CHAPTER - III

G E O L O G I C A L C O N S I D E R A T I O N

OUTLINE OF GEOLOGY OF GUJARAT

GEOLOGY OF SOUTH GUJARAT

GEOLOGY OF THE STUDY AREA

G E O L O G I C A L C O N S I D E R A T I O N

OUTLINE OF GEOLOGY OF GUJARAT

The geological and tectonic diversity of Gujarat is unique in many ways. One comes across within its limits, geological formations of different stratigraphic ages. Although nowhere in Gujarat a total and complete geological sequence is encountered, but by integrating the geological sequences as observed in the different parts of state, one happens to reconstruct a very interesting geological picture, with rocks ranging in age as old as Proterozoic to as young as the most recent Quaternary. The geological diversity of Gujarat reflects the tectonic framework of this part of West Coast and which, as will be seen in the subsequent pages of this thesis, has important bearing on the morphotectonics of South Gujarat. Therefore to provide an appropriate background to the present study, the author has given a brief outline of the geology of Gujarat.

On the basis of geology and geomorphology, Gujarat can be divided into following three main units :

i) The Mainland Gujarat
ii) The Saurashtra Peninsula, and
iii) The Kutch.

The Mainland Gujarat extends from Ambaji in the north to Umbargaon in the south and comprises rocks ranging from Precambrian Banded Gneissic Complex to Recent deposits. The

Saurashtra peninsula is bound on three sides by sea except in the northeast, where it is flanked by the alluvial plains of the Mainland Gujarat; its rocks range from Juro-Cretaceous (sedimentary and volcanic) to Recent coastal deposits. The Kutch region forms the northwestern part of the Gujarat state, its northern limit is marked by the international border with Pakistan. To the south and west of Kutch lies the Arabian sea while in the east it is bounded by the Rann of Kutch. The rocks of Kutch show a fairly wide geological range. Over a Pre-cambrian basement rests a striking and almost unbroken Mesozoic (Jurassic-Cretaceous) and Cenozoic (Tertiary-Quaternary) sedimentary sequence.

Detailed mapping by various agencies, viz. the Geological Survey of India (GSI), the Geology and Mining Department of Gujarat (DGM), Oil and Natural Gas Commmission (ONGC), and the subsurface geological and geophysical investigations by the ONGC and the National Geophysical Research Institute (NGRI) have greatly updated and filled in valuable gaps in the geological knowledge of Gujarat. The details of the various formations occurring in the three units (Fig.III.1) are summarized in the accompanying table (Table III.1). Within a relatively small areal extent comprising the state of Gujarat, its three main constituent units show considerable geological and structural diversity, pointing to evolutionary histories for each unit, quite distinct from one another.

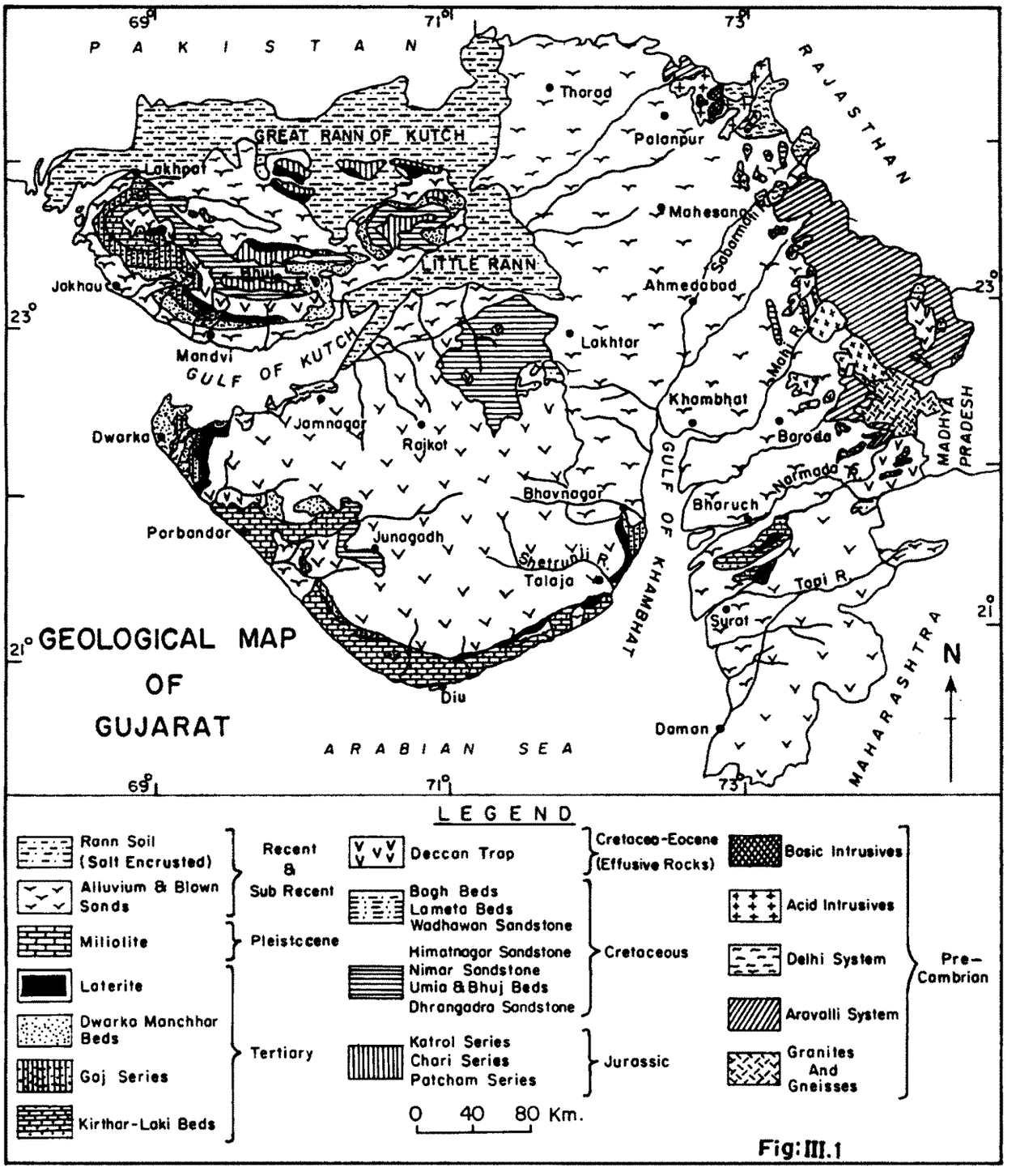
69°
71°
73°
PAKISTAN
RAJASTHAN
Thorad
Palanpur
GREAT RANN OF KUTCH
Lakhpat
Mahesana
Sabarmati R.
LITTLE RANN
Bhuj
Jokhau
Ahmedabad
23°
Lakhtar
Mandvi
GULF OF KUTCH
Mahi R.
Khambhat
Jamnagar
Rajkot
Dwarka
Baroda
MADHYA PRADESH
GULF OF KHAMBHAT
Narmada R.
Bhavnagar
Bharuch
Porbandar
Junagadh
Shetrunji R.
Talaja
Tapi R.
Surat
21°
GEOLOGICAL MAP OF GUJARAT
Diu
MAHARASHTRA
N
Daman
ARABIAN SEA
LEGEND
Rann Soil (Salt Encrusted)
Alluvium & Blown Sands
Miliolite
Laterite
Dwarka Manchhar Beds
Goj Series
Kirthar-Laki Beds
Recent & Sub Recent
Pleistocene
Tertiary
Deccan Trap
Bagh Beds
Lameta Beds
Wadhawan Sandstone
Himatnagar Sandstone
Nimar Sandstone
Umia & Bhuj Beds
Dhrangadra Sandstone
Katrol Series
Chari Series
Patcham Series
Cretaceo-Eocene (Effusive Rocks)
Cretaceous
Jurassic
Basic Intrusives
Acid Intrusives
Delhi System
Aravalli System
Granites And Gneisses
Pre-Cambrian
0 40 80 Km.

