CHAPTER-III

GEOLOGICAL SETTING

In order to set the scene for the description of the geology of the study area, a regional description of this aspect has been made.

REGIONAL GEOLOGY OF SAURASHTRA

Two third of Saurashtra is occupied by the Deccan Trap, forming a generalised plateau. These Trappean rocks overlie the upper Mesozoic rocks which are exposed in the northern part of Saurashtra. The Tertiary and Quaternary sediments fringe the Traps along the coastline.

The generalised geological succession (Fig. 6) in Saurashtra is given in Table : 3, (after Shrivastava, 1963 in Ganapathi, 1981). A brief description of the geology is given below (after Ganapathi, 1981).

MESOZOIC ROCKS

The Dhrangadhra Formation, exposed around Dhrangadhra and Than towns and occupying an area of 4,200 sq.km is the oldest rock type in Saurashtra. Oldham (1893) named them as "Kathiawar beds" , while Fedden (1884) denoted them as "Umia beds". Shrivastava and Rizvi (1960) denoted these beds as a

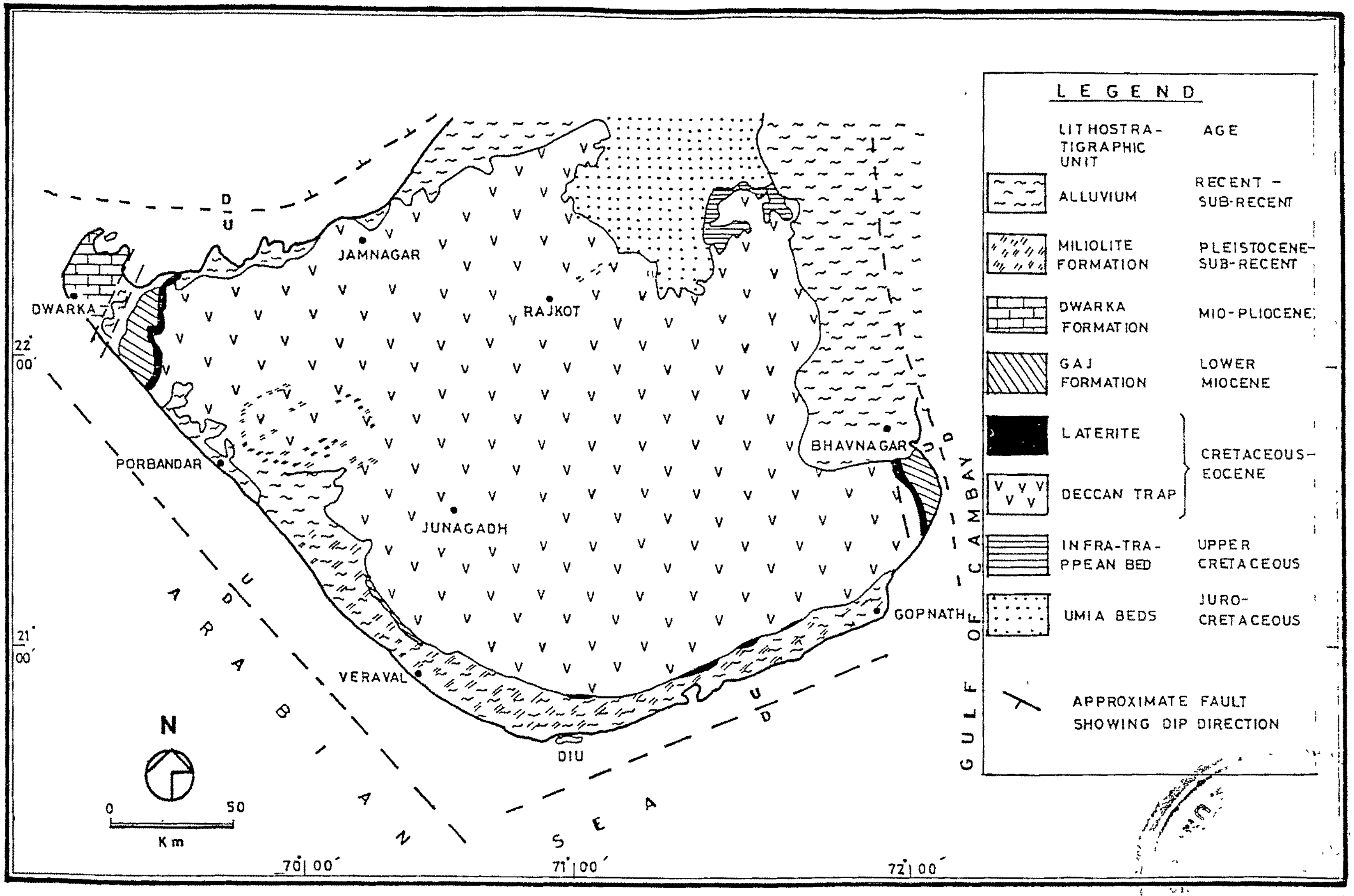

FIG. 6. GEOLOGICAL MAP OF SAURASHTRA AND ITS TECTONIC FRAMEWORK
(after Poddar, 1964 ; In Ganapathi, 1981)

TABLE - 3

Generalized Stratigraphic Sequence Of The Saurashtra Peninsula (after Shrivastava, 1963)

Formation	Lithology	Environment	Age
Recent Deposit	Alluvium, coastal dunes and beach sand, Rann clays, mud flats, and soils etc.		Recent and Sub - Recent
- - -	- - - Unconformity - - -		
Agate Conglome-rates	Agate conglomerates and associated ferru-ginous sandstones.	Fluviatile	Pleistocene to Sub - Recent
Miliolite Formation	Calcarenites, Calc-rudite, with inter-calations of clays.	Littoral	
- - -	- - - Unconformity - - -		
Dwarka Formation	Dark brown silty clays, yellowish calcareous clays and limestone with gypseous clays.	Littoral to epiner-itic	Upper most Miocene to Pliocene.
Piram Beds	Fossiliferous conglome-rates, grits and sandy clays.		
- - -	- - - Unconformity - - -		
Gaj Formation	Varigated shales, sand-stones, marls, conglo-merates and impure limestones with inter-calation of gypseous clays.	Epineritic	Lower Miocene
- - -	- - - Unconformity - - -		
Lateritic Rocks	Red, brown and yellow-ish brown laterites.		Paleocene
Deccan Trap Formation	Plutonic masses and dykes intrusive in the Trap flows.		Cretaceous to Paleocene
- - -	- - - Unconformity - - -		
Wadhwan Formation	Red and brown colour sandstones with inter-calation of shales.	Shallow marine	Middle Cretaceous (Albian to Cenomanian)
- - -	- - - Unconformity - - -		
Dhranga-dhra Formation	White and coloured felspathic sandstones with gritty layers, lenses of grey and yellowish shales and carbonaceous shales with coal layers and plant remains.	Deltaic	Juro-Cretaceous (Tithonian to Albian)
- - -	- - - Base not exposed - - -		

"formation". This formation can be divided into two units : the lower, consisting of soft, yellow sandstone, with ferruginous concretions and intercalations of fossiliferous carbonaceous shales and thin coal seams ; and the upper, comprising of purplish or dark coloured, gritty sandstones with conglomeratic layers. The texture, structure and plant fossils point towards a deltaic depositional environment in areas of subsidence (Shrivastava, 1963).

The Dhrangadhra Formation is overlain by a thick sequence of red and brown coloured sandstones with intercalations of shales. Fedden (1884) denoted these rocks as Wadhwan Sandstone after the town of Wadhwan. Shrivastava and Rizvi (1960) classified these rocks as Wadhwan Formation, and divided them into three members. The lithology and marine fossils in the formation point to a shallow marine environment of deposition.

Fedden (1884) regarded this formation as equivalent to the cherty members of the Bagh beds. According to Fox (1931), the Wadhwan sandstones were of Lower Cretaceous age similar to the Nimar Sandstones of Narmada valley. Krishnan (1968) supported Fedden's view and further correlated these Wadhwan Sandstones with the Umia plant beds of Kutch, the Himatnagar Sandstones of Gujarat mainland and the Barmer Sandstones of Rajasthan. Shrivastava (1963) assigned them an Albian to Cenomanian age.

THE DECCAN TRAP

The Deccan Trap constitues the most dominant formation of Saurashtra peninsula. Mainly consisting of lava flows, the Trappean rocks show the usual varieties, viz; dark grey compact, porphyritic, vesicular and amygdaloidal, etc. Rao *et al.* (1962) and Shrivastava (1963) estimated an exposed thickness of about 600 m for this formation in Saurashtra. Besides the usual varieties of dolerites and basalts, many interesting differentiates have been encountered in the hills of Barda, Girnar, Osham and Gir Range.

On the whole, Infra-trappean beds are scarce in Saurashtra. However, according to Fedden (1884) a few hard bands, probably of consolidated volcanic material have been observed near Dhandhalpur. Volcanic ash beds occur in the Chotila hill.

Numerous dykes cut across the basalts and ideally follow the fracture pattern in the Traps. These dykes often provide remarkable topographic expressions to the major lineaments of the area. They vary considerably in size, ranging from a few to as much as 60 m in thickness. The dyke rocks are mostly coarse basaltic or doleritic in composition and are usually devoid of vesicles. Acidic dykes are also common.

THE LATERITIC ROCKS

Resting over the Traps along its fringes, lateritic rocks form an important rock unit, overlain in turn by the younger Tertiary and Quaternary deposits. Essentially comprising a residual alteration product of the Deccan Trap, the laterites are quite important from the point of view of their economic value. These occur as a narrow discontinuous band all over the periphery of the peninsula, and forms fairly extensive exposures near Bhavnagar, Longdi, Jafrabad, Veraval and Bhatiya. Typically unstratified and mottled, the laterites show a wide range of colours like red, brown and yellowish brown, and bauxitic laterites provide a good source of aluminium ore.

TERTIARY ROCKS

Rocks of Lower Miocene age, resting over the Deccan Trap and the laterites along the peninsular fringe have been designated as Gaj Formation.

Originally, named as Gaj beds by Fedden (1884), these marine rocks show good exposures in Bhavnagar-Ghogha area and in Okha Mandal. In other places, as it is overlapped by younger formations, it does not outcrop on the surface.

Gaj rocks comprise variegated shales, sandstones, marls, conglomerates and limestones with intercalations of gypseous clays. Pascoe (1973) has reported the following invertebrates from these rocks : Bryozoa, Echinoidea, Pelecypoda, Gasteropoda, Cephalopoda, Crab and Foraminifera.

The rocks of Gaj Formation are considered to have been deposited in a shallow marine environment, perhaps under epineritic conditions (Fedden, 1884; Shrivastava, 1963; Pascoe, 1973; Wadia, 1975).

Beds resting over Gaj rocks in Okha Mandal were designated as Dwarka beds by Fedden (1884). Consisting of dark brown arenaceous clays and limestones with intercalation of gypseous clays, these were called Dwarka Formation by Shrivastava and Rizvi (1960). Rocks of Dwarka Formation are best exposed in the Okha Mandal area, where they rest disconformably over the Gaj rocks. Along the south coast near Jafrabad, an isolated patch of Dwarka rocks has been reported by Verma and Mathur (1978). The Dwarka rocks are less fossiliferous as compared to the Gaj, except for some foraminifera and broken molluscan shell fragments. According to Shrivastava (1963), they were deposited under littoral to epineritic conditions and could be considered of Mio-Pliocene age.

In the Bhavnagar-Ghogha area the rocks equivalent to the Dwarka Formation are represented by Piram Beds. Resting disconformably over the Gaj rocks, these are exposed in the intertidal area only and are well-known for their mammalian fossil content. Piram Beds comprise hard and well cemented fossiliferous conglomerates with intercalations of sandstones and clays. A rich mammalian fossil fauna are the characteristics of the conglomerate layers (Fedden, 1884; Rao & Jain, 1959).

