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Special Invited Review

CONCEPTS ON THE ORIGIN OF INDIAN LATERITE IN HISTORICAL PERSPECTIVE*

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In Indian geology laterite occupies a place of special significance. It is widespread either as a rock crust or as extensive soil mantles. Its economic potential is great, being the source of industrial minerial like bauxite, manganese ores, etc. It has been the source of iron ore for the indigenous smelting industries from time immemorial. The acquaintance with laterite, therefore, has been quite common for most of the Indian geologists. No wonder the literature on Indian laterite is rich and comprehensive and still serves as the very foundation for world over studies. The spark set by Francis Buchanan in 1807[1] by coining the term laterite was kept ignited by later workers with periods of somnolence caused by diversions resulting from either the excitement of new discoveries or prejudice born out of too much familiarity with the rock. However, the compulsion of coverage of laterite as part of the systematic geological mapping programme and launching of special investigations to enhance the resources of aluminium, manganese and nickel ores brought out immense volume of data which are being increasingly used for qualitative improvement on the concepts on the origin of Indian laterite which also holds the key to solve problems in the global context. Though considerable ground has been covered in the understanding of the processes of lateritisation there are still confronting problems to be resolved and the author advocates to induct new concepts as being applied for such a global phenomenon and thereby maintain the leaderhip in the study of laterite.

Key Words : Indian Laterite; Brickstone; Volcanoelastic

Introduction

The term 'laterite' has been used with different connotations by various workers. The early workers were mainly guided by the morphological characters and field setting while discussing the nomenclature, classification and origin of laterite, whereas the present-day workers lay emphasis on chemical and mineralogical composition in the treatment of various features of laterite. Though of varied appearance and described as brick-stone, iron-clay, etc., the term laterite to the early pioneers signified a rock mass derived from 'muddy eruption' or lacustrine, fluviatile or even marine sedimentatations. With the passage of time and recognition of the characteristics of the laterite profile, it became necessary to evoke an

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in situ weathering mechanism that would not only explain the formation of laterite from diverse parentage but also the chemical segregation in the resultant residuum. The stage of segregation in a profile may define the degree of their maturity. Most of the occurrences of laterite in India are derived from the Deccan trap basalt. Lateritization is a process involving continuous leaching of alkalies, bases and silicas with relative concentration of ferric oxide, alumina and titania in the residuum. Transformation of basalts into laterite results in a weight loss of 65 per cent and volume reduction of 35 per cent. Some of the outstanding problems of laterite genesis are mechanism of the layered structure and variable spatial position of the bauxite zone in the laterite profile and conditions inducing and terminating the lateritization process.

Although the object of this paper is to give an outline of the current thinking on the origin of laterite based on recent study, it is necessary to give a brief sketch of the observations of early pioneers so as to appreciate the evolution of ideas which made impacts on genetic studies and may still provide a solution to some of the outstanding problems.

EARLY WORK

Most of the very early observations were confined to the morphological and megascopic features of laterites and its field setting.[2] To these pioneers laterite is a brickstone,[1] iron-clay,[3] red ferruginous clay,[4] indurated clay,[5] ferruginous banded clay,[6] etc. The occurrence of laterite as thin surface blankets on high plateaus or coastal areas, the presence of a clay zone at the base and other broad features of the laterite profile were recognised quite early. Based on the mode of occurrence laterite was divided into high-level and low level,[7] plateau, terrace or valley laterites,[6] etc.

As regards the origin of the rocks, the early pioneers propagated divergent views. Several workers supported lacustrine,[8,9] fluviatile[6] and even marine[4] origin, guided by the occurrence of laterite on diverse rock types and also by the presence of some sedimentary features. Other observers claimed that laterite was an *in situ* product of alteration of underlying rocks.[2,10] Faced with conflicting evidences, Lake, Foote and others also advocated detrital as well as *in situ* origins for laterites occurring in different areas. Foote[4] also evoked a process of 'concentric solidification' while Mallet[8] thought that chemical precipitation in lakes aided by organisms was partly responsible for the formation of laterite.

The slag-like or scoriaceous appearance of laterite led Carter[11] to propose a volcanic origin and Voysey[3] to visualize a 'muddy cruption'. But the observation of Fedden[12] that the laterites of Gujarat were alteration products of volcanic ejectments is considered a very significant contribution in the light of more recent evidences.

From the beginning of the twentieth century there has been a shift in emphasis towards chemical properties, geochemistry of weathering and economic aspects of laterite. Holland[13] outlined the broad chemical changes involved in lateritisation and strongly advocated an origin due to tropical weathering. Modern workers owe a great deal to Maclaren[14] who advocated that lateritisation was brought about by the action of carbonated waters in the presence of humus in areas of hot climate with heavy rainfall. The geographical and chemical conditions favouring lateritisation first outlined by him have been amplified by Fox[15] and are accepted by most modern workers. Although the theory of detrial origin of laterite was briefly revived,[16,17] the general consensus of opinion was in favour of an *in situ* origin.

