

# CHAPTER-1

## INTRODUCTION

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### 1.1 BASIC CONCEPTS

It is indeed necessary to understand the philosophical tenets behind the study proposed to bring out logical and common conscious solutions. In the field of geological sciences, various dogmas are put forward for understanding; how much is related and subjective is a matter of discussion. Understanding the strength of geological data and their global implications, the present investigation is carried out in time-bound succession with limited aerial extent, and monotonous sources of sediments, barring chemically formed siliceous and carbonate bands. Considering the limitations in exploration, the investigator took a challenge and selected the area under investigation, which has limited aerial extent, patchy outcrops, intensely disturbed successions by the extrusive igneous rocks, highly denuded and covered (by scree) successions, and mostly capped by younger lava flows.

The area proposed for investigation is an intertrappean succession, confined between two lava flows, exposed on the central northern part of the Saurashtra Peninsula of Gujarat State. An evaluation of the sedimentary basins, small or large, tectonic or atectonic, marine or nonmarine, largely depends on a comprehensive study. However, the paleogeographic condition of the basin has played an important role because it has influenced sedimentation patterns and organic life. There are many such basins where sedimentation patterns displayed are identical to the modern basins and are worked out based on actualism.

The intertrappean basins are a closed system that has evolved in topographic lows during the lava outpouring; the unique features of the host and provenance make them exceptional and difficult for analogy study with actualism. Moreover, the paleogeographic condition of the Indian Plate was unique, the Insular India had suffered a devastating mass extinction event during the Late Cretaceous/Paleocene. This global event has brought about a change in the biosphere, lithosphere, and hydrosphere. The intertrappean succession of the Saurashtra Peninsula has a well-preserved piece of organic evidence in the form of organic-walled microfossils, molluscs, and vertebrates, especially fishes, of the Paleogene time, during the northward drifting of the Indian Plate. The study is focused on sedimentary succession

preserved as intra- and intertrappean; even though it had limited geographic and stratigraphic extension, it preserved a wealth of information on sedimentation patterns and biota, including signatures of paleoclimate, salinity, redox, etc.

A systematic attempt has been made to evaluate the succession in an orderly manner, where all possible information was gathered, systematic sample collection was done, and they were analysed for petrography, geochemistry, and palynology to obtain different kinds of the dataset. This data is used for inferring palynostratigraphy, and an integrated approach was made to deduce the various paleoenvironmental parametric interpretations. The last, and by far the most attempted, was to reconstruct the paleogeographic condition of the Indian Plate during the deposition of the intertrappean succession of the Saurashtra Peninsula.

A holistic approach was taken in the present investigation to draw logical conclusions by attempting various kinds of scientific analysis. Before that, one must understand the paleogeographic condition of the Indian Plate that is discussed in the subsequent paragraphs, and later, the whole part of the investigation is described systematically throughout the thesis by the investigator.

## **1.2 PALEOGEOGRAPHY**

The Phanerozoic Eon is characterised by a diverse group of mega- and microfossils; among them, each element is significant and helps in understanding paleobiogeography. The continent's conditions and positions continuously change due to either vertical or lateral movements. Each one preserves the biotic and abiotic pulses, providing the greatest evidence that, with time passing, evolutionary revolutions are observed by studying the different types of material. As far as the Indian subcontinent is concerned, the impressions of two global events are decoded: first, the formation of the Pangea which started during the Early Permian and ended in the Late Triassic, and second, in the Middle Jurassic, a break in Gondwanaland and northward drifting of the Indian Plate until it collided with Eurasia and subduction started during the Paleogene, and it is continuing till today.

The separation of the Indian Plate from Gondwanaland and its subsequent northward drift in the Tethys Ocean is by far the most studied model of biotic evolution and plate tectonics (Verma et al., 2016 and references therein). By the Middle Jurassic, approximately 170 Ma, the process of separation between East and West Gondwana had been initiated (Chatterjee and Scotese, 1999; Rogers and Santosh, 2004) (Fig. 1.1a). During the later 50 million years, the

