

Executive Summary of the Thesis entitled
PALYNOLOGY OF THE INTERTRAPPEANS OF SAURASHTRA
PENINSULA, WESTERN INDIA: BIOSTRATIGRAPHIC AND
PALEOENVIRONMENTAL IMPLICATIONS

To be submitted

As partial fulfilment for the award of the degree of

DOCTOR OF PHILOSOPHY

in
Geology

By

Nishi H. Shah

Under the guidance of

Prof. Satish J. Patel



DEPARTMENT OF GEOLOGY

FACULTY OF SCIENCE

THE MAHARAJA SAYAJIRAO UNIVERSITY OF BARODA

VADODARA

January 2024

***PALYNOLOGY OF THE INTERTRAPPEANS OF SAURASHTRA
PENINSULA, WESTERN INDIA: BIOSTRATIGRAPHIC AND
PALEOENVIRONMENTAL IMPLICATIONS***

During the northward drift of the Indian Plate, Insular India experienced huge volcanic eruptions, the Deccan Continental Flood Basalts, covering nearly 5,00,000 sq. km in western and central India. It was completely detached from the Gondwanaland and had experienced the outpouring of several lavas flows of reunion hot spots during the Late Cretaceous-Paleogene (Mahoney, 1988), which had resulted in an undulating topography. This led to the formation of perennial and ephemeral freshwater pools due to seasonal and residual water drawing streams which became hosts to various life forms. These pools, usually formed across the Cretaceous-Paleogene, filled by the sediments were covered by the subsequent Deccan lava flows forming intertrappean sedimentary succession which has patchy occurrence in the Indian continent (Blanford, 1872; Khosla and Sahni, 2003; Chenet et al., 2008).

The Saurashtra Peninsula is a horst bounded by three intersecting rifts, the North Kathiawar Fault (western extension of Great Boundary Fault) towards the north, the western extension of Narmada Fault towards the South, the Western Margin Fault of Cambay Basin towards the east and the west Kathiawar Fault towards the west (Biswas, 1987). The Saurashtra - Kachchh sub-province (Kale et al., 2020a; Tandon and Gupta, 2020; Mittal et al., 2021) a part of the Deccan Igneous Volcanic Province, which is covering the major part of the Saurashtra Peninsula (Fig. 1b) and is characterized by several undulating topography, hills (Girnar, Barda, Alech, Osham, etc.), intrusive and dykes, and dyke swarms, composed of a varied range of rocks including basalt, granophyre, rhyolite, tholeiites, diorites and associated volcanic (Sheth et al., 2012, 2022; Sheth and Pande, 2014; Cucciniello et al., 2015; Sheikh et al., 2020). The Paleogene intertrappean sedimentary rocks are informally named using local geographic names and are described by various workers (Fedden, 1884; Borkar, 1973; Samant et al., 2014). The systematic work on various geological aspects is carried out in the present study by the investigator on such as lithostratigraphy, sedimentology, geochemistry, palynofossil, and biostratigraphy to infer the various paleoecological parameters and climatic conditions of the Insular India.

The Saurashtra Peninsula experienced the Deccan Traps lava outpouring during the Late Cretaceous – Early Paleogene time. The flows are intermittently erupted, and the time gap

represents intertrappean sedimentary rocks, which are well developed around the Chotila and Ninama area of the Surendranagar district of the Saurashtra. These are rocks highly disrupted due to volcanic eruption, preserved as intra-, intertrappean and are exposed as patchy outcrops or covered by shrubs, soil and scree materials of the younger volcanic flows. It has patchy exposure and hence is mainly observed as stream sections, well sections, road cut sections, quarry sections, and low-lying plain surfaces due to erosion of the younger lava flows. In the present investigation, preserved sequences of the intra-, and intertrappean are observed at fifteen localities (Fig. 1), which includes, 1- Ninama hill sections, 2- Sukhbhadar river section, 3- Ninama well section, 4- Motamatra well section, 5- Motamatra road section 6- Shekhdod hill, 7- Lakhvad, 8- Chanpa hill section, 9- Bamanbor – Navagam section, 10- Bamanbor road section, 11- Rangpar GIDC section, 12- Redren Industry section, 13- Garida section, 14- Jalida section, 15- Jalsika section.

