CHAPTER - VI

DEPOSITIONAL ENVIRONMENTS

GENERAL

On the basis of field studies in the various river sections, bore-hole data and depositional and erosional landforms in the study area, a very well defined sequence of continental deposition has emerged. The composite sequential stratigraphy (Fig. 4.1, Table 4.1) not only provides a good insight into the succession of geological events of the late Quaternary; the entire thickness furnishes numerous evidences towards prevalence of depositional conditions fluvial as well as aeolian, periods of non-deposition and pedogenesis and effects of neotectonism at all stages of the landscape evolution.

In this chapter, the author has highlighted the importance of data generated by him through a number of laboratory analyses. In order to understand fully petrographic and lithologic details relevant to the diverse processes of deposition and erosion, representative samples of sediments belonging to different horizons from several localities were collected and analyzed in the laboratory. It may however be noted that as the main thrust of the present study was field based on the actual outcrops which provided almost all the major details, the author has put limited emphasis on laboratory investigations restricting them only to the most essential ones with a view to obtain supportive evidences.

His investigations towards analysing and interpreting the nature of the sediments mainly consisted of (i) visual appraisal of gross-lithology, (ii) granulometric studies with emphasis on particle size variation, (iii) thin section studies of the different components of gravel beds, (iv) XRD studies for the identification of minerals and (v) EDXRF for knowing the chemical nature of silts and clays.

ANALYTICAL HIGHLIGHTS

The various analytical procedures listed above were selectively carried out, taking into consideration the nature of the various formations. The salient features of the information obtained have been described in the following lines.

(i) Visual appraisal of the various sediments

The samples of all the horizons from different locations were visually examined to know their approximate grain size, grain size variation, variation in colour and texture, degree of compaction and other distinguishing features. On the basis of such a study which was carried out for all the formations, it was possible to obtain a first hand and dependable lateral and vertical variation in different part and enabling the author in appropriately correlating the various horizons. Such an examination was also found useful in respect of the samples which were subjected to various analysis.

(ii) Thin section studies

Thin section studies were carried out for gravelly horizons with a view to understand the nature of the finer clastics and matrix. These studies have thrown light on the lithology of the finer clastics, their shapes and sizes, revealed their likely provenance, and the presence of various diagenetic and pedogenetic components. Petrographic studies were carried out for the gravelly horizons I and II.

(iii) Granulometric studies

These studies included size and shape studies with greater emphasis on particle size variation. The data was utilised for determining (i) Mean size (ii)

Standard deviation (iii) Skewness and (iv) Kurtosis. These studies were carried out for the silty (fluvial as well as aeolian) layers as well as sands mostly aeolian.

(iv) X-Ray Diffraction Studies

This study was carried out on the samples belonging to the basal clay horizon and to those of pedogenised horizons. This investigation has led the author to understand the mineralogical changes related to the phenomena of pedogenic processes.

(v) X-Ray Fluorescence Studies

This technique was applied for studying the chemistry of the clay horizon, rubified and other pedogenised horizons, to obtain information in respect to percentages of various elements present in them. The information obtained was to a certain extent useful in understanding the exact nature of rubification.

HIGHLIGHTS OF RESULTS

The results obtained from the various analytical studies carried out on the sediments of various horizons go a long way in furnishing crucial information which provide an insight into the depositional environments, sedimentary processes and post-depositional subaerial changes. Highlights of the results pertaining to the successive lithostratigraphic units are briefly described.

Basal Blue Clays

This basal clay horizon which has been reported from the Mahi and Narmada river basins (Pant and Chamyal, 1990; Chamyal and Merh, 1992 and Merh and Chamyal, 1993), obviously shows its development practically all over Gujarat plains and according to Merh (1992, 1993) it could be representing a marine clay of Middle-Pleistocene age. Although these clays could not be investigated in detail, but considering their bluish green mottled colour and almost uninterrupted presence towards the sea, they do appear to comprise tidal clays. The granulometric data reveals that the main bulk consists of about 70-75% clay fraction. The clay minerals in order of decreasing abundance are illite, chlorite and montmorillonite. Small percentage of smectite and vermiculite are also noticed, the absence of kaolinite is significant. Chemically the clays are found to be rich in SiO_2, Al_2O_3 and CaO. The high CaO content is attributed to the phenomena of calcretisation (Table 6.1).

