Chapter - I

I N T R O D U C T I O N

PREAMBLE

The high energy coastal segment of Saurashtra Peninsula has remained a site for the generation and accumulation of bioclastic carbonate deposits since Middle Pleistocene and has preserved the imprints of the various climatic changes related to the fluctuating sea levels. These Quaternary deposits, identical in all respects to those of Kutch, resemble very much to those of the other tropical and subtropical organogenic carbonate sand generating coasts of the world like viz. UK (Bermuda), USA (Bahamas, Miami), West Indies (Barbadose, Jamaica), South Africa, Australia, Israel, Arabia etc.

The Saurashtra Peninsula is dotted with three types of Quaternary bioclastic carbonate deposits viz (i) ancient beach rocks, (ii) miliolite limestones and (iii) stabilised sand dunes. The ancient beach rocks are white to dirty white coloured unsorted shelly fragmental rocks, formed in the littoral and spray-zone areas of Middle Pleistocene high sea. Confined to a narrow coastal strip, these rocks underlie the miliolite limestones and exhibit typical beach-dune complexes. The miliolites (*Sensu Stricto*) are white to buff coloured, medium to fine & very fine grained, well sorted pelletal/peloidal limestones and are devoid of any marine megafossil and are formed by the aeolian actions during the regressive phase of Middle to Late Pleistocene sea. The stabilised carbonate dunes are highly friable and loosely consolidated, rich in foraminiferal and pelletal sands, representing the coastal dunes of Holocene sea. They are analogous in many respects to the miliolites but contain slightly higher amount of quartz. Among these, the miliolites have posed an interesting debate since their first report by Carter (1849) regarding their origin, whether they have been deposited in marine environment or by the terrestrial (aeolian) processes. Number of workers have attempted to delve into these rocks taking into the account various aspects viz. constituents, mineralogy, chemistry, micropalaeontology etc., and have tried to explain the present disposition of miliolites either by sea level changes, strong wind actions or by neotectonic activities. However, no integrated study has been made that enlists all aspects in explaining the mode of occurrence and depositional environment of these carbonate deposits of Saurashtra.

The present account dwells on all these carbonate deposits in general and the miliolite rocks in particular. The author has, in the forthcoming chapters endeavoured to give a critical account of various aspects of these consolidated and semiconsolidated bioclastic carbonate deposits which provide vital clues in resolving still unexplained problems in the Quaternary geology of Western India.

LOCATION AND EXTENT

The Quaternary carbonate deposits occur all along the western and southern coastal tract, right from Okha-Dwarka in NW upto Diu-Mahuva-Gopnath in SE (Fig I.1). The inland deposits, forming dunes and sheets, are widely spread all over the Saurashtra Peninsula, facing on its north, west & south the roaring waters of the Arabian sea and separated from the Mainland Gujarat in the east by a narrow marshy saline tract remnant of an ancient sea.

The study area lies between North latitudes 20° 40' & 22° 57' and East longitudes 68° 57' & 72° 18', covering an approximate area of 64340 sq.km. The area falls in Survey of India Toposheets 41 B, F, G, J, K, L, N, O, P and parts of 46 B & C.

COMMUNICATION AND TRANSPORT

Rajkot, an industrial capital of Saurashtra, lies in the heart of the study area and is linked by a 435 km long National Highway that plys between Ahmedabad and Porbandar via Chotila.