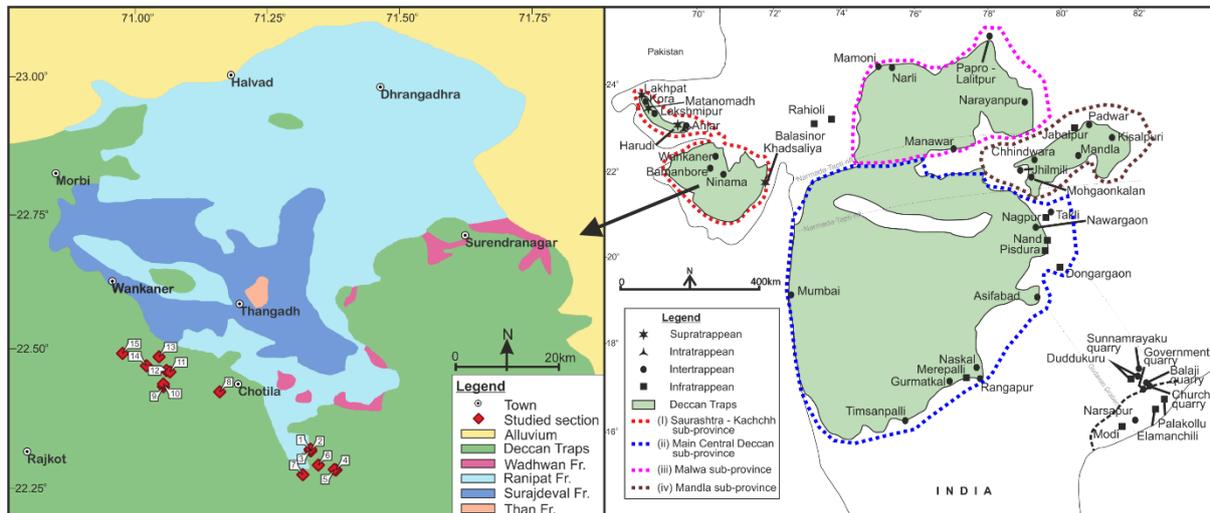


Fig. 1 Four Sub-provinces of the Deccan Volcanic Province of India with and infratrappean, intertrappean, intratrappean, and supratrappean localities, (modified after, Deshmukh and Sehagal, 1988; Mahoney, 1988; Kapur et al., 2018; Kapur and Khosla, 2019; Kale et al., 2020b; Mittal et al., 2021); all the intertrappean successions are developed on the periphery of the sub-provinces and a geological map of part of the Saurashtra region (modified after Khan and Ahmad, 1998) with studied locations of intra-, intertrappeans.

1. AIM AND OBJECTIVES

The present study aims to investigate all possible intertrappean sites of Saurashtra peninsula for their sedimentology and palynology, to establish the biostratigraphy and paleoenvironmental conditions prevailing during their deposition.

The objectives are:

1. Sedimentology and lithostratigraphy of the intra-, Intertrappean sequences.
2. Analysis of palynomorphs at high-resolution of different sections.
3. Identification and documentation will be attempted for palynomorphs and biostratigraphic framework will be established.
4. Integrated palynological and sedimentological data will be utilized to infer the paleoenvironment.

2. METHODOLOGY

Integrated approach of sedimentology and palynology can be utilised to understand the paleogeography, paleoclimate, and paleoecology of the area.

Field expeditions and laboratory techniques

1. Stratigraphic sections have been measured at different localities and lithologs are prepared.
2. High-resolution systematic sampling, laterally as well as vertically has been done in different sections.
3. Collected samples have been analysed for textural and mineral composition.
4. Samples have also been disintegrated by following the standard techniques to separate the palynomorphs.
5. Separated palynomorphs have been identified and documented.
6. Qualitative and quantitative analysis of the palynomorph data has been done, different biostratigraphic zones have been established and correlation have been attempted between different sections.
7. Based on sedimentological, lithostratigraphic, geochemical and palynological data, two geological aspects are interpreted, palynostratigraphy, paleoenvironment and climate.

The present research work is divided into Ten chapters briefly described below.

Chapter: 1 Introduction

This chapter described the basic concepts of the of the present investigation, strength and limitation of the intertrappean succession. It provides an information on the phases of the Gondwana breakup and paleogeographic position of the Insular India, Deccan volcanism, and

extinction events of the Cretaceous Period, complete isolation from the other continents and cessation of the biotic interaction. It also introduces the Saurashtra region including people and culture, flora and fauna, climate and weather, rainfall, physiography, transportation, and physiography. A brief historical review, implication of the organic walled microfossils and their applications in solving geological problems are discussed. This chapter is concluded with the introduction of the study area, its aim and objectives, and the methodologies that followed for present investigation.

Chapter: 2 General Geology

This chapter describes the general geology of the Mesozoic and Cenozoic era of the Saurashtra region, structures and tectonic history, basin evolution and mineral wealth. This peninsula hosts several geological formations, each with its own distinct lithological characteristics and age. The Mesozoic sedimentary covers ~5000 km², overlain by a thick tholeiitic and alkali basalt lava flows (Deccan Traps) of the Cretaceous-Paleogene time. Volcanic province preserves the fossiliferous intertrappean successions of Paleogene. The Deccan Traps are fringed on the coastal belt by sequence of sedimentary rocks of Paleogene, Neogene, and Quaternary. Lastly, it was mentioned about the economic mineral deposits of the Saurashtra region.

