CHAPTER - IV

GEOMORPHOLOGICAL SET-UP

PREAMBLE

The aim of a geomorphological survey is to provide a concise and systematic picture of landforms and related phenomena. The maps produced are not only scientific documents in their own rights, but also valuable tools in the assessment of resources because of the relations existing between the geomorphological characteristics of the land and other environmental factors (Verstappen & Va Zuidan, 1968).

A landform is defined (Howard & Spock, 1940) as "any element of the landscape, characterised by a distinctive surface expression, internal structure or both, and sufficiently conspicuous to be included in a physiographic description". The landforms are thus, the basic elements in any landscape and a geomorphic analysis involves the study of the geometry of the landforms and their attributes, considering the landscape as a relatively static form at the time of observation and the processes that strive to modify them (Subramanyam, 1989).

However, the definition of a landform is necessarily subjective. One observer may consider a hillside as a continuous and homogenous landform. Another observer sees gullies, ridges and many other small topographic features that either break the continuity of the hill side or establish its continuity, depending on the mental concepts. There is no lower limit to the scale of observation. Therefore the landform is simply defined as a continuous surface that can be viewed by an observer in its entirety, whether the observer is on hands and knees on the ground, or in orbiting spacecraft (Bloom, 1983).

GEOMORPHOLOGICAL CLASSIFICATION OF SAURASHTRA

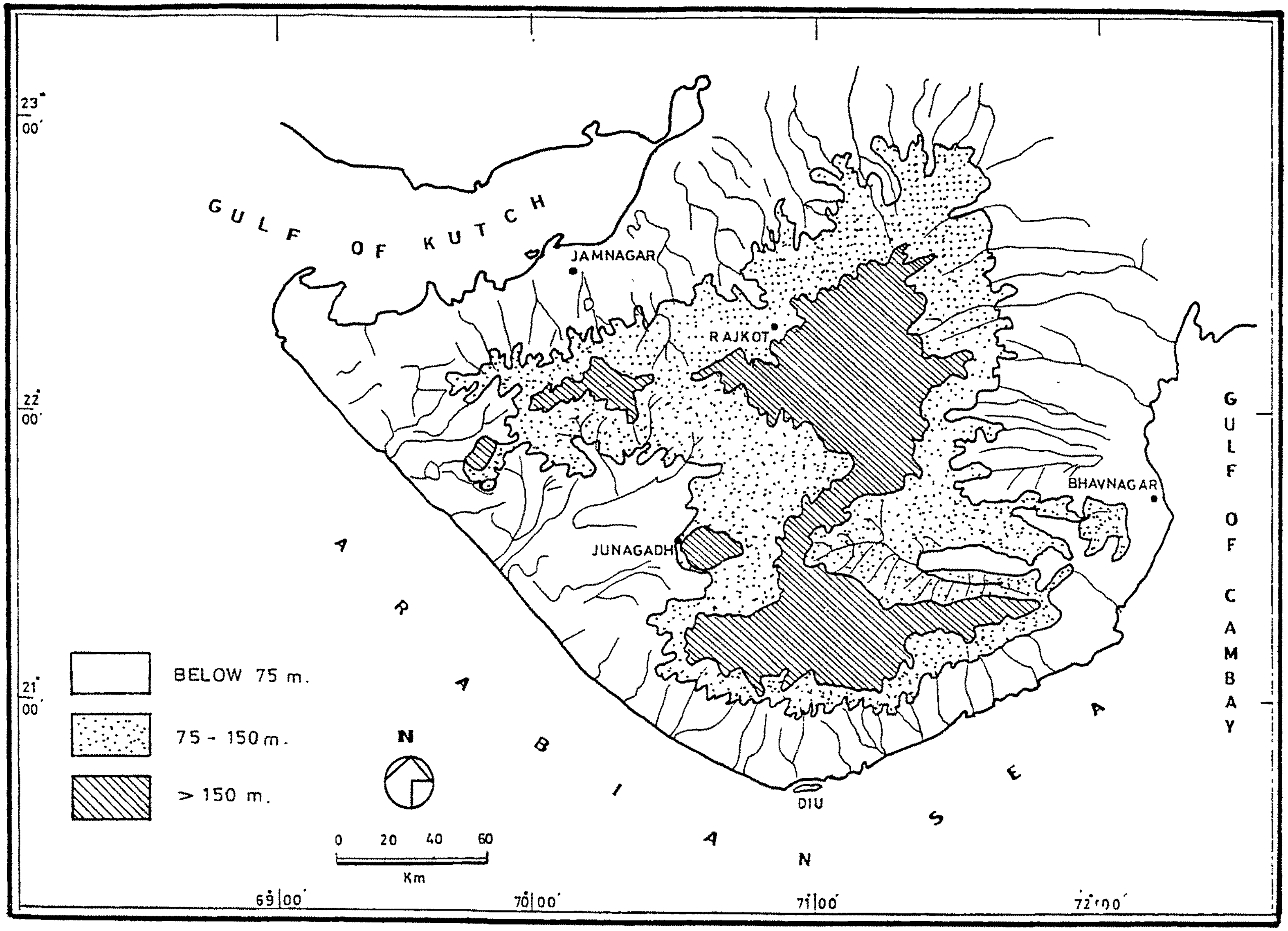
The description of the regional geomorphology has been compiled from the works of Ganapathi (1981), Subramanyam (1981), Sood et al., (1982) and Pappu & Marathe (1982).

The present surface configuration of Saurashtra, the variety of landforms, the drainage characteristics and the relief pattern, all these geomorphic facets, clearly reveal a complex interplay of tectonism, lithology and Cenozoic processes of erosion and deposition. A major portion of the peninsula, being made up of the Deccan lava flows, typically comprises a much dissected tableland, sloping seaward on three sides in the north, west and south. Its northeastern flank dips below the alluvial fringe of the mainland Gujarat. The Deccan basalt scenery of Saurashtra peninsula is indeed varied, though developed on nearly the same type of basalt, in its dominantly structural landforms over horizontal, inclined and much less commonly, folded basalts. The range of altitudes in which the Deccan basalt landforms are distributed is from sea level along the west coast, to 1117 m at the Girnar in Junagadh. Within this altitudinal range the basalts form an extensive plateau, dissected for the most part, reaching an altitude from 300 to 400 m. This plateau carries on it many minor plateaux, ridges and hills. The plateau region includes the area enclosed between the 75-300 m contours and occupies nearly two-third area of the peninsula (Fig. 10). The surface of the low land rises from all sides gently towards the centre, where it develops into some sort of hills and ridges. The hilly highland region is characterised by rocky, forested and heavy rainfall terrain of the peninsula in the central portion, confined above 300 m contour. These highlands of Saurashtra have formed as a result of denudation of the extensive basaltic plateau and are present at a number of places.

A study of profiles across the Saurashtra peninsula reveals that :

(1) The major portion of the land surface (60-70%) forming a plateau region is confined between the altitude 50-200 m.

