ELSEVIER
Catena 47 (2002) 117–131
CATENA
www.elsevier.com/locate/catena

A critique of the Schellmann definition and classification of 'laterite'

Robert P. Bourman[a,*], Clifford D. Ollier[b]

[a]University of South Australia, School of Environmental and Recreation Management, Mawson Lakes Boulevard, Mawson Lakes, South Australia 5095, Australia
[b]Centre for Resource and Environmental Studies, Australian National University, Canberra, ACT, 0200, Australia

Received 19 June 2001; received in revised form 9 July 2001; accepted 19 July 2001

Abstract

Schellman's definition and classification of 'laterite' are based on the SiO_2, Al_2O_3 and Fe_2O_3 contents of weathered formations in comparison to the chemical composition of the underlying rocks, from which the weathered materials are assumed to be derived. This approach is open to misinterpretation because many regolith materials have formed by lateral transport, both physical and chemical; it ignores the role of absolute accumulation; it pays little attention to the morphological characteristics of 'laterites' that give clues to their origins; it ignores the detailed mineralogical compositions of weathered materials and 'laterite'; and it does not permit field identification. Understanding of geology, stratigraphy, geomorphic evolution, mineralogy and micromorphology are essential ingredients of regolith investigations. Chemical analysis alone is insufficient. Schellmann's chemical classification seems appropriate only to a small subset of potential 'laterites' in which the whole profile is of bedrock and saprolite, and where there has been no lateral movement of solids or solutions. Schellmann's definition demands formation by tropical weathering, which eliminates ferruginous duricrusts formed outside the tropics. His approach produces confusion by grouping disparate ferruginous/aluminous materials together as 'laterite.' The range of applications of the term 'laterite' is so broad that it has become meaningless and the Schellmann approach has not resolved this issue. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: 'Laterite'; Ferricrete; Kaolin; Chemical classification; Definitions

---

[*] Corresponding author. Tel.: +61-8-8302-5177; fax: +61-8-8302 5082.
E-mail address: r.bourman@unisa.edu.au (R.P. Bourman).

PII: S0341-8162(01)00178-3

1. Introduction

Clear definitions and classifications of ‘lateritic’ materials are necessary for mutual understanding and fruitful communication between different regolith researchers, and agreed definitions would be even more helpful. Unfortunately, both the definition and classification of ‘laterite’ remain enigmatic and confusing.

Schellmann (1983) pointed out the difficulties involved in developing a satisfactory definition of ‘laterite’, and noted that variations in definitions have even influenced the trend of ‘laterite’ research. He proposed definitions of his own related to a classification based on chemical plots on ternary diagrams. His ideas are well known and still often used today (e.g. Aleva, 1994; McAlister and Smith, 1997; Bowden, 1997). It was noted by Eggleton and Taylor (1999, p. 212) that the compilation of Aleva (1994) “draws heavily on Schellmann (1983) for its definition of ‘laterite’”. Recently, they highlighted some problems associated with this usage, and wrote of their own work: “This paper represents an opening salvo of what we hope will be an on-going discussion and clearing of the air regarding ‘laterite’ and other ferruginous materials”. (Eggleton and Taylor, 1999). The present paper is presented as part of this on-going discussion, focussing narrowly on Schellmann’s definition and classification, which appear to have won too wide an acceptance in the past two decades and have overemphasized the role of in situ weathering as opposed to lateral transport of regolith materials in the development of ‘laterite’.

2. The Schellmann method: definitions and classification

Schellmann (1981; Abstract and p. 6) defined ‘laterites’ as follows: “Laterites are products of intense subaerial weathering whose Fe and/or Al content is higher and Si content is lower than in merely kaolinised parent rocks. They consist predominantly of mineral assemblages of goethite, hematite, aluminium hydroxides, kaolinite minerals and quartz”. He considered that the $SiO_2/(Al_2O_3+Fe_2O_3)$ ratio of ‘laterite’ must be lower than that of kaolinised parent rock, in which all of the alumina of the parent rock is present in the form of kaolinite, all the iron in the form of iron oxides, and which contains no more silica than is fixed in the kaolinite, plus the primary quartz.