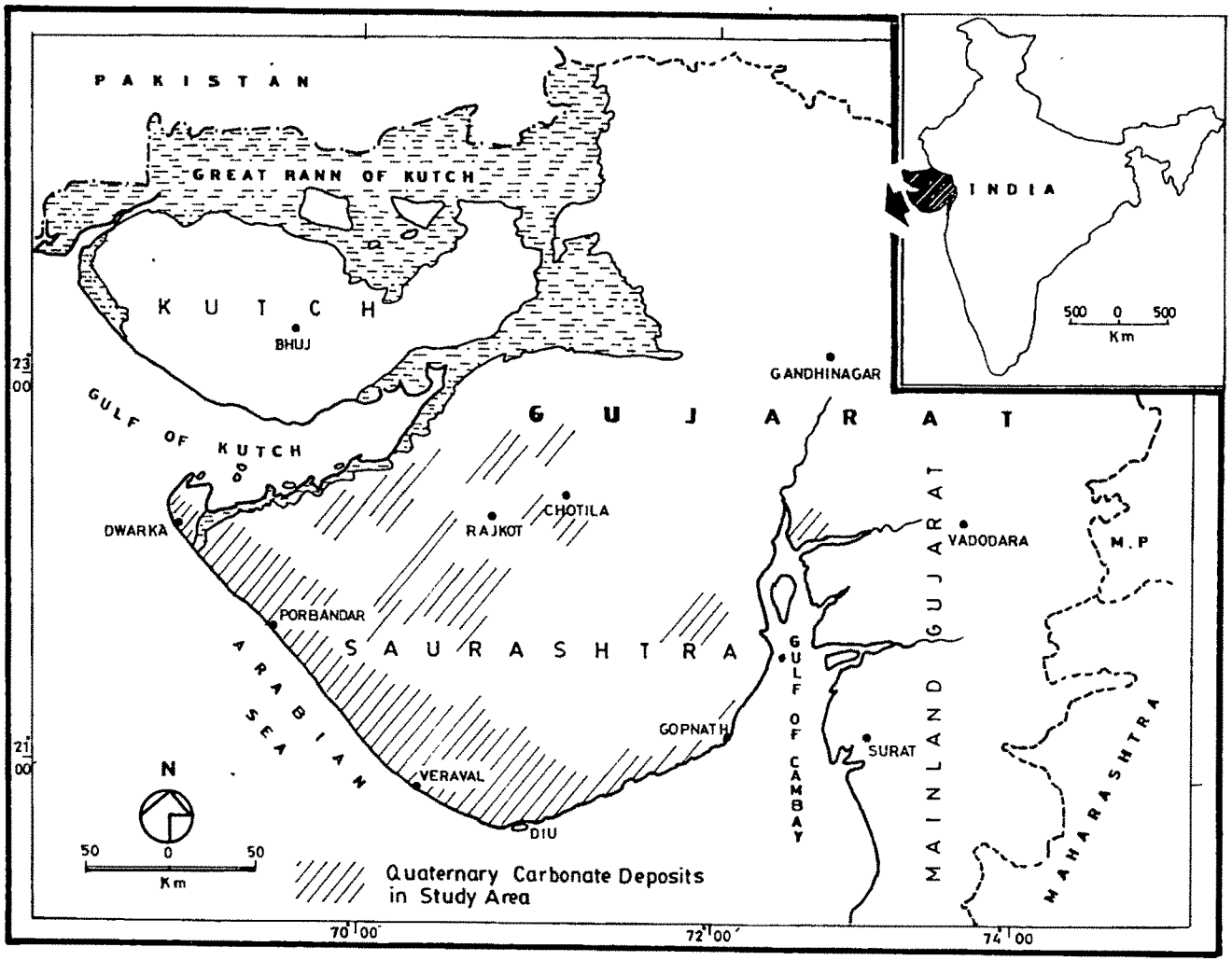

FIG. 1.1. LOCATION MAP

Rajkot is connected with the other major towns like Dwarka, Jamnagar, Keshod, Veraval, Bhavnagar, Amreli etc by all-weather state highways. The communication of the interior villages is circuited through a net-work of all season tar roads by State Transport buses, taxis and three wheeler tempos. Most of the cities are linked with major cities of Mainland Gujarat and Kutch by State Transport buses. Camel and bullock carts are only means to reach distantely placed interior hamlets.

In addition to the roadways, Ahemdabad-Rajkot-Dwarka Broad Gauge railway tract passes through the E-W axis of the study area. Meter Gauge and Narrow Gauge rail-tracts also link the major towns of Saurashtra. As per 1981 census, the Saurashtra peninsula forms a net-work of about 2217 km long railway tract having 291 railway stations.

The major cities like Rajkot, Jamnagar, Porbandar, Keshod and Bhavnagar are connected with Bombay by Indian Airlines services. Saurashtra also possesses nine major sea ports viz. Navlakhi, Sikka, Mithapur, Dwarka, Porbandar, Veraval, Jafrabad, Mahuva and Bhavnagar. Besides these several other small ports are utilised for fisheries.

PHYSIOGRAPHY

The Saurashtra Peninsula can be divided into three physiographic units viz. (i) the coastal plains, (ii) the central platue and (iii) the trappean hills (Fig. I.2). The present

