CHAPTER - VII

GENETIC ASPECTS

GENERAL

CONTROLLING FACTORS

GENESIS OF MAINLAND GUJARAT LATERITES

GENETIC ASPECTS

GENERAL

The process of lateritistion and the precise factors responsible for the mineralogical and geochemical changes, and for the 'redistribution' of various elements in distinct horizons, are not yet fully understood. Although, a lot of attention has been given to the laterite occurrences the world over, with large number of workers describing lateritic and bauxitic rocks in various areas, no acceptable model has yet emerged. Inspite of a wealth of information provided by them, the genesis of a laterite profile has remained an enigma. The present author does not propose to go into the controversy that centres around laterite, and has prefered to summarise a few salient points of the problem, based on the excellent treatise on laterites by McFarlane (1976). He has preferred to confine his discussion to a few generally accepted mechanisms and factors that are important from the point of view of lateritisation and are of relevance to his own study.

There are essentially two main categories to which the laterites have been supposed to belong, viz. (i) Laterite as a residium (ii) Laterite as a precipitate

The concept of laterite as a residual deposit has been quite old, and by and large invokes the role of subaerial weathering processes aided on a limited scale by groundwater. The accumulations are attributed to the relative immobility of the constituents. It is assumed that the differing constituents accumulate essentially as residuum. Nevertheless, limited role of two phases of mobility have been invoked. First, a short phase when constituents were released from the parent material by weathering processes and regrouped into relatively immobile precipitates, followed by a second protracted mobile phase bringing about resolution and alteration of the residuum by groundwater.

On the other hand, those who have considered laterite to comprise essentially a precipitate, emphasize on the role of groundwater, which acted as a vehicle for enrichment. It is believed that the enrichment was caused by iron and aluminium in solution, moving into the enriched zones and being precipitated there. The validity of the mobilisation and precipitation mechanism is supported by the recognition of the fact that pallid zones (saprolite) typically underlie laterites. Two mechanisms have been invoked for this enrichment : capillarity and the water table fluctuations. Some of the early workers (Maclaren, 1906;

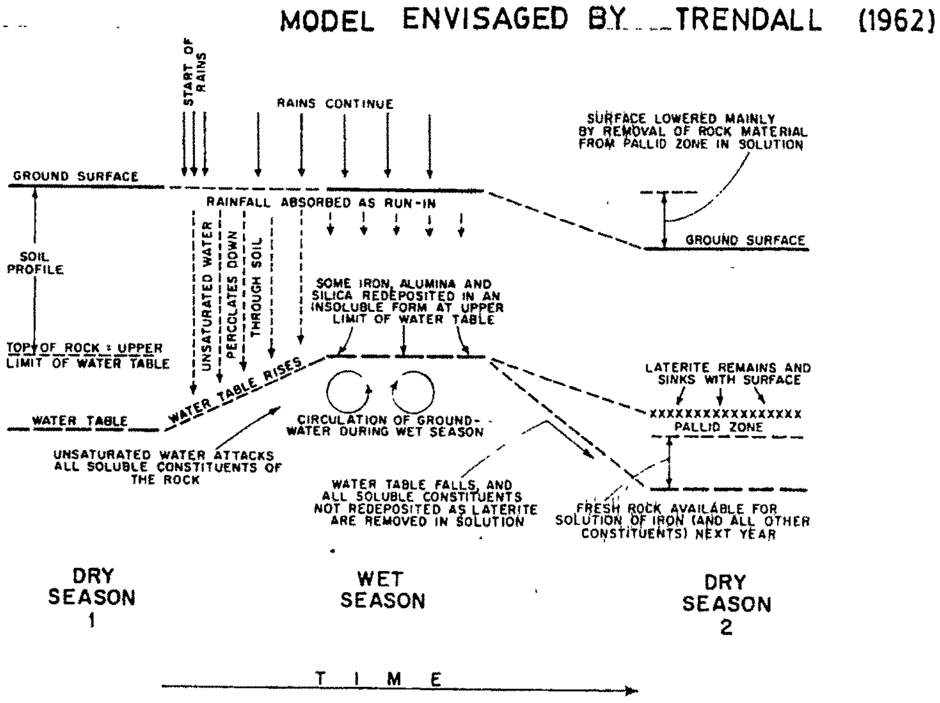
Harrassowitz, 1930; Woolnough, 1927 and Holmes 1914) attributed capillary action of groundwater to explain laterite formation. Although, this mechanism as a major factor, is no more acceptable to many, it has not yet been fully abandoned, and perhaps, has been found to be effective in some localities to explain the formation of duricrusts (Loughnan et al.1962; American Geological Institute, 1962; Stamp, 1961).

The effectiveness of the water table fluctuation in bringing about upward movement of iron and alumina is more widely accepted. This mode of enrichment envisages that the enriched solutions are carried upwards in the profile with the seasonal rise of the water-table and get precipitated near the upper limits of the range of fluctuation.

Two other models of laterite formation have also received some attention viz. detrital model (Mignien, 1966; McFarlane, 1969; Goudie, 1973) and model that combines the two original concepts of laterite as a residuum and that as a percipitate (Du Bois and Jeffery, 1955; Trendel, 1962).

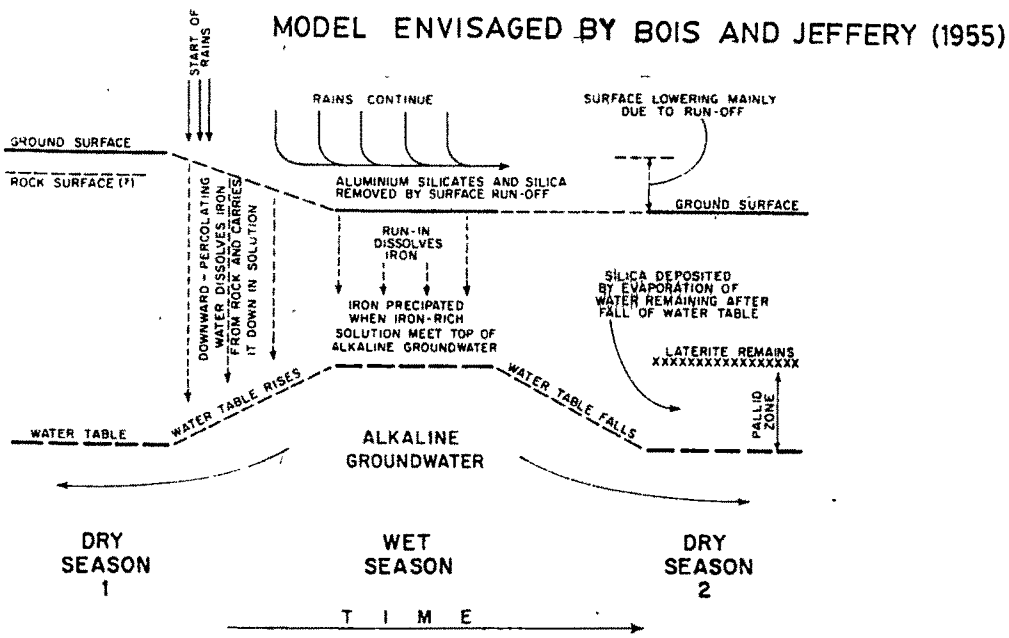
The various accepted models briefly described above are shown diagrammatically in the Fig. VII.1,2 and 3.