While Fedden (1884) thought that these Piram Island rocks were deposited under shallow marine or estuarine conditions, Shrivastava (1963) has suggested fluviolittoral environmental conditions for these beds, assigning them a Mio-Pliocene age, correlatable with the lower part of Dwarka rocks of Okha Mandal area.

QUATERNARY ROCKS

The Quaternary rocks, are unique in the sense that they comprise most striking accumulations of carbonate sands over a dominant portion of the Saurashtra coast. Grouped into the Miliolite Formation, these include calcarenite and calcrudite with intercalations of clays. These carbonate deposits form a 12 to 20 km wide belt all along the coast from Porbandar to Gopnath, overlapping the Gaj and Dwarka rocks and resting directly over the Trap at some places. Rocks of this formation also occur as outliers in Chotila, Junagadh and Chamardi hills as inland miliolites. These pelletoid and oolitic calcarenites characterised by a warm and shallow marine microfauna, dominantly foraminifera, have remained highly controversial in respect to their mode of origin. It appears that the various miliolite occurrences are quite often aeolian accumulations - coastal dunes having originated by reworking of the coastal sands by stormy winds. According to Merh (1980, p.21) these Quaternary deposits are "partly marine partly aeolian consisting of more than one generation of carbonate sands deposited under shallow marine conditions and subsequently reworked by winds to form coastal dunes, all this having taken place during the successive periods to transgression and regression of the Quaternary sea."

Stratigraphically equivalent to the Miliolite, and resting unconformably over the dissected hills of lateritic rocks in the coastal areas south of Ghogha, occurs a formation consisting of `agate bearing ferruginous sandstones'. These rocks were mapped as Rampur Formation by Datta (1959), while Rao and Jain (1959) and Shrivastava (1968b), described them as Agate conglomerates and associated sandstones. Shrivastava (1968b) thought that they were deposited under fluviatile conditions and assigned them a Pleistocene or Sub-Recent age.

RECENT DEPOSITS

Recent deposits include a variety of unconsolidated sediments of estuarine, marine, freshwater and subaerial origins. In the eastern Saurashtra, a belt of alluvium stretches eastward towards the plains of Gujarat and extends northward upto the Gulf of Kutch. The other alluvial covers are along the southeastern coastal region and the western coast near the Bhadar and Ojat river mouths. The alluvial sediments comprise dark grey and black soil on the top, with underlying kankary or lateritic soil. The Okha rann clays consist of yellowish and grey saline clay and silts of marine origin. Saline marshes are common at the heads of the various creeks all along the coast. The coastal dunes and beaches are made up of carbonate sands from Okha to Gopnath point, whereas those between Shetrunji estuary and Ghogha consist of arenaceous sands. The soil cover, a product of "in situ" sub-aerial weathering, varies from black cotton soil to yellowish brown sandy soil. The former is derived from the Trap while the latter has originated from the Tertiary rocks.

TECTONIC FRAMEWORK

The peninsula of Saurashtra shows a unique structural set up. Essentially bounded by a number of major faults on all sides (Poddar, 1964; Fig. 6), its rocks reveal an interesting fracture pattern related to the various faults. The Saurashtra peninsula as a whole might not be showing spectacular uplifts and subsidences as a single block, but there are ample evidences to suggest that its various parts did undergo differential movements essentially during the

Quaternary period. The geological and geomorphological evolution of the different segments of the Saurashtra coastline is obviously controlled by these tectonic features.

Following four major faults delimit the Saurashtra landmass :

1. Ghogha -Sanand fault (Western Cambay Basin Border Fault).
2. Extension of Narmada Fault.
3. Gulf of Kutch Fault.
4. West Coast Fault.

STRUCTURAL HISTORY

Shrivastava (1963) has ideally summarised the structural history of the Saurashtra peninsula in the following words : "A careful consideration of the geological and geophysical evidences in Gujarat appears to show that the structures of the region are mainly controlled by faults. The northern part of the plateau is bound by the little Rann and the Gulf of Kutch, and it is likely that a concealed fault is present running in a general ENE - WSW direction, and probably the cause of a somewhat linear northern coastline of Saurashtra, and the rather abrupt termination of the Tertiary rocks of the Okha Mandal region and the Deccan Trap against this straight coastline. This fault may belong to the set of general east-west trending faults in Kutch. Rao et al. (1962) regarded the high dips in the Dhrangadhra Formation, at some places in the northern part of its exposure, as probably caused by a concealed fault beneath the alluvium. The gravity and magnetic work in the alluvial areas northeast of Dhrangadhra, shows indications of an east - west fault in line with the north coast of Saurashtra. The above authors regard the area of the little Rann and the Gulf of Kutch as a zone of weakness; probably a graben or half graben".

"Similar faulting can also be said to have taken place along the western margin of Saurashtra which again shows a strikingly straight coastline between Okha and Kodinar. The fault is probably the extension of the fault which is believed to have caused the almost straight western coast-line of India. The southern coast-line also shows similar characters with some steep scarp faces. If it is due to a fault, the fault will almost certainly be the extension of the zone of weakness along which the Narmada faulting in the ENE - WSW direction has taken place. The northern coastline fault would be almost parallel to this fault. The eastern margin of the Saurashtra plateau is bound by the faults of the Cambay graben which are parallel to the west coast fault. Thus, it would appear that the almost rectangular Saurashtra peninsula is bound on all sides by faults on the continental slopes. It is noted that the Pleistocene Porbandar Formation overlies the older formations along the coast and in the central highlands of Saurashtra at high elevations e.g. on top of the Chotila hill (1,173 feet altitude), providing a clear proof of the elevation of the plateau in recent times.

It may be assumed that the movement was along fault planes, since folding movements have not affected the Porbandar beds. All these faults were active during Tertiary times, and till Late Pleistocene, but it is likely that they existed even earlier. The Saurashtra peninsula was subjected to submergence and emergence during different movements along the fault planes. As a result of the late upheaval of the Saurashtra block, the earth is evidently under considerable strain (Crookshank, 1938), indicating that certain instability still persists. Crustal adjustments by movements along similar faults also occurred in the Kutch region to the north of Saurashtra, causing the great earthquake of Kutch in 1819. The dislocation during this earthquake had a general E - W alignment parallel to the E - W fault trends of Kutch - Saurashtra region".

"Certain dykes in the southeastern Saurashtra are undoubtedly associated with faults. In all probability, there are many more faults in the peninsula which have not so far been brought to light. Dislocations along many of the faults occurred from time to time till Sub-Recent age".

"Field observations clearly indicate that the rocks in Saurashtra have not been subjected to intense folding since the Upper Jurassic times. The folding in the Mesozoic rocks here is of a very gentle nature as compared to the folding in the similar rocks just to the northwest, in Kutch. The dips recorded in the Trap are suggestive of gentle and regional tilting caused by movements of large blocks along fault lines, and by the intrusive plugs. Auden (1947) considers that the pattern of occurrence of dykes in Saurashtra is related to the folding in the Trap".

"The Post-Trappean tectonic history of Saurashtra in general, is characterised by the epierogenic movements along various fault planes from time to time. This feautre has controlled the marine transgressions and regressions, and the Tertiary sedimentation along the coastal region. The greatest marine transgression in the known geological history of the peninsula occurred in the Pleistocene during which the Porbandar Limestones were formed. The upliftment commenced in the Late Pleistocene and Sub-Recent, and is probably still under progress. The exposed Tertiary sediments all along the coastal regions are almost unaffected by folding except those in the Ghogha area, where the gentle folding might be related to the regional movements along the faults".

NEOTECTONISM

Another important aspect of the Saurashtra tectonics has been brought out by Merh (1980), who has invoked a northward tilting of the peninsula during Quaternary period. While the northern coast of Saurashtra has been gradually submerging, the southern counterpart points to emergence. Thorat (1980) has carried out a critical analysis of the geomorphic and drainage attributes of the northern coast of Saurashtra and has come across numerous evidences to support a submerging coastline. In contrast, the geomorphological and geological attributes of the southwest and south coast, very clearly point to an emergent coast.

Neotectonic uplift is very well illustrated by the miliolite occurrences of the various rivers of southern Saurashtra. The rivers like Hiran, Shingoda and Machhundri perhaps follow fault lines. According to Merh (1980), these cut across miliolite, show variable thickness of these rocks within a short eastwest distance. This aspect has beeen explained by Dr. B. Roy (in Merh, 1980). He has worked on the southern Saurashtra coast and has reported that the miliolite rocks of same stratigraphic age occupy different topographic levels, and there some of the striking evidences of tectonism are observed in the river valley in the form of differential river gradients, variation in thickness of miliolites, convergence of terraces and antecedence of streams. Rivers Hiran and Sonarki offer good evidence of differential uplifts. The former has a steep gradient with a number of nick points, and is seen entirely cutting through a 60 m thickness of miliolite and finally flowing over the underlying Traps. The Sonarki river in direct contrast, which lies only 13 km west of Hiran, has a smooth profile, with a miliolite thickness of about 5 m only, and occurring at a maximum level of 25 m. Dr. Roy has stated, "I envisage certain 'down faulted pre-miliolite river valleys along which sea' ingressed during transgressions. These linear weak zones, depressed to different depths, thus gave rise to variable thickness of miliolites, and these were subsequently uplifted along some prominent faults in varying amounts. Those differential movements along faulted blocks, probably correlatable with the major offshore lineaments have given rise to the confusing miliolite topography".

The structural set up and tectonism of the Saurashtra peninsula has been explained by Dr. S. P. Sychanthavong, invoking the concept of plate tectonics. His ideas have been summarised by Merh (1980) in the following lines, "He has divided the Saurashtra coastal area into following four main tectonic zones of instability with varying intensities of movements either vertical or lateral :

1. Western Cambay Basin Border Fault,
2. Narmada Fault,
3. Gulf of Kutch Fault, and
4. West-coast off-shore Fault.

The airphoto and satellite imagery reveal a fracture pattern, criss-crossing the entire Saurashtra, comprising three pairs of conjugate sets of fractures, parallel to the tectonic zones (1) and (2), (2) and (4) and (1) and (3). These tectonic zones and the related fracturing, according to Dr. Sychanthavong, are the manifestation of the stress distribution derived from the main stress field related to the northeastward movement of the Indian plate. This northeast direction represents the movement of the stress field which generates and distributes various kinds of force into the above four tectonic zones.

Analysing his lineament data for the southern Saurashtra coast, Dr. Sychanthavong also, has advocated the role of differential tectonism of subtectonic zones bound by a few major conjugate fracture sets, each sub-zone uplifting or sinking differently. Such a situation is adequately reflected in the heights and thickness of miliolites in the various river sections on the south Saurashtra coast".

GEOLOGICAL SETTING OF THE STUDY AREA

The geology of any area forms the base of all natural resources including soils, surface and sub-surface water etc. Hence, it was essential to have an idea about the geological setting of the Gir Wildlife Sanctuary. Unfortunately, very scanty geological data exists for this densely forested area, making the problem of initiating the work very difficult. The geological mapping was carried out with the objective of studying form, extent and lithology of the lava flows and the associated rock types.

The mapping was done on 1:50,000 scale using Survey of India Topographic Map Nos. 41 K/8, 11, 12, 15, 16; 41 L/9 & 10, 13; 41 P/1 and 41 O/4 as the base.

Methodology

A study of aerial photographs (wherever available) and satellite imagery (1:50,000 scale approximately) was done prior to detailed field mapping. The lineament map based on IRS-1A satellite imagery (LISS 2 Band 2,3 and 4, False Colour Composite) was prepared on a 1:50,000 scale. The dyke and lineament systems interpreted were then checked in the field. Traverses were made along available roads and approaches only, taking into consideration the variation in topography, rock types, lineaments etc. Permission to make cross-country traverses was denied by the Forest Department because of the presence of carnivores. This fact combined with the thick vegetation and extremely rugged terrain made access to many localities next to impossible.