Fermor[18] tried to bring order into the jumbled nomenclature of laterite and proposed a three-fold division, viz. laterite, lateritoid and lateritite, based on geological and chemical characteristics of the rocks. Fox[19] obtained chemical analyses on Buchanan's type laterite and found that it would correspond to lateritic lithomarge in Fermor's classification; but he wisely desisted from introducing new terms or redefining established ones.

Thus, by the first quarter of the present century, several of the main features of the profile, chemical characteristics, economic aspects, genesis and conditions favouring the formation of laterite were broadly outlined. Fox[15] presented a sophisticated theory and outlined the role of sols and gels in the formation of laterite and bauxite suggesting that the alumina-rich layer acted as a semipermeable membrane preventing the movement of iron oxide downward and colloidal silica upward. But this last suggestion of Fox is not supported by field evidence.

The foregoing is a brief outline of the early work, the details of which are to be found in the contributions of Lake[6] and Fox[15] who have provided an extensive annotated bibliography and critical review of the past work.

Renewed Attention

Although mapping programme continued in the laterite covered areas this formation like the recent and Quarternary alluvial deposits received scanty attention since the work of Fox[15] who made a bold attempt to revive the spirit of enquiry, though primarily laying emphasis on bauxite deposits. The situation, however, changed with the launching of mapping programme in the laterite capped plateau regions of Bihar and Madhya Pradesh by Roy Chowdhury[20,21] and by Sahasrabudhe[22] in similar terrain of the Western Ghats in Maharashtra. The necessity and urge for locating bauxite and to a lesser extent demarcating richer areas of manganiferous, nickeliferous and uraniferous laterite prompted to field large number of geologists by different organisations to cover extensive laterite terrains of Orissa, Andhra Pradesh, Tamil Nadu, Kerala and Goa culminating in the discovery of East Coast bauxite. The IGCP (International Geological Correlation Programme) Project—129 of UNESCO-IUGS on Lateritisation Processes initiated by Roy Chowdhury in 1973 as a member of the IGCP Board and finally accepted in 1975 took root in international cooperation drawing together active members from the country and abroad. As a Lead-Organisation the Geological Survey of India having Banerji and Venkatesh as members of the Working Group organised the first International Seminar on Lateritisation Processes at Trivandrum in December, 1979 in which a large number of geologists active in the field of laterite geology from India and abroad participated with valuable contributions which were circulated with a printed copy of the abstracts and later the selected papers were published as a special volume. The Seminar was a landmark in the international co-operation for global studies on laterite which acts as a barometer of the erosional and weathering cycles of the earth's history.

The contributions on laterite by foreign scientists have always influenced the work in India which provided ideal field settings for developments of new concepts. While discussing the various aspects of laterite geology in the following pages, no attempt has been made to quote or refer to the numerous contributions from abroad as these are embodied in the respective Indian publications.

Nomenclature and Classification

Launched into geological terminology almost two centuries back by Buchanan,[1] the term laterite and its connotations have gone through many vicissitudes to survive and gain wider currency with the march of time. It has been used for various allied rocks that occur as superficial cover on varied geological and geographical settings. While some workers were rigidly discriminating in nomenclature others used the term with great latitude. Consequently, there have arisen periodic appraisals as to the exact definition of laterite, prominent among them being the contributions of Holland,[13] Maclaren,[14] Fermor,[18] and Fox.[19] To these the names of Creek,[23] Evans,[24] Scrivener,[25,26] Lake,[27] Pendleton,[28] Schaufelbedrger[28a] Valeton[29] Norton,[30] Fairbridge & Finkle[31] and Aleva[32] may be added, though by no means an exhaustive reference on the subject.

The pedologists had been rather hesitant to accept the term laterite of the geologists as the former deal with the early phase of weathering whereas the latter is concerned with rocks of mature profiles. Occasional attempts to lump them together under pedological nomenclature did not succeed and the overwhelming majority of geologists all over the world still retains the term laterite conceived by Buchanan[1] and follows the classification based on structures, textures and void geometry.[32] The following interdisciplinary definition proposed in the Sixth International Working Meeting of Soil Micromorphology, held in London in August 1981, partially meets the nomenclature of rock laterite as known in India, Africa and South America :

> **"Laterites are surficial accumulations of the products of rigorous chemical selection, developing where conditions favour greater mobility of alkalies, alkali earth and Si than Fe and Al and characterised by segregation of Fe and/or Al such that the material or parts of it, are hard or will harden on exposure."**

Recognition and description of laterite in India conform to certain basic features and no doubt have influenced by descriptions of foreign occurrences. The cardinal features forming the basis of the definition are : (1) presence of large amount of iron, aluminium and manganese oxides and titania, all in varying proportions; (2) depletion of free silica (quartz); (3) higher percentage of alumina than necessary to combine with silica to form kaolin; (4) negligible or no bases and alkalies; and (5) hardening on exposure to air.

Mineralogically, laterite is essentially a mixture of varying proportions of goethite, hematite, gibbsite, boehmite and kaolin and also leucoxene, anatase and rutile to a lesser extent. Different opinions have naturally been expressed concerning the limits of chemical and mineralogical constituents in rocks called laterite. The nature of the anomalies in nomenclature is typified by the fact that Buchanan's type laterite shows 45 per cent Kaolin, as calculated from the analytical data presented by Fox.[19] Though lithomarge and bauxite are obviously products of true lateritisation process, these would not be strictly classed as laterite in the petrographic sense.