Although it is generally agreed that the process of lateritisation is one of repeated solution and deposition, yet considerable gaps exist in the precise mechanisms bringing about



MODEL ENVISAGED BY TRENDALL (1962)

Enrichment is entirely upwards from the underlying pallid zone. Groundsurface, laterite, and pallid zone sink, thereby incorporating progressively more lateritic constituents, so that the total quantity of concentrates in the laterite exceeds the depletion from the existing pallid zone.

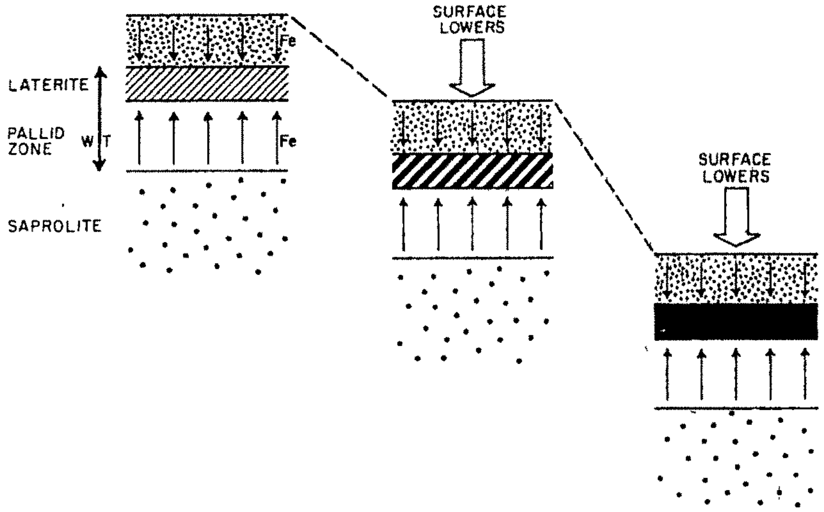


MODEL ENVISAGED BY BOIS AND JEFFERY (1955)

The laterite horizon remains stable. Enrichment derives entirely from an overhead source, no contribution being postulated from the underlying material.

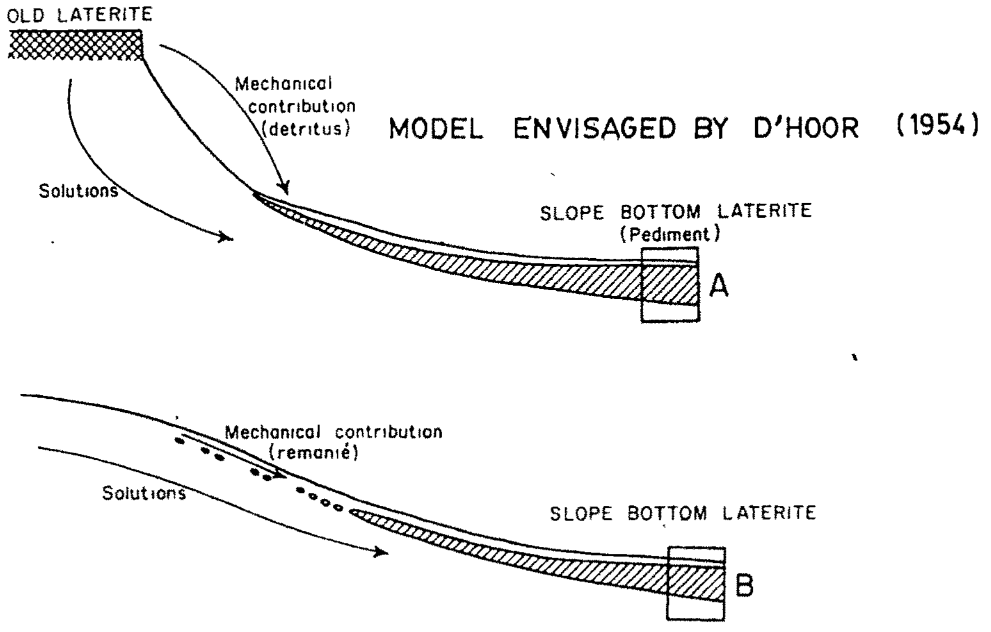
Fig: VII.1.

MODEL ENVISAGED BY SWARDT (1961)



The laterite accumulation is largely residual, deriving from an overhead source, but an upward contribution from the pallid zone is also postulated.

MODEL ENVISAGED BY D'HOOR (1954)

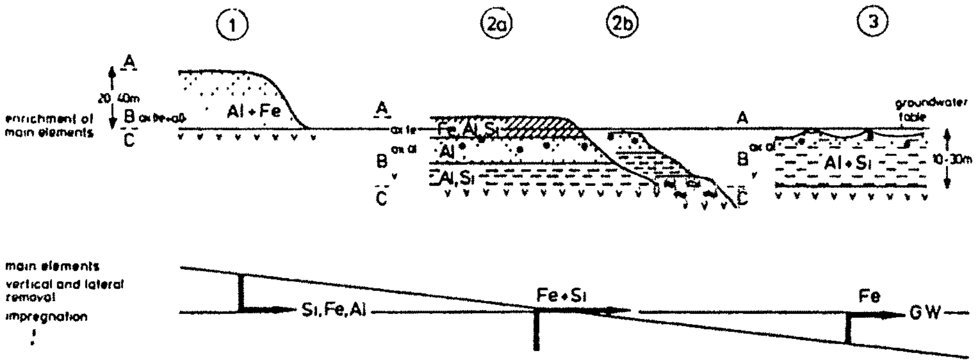


LATERITE DEVELOPMENT BY ABSOLUTE ACCUMULATION

Slope bottom laterites receive lateral contributions from higher topographic positions. These may be mechanical or in solution. Compare the laterite in situations A and B which are essentially similar although A is reputedly "secondary" and B "primary".

Fig: VII.2.

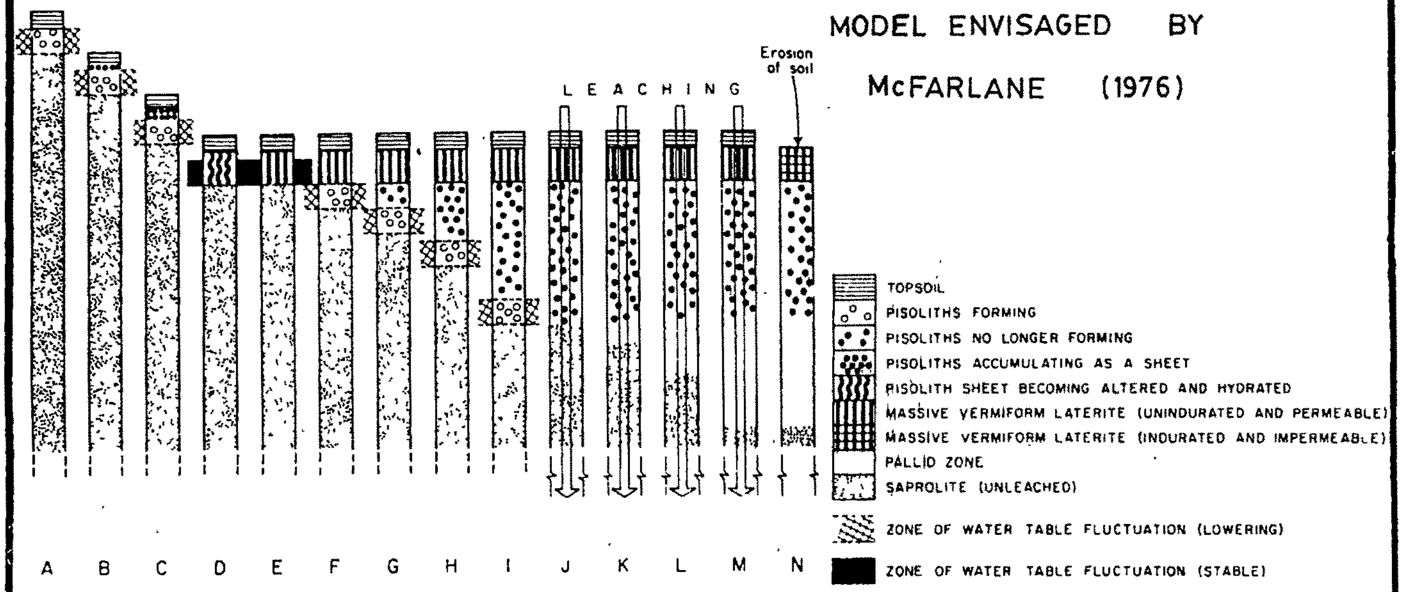
MODEL ENVISAGED BY VALETON (1983)