separation of East and West Gondwana was caused by the rifting of South America and Africa from Madagascar, the Seychelles, India, Antarctica, and Australia. Madagascar underwent a displacement along the Davie Fracture Zone, together with East Gondwana, following a trajectory parallel to eastern Africa (Rogers and Santosh, 2004). Following the breakup in the Early Cretaceous (~132 Ma), Australia and Antarctica began to drift from India and Madagascar (Rogers and Santosh, 2004). The Middle Cretaceous (~99.6 Ma) presents a noteworthy scenario. During this time, India, Seychelles, and Madagascar were geographically isolated from Australia and Antarctica by the widening of the ocean, following which the 90–85 Ma Late Cretaceous foresaw India, the Seychelles, and their separation from Madagascar (Rogers and Santosh, 2004) (Fig. 1.1b). By 83.5 Ma, in the Late Cretaceous, Insular India had suffered a significant degree of isolation (Fig. 1.1b). During this time, India's physical connection with other major continents was limited and characterised by significant discontinuity, where India maintained a link with Africa through the Seychelles Block, Almirante Ridge, Providence Bank, the northern tip of Madagascar, and the east coast of Madagascar (Fig. 1.1b). The Indian Plate also marks its passage over the Reunion Hotspot during this time (Kale et al., 2020) with the development of shallow rifting, local marine incursions, and precursory igneous activity. It followed the first eruptive pulse of the large igneous activity of the Deccan Volcanic Province (DVP) during the Late Cretaceous, 67.7 Ma. India also attained the maximum degree of geographical isolation during this time. The land was surrounded by a vast Tethys Ocean. Additionally, throughout this time, the elevated global sea levels resulted in the submersion of significant areas in west, north, and east India, as well as major portions of Arabia, eastern Africa, and north-eastern Africa. The physiographic structure present in the region likely resulted in a decrease in biological interactions within the subcontinent. India's connection with other major continents was established through a pathway leading to Africa, specifically by way of the Madagascar-Providence Bank-Amirante Ridge-Seychelles (Parmar and Prasad, 2020). The northern portion of Insular India was submerged, and during the Paleocene epoch, around 55.9 Ma, it was located at a low northerly latitude (Fig. 1.1c). The Seychelles block had separated from India, which coincided with the eruption of the Deccan Traps. The late volcanic phase of DVP with intrusive and the evolution of Laxmi Ridge are also marked in the Early Paleocene. The Late Paleocene and Early Eocene are subsequently characterised by the tilting of the peninsular block towards the east and volcanism along the Lakshadweep and offshore parts of the Arabian Sea (Mallik, 2017)(Fig. 1.1c,d).

During the Paleogene period, the Indian Plate was completely isolated from the other continents (Fig. 1.1c,d), resulting in the cessation of continental biotic interaction. During this time, the intertrappean sediments were deposited in the lake environments that formed in the topographic lows in the Deccan Trap country in the western part of the Indian Plate, presently known as the Saurashtra-Kachchh sub-province of the Large Deccan Volcanic Province of India (Patel and Shah, 2023).

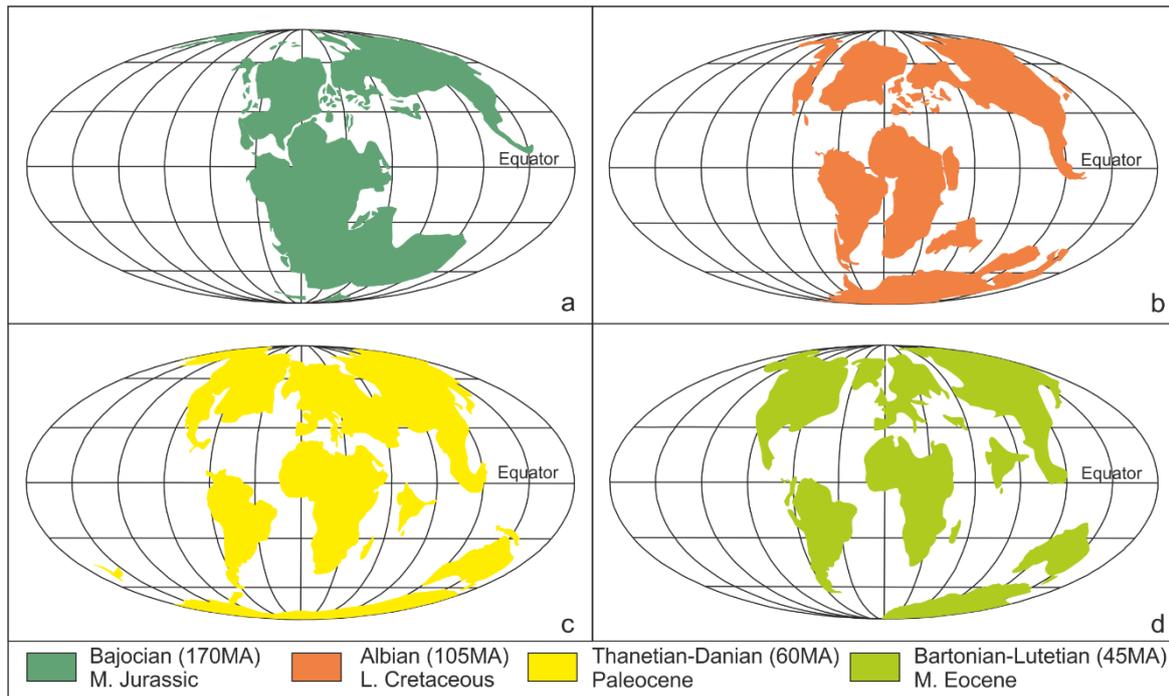


Fig. 1.1 Paleogeographic map shows the position of the different continents. a. Bajocian, M. Jurassic, shows the splitting of east and west Gondwana, b. L. Cretaceous-Albian, shows south-eastward movement of Indian Plate, c. Paleocene, Thanetian-Danian, shows the northward drifting of Indian plate lying in southern hemisphere, and d. Indian plate lying in northern hemisphere during Bartonian-Lutetian, M. Eocene (Smith et al., 1994).