Chapter: 3 Methodology

Systematic and stratigraphic sampling was carried out from the different section subjected for the petrographic, geochemistry and for palynology.

The petrographic study was attempted for textural and mineral composition analysis. The inorganic geochemical laboratory analysis was carried out to determine the chemical compounds of the rocks that support present investigation to interpreting the various paleoecological parameters. To get geochemical information, major, minor and trace elements were determined using an advanced Heavy Element energy dispersive X-ray fluorescence spectrometer.

Laboratory extraction and slide preparation of palynofossils:

1. Cleaning, disaggregation and weighing.
2. The collected samples were crushed into pea-sized particles using a mortar and pestle, weighed to 20 grams and added to labelled PPE beakers.

3. The collected samples in the beakers are then reacted with 10-40% HCl (Hydrochloric Acid) to remove carbonates depending upon the carbonate content of the sample.
4. The beakers are kept untouched for 8 to 10 hours until the reaction seems to have stopped (the time of reaction depends on the sample).
5. Once the reaction is complete, the beaker is filled with distilled water to its brim and the samples are washed until neutral.
6. The samples thereafter are treated with 40% HF to remove silicates.
7. Once the samples are completely deflocculated and as the reaction ceases, they are washed with distilled water until neutral.
8. Finally, the samples are reacted with the nitric acid (HNO₃) to readily remove the ferruginous content in the samples via oxidation, followed by washing until neutral.
9. The final residue is then treated with 5%- 10% KOH depending upon the amount of humic matter, to remove the unwanted amorphous organic matters. The treatment where an appropriate proportion of KOH is diluted in the respective beakers and kept resting for 15 to 20 minutes until the unwanted sediments are dissolved in the water. These unwanted are then decanted into the sink.
10. Once all the beakers with the samples are clean and clear they are then sieved using the 120ASTM, followed by a 10µm sieve.
11. The fine sieved samples are then collected into the beaker along with some distilled water, stirred and poured quickly into their respective blue-capped veil (centrifuge bottles) and closed tightly. The remaining samples are filled into their respective labeled white-capped veil for further emergency cases.
12. The samples are then centrifuged at 900 to 1000 rpm for 10 mins.
13. The water from the centrifuge is decanted and the collected palynomorphs are mixed with polyvinyl alcohol, ready to be smeared on the slides.
14. The palynomorph containing slides are now dried after which, mounted with Canada balsam.
15. To dry the slides and for permanency, the slides are cooked at 60-70°C until golden in color in an oven or over a hot plate.

Chapter: 4 Stratigraphy of The Study Area

An introductory remark is made on the concepts of lithostratigraphy, and successions are divided into formal lithostratigraphic units assigning the stratotypes. The intra-, intertrappeans succession of Saurashtra Peninsula are characterized by two distinct

sedimentary rock units, named as two different basins, Ninama and Chotila. The sequence of both these areas is classified lithostratigraphically according to the ISSC norms and assigned the stratotypes. Ninama Basin succession is divided into two formations, Sukhbhadar Formation and Ninama Limestone while Chotila Basin is divided into three formations, namely, Rangpar Formation, Chotila Chert and Bamanbor Formation in an ascending order. Based on palynofossils assemblages the age of the Ninama basin is considered Paleocene to Early Eocene (Samant et al., 2014) while based on fish remains and palynofossils assemblages, age of the Chotila basin is considered as Paleocene to Early Eocene (Samant et al., 2014)

	Chotila Basin		Ninama Basin	
Age	Formation	Lithology	Formation	Lithology
Deccan Traps				
Paleogene (Paleocene –Eocene)	Bamanbor	Red, buff, grey mudshale, fossiliferous sandstone - siltstone, chert and nodules of claystone with bivalves and gastropods	Ninama Limestone	Fossiliferous limestone, nodules of chert, argillaceous limestone, Marlite and calcareous shale
	Chotila Chert	Bedded and banded chert, mudshale		
	Rangpar	Mudshale, siltstone, claystone	Sukhbhadar	Mudshale, siltstone, mudstone, claystone, lithic arenite
Deccan Traps				

Table 1 Formal lithostratigraphic units of the Saurashtra Peninsula (Patel and Shah, 2023).
Note: Two different types of lithological succession are divided into two separate lithostratigraphic units owing to their distinctness in the nature and geographic positions.