vertical differentiation of alteration profile	weak	extremely good	weak
direction of drainage	downward	mainly upward	upward
textures	mainly relic	- mainly neoformation - " neoformation - " relic	mainly neo formation
mineralogy	gi, go (he)	- he ka - gi (bo, di) - ka - bt	- ka (he) - ka (di, bo)

Schematic sections of the three main types of bauxitic alteration blankets. 1: Formation of bauxites at various levels above the watertable, without separation of Al and Fe. 2a: Low-silica type, and 2b high-silica type; top of the section near the surface of the groundwater level; shows strong separation of Fe and Al in the B_{ox} horizon; the saprolite, $B_{t(=v)}$ horizon, is either kaolinitic or bentonitic below the kaolinite. 3: formation of flintclay below groundwater level by total extraction of Fe.

MODEL ENVISAGED BY McFARLANE (1976)



A. Iron is segregated into pisoliths, within the narrow range of oscillation of the groundwater table, during a late stage of landsurface reduction.
B, C. Zone of precipitate formation lowers as landsurface is reduced and the precipitates accumulate as a sheet at the base of the soil.
D, E. Landsurface reduction ceases and the accumulated sheet of pisoliths becomes altered and hydrated to form a massive sheet of planation surface laterite.
F. Water-table once again begins to lower upon initiation of the succeeding cycle and pisolith formation resumes.
G, H, I. With continued water table lowering, the zone of pisolith formation lowers leaving above it a spread of pisoliths.
J. The water table is ultimately lowered beyond the depth at which pisoliths can form.
K, L, M. Leaching through the carapace depletes the saprolite underlying the spread of pisoliths, forming a pallid zone.
N. Deforestation leads to induration of the laterite and its loss of permeability. Pallid zone formation ceases.

Fig: VII.3.

these changes. The problem of explaining the removal of quartz and kaolinite occurring as inter pisolith material has been considered by some to be purely a mechanical phenomenon (Leprun, 1981). Such a mechanical removal could be due to climatic change desiccation followed by heavy rainfall that would flush out the fines leaving the heavy pisolithic residua. On the other hand, several authors have opined that whereas the pisoliths might have been concentrated mechanically, the removal of kaolinite and quartz could be chemical. The extent of quartz dissolution has been emphasized by some workers (Jepsen et al. 1974, Gikes et al. 1973, Patterson, 1982). This chemical mobility could be either due to pH control or by microbial activity (McFarlane,1986). Microbial role might have been effective in Fe-phase changes and this factor is vital towards understanding of the behaviour of Fe in laterite profiles.

It has been maintained that the essential starting point for the understanding of mobilisation and retention of materials in laterites is the Eh/pH control. It is now becoming increasingly clear that the role of the element mobilization in organic complexing has been underestimated. There has been now a growing awareness of the role of micro-organisms in the formation of a variety of 'chemical' sediments (Goudie and Pye, 1983). Recent leaching experiments (Perviz, 1983) using organisms indigenous to a pedogenetic laterite from Kenya, which simulated both vadose and phreatic conditions, produced significant Fe mobilisation at inhibitive pH values. Clearly microbial complexing provides a means by which trivalent Fe can be mobilised, by-passing the constraints of the Eh/pH, thus providing an explanation for the mobilities deduced from the geomorphological and mass balance studies (McFarlane, 1986).

To categorise any particular laterite into one or the other genetic type is almost an impossibility. Genetic generalisations evolved in one area are of little value if it is not possible for an individual elsewhere to understand whether or not his particular laterite is of the same trend. Moreover, differences in the effectiveness of vertical and downslope mobilities of individual elements and minerals in groundwater and pedogenetic laterites pose problems to account for failure to distinguish between the various genetic types, a failure directly attributable to a yet inadequate descriptive terminology.

The present author, on the basis of his own observations, has come to conclusion that the lateritic rocks of the study area appear to have originated by processes wherein the groundwater played a dominant role, bringing about rearrangement of constituents into well-defined horizons in a subaerially weathered basalt. Two main additional factors that need be highlighted are those of (i) the nearness of a shoreline and (ii) fracturing of the parent rock. In the following pages, the subject matter has been described in greater detail.

CONTROLLING FACTORS

Following factors appear to have played a vital role in the formation of laterites :

1. Climate
2. Topography
3. Vegetation and Microbial action
4. Sub-surface water
5. Proximity of the strandline
6. Fractures and joints
7. Parent rock

Climate

A tropical to sub-tropical continuously humid climate in which rainfall exceeds evaporation for the most of time, and temperature and humidity are periodically interrupted by heavy rainfall and contrast wet and dry seasons, has been universally invoked for promoting formation of laterite.

Wet and dry seasons are considered to be favourable if not essential to laterite genesis (Du preez, 1954; Sabot, 1954; Fisher, 1958). Alternating conditions are required for sesquioxide precipitation of laterite. Higher the temperature of percolating water the more effective it is in decomposing the rocks and lowering the silica content (Russell, 1962).

According to Gordon and Tracey (1952), the climate should be more or less continuously moist, and there exists a distinct relationship of increasing aluminium content and decreasing silica value with rising rates of rainfall (Tanada, 1951; Van der Merwe and Heystek, 1952; Sherman, 1953; McFarlane, 1976).

A tropical climate necessary for the formation of laterite is restricted to the linear equatorial zone and such climatic conditions suitable for bauxite and laterite formation are currently satisfied only between the latitudes 30 N and 30 S. The tropical climate necessary for the formation of laterite is strictly restricted to the linear equatorial zone. In order to explain the formation of Gujarat laterite alongwith the thick forest present then, one has therefore to take into consideration the drift tectonics of the Indian plate as it was moving across the equatorial zone and postulating that these Palaeocene laterites must have developed when the Indian plate was in the equatorial zone (Sychanthavong and Patel, 1987) (Fig. VII.4).

Topography

Topography influences weathering not only because of its control over micro-climate, vegetation and drainage but also because of downslope movement of constituent elements towards depressions or low relief both at and below the surface. Understanding surface movement is no problem, but groundwater is also seen affected. If topography is hilly but not rugged with moderate to gently sloping surface, it will allow free lateral movement of water table or sub-surface drainage (Esguera, 1964).