During the geological mapping, the absence of specific marker horizons, paucity of good exposures, the rugged terrain, the large numbers of intrusive bodies and dense vegetation posed problems in demarcating individual flows. This problem was further compounded by the alteration / weathering of the various lava flows. Due to the above cited problems, though several rock types were encountered, their exact demarcation was not possible, hence for the ease of description and presentation, only three lava flows have been discerned and presented. Nevertheless, the various rock types encountered have been described.

The major rock types encountered and recorded include various Deccan Trap lava flows and related intrusive bodies, miliolite limestone, soil and alluvium.

Based on the field study and petrographic analysis of the samples, a geological map was prepared on a 1:50,000 scale and the presentation scale is 1:250,000 approximately (Fig. 7).

For ease of description, the entire study area has been divided into segments I and II (Fig. 7).

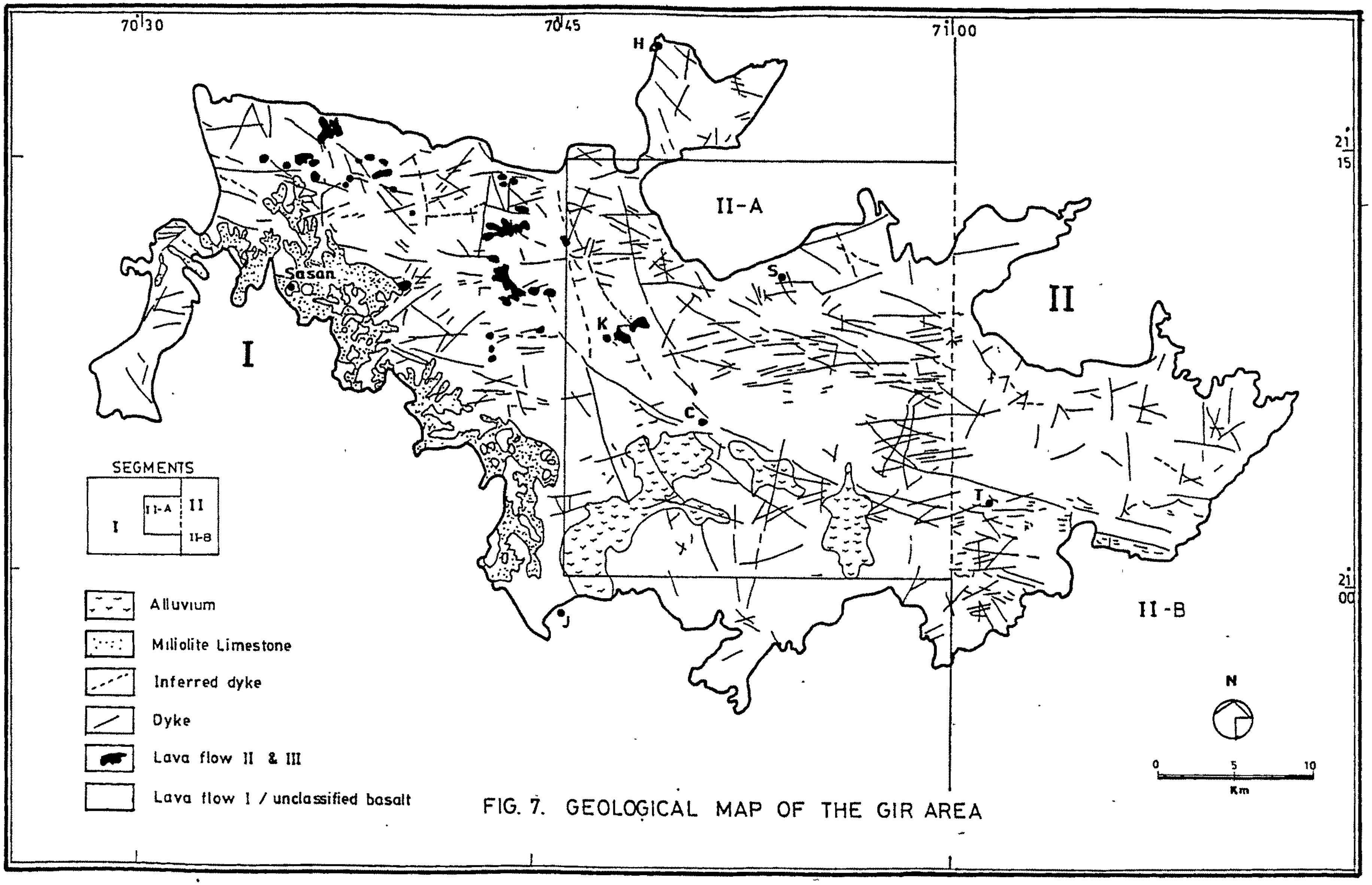

FIG. 7. GEOLOGICAL MAP OF THE GIR AREA

GENERAL GEOLOGY

Fedden (1884), the pioneer worker on the geology of Saurashtra, did provide some information on the stratigraphy of the study area, but the same was only as a part of the description of the stratigraphic framework of Saurashtra as a whole. As such, he did not give any details. Later on, Shrivastava (1963) gave a detailed account of the stratigraphy of Saurashtra.

According to the present author, the generalised geological succession/stratigraphy of the study area is as follows (modified after Fedden, 1884) :

Age	Formation
Recent to Sub-Recent	Soil and Alluvium Miliolite Limestone.
---------------- UNCONFORMITY / DISCONFORMITY --------------	
Cretaceo-Eocene	Deccan Trap lava flows (III-Fine to medium grained basalt, II-Glomeroporphyritic basalt, and I-Olivine basalt) and their associated intrusive bodies.
------------------------ BASE NOT SEEN ---------------------	

DECCAN TRAP LAVA FLOWS

The oldest exposed rocks in the study area are Deccan Trap lava flows. These Trappean rocks comprise slightly / low dipping lava flows and cover a large portion of the study area, concealing all the older rocks. They are essentially basalts, associated basic and acidic intrusives. Owing to their highly weathered nature, the rocks show grey, dark grey, greenish grey, brown, reddish brown colours in the field. All these rocks are highly jointed, showing several sets, mainly in NE-SW, E-W, NW-SE to WNW-ESE directions. The fracture pattern in the Traps shows a distinct relationship with the various major lineaments. The basalts are traversed by numerous well defined dykes and significantly, they show well defined trends in conformity with the joint patterns. The dykes are common throughout the study area, whereas dyke clusters are encountered in only the northeast, east and southeastern parts.

The Trap rocks are made up of different flows of varying thickness. The general lava flow succession in the study area is as follows :

Flow III - Fine to medium grained basalt (Plate : 1)

Flow II - Glomeroporphyritic basalt (Plate : 2)

Flow I - Olivine basalt (Plate : 3)

Areal extent

Flow I - The oldest exposed flow is of olivine basalt. It covers extensive areas and is uniformly distributed throughout the study area.

Plate 1 - Fine to medium grained basalt flow.

Plate 2 - Glomeroporphyritic basalt flow.

Plate 3 - Olivine basalt flow.

Flow II - The glomeroporphyritic basalt occurs in small patches in the western, northwestern and northern parts of the study area, whereas it occupies a major portion in the eastern portion. However, it was not possible to demarcate the junction of this flow and therefore, it has not been indicated in the eastern portion (segment II) of the study area.

Flow III - Fine to medium grained basalt flow is restricted to the higher hills in segment I (western portion), whereas in segment II (eastern portion), it is totally absent.

MILIOLITIC LIMESTONE

The Deccan Trap lava flows are overlain, either unconformably or disconformably, by miliolite limestone.

The miliolite limestones have been referred, by the previous workers, to be belonging to Pleistocene and Sub-Recent ages. Of course, no one has examined the miliolite limestones of the study area in particular, but the work of earlier investigators, on the miliolite limestones of Saurashtra in general has much relevance to the study area as well.

In the study area, miliolite limestones are restricted to the western and southeastern portions, and are found upto a height of 200 m only. Karst topography is visible wherever miliolite limestones are exposed.

SOIL AND ALLUVIUM

A major portion of the study area is covered by black cotton soil which supports rich vegetation. Alluvium is restricted to areas near river banks. The notable areas covered by alluvium are in the southern portion, near Kalipat Nes and Kardapan.

SEGMENT - I

Segment - I covers a part of the study area that falls in the Survey of India Topographic Map Nos. 41 K/8, 11, 12, 15 ; 41 L/9 & 10 and 41 L/13.

The lithologic succession in this segment is as below :

Recent		Soil & alluvium
Quaternary		Miliolite limestone
----------Unconformity----------		
Lower Eocene to Upper Cretaceous	--> Deccan Traps -	Acidic intrusives Basic intrusives Basic lavaflows (Flow III-Medium grained basalt, Flow II- Glomero-porphyritic basalt, Flow I- Fine grained olivine basalt).
----------BASE NOT SEEN----------		

The area has exposures of Deccan Trap lava flows and related intrusives (Cretaceo-Eocene), overlain unconformably by Miliolitic Limestone (Quaternary). A total of three lava flows were demarcated in the area. The lowermost flow in the area is greenish grey to dark grey coloured, fine grained olivine basalt. This flow occupies a major part of the area. It is overlain by greenish grey coloured, glomeroporphyritic to porphyritic basalt, which in turn is overlain by a dark grey coloured, medium grained basalt. The last flow is exposed in small patches only in the northern and central parts of the area.

All the flows are of compound `pahoehoe' type. The lava flows in the northern and north-eastern part of the area dip due north, and those in the south-western part of the area, dip due south at moderate angles ranging from 5^{o}-9^{o}. Erratic dips are also observed at places. These dips may be as a result of a gentle warping, or they may be attributed to the irregularity of the palaeo-surface, on which the lava flowed.

The lava flows are intruded by a large number of basic and acidic dykes. The north-eastern part of the area consists of dyke swarms. The dykes vary in trend from N-S to WNW-ESE, E-W to ENE-WSW. Few dykes are curvilinear and trend NNW-SSE, and also in a N-S direction. These dykes are of more than one generation. They are doleritic, microgabbroic, gabbroic and dacitic in composition. Besides the basic dykes, there are many shear zones trending N-S to E-W. They are intruded by rhyolite dykes and are subsequently filled by chert veins.

Deccan traps are overlain by buff coloured miliolitic limestone which are restricted to the western, south-western and southern parts of the area, and are overlian by soil and alluvium.

GEOLOGY

The area is covered by Deccan Trap basalts, which are weathered to black cotton soil at places. The lava flows are intruded by basic and acidic dykes. The Deccan Trap is overlain by miliolitic limestone of Quaternary age.

A major part of the area is covered by olivine basalts, and a small portion by tholeiitic basalts. In general, lava flows dip due SW. But, north of Chasa Gola the flow dips due north. At places, haphazard dips are also encountered. Miliolite limestone is exposed only in the western, south-western and southern parts of the area.

Description of the lava flows

Surfaces of lava flows wherever exposed, are smooth and rolling. At a large number of places, pipe amygdules (Plate : 4) were seen at the base of lava-flows. In a single lava flow, several alternating flow units were also observed.

Plate 4 - Pipe amygdules at the base of lava flows.

In the present study area, a total of three basic lava-flows were recognised on the basis of grain size, mineral constituents, size, shape and arrangement of phenocrysts, glassy matter in the rock, nature of amygdules and weathering colour. Based on these criteria, the lava flows were demarcated only to some degree of accuracy. This was due to the absence of marker horizons in the area and the weathering surfaces between different flows. The thick vegetation covered most of the outcrops, adding to the difficulty in the demaraction of flow boundaries.

All the flows are sub-horizontal, with gentle dips either to the SW or to the NNE.

