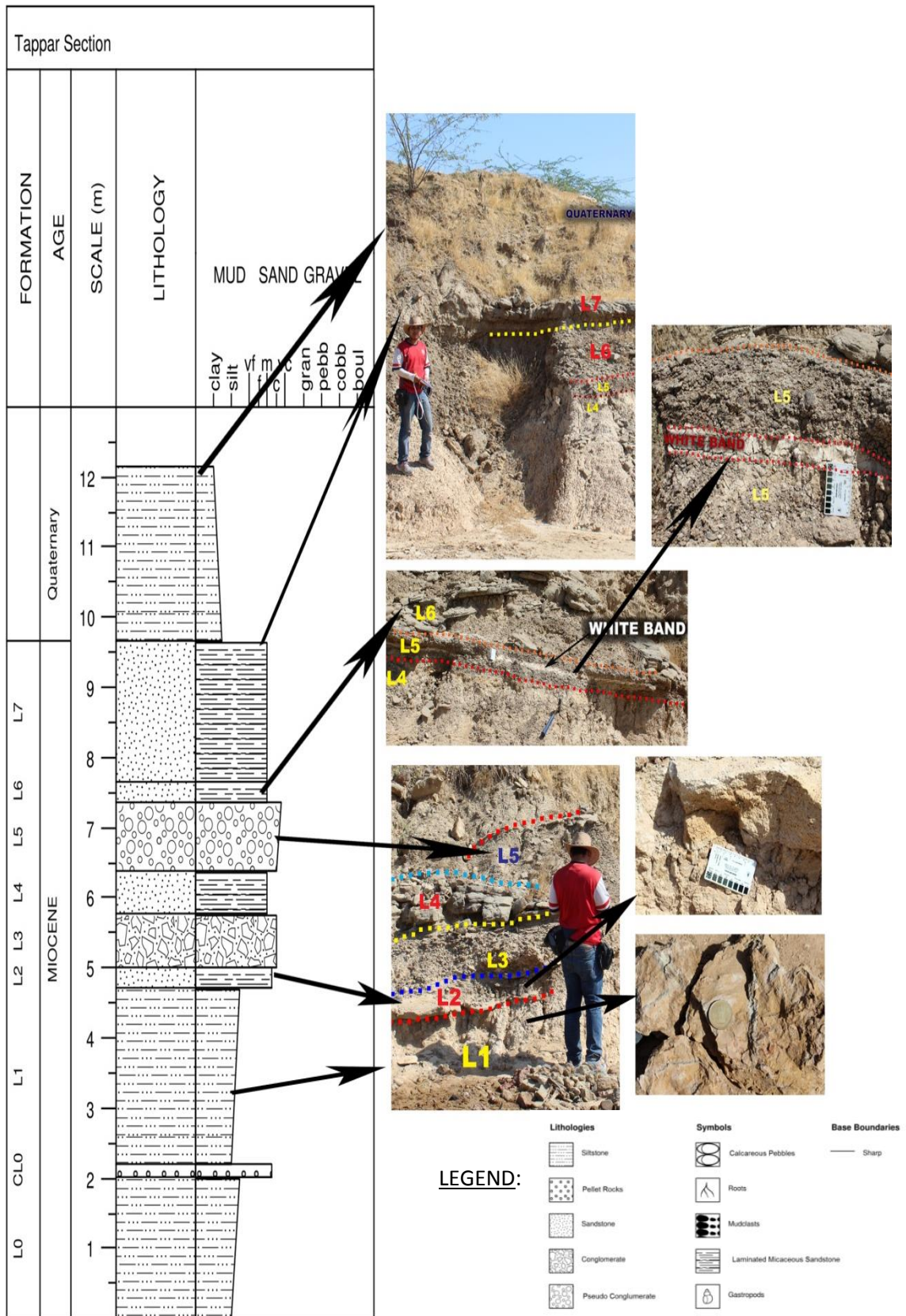


Figure 2: Field Photographs comparing the Litholog

Though Matanomadh Formation is unproductive of fossils it is nevertheless locally rich in microflora dicot leaf impression, occasionally with fossil fruits and wood (Biswas, 1992). In this Formation, the floodplains are comprised of variegated clay, and with channel filling and crevasse splays in road cutting section. The presence of cross-cutting sedimentary structure on sandstone and moderately sorted coarse grain, represent upper delta plan setting (Catuneanu, 2017).

2. Naredi Formation

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

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

i) Gypseous shale member: This member is characterized by a thickness of about 24 m 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 – *Venericardia* 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: The characterizing feature of 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, and it 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 Nadi. The Naredi Formation is

separated by disconformity from the Matanomadh Formation and also form the upper Haudi Formation. The deposition environment of this formation varies from lagoonal to marine inner shelf (Biswas, 1992).

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 characterizing feature of Harudi Formation is its thinness (only 14 m thick) as compared to other formations. In addition to that, this Formation consists of claystone and siltstone and a layer of gypsum and carbonaceous shale. Harudi Formation is having a non-conformable contact on top of the laterite bed of Naredi Formation. It is assigned as Middle Eocene age as indicated by Foraminifera assemblage. Biswas (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 distinctive 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 (Biswas, 1992).

1. 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. Its characteristics include a thickness of 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 (Biswas, 1992). The lithologies of this Formation are entirely made up by massive to thickly bedded, white, and buff-colored foraminiferal limestone. The limestone is fossiliferous micrites, biomicrites and biomicrosparite locally silty (Hardas and Biswas, 1973).

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

Table 1: Classified Stratigraphy of Tertiary sediments of Kutch (Source, Biswas 1992).

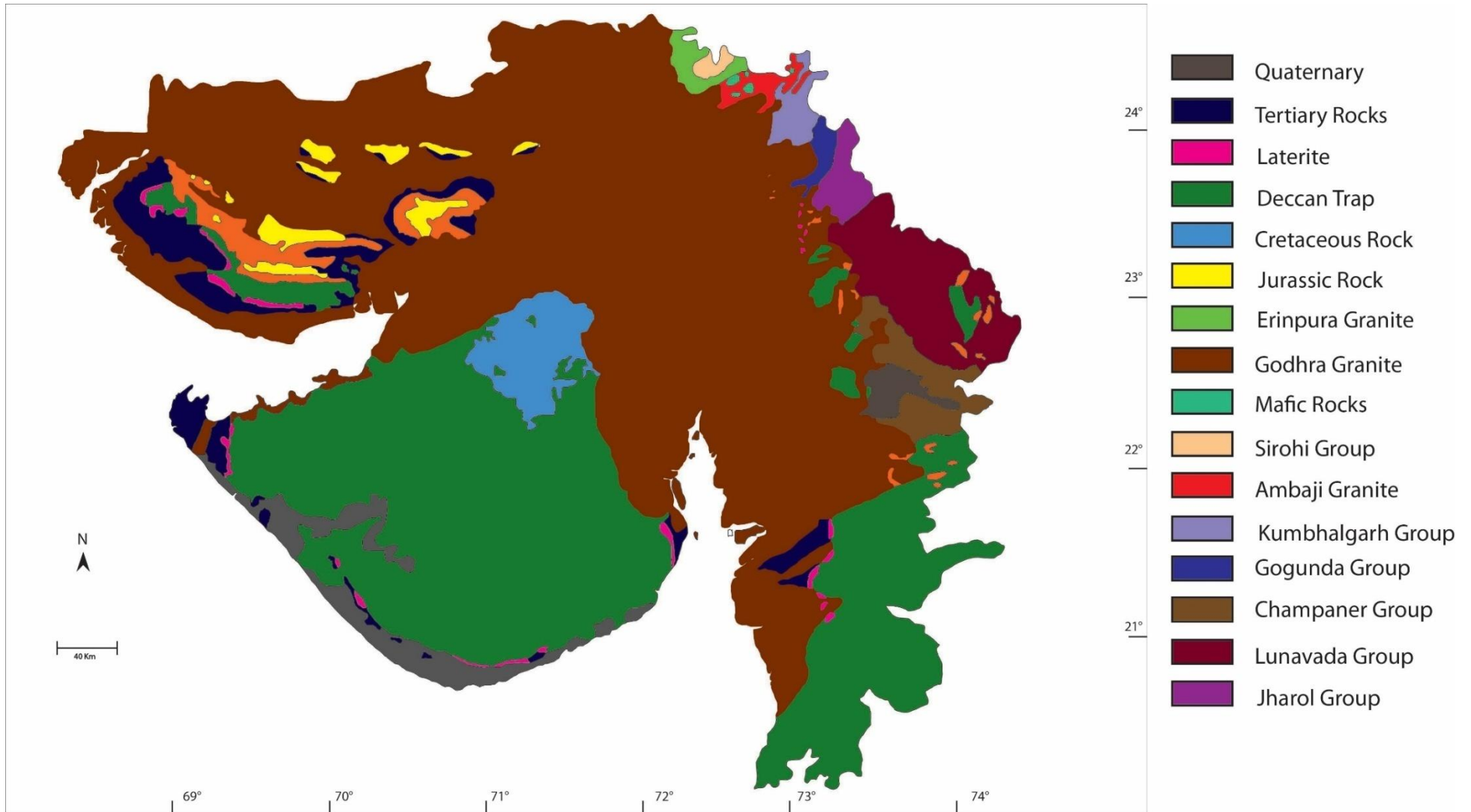


Figure 3: Geological map of Gujarat (Redrawn after Merh. 1995)

The Formation is conformably contacted in the lower part, and the upper part is contacted with paraconformity. The deposition environment of this Formation as characterized by the foraminiferal assemblage indicated low energy, clear waters probably under middle shelf environment (Biswas, 1992). Fulra Formation is well fossiliferous and abundance of foraminiferal assemblages has been reported (Mohan and Soodan, 1970) along with a record of nannoplankton form (Singh, 1986) and vertebrate fossils (Sahni and Mishra, 1975).