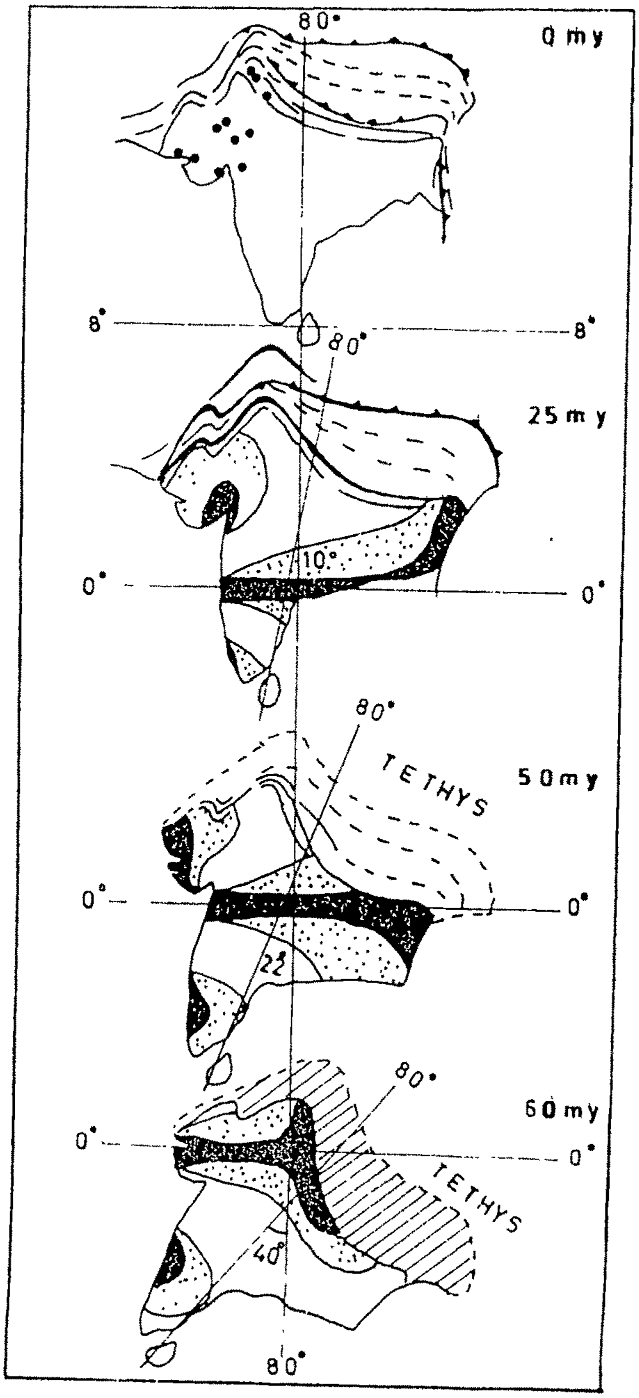


Fig:VII.4. PALAEOCLIMATIC RECONSTRUCTION OF THE INDIAN CONTINENTAL PLATE DURING ITS COURSE OF DRIFTING ACROSS THE EQUATORIAL ZONE

AFTER SYCHANTHAVONG & PATEL(1987)

Steep slopes cause rapid run off and indiscriminate removal of weathering products, while shallow slopes allow an ingress which cause the differential removal of the more soluble constituents and the accumulation of the less mobile weathering products. Woolnough (1918) has stated that "lateritisation can occur only in areas where drainage is almost at standstill. This usually involves the existence of peneplain more or less at sea-level". If topography is low, then the level of groundwater is high anad length of vertical percolation is small, therefore, weathering of rocks is slight. The topographic relief should be hilly but not very rugged (peneplain with gently sloping depression towards the middle of peneplain) which allow free movement of groundwater and sub surfce drainage. Many worker have observed laterite and bauxite formation takes place at slope of 3 to 16 (Bardossy, 1981; 1986; 1989a; 1989b; Bardossy and Aleva, 1989).

Vegetation and Microbial action

The role played by vegetation in laterite genesis is evidenced by two facts. First is the circumstantial evidence of the often seen association of laterite and grassland, which favour the hypothesis that laterite is a precipitate forming at the upper limits of a seasonally fluctuating water table. Second, detailed studies of the effects of vegetation on desilicification and iron stability suggest that well vegetated conditions are not inherently unfavourable to the development of laterite.

The factor of vegetation along with that of rainfall is important for the changes in pH-Eh of the surface and sub-surface aqueous environments.

Grubb (1970) has considered that dense forest cover would provide the greatest moisture-capture capacity, maintain high humidity, inhibit direct rain splash and reduce vertical corrosion in favour of uniform slope wash and percolation through profile. The consumption of humus by abundant microflora in the soil and the consequent reduction of the concentration of humic acids in solution is recognised as one of the means by which the pH of humid soils is kept high. The acidic nature of forest floor that accumulated on the surface of the soil, would also be carried into the soil by percolating waters, increasing soil acidity and developing reducing conditions that favour reduction of ferric iron and promoting its leaching from soil column. Bloomfield (1953) has shown that although aqueous leachates of forest litter readily dissolve hydrated ferric and aluminium oxides with the formation of soluble ferrous and aluminium complex compounds, sorption of the reaction products take place concurrently with the solution process and the sorption has the effect of inhibiting further solution of the ferric oxides.

The role played by micro-organisms in the mobility of Si and Fe has to be taken into account {Mitchell (1955); Krety (1972); Hall (1972) Dommergues and Mangenot (1970); Heinen (1962); Stotzky and Rem (1966); Heinen (1968); Kuznetsov (1975); Wolfe (1964); and Kleinmann and Crerar (1979)}. Some bacteria and fungi are important agent in the mobilization of silica in nature, and in a highly vegetated terrain, water percolating from above would indirectly bring about silica migration through the production of chelates, or the production of mineral/organic acids or through the production of ammonia or amines. The microbiological factor is also important in the redistribution of iron. Since in environments of natural pH, ferric iron precipitates readily from solution, and since in this insoulble form iron cannot be readily taken up by cells, a number of micro-organisms acquire the ability to synthesize chelators which help to keep ferric iron in solution.

Role of sub-surface water

The role of percolating water from above as well as that of the groundwater is very important, perhaps the most vital factor. Although the entire topic is controversial and there are many gaps in the knowledge, yet certain generalisations can be made which are of relevance to the process of lateritisation (Cowsey and Mellon, 1983).

Chemical weathering depends on the reactions of silica and alumina with water and other very dilute solutions, as the major constituents of rocks are combined as aluminosilicate minerals. The breakdwon of the minerals proceeds through solution or partial solution of some of the constituent cations of the mineral. However, not all cations are taken into solution with the same ease. Some tend to be readily lost to the percolating groundwaters, whereas, others are resistant and become progressively concentrated in the residue. Moreover, variations in the physico-chemical factors may result in solution of a particular cation in certain parts of a weathering environment and precipitation elsewhere.

Experimental investigations have confirmed that water is the most important agent of chemical weathering, acting through the processes of dissolution and hydrolysis and that the progress of chemical weathering in a given rock body is influenced by three principal factors, oxidation, pH and drainage.

