CHAPTER - V

D E P O S I T I O N A L   E N V I R O N M E N T S

INTRODUCTION

The depositional environment is the complex of physical, chemical and biological conditions under which sediments accumulate (Krumbein and Sloss, 1963). The environment regime that controls the process of sedimentation accrues out of a combination of various processes associated with sedimentation. In determining the sedimentary environment it is imperative to take into account the physical sedimentary aspects of clastic sequence which is related to the chronology and the nature of stratification within a stratigraphic section. The lateral persistence or lenticularity of bedding planes and the thickness of individual bed gives the information on continuity of any depositional process. The variation in lithological units in the stratigraphic sections together with their colour, cementing material and mineral constituents play an important role in reconstruction of any environment. The relative proportion of minerals like quartz, felspars, micas and heavies also serve as essential parameters in recognizing the environment.

The vertical stratigraphic succession, grain size and their sorting are directly used in interpreting the energy level. The presence of various primary sedimentary structures throws considerable light on the energy supplied by depositional medium to the clastic detritus. The current velocity, wave action and settling velocity that give rise to graded bedding, cross bedding, ripple mark etc. characterises the processes of sedimentation. The occurrence of cyclic sedimentation is suggestive of tectonic & eustatic changes and fluctuation in provenance or deposition by point bar. The clay minerals and plant fossils play equally decisive role in interpretation of environment. The flucuation in paleoclimate and stability of depositional basin is of prime importance in reconstructing the depositional environment.

STUDY AREA

The author in the following text has attempted to interpret the depositional environment of Himatnagar sandstones on the basis of colour, variation in grain size, sedimentary structures, mineral maturity and occurrence of organic matters.

Colour

The most conspicuous aspect of these sandstones is their consistent pink red colour in most of the sections examined throughout the study area. The pink colour is mainly on account of finely divided hematite (Fe_2O_3). This hematite pigment occurs either as a coating on quartz particles or as isolated opaque grains. However, where two quartz grains are in immediate contact such red coating is missing. The red pigment is originated in marine as well as non-marine environments by more than one mechanism (Freedman & Sanders, 1978), and consists mostly of hematite. The diagenetic process includes the aging dehydration of brown amorphous ferric oxide to goethite (limonite), hematite and dehydration of goethite to hematite in modern sediments. The warm climate promotes the alteration of brown limonite to red hematite pigments covering sand grains. In humid tropical climate hematite is formed by oxidation of ferrous iron derived form rock forming mafic minerals (pyroxene, honblende, biotite, chlorite). Hematite gets physically transported to the site of deposition. In moist tropical climate, the hematite formed from yellowish and brownish hydrated ferric oxide gets into alluvial sediments either as (a) finely divided soil weathering products, transported and deposited by river or (b) insitu alteration products of fresh ferro-magnesian silicates. The machanism of forming thin film of hematite on quartz particles appears to be obviously a chemical precipitation. In hot arid climate the insitu alteration of hydrated brownish iron oxide derived form oxidation of mafic silicates gives rise to hematite in span of time.

Walker (1967) has advocated insitu weathering of iron rich minerals as major source of ferric oxide in desert red sands. The hematite that forms as an early diagenetic product acquires its chemical remnant magnetism as it grows through critical crystal size and continues to grow as long as limonite is available. Van Houten (1968) has suggested that the common black oxide grains include not only hematite but magnetite, ilmenite and titaniferous hematite originated in relation of magnetism. Both Van Houten (Op-Cit) and Walker (Op-Cit) believed that most of the diagenetic hematite in sandstones owes its origin to inplace alteration of iron rich minerals in hot dry regions.