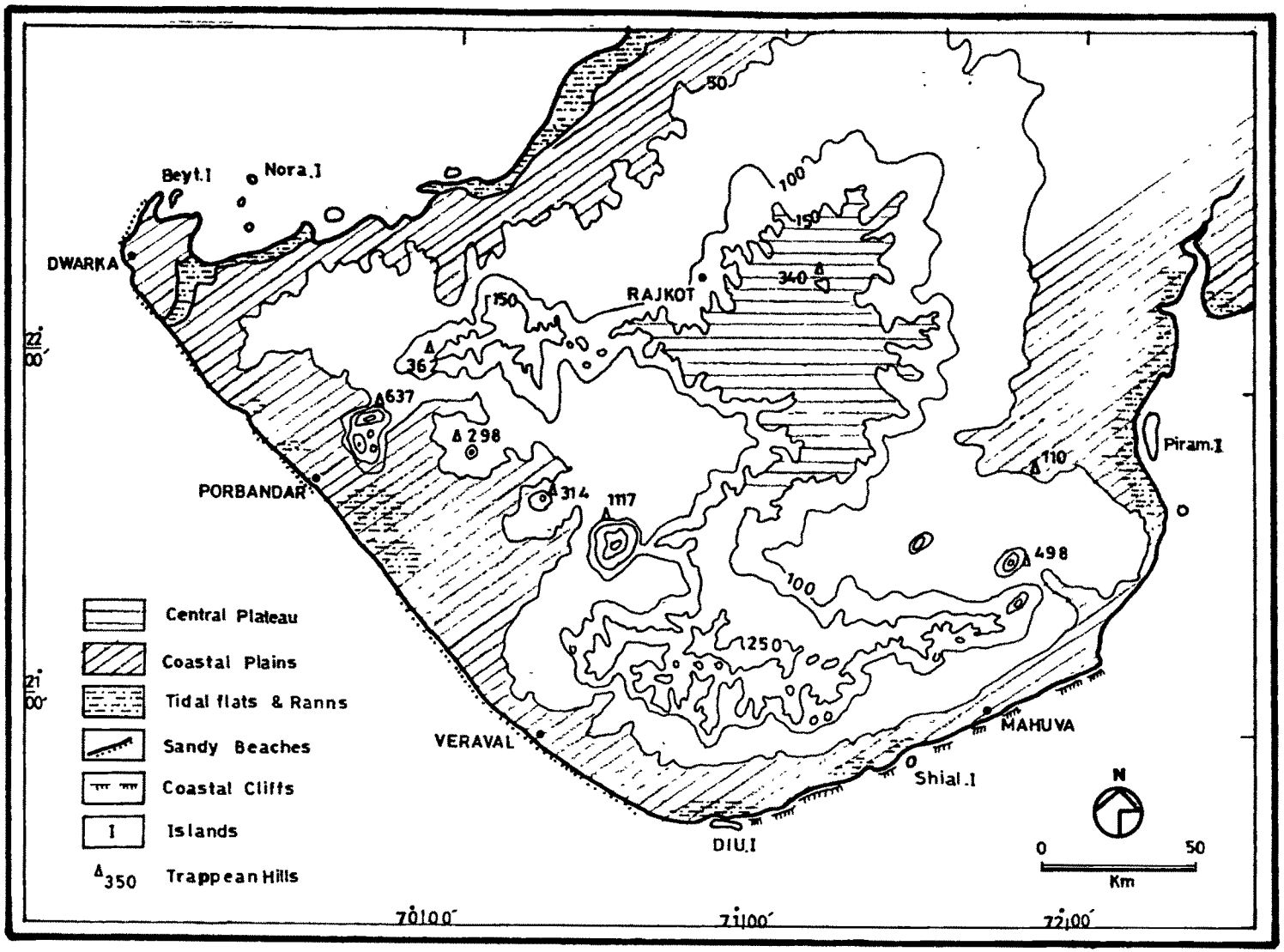

FIG. 1.2 PHYSIOGRAPHIC MAP OF SAURASHTRA

disposition of Quaternary carbonate deposits in the study area is mainly controlled by the topography of the Peninsula.

The coastal plains rises very gently from the present shoreline upto 50 m contour and comprise the raised mudflats, beaches, alluvium and tidal muds near estuaries. These coastal plains extend approximately upto 20-30 km inlandward on western coast while their spread on northern and southeastern coasts is upto 10-15 km or even less. The Saurashtra coastline can be described as per Inman & Nordstrom (1971) classification as 'trailing edge coast'. Along the North Saurashtra coast and Gulf of Cambay, the low energy coastline is marked by extensive mudflats whereas the southwestern segment between Okha-Dwarka and Diu form a characteristically high energy sand generating coast giving rise to the present-day sandy beaches. The coastline between Diu and Gopnath shows low to moderate coastal cliffs and well developed shore platforms in miliolite rocks. The central platue of Saurashtra rises upto 250-300 m altitude. It is connected with Gir hills in South, forming a major barrier to the southwesterly winds. This high lands are dotted with number of trappean hills ranging in altitudes between 200 and 400 m. The Girnar hill which rises upto 1117 m, is the highest topographic expression of the Peninsula. The Alech (298 m), Barda (637 m), Chamardi (110 m), Chotila (340 m), Gop (300 m), Osam (314 m) etc. are also conspicuous among the other hills.

The Saurashtra is carved with numerous ephimeral to semi-perennial rivers and their tributaries which carry the waters for a short period, particularly in monsoon. These rivers

individually show dendritic to parallel type of drainage system wherein the waters flow from central part of the Peninsula to all directions debouching them into the Arabian sea, and form a typical radiating drainage pattern (Fig. I.3). The major rivers of Saurashtra are Aji, Bhadar, Bhogavo, Fuljar, Ghi, Hiran, Lalpuri, Machchhu, Minsar, Ozat, Saraswati, Shetrunji, Somat, Vartu etc. The Quaternary carbonate deposits, especially the miliolites occupy sheltered sites in some of these river channels.

CLIMATE

In the coastal areas the climate remains generally pleasant while the plains are hot, and in the hilly areas it is uncongenial. The year may be divided into three seasons. January is the coolest month in which the mean daily maximum temperature in the coastal areas remains around 28°C and minimum 15°C. Winter is followed by summer from March to June. May and June are the hottest months with mean daily maximum and minimum temperatures around 30°C and 27°C respectively. In monsoon the temperature drops a little but in the post-monsoon, the days become hotter than in the summer while the nights are cooler and pleasant. The interior regions of Saurashtra generally show 5° to 10° C higher temperature than the coastal areas.

Relative humidity is generally over 80% during SW monsoon, otherwise the air remains drier in rest of the year, particularly in the interior areas. The average annual rainfall received during the southwest monsoon season aggregates a period of one or