### 1.3 LOCATION OF THE STUDY AREA

The study area is situated in the north-central part of the Saurashtra Peninsula, adjoining the southern periphery of the Mesozoic sedimentary rocks. It mainly comprises Mesozoic sedimentary, Deccan volcanic rocks; and intertrappeans, that exposed as road cut sections, well sections, and along the construction and quarries sites. The study area is encompassed in Rajkot and Surendranagar districts (Fig. 1.2). It is lying between latitudes N 22° 00' 00" and N 22° 45' 00" and longitude E 70° 45' 00" and E 71° 30' 00". The localities, where intra-, and

intertrappeans successions are studied, include, 1. Ninama hill section (N 22° 18' 14.58"; E 71° 19' 46.272"); 2. Sukhbhadar stream near Ninama village (N 22° 17' 59.73"; E 71° 20' 03.66"); 3. Ninama well section (N 22° 18' 11.81"; E 71° 19' 59.19"); 4. Motamatra well section (N 22° 15' 52.25"; E 71° 23' 02.89"); 5. Motamatra road section (N 22° 16' 00"; E 71° 22' 48.36"); 6. Sekhdod hill (N 22° 16' 24.24"; E 71° 20' 51.72"); 7. Lakhavad (N 22° 15' 18.86"; E 71° 19' 6.6"); 8. Chanpa Hill section (N 22° 24' 41.328"; E 71° 09' 45.288"); 9. Bamanbor - Navagam section (N 22° 25' 17.287'; E 71° 03' 19.26); 10. Bamanbor road cut section (N 22° 22' 40.44"; E 71° 03' 27.899"); 11. Rangpar section (GIDC) (N 22° 26' 57.84"; E 71° 03' 58.859"); 12. Redren industry section (N 22° 27' 12.21"; E 71° 03' 39.01"); 13. Garida road section (N 22° 28' 42.24"; E 71° 02' 49.74"); 14. Jalida section (N 22° 27' 40.931"; E 71° 01' 26.112"); 15. Jalsika road section (N 22° 29' 11.83"; E 70° 58' 35.43"). The coordinates mentioned herewith are of the intra-, intertrappean exposure sites.