Fig: III.1

Table:III.1 GENERALISED STRATIGRAPHIC SUCCESSION OF GUJARAT

GEOCHRONOLOGIC UNIT		MAINLAND GUJARAT		SAURASHTRA		KUTCH	
PERIOD	EPOCH	FORMATION	LITHOLOGY	FORMATION	LITHOLOGY	FORMATION	LITHOLOGY
QUATERNARY	HOLOCENE	ALLUVIUM	NEOALLUVIUM, MUDFLATS, BEACHES DUNE SANDS & SOILS	ALLUVIUM	ALLUVIUM, MUDFLATS, BEACHES AND DUNESANDS SOILS	ALLUVIUM	ALLUVIUM, SANDS & CLAY, SOILS RANNCLAYS ETC
	PLEISTOCENE	OLDER ALLUVIUM & LATERITIC ROCKS	SANDS & CLAYS, ALLUVIUM, LATERITES	AGATE CONG AND SANDSTONE MILIOLITE	AGATE CONGLOMERATEAND ASSOCIATED SANDSTONES CALCARENITE, CALCRUDITE WITH INTERCALATION OF CLAYS	MILIOLITE FORMATION	CLAY ARENITE AND OOMICRITES
TERTIARY	PLIOCENE			DWARKA FORMATION	SILTY CLAYS, GYPSIOUS CALCAREOUS CLAYS & MARLS, ARENACEOUS LIMESTONE FOSSILIFEROUS CONGLOMERATES	KANKAWATI SERIES	SANDSTONES, FOSSILIFEROUS CALC-GRITS AND CONGLOMERATES WITH SHALES
		JAGADIA FORMATION	CALCAREOUS AND MICACEOUS SANDSTONES AND SANDS	PIRAM BEDS	GRITS AND SANDY CLAYS SANDSTONE & CONGLOMERATES		
	MIOCENE	KHAND FORMATION	LIMESTONES & FERRUGINOUS AGATE CONGLOMERATES	SAJ FORMATION	FOSSILIFEROUS GRITS, GYPSEOUS CLAYS WITH THIN BANDS OF LST	KHARI SERIES	GRAY CLAY WITH FOSSILIFEROUS MARL, VARIAGAIED SILTSTONES
		TARAKESWAR FORMATION	SILTY CLAYS WITH LENSES OF LATERITES				
	OLIGOCENE					BERMOTI SERIES	SILTY SHALE, MARL, SANDS, LIMESTONES, CALC-CLAYS & SHALES
	EOCENE	NUMMULITIC FORMATION	FERRUGINOUS CLAYS & LIMESTONE WITH BENTONITIC BANDS			BERWALI SERIES	LIMESTONES CLAYS LATERITES LIGNITE AND BLACK SHALE
		VAGAD-KHOL FORMATION	TRAP WASH, FERRUGINOUS SANDSTONE	LATERITIC ROCKS	RED BROWNLATERITES, BAUXITE TUFFACIOUS MATERIAL	MAD SERIES	LATERITES, TUFFACIOUS SHALES, BENTONITIC CLAYS VOLCANIC ASHES
	PALEOCENE	DECCAN TRAP	BASALTS WITH ALL ALKALINE VARIETIES & DYKES	DECCAN TRAP	BASALTS, PLUTONIC MASSES AND DYKES, THIN INTERTRAPPEAN BANDS	DECCAN TRAP	MASSIVE BASALTS & AMYGDOLOIDAL BASALTS WITH INTERTRAPPEAN BEDS
CRETACEOUS		INFRATRAPPEAN LAMETA BEDS	SANDSTONE	WADHWAN SANDSTONE	SANDSTONE WITH INTERCALATION OF CLAYS		
		BAGH BEDS	LIMESTONES & SANDSTONE				
		HIMATNAGAR SANSTONE	SANDSTONES	DHRAGADHRA FORMATION	SANDSTONE GRITS CARBONACEOUS SHALES WITH COAL & PLANT REMAINS	BHUJ FORMATION	SANDSTONES CONGLOMERATES AND SHALES
JURASSIC						JHURAN FM	SANDSTONES AND SHALES
						JUMARA FM	SHALES & LIMESTONES WITH OOLITIC BANDS
						JHURIO FM	LIMESTONES
PRE CAMBRIAN		ERINPURA GRANITE	ULTRABASIC, BASIC AND ACIDIC INTRUSIVES				
		DELHI SYSTEM	QUARTZITES PHYLLITES AND SCHISTS				
ARCHEAN		CHAMPANER SERIES (ARAVALLI SYSTEM)	GRANITES PHYLLITES, SCHISTS, DOLOMITES, QUARTZITES				
		BANDED GNEISSIC COMPLEX	GRANITIC GNEISSES AND MICA SCHISTS				

(Compiled after Krishnan, 1982; Shrivastava, 1963; Biswas 1971)

The terrain of Mainland Gujarat shows a very interesting diversity in terms of geology and geomorphology. It's various geological formations have imparted a fascinating panorama of landscape, thereby producing varied assemblages of landforms. The northeastern and eastern parts of Mainland comprise a mountainous terrain made up of Precambrian metasediments and associated granites. The hilly tracts along the southeastern boundaries of the state, are marked by dissected lava flows of Deccan basalts. The central parts of the state are made up of vast plains of Quaternary deposits, within which occur Mesozoic and Tertiary rocks as inliers. Deccan basalt, in Gujarat, though not so widely exposed, provides an ideal basement over which the petroliferous Cambay Tertiaries have been deposited. The Saurashtra peninsula is characterised by a basaltic tableland, the coastal fringes of which are overlain by Tertiary and Quaternary rocks. The Kutch peninsula is an important site of Mesozoic rocks, over which the Deccan Trap lava flows occur.

The three geomorphic - geologic units are obviously the reflections of the regional structural and tectonic framework. All throughout, crustal tectonics have caused subsidences, uplifts, tilting of blocks, and these were affected by marine transgressions and regressions. Diastrophic movements along a few major lineaments have acted differently in the three units thereby giving rise to quite distinct geological and geomorphic features for each of them.

Tectonically too, the area of Gujarat is complex, wherein various forms of positive and negative structures have originated allthroughout its protracted geological history. The northeastern part of Gujarat exhibits Precambrian, Delhi and Aravalli foldings. Tectonically controlled ridges and depressions are seen in the Kutch and Banni areas, which provide a good instance of Mesozoic upheavals. Saurashtra encompasses a large part of western Gujarat and is seen bounded by major fractures. The North-South trending Cambay graben is located in the central part. A principal deep-seated geofracture is indicated along the trend of the Narmada river extending WSW, cutting across the Mainland and extending along the southern margin of Saurashtra through the Gulf of Cambay. Various major and minor faults are also indicated trending ENE-WSW up to Surat and beyond.

According to ONGC work Biswas (1987), the older structural trends which cut across the centrally located Cambay graben are of mainly Delhi folding. The younger structural trend of Broach Surat area consists of WSW structural trends of Narmada Tectonic Belt. These older and younger structural trends cut across in Gujarat area, and give a varied look to the structure and tectonics, and generate interesting geomorphological expressions that reveal evidence of neotectonic activities involving Quaternary sediments.

GEOLOGY OF SOUTH GUJARAT

South of Narmada river, the geological formations range from Cretaceous to Holocene and nowhere older rocks are reported to occur whether on-surface or in sub-surface. Geologically, the South Gujarat has evolved with the break up of the Gondwanaland. Sedimentation and volcanism initiated, during early Cretaceous with the marine transgression along the Narmada geofracture gave rise to the equivalents of Bagh beds. Subsequent events comprised Deccan volcanism and development of the Cambay basin (Cambay and Narmada-Tapi grabens) which became the site of the Tertiary sediment accumulation. Quaternary deposits are equally well-developed and mostly comprise alluvial accumulations and coastal marine deposits. Based on the data available mostly from ONGC, a stratigraphy as shown in Table III.2 has been put forth :

TABLE III.2 STRATIGRAPHY OF SOUTH GUJARAT

QUATERNARY	Recent	Coastal sands, mudflats, alluvium, soils, etc.
	Sub-Recent	Raised beaches, mudflats, alluvium, soils, etc.
	Middle to Upper Pleistocene	Older Alluvium
TERTIARY	Middle Miocene	Jhagadia Formation
	Lower Miocene	Kand Formation
	Lower Miocene	Babaguru Formation
	Oligocene	Tarkeshwar Formation
	Middle Eocene to Upper Eocene	Ankleshwar Formation
	Paleocene to Lower Eocene	Vagadkhol Formation
	Paleocene	Laterites
	Cretaceo - Eocene	Deccan Trap basalt
	Cretaceous	Bagh beds (occurring to the NE portion of the area)
	Precambrian	Not exposed

BAGH BEDS

Strata of Cretaceous age are observed in a series of outcrops in South Gujarat, mainly all over the lower Narmada Valley. The Bagh beds are seen outcropping as isolated patches, either resting over the Precambrians (to the north of Narmada) or as inliers within the Deccan trap. The maximum thickness of the Bagh Group is around 700 m and is divisible into upper and lower, the lower part is arenaceous while the upper is mainly calcareous. Ray (1981) has designated these horizons as distinct formations, namely Songir and Uchad, respectively. The songir Formation is chracterised in its lower parts by a medium to fine grained sandstone sequence, mostly cross bedded and the upper one being finegrained ripple marked sandstone. The Uchad Formation, the upper calcareous unit of the Bagh group, conformably overlies the Songir formation and is in turn, unconformably overlain by the Deccan Trap. The lower part of the Uchad formation is characterised by an alternating sequence of hard, oyster-embedded beds and the upper part is made up of well bedded nodular limestone.