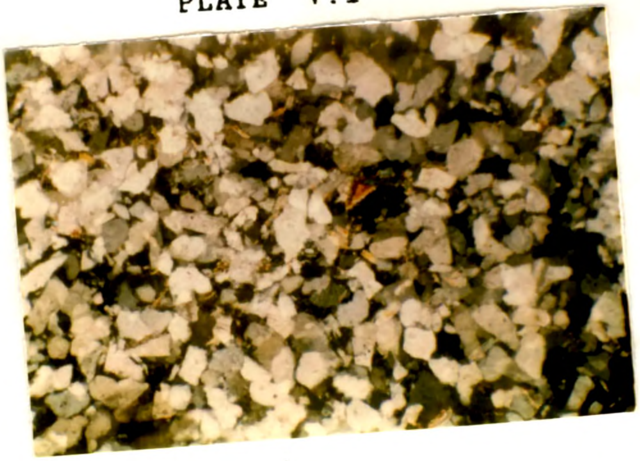
The presence of red beds suggests the role of warm climate as the modern reddish soils are seen in a belt around 30 N or S of Equator. In modern tropical region of Mexico-Columbia and PuertoRico, it is found that the pigment in alluvium is brown throgh the soils are red colour. With the passage of time and suitable environment, this brown pigment ultimately becomes hematite. Friedman and Sanders (Op-Cit.) have invoked two reactions (a) Creation of brown pigment from minerals containing ferrous iron and (b) conversion of brown pigment to red pigment due to either a hot dry or a tropical moist climate. This alteration may take place in a time ranging from hundreds or thousands of years to a few million years. The conversion of the brown pigment to red hematite could take place in soil profile as well as intrastratally within alluvium. Most of the pigments are formed probably in situ but some of them may have transported with other mineral particles.

The source material for Himatnagar sandstones is from Delhis/Aravallis and Erinpura granites brought to the present site by fluvial agencies. The hematite seems to be derived from the ferro-magnesian minerals of the provenance rocks like granites (biotite, tourmaline and hornblende), basic intrusives (pyroxenes, olivine and opaques) and metamorphic Delhis & Aravallis (staurolite, biotite and hornblende) under the influence of climatic variation. It is seen that the Himatnagar and the surrounding area lying around 23 N Latitude is experiencing humid tropical to tropical climate.

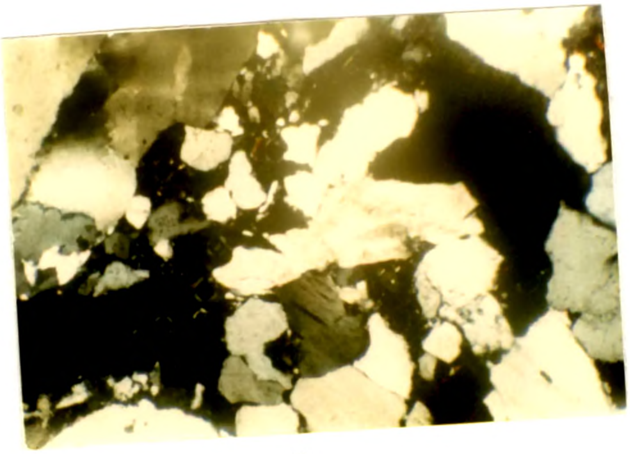
Grain size variations (Cyclothems)

The conspicuous feature of Himatnagar sandstones is that it shows the variation in grain size decreasing from bottom to top giving rise to the fining upward sequence (cyclothem) in many outcrops. The fining upward sequences with more than one cycle are seen in the number of exposures in the study are and have been described at length in chapter III. They are frequently seen in the river bed of Hathmati near Himatnagar and low lying exposures of Panpur and Ilol (Plate V.1). Generally the lower part is coarse grained, at places gravelly conglomeratic, and is overlain by medium to fine grained sandstones and finally silty

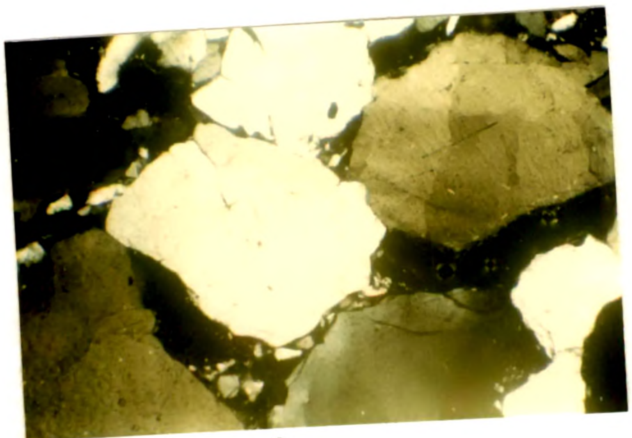
PLATE V.1



A



B



C

Photomicrograph Showing Fining Upward Sequence in Sandstones
(a) Fine Grain, (b) Medium Grain, (c) Coarse Grain
(Crossed Nicols, x 30 (a & b), x 60 (c))