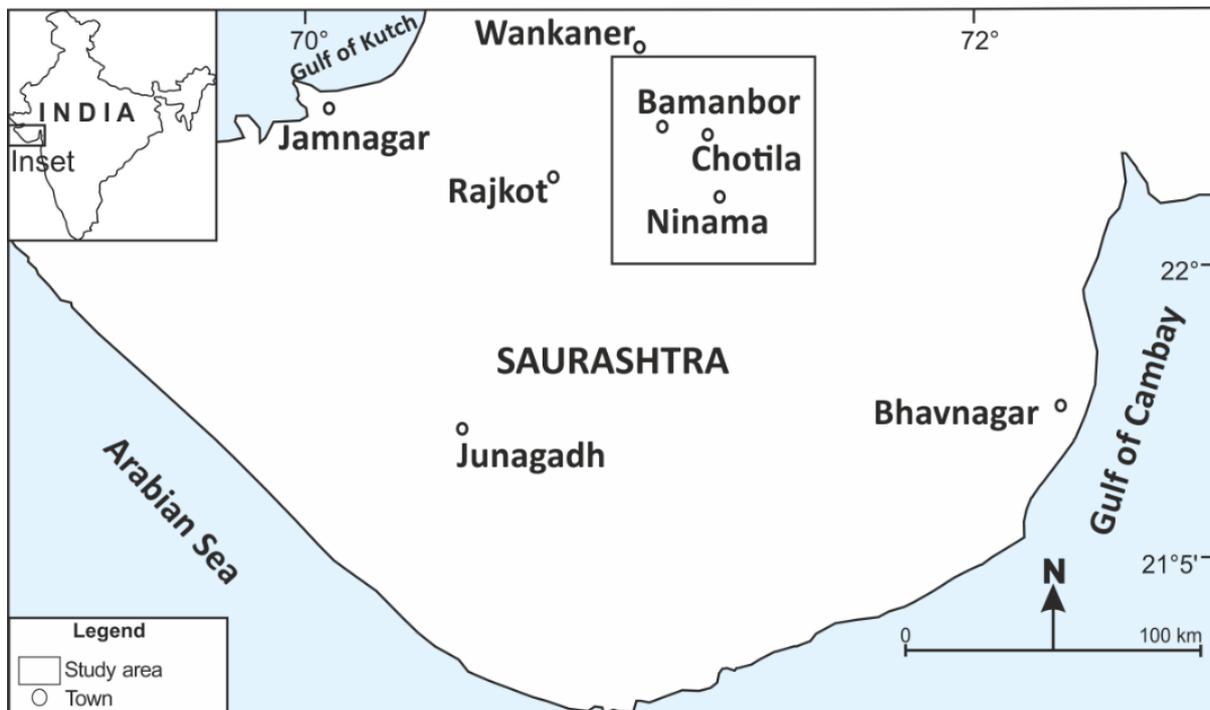


Fig. 1.2 A part of Saurashtra Peninsula map showing the location of the study area.

## 1.4 SAURASHTRA REGION

### 1.4.1 People and Culture

Saurashtra is also known as Kathiawar or Sorath; Kathiawar means the land of the Kathi, a Kshatriya caste who migrated to the region in the 8<sup>th</sup> century and spread over the region (Chandrani, 2013). The name Sorath remained limited to the region for a long time when the

Chudasama Rajput ruled from 875 to 1473 AD. Major Rajput clans that have significantly influenced this region include the Walas (Kathis), Jethwas, Raijadas, Chudasamas, Gohils, Parmars, Jhalas, Jadejas, Chavdas, Solanki, Patgirs or Pargirs, and Sarvaiyas, Savjis with a few other castes like Ahirs, Mers, Bharwads and Charans.

The people of Saurashtra are daring, courageous, and skilled in trade and commerce. The Saurashtrians are dispersed over several regions of the Indian subcontinent, playing a key role in the commercial sector. Majority of places on the peninsula preserve a small-town atmosphere, the Kathiawadi dialect of Gujarati. Religious temples, nature sanctuaries, and sites and artifacts of royal legacies are abundant throughout the region. The inhabitants of Saurashtra are robust, well-built, courageous, aggressive, and emotional. They are reputed to be a hardy, prolific, and active race, possessing audacity, a love of adventure, and chivalry that frequently led to adventurism and exploration, yet frequently motivated by avarice.

#### **1.4.2 Transportation**

The Saurashtra area is connected to the rest of India via a robust transportation network. Through a network of national and state highways, Saurashtra is linked to the rest of India. The National Highways 8A, 8B, and 8E traverse the region and connect it to major cities such as Mumbai, Ahmedabad, and Vadodara; an intricate network of state highways improves the accessibility of towns and villages. It is also well connected to the rest of India via train. Rajkot, Bhavnagar, Junagadh, and Porbandar are the principal train stations in the region. The Western Railway and the Saurashtra Railway operate trains in the region. Two airports serve the region: Rajkot Airport and Bhavnagar Airport. These airports provide regular flights to major cities in India, including Mumbai, Delhi, and Ahmedabad. In the region, both public and private buses provide an affordable form of transportation. The Gujarat State Road Transport Corporation (GSRTC) provides a bus network connecting Saurashtra to other regions of Gujarat and bordering states.

Chotila is accessible via NH 47 from Baroda, Ahmedabad, and other major cities. Chotila does not have a direct train connection. 'Thangadh Junction' and 'Rajkot Junction' are the closest train stations, located between a half-hour and an hour commute from the city of Chotila, respectively. Rajkot Airport, Bhavnagar Airport, and Ahmedabad Airport are the closest to Chotila. The distance between Rajkot Airport and Chotila is around 50 km and it may take up to one hour to travel by road. In the city, GSRTC has its bus depot. From Rajkot, Surendranagar, Ahmedabad, and Limbdi as well as other areas of the state, GSRTC operates a

substantial number of public buses. In addition to GSRTC buses, buses from Rajkot and Ahmedabad also operate to and from Chotila. The area under study is accessible via tar roads, including national, state, and district highways.

### **1.4.3 Flora and Fauna**

The forests of the Saurashtra are dry deciduous teak forests of Junagadh district (Girnar and Barda) and non-teak forests of Rajkot district (Hingolghadh, Chotila, etc.); scrub forests on the plains; and mangrove forests and 'man-made forests' in the coastal region. Open scrub vegetation with abundant graminoids, known as scrub savanna, intergrades into sparsely vegetated grasslands used for cattle grazing for generations. Locals call these grazing grounds Vidi (Johri et al., 2012). The plant species are high with more than 314 species of plants, such as gorad, desi baval, kassod, neem, gugal, thor, satodi, batkumi, etc. Cultivated mangoes trees are observed in entire region and amongst the Kesar Mango is famous and exported across the Gujarat, India and other countries.