Oxidizing conditions convert Fe^{++} to Fe^{+++} affecting Fe^{++} within silicate minerals and aiding disruption of the crystal lattice, and leached out Fe^{++} in solution. The insoluble Fe^{+++} hydroxides which tend to form, remain in the zone of weathering, leading to a residual concentration of iron in the weathering profile. Under reducing conditions however, the opposite effect occurs, enabling iron to be mobilized as soluble Fe^{++}, and leached from the profile.

Low pH promotes hydrolysis of silicate minierals by providing additional H^+ ions which enter the crystal lattice, displacing metal cations, and disrupting the silicate framework. The solubilities of several components common in the weathering system, have shown in the laboratory to be dependent on pH, but within the normal range of pH of natural waters (pH 4-9), these solubilities are relatively constant. Only when the pH is greater than 9 does the solubility of silica increase appreciably, and aluminium and iron hydroxides are soluble at pH less than 4.

The quantity of water passing through the zone of weathering influences the nature of the secondary minerals which form. Where there is a large amount of water entering the zone of weathering and drainage is good, even poorly soluble products of hydrolysis may be leached out, ultimately leaving an insoluble residue, largely of Fe^{+++} and Al hydroxides. Where drainage is impeded or where there is insufficient water to leach out all the products of weathering, clays will be the stable secondary minerals.

According to Mason (1952), the pH values of natural waters normally lie between 4 to 9. It is necessary, therefore, to consider the influence of variations within this range on the mobilities of the principal components involved in weathering of the silicate minerals (Fig.VII.5) represents a compilation from many sources, the solubilities of the more important components

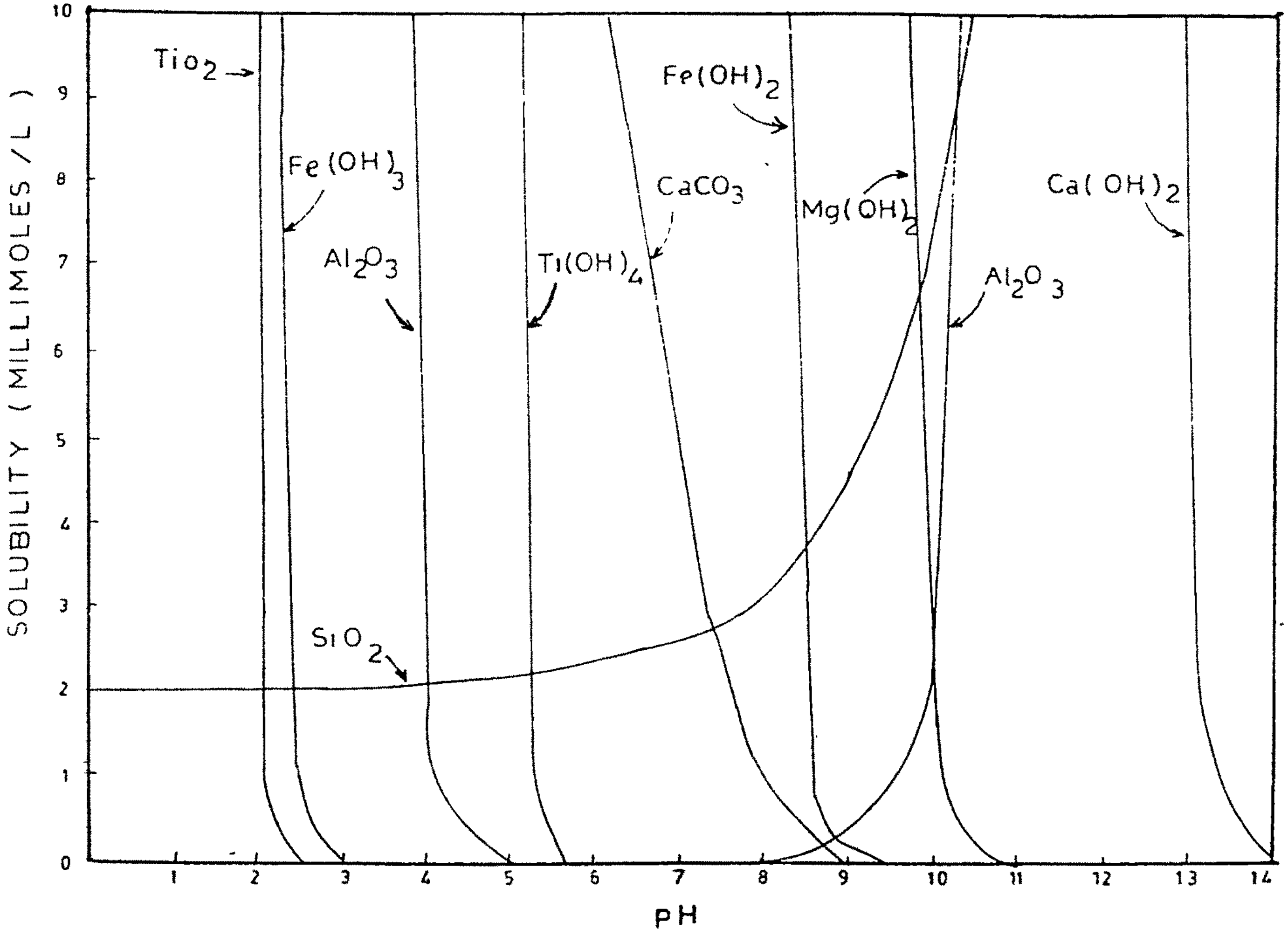


Fig:**VII. 5.** SOLUBILITY , IN RELATION TO P^H FOR SOME COMPONENTS RELEASED BY CHEMICAL WEATHERING as plotted against pH. The curves for Al_2O_3, SiO_2, TiO_2 and $CaCo_3$ have been taken directly from Correns (1949,1959), while the remainder have been calculated from their solubility products at 20°-50° C.

This diagram shows that within the "normal" pH range of groundwaters, $Ca(oH)_2$, $Mg(OH)_2$, and the alkalies (not shown) are completely soluble, whereas TiO_2, $Fe(OH)_3$, and Al_2O_3 remain insoluble and hence cannot be mobilized. The solubility of silica, although low, is constant and unaffected by variations in the pH. The curve for SiO_2 refers to amorphous silica or silica released from silicates and not quartz which, according to Krauskopf (1959), has a solubility of approximately one-tenth of amorphous silica (Loughnan, 1969). Silica is soluble though only slightly at all values between 4 and 8, whereas alumina is only soluble below pH 4 and above pH 8.5. The solubility of silica is 6 ppm; quartz therefore, is slightly soluble at the temperature of rock weathering. Amorphous silica is soluble to the extent of 115 ppm, or nearly 20 times as soluble as quartz. At pH values above 9, the solubility of silica increases abruptly because of the ionization of H_4SiO_4, but in weathering, pH 9 is only attained during the initial alteration when felspars become hydrolysed. For the most part, in geochemical and pedochemical weathering, silica in small quantities is continuously leached out and alumina accumulates in the clayey residue (Loughnan, 1969). Alumina is practically insoluble between pH 4 and pH 8.5, that is, in the pH field of rock weathering and soil formation. Alumina is amphoteric; at low pH values it is in solution as Al (OH) , and at high pH values as Al $(oH)_4$.

For the solution, migration and precipitation of major and trace elements within the laterite, the groundwater conditions envisaged by Valeton, (1983) are (1) net flow towards the sea, (2) groundwater levels must be high and oscillatory in nature and (3) Eh conditions must be reducing, for solution and migration of elements.