DECCAN TRAP

The basaltic lava flows of the Deccan Trap constitute the major rock formation of South Gujarat. These trappean rocks comprise horizontal lava flows and cover a large portion of the area. They are compound flows and each flow unit consists of different subflows. Due to variation in hardness of the

different flows, and of parts of the flows, the trap show flat-topped hills. The traps attain their maximum elevation near the border of Gujarat and Maharashtra, i.e. Dangs area. Here they show escarpments of about 1200 m height. Lava-flows comprise dark grey basalts of several varieties, quite often amygdaloidal and / or porphyritic, the trappean rocks are highly jointed showing several sets, mainly ENE-WSW, to E-W and NNE-SSW to N-S directions. Intrusive dykes within the basalts are quite common, and show ENE-WSW, N-S and NW-SE trends (Blandford, 1869; Krishnamacharlu, 1972; Krishnan, 1982).

The traps weather with a characteristic spheroidal exfoliation which gives rise to large rounded boulders on the outcrops. Another product of weathering is laterite, a material from which silica, alkalies, and alkaline earths have been leached away leaving behind alumina, iron, manganese, and titanium. It has a vermicular or pisolitic structure.

DSS studies carried out by Kaila et.al (1981,1988) have shown that the maximum basalt thickness is around 1.1 km. in the Ankleshwar region, of south Gujarat.

LATERITES

The subaerial weathering of the basalts under tropical conditions have given rise to lateritic rocks, which form a distinct horizon below the Tertiary sequence. These rocks invariably rest over the trap. Outcrops of laterite occur along

the western margins of Deccan Trap and are seen covered by a thick spread of alluvium.

The laterites of South Gujarat are seen as outliers capping the trap. Now occurring as isolated patches, one time laterites must have formed a continuous horizontal sheet, as did the trap on which it lies, the dissected outliers being the result of denudation. According to Pascoe (1964), the thickness of these rocks ranges, from 2 to 10m. with areal extent of few sq.km.

The laterites are seen as typically unstratified richly coloured in red, brown, and yellowish brown, quite often considerably mottled, with numerous lenses and pockets of bentonite and kaolinite. By virtue of their resistence to weathering and striking hues of colour, laterites stand-out prominently, occasionally forming colourful ridges.

TERTIARY ROCKS

The Tertiaries of South Gujarat are exposed between the Narmada and Tapi river comprising two patches separated by Kim river alluvium. The entire Tertiary sequence of the area ranges in age from Paleocene to Mio-Pliocene over which rest the Quaternary sediments with a pronounced unconformity. Much information has been generated by ONGC during last 30 years and a reasonably good stratigraphic picture of the Tertiary sequence of South Gujarat is now available (Rao, 1969; Chandra and Chowdhary,

1969; Sudhakar and Basu, 1973; Gadekar, 1975, 1980 and Agarwal, 1984). The maximum thickness of Tertiary and Quaternary sediments have been found to be 6000 to 7000 m in the Jambusar-Broach Graben. The thickness rapidly decreases towards Ankleshwar and further south, it is 300-400 m only. The sequence in South Gujarat based on surface and subsurface data consists of various formation, viz. Vagadkhol, Ankleshwar, Tarkeshwar, Babaguru, Kand and Jhagadia in an ascending order.

Vagadkhol Formation

The Vagadkhol Formation lies with an erosional unconformity over the basalts, and its main constituents are conglomerates and variegated clays. Basically the formation consists of the material derived from the weathering of Deccan Trap basalts. The lithological characteristics are indicative of fluvial to shallow water environment under oxidising conditions and rapid deposition accompanied with short transportation. The thickness of this formation is more than 50 m. and the age is tentatively shown as Paleocene to Lower Eocene from its general stratigraphic position.

Ankleshwar Formation

This formation occurs over Vagadkhol Formation with an unconformity. It consists of marine shelf facies and is overlain unconformably by Tarkeshwar Formation, the thickness is about 500 m.; lithologically it consists of fossiliferous limestones and

limestones of yellow and brown colour. The age assigned to this formation is Middle Eocene to Upper Eocene

Tarkeshwar Formation

The sediments of this formation are indicated to have been derived from the reworking of Upper Cretaceous Bagh beds exposed in Narmada Valley. The red and brown volc-arenites and agate-rudites indicate to have come from volcanic rocks from the nearby areas. This formation is overlain by the Babaguru Formation and is about 175 m thick. The age assigned to this formation is Oligocene.

Babaguru Formation

The sedimentary sequence of the Babaguru Formation consists of cherry-red sandstones and highly ferruginous agate, conglomerates and is 200 to 300 m thick. The formation is overlain by the Kand Formation.

No fossils are found in the sequence, and its precise age is therefore not known. However the approximate age of the Babaguru Formation may be Lower Miocene.

Kand Formation

The Calcareous sandstones, clays, marls and thin bands of fossiliferous limestone constitute the Kand Formation. It overlies the Babaguru Formation with an unconformity. At times

the limestone bands are about one meter thick, hard and compact, and occur as mounds. The clays are generally grey to light grey in colour and are highly calcareous. The approximate thickness of this formation is 200 - 400 m. The fossils contained in the limestone bands include species of lamellibranches, gastropods, echinoids, cirripedia, calcified fossilwood and leaf impressions. On the basis of these fossils a Lower Miocene age has been assigned to the Kand Formation.

Jhagadia Formation

The Upper Tertiary sedimentary sequence constitutes the Jhagadia Formation, and consists of sandstones, gritstones and pebble to cobble conglomerates. They are generally soft, friable and massive with calcareous bands. Its thickness is variable maximum being about 200 m. The formation are devoid of fossils, and considering its place in the order of superposition, a Middle Miocene to Lower Pliocene age could be assigned. The lithostratigraphic characteristics of Jhagadia Formation point to a continental fluviatile depositional environment.

QUATERNARY DEPOSITS

The tectonic framework of the western continental margin has significantly controlled the Quaternary deposition. The Narmada geofracture has played an important role in the northern block (Jambusar- Broach block) of Cambay basin which has been active all throughout Tertiary and Quaternary periods whereas, the

southern block (Narmada block) has been less active during the Quaternary period. The northern block consists of a huge pile of about 150 m thick Quaternary alluvium, whereas the southern block has a somewhat reduced alluvial thickness, less than 100 m; in both cases the alluvial sediments are resting over the Tertiary rocks (Agarwal, (1984).

Based on the subsurface geology, the Sub-Recent to Recent deposits are called Gujarat Alluvium (Chandra & Chaudhary 1969). It rests unconformably over the Jhagadia Formation, it's thickness is variable, but never exceeding 100 m. The same formation has been named as Narmada Formation by Agarwal (1984). They are constituted of unconsolidated sands, silts, gravel and clays. They are typically marked by an uncompacted nature and lack of sorting. On the basis of lithology and mode of occurrence they have been divided into three members as residual soil, black soil, flood plain.

Most of the exposed Quaternary sediments in South Gujarat are restricted to the western portion of the area that mainly forms the coastal plains. Here, the Quaternary deposits, show the following sequences.

Present day mudflats, beaches, dunes, etc.	- Late Holocene (Recent)
Raised mudflats, paleodunes and coastal ridges	- Early Holocene
Older Alluvium	- Mid to Upper Pleistocene

GEOLOGY OF THE STUDY AREA

Within the limits of the study area, only the basalts of Deccan Trap and the Quaternary deposits are encountered. The hilly terrain is occupied by the basalts, whereas the Quaternaries make up the Coastal plains.