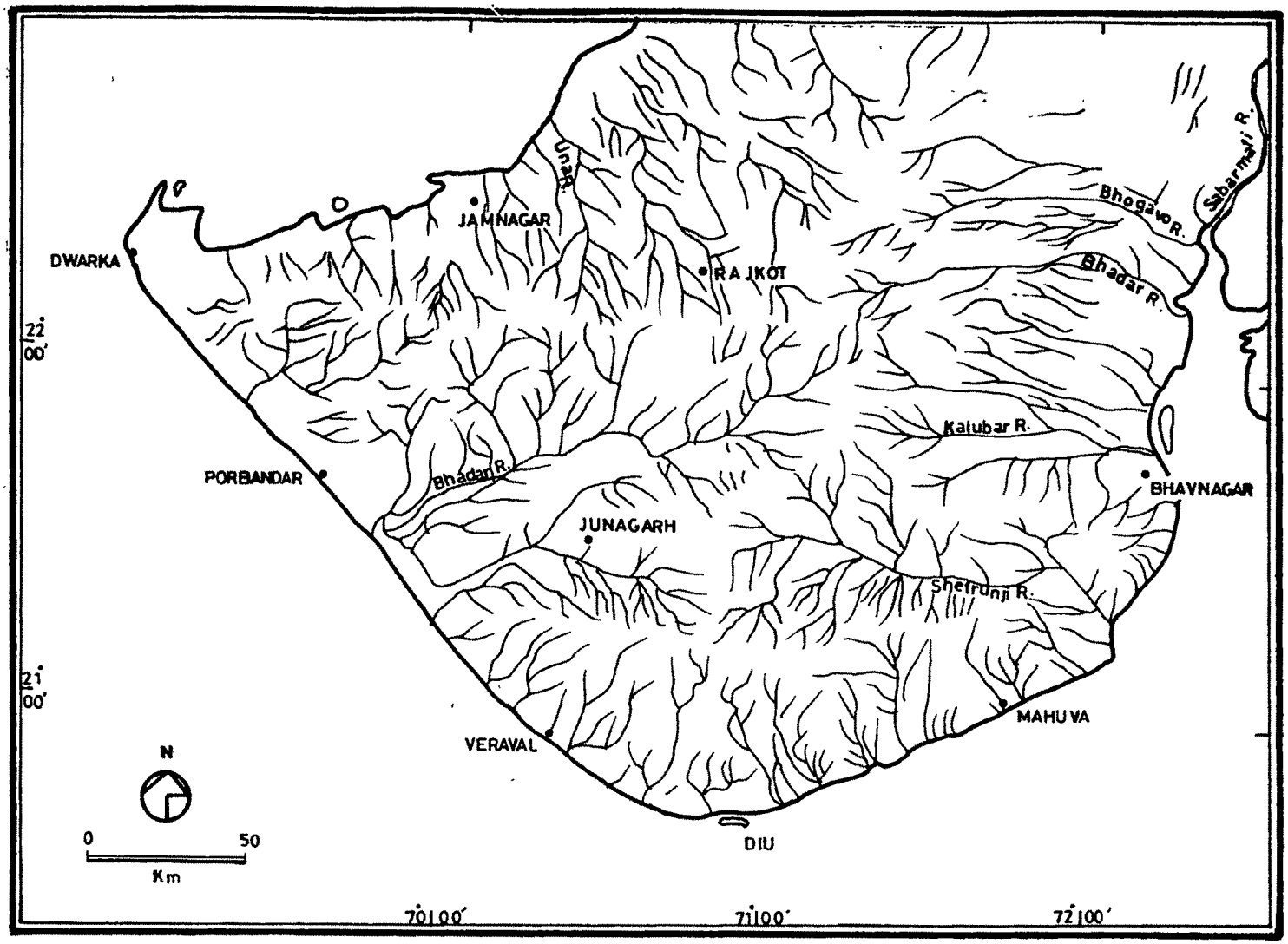

FIG. 1.3 DRAINAGE MAP OF SAURASHTRA

two months; the highest being in July. The Gir hills experience the highest amount of rainfall (Fig. I.4).

Throughout the year the winds in Saurashtra blow mainly from SW and W but the prominent effective wind direction is from SW to NE during summer and monsoon. Heavy storms and depressions in the post-monsoon and also in May & June affect the weather causing wide spread heavy rain and gusty winds. Thunder storms occur during May & June and increase during the southwest monsoon season. During winter season, the mild winds blow mainly from the direction between NW and NE.

FLORA AND FAUNA

The glory of the Saurashtra landscape is its hills and adjoining forests like Gir and Barda. These forests are of tropical deciduous type and exhibit many varieties of vegetation. Some of them are also seen in the plain areas around villages. The chief among these flora are Teak (*Tectona grandis*), Sajad (*Terminalia tomentosa*), Saladi (*Boswellia serrata*), Khair (*Acacia catechu*), Bawal (*Acacia arebica*), Gorad (*Acacia senegal*), Hingor (*Balanites aegyptica*), Khakhro-keshudo (*Erythrina indica*), Rayan (*Manilkana hexandra*) etc. The coastal and swampy areas are characterised by growth of mangroves, and hill slopes are occupied by various types of grasses & shrubs providing grazing grounds for the livestocks of Maldharis & Rabaris, the tribal people of Saurashtra whose only occupation is animal husbandry. The fertile 'regur' or black cotton soils are occupied by variety of cereals like Bajra (*Pennisetum typhoideum*), Jowar (*Andropogau sorghum*),