FLOW - I

This is an olivine bearing flow occupying a major part of the area. However, small patches of olivine free, fine grained basalt are found underlying this flow near Sandhbeda Nes and north of Janwadla. This olivine free basalt is probably the oldest flow exposed in the area.

Olivine-free basalt

This flow is fine grained in hand specimen. Near Janwadla, it becomes slightly medium grained. The fresh surface has a greenish grey colour. Only small pyroxene plates are visible in the hand specimen. Amygdules are filled mostly with zeolites, calcite and silica. They are mostly sub-rounded, and range in size from 3 mm to 1 cm. On weathering, the flow rock turns ash grey in colour.

Petrography

Under the microscope, the rock is fine grained and ophitic in texture. It consists of large crystals of pyroxene which are in optical continuity and enclose a large number of under developed laths of plagioclase. In between the pyroxene phenocrysts, pale yellow coloured, devitrified volcanic glass occurs. Pyroxenes are identified as augite, which is normally twinned. An appreciable amount of iron ores are also present as well developed crystals.

Fine grained olivine basalt / Flow - I

Fine grained olivine basalt has been designated as Flow - I, as it occupies extensive areas. It is exposed around Sasan, Dudhala Nes, Alawani, Hiran Dam, Kankai, Wansali, Bhilgala and Sirwan. Actually, this flow has two units :

- Medium grained, highly porphyritic (Plate : 5), and
- Fine grained, containing dark laminations of volcanic glass (Plate : 6).

Both the units contain olivine, though it is more abundant in the first unit. These two units may be the different cooling

Plate 5 - Medium grained porphyritic basalt.

Plate 6 - Fine grained olivine basalt.

products of the same magma as they show great similarity in physical and mineralogical characters, and often occur in an inter-tonguing fashion. However, because of their physical and mineralogical differences, the two flow-units have been described separately.

(i) Fine grained unit

This unit is well exposed to the north of Janwadla. The maximum thickness of this flow unit is around 30 m.

Megascopically, the rock is dark grey and fine grained. It shows fine laminations of grey to brown coloured glassy material, which in some cases alters to a brown material. The rock contains large sized amygdules filled with silica.

Petrography

Under the microscope, the rock is fine grained and exhibits porphyritic and intersertal textures. Phenocrysts are of pyroxene, and slender laths or microlites of plagioclase are also seen. Plagioclase are identified to be labradorite. In some cases, a few well developed plagioclase laths are also seen. Pyroxene occurs as augite which is mostly altered to chlorite. Very few small grains of olivine are also seen scattered here and there in the section. Iron ore occurs as very small elongated grains. The inter-spaces between phenocrysts are filled in by green devitrified glass.

(ii) Medium grained unit

This is a little coarser grained unit than the earlier one, and has a wide spread areal extent. It is seen to be best exposed on the hill just north of Sirwan village (Plate : 7). It is also exposed around Kankai, Wansali, Hiran Dam and Sasan. A maximum thickness of 105 m of this flow unit is exposed on .329 hill situated to the NE of Ambliala. The medium grained unit is actually a group of flow-units. Each unit has a massive dark grey coloured basal part and a khakhi coloured, amygdular upper part.

Megascopically, the rock is medium to slightly coarse grained, very dark grey in colour and highly porphyritic. Phenocrysts of plagioclase laths are 2-3 mm in size. Pyroxene plates are also seen in abundance ranging, in size upto 2 mm. Honey yellow coloured phenocrysts of olivine are also seen in the fresh samples. In others, reddish grains of iddingsite (an alteration product of olivine) are also seen. The weathered rock of this unit has a yellowish brown coloured coating / skin, which may be due to the oxidation of the ores that are present in the rock. Moreover, the surface also has a pitted appearence which may be due to the leaching out of some unstable minerals like olivine. The amygdular part of this rock is khakhi coloured. Amygdules of silica and zeolites are very abundant. They are also very irregular in shape.

Petrography

Under the microscope, the rock is medium to coarse grained, mostly intergranular, but some glass is present in the interstitial spaces. Subhedral to euhedral laths of labradorite are seen. Pyroxene (mostly augite) occurs as anhedral to subhedral crystals, and is generally altered to antigorite. Olivine occurs as numerous anhedral phenocrysts. These are altered to pleochroic antigorite or to serpentine along the cracks. Iron ore is abundant. It occurs as big and small sized euhedral crystals. The intergranular spaces are occupied by dirty green to pale green coloured, devitrified volcanic glass. It is mostly pigmented by iron ores.

FLOW - II

This flow is greenish grey coloured, fine grained and glomeroporphyritic in nature (Plate : 2).

Glomeroporphyritic basalt

This flow has a limited areal extent, and is found to the NE of Kankai on the lower parts of .303 hill, north of Wansali, north of Dayra Timbi, Bhilgala, Kosra Dungar and Kumbhakot Dungar. Near Kankai, this flow consists of two units. The approximate total thickness of this flow is around 40 m.

Plate 7 - Exposure of **medium grained** basalt unit.

Plate 8 - Medium to fine - grained basalt.

Megascopically, the rock is greenish grey in colour. The typical feature of the rock is the presence of leucocratic rounded clusters of plagioclase laths. The clusters are studded in a fine grained groundmass and range in size from 2 mm to 4 mm, as seen in the upper unit near Kankai. At other places, the glomerocrysts are small in size. A few rounded, dark greenish, spherical globules of around 1-2 mm diameter are seen. The amygdules are seen mostly circular in cross-section and are filled in by silica and zeolites.

Petrogrpahy

Under the microscope, the rock is highly glomeroporphyritic with large phenocrysts of plagioclase arranged in circular clusters. These plagioclase clusters are surrounded by a medium -to - fine grained groundmass of plagioclase and pyroxenes. Most of the rock is intergranular but very little interstitial glass is also present. Megacrysts of plagioclase are mainly of labradorite, and are seen altered to sericite. The groundmass plagioclase occurs as very small, not so well-developed laths. Pyroxenes occur only in the groundmass as small, anhedral phenocrysts. They are mostly augite. An appreciable amount of olivine is present as well-developed phenocrysts. It is altered to reddish yellow iddingsite, and to serpentine along the cracks, and also on the periphery. Iron ore occurs as numerous, small sized subhedral grains.

FLOW - III

This is a medium grained, dark grey coloured basaltic flow, and is found exposed only at Kumbhakot Dungar, north of Makhaniya and in a few patches in the central part. The thickness of this flow is around 30 m.

Medium grained basalt

Megascopically, this rock is medium to fine grained, dark grey in colour, and porphyritic in nature (Plate : 8). Alongwith some pyroxenes, 1 to 2 mm sized, slender laths of plagioclase are seen. Very few spherical globules (1-2 mm size) of dark greenish grey colour are present. Amygdules are few and filled in by silica and zeolites. They range in size from 3 mm to 6 mm.

Petrography

Under the microscope, the rock is medium grained and glomeroporphyritic. But the glomerocrysts are not as prominent as in the flow described earlier. Clusters are small in size and they are composed of plagioclase. The groundmass is fine grained and is composed of plagioclase and pyroxenes. Plagioclase are of two types. The phenocrysts are euhedral, labradorite, altered at places to sericite. The groundmass plagioclase occurs as small subhedral laths.

Pyroxene is commonly augite. It occurs as small, anhedral crystals, altered to antigorite. Olivine occurs as small subhedral grains. Most of it is altered either to pleochroic antigorite or to serpentine. Besides these, there are small rounded grains of greenish yellow chlorophaeite. The interspaces are filled in by pale yellow, devitrified volcanic glass.

INTRUSIVES

Dykes are the only type of intrusions in the area. Calcite veins occur either independently or at the periphery of basic dykes.

In general, dykes are very abundant in the area. However, the density of dyke occurrence is more in the north and northeastern part of the area, which constitutes a dyke cluster zone. The concentration of dykes is maximum to the north of Bhilgala.

The dykes have intruded in more than one phase. This inference is drawn after observing one set of dykes abutting against the other, and also from the lateral shifting of the earlier dyke along a younger dyke. Moreover, it is observed that only some dykes out of a set of dykes trending in a common direction cut across a particular dyke, while others about against that dyke. This fact suggests that there is more than one phase of intrusion for the dykes trending in a particular direction. A majority of the dykes trend NW-SE to WNW-ESE. The second set trends EW to ENE-WSW. Very few curvilinear dykes are seen trending NNW-SSE and also in the N-S direction. It is generally seen that the dykes trending N-S and WNW-SSE are the youngest among the basic dykes present in the area. In segment - I, five types of dykes are found, as described below.

(1) Dolerite dyke

These are most abundant in the area. They have been further differentiated on the basis of grain size, such as fine, medium and coarse dolerite. Fine and medium doleritic types of dykes occur mostly as depressions or as low-lying outcrops. Coarse dolerite dykes generally are little more resistant and stand out above the country rock (Plate : 9). The width of these dykes varies from as much as half a meter to about six meters. Well developed joints parallel to the length of the dyke and perpendicular to it are prominent in these dykes.

Megascopically, the rock is very dark grey in colour and fine to medium grained. Only slender laths of plagioclase (2-4 mm size) are seen. In the coarse dolerite dykes, a few 1 to 2 mm sized plates of pyroxenes are also seen.

Plate 9 - Exposure of dolerite dyke.

Plate 10 - Micro-gabbro dyke.

Petrography

Under the microscope, the rock is mostly fine to medium grained, ophitic in texture. Dominant phenocrysts are large pyroxenes which enclose subhedral laths of plagioclase in an ophitic pattern. In coarser varieties, plagioclase occur as well-developed laths. It is seen that iron ore is arranged along the cleavages of plagioclase laths. Plagioclase are generally labradorite. Clinopyroxene (augite) is present as large, subhedral to anhedral crystals. The crystals are occasionally zoned. Small, isolated euhedral crystals of olivine are seen altered to chlorite-serpentine along the cracks. Iron ore occurs as numerous small subhedral grains. Glass occurs as very few rounded globules, which are pale green in colour. Very little, almost colourless devitrified glass is seen.

(2) Micro-gabbro dyke

This type of dyke is also very abundant in the area. Generally, these are resistant to weathering and standout prominently, as linear ridges (Plate : 10). They range in width from 3 m to as much as 12 m.

Megascopically, the rock is dark grey coloured, medium to slightly coarse grained. Plagioclase laths upto 4 mm size are seen. Besides this, iron ore is also seen. Pyroxene plates upto 2 mm are also seen.

Petrography

Under the microscope, the rock is mostly intergranular, but small amounts of interstitial glass is also seen. Plagioclase and pyroxene are sometimes seen inter-tonguing with each other, sometimes, in a sub-ophitic fashion. Plagioclase occur as euhedral zoned phenocrysts. They are identified as labradorite. Augite occurs as subhedral to anhedral crystals. Olivine occurs as large, anhedral grains, altered to greenish antigorite. Small amount of biotite, which seems to have been formed after pyroxene, is also seen. Iron ores occur as small euhedral grains. Volcanic glass occurs as a pale-yellow coloured, devitrified matrix between plagioclase and pyroxene grains, in small amounts.

(3) Dacite dyke

These dykes are curvilinear and convex in a south-westerly direction (Plate : 11). The radius of curvature of these dykes lies towards Dhari. These are very resistant to weathering and are cut across by a number of fractures and dykes, and hence stand out prominently as isolated ridges.

Megascopically, the rock is light grey in colour, medium to coarse grained, and highly porphyritic with phenocrysts of pyroxene and hornblende.

Plate 11 - Curvilinear dacite dyke.

Plate 12 - Hill of leuco-gabbro dyke.