According to Dabadghao and Shankarnarayan (1973), semi-arid regions like Rajasthan, Gujarat, Western Uttar Pradesh, Delhi, and Punjab have *Dichanthium-Cenchrus-Lasiurus* grasslands. The Saurashtra grasslands cover 1810 km<sup>2</sup>, accounting for 20.08% of Gujarat's total grassland cover (Johri et al., 2012). Saurashtra and Kachchh livestock farmers depend on these pastures. Besides their ecological value, grasslands are a major source of fodder, especially during droughts (Sugoor and Ande, 2001).

The major fauna includes mammals like the Asiatic lion, Indian leopard, chinkara, blue bull, wild boar, wild ass, Indian wolf, Indian pangolin, Indian porcupine, Indian hare, Indian rock python, jackal, deer, ox, striped hyena, flying fox, sambar, chital, badger, wild pigs, blackbucks, mongoose, etc. Among the birds, red-vented bulbul, green bee-eater, spotted dove, shrike, woodpecker, Indian roller, etc. are common. The wildlife sanctuaries of Saurashtra include Gir National Park, Girnar Wildlife Sanctuary, Barda Wildlife Sanctuary, Hingolghadh Nature Education Sanctuary, Marine Sanctuary, and Porbandar Bird Sanctuary.

### **1.4.4 Climate and Weather**

The Saurashtra region exhibits a hot arid to semi-arid climate. The year is divided into four seasons, the cold season (Dec-Feb), the hot season (March-May), the southwest monsoon season (June-Sept), and the post-monsoon season (Oct-Nov). As the Tropic of Cancer passes through the northern border of Saurashtra, winters are severe and summers oppressively hot, except in the coastal tract. The mean annual temperature of the region ranges from 26°-27°C

with mean minimum and maximums of 11°- 40° C and extremes being 5°C to 46°C. The relative humidity of the region fluctuates between 65-70%.

#### **1.4.5 Rainfall**

The Saurashtra region of Gujarat experiences significant variability in rainfall patterns. The Mean annual rainfall of the Saurashtra region is about 660 mm recorded from 1980-2019. The average seasonal rainfall for various districts is between a minimum of 491 mm for Morbi and maximum of 908 mm for Gir Somnath district. The districts Gir Somnath, Junagadh and Jamnagar are among the districts with higher average rainfall than the rest of the districts. While Morbi, Botad and Surendranagar were among the districts with low annual average rainfall (Pandya et al., 2023). The monsoon starts in June and lasts up to September, but the heaviest rainy month is July; closely followed by August. November to May are rainless months, though rarely a few showers may be experienced by the end of December. These showers, however, make no difference to the climate and hence a change in vegetation. The rainfall is erratic and irregularly distributed throughout. In addition to considerable rainfall, the region has also witnessed intense cyclonic storms in the Arabian Sea following the monsoon with frequent thunderstorms from May through October.

#### **1.4.6 Physiography**

The peninsula of Saurashtra is a plateau composed of Deccan lava flows. The region is characterised by a terrain that is undulating in nature, with hills and several rivers that run in different directions, creating a rugged topography. There are primarily three major uplands in Saurashtra that extend almost parallel to one another from northeast to southwest. The low-lying area that marks the historic sea connection between the Gulfs of Kachchh and Khambhat is located on the eastern edge of the peninsula that separates Saurashtra from the Gujarat Mainland (Merh, 1995). This narrow neck of low-lying land connects the Saurashtra Peninsula to the mainland of Gujarat.

Gir, Girnar, Barda, Alech, Chotila, and Shetrunjaya are the major elevated regions (hills), in this region. These hills were primarily formed due to volcanism. The forest region is harsh and steep, ranging from 152 to 530.66 m above MSL. The central portion of the Peninsula consists of a raised, Jasdan plateau which dips gently towards the margin of the peninsula. The coastal track provides an almost flat landscape of the Neogene-Quaternary sedimentary rocks. Principal geological formations include the Mesozoic sedimentary sequences, Deccan Trap, and bioclastic and miliolitic limestones. The soils are variable in composition and influenced

by the host rock formations. It is normally black and contains various amounts of loam. The northern portions of the districts of Rajkot and Surendranagar are characterised by sandy soils due to coarse sediments. Other soil types include red, yellowish-white, clayey, and sandy loam. The coastline is characterised by saline alluvium.