The present usage of the term by Indian geologists follows some well-established though not very clearly-defined criteria. Rocks predominantly rich either in alumina or combined silica (kaolin) that are associated with a laterite profile or lateritic weathering are designated bauxite and lithomarge respectively. Similarly, a rock very rich in manganese or iron is referred to as lateritic manganese—or iron ore, if found in a laterite blanket. Qualifying terms like ferruginous, aluminous and siliceous are often used to indicate the wide variations in composition of allied material. Laterite is used as a petrographic term for a rock, generally cavernous and vesicular, rich in hydrated iron and aluminium oxides and depleted of bases and alkalies. But as a general term and also in the stratigraphic sense it is used for the entire blanket or cappings irrespective of their size and layered sequence such as bauxite, lithomarge, etc. Recent work shows[33] that this is quite justified as the aggregate chemical and mineralogical composition of the entire residual blanket conforms to a typical laterite. For the related rocks associated with the high grade gibbsitic bauxite of Gujarat, Sahasrabudhe[22] used such terms as clayey bauxite, siliceous bauxite, etc. In contrast to the low silica and low iron of Gujarat bauxite; the material with moderate alumina (35 per cent), high iron (16–27 per cent) and total silica, but low reactive silica (2–5 per cent) and titania (2 per cent) from the Shevaroy Hills, Salem district, has been generally referred to as bauxite and aluminous laterite[34] though such adjectives as clayey or siliceous have been used to refer to similar material. Evidently the kaolinitic content of the material is high and, under Fermor's system[18] this would not qualify to become true laterite but only lithomargic laterite. The term pseudolaterite has been applied to this material from the time of King and Foote.[35]

The property of hardening was considered a non-essential feature[18] as some of the high-level laterite of Balaghat do not show this tendency to any marked extent and as some lithomarge material of Orissa also hardens on exposure.[10] Hardening is almost a universal property of laterites but the lack of it does not prevent Indian geologists from calling them as such, if in other respects they deserve the name. This is in conformity with the recent suggestion of Schellman.[36]

According to current usage, the term laterite carries no significance in regard to level or mode of occurrence, process of formation and origin[5] which are conveyed by means of suitable adjectives prefixed to the term.

ORIGIN

More than the nomenclature and classification of laterite, the process of formation and origin of these rocks have been the subject of several vigorous and conflicting opinions. Some of these, however, have been resolved and a better understanding is emerging with the increased field observations over extensive areas in recent years.

The source of major disagreements as to the origin of these rocks is to be found in the presence of evidence of residual or *in situ* alteration and weathering as well as undoubted detrital or sedimentary features, not infrequently in the same laterite blanket or area. Numerous descriptions are available of the topmost layer of pisolitic ferruginous laterite and the pebbles and boulders of quartz, quartzite, bauxite or other extraneous rocks within it. The sharp lower contact of this material, its discontinuous or patchy distribution due to erosion, undoubted detrital character and formation post-dating the main laterite mass have been known[2,18] and are supported by more recent work. According to Roy Chowdhury,[20] the low lying occurrences of bauxite of Katni area, Madhya Pradesh are of detrital nature as evidenced from their mode of occurrence as small detached bodies on diverse rock types, often perched on hard Bijawar puartzite without being a constituent of a distinct laterite profile and being conspicuously bouldery in nature. Long transport of the material from the source which could be high level laterite caps on the Maikala range of hills to the east probably helped in the alteration of original material to high quality bauxite and removal of soft lateritic material in the process. Sahasrabudhe[22] has recognised reworked and transported type of bauxite in Saurastra derived from the bauxite formed by *in situ* alteration of pyroclastic facies of the Deccan lava flows like agglomerates with bombs, breccia, tuffs and ash beds. This type of deposit can be divided into pseudo-brecciated bauxite with depositional features and bauxite conglomerates and grits depending on the distance of transport from the source area. Roy Chowdhury *et al.*[37] have reported from the Phutka Pahar area of Bilaspur district, Madhya Pradesh a distinct topmost layer of bauxite conglomerate on the laterite profile with rounded and sub-rounded boulders and pebbles of bauxite set in martrix of pisolitic laterite which is otherwise a constant top member of the high level laterite profile on Central and East Central India. Such surficial recent conglomeratic laterite, though less conspicuous by smaller pebbles of bauxite and laterite are a common sight on these plateau tops e.g. in the Amarkantak area and was probably formed by local erosion and transportation during heavy rain falls. Detrital conglomeratic laterites have been reported from many other places, particularly from the coastal areas. Conglomeratic and pseudo-brecciated laterites with depositional features have been reported by Sahasrabudhe[22] from the coastal areas of Maharashtra. Pseudo-conglomerates of recemented nodules and pebbles of laterite sometimes with nuclei of quartz pebbles, commonly observed on the coastal laterite of Tamil Nadu,[38] and Andhra Pradesh,[39] obviously represent locally reworked surfaces. However, the top pisolitic laterite itself is an integral part of the laterite profile but its conspicuous sharp contact with the underlying aluminous laterite or bauxite defies a continuous chain of universally accepted weathering and leaching process.