Petrography

Under the microscope, the rock is coarse grained with a porphyritic and intergranular texture for the major part. However, an appreciable amount of volcanic glass is also present. Plagioclase occurs as large phenocrysts. Untwinned alkali feldspars are seen in abundance. Feldspars are mostly saussuritized. Pyroxenes occur as large phenocrysts, but most of it is altered to hornblende and some to biotite. Well-developed crystals of primary calcite are seen. Secondary calcite is also seen at places. In the interspaces between phenocrysts, quartzo-felspathic intergrowth is seen. An appreciable amount of quartz is seen as anhedral crystals around quartzo-felspathic material.

(4) Leuco-gabbro dyke

These intrusives are actually very large dyke bodies and are seen to occur at two places viz. Chasa Gola Dungar to Raidi Dungar, and Sasan to Bhalchhel. Since the rocks composing these intrusives are very resistant, they form the highest hills in the area (Plate : 12).

Megascopically, the rock is light grey coloured and coarse grained. Pyroxene phenocrysts and plagioclase laths occur in isolated patches, thus giving rise to light and dark patches.

Petrography

Under the microscope, the rock is coarse grained, equigranular and intergranular. Plagioclase occurs as large, euhedral phenocrysts, and are identified as labradorite. Augite is seen to occur as large euhedral grains. Most of it is altered to yellowish iddingsite. Iron ores occur as large euhedral grains. The interspaces between grains are filled in by an intergrowth of quartz and alkali feldspar, which is very conspicuous.

(5) Rhyolite dyke

Only two dykes of this type were observed to the south of Kankai. These are shear zones which were subsequently intruded by rhyolite dykes and filled in by chert veins (Plate : 13). This is evident from the shifting of basic dykes that cut across these dykes. Moreover, breccia and vein fillings with chert and calcareous material are invariably seen along these dykes /shear zones. Since the chert veins and rhyolite are very resistant to weathering, they invariably stand out prominently. The ridges on which rhyolites are exposed have boulders of chert / rhyolites on both the sides, and the basalt flows are completely covered by these boulders. The width of these dykes varies from 3 to 9 m. These dykes can be recognised from a distance because of

Plate 13 - Exposure of rhyolite dyke.

Plate 14 - Buff-coloured miliolite limestone.

their prominent and bouldary outcrops, and also from their zigzag outline.

Megascopically, the rock is reddish brown, massive and very fine grained. But at a few places, it contains spherical amygdules of 3 to 5 mm size, which are filled with silica.

Two of these dykes trend N-S, and the main dyke trends E-W. The rhyolite dykes are the youngest of all the earlier sets of dykes as they cut across all the earlier sets.

<u>Petrography</u>

Under the microscope, it is seen to be a close felted mass of quartz and feldspar.

MILIOLITIC LIMESTONE

In the western, south-western and western parts of the area, buff coloured, miliolitic limestones are exposed (Plate : 14). At the base of this limestone, calcareous conglomerate is seen to be directly overlying Deccan Trap with a disconformity. It has been observed in the area that miliolitic limestone shows profuse current bedding. However, orientations of the current bedding are haphazard. In general, the miliolitic limestones dip to the south, but irregular dips are seen at many places.

Megascopically, the rock is buff coloured. The conglomeratic portion contains subrounded to angular granules of Trap. A bulk of the rock is however composed of well-rounded to sub-rounded grains of silica. Besides these, there are numerous shell fragments also.

Wherever miliolitic limestone is exposed, karst topography is present, as the cementing calcareous material is very easily leached out.

Petrography

Under the microscope, the grains are seen to be cemented together by a calcareous matrix. Calcite crystals are seen to have been stacked together against one another.

SOIL & ALLUVIUM

In a major part of the area, black cotton soil is exposed. Since it is derived by the weathering of basalts, it is rich in mineral elements, which support the thick vegetation of the Gir forest. In the southwestern part of the area, however, mixed soil is seen. It is little less dark in colour.

Small patches of alluvium also occur in the western, southwestern and southern parts of the study area (Plate : 15).

STRUCTURE

(1) Flow dips

Inclination of lava flows is the most conspicuous feature observed in the area. In general, the flows dip towards the north at low angles varying from 6^{o}-9^{o}, to the north of the arbitrary line passing through Kankai, Dayra Timi, Vansadhol and Karshangadh. To the south of this line, the flows generally dip in a southerly direction. In the north-eastern part of the area around Kankai and Ambliala Nes, the flows dip at angles of 6^{o}-7^{o} to the north-east. To the west of it i.e. near Karamdadi, flows dip to the north at angles of upto 9^{o}. Further west near Hiran Dam, the flows dip at 5^{o}-7^{o} in a NNW diretion. In and around Kumbhakot Dungar, Lava flows dip at around 5^{o} to the NNE. South of the arbitrary line mentioned above i.e. around Wansali and Amritvel, the flows dip at 5^{o}-7^{o} in a SSW direction. These are the generalised dips prevailing in the area. However, erratic dips showing a departure from the prevailing dips are also observed.

The above pattern of dips may be due to folding. If the line passing through Kankai, Dayra Timbi, Vansadhol and Karshangadh is presumed to be the axial line of a broad gentle warp, the area to the north of this line becomes the northern limb, and area lying to the south of the line becomes the southern limb of the warp. But the evidence in

Plate 15 - Alluvium exposed along a river valley.

Plate 16 - Vertical to sub-vertical joint sets.

favour of it being a fold is not very convincing. These variable dips may be just due to the undulations / irregularities in the palaeo-surface on which the lava flowed.

(ii) Fractures

In the present study area, there are a large number of fractures. The first category of fractures are those utilized by the dykes for intrusion. These fractures are genetically related to the dykes that intrude along these dykes. So, the chronological order of development of these fractures is the same as that of dykes which have utilized them as intrusion channels. There are other fractures along which no dykes have intruded. It may be that these fractures are not deep seated. Different sets of dykes are seen trending due N-S, NNW-SSE, NW-SE, NE-SW and E-W.

(iii) Faults

Numerous small scale faults are observed in the area. Most of these trend due N-S and NE-SW. A few faults trending NW-SE are also marked. In many cases, dykes have intruded along the pre-existing fault planes. This is evident from the shifting of the older dykes along the earlier faults which are dykes now. This feature is observed along the dacite dykes near Makhaniya Nes and Timba, where the western blocks appear to have moved to the north relative to the eastern blocks. Shifting is of the order of around 50 m.

(iv) Shear zones

As mentioned earlier, the rhyolite dykes have intruded along what were previously existing shear zones. This is evidenced by the presence, along the dykes, of numerous brecciated fragments of basalt and chert. Shearing seems to have taken place prior to the intrusion of basic and acidic dykes.

(v) Joints

Joints in the area could be observed only along the river sections. Most of the joint sets are vertical to sub-vertical (Plate : 16). The following sets of joints were observed.

N 80° E - S 80° E	- Vertical
N 10°-20° E - S 10°-20° E	- Vertical
N 40° W - S 40° E	- Vertical
N 30°-40° E - S 30°-40° W	- Vertical.

SEGMENT-II

Segment-II covers a part of the study area which falls in the Survey of India Topographic Map Nos. 41 k/16, 41 O/4 AND 41 p/1. For description purpose, Segment-II has been further divided into A & B parts (Fig. 7), where in Segment II-A covers part of the study area that falls in the Survey of India Topographic Map Nos. 41 K/16, and segment II-B covers Survey of India Topographic Map Nos. 41 O/4 and 41 P/1.

SEGMENT-II-A

The area has exposures of Deccan Trap lava flows overlain by miliolitic limestone with an unconformity. A total of two lava flows were demarcated in the area. The lower most olivine basalt flow occupies a major part of the area. It is overlain by a greenish grey coloured glomeroporphyritic flow.

Though all the lava flows show northerly dips, at places, erratic dips due south or south-west were also observed. The erratic dips may be due to the irregularities of the palaeosurface on which the lava flowed.

The lava flows are intruded by a large number of basic and acidic dykes. The present area seems to be a dyke swarm area because over most of the area, the density of the dyke distribution is at least one dyke over a kilometer. The dykes trend E-W, NW-SW and N-S, belonging to more than one generation. They are basaltic, doleritic and micro-gabbroic in nature. Besides dykes, there are many N-S to NE-SW trending shear zones also. These are filled by chert veins and intruded by rhyolite dykes.

Base-metal mineralisation near Banej Nes in the present study area is associated with quartz vein as an epigenetic cavity filling along the fracture surfaces of a fault striking N 10^{o} E - S 10^{o}W, and dipping steeply towards either side on the Deccan Trap basalts. The mineralised zone, containing galena, chalcopyrite, bornite and malachite is about 3 m thick and extends discontinuously for a length of 340 m. The individual veins range from a few mm to 20 cm in thickness, as exposed in an old working (Shekar & Mukul, 1966).

The numerous dykes of different kinds, which cut across the country rock along definite directions, are "synvolcanic". They are believed to have intruded along the pre-existing fissures which probably served as channelways for the lava flows.

GEOLOGY

Geologically, the area is covered by Deccan Trap lava flows comprising basalts, which at places are weathered to black cotton soil. The lava flows are intruded by basic and acidic dykes. Deccan Trap flows are overlain by miliolitic limestone.

The generalised stratigraphic sequence of different rock units is as follows :

Recent	-----------	Soil	
Quaternary	-----------	Miliolitic limestone	
Lower Eocene to Upper Cretaceous		Deccan Traps --	Acidic intrusives Basic intrusives Basic lava flows (Flow-II Glomero-porphyritic basalt, Flow-I Olivine basalt

-------------------- BASE NOT SEEN ------------------------

A major part of the area is covered by olivine basalts, the balance being covered by tholeiitic basalts. In general, lava flows dip gently to the northwest. However, haphazard dips are also encountered in the area. In the absence of any marker horizon it was not possible to physically trace individual flows from one place to the other and to make any noteworthy stratigraphic correlations.

The surface of the lava flow tops wherever exposed, are smooth and rolling. At a large number of places, pipe amygdules are seen at the base of the lava-flows. Miliolitic limestones are exposed only in the southern most part of the area as low lying outcrops.

Description of the lava flows

In the study area a total of two basic lava flows were identified on the basis of grain size, mineral constituents, the size-shape and arrangements of phenocrysts, glassy matter in the rock, nature of amygdules, weathering colour and presence of pipe amygdules (Plate : 17). Based on the above mentioned criteria, the lava flows were demarcated only to some degree of accuracy. This was due to the fact that there were no visible marker-horizons in the area and the weathering surfaces between the different flows were altogether absent. The problem was compounded by the thick vegetation which inhibited the clean demarcation of flow boundaries.

The two lava flows discernible are as follows :

Flow-II Glomeroporphyritic basalt (Top)
Flow-I Olivine basalt (Bottom)

Both the flows are subhorizontal with gentle northerly dips. But there are small variations also, when the flows show haphazard or reverse dips.

Plate 17 - Pipe amygdules.

Plate 18 - Yellowish-brown coating over olivine-basalt flow.

FLOW-I

This is the oldest flow in the area, with exposures stretching right from north of Patla Mahadev to Lotha Nes, including Banej Nes, Panwadi Nes, Chhodaudi Nes, Vakumba Nes, and Hadala Nes at Babrot Dungar. The approximate maximum thickness of this flow has been estimated to be around 200 m.

Olivine basalt

This flow is medium grained and very dark grey in colour. The weathered surface is pitted,which may be due to the leaching out of some unstable minerals like olivine. Moreover, the weathered surface is covered by a yellowish-brown coating (Plate : 18) of limonite, formed by the oxidation of iron ore which is abundantly found in the rock. The amygdular portion of the same flow is more often weathered. The amygdules are spherical to irregular in shape, ranging in size from 2 mm to 10 mm. Plagioclase feldspar ranging in size from 1 to 6 mm are also seen. Plates of pyroxenes are also observed. Besides these, an appreciable amount of olivine grains are altered to reddish brown coloured iddingsite.