Stratigraphy of the study area is as under :-

Newer alluvium (Younger flood plains and alluvial deposits); Residual deposits; Coastal deposits	-	Holocene to Recent
Older alluvium, (older flood plains and alluvial deposits) Older residual deposits, etc.	-	Middle to Late Pleistocene
Lateritic rocks occurring as thin discontinuous layers and pockets	-	Paleocene
Basaltic flows with intervening layers of tuffs, agglomerates, andesites etc. (Deccan Trap)	-	Late Cretaceous to Paleocene

DECCAN TRAP

Distribution and mode of Occurrence

Basaltic rocks of Deccan trap occupy a large portion of South Gujarat, approximately about 8500 sq.km. Practically, the entire hilly terrain within the study area is made up of a thick pile of near-horizontal lava flows, rising to altitudes as high as 1200 m above mean sea level, the highest portion flanking the eastern border of the Gujarat State. In a general way, the basaltic hills within the limits of the study area show altitudes around 700 m but then they abruptly rise by about 400-500 m,

towards the Maharashtra, forming a steep escarpment which has been referred to as the Great Escarpment by Ollier and Power (1985).

Field Characters

Like any other Deccan basaltic terrain here too, the landscape is characterised by a step-like topography (Plate III.1), abounding in flat topped ridges, hills and steep scarps. At many places, the horizontality of the flows and the thickness of various basaltic types is very well seen in panoramic views (Plate III.2). The geomorphic and landscape aspects of basalts are discussed in another chapter. Obviously, the petrological variation of the various flows and sub flows as well as the control exercised by the faulting and jointing have significantly contributed to the nature and mode of the occurrence of the basalt outcrops.

It may however be pointed out that demarcating the flows and subflows and computating their precise thickness has always been a problem with all workers who have studied Deccan Trap, and the present author too encountered considerable difficulty in this respect. The entire Deccan Volcanism has been observed to be repetitious, such that identical rock types are seen to occur at several levels. The author found it difficult to work out the total thickness and the number of flows on account of two reasons. Firstly, the petrographic and chemical variations and textural differences are quite often gradational, and in such

PLATE III.1 Panaramic view from Wilson Hill looking north, showing overall step-like topography, East-looking.

PLATE III.2 East-looking Panaramic view from village Garkhadi showing horizontal flows, flat topped hills, different types of slopes and various landforms.

cases it was found rather difficult to conclusively make out the clean-cut variations and also to count the number of flows and compute their thicknesses. Secondly, due to step faulting, certain amount of repetition of flows is observed.

Very little published work is available on the basaltic rocks of the study area and much of the details about these rocks had to be collected by the present author personally with the help of numerous traverses. He has, in the following lines attempted to present an overview of the basaltic rocks in the study area as they occur to-day. His description is based mainly on field observations, and petrographic study of a few representative samples.

Classification

The total thickness of exposed basaltic rocks in the study area is around 700 m and it is seen to comprise a mass of repetitive flows of (i) hard, compact, dark grey, finegrained basalts (ii) coarse, porphyritic basalts and (iii) andesite. Although it is difficult to make very precise categorisation on account of the complicating factors enumerated above, in a generalised manner, following could be stated to describe the basalt sequence :

1. Upper portions : (eastern and southern parts)

Thickness around 200 m	Dominantly coarse porphyritic basalts

2. Middle portions : (central parts)

Thickness around 300 m	Finegrained grey basalts with a few andesitic layers

3. Lower portions : (in the western northwestern parts)

Thickness around 200 m	Finegrained grey compact basalt.

The above categorisation is rather generalised and based on the dominant rock types only. The occurrence of porphyritic layers in the lower portion is not ruled out, nor the upper porphyritic horizon is free from non-porphyritic compact basaltic layers. Broadly, this sequence is correlatable with Jawahar Formation of Subbarao et.al (1988).

It is further observed that in most of the individual flows, the upper portions of the porphyritic as well as non-porphyritic basalts, are vesicular marked by concentration of amygdules of zeolite, chalcedony quartz, and calcite etc. The amygdaloidal zones are generally one to two meter thick, but sometimes they are as thick as 30 m, wherever there is large scale development of amygdules the rock tends to be coarser and softer. The amygdaloidal variety generally merges into massive basalt and vice-versa. In many, instances, the base of the flows are also marked by a narrow zone of vesicles, but in such cases, they are diagnostically seen to be pipe-amygdules, aligned parallel to the flow surfaces. Even within the main body of the flows thin strings of amygdules are not uncommon (Plate III.3). There is quite often considerable grain-size variation within a single

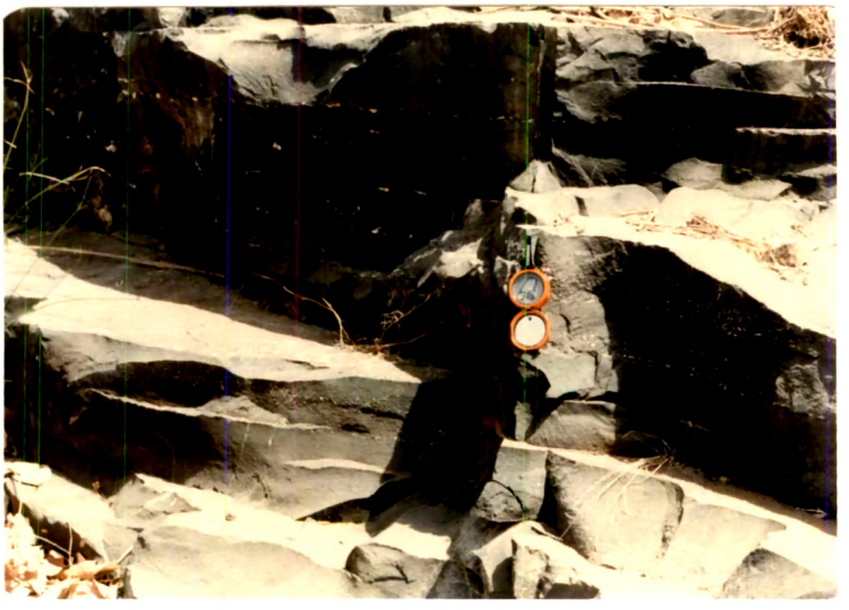

PLATE III.3 Fine compact basalt within thin strings of amygdules. Location : NE of Khatal village.

PLATE III.4 Tuffaceous layer between two different flows. Location : Par river bed West of village Kachigam.

56

flow, and presence of tuffaceous layers and/or agglomerates is also very common (Plate III.4). In fact, these are the diagnostic features separating one flow from the other. When seen from a distance, the striking horizontality and layered profiles of basalt hills, are the two features which catch ones attention immediately. This phenomenon is due to lines of contrasting vegetation and breaks in slopes and are good indicators of layerwise mineralogical and/or textural variation, and the response of the rocks concerned to weathering (Plate III.5 & 6).

The total number of flows in the area is around 20, belonging to one or the other petrographic type. It is however not un-likely that they comprise sub-flows of a few major compound flows (Walker, 1972). Also due to absence of marker horizons such as inter-trappean beds or red bole beds, the correlation of flows in different parts of the study area is rather difficult. Moreover, tectonic uplifts and subsidences along the various tectonic lineaments have to be taken into account while constructing an integrated sequence of trappean flows. sketches of a few typically well-exposed sections give a good insight into the mode of occurrence and nature of the trappean rocks of the area (Fig. III.2)

The basaltic terrain is criss-crossed by numerous dolerite and basaltic dykes. The author has come across some of them, while others have been reported by previous workers (C.G.W.B.

PLATE III.5 A view looking north from village Hatgad showing slope breaks and contrasting vegetation.

PLATE III.6 A close up view of the weathered basalt layers Location : 1 km. South of Ahwa on Ahwa-Saputara road.