The Eh-pH of the groundwater involved in the lateritisation process is important. Most genetic models envisage elemental redistribution through the process of leaching (solution and migration) and of precipitation (deposition), mostly brought about by fluctuating groundwater and changing Eh and pH values. Alkaline conditions would be conducive to dissolution of Si and Al, with pH values 10 or more, Al_2O_3 is very soluble and Sio_2 is relatively soluble. These are carried in solution provided rainfall is available. If the rainfall is scanty, the decay products Al_2O_3 and SiO are not removed but combine to form clay. So kaolinite would form under alkaline and poor leaching conditions (Bates 1952).

Alkalinity of groundwater could be due to two factors. Under certain conditions, high pH values could result due to its reactions with rock minerals on account of replacement of metal cations by hydrogen ions from water. Secondly, the percolating water from above carried with it the required substances like Cl^-,

Na^+, SO_4^{2-}, Mg^{2+}, Ca^{2+}, K^+ etc. adding to the alkalinity of the groundwater. The increased alkalinity of groundwater could also be due to nearness of the sea, either by a direct contamination with sea water or solution of blown salt in the percolating rain water.

Acidity (low pH) could be attributed to the presence of organic acids mainly humic and fluvic acids, these being products of plant decay. However, the widespread development of groundwater acidity requires a more general explanation. Water molecules belonging to the layer actually in contact with solid cations, appear to become polarised by the presence of strong surface electrical fields. This results in a high degree of dissociation in which the ratio of $H^+ : H_2O$ may be in the order of 1 percent, equivalent to the acid strength of an N/100 solution. Furthermore, H^+ can combine with water molecules to form an unstable H_2O on silicate surfaces. They lead to a partially irreversible hydration by absorption of water, followed or accompanied by the first stage in hydrolysis involving a cationic exchange between H^+, H_2O and alkali or alkali earth cations in, for instance, the feldspar lattice. These may be regarded as the first essential step in the breakdown of silicate minerals into clays.

Groundwater pH may also be affected by the nature of individual rocks - the more acidic type liberating more silica to give an acid reaction. Variations in pH also occur with depth, the value tending to increase downward (Nye, 1955).

Proximity of the strandline

Most of the laterites of Gujarat state including those of Mainland Gujarat are found on continental margins. The interfingering of marine, fluvial and terrestrial sediments in this laterite belt (Valeton, 1983) indicates that the alteration which took place from Deccan basalt to laterite occurred in a nearshore environment. The variation in the Eh-pH condition would be related to a phenomenon that could be attributed to the incursion of marine water through the fracture zone i.e. fluctuation of paleoshorelines or seasonal stagnation and accumulation of alkaline materials.

According to the sedimentary chemical model of origin of bauxite by Archangelsky (1933,1937), aluminium and iron compounds are transported from the weathering areas in the form of molecular or colloidal solutions and precipitated either in limnic swampy depositional basins, or in marine lagoons mainly as alumina ferric gels, organic matter acting as an important stabilizer of solutions leading to the formation of lignite or coal seams, which commonly accompany deposits of bauxite and bauxitic clays.

Balasubramaniam (1987) too has related marine transgression and regression with the various stages of lateritisation in this region. Such fluctuating strandline conditions would cause an imbalance in the intake and output of water in these basins, i.e. the rate of evaporation would be more than the rate of accumulation with the liberation of carbon dioxide. At the same time there would be an will abrupt decrease in Eh and a gradual increase in pH values. $CaCo_3$and SiO_2would dissolve, reaching saturation and get precipitated.

At the same time Eh decrease would abruptly and pH increase gradually; $CaCO_3$and SiO_2 would dissolve, reaching saturation and reprecipitate with authigenic minerals such as sulphides of Fe, Cu, Pb and Zn and siderite (Balasubramaniam, 1987).

Fractures and Joints

Surprisingly, few workers have appreciated the role played by fractures and joints in the process of lateritisation. Only Bardossy (1982) has suggested that fractured zones with open joints, or fissures are preferential places of down leaching and bauxitisation. Fractured and jointed parent rock would provide suitable locations for the sub-aerial weathering, groundwater accumulation and movement, contribute to its effectiveness in bringing about the lateritisation. The intensity and depth of fractures would control the requisite groundwater conditions requisite (Sharifabadi, et al. 1988; Sharifabadi and Synchanthavong, 1989).

It is significant that lateritisation of basalts in Gujarat, is restricted to certain highly fractured zones only. The Mainland Gujarat laterite occurrences are all located along a

NNE-SSW linear zone extending from N to S Gujarat. This zone perhaps marks a major fault-line. The basalts in Gujarat typically show two sets of fractures and joints, NNE-SSW and ENE-WSW. These joint sets differ in intensity from place to place and it is obvious that the lateritisation is directly related and proportional to the intensity of fracturing especially NNE-SSW. The selective lateritisation, generally restricted to linear zones, therefore can only be explained by highlighting the role played by fractures. So far as Gujarat is concerned, it can be said that though the whole of trap basalt was subjected to more or less identical climatic conditions and was equally close to the shoreline, yet only narrow strips and patches got lateritised, leaving vast areas untouched. This can be explained only by invoking the tectonic factor. Such a selective lateritization is obviously related to the presence or absence and intensity of fracture zones, which in turn are relatable to the regional tectonic framework.

Parent Rock

Laterite development has often been related to what are described as 'suitable rocks' (Woolnough, 1918; Hanlon, 1945) but different authors have conflicting opinions as to what constitutes suitability and many believe that laterite development is not confined to certain rocks only, but occurs over a great variety if not all rock type (McGee, 1880; Du preez, 1949; Mennell, 1909; Mulcahy, 1961; Alley 1970). Accordingly depending upon the chemical and mineralogical compositions of the parent rocks, laterites have been categorised into several groups (Harder, 1951), having been derived from (i) rocks rich in alkali - aluminium silicates, but no quartz (ii) limestones (iii) intermediate and basic igneous rocks, (iv) sedimentary clays with little free quartz and (v) moderately aluminous igneous, metamorphic and sedimentary rocks.

The variations of laterite with lithology suggest that environmental factors other than geology have had a more significant influence on the nature of the end product. The apparent lack of a direct relationship between laterite and lithology is a supporting argument that laterite is not a residium, but a precipitate from enriched groundwaters.

GENESIS OF MAINLAND GUJARAT LATERITES

Laterites of Mainland Gujarat provide a good example of chemical - mineralogical changes associated with the various alteration processes comprising redistribution of rock constituents through mechanisms of leaching and precipitation, in which groundwater played a major role. Laterite formation has taken place under tropical to sub - tropical climatic conditions, characterised by high rainfall, alternating wet and dry spells and fluctuating groundwater level. A peneplained basaltic terrain with gentle slopes and shallow depressions, marked by intense fractures and joints and located close to strandline, provided an ideal site for initiating the process of lateritisation. In a general way, Valeton's (1983) genetic model is more applicable in the present case as it explains most of the features shown by the Mainland Gujarat laterite profiles. The groundwater appears to have played a dominant role in the process of lateritisation.

The concept of the formation of laterite and bauxite in a vadose zone which was permanently above the water table (Nayak, 1979) does not appear to be valid. Secondly, it has been conclusively recorded that at all the localities, even in North Gujarat, the parent rock has been a basalt. No where, limestones changing to laterite, as envisaged by Shukla et al. (1983) are observed. Further, the chemical and minerological data does not support Rao's (1976) concept of resilicification for the change over of bauxite to kaolinite.