2. Maniyara Fort Formation

This Formation is mainly exposed in Ramani stream, Waior stream, Berwali Nadi, Bermoti stream and around the Lakhpat. The Formation gets its name from Maniyara Fort. Its characteristic feature includes yellow to ochre colored foraminiferal limestone with basal greyish green glauconite siltstone. Maniyara Fort Formation has a total thickness of about 35m 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 features about 4.3m thickness and contains alternating beds of foraminiferal, glauconitic, brownish to yellowish siltstone and calcareous, gypseous claystone. The presence of green pellets of glauconite acts as a distinctive element which separates this member from the underlying Fulra Limestone.

ii. The lumpy clay member

It comprises of grey color to brownish calcareous, lumpy claystone, occasionally containing thin limestone and marlite beds, and a thickness of about 4.7 m.

iii. The Coral limestone member

This member being well exposed in the Ramania has about 9.14 m thick and contains dirty white nodular limestone and its lower part contains calcareous claystone. The upper part comprises grey to dirty white massive limestone with the presence of coral, small bioherms. The limestones are glauconitic, biomicrites and biosparite (Hardas and Biswas, 1973).

iv. The Bermoti member

The Bermoti member is about 11m thick which is developed in the Bermoti, Waior, Maniyara Fort Hill areas. This member consists of 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 marginal marine, littoral to shallow inner-shelf.

Geology of Miocene deposit of Kutch

The sedimentation of Miocene deposit of the Kutch regions, covering about 30 percent of the total Tertiary deposits at Kutch, trends nearly east-west. Biswas (1992) classified Miocene deposits of Kutch into three formations as given below: -

i. Khari Nadi Formation

Khari Nadi Formation, also known as Arenaceous Group (Wynne, 1872) and Gaj Beds (Poddar, 1959; Mohan and Bhatt, 1968). Khari Nadi Formation which infers as Lower Miocene (Aquitania) overlies the Maniyara Formation of Oligocene Epoch. The Formation encompasses 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 extending to the north to Lakhpat. Around the peripheries of the Rann Island and Wagad Highland, the Formation unconformably lies above the Jurassic rocks. This Formation has a thickness of 65m which reduces along the Kankawati river section at around 47 m and in the Rann Island, the thickness is again lesser and varies from 15 to 35 m (Biswas, 1992). The lithology of this Formation comprises laminated to very thin bedded red and yellowish color to variegated siltstone and very fine-grained sandstone with random grey and brown gypseous claystone.

On the Eastern Kutch, a red lateritic conglomerate with agate pebbles, purple ferruginous sandstone, white-felspathic and tuffaceous sandstones with

laminated claystone constitute the lithology of the Formation. Its mottled variegated appearance is due to the bioturbation which is common in the basal part of the Formation. The vertical burrows are filled up with red haematite in contrast with the bright yellow color of the burrowed siltstone. The formation is contacted conformably on the lower part as well as 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 (Biswas, 1992).

ii. Chhasra Formation

The Formation derives its name from the Chhasra village. This Formation is originally described as Vinjhan shale (Biswas and Raju, 1971, 1973) and Gaj Beds (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 and is the best reference section. At 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 Matanumadh Formation. Chhasra Formation which infers as Lower Miocene (Burdigalian) conformably overlies the Khari Nadi Formation of Lower Miocene (Aquitania).

The lithology of this Formation has divided into two distinct members as: -

a. A lower claystone member

The best exposure of this member is about 80 m thick and comprises grey and khaki colored, laminated to splintery, gypseous shale and claystone with alternations of thin, yellowish, highly fossiliferous argillaceous limestone. This member yields a megafossil like *Turritella*, *Ostrea*, and *CONUS* (Biswas, 1992).

b. An upper siltstone member

It has a thickness of about 35 m thick and is well exposed along the Kankawati River. This member predominantly comprises of alternating micaceous siltstone and laminated silty shales of dull khaki color with the upper part this Formation is reddish (Biswas, 1992).

iii. Sandhan Formation

Sandhan Formation infers as Middle to Upper Miocene non-conformably lies above the Chhasra Formation of Lower Miocene Burdigalian age (Biswas, 1992). The Formation is dominated by sandstone and is also the highest in the tertiary sequence of Kutch. The Formation derives its name from the Sandhan village. The Formation is exposed in a widely 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. It exposes in the plain lands of the eastern Kutch, and also in the patchy outcrops overlying the Chhasra Formation. The thickness of the Formation is 294m in south-western Kutch but is thin continuously toward the East.

This Formation is characterized by lithologies comprising of 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; and in the Middle part conglomerates and coarse-grained sandstones with lenticular bodies of conglomerates. Hard, calcareous grits, overlain by pink and grey mottled silty sandstone with calcareous nodules are mainly composed in the upper part of this Formation. Sandhan Formation is disconformably overlain on the Chhasra Formation. The depositional environment of the Formation is fluvial sedimentation and supra-tidal to littoral to deltaic or foreshore environment (Biswas, 1992).