Petrography

Under the microscope, the rock is seen to be medium to slightly coarse grained and holocrystalline. Mostly, its texture is porphyritic and intergranular, but at places intersertal texture is also seen. Plagioclase feldspars are of two generations viz. as phenocryst and in the groundmass. The phenocryst plagioclase are idiomorphic and sometimes occur in clusters, and are mostly labradorite tending towards bytownite. The plagioclase in the groundmass are subhedral to anhedral, and compositionally are labradorite. The plagioclase are altered to sericite especially in the amygdular parts, where they are found mostly altered. Most of the plagioclase crystals are zoned. The other dominant phenocrysts are pyroxenes which are generally altered to pinkish yellow coloured iddingsite, giving a pinkish-grey colouration to the rock at places. The intergranular spaces are occupied by dirty green coloured volcanic glass which is devitrified and altered. Besides these, there are numerous euhedral crystals of ore, which sometimes occur as accessories.

FLOW-II

This flow is comparatively less exposed in the area, with the main exposures found to the south of Jambura Nes, north of Jamwali Nes and near Sap Nes on Banasur Dungar. The estimated maximum thickness of this flow is about 40-50 m.

Glomeroporphyritic basalt

This flow is medium to fine grained and glomeroporphyritic in nature. Megascopically, the rock is greenish grey (Plate : 19) in colour. The characteristic feature of this flow is that the fresh surfaces exhibit a greenish grey colour, and that it contains large sized (3-6 mm) phenocrysts of plagioclase, which often occur in clusters giving a star-like glomeroporhyritic appearance. Amygdules are often filled with silica. They are mostly spherical in shape.

Petrography

Under the microscope, the rock is seen to be fine grained with a porphyritic and inter-granular to intersertal texture. The characteristic feature of the section is that it shows numerous leucocratic clusters of plagioclase feldspar which at places make up the bulk of the rock. This feature of the rock is very conspicuous. In the groundmass, phenocrysts are mostly of labradorite. The megaphenocrysts are mostly altered to sericite. Pyroxenes occur as small phenocrysts and are mostly augite. Light brown coloured glass is seen altered to a greenish coloured mass.

INTRUSIVES

Dykes are the only major intrusions in the area. Minor intrusions of calcite veins occurring independently or along the margins of major dykes are common. One large gabbroic intrusive is also present.

Plate 19 - Greenish-grey coloured glomero-
porphyritic basalt.

Plate 20 - Joint pattern in dolerite dyke.

In general, the dykes are very abundant in the area. A major part of the area lying between Lat. 21^{o} 04′ - 21^{o} 15′, and Long. 70^{o} 45′ - 70^{o} 50′, constitutes a dyke cluster zone.

Only at one place, to the east of Chhodaudi Nes, a multiple dyke was seen. The dykes have intruded in more than one phase. This inference is drawn after seeing one set of dykes abutting against another set, and also from the lateral shifting of the earlier set across the younger set of dykes. Various sets of dykes seen in the area, trend E-W, NE-SW, NNE-SSW to almost N-S. It is observed that only some dykes out of one set of dykes are trending in some other direction, while the others do not. This fact shows that there is more than one phase of dyke intrusion trending in the same direction.

Three major types of dykes depending upon composition, have been recognised in the area. They are described below.

(i) Dolerite dyke

These are most abundant in the area, occurring mostly as depressions or as low outcrops. The width of these dykes vary from as much as half a meter to about six meters. Well developed joints parallel to the length of the dyke and also perpendicular to it are prominent in these dykes (Plate : 20).

The rock is very dark grey in colour, often weathered to a yellowish-brown colour, fined grained, with only needle shaped plagioclase laths being seen.

Petrography

Under the microscope, the rock shows a medium grained sub-ophitic to ophitic texture. At a few places clusters of euhedral plagioclase are seen. The dominant phenocrysts are of plagioclase (labradorite) and anhedral pyroxenes (augite). A minor amount of volcanic glass is present. Iron ore occurs as very small-sized crystals, but in large numbers.

(ii) Micro-gabbro dyke

This type of dyke is also abundant, and forms prominent landmarks in the area. These dykes stand out as resistant ridges thus protecting the adjacent basalt flows (Plate : 21), and are found occurring as arcuate dykes, often branching and rejoining.

Megascopically, the rock is light grey in colour and a little more coarser grained than the doleritic dykes. Phenocrysts of 2-3 mm sized plagioclase are seen. At a few places phenocrysts of some feldspar are also seen.

Plate 21 - Protruding micro-gabbro dyke.

Petrography

Under the microscope, the rock is medium grained with a holocrystalline texture. Plagioclase phenocrysts are seen to be highly fractured. Pyroxenes are mostly anhedral to subhedral augite which are highly twinned, and altered to iddingsite. Another mafic mineral seen in the section is hornblende which shows a slightly inclined extinction, and is pleochroic from pale yellow to brown yellow to dark brown. Iron ore occurs as very few, large sized grains.

(iii) Rhyolite dyke

These are abundant in the southern part of the area i.e. to the south of Bhuragala Nes and to the south of Khacharwala Nes. These are actually shear zones which are subsequently intruded by rhyolite dykes and filled in by chert veins (Plate : 22). This is evident from the shifting of basic dykes that cut across these rhyolite dykes. Moreover, breccia and vein fillings with chert and calcareous material is invariably seen along these dykes/shear zones. Since the chert veins and the rhyolite are very resistant to weathering, they invariably stand-out prominently. The ridges on which rhyolites are exposed, are having boulders of chert/rhyolite on both the sides, and the basalt flows are completely covered by these boulders. The width of these dykes varies from 3 to 4 m, and can be recognised from a distance because of their prominent bouldary outcrops.

Plate 22 - Sheared rhyolite dyke.

Megascopically, the rock is reddish brown coloured and very fine grained. It is massive at most of the places. But at a few places it contains 3-7 mm sized spherical amygdules which are filled with silica.

Petrography

Under the microscope, they are seen to be composed of a close-felted mass of quartz and feldspar.

MILIOLITIC LIMESTONE

In the southern part of the area, buff coloured calcareous conglomerate and miliolite limestones are exposed. The conglomerates are exposed only at a very few places, e.g. north of Soruda Nes in the nala bed. At most of the places, miliolite limestones are seen overlying Deccan Traps with a disconfirmity. Field observations have shown that miliolite limestones are found exposed upto a height of 200m and above. The general dip is towards the south, but at many places irregular dips are also seen. Karst topography is usually associated with exposures of miliolite limestone.

SOIL AND ALLUVIUM

Parts of the area are covered by alluvium, with the most notable areas being around Kalipat Nes and Kardapan. Besides that, throughout the area, rich black cotton soil is seen supporting the growth of vegetation.

STRUCTURE

(i) Flow dips

Inclination of lava flows is the most conspicuous structural feature observed in the area. In general, the flows dip towards the north at angles of 7°-9°. But the amount as well as the direction of flow dips vary markedly over the whole of the area. In the eastern part of the area, i.e. around Jeinagar Nes, Babrot Dungar, Hadala Nes and Jamwali Nes, the flows dip at angles varying from 7° to 11° in directions varying from N 40° E to N 70° W. In the southwestern extremity of the area i.e. north of Jamwala, the flows dip at angles of 9° due N 10° E. In the middle part of the area i.e. west of Sudava Nes, the flow dips 12° due northwest. Near Sap Nes, the flows dip about 8° due NNE. Besides these, erratic dips in directions opposite to the regular dip-pattern in the area are also seen, but are not suggestive of any folding in the area. Rather, these northerly dips may be the result of the uplift of the southern coast of Saurashtra, which is only about 40 km from the present area. The erratic dips may be a pointer to the undulation of the palaeo-surface on which the Traps were erupted.

(ii) Fractures

A large number of fractures are seen in the area. The first category of fractures are those along which dykes have intruded. These fractures are genetically related to the dykes. So the chronological sequence of the different sets of fractures is the same as those of the dykes which have utilized them as channels for intrusion. There are other fractures which have not been utilized by dykes as intrusion channels, may be due to their shallow occurrence. These types of fractures mostly trend N-S and NE-SW. All the three major rivers of the area viz. Adak Nadi, Machhundri River and Ghodavadi Nadi follow N-S trending fracture zones.

(iii) Faults

Numerous small faults are observed in the area, mostly trending N-S to NE-SW.

In many cases, dykes have intruded along supposedly pre-existing fault planes. This is evident from the shifting of the earlier faults, which are new dykes. This feature is observed along the dykes passing through Jadajambu Nes. The western blocks appear to have moved to the north relative to the eastern blocks. The shifting is approximately of around 50m.

(iv) Shear Zones

Several N-S to NE-SW trending shear zones are seen in the area. Shearing seems to have taken place after the intrusion of basic dykes, but prior to rhyolite dykes. The rhyolite dykes observed to the north of Ravta Nes have intruded along what were shear zones previously. This is evidenced by the presence, along the dykes, of numerous brecciated fragments of basalt and chert.

(v) Joints

Vertical to subvertical joints in the area could be observed only in the river sections having the following orientations:

E-W	: Vertical
NE-SW	: Vertical
NE-SW to WNW-ESE	: Vertical

Of all the sets mentioned above, the first one is the most prevalent and consistent, and seems to be related to the faulting that is observed in the area.

SEGMENT-II B

The rock types recorded include lava flows and intrusion bodies of Deccan Trap, soil and alluvium. The Deccan Trap lava flows are mainly composed of olivine basalt and glomeroporphyritic to porphyritic basalt. The upper and lower parts of the flows are amygdular, and such amydaloidal basalts are very susceptible to alteration / weathering.

Intrusion bodies in the form of dykes are composed of basic and acidic rocks. The basic dykes are doleritic in nature. The acid dykes consist of dacite and felsite.

The basic dykes are emplaced along three prominent directions viz. WNW-ESE, ENE-WSW and NE-SW. The acid dykes are generally emplaced along NNW-SSE and NNE-SSW directions.

GEOLOGY

The rock types recorded in the area are mainly Deccan Trap basaltic lava flows which are intruded by basic and acidic dykes. The lava flows are composed of olivine basalt, glomeroporphyritic to porphyritic basalt, which show a fair amount of alteration/decomposition, as evidenced by the greenish and brownish colour.

Because of the thick vegetation, difficult terrain, the fairly altered nature of the lava flows, patchy nature of exposures and the presence of a large number of dyke bodies, it has been difficult to recognise and trace the physical continuity of different flow units. As a result, a large part of the area has been merged into a single olivine basalt flow in the map and has been considered as "unclassified basalt" (Fig. 7).

The above lava flows are amygdular, apparently at the top and bottom of the flows, though good sections are not exposed in the area for illustration. However, a certain degree of inhomogenity of the lava flows is found in terms of concentration and sizes of the phenocrysts.

The general succession in the area is given below :

Sub - Recent to Recent	Soil and alluvium	
Lower Eocene to Upper Cretaceous	Basic and acidic intrusives Basic lava flows	 (Flow-II Glomero-porphyritic basalt. Flow-I Olivine basalt.)

------------------------BASE NOT SEEN------------------------

Description of the lava flows

The lava flows are generally sub-horizontally disposed, but at some places they show southerly dips, as found in the area north of Tulsishyam. The hilly terrain, alongwith the presence of a large number of intrusive bodies posed a problem in demarcating the different lava flows in the area. This problem was further accentuated by the alteration of lava flows to varying degrees, giving rise to different shades of colour, ranging from light yellowish green to pinkish brown. All the lava flows are, however, sub-aerial in nature.

FLOW-1

Olivine basalt is the predominant basaltic flow in the area, both in the low lying and hilly regions.

Olivine basalt

The rock is generally dark grey to black in colour, fine grained to aphanitic in nature (Plate : 23). These flows are fairly altered and it is difficult to differentiate different types of lava flows on the basis of study of handspecimens. In the southern part of the area they occupy the low altitude areas and are overlain by glomeroporphyritic to porphyritic basalts.