The Schellmann classification of ‘laterites’ is determined by plotting the chemical compositions of the ‘lateritic’ materials on ternary diagrams of SiO_2, Fe_2O_3, Al_2O_3 for comparison with the mean composition of different parent rocks. Ternary diagrams were produced for weathered products derived from varying rock types because the nature of the parent material influences the compositions of the weathered derivatives. Fig. 1 as an illustration of the approach indicates the plots of the weathering products developed on granite bedrock only. The relative positions of the fields of ‘kaolinisation’, ‘weak lateritisation’, ‘moderate lateritisation’ and ‘strong lateritisation’ vary, depending on the parent rock material. Accepted by Schellmann as ‘lateritic materials’ are “crusts, yellow brown soft ‘laterite’, reddish-brown not incrusted ‘laterites’, mottled ‘laterites’, clay, kaolinised clay, and kaolinised sandstone”. However, the criteria for acceptance are not clear. Schellmann’s definition and classification of ‘laterite’ are thus based on the SiO_2,

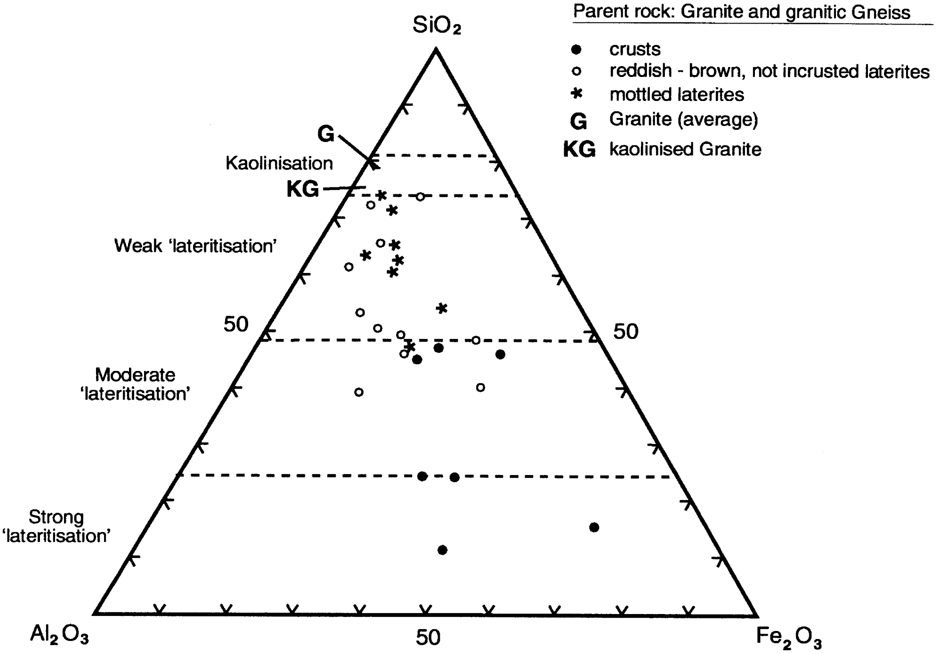

Fig. 1. Triangular diagram of Schellman (1983) showing the classification of 'laterite' on granite and granitic gneiss into zones of kaolinisation and weak, moderate and strong 'lateritisation'.

Al_2O_3 and Fe_2O_3 contents of the weathered formations and of the parent rocks. After all of this detailed analytical work, the classification that emerges is only one of 'weak, moderate or strong lateritisation'.

3. Assumptions built into the Schellmann method

Schellmann's ideas are based on several assumptions that are not always clearly stated.

3.1. Assumption that profiles are uniform

Primary or in situ 'laterite' was commonly considered to be genetically related to the underlying materials long before Schellmann developed his classification (e.g. Pullan, 1967). This has certainly been the case in Australia where the traditional notion of 'laterite' formation has dominated thinking until relatively recent times (see reviews in Hunt et al., 1977; Hunt, 1985; Bourman, 1993; Bourman et al., 1995; Ollier, 1994; Eggleton and Taylor, 1999). Fig. 2, which has been reproduced in many texts and papers (and so perhaps illustrates a consensus view) shows the perceived 'laterite profile'. It has a former soil at the top (often missing), a crust (often regarded as the 'laterite') followed successively by mottled and pallid zones over unweathered bedrock. Like many prede-