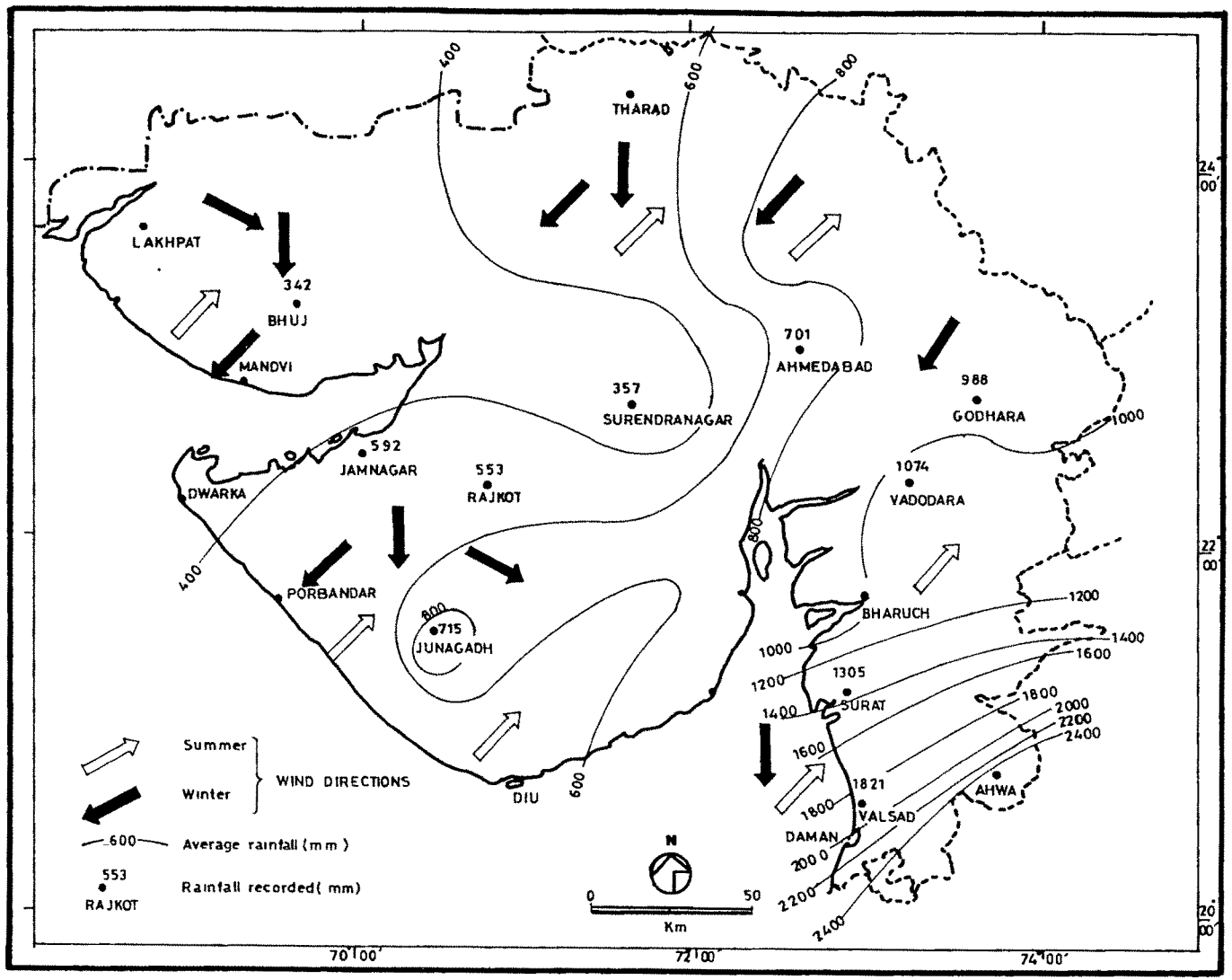

FIG. 1.4. WIND DIRECTION AND RAINFALL MAP

Peddy (*Oriza satiya*) etc., alongwith pulses and oil-seeds. The vegetables and fruit plantation are also practiced in some fertile and well irrigated areas. The 'Kessar' mangoes of Junagarh district are famous.

The Gir and Barda forests are rich in the wild life. Except Africa, nearly 275 lions (*Panthera leo*) in their natural habitate live nowhere else but only in the Saurashtra lion sanctuary. The other wild animals like Leopard (*Panthera pardus*), Zarakh (*Hyaena hyaena*), Jackal (*Canis aureus*), Wolf (*Canis lupus*), Fox (*Vulpes bengalensis*), Sambar (*Cervus unicolor*), Spotted deer (*Axis erxleben*), Chinkara (*Gazella gazella*), Antelop (*Tetracerus quadricomis*), Langur (*Prestbytis entellus*) etc. are encountered in these forests. The poisonous snakes like Kalotro or Cobra (*Naja naja*), Kodio (*Vipera russelli*), Nagin (*Echis carinatus*) and Chittal (*Bungarus coeruleus*) are also inhabitate together with some non-poisonous species like Ajgar (*Python molurus*), Andhi chaklan (*Eryx conicus*), *Natrix piscator* and *Ptyas mucosus* in forests and barren lands.

The flying life of Saurashtra is characterised by variety of birds like Grabes (*Podiceps ruficollis, P. cristatus, P. caspicus*), Pelicans (*Pelecanus onocrocotalus, P. phillippensis*), Vultures (*Gyps indicus, Pseudogyps bengalensis*), Eagles (*Acquila rapax, A. heliaca*), Kites (*Haliastur indus, Milvus migrans, Elanus caeruleus*), Falcons (*Falco jugger, F. chiquera, F. tinnunculus*), Flamingos (*Phoenicopterus ruberroseus, Phoeniconaias minor*), Pigeons (*Columba livia*), Parrots (*Psittacula krameri, P.*

cyanocephala, *P. eupatria*) and also our national bird Peacock (*Pavo cristatus*).