But the presence of pebble beds, conglomeratic bands or grits either intercalated in the laterite layer or at its base, in certain places is a formidable evidence against the residual weathering product of the laterite mantle. This is typified by the work of Burton[17] in Seoni, and elsewhere by Holland[13] and Wetherell.[16] The extensive field studies of Roy Chowdhury[20] clearly show that the grit or conglomerate bed at the base of the laterite conforms to the infratrappean Lametas and the confusion that arose in the past is due to the presence of a thin veneer of the Lametas overlain by an equally thin trap layers that are completely lateritized. His observations in Surguja area are revealing in this respect. It is also likely that the variegated nature and colour bandings of the lithomarge are due to Leisgang phenomena that might have been mistaken for bedding. The general belief is that the detrital character of some of the intervening layers within the laterite is most probably attributable to intertrappean sedimentary bands subjected to lateritization as suggested very early by Foote.[5] Thus, there is hardly anyone at the present time except a few stray workers like Roy and Bagchi[40] who would advocate a detrital or aqueous origin for the high-level laterites in Central India or for that matter in other parts of the country (Eastern or Western Ghats, etc.), the last champion of this view having been Burton.[17]

The terms high-level and low-level laterite[7] originally signified only their relative elevations. Later, these terms also became roughly synonymous with residual and detrital laterite. The distinction between primary and secondary laterites has the same general connotation and even Medlicott[41] appears to have used them in this sense.

The general belief is that low-level and secondary laterites are formed by denudation and transport of primary laterites and cementation of the accumulated detritus. Pebbles and boulders of extraneous material are generally characteristic of such low-level laterite. It is also seen that the bauxitic material tends to diminish as distance from provenance increases and generally the coastal laterites are devoid of such material except one or two workable deposits in Goa. In several places, a lithomarge zone has also been reported below the coastal laterite, a feature which is characteristic of the residual laterite profile. This perhaps prompted Fox[19] to consider most of the West Coast laterite to be primary in nature. There is some evidence to suspect that the accumulation of the lateritic debris induces or fosters a superimposed lateritisation process in the underlying bed rock which subsequently develops a profile with the lithomarge zone. This results in a secondary laterite layer underlain by younger primary laterite which is perhaps more common than is suspected in several low-level and particularly coastal laterites.[42,43] The converse appears to be the case in Raniganj Coalfield[44] where a primary laterite has been produced by lateritization of an earlier secondary laterite.[42] Clear profiles indicating undoubted residual origin as well as some transported and reworked sections are found in the low-level laterites of Gujarat and Maharashtra.[22]

Such multi-cyclic derivation produced by consolidation of debris and *in situ* alterations have complicated the understanding of the origin of the low-level laterite and rendered the distinction between primary and secondary laterites difficult in certain situations.

Apart from the different levels at which laterite is found and its detrital or residual characters in several places, the earlier workers were struck by the fact that it occurs on several different kinds of bed-rock, including such totally different types as sandstone, shale or basalt. But a major portion of laterite described happens to rest on trap flows in the central part of the country. This led Fox[15] to state 'Lateritisation of those basaltic lavas accounts either directly or indirectly for all the laterite in India,' though he later recognized that primary laterite 'is a residual weathering product of various types of sedimentary, igneous and metamorphic rocks.' This is the direct outcome of the observation starting with Newbold,[2] that the laterite 'ovelaps' the traps to rest on older rocks as at Gosalpur, Katni, Bagru Hill, etc. A particularly striking feature observed by Roy Chowdhury[20] is the remarkably uniform thickness of laterite caps resting on 'different types of gneisses and their inclusions like phyllites, mica schists, lime-silicate rocks, quartzite, etc.'. Since all these rock types cannot be prone to the same degree of alteration or lateritisation, he concluded that laterite must be the product of weathering of trap itself and not of the present bed-rocks.

A significant corollary is that the outliers of laterite in these areas represent the actual original extent of the trap spread.[19,20] Additional evidence for the original presence of trap is found in the form of geodic material and some trap fragments in Katni, Gosalpur, Lohardaga, etc.,[15,22] the lack of which in some places surveyed by Foote[5] prompted him to consider that the upper flows subjected to laterisation were probably devoid of geodes.

A remarkable feature of the laterite blankets on the uplands of Bihar and Madhya Pradesh, according to Roy Chowdhury[20] is their gentle southerly slope. This is most conspicuous in the Maikala Range in Madhya Pradesh and Roy Chowdhury states : *'The laterite capped plateaus occupy lower and lower elevations from north to south. At the extreme northern portion, no laterite occurs at an altitude of less than 1,143 metres whereas at the extreme south, cappings of laterite rest above the altitude of 700 metres. The denudation of a sloping blanket of laterite of uniform thickness and covering the entire area may give rise to detached cappings occupying lower and lower altitudes as in the present case. The same imaginary blanket if extended to the north does not touch any of the peaks outside the present laterite area and this may explain the absence of laterite on them.'* This probably represents an ancient peneplain. The absence of laterite on hills that fall below a particular level corresponding to an ancient peneplain could be accounted for by denudation.