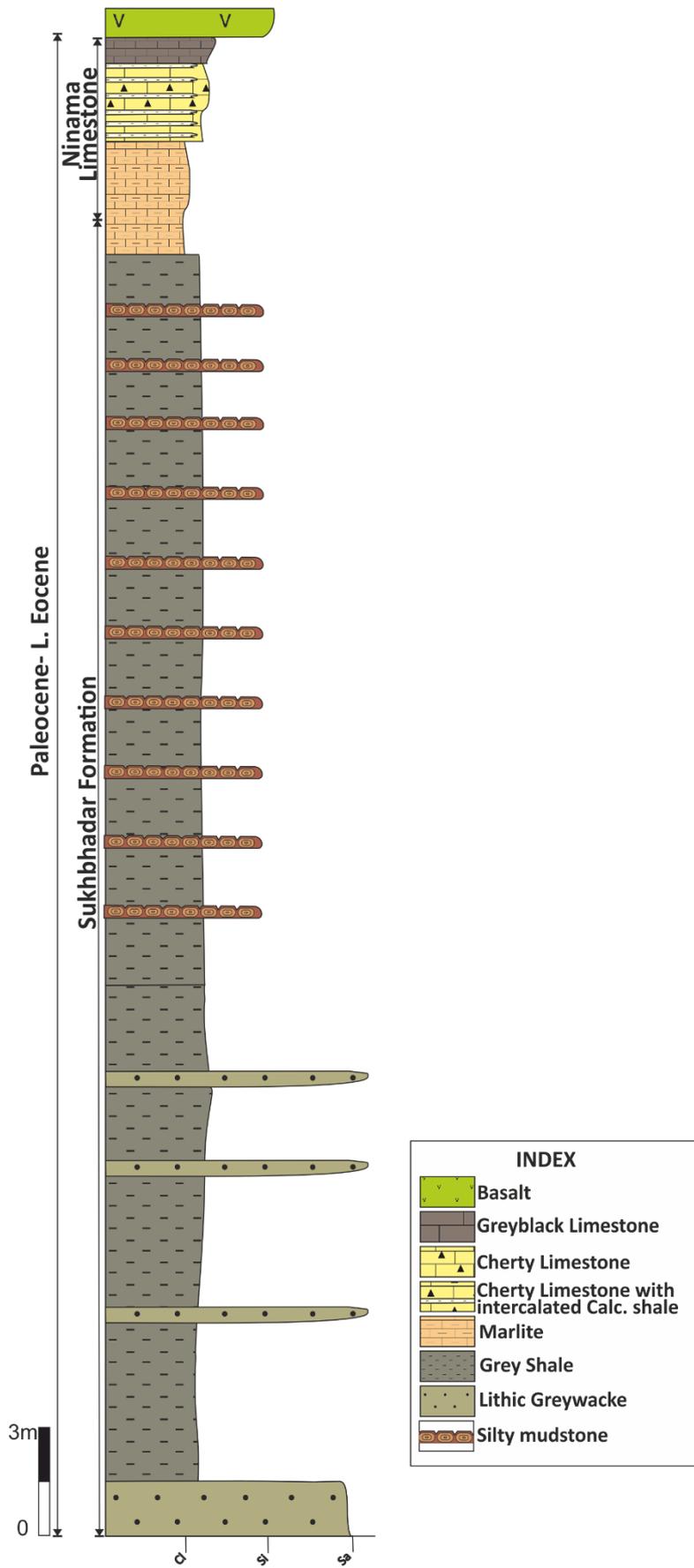


Fig.2 Composite litholog representing lithofacies of Ninama Basin.