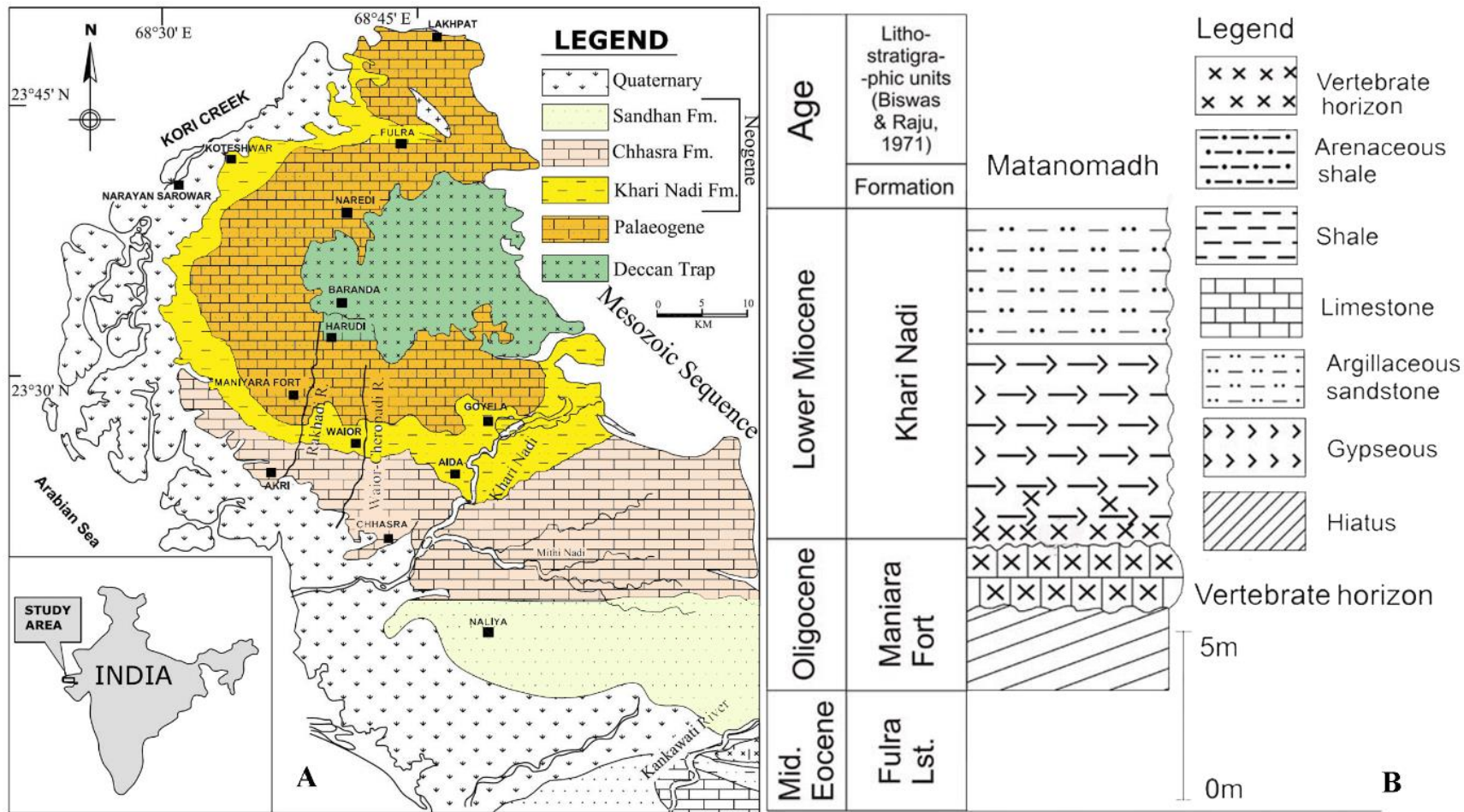


Figure 4: Generalised geological map of Kutch, Gujarat (Source Biswas 1992, Patnaik et al. 2014).

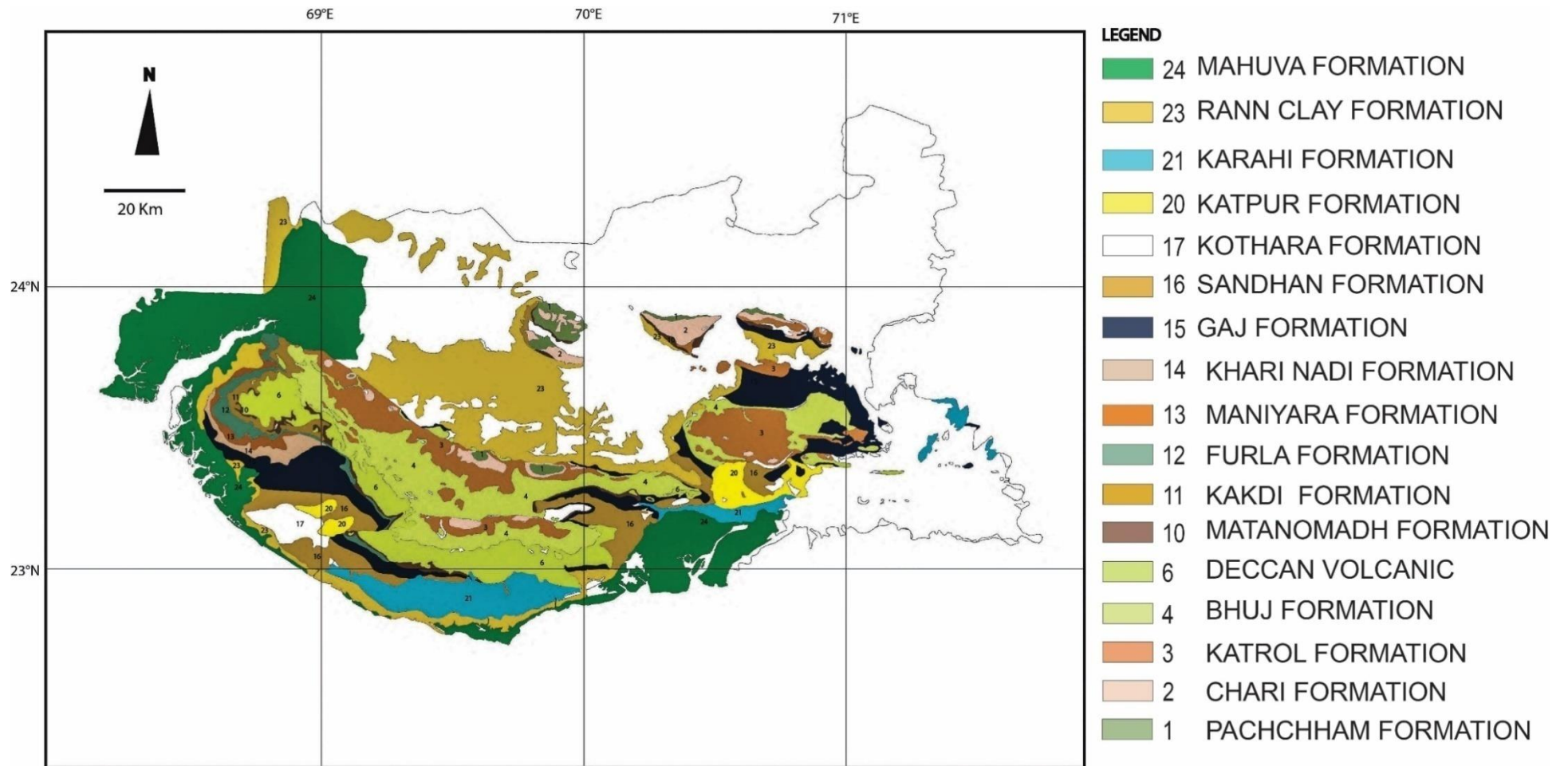


Figure 5: Geological map of the Kutch (redrawn GSI, 2002)

CHAPTER-04

SAMPLING AND ANALYTICAL METHODS

SAMPLE COLLECTION:

To accomplish the purpose some basics field and laboratory techniques have been used such as surveys of the study area for the collection of rock samples for clay mineralogy. Section measurement is done before collecting the samples. At every 6cm interval, samples are collected by N. Amardas Singh and Dr. K Millankumar Sharma for Paleontology and sedimentology studies without missing any bed. Samples weighing about 5Kg-10kg is collected according to required study.

Sample Preparation for X-RAY DIFFRACTION:

The sample preparation for XRD includes a few steps:

- a. **Removing the moisture content:** This done by drying the sample around 50°C to completely remove the moisture content of the sample.
- b. **Homogenize sample:**
 - i. A good mixture of the sample is made followed by pouring into a uniform conical pile.
 - ii. It is kept in mind that the natural selection within the pile is almost symmetrical.
 - iii. A flatted disc is then formed by flattening the collected sample from the cone.
 - iv. The formed disc-shaped is then divided into quarters of which two opposites are tossed out while the remaining are the amount of sample is mixed and thus formed the reduced sample.
 - v. The processes are repeated until the desired sample is obtained.
- c. An amount of about 10g has been taken for XRD analysis and the remaining sample is stored for further studies.
- d. The homogenized 10g of samples were then ground to less than 20-micron size using a stainless mortar which is followed by agate mortar. The desired sample is then collected and packed safely in airtightziplock bags.

X-ray diffraction analysis is a peculiar means in crystallinity determination of a compound. It is mainly used in:

- Identification of the crystalline material
- Identification of polymorph forms
- Distinguishing between amorphous and crystalline material
- Quantification of the percent crystallinity of a sample.

XRD can be really helpful in identification of fine-grained minerals and also in the mixture of intergrowth minerals which is generally difficult to identify with any other techniques. It can also be helpful in studying a mixture, where an XRD data can be analyzed to resolve the desired portion of the various minerals present in the mixed sample. It also helps to understand the degree of crystallinity and also the degree of hydration for minerals that contain water within their structure.

A three-dimensional structure of nonamorphous material, like mineral, is generally represented by regular, repeating planes of atoms forming the crystal lattice. Interaction of X-ray with these planes results in partial transmission, absorption by sample, refracted and scattered and part of which is diffracted by individual minerals in a distinct fashion. Diffraction happens if the distance traveled by one scattered beam is different, by a length equal to the X-ray wavelength, from the distance traveled by another beam scattered by an adjacent plane of the atom. This diffracted beam is called a first-order reflection. When the difference in distance traveled by the scattered X-ray between two adjacent layers of atoms is equal to two wavelengths, then it is said to be a second-order reflection. A higher order reflection takes place every time the path difference is a whole number multiple of the wavelength(Lindholm, 1987). The relationship can be expressed by Bragg's equation:

$$n\lambda=2d\sin\theta$$

Each mineral diffracts the X-ray in a unique pattern depending on the atoms which make up the lattice structure. X-rays are produced within a sealed tube which is under vacuum in an X-rays powder diffractometry. A filament heats up when current is applied within the tube. The amount of electrons emitted from the filament is directly proportional to the current applied. A high voltage of around 45kilovolts is applied within the tube. Electrons are accelerated due to the high voltage applied, which hits the target. The striking of electrons into the targets yields X-rays. The

wavelength of the X-ray produced is characteristics of the target. Collimated X-rays are allowed to strike the grounded fine powder of particules of around 20microns. The X-ray signal is detected by a detector which is then processed by a microprocessor or electronically, converting the received signal to a count rate. The X-ray scan is done by changing the angle between the X-ray source, the sample and the detector at a controlled rate.¹

On satisfaction of the Bragg's Law, the interaction of the incident ray with the samples exhibit constructive interference (and a diffracted ray). Using this law the lattice spacing in the crystalline sample can be correlated with the electromagnetic radiation to the diffraction angle.