The evolutionary model envisaged by the present author is illustrated in Fig. VII.6.

The laterite rocks originated from the Deccan basalts, and show following chemical-mineralogical transformations.

1. Kaolinization of Al-Si bearing minerals;
2. Formation of Fe oxides from Fe containing minerals;
3. Formation of Al hydroxides by incongruent dissolution of Kaolinite minerals (occasionally also directly from feldspar, etc.);
4. Congruent dissolution of kaolinite minerals;
5. Dissolution of quartz.

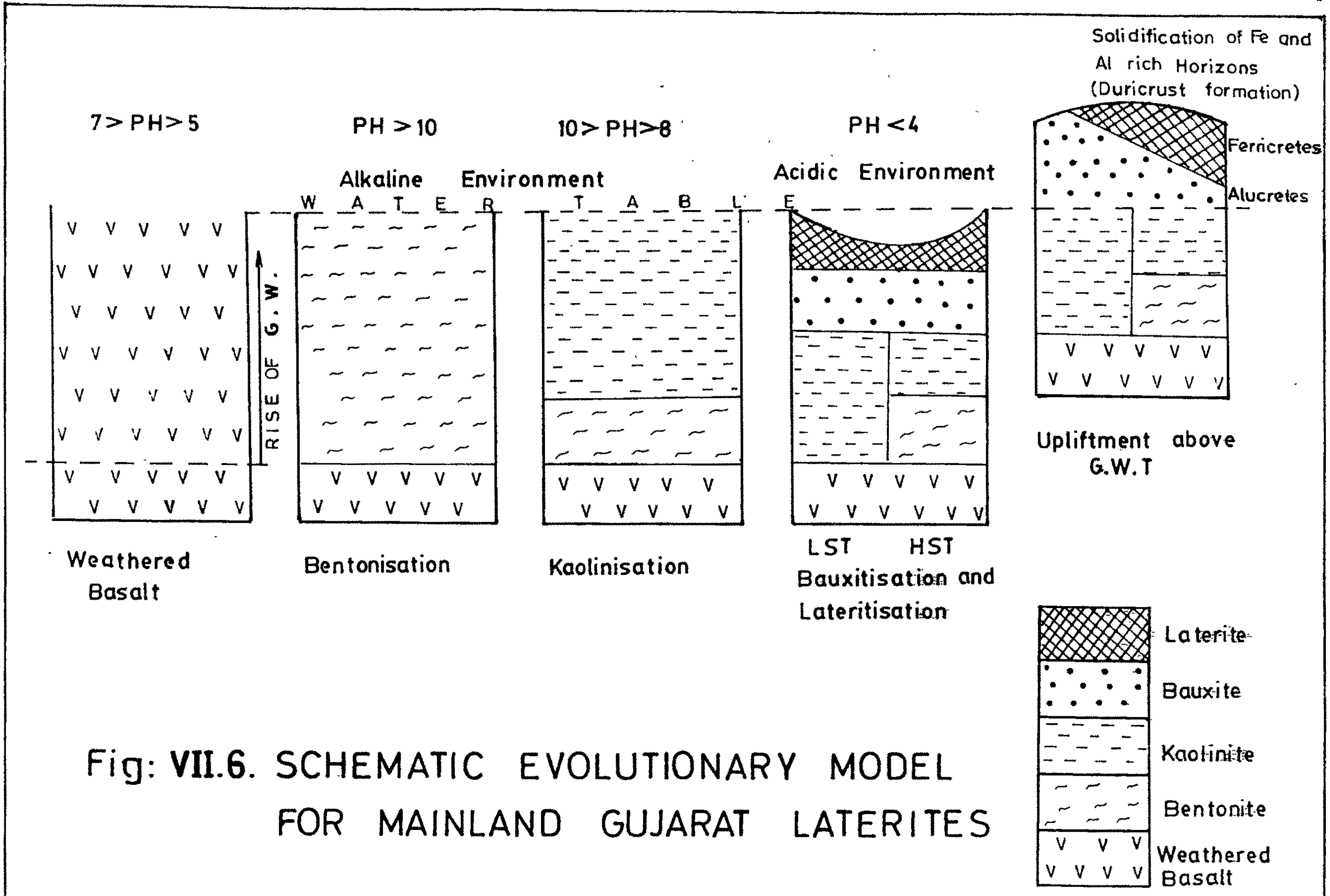


Fig: **VII.6.** SCHEMATIC EVOLUTIONARY MODEL FOR MAINLAND GUJARAT LATERITES

The entire phenomenon of transformation of basalt into laterite comprised several stages through which a subaerially weathered rock passed, to finally emerge as a laterite sequence. The various stages of lateritisation have been described below :

I. Weathering of basalt under tropical conditions :

The terrain had a low gradient with a subdued topography, with local depressions and mounds. Only jointed and fractured basaltic areas came under the influence of chemical weathering and thus selectively provided sites for lateritisation. The fractured zones were restricted to a NNE-SSW major lineament.

II. Rise of the water table to the surface:

This caused submergence of the fractured and jointed basalt below the groundwater table, giving rise to water-logged conditions. The groundwater was alkaline the basal portion with high pH values (more than 10) whereas upward it would tend to decrease to as much as around 8 or so. High alkalinity is attributable to the effect of the contamination by sea water and/or due to the hydrolysis of the parent rock minerals (augite, olivine, plagioclase). Through out such a groundwater column with decreasing alkalinity upward, hydrolysis of minerals took place.

III. Hydrolysis of the minerals :

At depths augite, olivine and labrodorite, produced Mg, Fe, Al montmorillonite minerals, the bases released augmenting to the alkalinity of the water. The formation of sticky non-porous bentonite, in turn, might have caused inadequate leaching conditions, rendering the environment to become a closed one, alkali confined environment of Valeton, (1983). With decrease in pH, the montomorillonite would become unstable and give rise to kaolinite.

IV. Lateral movement of groundwater :

Above the bentonite horizon, the concentration of alkalies would gradually decrease on account of their removal in solution by a lateral seaward movement of the groundwater. Such a decrease in pH in combination with the removal of alkalies, would open up the closed environment, increase the porosity and bring about, the change of bentonite to kaolinite. This transformation is brought about according to Altschuler et al. (1953), by a mechanism of intracrystalline leaching of interlayer cations and tertrhedral silica layers.

At most places weathered basalt is seen directly overlain by kaolinite. In the study area, sporadic lenses of bentonite layers are recorded at a few localities only and to explain this there can be two alteranatives. Firstly, at all places bentonite formed under a closed alkaline environment, which later on changed over to kaolinite with the oepning up of the environment and decrease in pH, in such a situation the bentonite zone only points to a few relicts, Alternatively, the bentonite never formed at all; at most localities, the hydrolysis and leaching took place under such environment that kaolinite formed direclty from the basalt minerals. In any case, there are localities where some kaolinite has definitely derived directly from the feldspar of the basalt (Fig. VII.7). Based on the presence or absence of bentonite horizon, the lateritic rocks under study, could be categorised into 'Low Silica Type' and 'High Silica Type' the former characterised by a kaolinite-saprolite and the latter by a bentonite-kaolinite-saprolite. According to Valeton (1983) the Low Silica and the High Silica Types within the Bt horizon of the lateritic soil section are a manifestation of the drainage intensity and Eh conditions; with good drainage and oxidising Eh conditions favouring the formation of Low Silica Type, while poor drainage conditions and reducing Eh conditions favouring the formation of High Silica Type. Thus, it is presumed that High Silica Type sections developed in basins with poor drainage conditions, and this explains the occurrence of bentonite deposits in the form of discrete pockets.