Roy Chowdhury's above observation has since been supplemented by other workers like Sahasrabudhe[22] who on the Western Ghats in Maharashtra recorded detached cappings of laterite varying in altitudes from 4710 ft. (1436m) from the north to 3244 ft (989m) in the south but in another set of plateaus the level of laterisatition show northerly slope as indicated by lower and lower levels of laterite cappings. Sahasrabudhe and Deshmukh[45] computed a southerly slope of 1:370 for the paneplained surface over a distance of 250km. According to him the difference in elevation can be attributed either to several period of paneplanation accompanied by lateritisation or a single planation surface which has suffered faulting parallel to the West Coast resulting in horst-like structure which also account for the lower laterite capped ridges forming the intermediate range between the coast and the high hill ranges. This is in conformity with the accepted regional faulting along the west coast in Lower Miocene or slightly earlier age[46] and the Mio-Pliocene sediments on laterite as observed at places on the west coast. In a paper to the Trivandrum International Seminar on Lateritisation Processes published in 1980 Subramaniam and Mani[38] postulated a single planation surface to account for the laterite cappings on the Nilgiri-Palni hills (1980–2280m) and Shevaroy-Kolamalai hills (1250–1550m) over a distance of 175km. conceiving a gentle easterly slope of 0°,20′. According to them frequency of lineaments studies on Landsat Imagery indicate the dissections suffered by the initial laterite cappings. However, from regional considerations and based on earlier geomorphic studies of the landforms in the southern part of the Indian Peninsula, Subramanian *et al.*[47,48] proposed in separate papers that multiple coexisting surfaces ranging in age from the Middle Jurassic onwards account for the formation of laterite at different altitudes. The spatial relation of the above landform with the coastal laterite on the Miocene-Pliocene surface is uncertain, though similar coastal laterites of Andhra Pradesh are considered by Raman and Vaidhyanathan[39] as homotaxial with the Eastern Ghat duricrusts and occupies the same planation surface. Linking the laterite profile development with tectonically controlled polycyclic geomorphic planation surfaces other contributors in the same seminar[43,49] accounted for the distribution of laterite in Kerala on four or five planation surfaces, subsequently faulted or uplipted. Morphotectonic classification of laterites on diverse geological set ups ranging in age from the Cambrian to the Holocene proposed by Banerji[50] by stretching the hitherto conceived restricted pulsating periods and creating intermittent suitable landforms and cyclic climatic condition is a new approach and merits confirmatory studies. In this scheme, Banerji has relegated the post-Gondwana Low level laterites which cover large areas of the Orissa plains to 'iron-stone' which according to him are not laterites *sensu stricto.* The absence of laterite on some plateaus though in the vicinity of other laterite capped table lands on the Western Ghats[22] are anomalous considering that lateritisation is a regional process and relates to paneplained surfaces. Similar anomalies exist in respect of the lateritic duricrusts on the Eastern Ghats[39,51] where the conical peak, steeper slopes and narrow linear ridges irrespective of their altitudinal accordance with a gently undulating or moderately sloping hills, do not have even a thin veneer of duricrust. In spite of this feature and despite marked difference in the altitude all the duricrusts could be ascribed to a single planation phase and planar surface. Thus, in the Indian scene as elsewhere in the world recent studies have not only reconfirmed that the planation or erosion surfaces are one of the pre-conditions for the formation of primary laterites but their subsequent structural modifications could satisfactorily explain the present disposition of laterite capped plateau landforms ignoring certain anomalies, and possibilities of their correlation with the low altitude occurrences. However, the concept of single or correlatable planation surfaces deserves more searching enquiry. Attempts for regional correlation of laterite covered planation surfaces, say a single or multiple planation surfaces linking the high level plateau regions of the Central and East Central India with Eastern Ghats to the south and Vindhyans to the north and even covering the low altitude laterites of Orissa and Ahdhra Pradesh through a single or consanguineous multiple surfaces will be a simplified formula for speculation.

Although a considerable part of the literature on Indian laterites is devoted to the laterite derived from the Deccan trap basalts, observers were aware from the very early days that laterite also occurs on several diverse rocks and far removed from any trap exposure. This peculiarity of a fairly uniform type of laterite capping occurring over so many kinds of rocks prompted the earlier workers[7,8,16] to consider them as sedimentary. But it is now conceded by most workers that laterite could be formed by weathering of different types of rocks and that in India such types as sandstone, limestone, shale, schist, epidiorite, granitic rocks, basalt, khondalite, leptynite, charnockite, etc., have given rise to laterite. The argument of an abrupt or sharp transition to the bedrock may be more apparent than real but this fact alone merits more searching enquiry than could be conducted so far. However, the main feature that taxed the understanding of most workers is how a fairly uniform type of rock like laterite could be formed from very diverse parent rocks, some of which are very poor in iron. Careful studies of several laterite profiles on diverse rocks conducted in recent years have afforded a better understanding of this aspect of the problem. Being confronted with a rather sharp transition zone of the basalt below the thick matured profiles of laterite and complete absence of laterite caps on extensive areas of Deccan trap basalts even on high plateau areas led Roy Chowdhury to search for clues for alternative parent rocks which could be a more favourable top lava flow by its composition and texture for complete alteration to laterite or volcanoclastic material resting on the last flow of basalts. Pursuing the latter concept some evidence, though not conclusive enough, was recorded from Phutka Pahar.[33] Later, Bhargava[52] from his studies of the chemistry and mineralogy of the laterite from the same area reported that its origin could be from agglomerates or ash beds. The most significant contribution on this subject came from Sahasrabudhe[22] who revived Voysey's 'muddy erudition' and convincingly advocated that Saurashtra bauxite/laterite was formed by *in situ* alteration of pyroclastic facies of volcanism (agglomerates, breccia, tuffs and ash beds) discarding alternative like sedimentary deposits and *in situ* alteration of Deccan lava flows. Even in the case of laterites on Deccan lava flows of the Maharashtra State he and Deshmukh consider[45] that the clinkery and fragmentary tops of 'aa' flows are amenable to easy weathering due to high permeability.