(2) The highlands in the form of hills and ridges have an elevation of more than 200 m, occupy a small portion in the central part of the peninsula. A gradual rise in altitude of landsurface from the coastal region towards



(after Ganapathi, 1981)

FIG.10. PHYSIOGRAPHIC MAP OF SAURASHTRA

the centre from all sides, is observed in all the profiles.

(3) A number of distinct planation surfaces are observable at the elevation of 20-40 m, 50-77 m , 120-140 m , and 150-170 m in the plateau region. These have been mainly developed on the Deccan Traps and owe their origin to the base level changes in the area.

Altimetric frequency analysis of the whole of Kathiawar reveals that the oldest erosion surface in the peninsula has been upwarped cymatogenically to 1117 m (Girnar complex) in the central part, and it falls off peripherally to 600 m. This upwarped erosion surface has been dissected during the cycle of erosion that followed and brought down to 400 m, which elevation, therefore, marks the second erosion surface. Due to rejuvenation, by possible uplift and subsequent erosion, this surface appears to have been lowered to 200 m where a third surface has developed. This might have been during the Pleistocene time.

During the recent times, a marine surface has started developing near the sea and has been working its way up the peninsula. This is the fourth erosion surface which has a gentle slope towards the sea.

It is thus seen that during the Quaternary era, the coast has been subjected to positive tectonic uplifts.

In a broad sense, taking into consideration the factors of altitude, slope and ruggedness of relief, the Saurashtra peninsula can be divided into three main geomorphological units as under :

1. The Trappean highlands.
2. The coastal plains.
3. The shoreline.

The above three units, show considerable diversity within each of them, depending on the rock types, their mode of occurrence and fracture pattern.

THE TRAPPEAN HIGHLANDS

The central elevated portion of the peninsula fringed on all sides by Tertiary and Quaternary deposits, marks the highlands considerably dissected by various rivers that flow out in all directions, the highlands provide a zig-zag outline and a rugged topography. The highlands roughly form three parallel elevated areas striking ENE-WSW, all connected by a NNE-SSW ridge. The three elevated areas themselves show much diversity and would broadly be divided further into three types :

(1) Dissected tableland made-up of sub-horizontal or very gently dipping lava flows, showing an un-even or

rolling topography due to weathering along various joint planes. In some cases, the relicts of these tablelands stand out as isolated conical hills (e.g. Chotila hill 340 m). The altitudes of the various tablelands vary from 325 m to 643 m.

(2) Circular hills or intrusive rocks within the tablelands. These are striking hill massifs standing out prominently to impressive heights, and are essentially made up of Trap differentiates, e.g. Girnar (Gorakhnath peak-1117 m), Barda (Venus- 637 m), Alech (298 m) and Osham (314 m).

(3) Linear dyke ridges in various directions, protruding above the basaltic surface. These generally show heights upto 10 m above the general level of the ground, and are made up of intrusive rocks like dolerites.

THE COASTAL PLAINS

The Trappean highlands are fringed by a narrow 5 to 50 km wide coastal plain. Abutting against the rocky mainlands, these plains show a maximum altitude of 50 m. On the whole, these plains are not so well developed, and comprise only a superficial soil and alluvial cover over the Traps, except in those areas where the Tertiary formations have deposited. The attributes of these coastal plains differ in different coastal segments. Along the northern coast, they are made up of a very thin veneer of residual soil over the Trap, never exceeding a few meters in thickness. The coastal segment between Dwarka and Kodinar in the west, is rather broad and somewhat better developed. Here, the plains consist of sporadic exposures of Gaj and Dwarka formations as well as of miliolite accumulations in the form of island ridges and sheet rocks. The alluvial covers are restricted to the mouth of Bhadar and Ojat rivers.

The southern coast, again shows poor development of these plains, except in the area between Port Victor and Talaja. But for a small proportion of Tertiaries, the rest of the southern coastal plain is made up of alluvium deposited by the various rivers.

THE SHORELINE

The shoreline of Saurashtra shows considerable diversity and its various segments provide good examples of different types of shoreline. From the point of view of geomorphology, the shoreline is divisible into following segments :

1. Shoreline between Jodiya and Okha (northern shoreline),
2. Shoreline between Okha and Kodinar (western shoreline),
3. Shoreline between Kodinar and Bhavnagar (southern shoreline), and

4. Shoreline north of Bhavnagar (eastern shoreline).

MORPHOGENETIC REGION

The Kathiawar peninsula falls in the west coast physiographic division of India (National Atlas, 1962). One of the important physiographic sections of the Kathiawar peninsula is the Gir Range around Girnar hills. It falls in the "semi-arid" morphogenetic region with a temperature range of between 1.6°C and 29°C, and a rainfall range between 250 mm and 630 mm.

GEOMORPHIC PROCESSES

Among the geomorphic processes, spheroidal weathering and fluvial erosion take place in the entire basalt country. Spheroidal weathering releases boulders of various sizes and is in fact one of the criteria that help distinguish one flow from another. It has been considered thermal in origin, but studies in thin sections of the outer weathered layers of basalt under the microscope reveal the presence of minerals like iddingsite, suggesting chemical action too.

A blackish clay loam results from the bio-chemical weathering of the basalts. The thickness of the profile varies from 10 cm to over 1 m depending upon the slope conditions. The pH of the soil varies from 6 to 8. The moisture content varies from

10% to over 20%. Only weathering profiles were observed on most of the flows without any palaeosols.

The soil profiles vary inversely with the angle of slope, the gentler the slope, the thicker the profile. Likewise, the distribution of certain species and communities of vegetation appears to be controlled by the slope. The absence of palaeosols on any of the basaltic flows clearly indicate that the flows were extruded in quick succession without allowing the formation of soils.

DRAINAGE

The drainage of Saurashtra provides an interesting example of a combination of lithologic and tectonic control in its evolution. Most of the previous workers have taken the drainage pattern to be radial with streams flowing out to the sea in almost all directions from the central highlands. From the perusal of the drainage map of Saurashtra (Fig. 11), it becomes evident that the Trappean highlands form a `Z´ shaped watershed, which would be divisible into two well defined units - the northern and southern, each typifying quite distinct drainage patterns.