The crystals present within the sample provide a unique "fingerprint" in a typical XRD analysis. Properly interpretation of XRD data with a standard reference pattern and measurements, the "fingerprint" allows identification of the crystalline form.

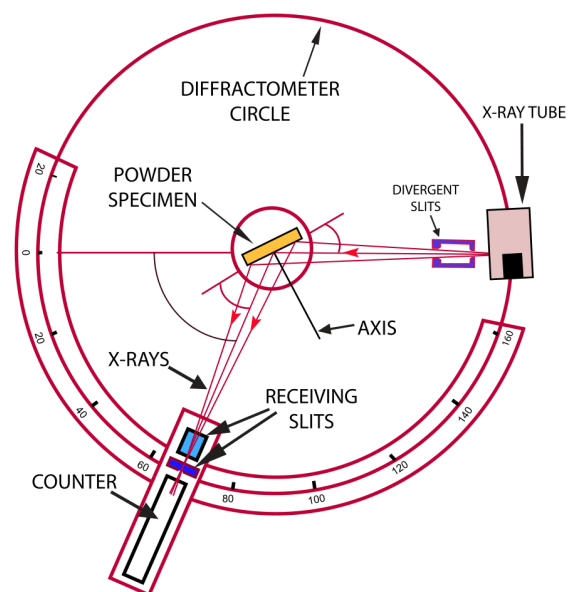


Figure 6: Schematic diagram of XRD diffractometer

¹USGS OFR01-041: X-Ray Diffraction Primer, Retrieved May 4, 2018, from <https://pubs.usgs.gov/of/2001/of01-041/htmldocs/xrpd.htm>

Table 2: Technical Information of XRD Instrument

Technical Information	
Instrument	PANalytical
Operating range	2°-80°2θ
Temperature	25°C (room temperature)
Sample amount	App. 10 mg
Step Size (2θ)	0.008°
Anode material	Cu

The powdered samples were analysed at Inter University Accelerator Centre (IUAC), New Delhi using the PANalytical XRD instrument. The 2θ value of is goniometer is set between 2° and 80°. The step size set (2θ) in the instrument is 0.008°. For the experiment, a Cu-anode source with K-Alpha1 [Å] of 1.54060 is used. For the source, current and voltage during the experiment were set at 40mA and 45kV respectively.

Raw data was received in *.xrdml was received from the IUAC. The X'Pert Highscore software was used to analyse raw data and identify different minerals and their semi-quantification.

SURFACE TEXTURE ANALYSIS OF QUARTZ AND GRAIN CIRCULARITY ANALYSIS:

In general, a particle shape is described by three related but different aspects of grains viz. form, roundness and surface texture. A form of a grain relate to the gross overall configuration of the grain and indicates variation in their proportion. Its form may resemble that of a rodlike form. Whereas roundness is the sharpness amount of angular corner of the grain. A grain with smooth corner is considered as well rounded grains whereas grains with sharp and angular corners are considered as poorly rounded grains.

The surface texture is the microstructure of micro-relief markings viz. pits, scratch and ridges within the grain surface due to physical process during the transportation process. Surface texture may result without the consequence of any form or roundness. According to Boggs (2012), "The three aspects of shape can

be thought of as constituting a hierarchy, in which form is a first-order property, roundness is the second order property superimposed on form and surface texture is a third property superimposed on both the corners of a grain and the surfaces between corners” (p.57).

Methodology:

Sandstones sections are preferably helpful for quartz separation as it is rich in quartz grains. A clear shape of the quartz grains is tried to attain removing the cementing material of the rock. Most of the samples have a high amount of calcium carbonate as cementing material.

1. About 10-15gm of samples are dissolved in H₂O₂ to disintegrate.
2. The boiled samples were left for to cool down and then washed with water about three times followed by oven dry.
3. Similar size of the sample, about 250MIC has been obtained through sieving.
4. Samples have been boiled with 15%HCl for about 10mins to disintegrate and clear of the surface of the grains.
5. The boiled samples were left for about an hour to cool down which later has been washed with mild-Q water until the decanted water was clean.
6. The washed samples were then oven dried at about 60°C.
7. About 15 Quartz grains are selected with great care under binocular stereozoom microscope LEICA 205C with homogeneity, as grains of similar diameters are preferred for surface textural study.
8. Selected quartz grains are placed on SEM sample holder for further study.
9. SEM study is carried out by CARL ZEISS MERLIN COMPACT 6073 FIELD EMISSION SCANNING ELECTRON MICROSCOPE at Central University of Punjab, Bathinda, Central Instrumentation Lab.

CHAPTER-05

MATERIALS AND THEIR ASSEMBLAGES

MINERAL ASSEMBLAGES:

Clay being one of the most common minerals and also being chemically sensitive to its formation helps in reconstruction the paleoclimate. Mudstone, siltstone, and sandstone mainly comprise of clay. Thus their constitution in a stratigraphic sequence assists us to understand the paleogeography and its environment of deposition. (Sharma *et al.*, 2016). The studied area of Tapar section consists mostly of Quartz, Calcite, Albite, Orthoclase, Kaolinite and a minor amount of Vermiculite, Dickite and Clinocllore.

Kaolinite:

Kaolinite $[Al_2(Si_2 O_5)(OH)_4]$ is the most dominant clay mineral in the studied area. The kaolinite group of minerals consists of dioctahedral and trioctahedral minerals, consisting unit of 1:1 tetrahedral and octahedral (T-O) sheet of silica (SiO_4) and Alumina (AlO_6) respectively². It has a d-spacing of 7.15Å and the basal reflection intense peak is detected at $2\theta=12.363^\circ$ (100), 24.85° (002) (Chaudhri & Singh, 2012). According to Chamley, (1989) “Kaolinite mainly forms in surficial environments through pedogenetic processes, but may also develop during early diagenesis. Dickite and nacrite are very close, but they usually correspond to specific hydrothermal environments and display large crystals” (p.7). Thus it may be an indication towards moist and tropical to moderate paleoclimatic conditions. The mean annual precipitation rate of above 50cms is preferable in making up of kaolinite (Sharma *et al.*, 2016). Usually significant aggregate of kaolinite presence is also an indication of intense warm and humid climate with a high rate of leaching (Chamley, H., 2001). Intense weathering of rocks like granite and basalt leads to the formation of kaolinite. The aluminosilicates act as a weak acid, which reacts with water resulting in the formation of silicic acid in soluble form along with numerous bases as well as clay as a secondary product. Intense hydrolysis aids to

² USGS OFR01-041: Kaolinite-Group Minerals. (n.d.). Retrieved May 4, 2018, from <https://pubs.usgs.gov/of/2001/of01-041/htmldocs/clays/kaogr.htm>

the kaolinite neofomatism. Thus resulting from leaching of K-feldspar and micaceous rocks lead to the development of kaolinite, as its major chemical compound necessity are silicon and aluminium. In general kaolinite, deposition indicates an acidic pre-existing source rock and a relatively neutral pH condition. (Chaudhri & Singh, 2012).

Kaolinite may be formed as a result of hydrolysis of aluminosilicates such as feldspar, amphibole, pyroxene, etc. According to Chamley, H. (1989) "Intense leaching in hot environment prevents the accumulation of organic matter and determines the flushing out of most of the mobile constituents of parent rocks" (p.30). However, the formation of kaolinite depends on the residual elements silica content.