LAKRODA FORMATION

This formation resting over the clays is divisible into two members and represents two fluvial cycles of deposition. As it has already been stated earlier the two cycles are separated by a thin weakly pedogenised fractured mud. Studies on the sediments of the two cycles have provided important information in respect of their depositional characteristics. The constituent rocks have been subjected to a very careful observation, both in the field as well as in the laboratory.

LOCATION	NO. OF SAMPLES ANALYSED	TEXTURAL			CLAY MINERALOGICAL					CHEMICAL							
		SAND	SILT	CLAY	ILL	MON	CH	S	V	SiO_2	Al_2O_3	CaO	MgO	TiO_2	Fe_2O_3	K_2O	MnO
Sadolia	2	12	18	70	35	30	20	8	7	72.2	12.5	4.3	1.5	1.06	4.6	2.26	0.09
Lakroda	3	8	20	72	39	38	16	4	3	70.1	15.5	4.5	1.7	1.08	3.7	1.01	0.08
Oran	2	10	15	75	42	33	15	5	5	68.7	14.2	5.9	2.8	1.08	4.32	2.31	0.09
Madhavghat	3	13	16	71	48	34	16	2	0	69.1	13.1	4.4	2.6	1.07	3.8	2.41	0.07
Sadra	2	8	20	72	39	35	21	3	2	69.5	12.2	5.6	2.3	1.09	4.12	2.31	0.06

ILL : Illite; MON : Montmorillonite; CH : Chlorite, S · Smectite; V : Vermiculite

Table 6.1 : Textural, clay mineralogical and chemical data of bluish clays.

The oldest gravel (Valasana member) is seen to comprise clastic grains showing a size variation ranging from cobbles to fine sand; at many places, the gravels tend to be clast supported, whereas at other places, the coarser clastics are embedded within a matrix of finer particles which may or may not show cementation. In case of cementation, either it is calcite or ferruginous matter. The gravels are crudely stratified and show both normal and inverse graded bedding. In hand specimes the clasts are found to be mostly of quartzite with some granite.Thin section studies of the finer clastics (matrix) reveals quartz and microcline feldspar. The quartz grains are of two varieties - rounded to sub-rounded and angular to sub-angular. The feldspar is almost invariably subangular. The cementing agency is calcite and mostly a sparite.

In totality these gravels give a picture of their containing sediments which show two sources of derivation. The rounded cobbles, pebbles and smaller clastic grains typically points to a distant provenance and a long journey of transport whereas angular quartz and feldspar are indicative of a nearby source. This textural feature is of much significance towards a proper understanding of the formation of this gravelly horizon.

The Sindari member, again a gravel which marks the beginning of the second fluvial cycle is separated from the underlying gravel by a pedogenised mud horizon and typically characterised by cross-stratification and numerous interbeds of finer gravel and coarse sand which shows normal as well as inverse graded bedding. The nature of this gravel is quite different from the underlying one. Though it shows presence of clasts with a wide range of variation from cobbles to coarse sand, the main bulk of coarser fragments is of pebble size, large size fragments being scarce. Significantly this gravel bed is highly compact, almost rock like and could very well be termed a conglomerate.

The coarser clastics are embedded in finer matrix and at places are cemented by calcium carbonate. The pebbles are of mostly quartzite with a conspicuous proportion of granite calc-silicate, feldspar (microcline and perthite), agate, jasper and chert. The calcareous cement is indicative of diagenesis by water rich in calcium carbonate occupying the interstices and subsequently precipitating sparitic calcite. This feature has considerable significance from the point of view of provenance rocks and the subsequent physico-chemical conditions responsible for the $CaCO_3$ precipitation.

HIRPURA FORMATION

This single member formation developed extensively all over Gujarat is more or less marker horizon and characterised by 6 m thick reddened (rubified) silt. Since it does not show any clearcut stratification it is difficult to decide whether the silts are fluvial or aeolian. The various laboratory studies have however established this silts to be of fluvial origin.