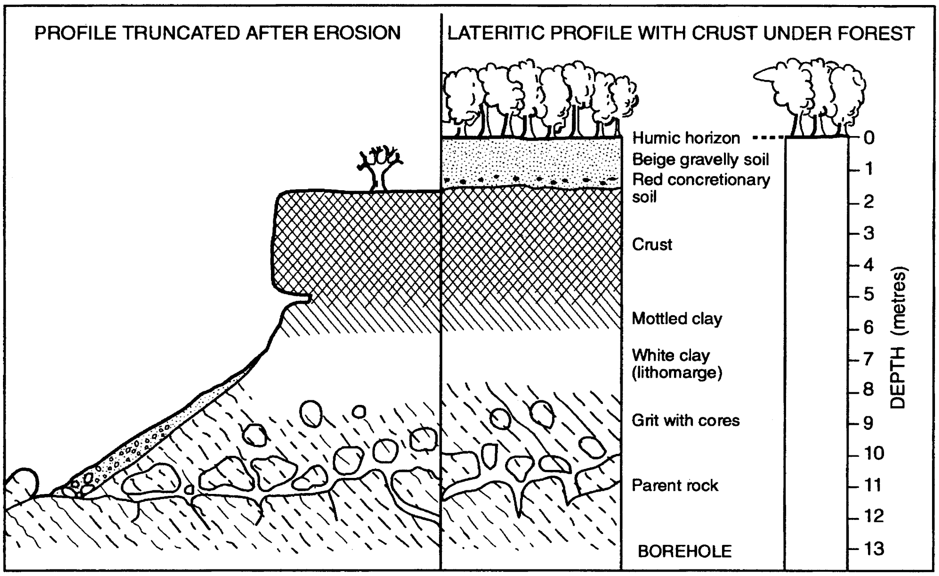

Fig. 2. Commonly accepted, standard or ideal 'laterite profile (source: Millot, 1970).

cessors, Schellmann makes the basic assumption that 'laterite' is genetically related vertically to the underlying bedrock from which it is assumed to have developed by weathering processes. It must be pointed out that 'laterite' is not necessarily developed on bedrock at all, but can be formed on transported materials such as alluvial deposits, or from the reworking of primary 'laterite' forming secondary or detrital 'laterite', which is

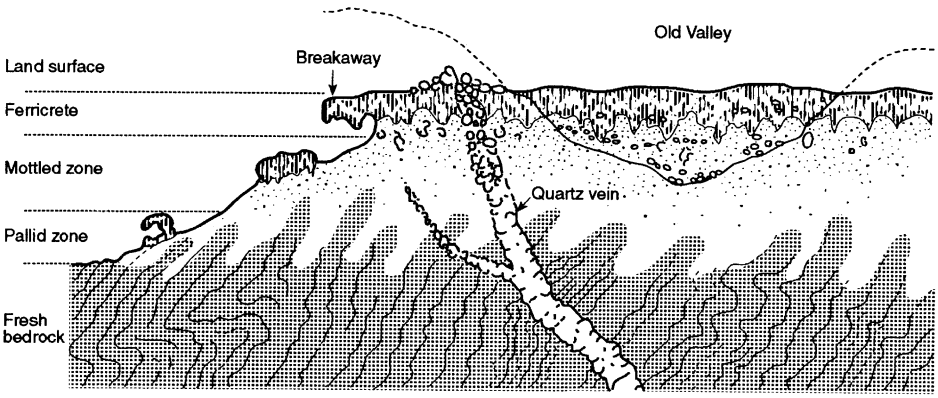

Fig. 3. The 'laterite' profile of Western Australia as described by Walther (1915). Deep weathering affects both saprolite, as evidenced by the presence of quartz veins, and transported material. The ferricrete forms a surficial crust across both saprolite and transported material.

further weathered. This was pointed out and illustrated by Walther as early as 1915. In his figure (reproduced in our Fig. 3), it would seem impossible to derive the iron in the 'laterite' shown on the channel fill from the underlying sand or the kaolin beneath it.

Many authors have described actual profiles that clearly show an upper unit of transported material that is not directly derived from the underlying bedrock. Indeed, Ollier and Galloway (1990) claimed that the majority of 'laterite' profiles contain an unconformity, which may be between saprolite and transported or reworked material, or between fresh bedrock and transported material.

Much earlier, Ollier (1959) had pointed out that many tropical soils have an unconformity between saprolite and resorted earth, sometimes followed by a stone-line, with pisolitic 'laterite' above the unconformity and vesicular 'laterite' below, merging into a mottled zone (Fig. 4).

3.2. Assumption of vertical movement

A major cause of confusion in 'laterite' studies has been the overemphasis on the view that 'laterites' have formed by movement of iron up or down the profile. This traditional model invokes vertical translocations of materials under humid tropical conditions, on peneplains, with the different parts of the profile being genetically related. Incomplete profiles are interpreted as reflecting variable degrees of erosion of the original 'ideal' profile. The possibility of the addition of materials from outside is ignored.