Dickite:

Dickite $[Al_2Si_2O_5(OH)_4]$ may be the resultant of diagenesis of Kaolinite. Kaolinite is generally found to form at about 62°C whereas that of dickite formation is around 86-96°C indicating a burial diagenesis with an increase in temperature. It has a basal reflection of $d=10.08\text{\AA}$ and $2\theta=8.76^\circ$ (100)

Clinochlore:

Clinochlore $[Mg_3(Mg_2Al)((Si_3Al)O_{10})(OH)_2O_3]$ is a polymorph of Chlorite. Basal reflection of $d=14.16\text{\AA}$ and $2\theta=6.23^\circ$ (100), 12.488° (002)

Vermiculite:

Vermiculite $[(Mg_{2.36} Fe_{0.48} Al_{0.16})(Al_{1.28} Si_{2.72}) O_{10}(OH)_2(H_2O)_{4.32}Mg_{0.32}]$ imitate the structure of talc where an octahedral (O) layer is sandwiched between two tetrahedral (T) layers forming a T-O-T formation. Basal reflection of $d=14.34\text{\AA}$ and $2\theta=6.157^\circ$ (100), 19.269° (002). It is generally formed due to the changes underwent, during the process of chemical and physical weathering by micaceous mineral viz. biotite, chlorite, muscovite etc.³. According to Chaudhri *et al.*, (2012) "Vermiculite forms as a result of selective fixation of potassium during diagenesis and a consequence of the alteration of fluorite and illite" (p.235). Transfiguration of iron-rich mica aids in vermiculite formation(Chaudhri & Singh, 2012).

³ USGS OFR01-041: Vermiculite. (n.d.). Retrieved May 5, 2018, from <https://pubs.usgs.gov/of/2001/of01-041/html/docs/clays/verm.htm>

Albite:

Albite ($\text{NaAlSi}_3\text{O}_8$) is one of the most common feldspar mineral occurring in pegmatites and felsic igneous rocks. This can also be found in a lower grade of metamorphic rocks and as authigenic albite in some sedimentary deposits⁴. According to (Mu *et al.*, 2016) “Formation of authigenic albite in sandstones is reported to be coupled to high temperatures between 100–150 °C” (p.31); however, it may also develop at around 60-100°C. The formation of albite generally develops with increasing depth of the deposition. It has also been found in previous studies that the main cause of albite formation is coupled to illite formation. Mu *et al.* (2016) found “Since the rate of illite formation increases at temperatures close to 100°C, precipitation of illite at the expense of smectite and kaolinite removes potassium from the pore water resulting in relatively high Na/K ratios. In such case the pore water becomes saturated/oversaturated with respect to albite and under saturated with respect to K-feldspar, enabling albite formation” (p.31); this might also alter the original mineral composition significantly along with formation of diagenetic products like calcite, kaolinite, dickite and illite may be formed which eventually modify the pore size and geometry.

QUARTZ GRAINS:

Roundness or angularity of grains serves as a characteristic feature of grain outline, which is further subdivided into three categories namely angular grains with sharp edges, sub angular grains with slightly blunt edges and rounded grains with smooth edges. The grain outline is concerned with the distance and size of the particle and mainly to the transportation mode, it is equally a function of the original grain shape of the particle in the source rock. Due to the need of high need for abrasions so as to round the edges, the upper flow regimes, or the intertidal zone owes to the production of sub angular to rounded grains. Angular grains owe their production in a high-energetic, subaqueous environment like glacial environments so that they can be crushed causing grain breakage, without a distinct edge rounding whereas smooth rounded grains are likely to be found in the fluvial and aeolian environment.

⁴ Albite | mineral | Britannica.com. (n.d.). Retrieved May 19, 2018, from <https://www.britannica.com/science/albite>

Examining the quartz grain surface can help us to distinguish from the quartz grains from the different deposited environment. Some of these include:

- a. The source material of the grain (i.e. close to bedrock)
- b. Diagenetic process it has undergone
- c. Glacial environment
- d. Littoral environment
- e. Both glacial and littoral combined environment
- f. Aeolian environment
- g. High-energy chemical (e.g. tropical)

CHAPTER-06 RESULT AND INTERPRETATION

XRD Results:

The studied section of the Tapar area from the late Miocene mainly consists mostly of sandstone, mudstone, and siltstone; Quartz, Calcite, Albite, Orthoclase, and Muscovite are some of the most common minerals presents in the collected sample. Rutile and Magnetite are some of the minor heavy minerals within the samples.

Kaolinite and Dickite and an insignificant amount of Vermiculite and Clinoclhore are observed within the collected samples. Diversification within clay minerals aggregate indicates the change in paleoclimatic condition, tectonic cyclicity and the modification undergone through diagenesis.

The XRD spectrum and data for each samples are given below:

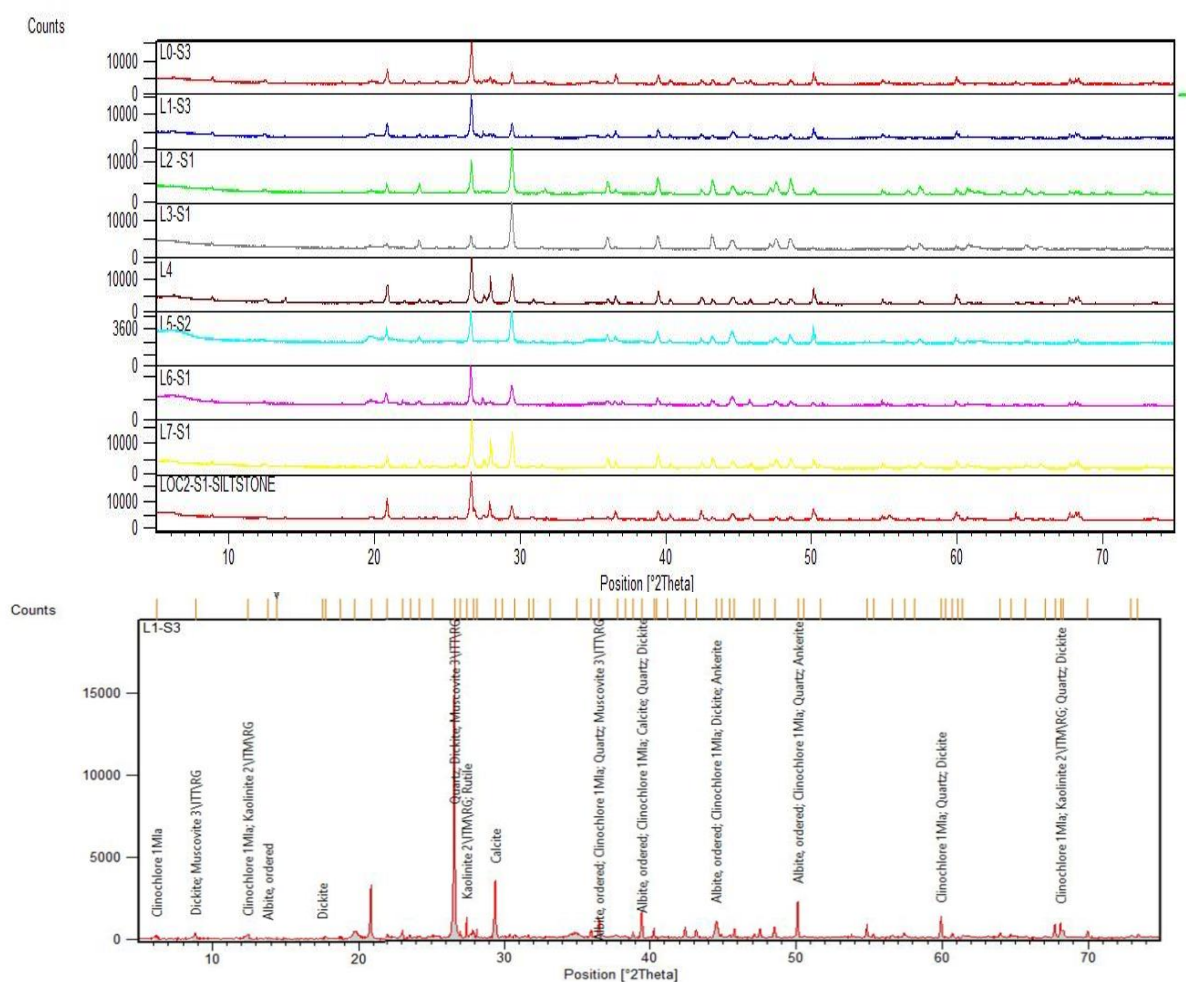
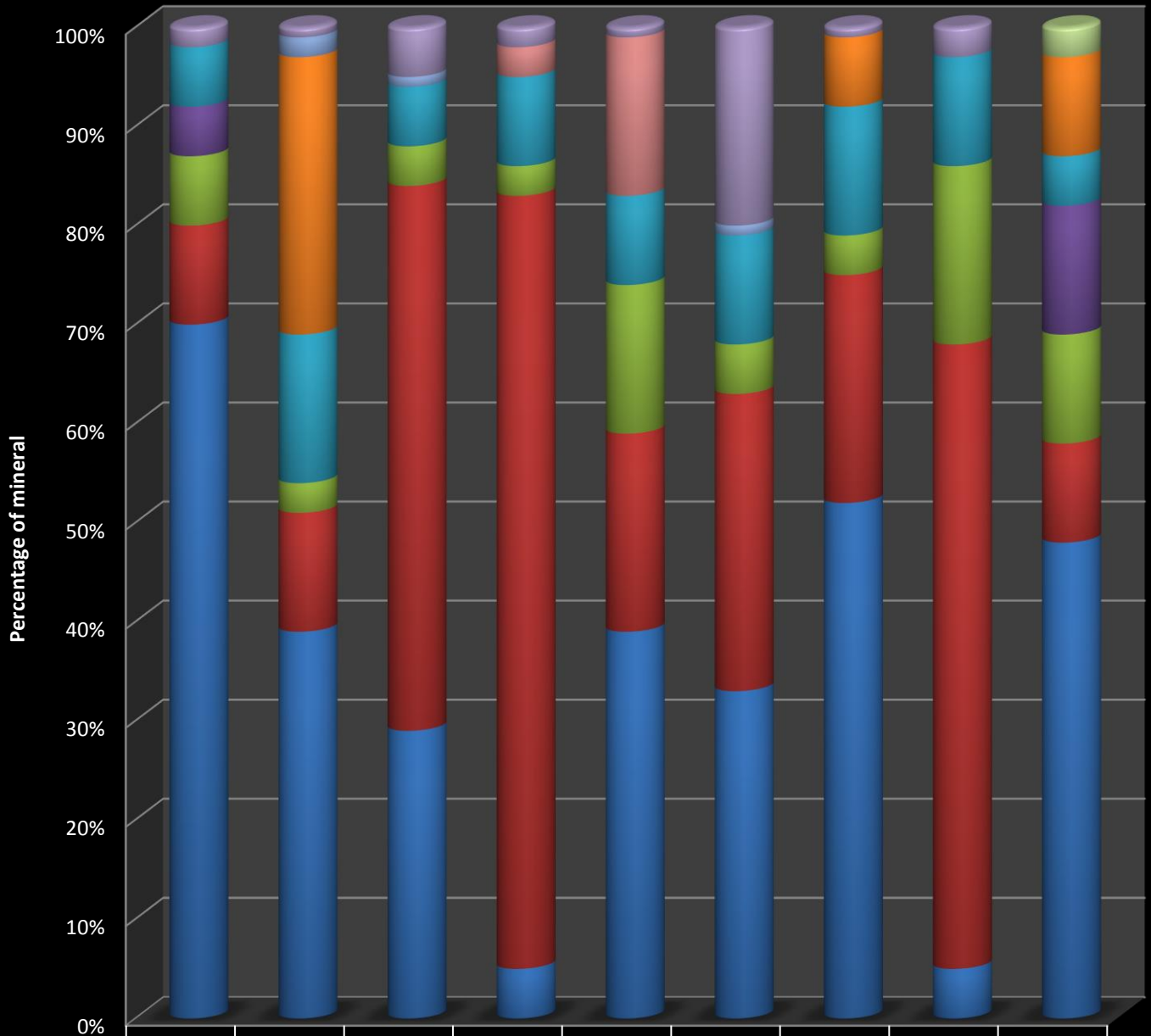