The Saurashtra Peninsula has one of the longest (843 km) coastlines in India and covers more than half part of the periphery of Gujarat. It is bounded by the Gulf of Kutch on northwest side, by Arabian Sea on the western and southern side and the Gulf of Cambay on eastern side. It characterised by rocky shore, beaches and dunes on the western and southern side, coral and mudflats on the northern side and exclusive mudflats towards the east side. The coast of Saurashtra is surrounded by various bays like Piram, Sultanpur and Jagri near Bhavnagar in Gulf of Cambay; Shiyal bay near Jafarabad; Diu Island in the south; Dwarka, Mora, Bahyadar, and Kalubhar bays near Gulf of Kutch. In the northwest of Saurashtra, the coastline is mostly straight, with rocky shores that are sometimes covered by sand and silt. The coast from Bet Dwarka to the Gulf of Kutch, of the Jamnagar district is characterised by corals especially in Pirotan islands. It is compositionally alkaline silt in nature. The Saurashtra coast is important for many reasons, such as studying sea level, geomorphic evolution, stratigraphic successions, cliffs, and notch-making processes (Bhatt and Bhonde, 2006).

#### **1.4.7 Drainage**

The drainages of the Saurashtra peninsula show radial pattern and their trends are controlled by volcanic highlands and plugs. They are debauching either in the Arabian Sea in the south and west, the Gulf of Kachchh towards the north, the Gulf of Cambay towards the east, and Bhal Pradesh towards the northwest. All streams are ephemeral in nature and flow during the rainy season. Relatively large streams carry residual water and that can flow a little bit more after the rainy season. Most of the period of the year they experience dryness (Singh, 2001). North and northwestward flowing streams merge into the soil of Kachchh Little Rann and Bhal Pradesh, respectively. The major rivers of the Saurashtra region are Bhadar, Shetrunji, Aji, Machchhu, Sukhbhadar, Utavali, Demai, etc., and their tributaries. The Bhadar River flows into the Arabian Sea; the Shetrunji into the Gulf of Khambhat; the Machhu into the Little Rann and the Aji into the Gulf of Kachchh.

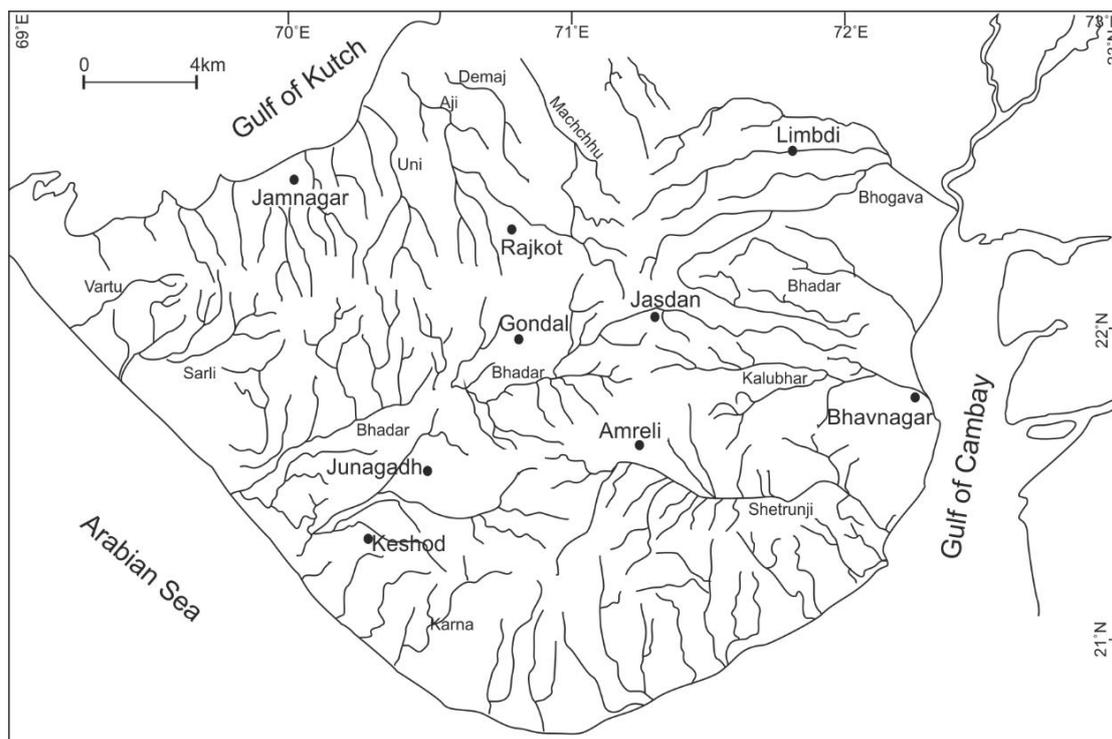


Fig. 1.3 Drainage map of Saurashtra Peninsula showing the radial pattern originating from the central Jasdan plateau.

## 1.5 IMPLICATIONS OF PALYNOLOGY

The science of organic walled microfossils has attracted Palynologists, Paleontologists and Paleobotanists due to their significance in solving many problems in geological science and petroleum exploration. A brief historical review and their applications are discussed in the following sections.