Vertical movement of iron through a weathering profile may be either up or down. One simple explanation of the sort of iron accumulation (crust) shown in Fig. 1 is that the lower, bleached zone has lost iron, which has somehow moved up the profile to form the

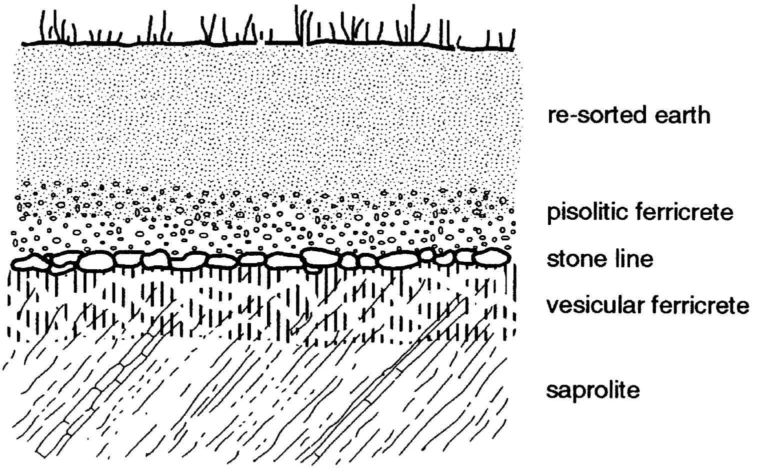

Fig. 4. A typical profile with an unconformity between saprolite (marked by quartz veins) and resorted or transported earth. The unconformity, often followed by a stone-line, marks a hydrological contrast. Pisolitic ferricrete forms in the resorted earth, vesicular ferricrete forms in the saprolite (Ollier, 1959).

crust. An alternative is that the iron migrated down from above, from weathering rock, which has since been removed. Trendall (1962) believed that whole landsurfaces were lowered in this way to form 'apparent peneplains'. He even calculated the amount of surface lowering from the amount of residual iron present. Under this hypothesis, kilometric amounts of landsurface lowering are required to explain the iron concentrations in crusts, assuming that the crusts were formerly continuous across the entire landscape. Both of these hypotheses invoke absolute accumulation of iron, chemically and physically, in both ferrous and ferric forms.

In reality, it has been shown in a great number of cases that iron- and aluminium-rich crusts have been derived from lateral sources rather than from underlying ones (e.g. d'Hoore, 1954; Maignien, 1966; de Swardt, 1964; Milnes et al., 1985; Ollier and Galloway, 1990). Almost all such crusts display some elements of lateral transport of iron and/or aluminium oxides, either physically or in solution, but even clearly transported ferricretes have also been subsequently affected by ongoing weathering processes. Furthermore, there is abundant evidence of lateral movement of iron in solution and physical movement of pisoliths in present-day landscapes (e.g. Bourman, 1996; Pain and Ollier, 1992; Phillips, 1999; Phillips et al., 1997).

In some places, the 'laterite' crust bears no genetic relationship to the underlying profile whatsoever. For example, extremely iron-rich bog iron ore, which occurs on a now

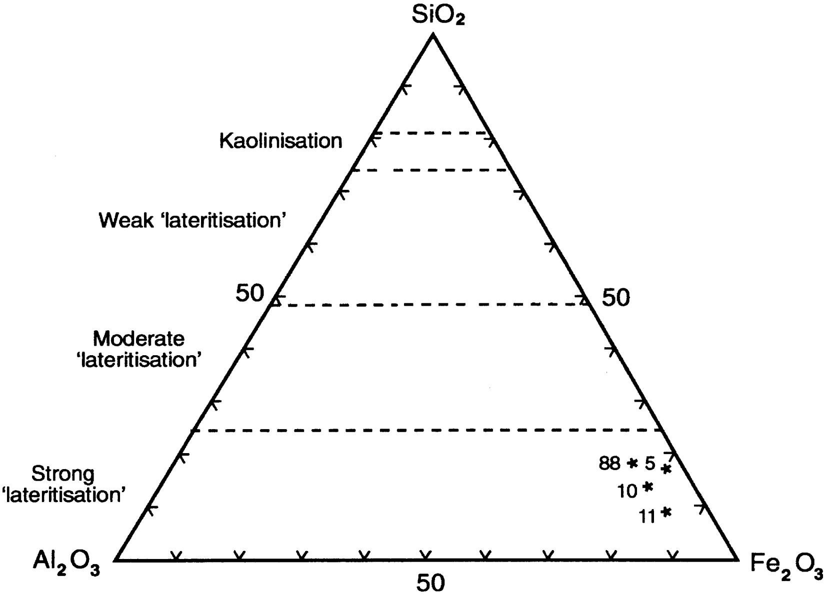

Fig. 5. Plots of vesicular ferricrete (bog iron ore) and weathered siderite, which on the Schellmann ternary diagram are categorised as indicating 'strong lateritisation' on granitic bedrock. In reality, they represent relative accumulation in a former swamp of laterally transported iron oxides (5, 10, 11) and oxidation of a pre-existing ferrous iron-rich material (88) (Bourman, 1993).