Figure 7: XRD Spectrum of all samples with mineral peak

XRD pattern of each samples



	L0-S3	L1-S3	L2-S1	L3-S1	L4	L5-S2	L6-S1	L7-S1	Siltstone
Others	2	1	5	2	1	20	1	3	
Magnetite									3
Biotite				3	16				
Rutile		2	1			1			
Muscovite		28					7		10
CLAY	6	15	6	9	9	11	13	11	5
Orthoclase	5								13
Albite	7	3	4	3	15	5	4	18	11
Calcite	10	12	55	78	20	30	23	63	10
Quartz	70	39	29	5	39	33	52	5	48

Figure 8: XRD data of bulk sample

The XRD diffractograms analysis of the Tapar area results in the presence of Kaolinite of about 50-90% and Dickite of about 15-20% out of the total clay assemblages, along with Vermiculite and Clinochlore of about 10-15% in few samples.

The graphical representation of each clay mineral within the samples is represented in the fig below.

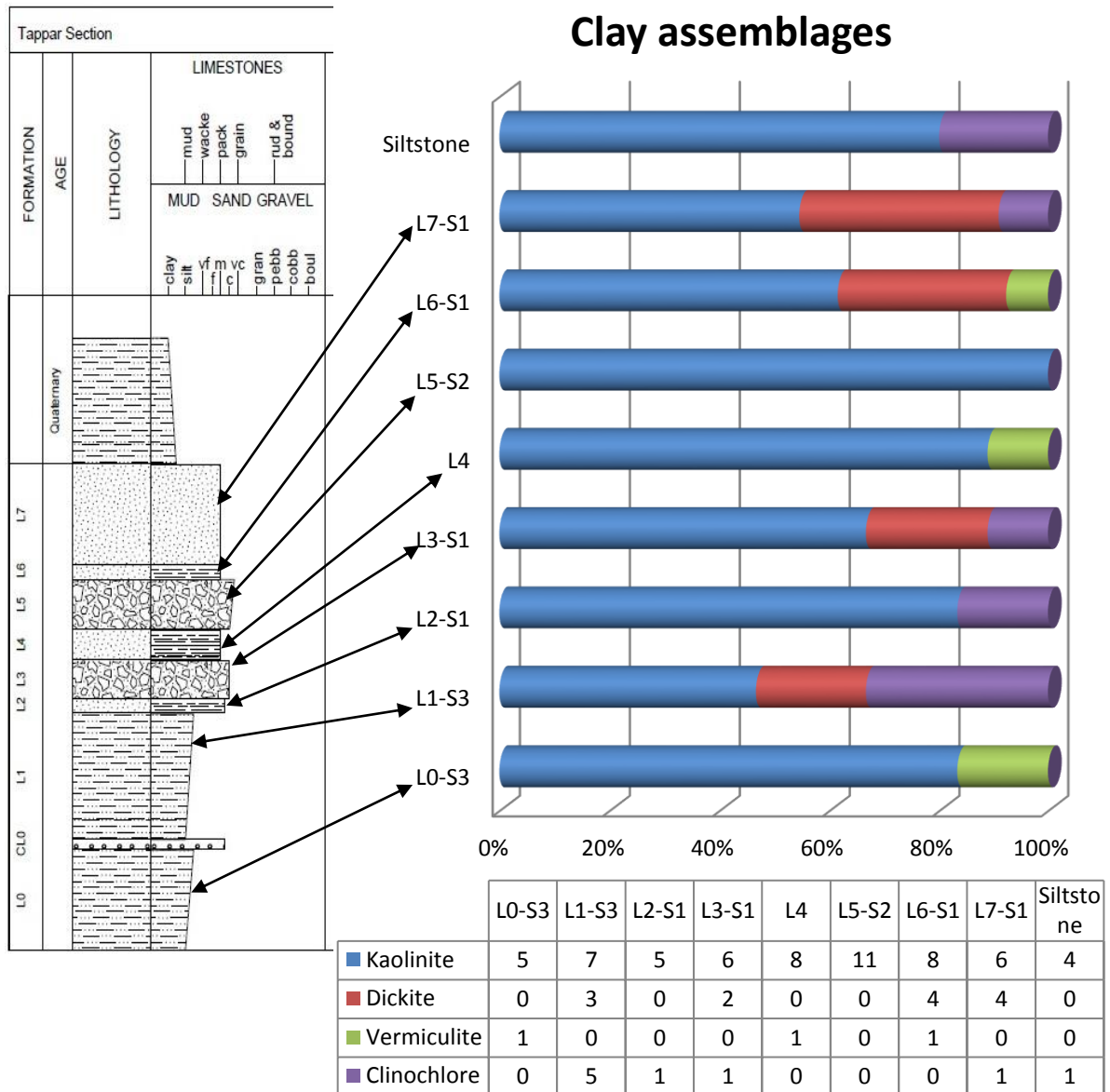


Figure 9: Clay mineral assemblages from each sample

Examination of the collected samples indicates a variation in the distribution of clay minerals in the sequence. Graphical representation indicates the change in Kaolinite, Dickite, Vermiculite, and Clinochlore of the collected samples. The fluctuation in the clay assemblage indicates towards a variation in the environment over time.