Granulometric studies have shown that the fine sands and silts which form the main bulk fall within the range of very well sorted to well sorted (Av. <0.35 to 0.51 Φ), the grains are very finely skewed (Av. 0.3 to 1.9 Φ) and platykurtic (Av. <0.67). The finely skewed trend is indicative of the fact that the sediments were derived from one source and are unimodal. The plots of skewness versus standard deviation (Fig. 6.1a) fall within the river area thereby suggesting that the sediments were laid under fluviatile environment. The bivariate diagram showing the mean size versus standard deviation (Fig. 6.1b) well illustrates the fact that the sediments are intermediately matured and fall within the well to very well sorted regimes.

The red colouration has been found due to the presence of finely divided ferric oxides. This pedogenised formation was perhaps made up of fine sand and silts dominantly quartz and clays and sandy silt. Subsequently pedogenesis imparted red colouration and generated secondary carbonate pellets.

SAROLI FORMATION

This formation overlies the Hirpura formation. On the basis of the grain size, it has been divided into three units. Its development is intermittent and is represented by a discontinuous horizon comprising lensoid bodies best seen in the Sabarmati river section. On the basis of grain size, the formation is seen to be made up of a lowermost mud layer over which rests a coarse sandy layer which is topped by discontinuous gravel occurrences. Studies have shown that the main component of the formation is fine sand and coarse silt, the gravels are less prominent.