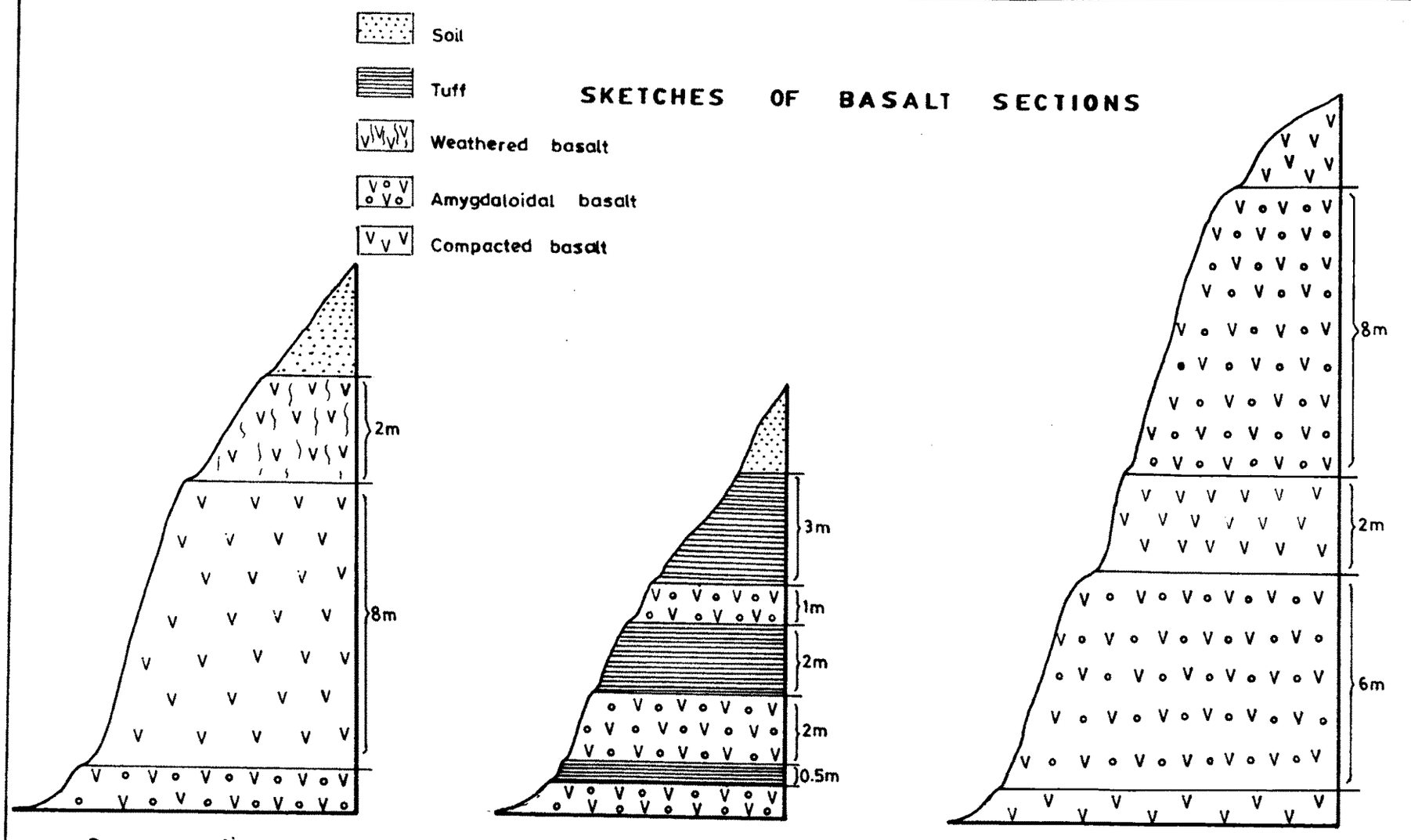
Soil
Tuff
Weathered basalt
Amygdaloidal basalt
Compacted basalt
SKETCHES OF BASALT SECTIONS
2m
8m
3m
1m
2m
2m
0.5m
8m
2m
6m
Quarry section near Parthi village
Section along the bank of Purna river
Section along the bank of Ambica tributary

Fig: III.2

Reports, Mittal, 1981; Patel & Tiwari, 1987). It is observed that the dykes follow the various fracture trends. They vary considerably in dimensions, some of them are several meters thick and extend for more than 1 km, while others are thin, a few cm, wide and extend for a few meters only. It is interesting to note that some of the dykes are affected by movement along joints and show some shifting (Plate III.7). It is obvious that the dykes have arisen along the various fractures, (NNW-SSE, N-S, NNE-SSW, NW-SE, NE-SW, ENE-WSW and E-W).

The basaltic rocks show a very conspicuous jointing pattern, the various joints, have been categorised as under :

1. Jointing due to cooling and contraction

   (i) Vertical, columnar joints (Plate III.8),
   (ii) Sheet joints (Plate III.9).

2. Joints related to tectonic activity

   Intersecting joints;
   Tensional, shear and conjugate (Plate III.10 & III.11).

The overall landscape typically reflects pronounced action of sbaerial weathering processes acting over a terrain marked by horizontally disposed lava flows of diverse lithologies and complex fracture. Pattern involving faulting and intense jointing. The South Gujarat experiences heavy monsoon and significant humidity variation and the diverse impact of weathering is considerably pronounced. The total geomorphic picture reveals a basaltic terrain marked by flat-topped hills,

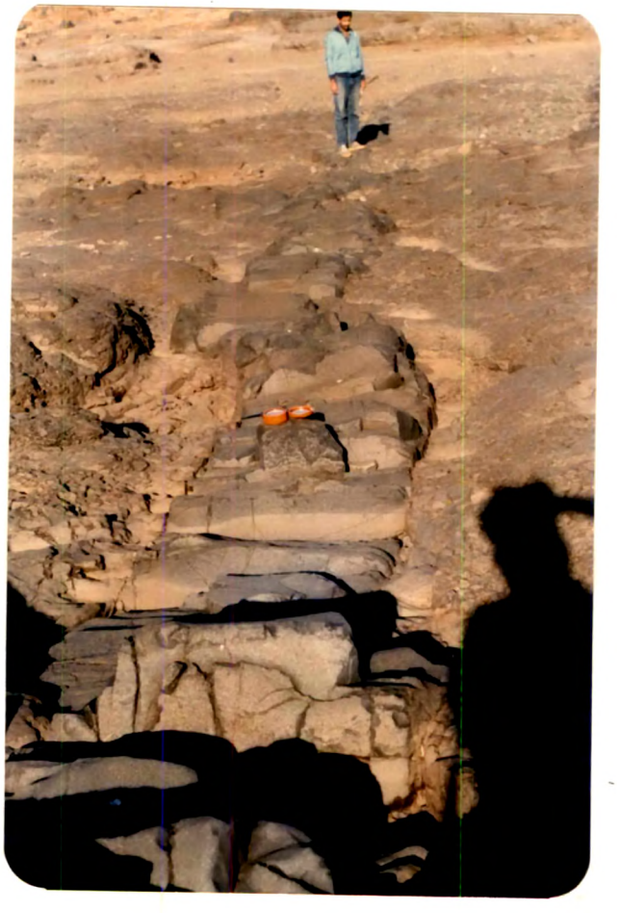

PLATE III.7 A NNE-SSW trending dyke in the bed of river Par, showing lateral shifting. Location : North of Vadkhamba village.

PLATE III.8 Columnar jointing in a quarry section in finegrained compact basalt. Location : Chikhli.

PLATE III.9 Sheet joints in basalts. Location : Purna river bed near Garkhadi village.

PLATE III.10 Conjugate joints in compact basalts. Location : Man river bed below the bridge Dharampur-Bansda road South of Karenjveri village.

PLATE III.11 Conjugate joints in amygdaloidal basalt. Location : Nirpan river bed West of Anklachh village.

steep scarps and slopes of different categories, the angles of slope depend on the response of different rocks to weathering and to the accumulation of debris at the breaking points of slopes. Spheroidal weathering is the most conspicuous feature of the trappean surfaces (Plate III.12).

Petrography

The petrographic account given here can by no means be taken as a full and exhaustive description of the basaltic rocks of the study area, the same being beyond the scope of the present study. As it has already been emphasized, texture and mineralogy of the basaltic flows have also played their due role in landscape sculpturing and the present author has endeavoured to collect representative samples from various parts of the areas and studied them under microscope. The description therefore essentially pertains to the samples collected by the present author from selected spots, relevant to the geomorphic expression and weathering response vis-a-vis overall landscape evolution.