### 1.5.1 History

Palynology is a field defined by baffling intricacies and varied composition, that comprises a vast array of organic wall fossils which are dispersed by normal natural processes. It includes a variety of organic wall microfossils from marine, non-marine and brackish water such as spores, pollen, dinoflagellates, diatoms, hystrichosphaerids, silicoflagellates, discoasters, chitinozoans, algal remains, scolecodonts, conodonts, *Nananoconus*, *Oligosregina* and other organic remains. It is recovered practically from all types of sediments and helps in quick dating and correlating between continental, marine as well and brackish sediments. These microfossils are also useful in determining the

environment and have proven their significance in coal and hydrocarbon exploration (Traverse, 2007).

Hyde and Williams (1944) coined the term "palynology". The term 'Palynology' was formed by a combination of the Greek stem '*Paluno*' meaning strew or sprinkle (*Pale* means fine dust, fine meal) and '*ology*' meaning to study, in other words, called a study of dust (organic). Assyrians and Egyptians were the first to comprehend and execute hand pollination, but pollen studies did not commence until the introduction of the microscope. The invention of Hooke's compound microscope in 1655 was crucial to the advancement of pollen study (Traverse, 2007). Goeppert, a German scientist, is credited with being the first to characterise ancient spores or pollen and depict them in a line drawing in 1838. Goeppert's plates contain pollen that resembles *Betula* and *Alnus* pollens. In the 1830s, Ehrenberg, a pioneer of micropaleontology, described the fossils, which are now identified as acritarchs and dinoflagellate cysts. Paleopalynology was established at the end of the 19th century when P. Reinsch (1884) published the first photomicrograph of fossil spores from Carboniferous Russian coals and also described methods for the extraction of palynomorphs from coal samples with concentrated potassium hydroxide (KOH) and hydrofluoric acid (HF) . Following this, the study of fossil spores and pollens kept on advancing and became a mainstream subject due to their academic and economic interest. The paleopalynological studies in India were pioneered by Prof. Birbal Sahni. The subsequent studies of Permian miospores were begun by Virkki (1937). Gondwana megaspores were studied by D. C. Bharadwaj (1962 and later papers). Several studies of assemblages were carried out by Venkatachala et al., (1968) on the Permian of Pakistan. The Birbal Sahni Institute of Palaeobotany has made several contributions to the study of Indian palynomorphs (Saxena and Tripathi, 2011; Mehrotra et al., 2012, etc.).

The Palynological Society, founded in India in 1964, was the first national society. It published two periodicals, the Palynological Bulletin and the Journal of Palynology, which began in 1965 and merged in 1972 under the latter title. The Palaeobotanist is still published by the Birbal Sahni Institute of Palaeobotany and has frequently carried out palynological research in recent times.

### **1.5.2 Applications**

Palynology is an important micropaleontological discipline. It enables the study of all kinds of deposits, from the Precambrian to the present, on land, in lakes, or at sea. The ability

of palynomorphs to preserve themselves despite the disintegration of silicious or carbonate materials gives them an advantage over other microfossils. Despite their presence found in all types of sedimentary rocks, their density and diversity are found more in fine-grained rocks which are subjected to qualitative and quantitative analysis. Preservation of palynomorphs may however be affected by advanced sub-aerial oxidation of organic matter, or a very alkaline environment (Halbritter et al., 2018). It is an important tool in paleoecology interpretation because it allows for the reconstruction of marine or lacustrine paleoenvironments. Because palynomorphs make up most of the refractory organic matter, palynology can be utilised to track the origin and composition of organic carbon. Moreover, the palynofacies and altered state of palynomorphs can be used as tracers of diagenesis in sedimentary and petroleum geology. It has made major contributions to a wide variety of applications, including Biostratigraphy, Geochronology, Paleoecology (Paleoenvironment), Climate change, Geothermal alteration, Taxonomy, and Evolutionary research. The 21<sup>st</sup>-century pollen studies peaked with the importance of palynology and its implications in various fields such as stratigraphy, aero-palynology, biostratigraphy, copropalynology, cryopalynology, forensic palynology, atropalynology, melissopalynology, paleopalynology, archaeology, paleoclimatology, and palynotaxonomy.

## **1.6 AIM AND OBJECTIVES**

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

The objectives of the Ph.D. work 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.

## **1.7 METHODOLOGY**

An integrated approach combining sedimentology and palynology is used, and the data is utilised to understand the paleoenvironment, paleoclimate, and paleoecology of the area.