The Northern Unit

The northern unit comprises an approximately ENE-WSW trending elevated ground, from which numerous small streams flow down

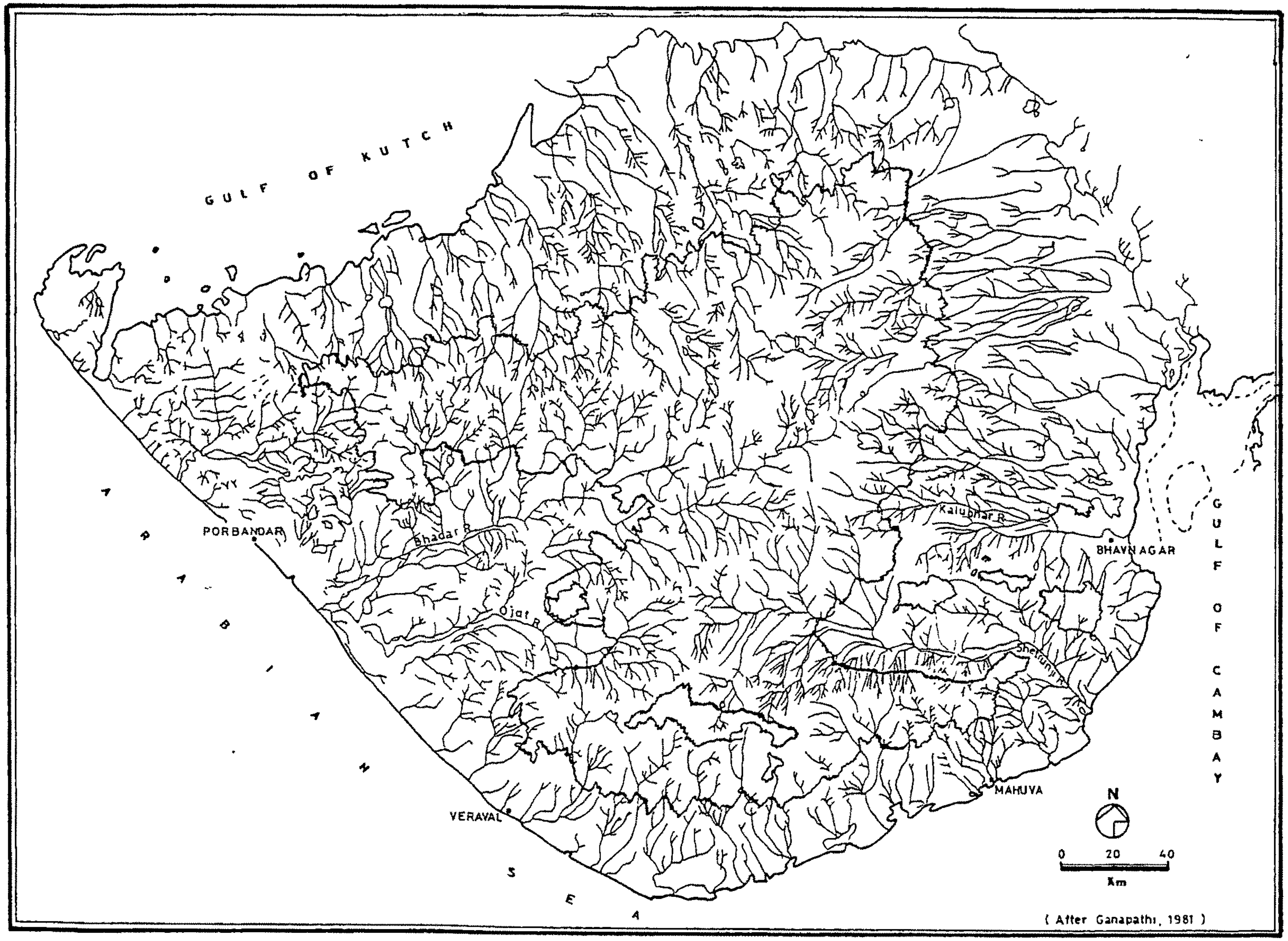


FIG 11. DRAINAGE MAP OF SAURASHTRA

in all directions. Various streams are more or less seasonal, except a few like Bhadar in the SW and Machhu in the north, and they are essentially slope controlled. The seaward slope has determined the north flow of the consequent streams. The insequent tributaries, that commonly make an acute angle with upstream parts of the consequent valleys have given rise to branching dendritic pattern. The streams that meet the Gulf of Kutch provide an ideal example of the phenomenon of drowning of their valleys due to the submergence of the coastline. The rivers that debouch their waters into the little Rann also reveal the phenomenon of truncation of their lower course, now buried beneath the Rann clays. Due to the fall of sea level in recent times, the upper courses of the eastward flowing rivers show the usual dendritic pattern, while in the lower reaches, meandering and water-logging is more common.

The Southern Unit

The Southern Unit (south of the Bhadar-Kalubhar line), exhibits a drainage pattern quite different from that in the north. Here, the various streams big and small, indicate a strong structural control. Almost all the major rivers flow along tectonic lineaments, while their tributaries or other smaller rivers follow either various joint sets or comprise slope controlled streams.

The hills of the east-west Gir range provide the main watershed, to the south of which flow down numerous small streams to the Arabian sea. While some of these south flowing streams are essentially slope controlled, quite a few major ones flow along well defined fractures. The streams flowing east and west, definitely follow fault lines.

The rivers that flow eastward show marked tectonic control. Emerging from the eastern slope of the N-S ridge which connects the Gir range and Mandev ridge, Kalubhar and Shetrunji rivers flow along major faults. The latter is perennial, whereas the former is seasonal.

The streams flowing due south originate from the Gir Range, and show variation in their lengths from 15 to 50 km, comprising only gullies in their upper course. These drain the coastal zone and finally meet the Arabian Sea. Though these streams are seasonal, they are important from their genetic point of view. The pronounced seaward slope of the Gir Range has controlled the pattern of these streams, which show a parallel drainage flowing over the tilted coastal plain. The stream courses have been controlled by the slope and are consequent to the origin. These streams provide an interesting example of the effect of sea-level fluctuations on the coastal drainage during the Quaternary. Right near the coast, the phenomenon of valley entrenchment due to sea regression is encountered. The valleys of rivers like Hiran, Shingoda, Machhundri and Dhantarvadi, all are typically seen downcutting their valleys very much near their mouths. In the upper segments of these streams, consequent tributaries have developed on the valley sides and on account of their cutting back up by headward erosion into the plateau, the overall patterns of the streams in their course are dendritic. In contrast, the lower courses with few tributaries are parallel to one another. According to Zornitz (1932), such a drainage cannot be called a parallel drainage, and should be included under dendritic pattern only.

The two major post-Trappean but pre-Tertiary westerly flowing rivers, the Bhadar and Ojat are controlled by the ENE-WSW lineaments (parallel to the Narmada Fault). The extensive occurrence of miliolite sheets along the valleys of these rivers for several kilometers inland and their heights, provide good insight into the sea level fluctuations of the Pleistocene period.

GEOMORPHOLOGICAL SETTING OF THE STUDY AREA

GENERAL

In the study area, the maximum elevation is 528 m (Nandivella hills) in the SE direction and the minimum elevation is below 100 m at the periphery, in the southern portion. The average relief is 200 m. A major portion of the study area comprises of Deccan basalts which are gently dipping lava flows showing an uneven or rolling topography. Towards the south, a small portion is covered by miliolite limestone showing karst topography, wherever exposed. There are three basaltic lava flows of varying thickness. The whole area oonstitutes a vast zone of dissection of the lava flows (Fig. 12) which has produced a striking landscape comprising of flat topped hills, ridges, mesas, questas, conical hills, radiating spurs multiple scarps, pediments, pediplains and valley fills.