isolated summit surface near Esperance in the southwest of Western Australia has accumulated through lateral transportation. The crust here has a total Fe_2O_3 exceeding 70%, iron oxides are exclusively goethite in which aluminium substitution is $< 1\%$. These chemical and mineralogical characteristics are typical of bog iron ore formed by the lateral movement of iron in solution into former peat swamps, with the iron in solution replacing the organic matter (Bourman et al., 1987). Consequently, if the Schellmann method is applied without detailed information about the character of the ferruginous material, then erroneous conclusions may be drawn. For example, Fig. 5 shows plots of vesicular ferricrete (bog iron ore) and weathered siderite, which on the Schellmann ternary diagram may be categorised as indicating 'strong lateritisation' on granite bedrock. In reality, they represent absolute accumulation of laterally transported iron oxides in a former peat swamp (Bourman et al., 1987) and oxidation of a preexisting iron rich material (siderite) originally formed in freshwater swamps (Bourman et al., 1995), and totally unrelated to the underlying bedrock. In the case of the Sydney 'laterite' overlying Hawkesbury Sandstone (Schellmann, 1981, Table 1), the Fe_2O_3 could have been derived laterally from the stratigraphically and topographically higher and more iron-rich Wianamatta Shale (Burgess and Beadle, 1952) and not from the sandstone.

Many other instances of lateral transport are recorded in the literature. Pain and Ollier (1992, 1995) described examples of ferricrete formation on footslopes and in drainage lines, which eventually lead to inversion of relief. Similar examples are provided from the USA by Phillips (1999) and Phillips et al. (1997). Some drainage-line ferricretes occur on a huge scale, such as the Hammersley iron ore deposits (Twidale et al., 1985).

4. Problems of the Schellmann classification

4.1. Weathering, saprolite and mobilised materials

Within weathering profiles, some weathering has obviously occurred in situ and isovolumetrically to produce saprolite. This is indicated by the preservation of bedrock features such as quartz veins, bedding and joints that cut across both mottled and bleached zones. Upper parts of the profile have almost always been disturbed and expanded. This important distinction is not recognised by Schellmann, who appears to believe his weathering profiles are confined to saprolite.

4.2. Selection of possible 'lateritic' materials

All things are regarded as 'lateritic' by Schellmann provided that they meet the chemical criteria, and Schellmann's definition has the potential to allow a great variety of different materials to be grouped together. For example, he accepts as 'lateritic' varieties of different materials such as "crusts, reddish brown, not incrusted 'laterites', mottled 'laterites', kaolinised granite and yellow-brown soft 'laterites'". He considered that limiting 'laterite' to indurated varieties would exclude a large number of 'lateritic' materials such as the earthy weathered covers over basic rocks.

The great diversity of materials he included under the family name of ‘laterite’ led him to the conclusion that they should be defined on the basis of their degree of weathering as expressed in their chemical compositions. Schellmann used ‘laterite’ as a family name independent of specific secondary properties such as hardening or colour and included both ‘lateritic’ crusts and Buchanan’s ‘laterite’ because of their chemical compositions. The materials analysed by Schellmann are very variable in character and come from different parts of the profile and from different microenvironments. For example, he talks about the ‘laterite’ of the mottled zone. On the other hand, some intensely coloured and indurated surface covers are excluded because they are not sufficiently enriched in iron and/or aluminium.

Grouping of disparate types of materials as ‘laterite’ produces confusion in the definition and classification of ‘lateritic’ materials. It seems that Schellman (or some other worker) first decides that a material is ‘lateritic’ in the field, following which analysis is used to demonstrate its ‘degree’ of ‘lateritisation’ to verify or negate it. Regardless of the chemical analysis to determine the ‘degree of lateritisation’, it is not clear how one decides if a material is ‘lateritic’ in the first place. This leads to the next problem.

4.3. Lack of field application

Schellmann (1981 p. 2) lists as his last criterion for a good nomenclature, “A nomenclature should be practical and fulfill the desired requirements, but in no case should demands be made that are not appropriate”. However, he acknowledges (Schellmann, 1983, p. 20) that his method of ‘laterite’ classification is not simple and does not permit differentiation in the field. In our opinion, this makes his classification impractical.