Megascopically, the olivine basaltic rocks are dark grey to black in colour and fine grained to nearly aphanitic. Amygdaloidal cavities, when present, contain dark green chloritic material, calcite and secondary silica.

Petrography

Under the microscope, the thin section of the specimen shows that the rock is microporphyritic with phenocrysts of plagioclase (labradorite) and thoroughly altered olivine (with a ferruginous border), plagioclase phenocrysts are also largely altered, with release of calcite. The groundmass is fine-grained and composed mainly of fine microlites of

Plate 23 - Grey to black coloured olivine basalt.

Plate 24 - Dark brown to black coloured basalt.

labradorite and augite. Some amount of basic glass and a little amount of fine grains of iron-oxides are also present. Clinopyroxene granules in the groundmass are altered; they usually have a ferruginous grain boundary and are partially replaced by calcite. Besides the microporphyritic nature of the lava, the groundmass texture is basaltic.

FLOW-II

Exposures of glomeroporphyritic basalts are found in the north-eastern part of the area. They are underlain and overlain by fine grained basaltic rock which is both non-porphyritic to poorly porphyritic.

Glomeroporphyritic to porphyritic basalt

Megascopically, the rock is dark brown to black in colour (Plate : 24), fine to very fine-grained, with small phenocrysts of plagioclase feldspar, often clotted together (about 2mm in diameter), thus giving the rock a very characteristic look, particularly on its weathered surface. The lava generally contains circular to oval amygdules, filled with agate, calcite and secondary silica. At places where the lava becomes rich in amygdules, the concentration of the plagioclase phenocrysts reduces considerably. The size of the phenocrysts also vary.

Petrography

Under the microscope, the rock is composed of small phenocrysts of plagioclase (labradorite), and altered olivine. The texture is medium-fine grained, glomeroporphyritic to porphyritic. The groundmass is fine to medium grained, with fine laths of plagioclase (labradorite) and small granules of clinopyroxene (pale brownish augite). Fine, subhedral to anhedral grains of iron-oxide is common, basic glass (charged with fine dots of iron-oxide) being less common in the groundmass. Small patches of secondary calcite and also chlorite are very common. Minor amount of limonitic material is present.

INTRUSIVES

The lava flows described above are intruded by basic and acidic dykes, with the former being predominant. The intrusives are mostly in the form of linear dykes. A few arcuate dykes are also recorded. The most prominent direction of the emplacement of basic dykes is along a WNW-ESE to E-W direction. The other important directions are, however, due ENE-WSW, NNE-SSW, NNW-SSE, NE-SW, and NW-SE. Acidic dykes in the area are comparatively few and these are mostly aligned along a WNW-ESE direction, though a few of them are emplaced along ENE-WSW and NNW-SSE directions. Besides these, small to very small basic dykes, aligned in all the directions memtioned above are also recorded.

Basic dykes

A large number of basic dykes are found to have been emplaced within the lava flows. They vary in their length from 250 m to more than 6 km. The basic dykes are mainly olivine basalt /dolerite, fine to medium grained dolerite, porphyritic basalt/dolerite, light coloured dolerite dykes and basaltic dykes.

(i) Olivine basalt / dolerite dyke

The olivine basalt / dolerite dykes are generally short in length and are emplaced in all the directions as mentioned above. One such thick and fairly large dyke is found about 500 m east of Jambudi Nes (Plate : 25). The rock is black in colour and fine to coarse grained. The weathered surface of such rocks are also characterised by dark brown, pitted encrustations.

Petrography

Under the microscope, the rock is medium grained and highly porphyritic with frequent phenocrysts of olivine and occasional pale brownish clinopyroxene (augite). The groundmass of the rock is fine-grained, and composed mainly of fine laths and microlites of plagioclase feldspar (labradorite) and pale brownish clinopyroxene (augite). Minor amounts of small euhedral to subhedral grains of iron-oxide are also present. Small to large anhedral patches of greenish chloritic material are common in the groundmass. Labradorite is comparatively more abundant than augite in the groundmass. Olivine phenocrysts are fairly fresh with minor alteration to chlorite and ferruginous material. The groundmass textures of the rock are mainly intersertal and also sub-ophitic to ophitic.

(ii) Fine to medium grained dolerite dyke

Fine to medium grained dolerite dykes are quite common in the area. Megascopically, the rock is generally dark grey in colour, non-porphyritic to poorly porphyritic in nature.

Petrography

Under the microscope, the rock is medium to fine grained, poorly porphyritic, with occasional to rare, small phenocrysts of plagioclase feldspar (labradorite) and pale brownish clinopyroxene (augite) in subequal amounts. Small grains of euhedral to subhedral iron-oxide form a minor part of the rock. A little amount of alkali feldspar, often cryptographic with minute quartz grains are found in the interstitial spaces. Rare anhedral patches of secondary calcite are present-occasionally associated with the alteration of augite. The textures of the rock are intergranular and also subophitic to ophitic.

(iii) Porphyritic basalt / dolerite dyke

Porphyritic basalt/dolerite dykes are not very common in the area. Wherever present, the rock is dark grey, fine to medium grained and fairly to highly porphyritic. One such dyke located about 3 km SSW of Jambudi, trends N 50^o E - S 50^o W.

Petrography

Under the microscope, the rock is medium to fine grained porphyritic with phenocrysts of plagioclase feldspar (labradorite) and occasional to rare, clinopyroxene (pale brownish augite). The plagioclase feldspar partially encloses clinopyroxene (augite), and clinopyroxene (augite) encloses laths of plagioclse feldspar, sub-ophitically. The groundmass of the rock is fine to medium grained, and composed of fine laths of plagioclse (labradorite) and small grains of clinopyroxene (pale brownish augite) in sub-equal amounts.

Minor amounts of subhedral to euhedral grains of iron-oxide are also present. The augite marginally alters to amphibole (hornblende-pleochroic from pale yellow to green) and greenish chlorite. Secondary brownish -green chloritic material is found in the groundmass in minor amounts.

Plate 25 - Olivine basalt/dolerite dyke.

Plate 26 - Grey coloured dacite dyke.

Groundmass textures are intergranular and also subophitic to ophitic.

(iv) Light coloured dolerite dyke

Light coloured dolerite dykes have a preferred orientation, usually along a WNW-ESE direction. The long dyke lying about 500 m north of Tulsishyam is grey in colour, and fine to medium grained.

Petrography

Under the microscope, the rock is medium grained intergranular, often sub-ophitic, composed mainly of plagioclase feldspar (labradorite) and clinopyroxene (pale brownish augite). Medium sized euhedral to subhedral grains of iron-oxide are present in minor amounts. Small amounts of micrographic intergrowth of quartz-alkali feldspar are found in the interstitial spaces. Clinopyroxene (augite) alters to brownish -green biotite, amphibole (hornblende pleochroic from pale yellow to pale green) and rarely chlorite.

Acidic dykes

The acidic dykes form a minor population when compared with the freuquency of the basic dykes in the area. Two types of acidic dykes were recognised in the area, viz. dacite and felsite, and are described below.

(i) Dacite dyke

The dacite dykes are somewhat dominant amongst the acid dykes. Megascopically, they are grey in colour and porphyritic, with small to very small phenocrysts of feldspar (Plate : 26). A typical dacite dyke is found about 250 NW of Jambudi.

Petrography

In thin section, the rock is medium to fine grained, porphyritic with phenocrysts of plagioclase feldspar (highly saussuratised), and occasional to rare microphenocrysts of pyroxene (thoroughly altered to chlorite and largely replaced by calcite). The groundmass is very fine-grained and composed mostly of very fine laths and microlites of plagioclase feldspar set in a felsitic mass. Some amount of small anhedral quartz and a little amount of thoroughly altered pyroxene (altered to chlorite with fine dots of iron oxide enclosed) are also present. Besides, small patches of anhedral secondary calcite, and less frequently greenish chlorite are common. Minor amounts of small to fine grains of iron-oxide and needles of apatite as accessory, are also present. A few drusy cavities are filled with calcite and rarely quartz.

(ii) Felsite dyke

The dykes of felsite porphyry rocks are common among the acid dykes. Megascopically, they are dirty grey (with a greenish tinge) in colour and rarely aphanitic (Plate : 27). Small phenocrysts of feldspar are seen clotting together along with infrequent pyroxene grains.

Petrography

The thin section reveals that the rock is highly porphyritic, with phenocrysts of plagioclse feldspar and a much less common ferromagnesian mineral (clinopyroxene ?), thoroughly altered to greenish chlorite. Fine flakes of brownish biotite are also seen. The groundmass is mainly composed of a micrographic intergrowth of quartz and alkali feldspar. Small iron-oxide grains are also present. Secondary greenish chlorite and biotite are present in the groundmass as micro-constituents. Occasionally, small grains of plagioclase and rarely quartz are found at the cone of micrographic intergrowths of quartz and alkali feldspar.

MILIOLITIC LIMESTONE

In contrast to the study area in segment II-A, fieldwork has revealed that miliolite is not found in this part of the study area.

Plate 27 - Dirty grey coloured felsite dyke.

SOIL AND ALLUVIUM

Most of the area is covered by reddish / black cotton soil. Alluvium is found along the river banks in some parts of the area.

STRUCTURE

The general dip of the lava flow in the area could not be precisely measured because of lack of good exposures and frequent interference by the intrusive bodies. However, it is somewhat clear that the lava flows show a general southerly dip at a very low angle of about 10^{o}.

The area is highly intruded by dykes trending in two prominent directions viz. WNW-ESE and NE-SW. However, dykes trending in other directions are also found.

Due to paucity of exposures in areas of dyke junctions, the relations of dyke-emplacement could not be properly understood. In one intrusive, an E-W basic dyke has cut across an acidic dyke trending NW-SE, but when this basic dyke is followed, it is found that the western end of the basic dyke swings in a WNW-ESE directin, and this is cut across by another acidic dyke trending ESE-WSW. If only this occasion is considered, it can be inferred that there must have been a time gap between the emplacement of the acid dykes into two directions i.e. the NW-SE acidic dyke must be older than the ENE-WSW acidic dyke.

TECTONIC INTERPRETATION OF THE STUDY AREA

Saurashtra peninsula consists of rocks of Mesozoic, Deccan Trap, Tertiary and Quaternary ages. The Mesozoic rocks comprise ferruginous sandstones occasionally conglomeratic, limestones and shales. These in turn are unconformably overlain by the Deccan basalts which have been intruded by basic dykes and plutonic plugs at the end of the volcanic activity. These Trappean rocks have sufferred from extensive chemical weathering forming lateritic caps over the plateau prior to the extensional rifting of the region, when the Cambay basic was developed (Babu, 1981; Sychanthavong and Patel, 1987). The Tertiary rocks were deposited in the rifted areas from Upper Eocene onwards and are lying unconformably over the laterite horizon, and at places on the lignite seams. The Quaternary sediments include the miliolitic limestones, both aeolian and marine, of Pleistocene age, and loose alluvium and residual soils of Holocene age, lying unconformably over Mesozoic, Deccan Trap and Tertiary rocks.

Tectonically, Saurashtra peninsula has got imprints of several tectonic episodes since Mesozoic times. Tectonics and geodynamics are inter-related processes and attributed to the crustal instability that has (and is being) occurred periodically in this region. Submergence of the land and incursion of the sea into inland areas by rifting processes, and emergence of the land by differential uplift and tilting processes occured in the past in this region, as evidenced by the deposition of the Mesozoic and Tertiary rocks which were later uplifted to the present position of the landmass. The occurrence of marine miliolite limestones at different heights also indicates differential uplifts and tilting of the Saurashtra peninsula. When there are such differential and tilting uplifts, there has to be faulting between the uplift and sinking blocks. The study of these faults, major as well as minor, is equally important in deciphering various events of tectonic instability of the region.