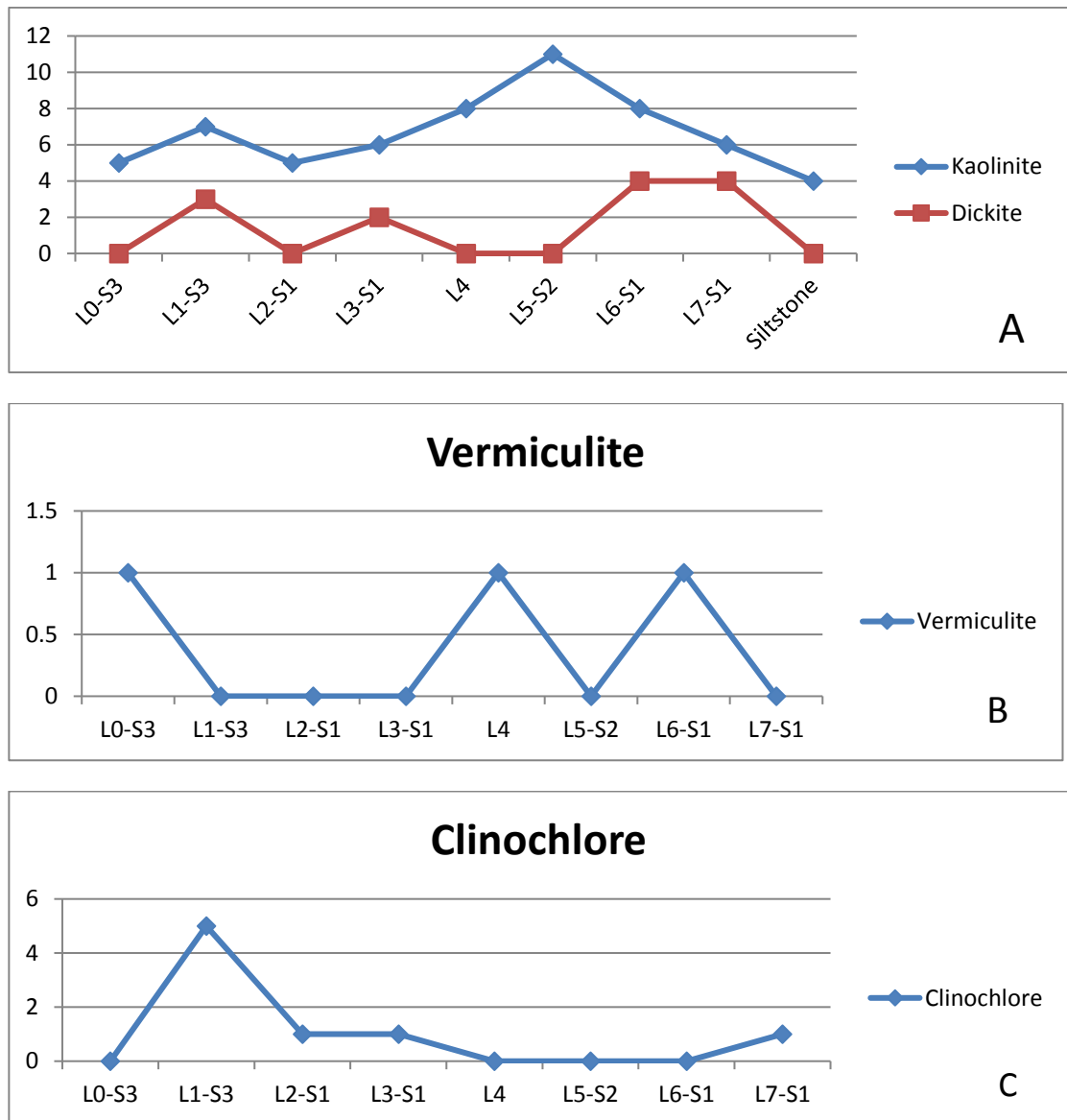


Figure 10: (A) Kaolinite and Dickite (B) Vermiculite (C) Clinochlore assemblage changes within the samples

SEM IMAGERY:

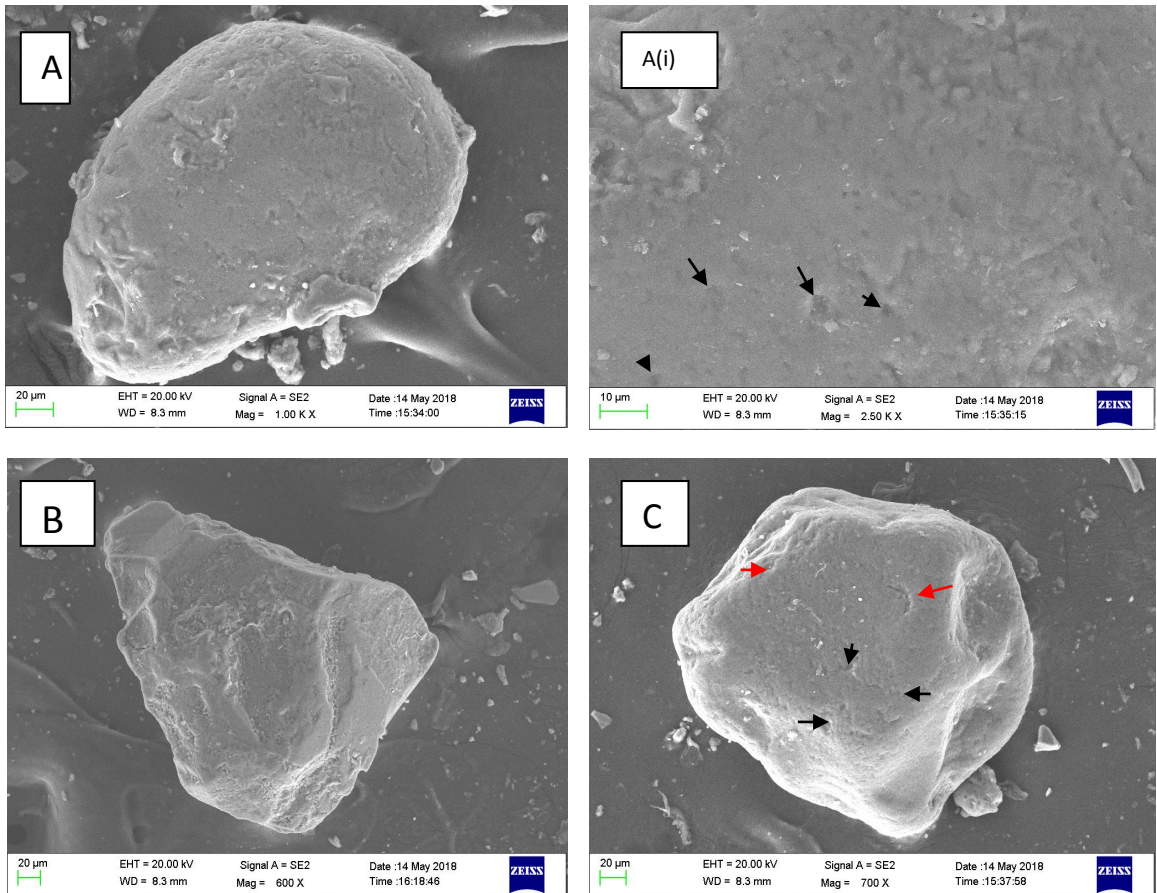


Figure 11: Plate 1 (Sample:L6): (A) and (C) Sub-rounded grain indicate larger amount of transportation, A(i) Magnified image of (A) showing V-shaped Percussion marks: Randomly occurring collision between grains (B) Slow silica precipitation may form crystalline growth due to burial diagenesis (C) Red arrow shows crescentic percussion marks and black arrows show abrasion fatigue is indication of High-Energetic fluvial sediments.