4.4. Genetic or non-genetic classification

The Schellmann (1981, p.1) definition and classification of ‘laterite’ are based on degrees of weathering and he considered his definition of ‘laterite’ to be independent of a genetic interpretation. He later states that “the common genetic criterion of ‘laterites’ is their formation by intense subaerial rock weathering” (Schellmann, 1981, p. 3). It is true that the chemical analyses (criteria for classification) are independent of genetic connotations, even when they are plotted on a ternary diagram. However, if the criteria are considered to be part of a weathering continuum (the degree of ‘lateritisation’ compared to the parent material), surely such a classification is genetically based.

Schellmann stressed the role of intense tropical weathering, but is this really the case? See, for example, Bourman (1993), who demonstrated that iron is mobile and iron-enriched crusts (ferricretes) are currently forming in Mediterranean and semi-arid climatic zones in South Australia. If an otherwise acceptable ‘laterite’ were formed in a savannah climate, would it be excluded by definition? Would the ferricretes of Texas or North Carolina (Phillips, 1999; Phillips et al., 1997) be excluded from the class ‘laterite’ because of the climate, even though the analysis would show the upper part of the profile to be richer in iron? Furthermore, Taylor et al. (1992) have described what they call cool climate ‘laterite’ or bauxite.

4.5. Absolute and relative accumulation of iron

It has long been known that ferruginous and aluminous crusts may form as a result of physical and/or chemical lateral translocation of iron oxides. d'Hoore (1954) distinguished relative (accumulation of Fe_2O_3 and Al_2O_3 with loss of SiO_2 and bases) and absolute (imports of Fe_2O_3 and/or Al_2O_3) accumulations of iron and aluminium oxides in the formation of primary and secondary 'laterites'. Herbillon and Nahon (1987) endorsed the Schellmann scheme as they claimed that it accommodates the concepts of 'relative' and 'absolute' accumulations, regarded in the French literature as the key geochemical processes leading to the formation of 'laterite'.

Schellmann (1981) acknowledges that absolute accumulation occurs but states that it is secondary to relative accumulation (residual accumulation). Despite this, he seems to ignore absolute accumulations in his classification.

Absolute accumulation can occur in either transported materials or in saprolite, and does not support or disprove the simple vertical hypothesis.

4.6. Morphology

Although 'lateritic' materials are recognised on form (crusts, mottles), the Schellmann scheme pays little attention to the morphological characteristics of the 'laterites' which may give clues to their origins. Schellmann acknowledges that there is a need for additional information about 'lateritic' materials such as fabric, consistency, colour and composition. However, the grouping together of mottles, clays and crusts and then classifying them on their degree of 'lateritisation' should surely come after their possible genetic relationships have been determined on morphological and field criteria.

4.7. Need for chemical analysis before classification

Adoption of the Schellmann method means that every bit of potential 'lateritic' material in the world has to be analysed chemically, and the analysis compared with other analyses in the same profile, before it can be classified.

4.8. Anomalous attitude to kaolin

Schellmann (1981) considered kaolinisation to be a non-'lateritic', earlier stage of weathering. He justified this because kaolinisation also occurs in temperate climates. Such an idea does not explain the source of the iron incorporated into 'lateritic' materials at a later time. 'Kaolinite and saprolite' were regarded as less weathered rocks. 'Laterites', on the other hand, were regarded as the 'most severely weathered of the residual rocks, regardless of the parent rock' (Schellmann, 1983, p. 11).

If the kaolin is older, the 'laterite' with its iron-rich top is younger. The question is where does the iron come from and how does it get there? It cannot be derived from the kaolin, which has no iron. If derived from the rock below, it has to pass through the kaolin layer, which seems highly unlikely. To come from above, there would have to be wind-blown sources (e.g. Brimhall et al., 1991) or some other extraneous source, which would not fit the Schellman model of derivation from below. It could, of course, come laterally, a process favoured by many, but not fitting the Schellmann scheme.

4.9. One definition or many

Schellmann (1981, p. 1) wrote, "We can understand that each occupational group desires its own classification system, one that meets special demands" and goes on to say that "we [himself] can only represent the field of geology." We object to this on two grounds. Firstly, a definition must be independent of any particular field. There are many people who are engineering geologists, soil geomorphologists or have other combined fields of interest. They cannot decide which hat to wear before adopting a definition. We cannot accept the idea that "If we (Schellmann) realise that pedological and geological definitions and classifications are based on quite different requirements, misunderstandings need not arise...". It is precisely because different people use the term 'laterite' to mean different things that the confusion has arisen. Secondly, Schellmann cannot claim to represent geology. His definition is chemical, and geological data are absent. This must be remembered, despite his later statement that "'laterite' is a petrographic term".