Methodology

A base map for working out the geomorphological set-up of the study area was prepared from Survey of India Topographical Maps on a 1 : 50,000 scale. LANDSAT-5 Thematic Mapper False Colour Composite (TM FCC Band : 2, 3 & 4 : Path/Row - D 150-045 - 28/03/86 : D 149-045 - 24/03/87 and D 149-046 - 9/4/87) satellite imagery on a 1 : 50,000 scale were visually interpreted using Large Format Optical Enlarger (LFOE). The interpretation was carried out at the Remote Sensing Cell, Gujarat Jalseva Training Institute (GJTI), Gandhinagar.

The interpretation details from the LANDSAT-5 imagery were transferred onto the base map. All landform features of the study area have been broadly clasified into two groups viz. erosional and depositional (Fig. 13). The identification key (Table : 4) was prepared based on studies of aerial

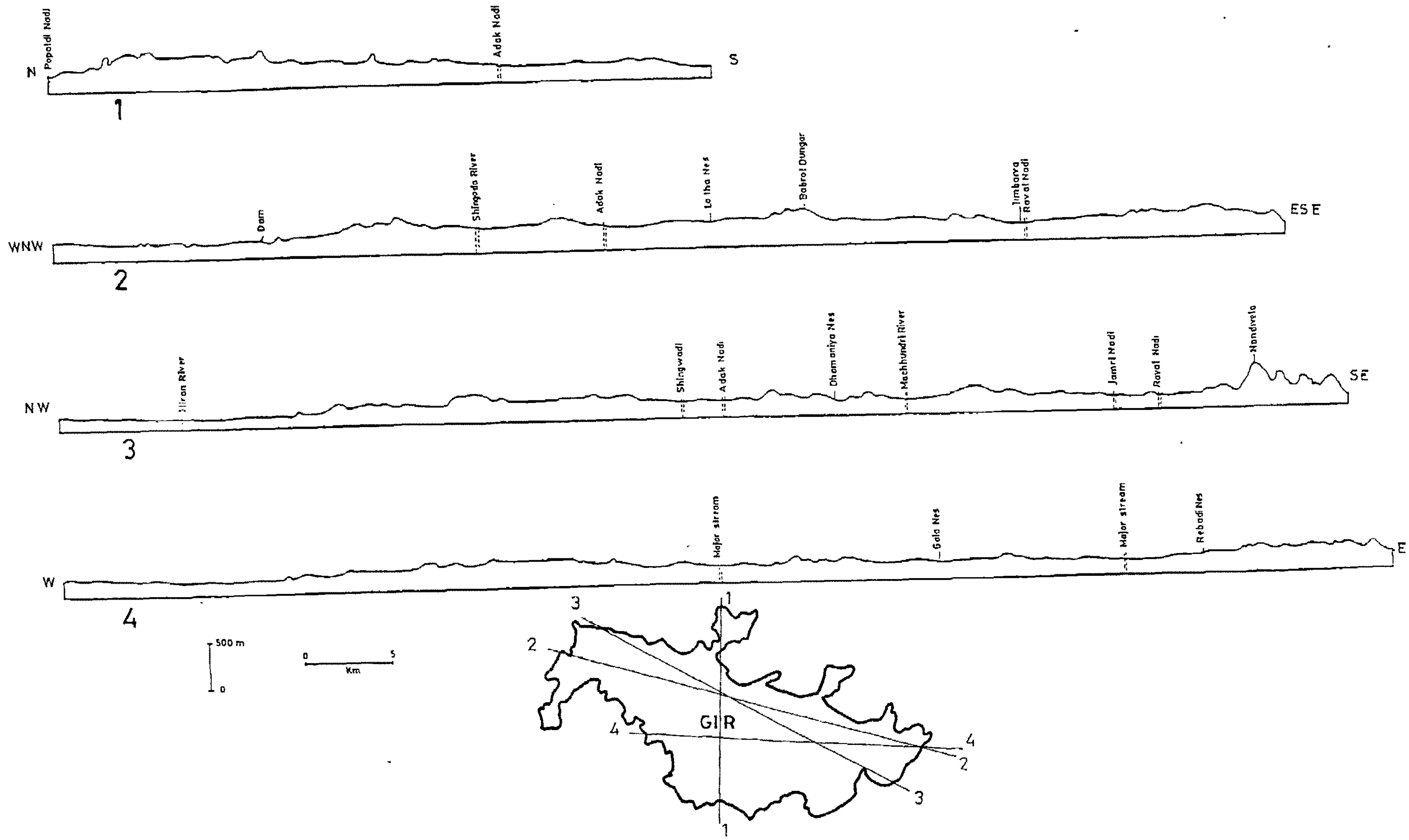


FIG. 12 . PROFILES ACROSS THE GIR AREA

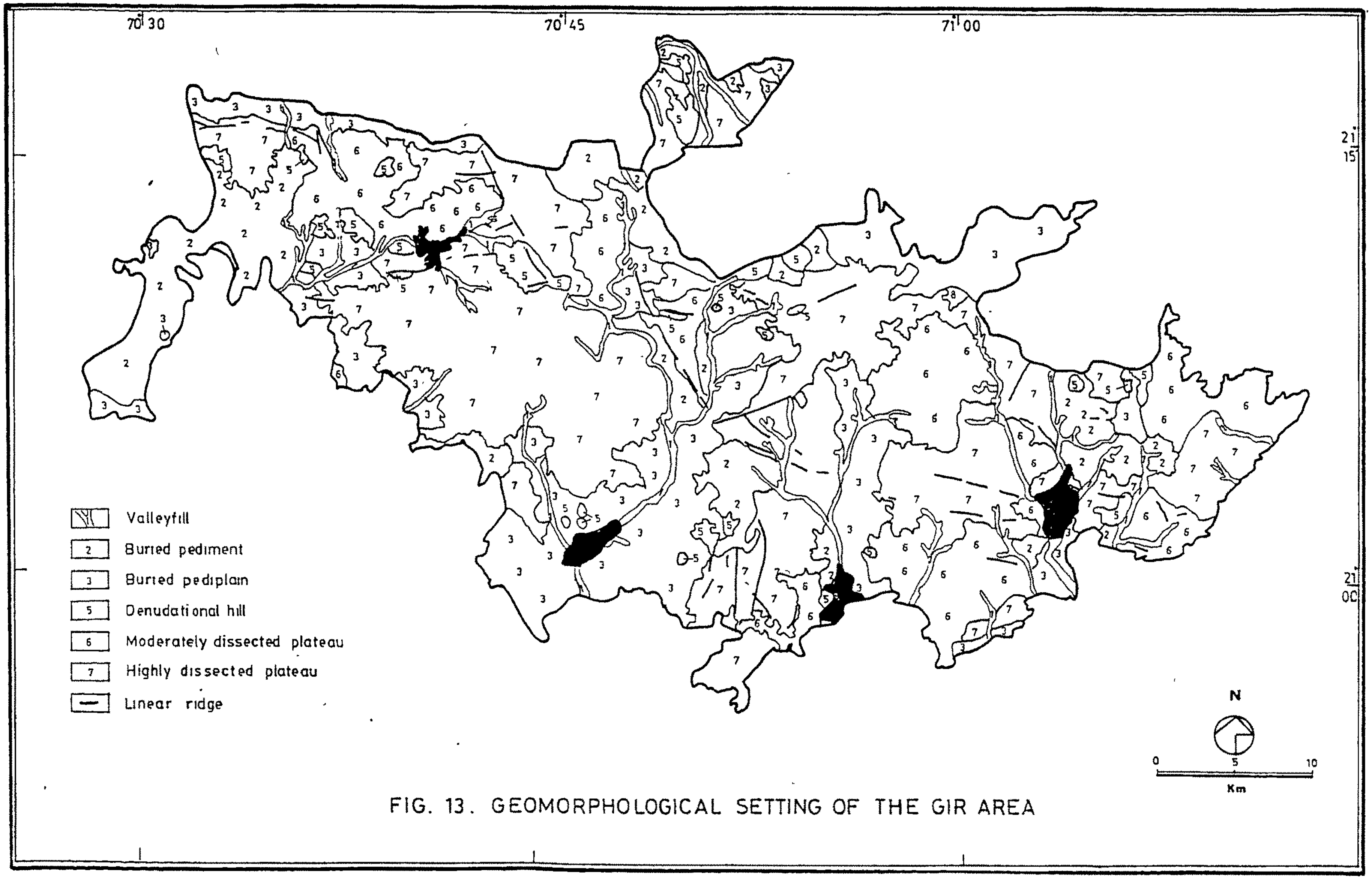


FIG. 13. GEOMORPHOLOGICAL SETTING OF THE GIR AREA

photographs (wherever available), LANDSAT satellite imagery, topographical maps, followed by ground truth checking.

Table - 4

Identification key for geomorphological categorisation from LANDSAT satellite data.

SR. NO.	CLASS	TONE	TEXTURE	OCCURRENCE (only type areas)
1.	Highly dissected plateau	Reddish black	Coarse	Around Wansali, Nimma Nes and Dayra Timbi.
2.	Moderately dissected plateau	Reddish with bluish tinge	Coarse	Around Alawani, Jambuthala and Dudhala.
3.	Denudational hill	Pale red with off-white tinge	Rough	Vansadhol hill.
4.	Buried pediment	Reddish brown	Smooth	Around Devaliya & Beriya Nes.
5.	Buried pediplain	Orange to dark red	Smooth	Around Amritvel, Sirwan & Janwadla
6.	Ridge	Dark red with greyish tinge.	Slightly rough	Along Chasa Gola
7.	Valley fill	Bluish with reddish tinge.	Rough	Along all major rivers/ streams.