To decipher the complete picture of tectonic activity of the Saurashtra region, a critical evaluation of the available data pertaining to the various known existing regional faults is essential. This is so, because the adjacent or parallelic smaller fractures were developed on account of the reactivation of these major faults during Tertiary and Quaternary tectonic episodes (Sychanthavong, 1984). The Gir forest area represents the zone of minor fracture intersection and is quite close to the intersection zone of the major fractures. The major fractures are the extensions of the Narmada geo-fracture which runs a few kilometers inland and parallel to the southern coast of Saurashtra (Crawford, 1978), the offshore-west coast fault system

(Sengupta, 1967; Kaila et al., 1981), and the Western Boundary Fault of the Cambay Basin. The first two major fractures intersect each other to the south of the Gir forest area. All the minor fractures recorded in the study area have been developed in the later stages of reactivation of these major faults. Several springs are located on the intersection points of these fractures. Many streams and rivers follow the fracture zones as shown in the regional tectonic map (Fig. 6), and also in the present tectonic map of the study area (Fig. 8).

Judging from the lineament map (tectonic map) of the study area, prepared from satellite images and air photos, it is proved that the Gir forest area is highly fractured and most of the linear features traced on the map represent planar structures. Such linear features taken into account are - segments of aligned offsets of several adjacent streams, aligned ends of consecutive ridge spurs, anomalous alignment of groups of continuous ridge crests with alternate straight reaches of streams, aligned tributaries over long distances, aligned saddles in ridges, aligned gullies across the ridges which are occupied by dykes, fault scarps having sedimentary fans, etc. Almost all these linear features have been proved to be not only faults but many of them are master joints as per the observations made during field checking by the present author. The WNW-ESE trending faults have been developed parallel to the offshore major fault system. The

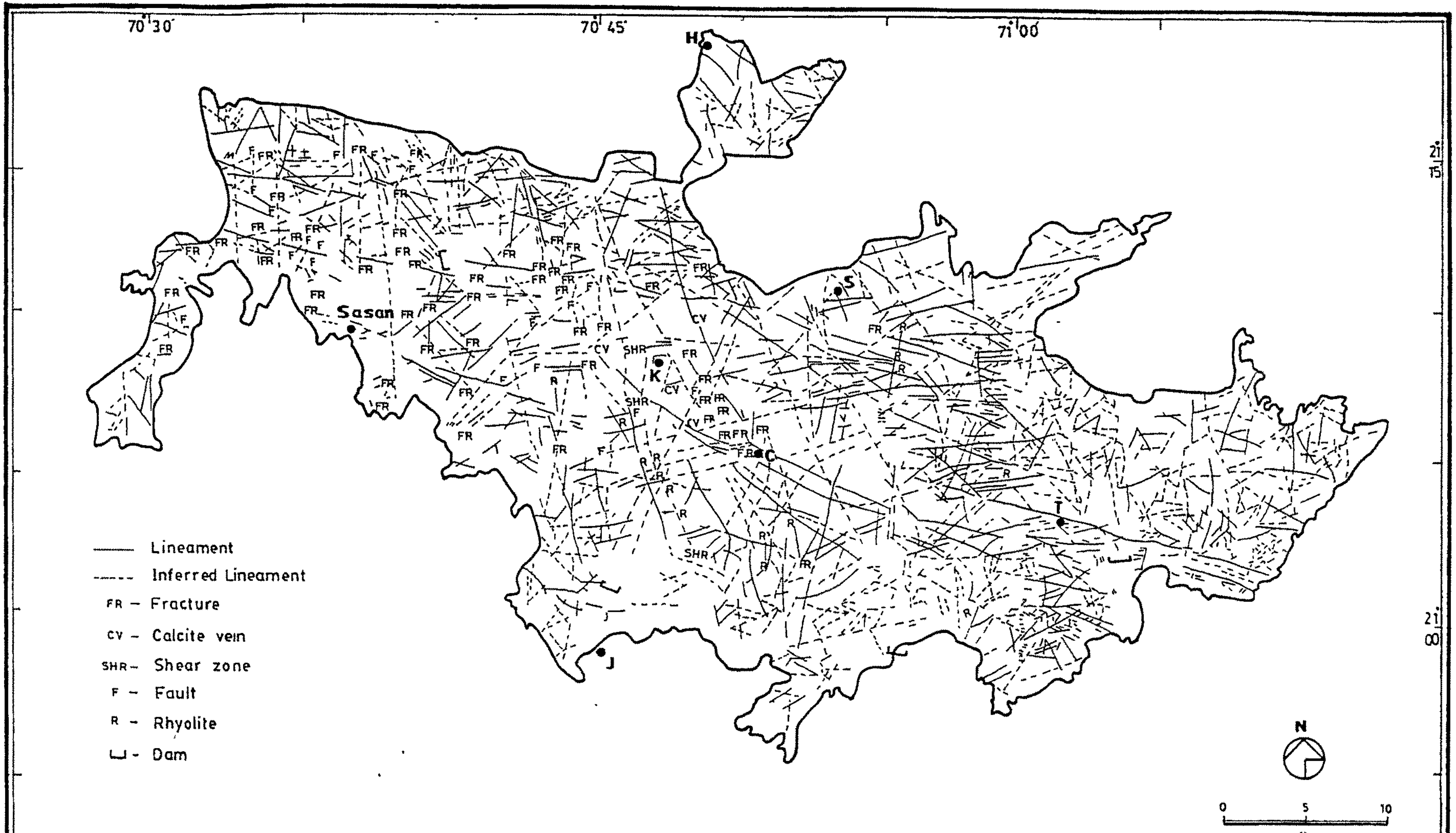

FIG. 8 TECTONIC MAP OF THE GIR AREA

ENE-WSW trending faults have been formed parallel to the Narmada and Dadar faults extending from the mainland Gujarat into Saurashtra, and the N-S fault of the Cambay Basin. The latter is less prominent because the study area is located quite far away from the N-S trending Cambay Basin tectonic regime. All these trends are revealed in the rose diagram representing these fractures (Fig. 9).

Sychanthavong (1984) has classified these fractures in terms of their dimensions, as first generation (primary regional faults described above), second generation (areal fractures), third and fourth generations (local fractures). The first and second generations of faults are Pre-Tertiary in age, developed in the Late Palaeozoic or Early Mesozoic times, since they occur as boundary faults of the Mesozoic and Tertiary sedimentary basins. None of these faults are passing through the study area, except the Dadar fault. The Narmada fault runs just a few kilometers to the south of the study area. The influence of these two major faults (Narmada and Dadar) reflects prominently in the development of the third and fourth generations of faults in the study area as revealed in the rose diagram (Fig. 9). It is easy to visualise that at any one time in the past, the Saurashtra landmass had been twisted, as it is bounded by several fault system on all sides (Sychanthavong, 1984). Any activation of the fault zones would have reactivated the major fractures as is evidenced by rock failure in the near vicinity. The

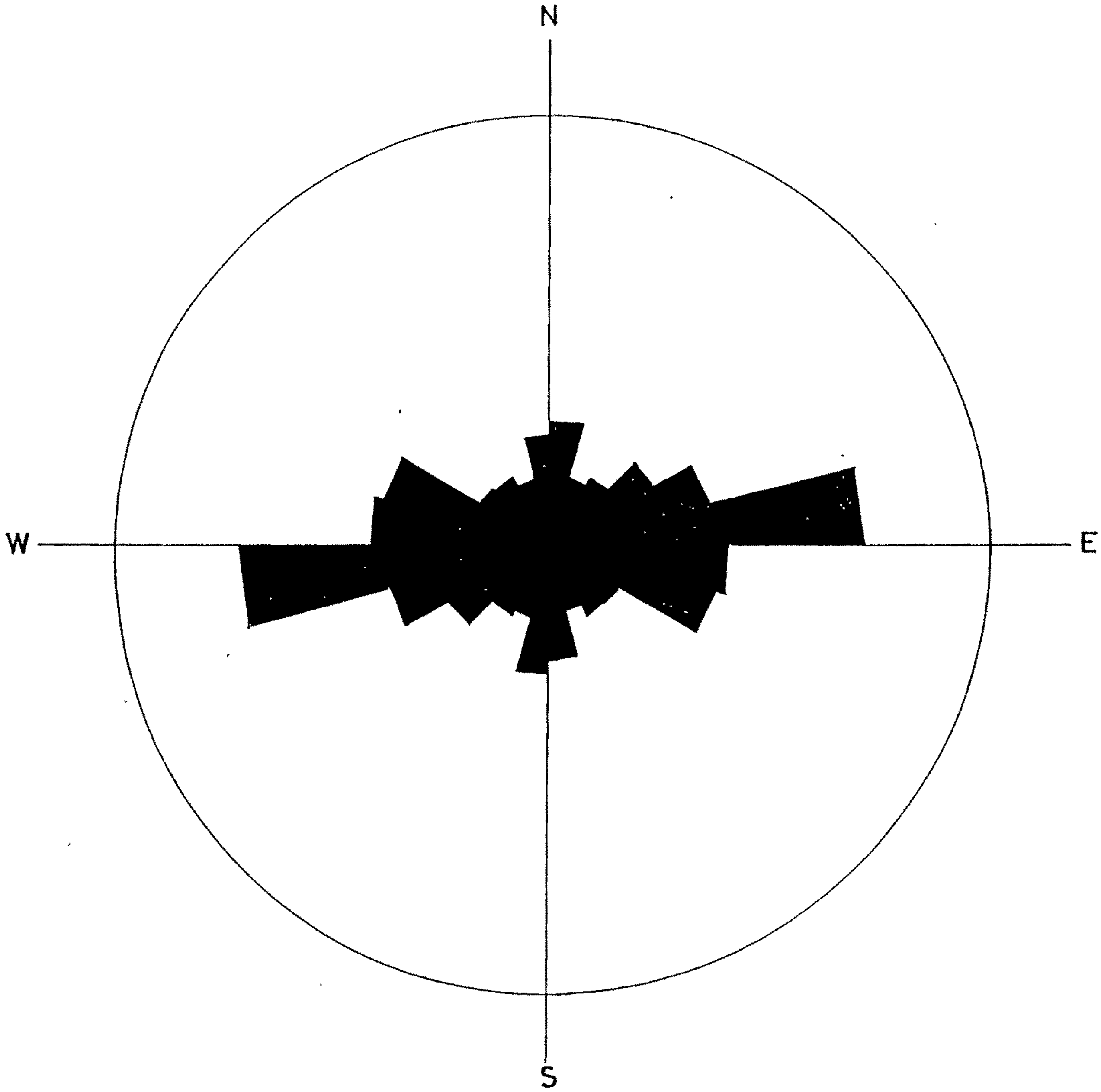

FIG. 9. ROSE DIAGRAM OF THE GIR AREA

concentration of minor faults in the study area reflects such type of tectonic acitivity in the region; the frequency of fractures increase with major fault reactivation. These fractures control the rate of rock erosion and weathering.

Fractures and rock erosion

An attempt has been made in correlating the above described fractures and rock erosion in the study area. It is found that fractures do control rock erosion, especially along intersection zones, where rocks have been sliced into pieces and exposed to fluid dynamics, which in turn control the decompositon of rock-forming minerals. It is also found that the overall slope of the Saurashtra plateau controls the acceleration of such erosion / weathering of rocks in the area, generally speaking. Several depressions in the Gir forest are found to have been formed by this process of erosion. It is also found that the compositon of Deccan Traps also helped in the acceleration of such erosion. Wherever the fractured flows consisted of more calcic plagioclase as compared with mafic silicate minerals, the calcic plagioclases were seen highly decomposed. The weathering of the in-situ deposited ferro-magnesian silicate minerals form a red residual soil horizon, sporadically found in the study area. This process has assisted in the widespread growth of vegetation in the study area as a whole.