## Field expeditions and laboratory techniques

1. Stratigraphic sections were measured at different localities and lithologies were prepared.
2. High-resolution systematic sampling, laterally as well as vertically was done in different sections.
3. Collected samples were analyzed for textural and mineral composition, and for geochemistry.
4. Samples were disintegrated by following the standard techniques to separate the palynomorphs.
5. Separated palynomorphs were identified and documented.
6. Qualitative and quantitative analysis of the palynomorph data was done, and different biostratigraphic zones were established.
7. Paleoenvironment parameters were interpreted using sedimentological and palynological data.

Palynofossils are characterised by their wide range and their separation procedure is identical to each type of fossil in question. With the advent of the knowledge and their utility, procedures are continuously redefined and differ based on the objective of the study and depending on the type, composition and age of the rocks. The standard procedure followed is according to the below given steps (Table 1.1) but is altered as and when its necessary.

The various steps include the standard digestion of the carbonates and silicates, followed by the oxidation and solubilization of humic matter and concentrating the palynomorphs by ultrasonic treatment, sieving, staining and slide preparation. The given below (Table 1.1) is the standard technique proposed by Green (2001).

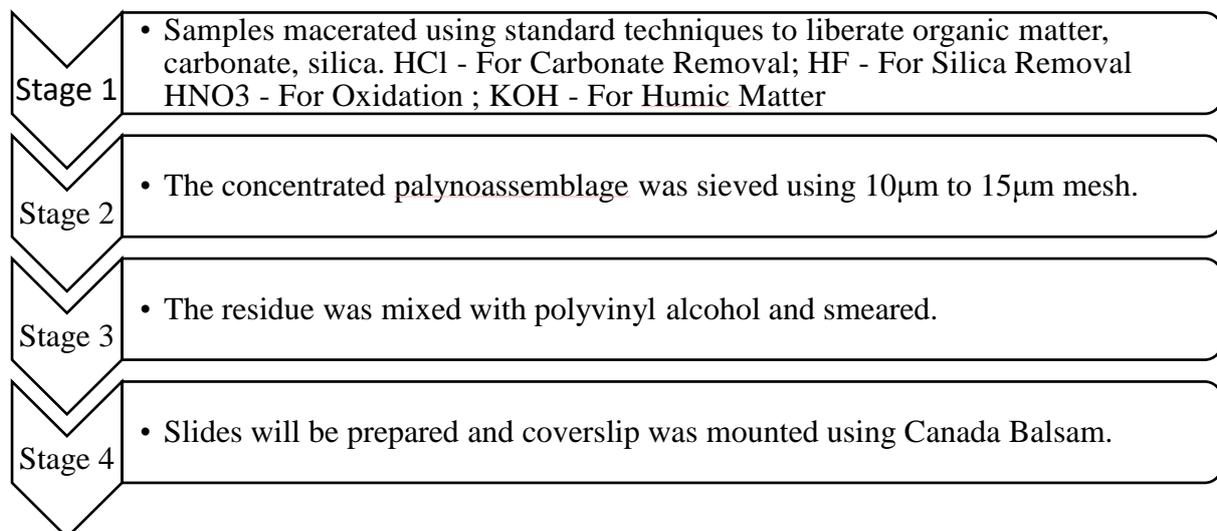


Table 1.1 Technique followed for palynomorph separation (Traverse, 1974; Green, 2001).

The samples are first treated with 100 ml of 20% concentrated or 10% warmed HCl, and around 50 ml of cold 40% HF to digest carbonates and silicates respectively. For the removal of heavy minerals like rutile, tourmaline and zircon, swirling technique in a large watch glass is used. Heavy mineral separation using Zinc Bromide ( $ZnBr_2$ , S.G. 2.1) by centrifuging the mixture which separates the light palynomorph rich fraction. Then after samples are treated with nitric acid ( $HNO_3$ ) (i.e., the removal of pyrite and lighting of palynomorph exines) for oxidation, care must be taken as the oxidation can destroy the palynofossils. Fine organic debris may be removed by alkali treatment with 5% potassium hydroxide (KOH). To disaggregate the palynomorphs, they are placed in ultrasonic bath for 10-30 seconds. It breaks down the aggregates and particles can be removed by sieving. A 10–15-micron mesh is standard, while 53 micron and 5-7-micron mesh are used to retain chitinozoans and large palynomorphs and smallest palynomorphs, respectively. The specimens if pale is stained by an aqueous solution of 0.1 % Safranine-O, Malachite green or Bismarck brown. The residue is then used to prepare permanent slides using glycerol jelly, polyvinyl alcohol, Elvacite 2044 for permanent mounts and Canada Balsam and epoxy resin as a mounting medium. The slides are examined under the light microscope or scanning electron microscope for organic content.

Investigator has also followed the same steps but looking to the highly diversified nature of the lithology of the study area, the procedure is modified to obtain the optimum result. The detailed procedure from sample maceration to photography of the palynofossils is described in Chapter 3.