As Sauarashtra possesses more than 700 km long coastline, fishery is a major occupation of so many people. An institute for fishery training and development is also set up at Veraval. The fishes in the Arabian sea around Saurashtra peninsula are mainly Bumla (*Harpodon neherus*), Vichuda (*Pampus argenteus*), Pathu (*Pampus chinensis*), Halva (*Perastromateus niger*), Jinga (*Penaus indicus*), Kagga (*Arius caelatus*), Ravas (*Elcutheronema tetradoctylum*), Boyee (*Mugil dussumieri*), Magra (*Carcharias limbatus*) and many others.

Many pet animals like buffalos, cows, bullocks, goats, sheep, horses, camels, dogs, cats etc. also hover around villages.

BRIEF GEOLOGY OF THE AREA

Geologically the Saurashtra peninsula comprises exposures of Mesozoic sedimentary & igneous rocks alongwith Tertiary and Quaternary deposits (Fig. I.5). The generalised stratigraphy of the area is shown in Table I.1.

MESOZOICS

Dhrangadhra and Wadhwan Formations:

The Mesozoic sedimentaries exposed in Saurashtra comprise mostly sandstones with small intercalations of shales and limestones, and occupy the northeastern corner of the peninsula. They range in age from Juro-Cretaceous to Middle Cretaceous and

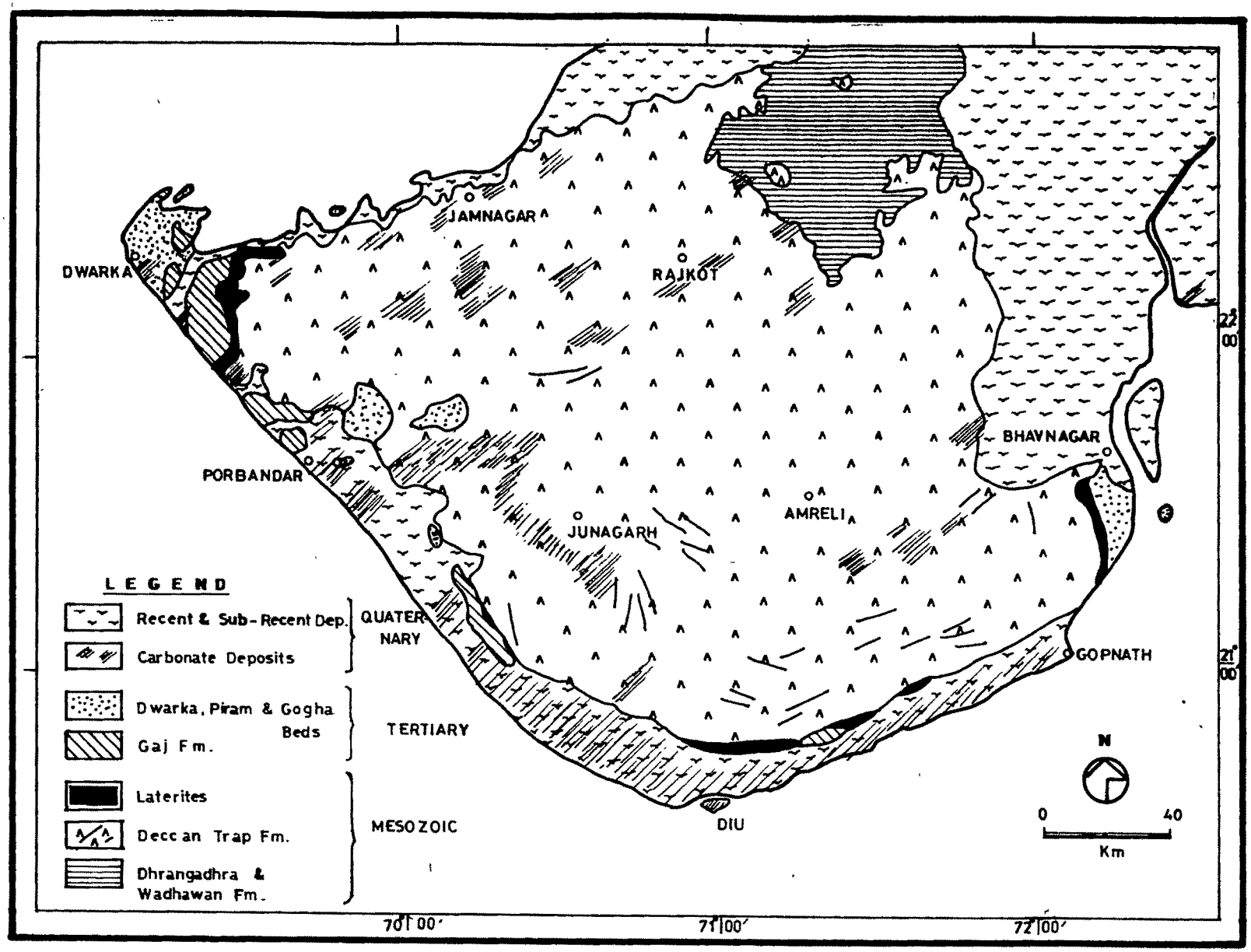

FIG. 1.5 GEOLOGICAL MAP: SAURASHTRA

(Modified after Marathe, 1981)

Table I.1 : General stratigraphy of the Saurashtra Peninsula
(Based on Shrivastava, 1963)