The petrographic description of the different trappean rocks mainly comprises megascopic and microscopic characters of the following rock types :

1. Basalt
   - i) Fine compact basalt
   - ii) Fine compact basalt with amygdules
   - iii) Porphyritic basalt
   - iv) Porphyritic basalt with amygdules

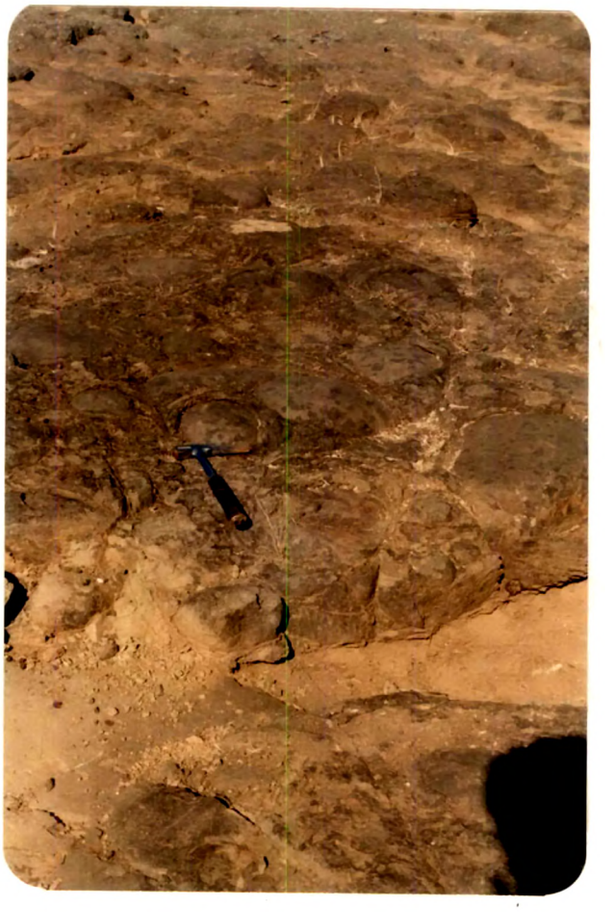

PLATE III.12 Spheroidal weathering in basalt. Location : Tan river bed near Kanpur village.

2. Andesite
3. Agglomerate (Tuff)
4. Dyke rocks (Dolerite, Basalt)

Basalts : Compact basalts are the most dominant types. Megascopically, they comprise hard, dark grey, finegrained rocks with or without amygdules. The amygdaloidal variety is mostly restricted to the top and bottom parts of the flows, and tend to be slightly coarser. The porphyritic basalts are fine to medium grained with abundant phenocrystic feldspar laths and they are also of two varieties distinguished from each other by the presence or absence of amygdules. The amygdules are of variable shapes and sizes. The most common being round or oval shaped vesicles and pipes. In diameter they vary from a few mm to as much as 10 mm or more and the cavities are filled with zeolites cryptocrystalline silica and druisy quartz. Under the microscope, the different variaties of basalt typically show a hemicrystalline texture; the compact variety is seen to from a finegrained intergranular groundmass in which are seen embedded relatively larger grains of plagioclase and augite (Plate III.13). The plagioclase becomes big and phenocrystic in the case of porphyritic basalts (Plate III.14). The intergranular texture is also seen to grade into subophitic and ophitic textures, when the pyroxene minerals (augite) enclose the feldspar laths (labradorite) either partially or completely (Plate III.15). The amygdaloidal varieties show usually a fine grained texture. Plagioclase feldspars ~~are the more~~ form both big laths as well as tiny needles. Pyroxene is dominantly the

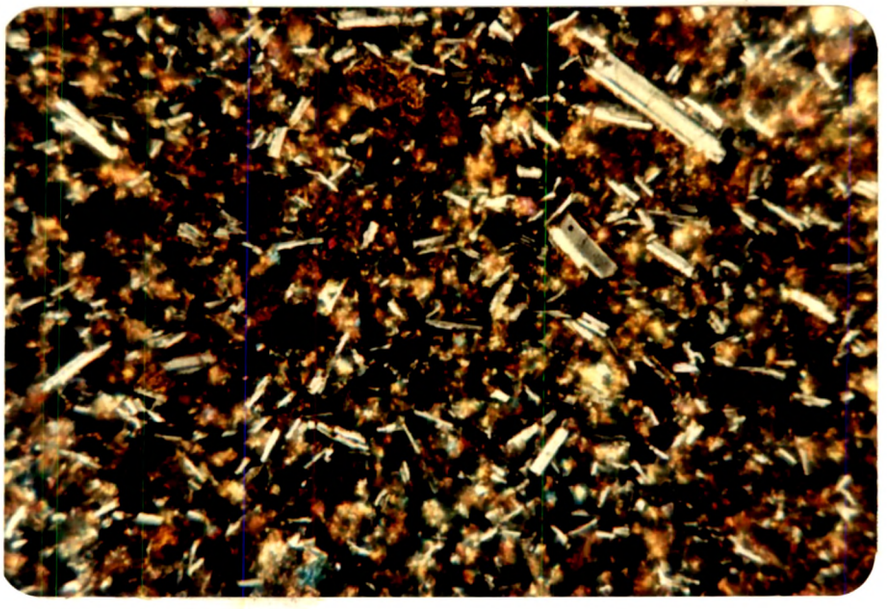

PLATE III.13 Photomicrograph of compact basalt, (x 55; cross-nicols).

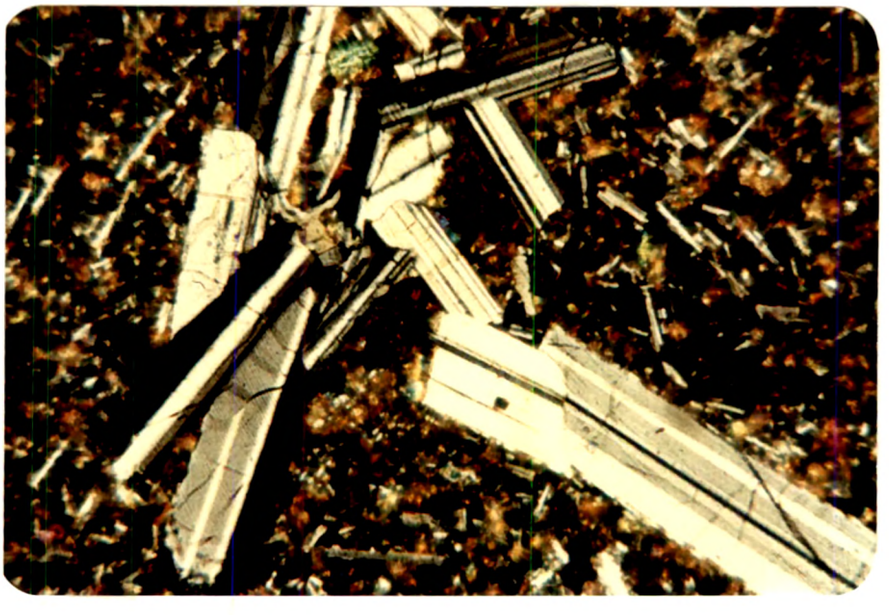

PLATE III.14 Photomicrograph of porphyritic basalt, (x 55; cross-nicols).

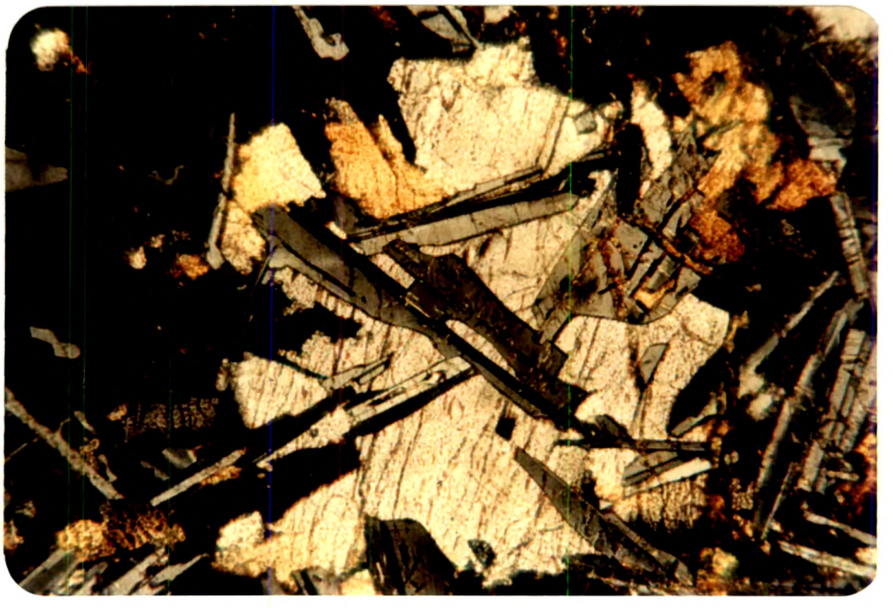

PLATE III.15 Photomicrograph of sub-ophitic to ophitic texture, (x 55; cross-nicols).