Although visually and physically similar, residual laterite deposits of diverse parentage do show some chemical variations. The titania content in residual laterites derived from pyroclastics,[21] Khondalite,[53] gneisses,[19] leptynites,[34] is in general much lower than in those derived from basalts.[20,54] Similarly, certain differences in the iron content of the profile are also present, not to speak of the trace element distribution and other minor chemical constituents.[22,37] It is also obvious that the chemical and mineralogical character of a laterite profile depends on its age and maturity[19] and hence, there are bound to be certain differences in laterites formed from different parent rocks and under diverse terrain conditions. In the Konkan area, Fox[19] noted the progressive enrichment of aluminium and depletion of silica northwards in laterite that are otherwise 'clearly similar of the same origin and mode of formation.' Hence, the idea of a uniform type of laterite formed from different rocks, given much credence in the previous century due to lack of chemical data, is strictly not tenable. Nevertheless, the formation from different parentage of a laterite residuum that has comparable physical characters, appearnce and certain fairly defined limits of chemical and mineralogical composition, which is the peculiarity of the process of lateritisation, cannot be overlooked.

In more recent years, considerable chemical data have become available for the high-level laterite profile from several parts of the country, chiefly where alumina rich layers or bauxitic zones are found. Some bore-hole data from Madhya Pradesh have also been obtained. Available information indicates that except in the cases of laterite duricrusts exceeding 50m in thickness the general upper limit of the thickness of laterite cappings on plateou areas is about 30m, inclusive of the uppermost pisolitic laterite and the lithomarge at the base. The exaggerated accounts of 30 or 60[9] of thickness are probably due to the erroneous impression given by the valley or lower level detrital laterite that in some places cover the slopes and valleys.[20] Breaking of large blocks, downhill transport of debris during scarp retreat and their reconsolidation at lower level produce grossly exaggerated impressions of thickness. Some of the sections presented by Lake[6] are revealing in this respect.

Some definite conclusions regarding the chemical changes involved in the process of lateritisation and in conformity with modern thinking in other countries can be drawn from the available data. Even in slightly weathered bed-rock the bases and alkalies are markedly depleted and are almost absent in the highly weathered rock and the entire overlying laterite. A concomitant increase in iron, alumina and titania occurs with the final maximum concentration of alumina and titania in the alumina-rich (bauxitic) zones. Depletion of silica is noted in the lithomarge zone and decreases progressively upwords in the profile. This general tendency is maintained in as widely separated areas as Kalahandi,[53] Shevaroy,[34] Bilaspur-Mandla[33] and Gujarat.[22] Such chemical changes proposed by Mallet,[8] Holland[13,55] and Maclaren[14] are now accepted with some refinements by most of the recent workers.

The presence of Kaolin-rich lithomarge zone, intervening between the bed-rock and the typical laterite overlying it, is almost a universal feature of nearly all high-level laterites in India and was observed by even the earliest workers.[1-3,10] Blanford[10] suggested that the lithomargic zone is an intermediate step in the formation of laterite. Chibber[56] envisaged three successive steps in the formation of laterite, viz. kaolinization, bauxitization and lateritization, as depicted in the Katni area. Difference of opinion has been expressed as to whether gibbsite can form directly from the silicates without passing through the stage of formation of kaolin. Some authenticated instances of gibbsite being converted to kaolin by a process of resilication have also been reported. In attempting to explain the invariable presence of a kaolin-rich material forming the base of the laterite, Indian geologists are divided on two alternatives. The first is that kaolin formation is perhaps the initial stage of an alteration process, the culmination of which is formation of laterite. This view is held by Fox,[19] Chibber[56] and others following the earlier workers like Blanford.[10] The second view is that formation of the kaolin-rich layer and typical laterite is a simultaneous process which does not bear any strict sequential order in the transformation process. The general consensus of opinion seems to favour that the formation of the different layers (Bauxite, laterite, lithomarge) is more or less simultaneous during the process of lateritisation with undoubted minor transformations of one to the other within these three broad layers. But the progressive increase in thickness of the laterite due to continued weathering tends to lateritise the earlier lithomarge zone and add fresh lithomarge from bed-rock and in this sense kaolinisation preceded other changes.