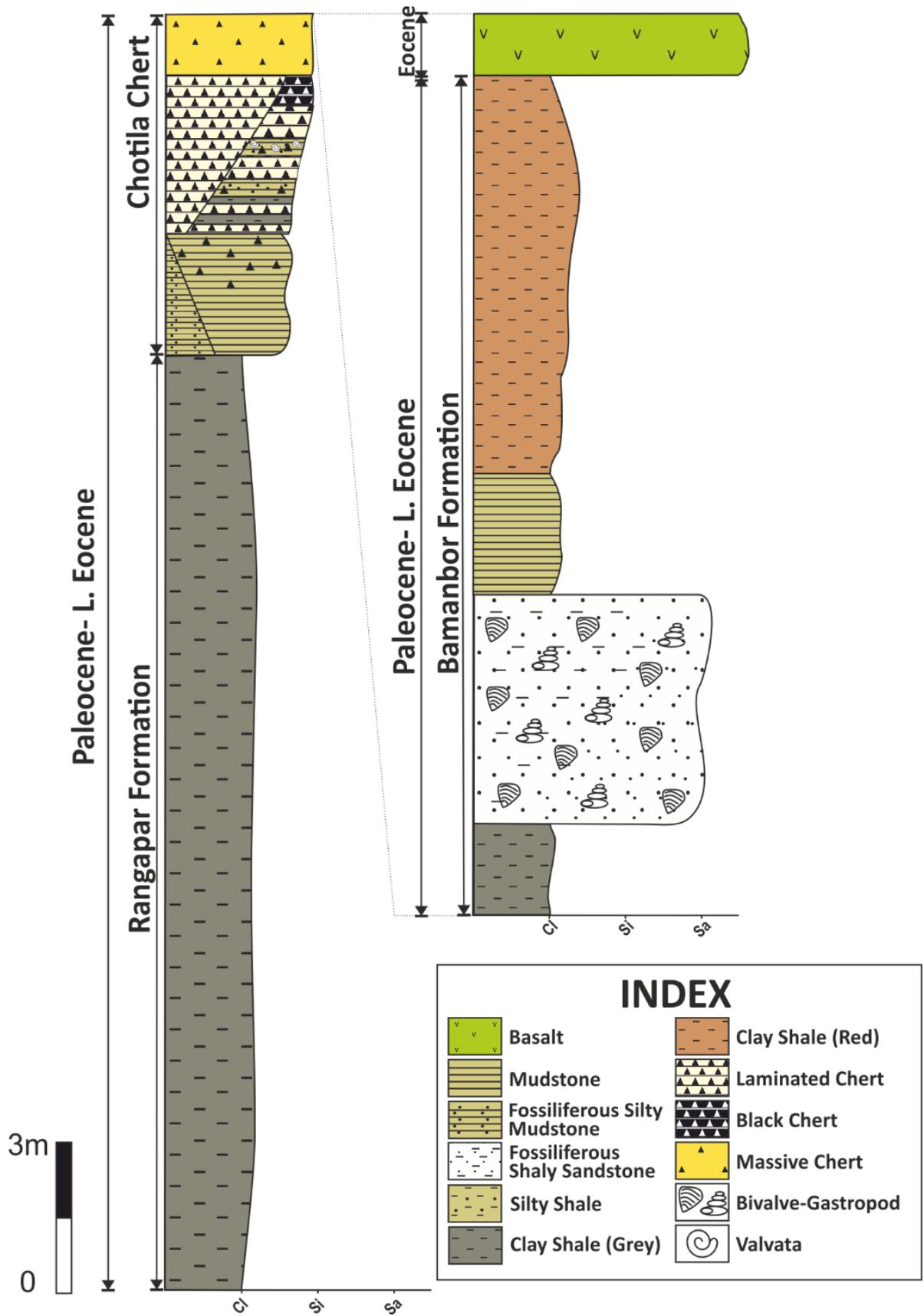


Fig.3 Composite litholog representing lithofacies of Chotila Basin.

Chapter: 5 Lithofacies and Geochemistry

To analyse the sedimentological characteristics, 15 localities of the intertrappean sites of the Saurashtra (Fig. 1) are studied for detailed lateral and vertical variation, which reveals fine-grained sediments, carbonates, and chert. The sequence is further analyzed based on field and laboratory study revealed seven lithofacies (Figure-2, Table 2) for Ninama Basin and eight lithofacies (Figure 3, Table 3) for Chotila Basin.

Sr. No.	Lithofacies	Description
1.	Grey Shale - GSH	Beige to grey in colour, well laminated and stratified, intercalated with SM and LGW. Variable in appearance, inconsequential amount of silt and sand-sized quartz.
2.	Calcareous Shale - CSH	Yellow to buff coloured, finely laminated to thinly bedded layers, highly friable.
3.	Silty Mudstone - SM	Reddish brown coloured, polygonal appearance due to shrinkage cracks, dominated by mud with some silt sized quartz.
4.	Lithic Greywacke -LGW	Greyish to black coloured, coarse grained, dominated by volcanic rock fragments, quartz grains which are poorly sorted in nature.
5.	Grey Black Limestone -GBL	Grey to black coloured, massive, highly compact and jointed limestone with occasional chertification, organic matter and iron oxide. Mudstone microfacies- highly sparitised, with subordinate amounts of chert, microspar and iron oxide in the groundmass.
6.	Cherty Limestone - CL	Yellow to buff coloured, irregularly laminated and otherwise, cherty limestone, thinly bedded in nature. Microfacies- Pelloidal wackestone-packstone microfacies- pellets, algal fragments and laminations with few bioclasts, microspar formation, pyritization and chertification are also noticeable as secondary processes altering the allochemicals. Bioclastic bindstone microfacies- cladoceran and ostracod shell fragments with algal filaments bounded together in algal

		mats. Cone in cone calcitic microfacies- fibrous sparry calcite layers arranged in organic matter and micrite resulting in wavy laminations giving cone in cone structures.
7.	Marlite - ML	Blocky and massive limestone, yellow to light orange in colour, thickly bedded, containing moderate amounts of argillaceous matrix. Cladoceran bindstone microfacies- calcified cladoceran and ostracod fragments with algal filaments bounded together in algal mats, with subordinate amounts of pellets, and few quartz grains.