If there are not to be several conflicting definitions, and if workers cannot agree on a common definition, it is perhaps best to dispose of the term 'laterite' altogether. In its place we might use the following terms:

ferricrete—indurated, iron-rich material;
Walther profile—the classic profile first described by Walther (1915), with crust, red, mottled and pallid zones;
bauxite—material enriched in aluminium to be of ore quality;
tropical red earth—a tropical red soil lacking ferricrete.

Eggleton and Taylor (1999) also suggested disposing of the term 'laterite' but concluded that it would be impossible to do so as it is so ingrained within the literature. They suggested that its "use be always informal or broadly descriptive, never defining".

5. An alternative use of the ternary diagram

Bourman (1993, 1996) utilised the ternary diagram, not to speculate on the degree of weathering, but to plot weathering materials with differing morphological characteristics. These included vermiform, nodular, pisolitic, nodular, massive to vesicular ferricretes as well as ferruginised quartzose sediments and ferruginised metasedimentary bedrock, which included ferruginous mottles (Fig. 6). Despite a certain amount of overlap, the different morphological types occupy relatively discrete fields on the diagram (Fig. 7) highlighted by the plot of the mean ferricrete type. The variation in the plots of pisolitic ferricrete and individual pisoliths suggests that there have been different modes of evolution for the two, supporting other data for the transport of the individual pisoliths in former landscapes.

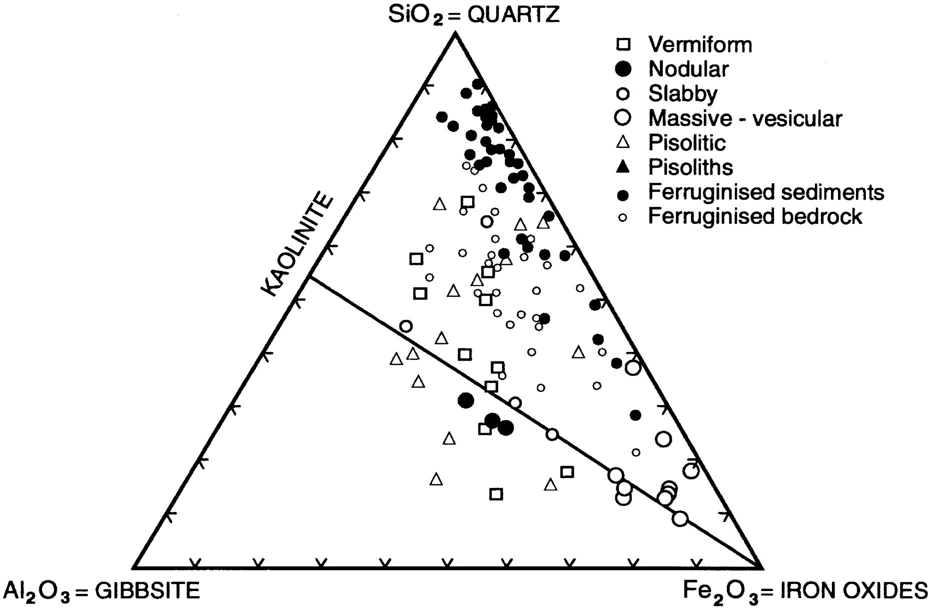

Fig. 6. Ternary plot of ferricretes and mottles with differing morphological characteristics (Bourman, 1993, 1996).