The important landforms are breifly discussed below.

EROSIONAL LANDFORMS

(1) Highly dissected plateau

This geomorphic unit shows maximum areal extent in the study area. It is well observed around Wansali, Dayra Timbi and Nimma Nes in the western part of the study area, where it forms a compact block. It ranges between 354 m to 160 m elevation. The dissection has resulted into steep to moderate slopes and "V" shaped valleys (Plate : 28). The top portions are generally covered by soil. This can be best described as a flat to gently sloping landform, with extensive dissection forming level lands alternating with deep valleys. Top portions of this unit are generally covered by soil, whereas the slopes have a very thin cover of soil or weathered material. Along the moderate slopes, the soil cover is medium in thickness. At some places, the parent rock is exposed along the escarpments. Bouldary outcrops are also common.

(2) Moderately dissected plateau

This geomorphic unit is well observed around Alawani, Jambuthala and east of Dudhala in the NW. It is also well represented in the NE, SE, east and central parts of the study area. The slopes are moderate to gentle (Plate : 29). It ranges between 323 m and below 200 m altitudes. The soil

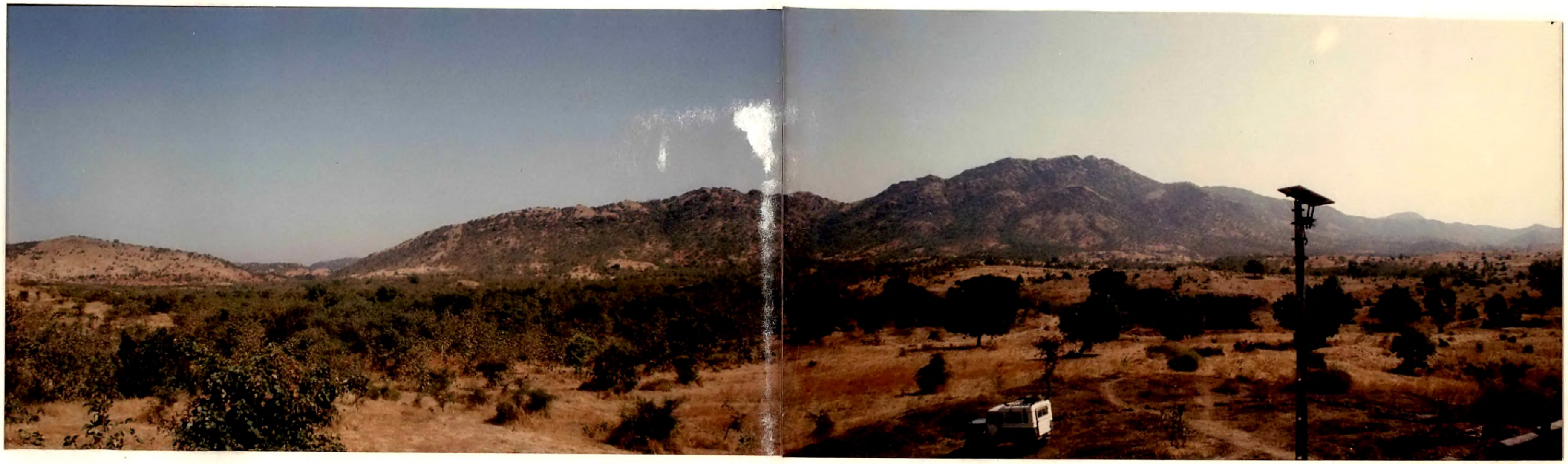


Plate 28 : Steep to moderate slopes and 'V' shaped valleys produced by dissection.

Plate 29 - Moderate to gentle slopes of a moderately dissected plateau.

Plate 30 - Isolated conical hill.

cover is moderate to thin. This unit exhibits relatively moderate dissection. Both the above (highly and moderately dissected plateaux) landforms also incorporate flat topped hills, radiating spurs, multiple scarps, mesas, cuestas and linear to curved ridges. Except ridges, other landforms are difficult to be indicated on the map.