Many observations spread over a large part of the country attest to the fact that the exact spatial position of the bauxite zone is variable within the laterite profile In parts of Ranchi plateau, bauxite is seen immediately overlying the lithomarge while in many parts of Central Indian highlands the bauxite zone is nearer the upper portion of the laterite column. The cause for this is not clearly understood and any theory of origin should take cognisance of this feature.

The formation of laterite cappings due to *in situ* weathering of basalt with no addition of material from outside is now established beyond doubt. Recently, Roy Chowdhury *et al.*[33] have attempted to trace the volumetric and gravimetric changes involved in the transformation of tholeitic basalt to laterite using the bulk demical composition is that lateritisation of basalt can be achieved by a mere leaching of 65 per cent by weight of certain constituents and that such alteration would produce laterite only two-thirds the thickness of the basalt thus transformed. Volume reduction appears to be a significant feature of the lateritization process.

The exact mechanism of the formation of a bauxite layer, generally sandwiched between typical ferruginous laterite, is still not clearly understood. The suggestion[15] that alumina-rich material behaved likes a semipermeable membrane permitting one-way transfer and accumulation of iron oxide above and silica below is untenable because ferruginous laterite is commonly found below as well as above the bauxite layer also.

Age of Indian Laterite

Since most geologists believe that laterite is a product of subaerial weathering, it has gained stratigraphic significance as a marker horizon indicating unconformable junction and paleoclimatic conditions. In India undoubted residual laterites occurring on most types of rocks exposed in the Peninsula have been recognised, and their age ranges from early Eocene to Recent. The actual dating of the laterite formation on the plateau has been beset with difficulty due to the absence of any overlying strata. The extensive laterite capping of the Deccan trap of Eocene Age (and the Rajmahal flows of supposedly Jurassic Age) could have formed at any time after the consolidation of the basalt. The age is even more indefinite in the laterite capping the Precambrian rocks that form the Eastern and Western Ghats and certain high mountains in South India. The general belief is that the residual laterite caps got formed during the Quaternary[15,44] or late Tertiary. Some of the coastal (detrital) laterites could be dated more precisely in some instances due to presence of artifact,[4] lignitic seams, plant remains, resins[5] and fossil wood[44] or associated fossiliferous beds. Some of the coastal laterite of Kolaba and Ratnagiri districts of Maharashtra represent lateritised Tertiary sediments homotaxial with Cuddalore sandstone of the Upper Miocene age.[57] Recent mapping in the coastal areas of Ratnagiri district[58] has brought out several sections of laterite underlain by sedimentary beds containing fragmentary fossil flora (leaf impressions and fruits) ranging in age from Upper Cretaceous to Recent.

In the coastal lateritic areas of Gujarat.[12,22] Tertiary sub-Nummulitic sediments are seen overlying the laterite. These overlying sediments are not lateritized and hence the actual time of lateritization could be fixed fairly accurately.[22]

Concluding Remarks

Although our understanding of the laterite problem has grown since the days of Buchanan, there are several aspects about which our knowledge is sketchy. We are yet to learn the exact mechanism by which the high-level laterite grows with a three-layered structure, the variable position of bauxite in a lateritic column; the conditions under which lateritisation is induced in the bed-rock by the overlying debris, to mention only a few of outstanding problems.

The most baffling features of the laterite geology relate to topmost layer of highly ferruginous pisolitic laterite which rests on the matured profiles with sharp contact and comparatively thin alteration zone at the base of the profiles compared to the thick overlying sections of laterite including lithomarge. According to Roy Chowdhury[22] the bed of top pisolitic laterite is almost a constant member of the high level laterite of Bihar and Madhya Pradesh unless eroded to remnants of loose debris on the surface or completely removed at places. The sharpness of the contact is more conspicuous when it is underlain by compact and massive grey or creamy white bauxite. The pisolitic laterite is made up of either small pisolites or pellets of hydrated iron oxides and is of higher silica content than the underlying layered sequence of ferruginous or aluminous laterite or bauxite with the exception of lithomarge at the base. The most striking feature of this top pisolitic bed is that at places the pisolites are predominantly or entirely made up of aluminous material, particularly when it directly overlies the aluminous of bauxite horizon and therefore could be mistaken as locally reworked material. Mention has, however, been made of reworked pisolitic laterite and bauxite conglomerate with matrix of pisolitic material but these are local phenomena.[33] Pisolitic laterite, varying in thickness from 2m to 22m, occupying the topmost section of the laterite profiles over the Vindhyan formations has been classified as reworked material[59] but details about its exact relation with the rest of the profile are lacking. The pisolitic laterite when overlies the bouldery, lensoid of blocky bauxite e.g. Pokhra Pat in Lohardaga area and Rakti Dodar in the Amarkantak area it fills the intervening gaps and thereby the surface beds loose the characteristic sharp contacts. The sharp contact of the top ferruginous pisolitic laterite becomes more baffling when it is considered that it is an integral part of the laterite mantles or duricrusts defying a continuous chain of universally accepted weathering and leaching processes for the development of the whole profile. No doubt sharp breaks are noticed in the trend lines of the major elements at the base of pisolitic laterite, particularly when overlying the bauxitic litho units[33,45] but the reason for the same is far from clear. Nor does this explain why physical and chemical discontinuity should assign the pisolitic laterite to a separate identity unrelated to the formation of the profile as a whole.