to clayey layers at the top. In some exposures two to three such cyclothems have been encountered. The various workers have explained such deposits under dominance of fluvial regime where they have emphasised the nature and distribution of grain size, sorting and sedimentary structures developed commonly by fluvial processes Sundborg, 1956; Wolman and Leopold, 1957; Beerbower, 1964; Visher, 1965; Allen and Friend, 1968; Reneick and Singh, 1973; Klein, 1975; Friedman and Sander, 1978; Selly, 1982; Pettijohn, 1984 etc.). Visher (1965) considered that valley fill or point bar deposits are constructred by lateral accretion under fluvial regime. In such cyclothem the sequence from base to top of channel is deposited simultaneously. The various fluid flows distributed vertically within a channel during flood stage are responsible in producing the different lithological units and sedimentary structures. According to Visher (1965) the fluvial sequence comprises the following three litholigical zones from bottom to top.

I) The basal zone is coarse and containing pieces of wood or bones known as bedload zone, where the transport is primarily by traction or rolling along the channel bottom.

II) The middle zone is massive at the base and is characterised by festoon or planar cross-bedding. The variation and migration of features like irregular dunes or sand waves within the fluvial channel produces the festoon or planar cross bedding. The transportation in this zone is by traction and suspension.

III) The topmost zone is horizontally bedded comprising find sand, silt and clay, and is related to settling out of suspended sediments during the waning stages of the flood and/or accretion of sand during falling water velocities. The fine material is on account of the deposition of suspended sediments outside the fluvial channel due to reduction in flow velocity and water depth. Additionally, the presence of roots, leaves and stems characterises the flood plain sediments under fluvial regime.

According to Klein (1975), fining upward sequences are common in highly sinuous meandering streams. However, the braided sandy and gravelly systems according to above author, grade into fine alluvial silts and clays.

Selly (1982) considered the red coloured interbedded sequences of conglomerates, sands and shales to be of alluvial origin, largely related to the morphology of river channels deposited in (a) high sinuosity meandering channels and (b) low sinuousity braided channel complexes. The high sinuousity meandering river channels typically develop where gradient and discharge are relatively low in comparison to low sinuousity braided channel. In the humid vegetated areas where the seasonal discharge rate is fairly steady and sediment availability is relatively low (due to subdued topographical relief), the vegetation has impending affect on soil erosion and lateral erosion of channel margins. With increasing distance from the source, the gradient of river profiles and grain size of the sediments decreases while there is increase in sinuouisty. The resultant alluvium as a result, shows active channels, abandoned channels and over bank facies. In meandering channels the proportion of silt and clay is more with less sand and gravel. The more sedated lateral migration of meandering river channels generates a regular fining upward grain size, correlative with variety of sedimentary structures. The over bank or flood plain facies is usually laminated and ripple marked, deposited largely out of suspension during floods. The lateral migration of a meandering channel erodes the outer concave bank scouring the river bed and deposits sediments on inner bank (Point bar). This produces a characteristic sequence in grain size and sedimentary structure. At the base is an erosional surface overlain by intraformational pebbles and water logged drift wood. This originates as lag deposits on the channel floor and are overlain by a sequence of sand with general vertical decrease in grain size. The massive flat bedded and trough cross bedded sands of diminishing height. These in turn, grade into micro cross laminated and flat bedded fine sands grading finally into silts of flood plain subfacies.

DISCUSSIONS

The origin of fining upward sequence and its repetition is a matter of considerable debate. It is correlatable with eustatic sea level changes during ice age as far as the Quaternary alluvium is concerned (Turnbull et.al 1950). The erratic subsidence of basin founded by active faults may owe to the development of cyclothems in flood plain deposits. As also the cyclic climatic changes with resultant pulsating fluctuation in sediment input has been found responsible for upward fining sequences. Beerbower (1964) explained the repetitive cycles by lateral migration of a river channel across its flood plain, in co-ordination with a gradual isostatic adjustment of the basin floor in response to the weight of sediment. According to this author the cyclothems occur repetitively at any point and shows uncorrelatable section which are shortly spaced and of local extension.