Table 2. Lithofacies and their characteristic features of Ninama Basin.

Sr. No.	Lithofacies	Characteristic Features
1.	Fossiliferous Shaly Sandstone (FS)	Fine-grained, grey to yellowish in colour and compact but highly indurated sandstones contains bivalves and gastropods.
2.	Clay Shale (CS)	Characterised by argillaceous shale which is soft and crumbly in nature, and varies from dark grey to grey, red, and yellow in colour.
3.	Silty Shale (SS)	Silt dominated argillaceous shale, thinly bedded.
4.	Mudstone (MS)	Compact, thinly bedded clastic mudstone, white to red in colour.
5.	Fossiliferous Silty Mudstone (FSM)	Blocky, yellowish to greyish white silty mudstone with planorbid gastropods.
6.	Massive Chert (MC)	Massive yellowish white chert.
7.	Laminated Chert (LC)	Horizontally stratified chert contains bedding and laminations, compact, hard, white to grey with pseudo-ripples, locally folded and fish fossils. Most conspicuous in the Chotila Basin.
8.	Black Chert (BC)	Blackish grey to dark black in colour, due to the baking effect on the chert by the underlying and/or overlying Deccan lava flows, compact and laminated.

Table 3. Lithofacies and their characteristic features of Chotila Basin.

XRF For Major Oxide and Elemental Concentrations:

Geochemical analyses are pivotal in determining the distribution of major, minor, and trace elements within sediments, serving as indicators of provenance, weathering processes, and the tectonic setting of the depositional basin. The chapter also deals with the distribution and concentration of major oxides, minor and trace elements of both the basins, where 21 samples of Ninama Basin and 66 samples of Chotila Basin, of various lithofacies were analysed using XEPOS HE XRF. The concentrations of the various elements were used such as Ca/Ca+Fe, Sr/Ba, V/V+Ni, V/Cr, Fe/Ca+Mg, Ti/Al, Na/K, K/Fe+Mg, CIA-K and MAP to gain value of elemental ratios and it was compared with standard value and used to infer various paleoenvironmental parameters like, paleosalinity, paleoredox, paleodepth, paleoweathering and paleoclimate.

Chapter: 6 Paleontology

Total twenty-six, relatively well-preserved specimens of megainvertebrate, a bivalve from the fine-grained shaly sandstone of the Bamanbor Formation have differentiated them into seven species and are systematically described. The detailed morphological analysis such as shape, size, ornamentation, and dentition enabled to classify them into a new superfamily, Deccanoidea, family Deccanoidae nov., subdivided into two subfamilies, Deccanoinae nov. and Chotiloinae nov. The former subfamily consisting of two genera, *Deccanoida* and *Bamanboria* which include four species, *Deccanoida conrugis* gen. et sp. nov., *Deccanoida aleta* gen. et sp. nov., *Deccanoida costaria* gen. et sp. nov. and *Bamanboria oblongis* gen. et sp. nov.; latter subfamily comprises of one genus *Chotilia* and three species, *Chotilia trappeansis* gen. et sp. nov., *Chotilia tuberculata* gen. et sp. nov. and *Chotilia deccansis* gen. et sp. nov.

Chapter: 7 Palynology

The palynology of the Ninama and Chotila Basins has provided insights into the palynofossils type and paleovegetation. Both the basins comprise a smaller number of the palynofossils in their early deposits, but diversity and abundance increase later. They comprise palynofossils, opisthokonts, phytoclasts, freshwater algae belonging to Chlorophyceae (02), two specie of testate amoeba includes *Centropyxis aculata* and *Arcella arenaria*, dinoflagellates and other phytoplanktons, fungal fruiting bodies and 26 fungal spores includes *Ceratohirudispora* sp., *Diporisorites sirmaurensis*, *Frasnacritetrus indicus*, *Frasnacritetrus tougourdeavi*, *Fusiformisporites* sp., *Helicominites salvinites*, *Hypoxylonites minimus*,