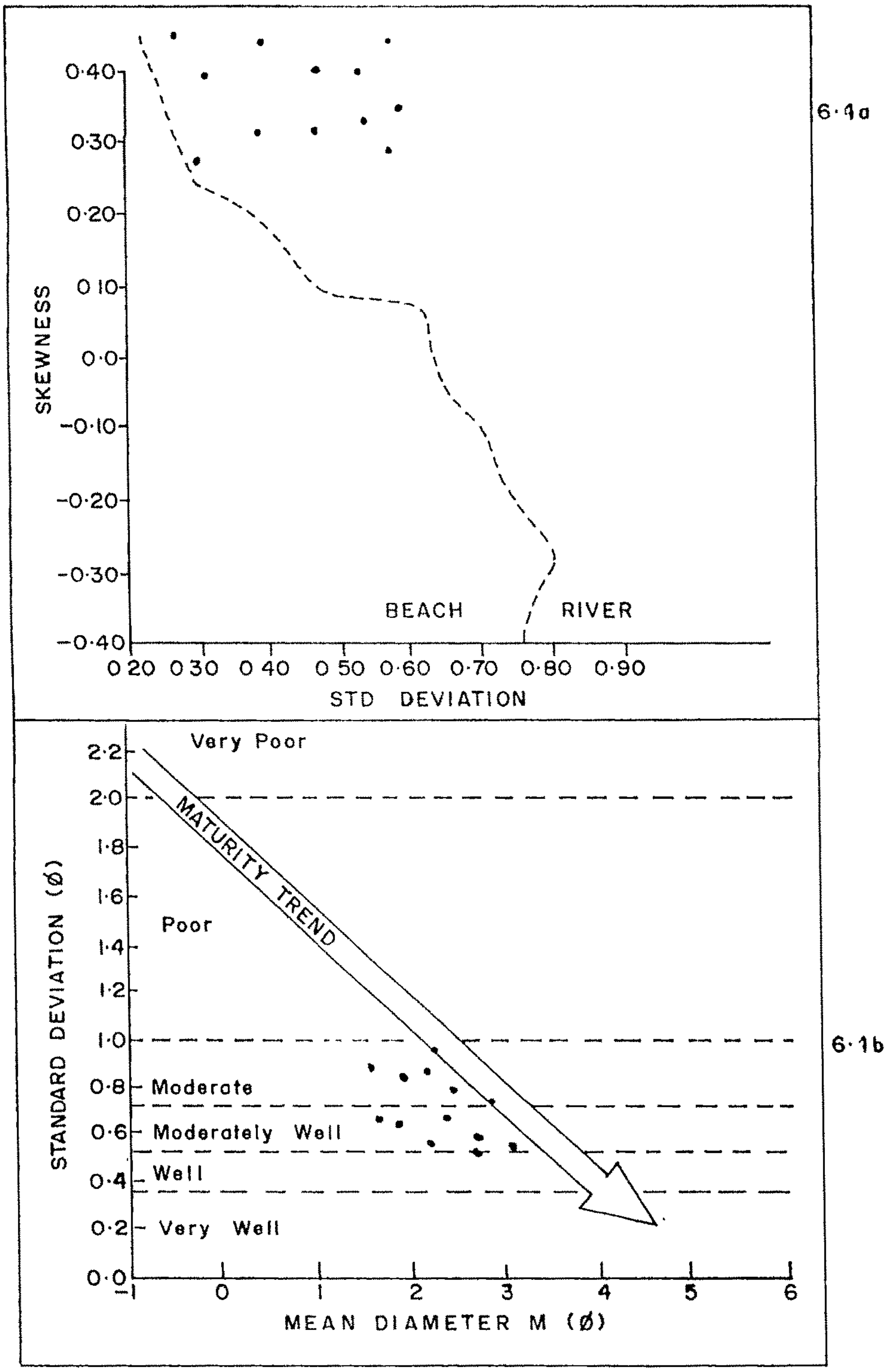

Fig. 6·1 PLOTS OF STANDARD DEVIATION VERSUS SKEWNESS AND MEAN SIZE

MAHUDI FORMATION

The two members of this formation viz. a lower one made up of mostly of medium to fine silts with some fine sand and the upper member being sandy and more or less unconsolidated. The plane of seperation is marked by a pedogenised surface except for the frequent part of stabilisation, the sands of the upper member are undistinguishable from the present day shifting sands. The top of this formation typically exhibits a dunal topography consisting of stabilised as well as unstabilised silts and sands.

Granulometric analysis has revealed the sediments of Deesa member to comprise mostly silts and fine sand, though their relative proportions may vary from place to place. The coarse silts are the most dominant and form 40 to 60% of the total grain size bulk. The sediments show a poor to very poor sorting (Av. 1.0 to 3.0 Φ), coarse to fine skewness (-0.3 to 0.3 Φ) and leptokurtic to very leptokurtic nature (Av. 1.11 to 2.1 Φ). These characteristics considered together with the structureless porous and homogenised thickness typically suggest an aeolian mode of deposition. In fact this entire formation points to its having been deposited since the onset of the Terminal Pleistocene aridity. The lower part (Deesa member) has been referred by most earlier workers (Chamyal and Merh, 1992; Merh and Chamyal, 1993) as loess like. These aeolian silts show considerable resemblance to the typical loess and its sections stand out as vertical bluffs in the Sabarmati river. Studies under microscope have shown that the constituent grains are of quartz, feldspar grains are angular to subangular, poorly sorted and devoid of any layering or laminated. Almost all over, the entire bulk of the thickness does not show any layering either based on size or mineralogy and this characteristic is a clear indication of their having been deposited by aeolian processes.

The upper part of this member is characterised by a very well marked pedogenesis and the entire thickness is replete with several layers of calcrete. The mineralogical and geochemical characters related to the pedogenesis have been described later on.

Whereas the top of the Deesa member invariably shows a buried soil horizon, the sands of the Ogadpura member which form the topmost part of the Quaternary sequence are more or less unconsolidated, mostly made up of very fine to fine sand particles.The periodic wet spells of the more recent times have imparted a certain degree of stabilisation to these shifting sands, but this phenomena is not universal and the major bulk of this member has to be included as forming the Recent sand accumulations of the present day Thar desert environment. No pedogenesis and calcretisation could be attributed to this member.

DISCUSSION OF THE RESULTS

The laboratory studies provide an insight into the nature of the deposits, both fluvial and aeolian and in addition to furnishing supportive data, also provide certain details which are important in understanding the finer details of the depositional processes, periods of non-deposition and pedogenesis. The successive events leading to the evolution of the existing continental landscape and the layered sequence are adequately reflected in the various sediment characteristics.