In ancient alluvial facies, upward fining cycles are repeated over great thicknesses of strata. This cyclicity of fluvial deposits or cyclotheme is described from Devonian Old Red sandstones of the North Atlantic margins of Applachians and South Wales near Spitzbragen (Allen and Friend, 1968; Allen and Friend, 1965 resp.)

Thus the cyclothems (variation in grain size) in Himatnagar sandstones represent, coarse grained at places conglomeratic gravel at the bottom, medium to fine grained in the middle and clayey in the topmost layers. The conglomeratic gravel beds correspond to channel lag deposition. The overlying medium to fine grained sandstone is indicative of deposition in point bar/channel environment of fluvial regime. The topmost silty and clayey layers suggest the floodplain deposition. Such cyclothems are suggestive of the deposition in channel and point bar deposits dominantly under fluvial regime.

SEDIMENTARY STRUCTURES

A variety of sedimentary structures seen preserved in Himatnagar sandstones are mostly inorganic in nature and belong to primary as well as secondary category of Pettijohn (1984). The primary structures recognised are the planar bedding structures (laminations, cross bedding & graded bedding) and bedding plane irregularities (cut & fill structure). The secondary structures are mainly accretionary structures that include the nodules, concretions, colour bandings etc.

Primary Structures

The sandstones are well bedded containing the planar as well as lenticular. The thickness of the individual bed in most of the exposures vary from 0.3 m to 1 m. The predominant internal structure in cross bedding. The planar as well as festoon cross beddings are seen in a number of exposures throughout the study area. These cross beddings owe their origin to the migration of sand waves under a shallow and turbulent flow at or above the profile of equilibrium (Pettijohn 1984). Cross bedding on a large scale with beds inclined at low angles is formed by accretion of sands on point bars during the migration of meanders (Blatt et al; 1972). The cross stratification may also originate due to migration of ripples, scour & channel fill and deposition on point bar (Reneick and Singh 1973).

In alluvial deposits the mean current direction is generally down slope. The Himatnagar sandstones are fluvial deposits, with the paleo current directions due west and suggests clearly that the sedimentation is by westerly flowing rivers systems. Graded bedding as seen in some of the sandstone exposures suggests the deposition in relatively deeper water, below the wave base (Pettijohn, 1984). Scour and fill structures indicate the erosion of the earlier sedimentation and refilling during the course of subsequent deposition.

Secondary structures

These are mostly the accretionary structures; the most conspicuous being the colour banding. They show white, grey, yellow, pink, brown, red, buff etc. coloured bands. The red, pink and buff colouration is due to the coating of ferruginous material on the surface of the quartz grains. This structure is developed due to accretion by precipitation or segregation under eH & pH conditions that show a range from 0 to 0.1 and 7 to 8 respectively.

The ferruginous nudules and egg shaped concretions along the bedding plane are frequently seen in Himatnagar and Panpur exposures. In cross section the concretions show differential alteration from centre towards the outer periphery. These concretions suggest the presence of ferruginous material in the pore space which later on redeposited around precipitating nucleus to give rise to the concretions.

STABILITY OF MINERALS.

GENERAL

The stability or maturity of terrigenous constituents throws much light in interpreting the depositional environments. The factor controlling the stability of any grain depends upon its chemical composition, deuteric, hydrothermal & weathering conditions, climate, topography etc. Minerals that form late in igneous rocks, crystallising under cooler and more hydrous conditions are most stable in sediments because they are more nearly adjusted to the relatively cold sedimentary environments. The order of chemical stability given below is approximately reverse of Bowen's reaction series (Folk 1968).

Quartz, Zircon, Tourmaline	These minerals can also be formed by chemical precipitation.
Chert	
Muscovite	
Microcline	
Orthoclase	
Albite	

Anorthite

Hornblende, Biotite

Pyroxene

Olivine

Quartz is ultra stable under nearby all surface conditions and very little quartz is dissolved by weathering. However, on burial in the sub-surface, only under moderate pressure and temperatures quartz may occasionally be dissolved giving sutured quartz grain. Felspars are unstable under deuteric, hydrothermal and weathering conditions. Alteration gives rise to Kaolinisation, sericitisation and bubble formation (Vaccuolisation). This felspar may alter from source rocks by (i) deuteric or hydrothermal activities or by weathering and (ii) Post depositionally by migrating connate water on deep burial or by exposition of the sedimentary rocks to surface weathering. Muscovite is stable except under very warm and humid condition. Biotite and chlorite are unstable under oxidizing conditions where both biotite and chlorite alter to limonite and clay minerals.