Hypoxylonites sp., *Hypoxylonites subrotundus*, *Inapertisporites kedvessi* *Inapertisporites maximus*, *Inapertisporites novus*, *Inapertisporites tetradus*, *Meliolinites spinksii*, *Monoporisporites circularis*, *Palaeomycites acinus*, *Palaeomycites* spp., *Papulosporites multicellatus*, *Perisporiacites varians*, *Pluricellaesporites globatus*, *Pluricellaesporites planus*, *Pluricellaesporites* sp., *Polycellaesporites saxenae*, *Polycellaesporonites bellus*, *Protocolletotrichum deccansis*, *Staphlosporonites setlyi* and *Udaria saxenae*; 28 angiosperm pollen includes, *Aquilapollenites ovatus*, *Araliaceoipollenites psilatus*, *Araliaceoipollenites reticulatus*, *Arecipites bellus*, *Barringtoniapollenites retibaculatus*, *Cupanieidites flaccidiformis*, *Cupuliferoipollenites ovatus*, *Cupuliferoipollenites psillus*, *Cythidites australis*, *Dermatobrevicolporites dermatus*, *Dermatobrevicolporites dermatus*, *Ephedripites* sp., *Florschuetzia rajpardiensis*, *Hammenisporis susannae*, *Incrotonipollis neyvelii*, *Lakiapollis ovatus*, *Longapertites retipilatus*, *Longapertites triangulates*, *Malvacearumpollis* sp., *Matanomadhiasulcites maximus*, *Meliapollis ramanujamii*, *Monocolpopollenites plicatus*, *Mulleripollis bolporensis*, *Palmaepollenites communis*, *Palmidites plicatus*, *Proxapertites cersus*, *Proxapertites crassimurus*, *Proxapertites* spp., *Rhoipites kuctchensis*, *Rhombipollis geniculatus*, *Rhombipollis* spp., *Tricolporopollenites* and *Yeguapollis* sp.; pteridophytes (02) and Amorphous Organic Matter (AOM).

Chapter: 8 Palynostratigraphy

Further analysis revealed number of biozones; four for Ninama Basin, includes (i) *Palaeomycites* spp. Abundance Zone, (ii) *Inapertisporites* spp. Abundance Zone, (iii) *Rhombipollis geniculatus* - *Proxapertites* spp. Assemblage Zone, and (iv) *Dermatobrevicolporites dermatus* - *Longapertites* sp. Assemblage Zone, and three zones for Chotila Basin, includes, (i) *Palaeomycites* spp. Abundance Zone, (ii) *Proxapertites* spp. Assemblage Zone and (iii) *Florschuetzia rajpardiensis* Assemblage Zone. The relative abundance of the each palynofossils are tabulated systematically with the litholog and at the end the age and environmental implications are discussed.

Chapter: 9 Discussion and Conclusions

This chapter contain integrated approach on the obtained geological data Saurashtra Intertrappeans and to rigorous attempt have been made to understand the evolution of the Ninama Basin and Chotila Basin. Lithostratigraphic and lithofacies units of both basins are interpreted logically and conventionally. The palynofossils of the Paleogene time, and their

affinity to the modern flora are tabulated to understand the gradient in the paleovegetation and correlated with nearby equivalent deposits such as Bhavnagar, Kachchh, and Cambay. The data sets are used herein to understand the paleoecological parameters, paleoclimatic conditions, depositional environments of the Saurashtra Intertrappeans, and paleogeographic position of the Insular India (Indian Plate). Integrated data of lithofacies, geochemistry and palynofossils, a 3-D depositional model is reconstructed for the Intertrappean basins which reflects three phases of evolution during the Paleogene on Insular India, dominantly controlled by the warm, humid, and tropical climate. At the end, the gist of the whole study is mentioned in the orderly manner in forty-four conclusive points.

Finally, the whole study is concluded telegraphically, *'The intertrappean successions of the Ninama and Chotila basins are unique as far as their time (Paleogene) span is concerned, as they are exclusively developed in Insular India. It is sandwiched between the two lava flows of the Large Deccan Igneous Activity of India and their top flow marked the cessation of the Deccan activity in the Indian Sub-continent. The presence of palynomorphs has resolved the many unsolved questions of Insular India, particularly on paleoecology, paleoclimate, age, and paleogeography. The uniqueness of the biota of the Indian Sub-continent is linked with the Gondwana, which later evolved allopatrically followed by their intermigration in Eurasia, resulting in high diversity'*.

References

- Biswas, S.K., 1987. Regional tectonic framework, structure and evolution of the western marginal basins of India. *Tectonophysics* 135, 307–327. [https://doi.org/10.1016/0040-1951\(87\)90115-6](https://doi.org/10.1016/0040-1951(87)90115-6)
- Blanford, W.T., 1872. Description of the Geology of Nagpur and its neighbourhood. *Memoirs - Geological Society of India* 9, 295–330.
- Borkar, V.D., 1973. Fossil fishes from the inter-trappean beds of Surendranagar district, Saurashtra. *Current Science* 42, 181–193.
- Chenet, A.-L., Fluteau, F., Courtillot, V., Gérard, M., Subbarao, K. V, 2008. Determination of rapid Deccan eruptions across the Cretaceous-Tertiary boundary using paleomagnetic secular variation: Results from a 1200-m-thick section in the Mahabaleshwar escarpment. *J. Geophys. Res* 113, 1–27. <https://doi.org/10.1029/2006JB004635>