On the basis of a selective study of the samples in the laboratory, it has been possible for the author to obtain a clearer picture of the various events that took place during the accumulation of the sediments of the study area. Apart from the variations in the nature of successive fluvial regimes, the most important phenomena that has affected the course of sediment accumulation, is that of several periods of pedogenesis which are preserved in the form of paleosol horizons, buried soils, calcretes etc. The author has highlighted his observations as under :

1) The oldest exposed Quaternary horizon in the study area, the basal bluish clay appears to have been deposited under marine conditions during the Middle Pleistocene high sea. This horizon comprises 70 - 75 % of clay and is rich in illite, chlorite and montmorillonite.

2) Subsequent to their deposition the clays were exposed to subaerial weathering processes, during which it underwent pedogenisation. This is evidenced by the development of calcrete veins, strings and tubes. The high CaO content is also attributed to this phenomena.

3) The overall geomorphic setting of the Valasana member of Lakroda formation marks the onset of fluvial sedimentation. The depositional direction was southwesterly. The mean direction of the longest axes of the

gravels is also NE-SW; the original flow direction was quite oblique to the present day river flow.

4) The gravel characteristics point to their formation by the process of a low viscosity debris flow (Bull, 1963 and 1977; Lindsay, 1968 and McArthur, 1987). The range of phi and the inclusive graphic standard deviations fall very well within the one suggested by Bull (1963), according to whom the phi deviation for the mud (debris) flow deposits ranges from 4.1 to 6.2 for semi-arid alluvial fans. That the gravels originated mainly by a combination of debris and muddy stream flows is evidenced by the fact that they fulfil the various criteria postulated by Ballance (1987), Bull (1963 and 1977), Hooke (1967), McArthur (1987) and Pierson (1981) for invoking a debris flow deposition. According to Pierson (1981) such deposits are formed during flood events in a humid climate when the gravelly channel oscillates between a very muddy stream flow to a debris flow.

5) Fractured mud horizon which overlies this gravel indicates that the energy conditions of the depositing streams progressively weakened and finally the deposition stopped and exposed to weathering. The pedogenisation of this mud points to the period of non-deposition before the onset of the next fluvial cycle.

6) The Sindari member overlying the Valasana member is characterised by the second gravel. The various characteristics point to their being a product of stream flow deposits (Hooke, 1967; McArthur, 1987).

7) The rubified sediments of Hirpura formation are typically fluvial; this is revealed by the textural characteristics. These sediments are reddened by a subsequent pedogenetic process; the red colouration is due to the presence of finely divided ferric oxides, chiefly hematite, magnetite and goethite.

8) Formation and preservation of red beds can occur only in relatively inactive or episodically active geomorphological environments and Hirpura rubified sediments indicate again a period of non-deposition and pedogenisation, prior to the onset of the next fluvial cycle.

9) The overlying Saroli formation that again consists of riverine sediments belongs to the third fluvial cycle. It however, points to a reduced energy system as compared to the processes responsible for the formation of the underlying gravelly deposits. The absence of coarse gravel units, the presence of sand, silt and mud reveals that the sedimentation took place through a fluvial form of intermittent flood deposits loosing energy after debouching from the pediment zone of the foothills.

10) The absence of pedogenetic features in the Saroli formation indicates a rapid onset of aridity, leading to deposition of the overlying windblown material without any time gap of appropriate climatic conditions that would have brought about pedogenesis.

11) The overlying Mahudi formation made up of aeolian silt and sand that forms a blanket like cover over the fluvial sedimentation is characterised by near total absence of layering or lamination. This feature is supported by appropriate grain size parameters and provide clear indications of aeolian processes being responsible for the deposition of this formation. Interestingly, a break in deposition and pedogenisation between the two aeolian members points to a brief somewhat wet spell intervening the two dry phases.

Field studies duly supported by laboratory data, have brought out the fact that the onset of more than one event of exposure of earlier deposited sediments to subaerial processes, thereby bringing about pedogenetic changes and giving rise to some well defined soil profiles. This striking feature is of considerable paleoclimatic and depositional importance. Both the aspects of this phenomena have been described in the following chapters.