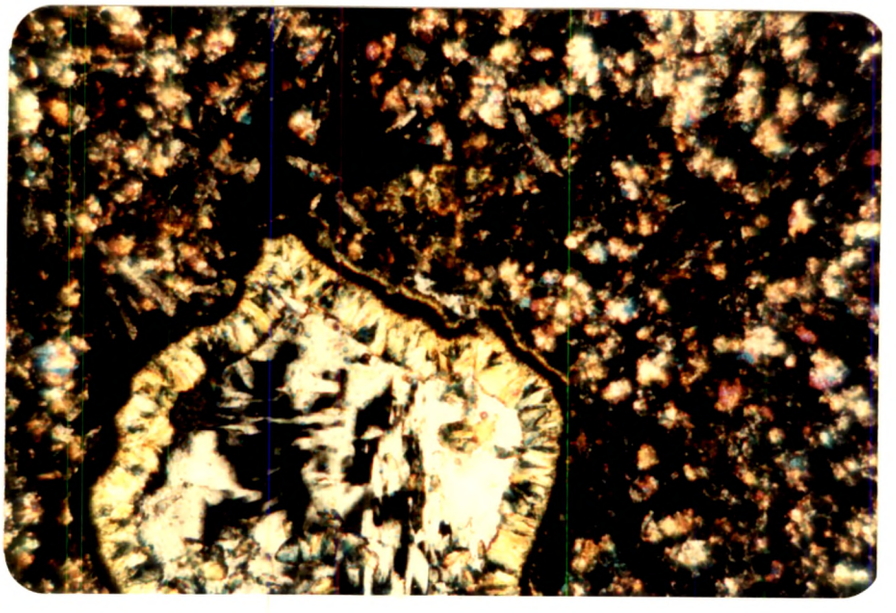

PLATE III.16 Photomicrograph of finegrained amygdaloidal basalts, (x 55; cross-nicols).

usual augite and occurs either as granules in the groundmass or as phenocrysts. Magnetite and Haematite constitutes the accessary iron ores. Both occur mainly in the groundmass. The amygdules are filled with the usual secondary minerals like silica, zeolites and calcite (Plate III.16,17 & 18).

Andesite Andesite are also greyish black but typically porphyritic usually they occur as finegrained with big crystals or laths of plagioclase embedded in a fine dark groundmass, in the field they are easily identified as they occur as discrete layers within the basalts. Under the microscope they show porphyritic texture; the laths of plagioclase are seen embedded in a groundmass. The plagioclase is typically an andesine, (Plate III.19). The groundmass comprises tiny laths of plagioclase and augite granules. Accessary iron ores are magnetite and haematite.

Tuff Tuff occurs as thin intervening layers between two comparatively thick layer of the amygdaloidal basalts. They are comparatively softer rocks, and their weathering has given rise to flat rocky bed of many rivers. Good exposures are seen on the banks of the Par and Purna rivers. In hand specimen; the tuff has an earthy greenish grey appearence and is seen to consists of very small sherds of volcanic material.

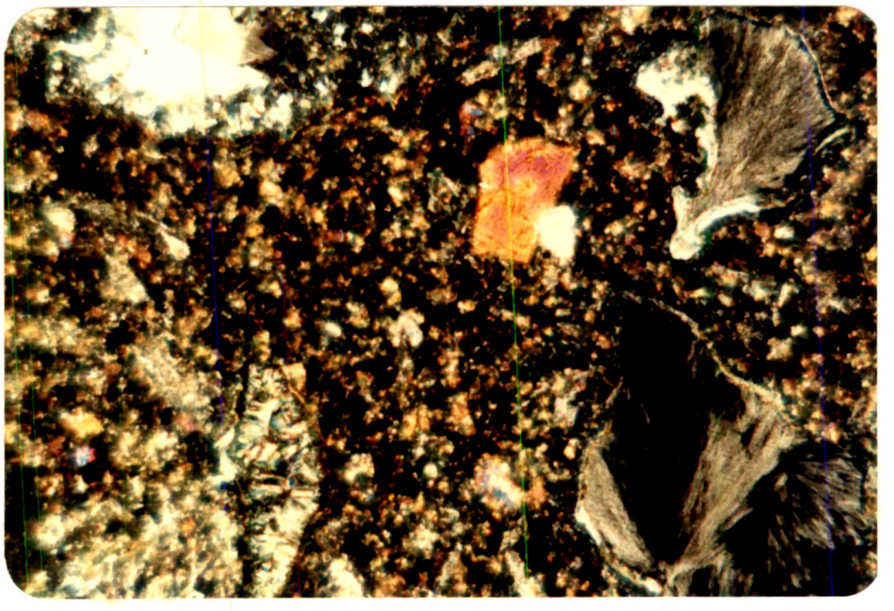

PLATE III.17 Photomicrograph of finegrained amygdaloidal basalts showing zeolites, (x 55; cross-nicols).

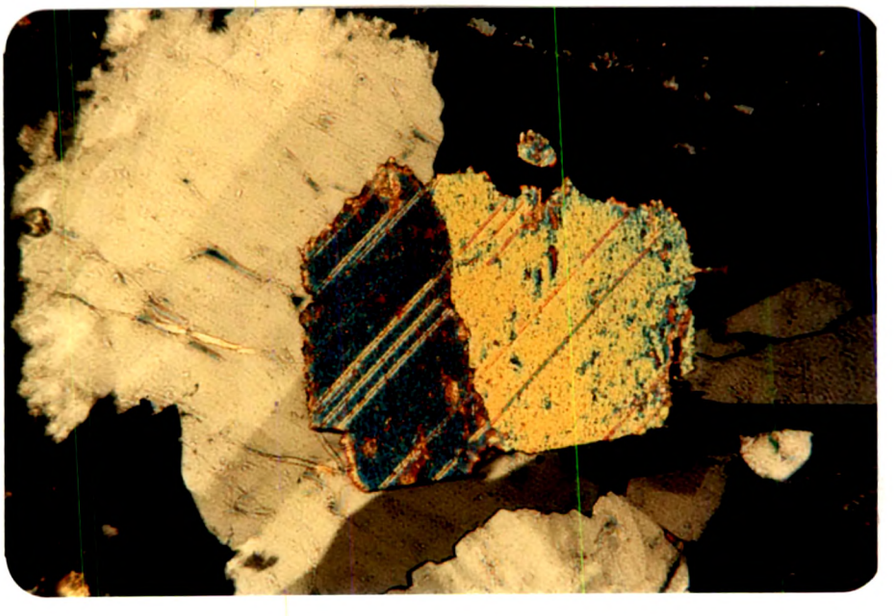

PLATE III.18 Photomicrograph view of calcite as infilling in amygdule, (x 55; cross-nicols).

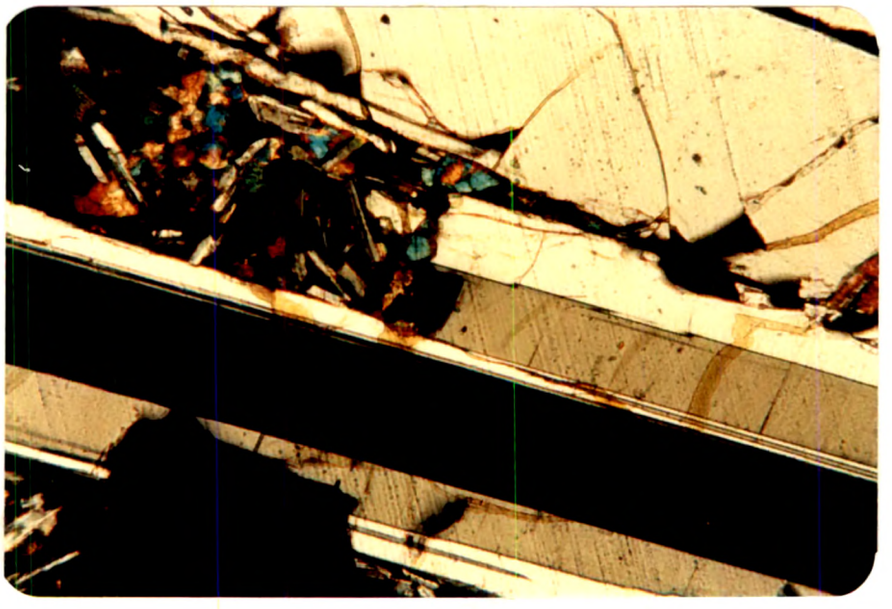

PLATE III.19 Photomicrograph of Phenocryst of Andesine in Andesite, (x 55; cross-nicols).

PLATE III.20 Photomicrograph of a dolerite, (x 55; cross-nicols).