(3) Denudational hill

This includes isolated conical (Plate : 30) to flat-topped hills (Plate : 31). It covers a very small portion of the study area and is well distributed. This geomorphic unit is best represented by the Nandivela hills, having the highest peak with an altitude of 528 m from m.s.l., lying in the SE corner of the study area. Selective denudation, as indicated by valleys and deep gorges is due to the removal of less resistant country rock as compared to the more competent intrusive bodies. The slopes are very steep and have given rise to radial drainage pattern. The phenonmenon of mass wasting is well exhibited and the landform is mainly covered by weathered material.

(4) Buried pediment

This geomorphic unit is described as a broad, gently sloping rock floor, erosional surface of low relief, covered essentially with relatively thicker alluvial, colluvial or

Plate 31 - Flat - topped hill.

Plate 32 - Weathered and colluvial material of buried pediment.

weathered materials (Plate : 32). Although well distributed, this unit is extensive in the western part of the study area. It is found bordering the dissected plateau unit and is well observed around Devaliya and Beriya. It ranges between 200 m to below 120 m elevation. The slope is moderate to very gentle. The soil cover, mainly black cotton soil, or weathered material cover is thick. Along the river channels, this geomorphic unit is covered by alluvium at some places, mainly in the central and eastern parts of the study area.

(5) Buried pediplain

The coalescence of a number of pediments towards the end of the cycle of erosion produces a pediplain, a broad landscape of low relief broken by isolated residual uplands (Plate : 33). When a thick overburden of weathered material overlies, it forms buried a pediplain. It ranges between 160 m to below 100 m altitudes. This unit, generally bordering the hills or plateaux, is well observed around Amritvel, Sirwan, Janwadla, in the southern part of the study area. It is also well represented in the NW, NE and central parts of the study area. It is extensively covered by soil and is usually cut across by valley fills.

(6) Ridges

Ridges are the most striking and well distributed topographical features in the area (Plate : 34).

Plate 33 : Isolated residual uplands in a low relief landscape.

Plate 34 : Striking ridges in the study area.

Chasa Gola, the high peak in the western portion of the study area is 480 m above m.s.l. and forms a part of a series of linear ridges aligned in a roughly E-W direction. In the north western and central portions, curved ridges trending NW-SE to NNW-SSE are prominent. These ridges are made up of dacitic flows, whereas in the southern portion, these are N-S trending, high, linear ridges composed of rhyolite and quartz veins. Most of the ridges are flat-topped. The slope is steep to moderate.

DEPOSITIONAL LANDFORMS

(1) Valley fills

Valley fills are the unconsolidated sediments deposited so as to fill or partly fill a valley (Plate : 35). This feature is commonly observed in the southwestern, central and eastern parts of the study area.

Valley fills are found in the major river and stream channels of Gir, viz. Hiran, Shingoda, Machhundri, Raval, Adak, Jamri Nadi, etc. Thickness of the alluvium generally increases as one moves from the west to east i.e. it is less in Hiran river and more in Raval. The valley fills become broad towards the south as they encounter miliolite limestone, which is easily weathered. The valley fills along Machhundri and Raval extend right from the north to the south of the study area.

Plate 35 - Unconsolidated sediments in a valley fill.

Apart from valley fills, along certain banks of all the rivers, thick alluvial deposits are also found (flood plains).

DRAINAGE

The study area is very closely drained by a number of rivers and streams (Fig. 14). The general slope is towards the south and so most of the rivers flow north to south. The drainage pattern shows mixed characters of dendritic and structural features. The total drainage network of the study area is shared by 17 river basins viz. Hiran, Saraswati, Dhatardi, Shingoda, Adak, Dhamaniya, Machhundri, Ghodavadi, Shingawadi, Rupen, Jamri, Raval, Malan, Dhantarvadi, Shetrunji, Popatdi and Ambaji.

The study area is split up by a number of watersheds from which streams run in all directions and feed six principal rivers viz. Hiran, Dhatardi, Shingoda, Machhundri, Ghodavadi and Raval, which are seasonal. The straight courses of the major rivers and streams indicate that they follow major lineaments.

For explanation purpose, the study area is divided into two units (1) the western unit, and (2) the eastern unit.