It is worth mentioning that whereas bentonite zone preserves the relict textures of basalt, the same are destroyed in the kaolinite horizon, which has resulted from bentonite. But

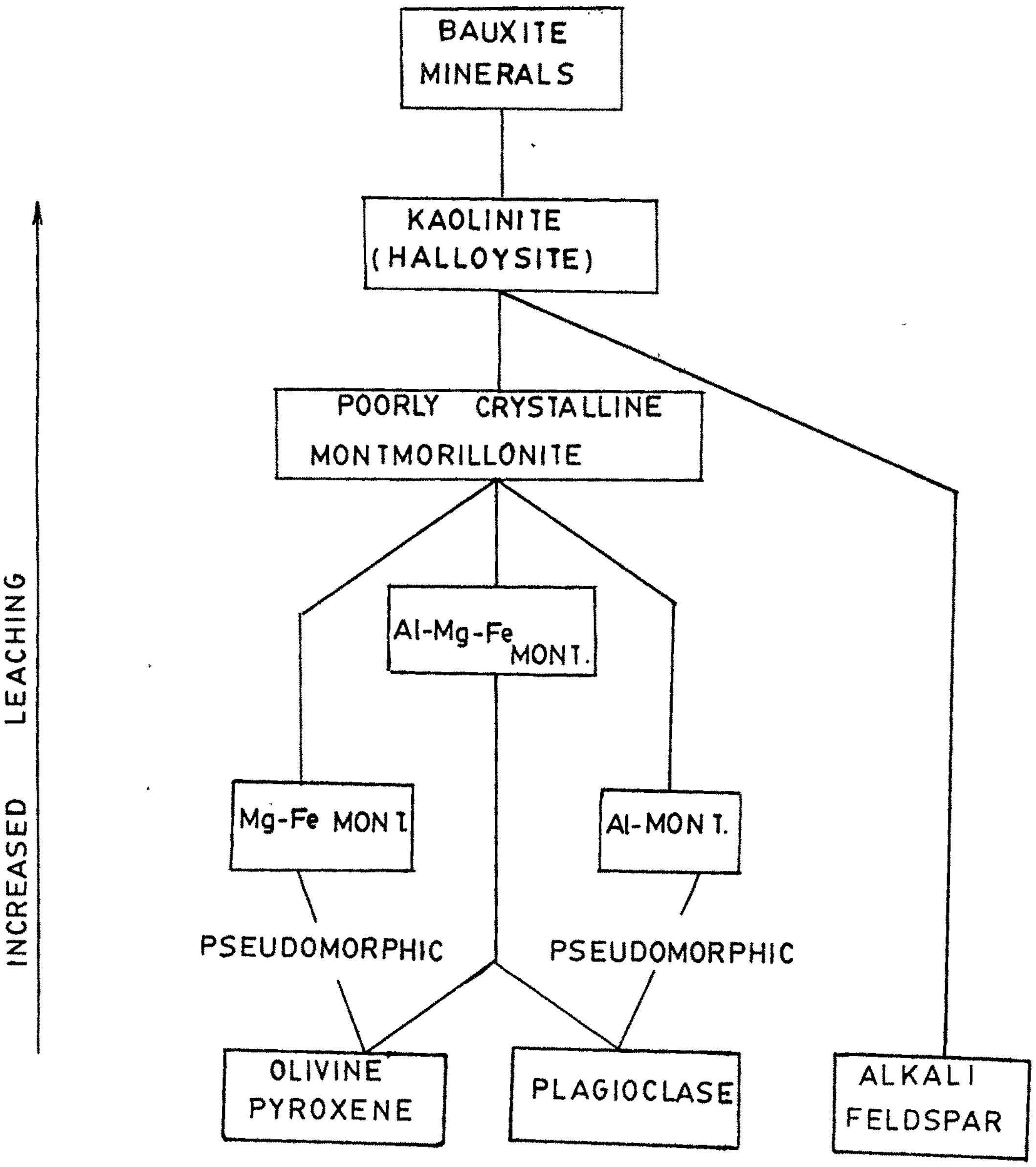


Fig: VII.7. DIAGRAMMATIC REPRESENTATION OF THE WEATHERING SEQUENCE DEVELOPED ON TERTIARY BASALTS IN NEW SOUTH WALES. (AFTER CRAIG & LOUGHNAN 1964) wherever kaolinite has developed without bentonite, even the kaolinite horizon shows relict basaltic textures.

V. Enrichment of Al and Fe in the upper portion (Box), followed by precipitation and duricrust formation :

It is to this zone that Fe and Al have migrated from below, and here they got precipitated later on. Fe was dissolved and transported upward in the bivalent state under reducing conditions. During high groundwater level, Fe migrated upward. Along with Fe, Al and Ti also migrated in solution, but because of their varying mobility they were transported to different levels of the alteration product. Lateral migration especially of Fe and Al, the two main constitutents, is reflected in the Al rich and Fe rich uppermost horizons. Valeton (1983) has ideally explained the phenomenon of Fe rich (lateritic) and Al rich (bauxitic) horizons and related duricrusts (Ferricrete and Alucrete) by invoking influence of strandline on the lateral movement of these constituents. She has stated that iron rich ferricretes are exposed on the landward side, adjoining the basalts whereas the Al rich alucretes are confined to the seaward side towards Tertiary rocks. She has stated that when the groundwater level intersected the paleosurface at the ferricrete/alucrete transition zone, the Fe (which also migrated upwards on the seaward side) was removed from this level by the groundwater flow Al, which is less mobile than Fe, remains and both zones are induated to form crusts when the region finally emerges beyond the reach of the water table (Valeton, 1983). During high groundwater level, Fe migrates upwards in the divalent state and during the dry period it is oxidized to Fe^{3+} and thus immobilized.

The various constituents were subsequently precipitated and fixed at various horizons, the process being essentially controlled by the changes in the Eh and pH values. Water percolating from above, on account of vegetational cover, humus etc. tends to have low pH values. Thus a progressive dilution of alkaline environment on account of increasing contamination by meteoric water from above, would tend to render the environment acidic to netural, and this in turn, would cause precipitation.

The last stage in the laterite formation is the subsequent uplift and hardening of both the Al and Fe horizons, giving rise to Fe/Al rich duricrust (Ferricrete/Alucrete).

In conclusion, the present author would like to highlight the role played by the regional tectonics in the process of lateritisation. The various occurrences of laterite on the Mainland Gujarat follow a trend which coincides with a major NNE-SSW lineament. Only such basaltic rocks that were located along this fault on the eastern flank of the Tertiary Cambay basin got lateritized. The control exercised by this tectonic feature would manifest in many ways. Intense fracturing along the fault zone facilitated weathering and subsequent processes of leaching and enrichment. Vertical subsidences and uplift controlled to a certain extent the variation in the groundwater table. Final uplifts were also perhaps related to this tectonic factor. Thus, when viewed in a larger perspective, the lateritisation appears to be a Paleocene phenomenon related to the major rifting of India's western continental margin and its subsequent NE ward drift (Biswas,1988).