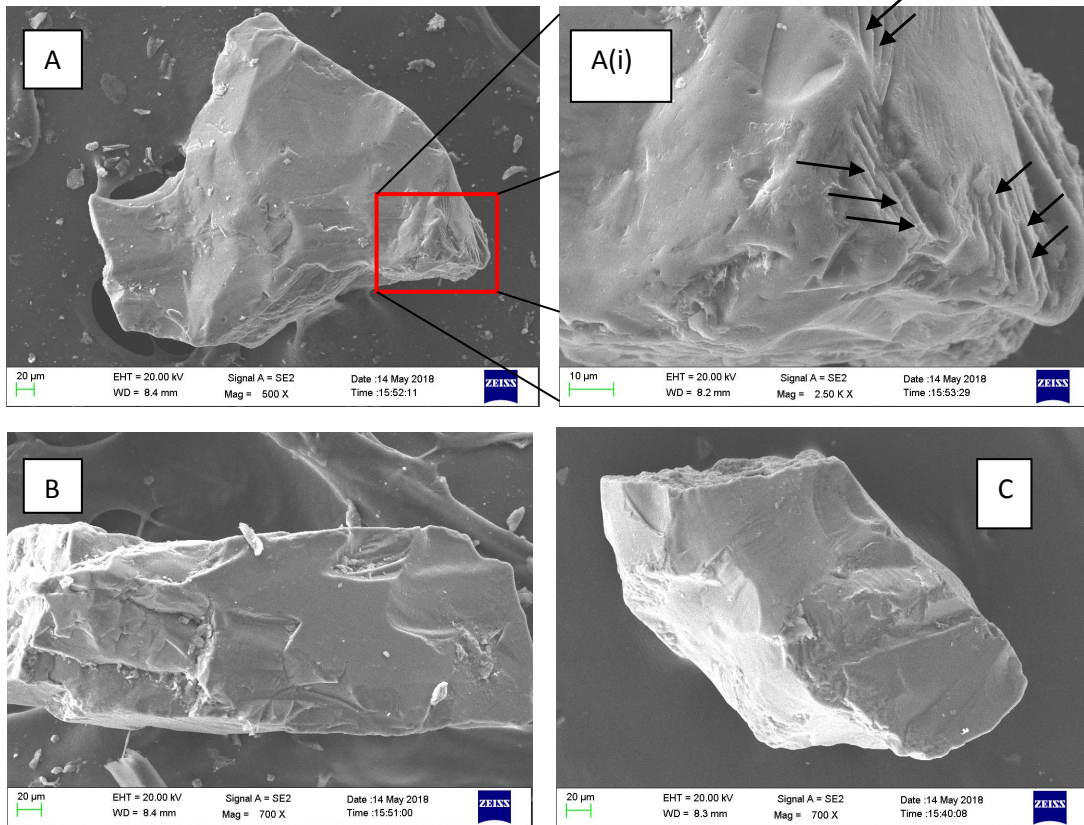


Figure 13: Plate 2 (Sample L7): (A)Angular to sub rounded grain with Graded arc, A(i) showing magnified image of the (A) grain within the box. (B)Concoidal fractures due to mechanical weathering.

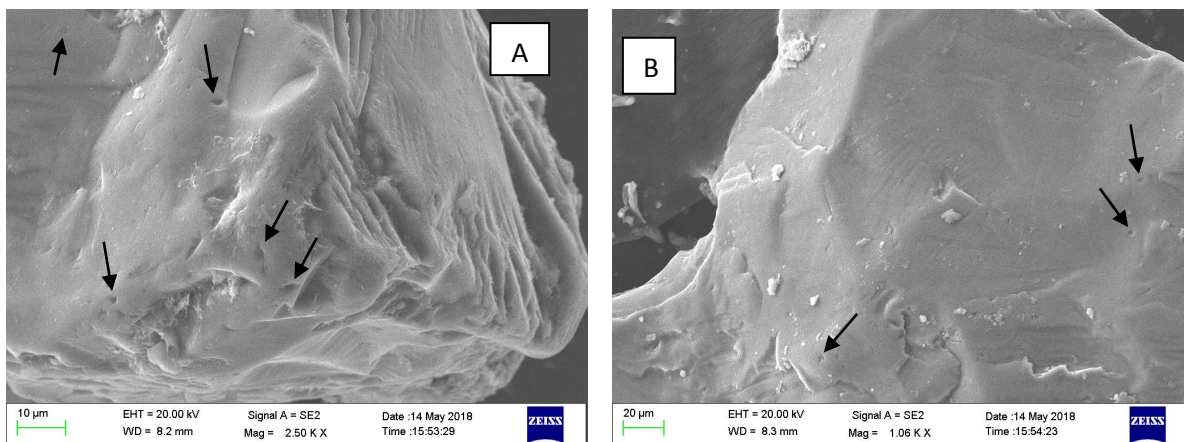


Figure 12:Plate 3: Magnification of plate 2(A) sample showing solution pits due to dissolution of chemical activity.

INTERPRETATION OF RESULTS:

XRD :

Kaolinite being the single most abundant clay quantity within the Tapar is indicative of warm humid climate with intense leaching condition, might be with the viability of granitic and basic rocks in the source of origin. Clay and claystone rich in kaolinite group minerals precipitate in freshwater and not in marine environments because kaolinite quickly transforms into complex clay minerals in seawater (Haldar *et al.*, 2014). The very little to absent of Clinocllore in a few samples is an indication of the absence of harsh climate since its occurrence indicates towards a cold or dry climate (Chamley, 1989). According to Sharma *et al.*, (2016) "The presence of significant amount of kaolinite in the clay assemblages normally interpreted as the presence of warm and wet conditions associated with high leaching rate."(p.221). Dickite a polymorph of kaolinite is generally found to develop at a greater temperature than the latter. The minimum temperature for kaolinite formation is about 62°C whereas that of dickite formation is around 86-96°C. This infers to the fact that Dickite must be formed as a result of burial diagenesis which elevated the temperature of around 90°C, which is the minimum required temperature for Dickite formation. Presence of vermiculite in a sample may be due to the presence of Fe-rich mica in the provenance of which alteration results in its formation (Chaudhri, 2012).

Albite one of the most common mineral found in almost all the samples may be due to its association with illite and elevated temperature. Authigenic Albite in sandstone might be related to overgrowth due to precipitation from saturated solution or replacement of K-feldspar or plagioclase by albite.

Neomorphism of muscovite and authigenesis of kaolinite are the first diagenetic alteration almost in all non-marine sediments and are resultant of freshwater diagenesis. It is presumed that the porewaters were meteoritic initially having a pH value of about 7-7.5. Anaerobic bacteria might have also released bicarbonate ions into the solution and thus resulting in an acidic solution. Supply of continuous freshwater might help to induce a low pH, positive Eh low salinity which might have also resulted in kaolinite precipitation and also the neof ormation of muscovite (Chamley 1989).

Surface Texture of Quartz grains (SEM):

Conchoidal fractures result due to heavy pressure on the grain surface leading to curved, shell-like breakage patterns and it generally forms on minerals which lack distinct cleavage directions (Plate 2A, B,C). Conchoidal fractures can be defined as most commonly occurring microtextures on quartz grains. The step-like features that are mostly seen on conchoidal fracture planes are called as Arcuate and straight steps, they are formed by the intersection of the conchoidal fracture with the cleavage planes of the quartz crystal. Thus they are innately related to conchoidal fractures.

Similar to conchoidal fractures, Graded arcs are formed as a result of heavy pressures and shocks, where each arc series is characterized by a fan-shaped pattern. They are an arc-series which are concentric, circular and semi-circular in shape grading from 3 up to 400 μm in diameter.

Due to the collisions between grains, V-shaped percussion cracks (Plate 1A) are randomly oriented and are triangular shaped depressions with a diameter ranging to 5 μm and an average depth of 0.1 μm .

A reactive surface expressed on quartz grains is called abrasion fatigue (Plate 1C) which is characterized by numerous cracks and dislocations in which small grains (<3 nm) attach. It owes its formation to the high-energetic collisions when the energy wave is transferred to the grain. This microtexture is diagnostic for eolian transport or glacial gliding.

Crescentic percussion marks (Plate 1C) which results from grain-to-grain collisions are cone-shaped fractures on the surface of the quartz grains. The corners of the shape may vary between 1 and 30 μm . This may indicate towards the eolian environment.

Solution pits seen in Plate 3A, B may be due to chemical weathering where the pit diameters range upto 10 μm . It depends on the chemical activity and the time of dwelling in the environment which is prominent to quartz dissolution.

CHAPTER-07

CONCLUSION

The preliminary survey of the Tapar section overlying the Deccan trap is approximate of the late Miocene epoch.

- (i) The calcareous nodules in few sections is an indicator of tropical humid environment.
- (ii) The alternative laminated micaceous sandstone and pellet rocks are an indication of fluvial deposition.
- (iii) Discovery of vertebrate fossils by Bhandari *et al.* 2015, infers towards a terrestrial deposit.
- (iv) Among the clay assemblages, Kaolinite being the majority indicates towards a tropical climate with high intensity of leaching.
- (v) A relative increase of Kaolinite from L3 to L5 and again gradual decrease towards L7 may infer towards a gradual change in climatic condition.
- (vi) A minor amount of vermiculite and dickite indicates towards a burial diagenesis of illite and kaolinite respectively.
- (vii) Minor amount to absent of clinocllore in samples indicates the absence of cold and harsh arid climate.
- (viii) The SEM imagery showing rounded to sub-rounded grains indicates towards a fluvial mode of transportation whereas angular grains along with conchoidal fractures and graded arcs may be the result of higher energy mode of transportation.
- (ix) The abrasion fatigue may the result of higher sedimentation load which results in grain to grain collision creating the texture on the surface.

To reconstruct the paleoclimate of the area more precisely a detail analysis by clay assemblages by clay separation method is recommended.

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