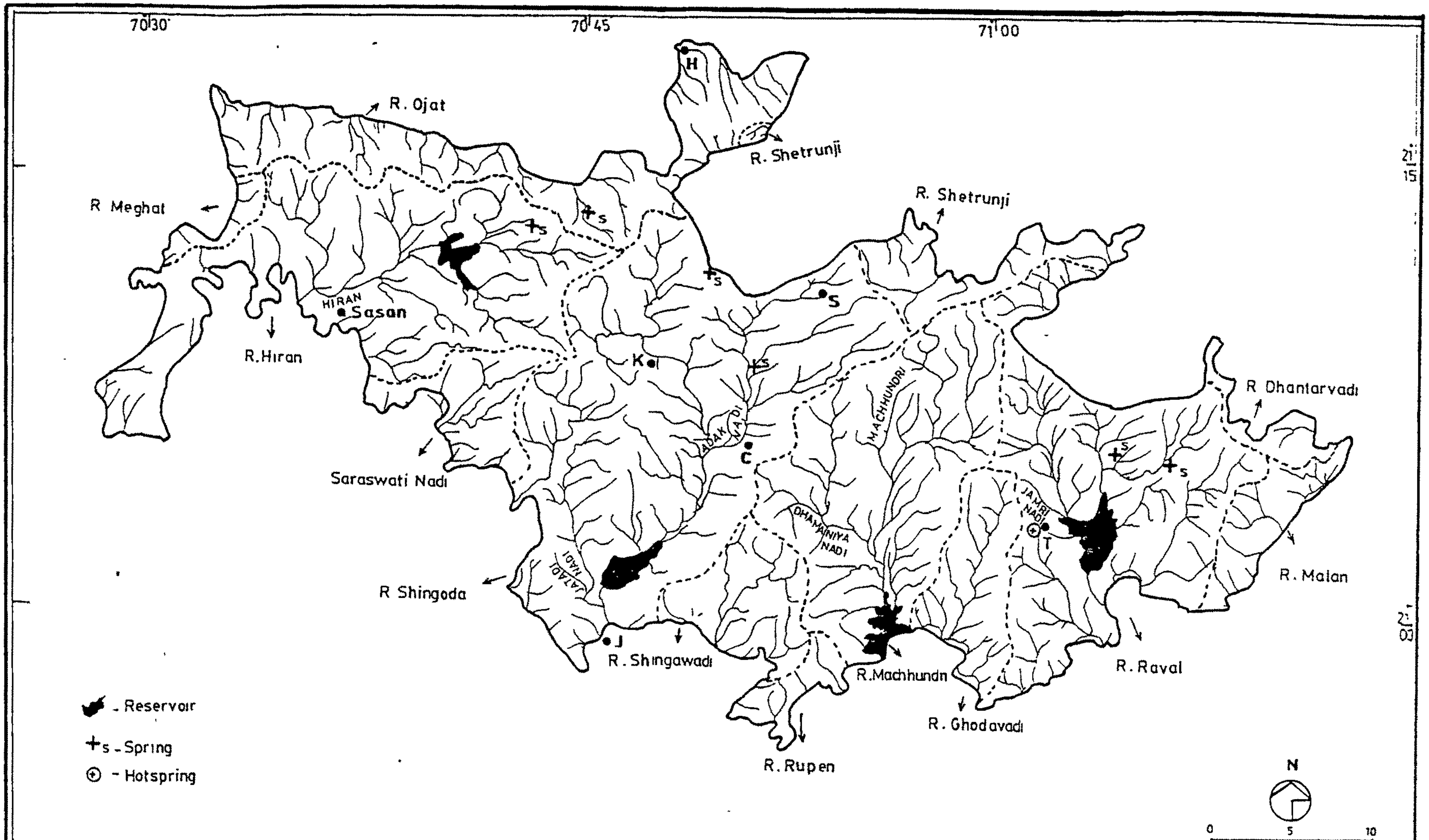


FIG. 14. GENERALISED DRAINGE MAP OF THE GIR AREA

The Western Unit

The western unit comprises part of the study area falling in Survey of India Topographical Map nos. 41 K/8, K/11, K/12 and 41 L/9 & 10.

Drainage pattern in the western unit is sub-dendritic to parallel or trellis. This is due to the dykes (which are easily weathered) and the large number of fractures that cut across the area in a definite pattern. A water divide occurs in the northeastern part of this unit in the form of ridges, trending nearly E-W from Khajuri to Alawani Nes to Dudhala Nes to Kosra Dungar. A major part of the area that lies to the south of this water divide is drained by Hiran river in the west, Saraswati Nadi in the south-west and Dhatardi Nadi in the south-central part of the unit. All these rivers flow towards the south and drain the area towards the coast further south. The area lying to the north of the water divide is drained by the tributaries of Ojat river. All the rivers in this unit are seasonal.

The Eastern Unit

The eastern unit comprises part of the study area falling in the Survey of India Topographical Map nos. 41 K/15, K/16, 41 L/13, 41 O/4 and 41 P/1.

Drainage pattern in the western half of this unit is mainly subparallel to trellis. This is due to the dykes (which are easily weathered) and the large number of fractures that cut across the area in a definite pattern. The drainage pattern in the eastern half is mainly radiating and dendritic at the higher altitudes. A prominent stream in the central part of this unit forms a gorge. The major streams are generally aligned in N-S orientation and are oblique to the structural trend of the area which has been dictated by the prominent long dykes emplaced along ENE-WSW and WNW-ESE directions.

Three water divides occur in the north and north-eastern part of this unit, as given below.

(1) Water divide occurs in the form of ridges trending nearly E-W from Lasa Dungar to Goradwala Nes to Khajuri, in the western unit.

(2) The WNW-ESE trending water divide occurs in the form of high hills passing through Hadala Nes to Jamwali Nes to Sap Nes to the adjoining Sarkala Dungar and finally to Karkaria Dungar and further northwest.

(3) The nearly E-W trending water divide passes through the north of Khadadhar to .377 hill to adjoining Chakosar Dungar and further north.

A major part of the area that lies to the south of these water divides is drained by Jatadi Nadi, Adak Nadi, Shingoda river and tributaries of Hiran river in the west; tributaries of Shingawadi Nadi and Rupen Nadi in the south; tributaries of Malan Nadi in the east and Jamri Nadi and Raval River in the central part of this unit. All these streams flow towards the south and drain the area towards the coast, further south.

The area lying to the north of these water divides is drained by the tributaries of Dhantarvadi Nadi and Shetrunji river in the northeast; Popatdi Nadi, tributaries of Ambaji Nadi, Fuljar Nadi, Devthaniya Nadi and Badhukiya Nadi in the northern part of this unit. All the rivers in this unit are seasonal. A hot spring, in the central part of this unit exists at Tulsishyam. The water shows a temperature of 51^{o}C, emits a sulphurous odour and is supposed to be of great medicinal value.

SLOPES

A slope is the property of inclination of the ground surface or of a profile line from the horizontal or dip of ground surface. All the landforms exhibit a variety of slope elements and it is for this reason that the slopes are expressed as steep slopes, moderate slopes, gentle slopes, etc. i.e. simultaneous expression of actual land surface and its orientation in space. Slope constitutes one of the most important geomorphic element in the evolution of landscape, as it is the function of lithology, structure and climate. The slope analysis is of prime importance in the development of soil and in the evolution of landforms as well, because the gradient controls the amount of run-off, the degree of rock disintegration and the development of soil. Moreover, slope development is primarily related to erosional processes and hence a slope map can easily reveal the erosional characteristics of the region.

The slope is described in a number of ways. According to Young (1972), the slope may be classified as `level' ($0^o$ to $0^o$ 30'), `almost level' (0^o 30' to 1^o), `very gentle' ($1^o$ to $2^o$), `gentle' (2^o to 5^o), `moderate' ($5^o$ to $10^o$), `moderately steep' (10^o to 18^o), `very steep' ($30^o$ to $40^o$) and precipitous to vertical ($45^o$ or more). The first three classes represent the `flat' areas of a typical erosional landscape. Gentle slopes are usually exhibited by pediplains. Moderate and moderately steep slopes are typically found in regions transitional between plains and deeply dissected areas, whereas the steep to very steep and vertical slopes are the characteristics of deeply dissected regions.

The slopes have also been described as `gentle', `steep', `sigmoid' or `concave' corresponding respectively to youth, maturity and old stages of the cycle of erosion (Davis, 1930). Savigear (1956) has described slopes as `convex', `concave', `straight' or `rectilinear', `concave-convex' and `complex'. King (1957) and Miller and Summerson (1960) described the slopes as `waxing', slopes with low angles of $1^{\circ}$ to $2^{\circ}$ on hill tops, `free face', slopes with high angles of 45° or more, `debris', slopes with angles of $15^{\circ}$ to $35^{\circ}$ lying immediately below the `free face' slope and `pediment', slopes with $3^{\circ}$ to $15^{\circ}$ angle lying in front of `free face' and `debris' slopes.

The study area is characterised by `convex', `concave' and `straight' or `rectilinear' slope profiles, with all transitions of slope from `waxing' to `free face' to `debris' to `pediment' slope. The Gir, thus shows `complex' type of slopes that are `convex', `concave', `straight' or combinations of all the three, which is indicative of a polycyclic and/or structurally and lithologically controlled terrain (Savigear, 1956).

The slope is a very significant geomorphic feature that requires utmost consideration not only in the study of the evolution of landscape, but also in the study of development of soils and growth of vegetation. Keeping this in mind, an average slope map of the area (Fig. 15) was prepared following the method described by (Strahler, 1956; Singh & Singh, 1981).