STUDY AREA

As far as the mineralogical maturity of Himatnagar sandstone is concerned, it constitutes > 95% quartz. The source rocks are either metasedimentaries or igneous ones, lying northeast of the study area in N.Gujarat. It is also seen that most of the quartz grains are angular to sub angular which suggests the nearness of source. In circumstances when the source of sandstone is also from nearby Erinpura granites, with less transportation, there could be abundance of felspars in sandstone. However, the Himatnagar sandstones are impoverished in felspar content, and this throws a considerable light on climate and tectonism that the study area has experienced during their deposition. This aspect has been discussed in the following text :

The origin and significance of felspars in sandstone has been a subject of considerable debate. According to Mackie (1899), in arid and extremely cold climate, the process of chemical weathering could be slow hence felspars will not be decomposed, and would accumulate in sediments. Thus the felspar bearing sedimentary rocks are indicators of ancient desert or glacial environment. Krynine (1935) emphasises higher relief with consequent rapid erosion of granitic rocks for the formation of felspathic sandstones. Gibbs (1967) considered the absence of felspar in the suspended load of tropical tributaries of Amazon basin mainly due to climate. According to Folk (1968) the rate of intensity of decomposition of felspar is dependent upon climate while the rate of erosion of felspar bearing plutonic rocks is controlled more by relief. Strakhov (1969) has suggested that in a humid climate and granitic drainage basin, active tectonism would produce felspathic sandstone and passive tectonic condition would form quartz rich sandstones. Pettijohn (et al., 1972) opined that high relief and not rigorous climate is responsible for formation of felspathic sandstone. Subsequently he (Pettijohn, 1975) reiterated that felspars are poorer in tectonically stable areas and under such conditions at or near base level, chemical decomposition of source rock is complete and only material of sand grade is mainly quartz. If the relief is low, rate of erosion is slow and climate is favourable the felspar will be completely decomposed. The impoverishment of felspar could be the result of decomposition of felspar in the weathering profile. The presence or absence of felspars is therefore "the result of balance struck between the rate of decomposition and rate of erosion." The quartz rich sandstones are characteristic of a stable platform or cratonic area. Raiverman (1975) considered the paucity of felspars near granite provenance due to deep weathering of granite before on set of sedimentation. Hoque (1976) considered two cycles of deposition on Cretaceous sandstones of Southern Nigeria, the one rich in felspar is of near source while the second one, poor in felspar, is away from provenance. According to him (Op cit) the humid climate was not effective enough in removing all the felspars because of high relief in the first cycle. The humid climate and longer transportation between source area and site of deposition could remove effectively all labile particles like felspars from detrital and produce mineralogically mature sands in second cycle. The tectonic stability could be the governing factor in Cretaceous sandstones of Southern Nigeria.

The author is of the opinion that the paucity of felspar in Himtnagar sandstones is due to following reasons.

1. Where the provenance is Erinpura granite-the quartz has angular to sub angular grains, suggesting nearness of source. The less transportation of sediments with paucity of felspars indirectly suggest that the abrasive processes during transportation might have played insignificant role

in the decomposition of felspars. The deep weathering of granite in the provenance area might have resulted into near complete decomposition of felspars prior to on set of or contemporaneous with sedimentation.

2. The terrigenous material derived from metamorphic terrain (Aravallis & Delhis) may also inhibit the supply of felspars.

3. The deposition of Himatnagar sandstones over a long period of time in a low relief and tropical climate in mildly unstable platform or cratonic basin could have resulted in near complete decomposition of felspars.

ORGANIC MATTERS

The presence of fossillised wood and plant leaf impressions in shaly sandstones indicate the dominance of fluvial environments during the deposition of Himatnagar sandstones.

Thus the Himatnagar sandstones point to their deposition by channel/point bar deposition of meandering streams dominantly under fluvial regime with almost westward paleocurrent direction in oxidising environments, humid & tropical climate, in mildly unstable platform or cratonic basin.