		Formation	Lithology	Age
	Q U A T E R N A R Y	Recent Deposits	Alluvium, Coastal dunes & beaches, Tidal clays, Soils	Recent and Sub-Recent
C E N O Z O I C		Agate Conglomerate	Conglomerate and ferruginous sand-stones	Holocene to Middle Pleistocene
		Miliolite Formation	Calcarenites, Calcirudites and intercalated clays	
	----------Unconformity----------			
	T E R T I A R I E S	Dwarka Beds	Variegated flaggy limestones, yellow gypseous clays	Pliocene to Upper Miocene
		Gogha and Piram Beds	Fossiliferous conglomerates, grits and sandy clays	
	----------Disconformity----------			
		Gaj Formation	Variegated shales, sandstones, marls, conglomerates and impure limestones with intercalations of gypseous clays	Lower Miocene
----------Unconformity----------				
M E S O Z O I C		Lateritic rocks	Red, brown & yellow laterites	Palaeocene
		Deccan Trap	Trap flows and intruded plutonic masses & dykes	Upper Cretaceous
	----------Unconformity----------			
		Wadhwan Formation	Red & brown sandstones with intercalations of shales	Middle Cretaceous
		Dhrangadhra Formation	White and coloured arkosic sandstones	Juro-Cretaceous
	----------Base not exposed----------			

can be grouped into Dhrangadhra Formation and Wadhwan Formation which in turn have been followed by Deccan Traps and alluvium. These Mesozoic sediments are correlated with Umia beds of Kutch and Bagh beds of Mainland Gujarat and are similar to the Nimar sandstones of Narmada valley and Himatnagar sandstones of North Gujarat.

Deccan Trap Formation:

The Deccan Trap, occupying almost entire Saurashtra except its margins, have been emplaced during the close of the Cretaceous and continued till Palaeocene. The trappean rocks of Saurashtra form the extension of Gujarat and that of Malwa plateue and show its further northward extension in Kutch. The flows of these basaltic rocks vary considerably in thickness, composition and texture; the lower flows are often decomposed and agglomeratic in nature while the upper ones are more of trachytic, felsitic and dioritic in composition and occasionally with lenticular masses and thin bands of uncrystallised rocks like pitchstone and obsidian. Some of the flows are thoroughly crystalline, often showing a porphyritic appearance; others are homogeneous and compact. Some flows are amygdoloidal having geodes and vesicles filled with zeolites, chalcedony, agate and calcite. Scoriaceous breccia, agglomerates, tuffs and ash beds are also occasionally found interbedded. In the lower part of Chotila hill there occurs a horizon of volcanic ash. On account of the magmatic differentiation, the Girnar, Osam, Alech and Barda hills show variety of rocks like diorite, granodiorite, granophyre, monzonite, gabbro, syenite etc. The thickness of Saurashtra traps

varies from 300 to 900 m and they are highly jointed, and often show typical spheroidal weathering. The trappean rocks of peninsula are seen traversed by numerous swarms of basic and few acidic dykes that form low knolls, elongated mounds or serrated ridges. Many of them are traceable for more than 70 km. Most of the dykes trend E-W while others run N-S and NW-SE.

Some inter-trappeans like grits, sandy shales, marls, limestones etc suggest their fluvial and lacustrine sedimentary deposition often showing well developed stratifications; their thickness rangeing between 1 and 4 m.

The Deccan Trap Formation, at places, is subjected to lateritisation. Two such thin zones of varying thickness occur between Deccan Trap and Tertiaries in Amreli district. Other good exposures lie between Bhatiya and Harshad where they form workable deposits of bauxite. They are also common in Junagarh district.

CENOZOICS

Tertiary Deposits

Gaj Formation:

The Gaj rocks are characterised by limonitic limestones, sandstones, grits, conglomerates and clays which have a typical yellow colour and gypseous nature. They represent the marine transgression during the Lower Miocene time and contain highly fossiliferous dirty yellow marly limestones with an apparently high ferrugenious content. The fossils of the Gaj beds belong to the zoantharia, bryozoa, pelecypoda and gasteropoda groups.

Oysters and few small detached masses of corals *Stylocoenia vicaryi* and *Halima* are also associated with limestones. The fossils occurring in marly limestone are *Cardium, Pecten, Cardita, Arca, Ostraea, Cypraea, Natica* and *Fusus*. The foraminifera in these rocks are of the families Textularia, Lagenidae, Globigerinidae etc. The Gaj rocks occur as isolated outcrops along the margins of the traps and laterites and also as inliers in alluvium. The largest spread of the Gaj rocks is in the area approximately of 30 sq.km covering the country between Mithapur and Lunsapur in NW portion of the Saurashtra peninsula.

Gogha and Piram Beds:

The Mio-Pliocene strata overlying the Gaj rocks on the east coast of Saurashtra have been named as Gogha beds and Piram beds after their occurrences around these localities. The Gogha beds form thin bedded grits and sandstones and the Piram beds consist of conglomerates, grits and clays with vertibrate faunal remains resembling those of Middle Siwalik age (Krishnan, 1968), and are considered homotaxial to Dwarka beds though lithologically they differ from each other.

Dwarka Beds;

The Dwarka beds are largely developed near Dwarka in the low lying areas of Okhamandal and Byte island. They comprise variegated limestones, earthy, marly and clayey beds which are partly gypseous with iron stained bands. Fedden (1884), who first mapped these rocks, has also included a group of highly fossiliferous limestones under this formation giving a name 'coast fringing rocks' and has suggested their shallow littoral

deposition assigning Mio-Pliocene age to the Dwarka Formation. According to Verma et al. (1975) atleast the lower portion of Dwarkas is positively of Lower Miocene age, but there is practically no evidence of upper age limit.