From the data for slopes (Table : 5), it is observed that out of a total study area of 1412.13 sq.km, a majority of the

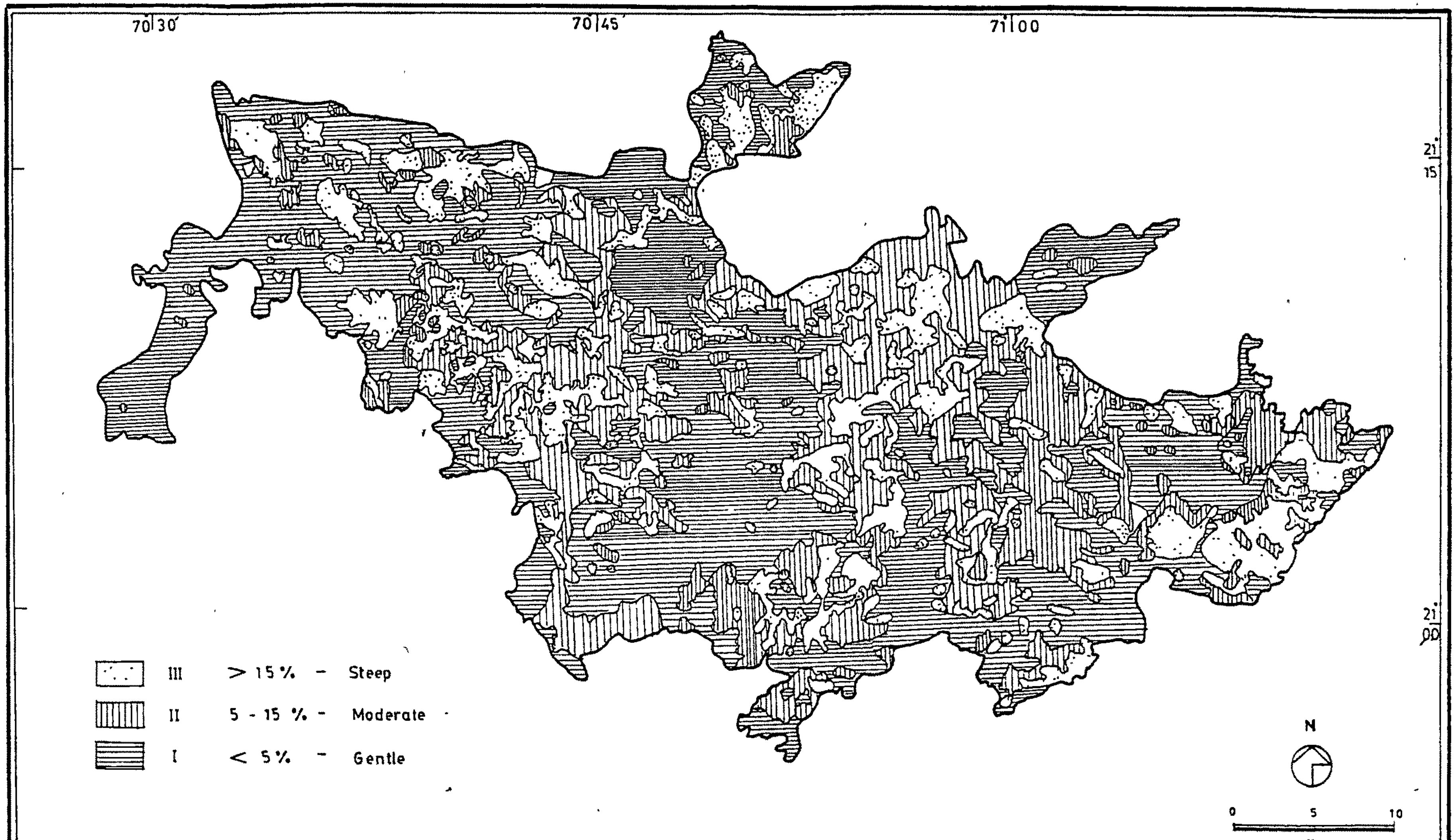


FIG. 15 AVERAGE SLOPE MAP OF THE GIR AREA

area is occupied by level to gentle slopes (651.07 sq.km, 46.11%), 315.90 sq.km (22.37%) area is occupied by moderate to moderately steep slopes and the remaining 445.16 sq.km (31.52%) area exhibits steep to very steep slopes.

Table - 5

Slope analysis of the study area

Slope category	Slope class	Slope in percentage.	Area occupied (in sq. km).	Area occupied in percentage
Gentle	I	0-5%	651.07	46.11 %
Moderate	II	5-15%	315.90	22.37 %
Steep	III	> 15%	445.16	31.52 %

The moderate to very steep slopes are seen to correspond, geomorphologically, with dissected plateau and denudational hills; while the gentle slopes are seen to be correlatable with valley fills, buried pediments, buried pediplains and dissected lowlands. During field work it was seen that the gentle slopes were characterised by the development of a somewhat thicker soil profile, in contrast to the thin and sparse soil cover corresponding to the moderate and steep slopes.

GEOMORPHOLOGY-VEGETATION RELATIONSHIP

The relation between the sciences of geomorphology and vegetation differs essentially from that existing between geomorphology and the earth sciences. The reason for this is that a landscape-ecological relation is concerned between two elements of the land, both of which are visible in the field as well as in satellite imagery. As a result, the two sciences mutually support each other when thematic mapping is at hand and in various degrees, depending on the environmental situation (Verstappen, 1983).

The philosophy behind this concept is that the vegetation occurring at a certain locality reflects the effects of all environmental parameters combined. A study of the vegetation offers a clue to the role of each of these environmental parameters in the ecological situation prevailing at that locality, and thus yields information of practical importance for the study and development of an ecosystem (Verstappen, 1983).

The geomorphological situation sets the scene for the development of the ecosystem (Howard & Mitchell, 1980). Landform, and particularly its vertical component, relief, is an important factor. Broad vegetation patterns often show a close relationship with the topographic situation. The reason for this is that landform and particularly elevation, affect

Table - 6

Geomorphology - Vegetation relationship in the study area

Forest type	Geomorphic feature	Some typical flora
Dry deciduous teak forest	Buried pediplain & pediment	T.grandis, Boswellia, Sterculia, A.catechu
Dry deciduous mixed forest	Highly and moderately dissected plateaux, and occasionally denudational hills and valleys	T.grandis, T.crenulata, A.catechu, Bosewellia
Open scrub forest	Buried pediment and pediplain, and ridges	A.latifolia, A.catechu, T.crenulata, B.monosperma
Riverine forest	Along the river valleys, streams and nallah banks	P.pinnata, S.rubicundum, T.grandis, F.benghalensis
Thorn scrub forest	Buried pediplain, low ridges and moderately dissected plateau	A.nilotica, A.catechu, Z.mauritiana, A.senegal
Savanna	Highly and moderately dissected plateaux, and ridges	Acacia & Zizyphus species, D.cineria

the climatic and/or microclimatic situation and influence the environmental conditions for plant growth.

A close examination of the vegetation data (Fig. 4; Table : 1), and the geomorphological features (Fig. 13), reveals that there is a close relationship between the two. This is aptly brought out in Table : 6.