- Cucciniello, C., Demonerova, E.I., Sheth, H.C., Pande, K., Vijayan, A., 2015. $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology and geochemistry of the Central Saurashtra mafic dyke swarm: insights into magmatic evolution, magma transport, and dyke-flow relationships in the northwestern Deccan Traps. *Bulletin of Volcanology* 77, 1–19. <https://doi.org/10.1007/s00445-015-0932-0>
- Deshmukh, S.S., Sehagal, M.N., 1988. Mafic Dyke Swarms in Deccan Volcanic Province of Madhya Pradesh and Maharashtra. *Memoir- Geological Society of India* 10, 323–340.
- Fedden, F., 1884. The Geology of the Kathiawar Peninsula in Guzerat. *Memoirs of Geological Survey of India* XXI, 73–136.
- Kale, V.S., Bodas, M., Chatterjee, P., Pande, K., 2020a. Emplacement history and evolution of the Deccan Volcanic Province, India. *Episodes* 43, 278–299. <https://doi.org/10.18814/EPIUGS/2020/020016>
- Kale, V.S., Dole, G., Shandilya, P., Pande, K., 2020b. Stratigraphy and correlations in deccan volcanic province, India: Quo vadis? *Bulletin of the Geological Society of America* 132, 588–607. <https://doi.org/10.1130/B35018.1>
- Kapur, V. V., Khosla, A., 2019. Faunal elements from the Deccan volcano-sedimentary sequences of India: A reappraisal of biostratigraphic, palaeoecologic, and palaeobiogeographic aspects. *Geological Journal* 54, 2797–2828. <https://doi.org/10.1002/gj.3379>
- Kapur, V. V., Khosla, A., Tiwari, N., 2018. Paleoenvironmental and paleobiogeographical implications of the microfossil assemblage from the Late Cretaceous intertrappean beds of the Manawar area, District Dhar, Madhya Pradesh, Central India. *Historical Biology* 31, 1145–1160. <https://doi.org/10.1080/08912963.2018.1425408>
- Khan, A.Z., Ahmad, A.H.M., 1998. Diagenetic history of Dharangadhra sandstones (Lower Cretaceous), Saurashtra Basin , Gujarat. *Indian Minerals* 52, 33–44.
- Khosla, A., Sahni, A., 2003. Biodiversity during the Deccan volcanic eruptive episode. *Journal of Asian Earth Sciences* 21, 895–908. [https://doi.org/10.1016/S1367-9120\(02\)00092-5](https://doi.org/10.1016/S1367-9120(02)00092-5)
- Mahoney, J.J., 1988. Deccan Traps. *Continental Flood Basalts*. Kluwer Acad. Pub., 151–194.
- Mittal, T., Richards, Mark A., Fendley, I.M., 2021. The Magmatic Architecture of Continental Flood Basalts I: Observations From the Deccan Traps. *Journal of Geophysical Research: Solid Earth* 1–54. <https://doi.org/10.1029/2021JB021808>

- Samant, B., Mohabey, D.M., Srivastava, P., Thakre, D., 2014. Palynology and clay mineralogy of the Deccan volcanic associated sediments of Saurashtra, Gujarat: Age and paleoenvironments. *Journal of Earth System Science* 123, 219–232. <https://doi.org/10.1007/s12040-013-0390-z>
- Sheikh, J.M., Sheth, H.C., Naik, A., Keluskar, T., 2020. Widespread rheomorphic and lava-like silicic ignimbrites overlying flood basalts in the northwestern and northern Deccan Traps. *Bulletin of Volcanology* 82. <https://doi.org/10.1007/s00445-020-01381-9>
- Sheth, H.C., Choudhary, A.K., Cucciniello, C., Bhattacharyya, S., Laishram, R., Gurav, T., 2012. Geology, petrochemistry, and genesis of the bimodal lavas of Osham Hill, Saurashtra, northwestern Deccan Traps. *Journal of Asian Earth Sciences* 43, 176–192. <https://doi.org/10.1016/j.jseaes.2011.09.008>
- Sheth, H.C., Duraiswami, R.A., Ghule, V., Naik, A., 2022. Flood basalt structures and textures as guides to cooling histories and palaeoclimates : the Deccan Traps of Saurashtra , western India. *Geological Magazine*. <https://doi.org/10.1017/S0016756822000279>
- Sheth, H.C., Pande, K., 2014. Geological and $^{40}\text{Ar}/^{39}\text{Ar}$ age constraints on late-stage Deccan rhyolitic volcanism, inter-volcanic sedimentation, and the Panvel flexure from the Dongri area, Mumbai. *Journal of Asian Earth Sciences* 84, 167–175. <https://doi.org/10.1016/j.jseaes.2013.08.003>
- Tandon, S.K., Gupta, N., 2020. Introduction to geodynamics of the Indian plate: Evolutionary perspectives, Springer Geology. Springer. https://doi.org/10.1007/978-3-030-15989-4_1