Quaternary Deposits

Miliolite Formation :

These consolidated bioclastic carbonate deposits of the coastal as well as of inland areas of Saurashtra form a major part of the present study. Eversince their first report by Carter (1849) as 'Miliolite limestone', these rocks are referred to as 'Porbandar stone', 'Miliolites', 'Miliolite Formation' etc in the Quaternary geology. Mathur & Mehra (1975) have classified these rocks into two separate formations viz "Miliolite Formation" and "Chaya Formation" based on their distinct lithology; the former being pelletic & oolitic calcarenites and micrites which are completely devoid of megafossil, and the latter being calcirudites at places full of megafossil that rest over the Miliolite Formation. These workers (op.cit.) grouped these formations under the "Porbandar Group" assigning its Early Pleistocene to Holocene age. According to Patel (1991 a) the Chaya Formation of Mathur & Mehra (op.cit.) represents the littoral and beach accumulations along the fore-shore of an ancient (early Middle Pleistocene) high sea; the miliolites being the aeolian derivation of these reworked beach material. The miliolite rocks occur forming patchy exposures of dunes and sheets, resting over the pre-miliolite topography and geology.

Sub-Recent and Recent deposits;

The Sub-Recent and Recent deposits occurring in Saurashtra comprise dunal sands, beach sands, tidal clays, alluvium etc. Sand dunes are common in the vicinity of the coasts. They occur on western coast in the form of coastal ridges and on southern coast forming parabolic and longitudinal dunes. On the coasts where sea water enters through the creeks, saline calcareous clays are seen. Older raised mudflats are also encountered along the coastal tract of Saurashtra. A variety of geological and climatic factors has given rise to different types of soils in the area. The major amongst them are black cotton soil, red loam, lateritic soil, coastal sandy soil (Ghed) etc.

The miliolite limestones togehter with coastal beach rocks and stabilised dunal sands form the subject matter of the present account.

GROUNDWATER CONDITIONS

In general, the Saurashtra is lacking in having sufficient yield of drinking water. Soon after monsoon the water table in Surendranagar, Amreli, Bhavnagar and Rajkot districts goes down very much. The whole region in a broad way can be divided into three divisions for the groundwater conditions corresponding to the three geological units.

(i) Hilly and undulatory trappean terrain

(ii) Gently undulating and comparatively low topography terrain of sedimentaries like Dhrangadhra & Wadhwan Formations in NE and Gaj & Dwarka Formations in W & SW

(iii) The bordering monotonous plains covered by thick spread of alluvium, miliolites & Rann clays.

The Deccan Traps are not regarded as ideal host rocks for groundwater, although waters for domestic use may be obtained at depths usually between 5 & 15 m. Such waters are confined to the soil cover, decomposed rocks, junctions between flows, joints, fissures or redbole layers and vesicular flows. The yield in traps varies between 2000 & 4000 lit/day.

The Dhrangadhra and Wadhwan sedimentaries provide groundwater aquifers only in the Surendranagar district and the northern part of Rajkot district. These formations yield in general 3000 to 4000 litres water per day from the wells having depths more than 10 m. Water in Gaj beds occurs both, under confined and unconfined conditions. The upper granular beds comprising limestone and grit with yellow clay, form the only important water bearing zones. The quality of these waters is variable, generally hard with high bicarbonate contents.

Miliolite limestone is most important water bearing formation throughout the coast of Saurashtra. The limestone being porous in nature, helps in circulation of water to a considerable extent until it touches the impervious clays of the Gaj or Trap rocks at bottom. The general movement of groundwater is towards the Arabian sea. Dug wells with an average depth of 5 m delve in miliolites, yield in general 5000 to 6000 litres of water per day. The quality of water in the miliolites is generally good but, now a days over exploitation of groundwater in coastal areas has

disturbed the equilibrium resulting into seawater ingress and severe irrepairable damages to these sweet water sources.

SCOPE OF PRESENT STUDY

This account deals with the conjunct study of all Quaternary organoclastic carbonate deposits of Saurashtra in general and the miliolite limestones in particular. The report incorporates the mapping of all the three types of widely distributed surficial bioclastic carbonate deposits and their indepth petrography, which throws considerable light in the understanding the various depositional events and climatic fluctuations that took place during the Quaternary period in this part of terrain.

The author has carried out detailed mapping of these deposits on 1:50,000 survey of India toposheets during four field seasons of the year 1990 & 1991. Almost all coastal as well as inland exposures of these deposits were visited and data pertaining to their distribution, mode of occurrence, lateral & vertical extent, lithic characters, depositional features etc. were collected. These informations were systematically recorded in the diary and the field photographs of most of the exposures were taken in support of the field observations. More than 270 representative samples from different localities were collected and about 200 thin sections of beach rocks and miliolites together were made and critically examined under the polarising microscope to study their constituents and diagenesis. The representative samples were also subjected to X-ray diffractometry (XRD), Scanning Electron Microscopy (SEM), Thermoluminescence (TL)

studies and etching & staining techniques. In order to understand the relationships between the consolidated miliolites and semiconsolidated to uncosolidated dune sands, their carbonate constituents and acid-wash products were studied under the binocular microscope. Besides these, the textural parameters of stabilised dune sands were also studied by conventional sieving method.