Dykes Dykes are mainly of Olivine dolerite, and basalts. Megascopically they are seen as compact, dark green, medium to coarse grained rocks and consisting of Olivine and white feldspars and visible with the naked eye. Under the microscope, thin, sections of dolerite show the usual ophitic to sub-ophitic texture (Plate III.20). Pyroxene is seen enclosing the plagioclase laths either partially or completely. Olivine occurs as discrete grains uniformly scattered all over the rocks (Plate III.21). The pyroxene is an augite forms large plates of yellow to light brown colour. It is interesting to observe that some times, in the same thin section, part of the rock shows intergranular texture as well. Plagioclase a Labradorite, occur as laths and also as small needles within the augite. Olivine forms grains considerably serpentinized and chloritised. Iron ore is mainly magnetite which occurs as granular aggregates along the boundaries of augite and olivine. The basaltic dykes are mostly amygdaloidal show basalts with amygdules of zeolite, quartz and chalcedony and show diagnostic finegrained porphyritic texture (Plate III.22). The groundmass are mainly of pyrexene and plagioclase and the iron ore is mainly of magnetite.

LATERITES

A thin discontinuous zone of lateritic rocks is encountered just above the traps in its western part. Its outcrops are scattered and good exposures occur at villages Ajrai, Khergam, Pathri near Gandevi and villages Munjlav, Ghale Nani Naroli near Tadkeshwar, and there are several small patches of laterite and

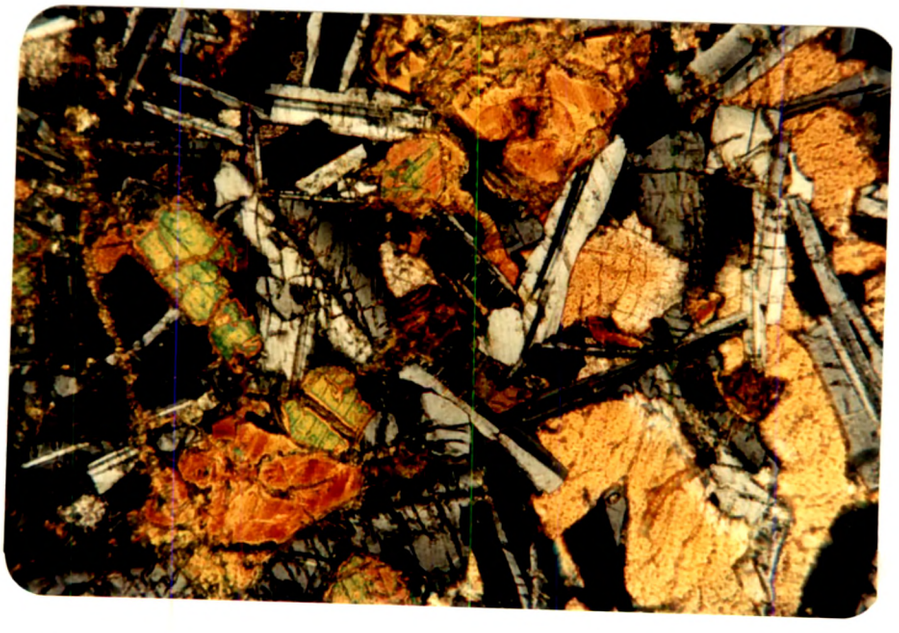

PLATE III.21 Photomicrograph of a olivine dolerite, (x 55; cross-nicols).

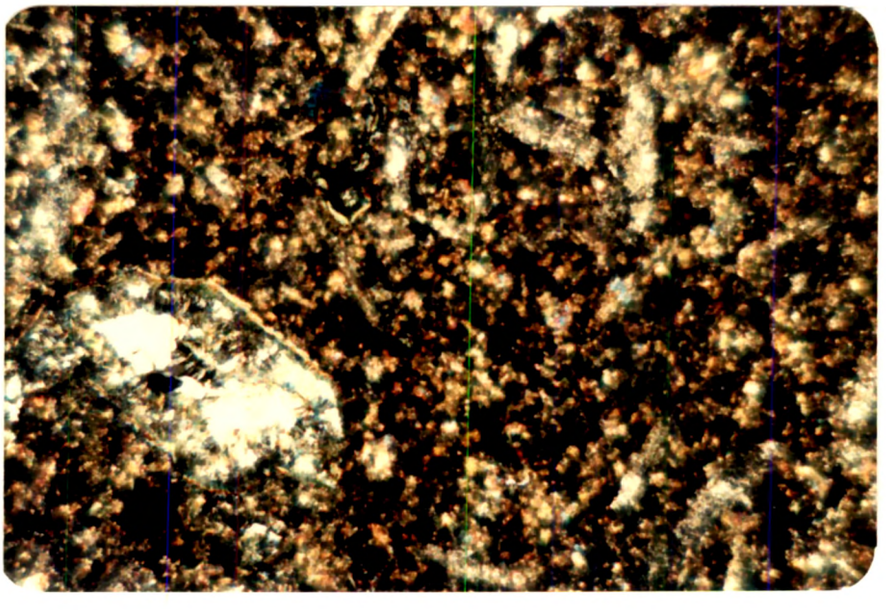

PLATE III.22 Photomicrograph of a basaltic dyke, (x 55; cross-nicols).

red soils near Dungar village south of Tapi. A good lateritic profile is seen at Tarbhon village southwest of Bardoli, which has been described by Sahastrabudhe (1978).

The laterites are derived from the basalts but their various exposures reveal incomplete profiles. Ardeshirian (Personal Communication) who is investigating these lateritic rocks, has found them to comprise both ferruginous as well as bauxitic varieties. The laterites of South Gujarat do not show complete profiles and at most places bentonite zone is absent and the zones of laterite and bauxite are not well differentiated.

An important factor controlling the laterization process, according to Ardesherian, is that of the intensity of fracturing of basalts, and the fractured and jointed basalts have provided suitable locations for initiating the process of alteration.

A typical laterite occurrence of village Munjlav near Tarkeshwar within the study area, shows the lateritic profile (Plate III.23).

QUARTERNARY DEPOSITS

The study area contains a wide variety of Quaternary deposits. Whereas the ground to west of the highlands, right upto the coastline is comprised of alluvial and marine sediments, hilly terrain itself has numerous occurrences of locally

PLATE III.23 View of a typical lateritic profile. Location : Village Munjla near Tarkeshwar.

accumulated alluvium, colluvium and residual soil cover. For the purposes of description, the Quaternary deposits of the study area have been categorised as under :

Highlands	Soils (residual), colluvium (Talus) and locally deposited alluvium, including reworked and transported weathering products.	
Coastal Plains	Alluvium	Newer
		Older
	Coastal marine deposits	

Highland Quaternary Deposits

The Quaternary deposits occuring within the hilly terrain belong to the following categories.

1 - Residual (in situ) soil cover occurring over horizontal or gently sloping trappean surfaces at all altitudes. At higher levels the soil cover is around 1-2 m, but at the base of the prominent hills and ridges, the residual soil cover could be as thick as 5 m, which includes scree accumulations (colluvium deposits).

2 - Locally accumulated alluvial sediments, deposited by the various small and big streams, at various altitudes. These are generally a few meters thick and are the sites of village locations within the highlands. By and large, they represent stream transported weathered material from higher altitudes.

3. Alluvium of major rivers like Tapi, Purna, Ambica, Par and Auranga. In the lower reaches of these rivers, cliffy sections reveal alluvial sediments. Two, distinct terraces are observed. The older and upper terrace about 10 m thick whereas the lower terrace is marked by the present day flood plains.

Coastal Plains

Alluvium forms two well defined terraces; the upper terrace is of Older Alluvium, probably of Middle to Late Pliestocene age, and consists of silty clays and forms the main soil horizon 50 to 250 m thick. (Vashi & Ganapathi, 1982). Its top surface, upto considerable depths (several meters) is invariably contains a thick horizon of calcrete (lime Kankar). The material of the present day flood plains, forms the Newer Alluvium. Its occurrence is restricted to the flanks of the major rivers of the study area in their lower courses constitutes a very fertile land. The two alluviums are recognised on the basis of the altitude, presence of Kankar and content of organic matter. The Older Alluvium has more lime and less organic matter as compared to New Alluvium.

All the coastal deposits are of Holocene age, and comprise sandy beaches, bars, spits, barriers and dune ridges. Two generations of the depositional features have been observed. These features are correlatable to the two strandline of Holocene (Vashi & Ganapathi 1982; Patel & Merh 1982). On the landward side there is a development of estuarine mudflat which are made up of

finegrained particles of silt and clays with a considerable percentage of biogenic matter. The shoreline is crenulated, dotted with river mouths and creeks through which the tidal waters enter and form mudflats behind the sandy barrier ridges. The process of the deposition of coastal deposits is still continuing.