It appears that the issue of comparatively thin alteration zones between the unaltered bed rocks and the overlying laterite profiles which may assume a thickness of more than 50m as on the Eastern Ghats has not received due attention or has been side-tracked by merely ascribing this feature as more apparent than real. When lithomarge which is commonly present at the base of laterite duricrusts and assumes thickness of more than 30m is included in the laterite profile the alteration zones of the parent rocks becomes insignificant. Based on the better understanding of the physico-chemical processes involved in the formation of lithomarge and critical analysis of the available evidences. Sahasrabudhe[45] concluded that the formation of lithomarge between the Deccan lava and the overlying laterite blankets was controlled by the general level of water table which existed during the process of weathering. However, the total quantity of silica that leached down in the process of lateritisation to form equal thickness, say 30m of lithomarge remains a puzzle. As a matter of fact the volume of all the leachates in the course of formation of laterite and their modes of disposal are yet to be established. Moreover, the exact position of the ground water seepages or spring lines commonly observed at the base of high level laterite cappings is mostly obscured by debris and could be above the impervious lithomarge or through the porous altered zones of the bed rocks below. In the Orissa planes it is a common sight that bare knolls and hillocks of granulites and gneisses are skirted at the base by growths of vegetations on altered ferruginous material, obviously at the contact of water table with the steeply sloping topography but no kaolinised material has been reported. With the present knowledge lithomarge may, however, be considered as part and parcel of the laterite profile and regarded as sign of 'maturity'. It is generally held that absence of lithomarge at the base of the high level laterite escarpments which is by far the most prevailing feature may be due to paucity of clear sections, being mostly covered by debris and in the case of coastal laterite such instances are explained by the detrital origin of laterite but such beliefs are not corroborated by facts. The thick (upto 30m) cappings of laterite which occupies 30 per cent of the territory of Goa and at places contains segregations of bauxite are no longer considered as detrital material and in this context it is interesting to note that Sriram and Prasad[60] report that it is not uncommon to find "knife sharp contact between the laterite covers and the underlying *in situ* rocks. The relict textures and in some cases relict structural features or easily recognisible 'undigested' parent rocks in the lower sections of the laterite profiles should normally be considered as undisputed fact that the mantles and duricrusts of laterite are actual alteration product of the underlying rocks, but how far these features are due to induced lateritisation from the top will remain a matter of conjecture. Considering that the distribution pattern of trace elements in the bed rocks to the overlying laterite profiles through the altered zones of saprolites and laterites could definitely establish the relationship between them, such studies have been carried out covering profiles of diverse rock types e.g., sandstone-shale-ochre series of the Kaimaur and Bhander formations of the Vindhyan super group.[59,61] Deccan lava flow.[22,54,62] Charnokitic suite of rocks[29,27,63] nickeliferous laterite on ultra-basics.[50] The data presented relate to the laterite profiles only, except in a few cases where borehole samples of unaltered rocks were available for comprehensive studies. Thus, the available information mostly represent a close circuit distribution of trace elements rather than tracing a continuous trail to make the studies conclusive.

The influence of drainage has long been considered as one of the primary conditions for the development of laterite mantles. This fact led Fox[15] and Roy Chowdhury[20] to describe the laterite cappings with segregations of bauxite in relation to the drainage regions. So far as the development of bauxite is concerned it was definitely established by Roy Chowdhury[20] that it was closely related to the degree of erosion. The more dissected portions of the plateaus and particularly the isolated ones are often crowned by good deposits of bauxite. Such occurrences are conspicuously observed in the Bihar plateau regions and Maikala range of hills[20] and Kolhapur district of Maharashtra.[22] The dissected table lands post-date the formation of laterite on extensive pineplained surfaces which were subsequently broken into segments by tectonic forces and generating drainage patterns with rapid erosion at head water regions forming the major water divides of the central and southern geomorphic segments of the country. The rapidity of incision by juvenile streams is reflected from the V-shaped deep gorges in the laterite capped plateau regions comprising the Western and Eastern Ghats, the Satpuras and the Vindhyans. The degree of erosion is further augmented by a process of "scarp retreat," a term coined by Roy Chowdhury.[21] The present is the destructive phase of the high level primary laterite.

Disregarding the problems and doubts on certain geomorphic features of laterite in India some of which are enumerated above and synthesising the concepts on its origin emerging from the bewildering observations and evidences put forward in the course of long historical perspective a stage has been reached when an acceptable genetic model is within easy reach. The major problems are now confined within the three well accepted basic premises, namely (1) laterite, excluding detrital types, is an *in situ* alteration product of tropical or sub-tropical weathering with alternate hot and wet climates, simply but aptly referred for as a "tropical disease"; (2) planar surfaces are pre-condition for the development of laterite mentles and duricrusts and (3) it formed within the time frame between early Eocene and Recent. If one is bold enough to induct new concept analogous to cosmic dust theory like volcanoclastic ash settling on post-Deccan lava planar surfaces the morphological and genetic problems arising out of multiple parent rocks may vanish forthwith but geologists are likely to shy away before applying such sticks to beat the devils.

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