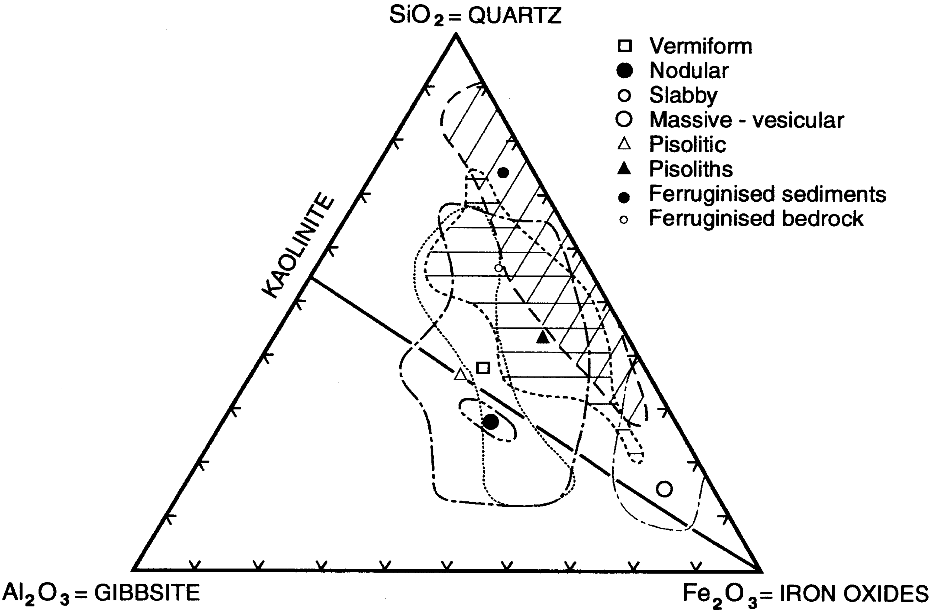

Fig. 7. Different morphological types occupy relatively discrete fields on the diagram highlighted by the plot of the mean ferricrete types (Bourman, 1993, 1996).

The diagrams did not include unweathered bedrock, saprolite or kaolinite, as these materials are clearly distinguishable from the iron-rich materials. The ternary plots of mineralogy (hematite, goethite and maghemite plus gibbsite) (Fig. 8) also produced discrete fields occupied by the different morphological types of iron-rich materials, suggesting varying environments of formation. Bourman (1993) also provided mineralogical and micro-morphological information as well as data on geology, geomorphology and the field relationships of the different ferruginous materials to each other, leading to the reconstructions of past environments of formation. From these investigations, it was demonstrated that there are many different types of ferricretes, reflecting different modes of formation, and many do not result from in situ weathering. Lateral movement of iron is very important and concentrations of Fe and Al in ferricretes do not necessarily reflect derivation from the directly underlying rocks.

Although there is a limited range of minerals present in weathered rocks and sediments, the relative concentrations of the minerals assist in the reconstruction of the palaeoenvironments in which the ferruginous/aluminous materials formed, especially when aluminium substitution in the iron minerals is known (Bourman, 1993). Even though Schellmann defines ‘laterite’ as a “mineral assemblage” his classification scheme takes no account of the varying mineralogy in different weathered materials, but simply their chemical compositions.

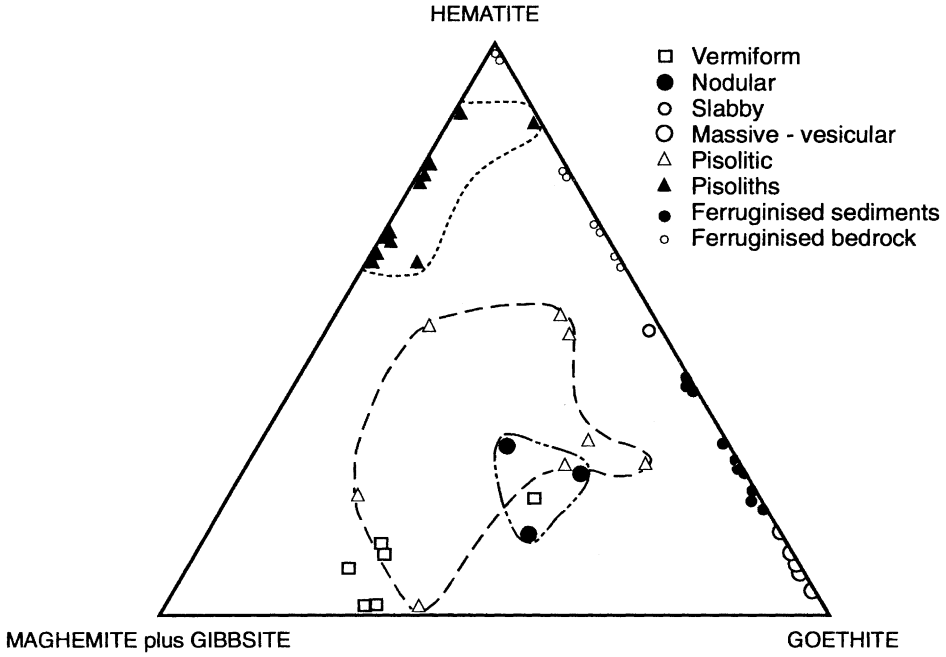

Fig. 8. Ternary plots of mineralogy (hematite, goethite and maghemite plus gibbsite) of different morphologically discrete weathered materials (Bourman, 1993, 1996).

6. Conclusions

The Schellmann scheme of classification of ‘laterite’ assumes a model of ‘laterite’ formation that involves vertical movements in weathering profiles formed from bedrock and genetically related to the underlying materials. The work of Schellmann (1981, 1983, 1986) has been very significant in providing detailed chemical analyses of regolith materials and in applying those analyses towards developing a classification of ‘laterite’. This classification system is applicable in situations where there is no doubt that lateral translocations of minerals, physically and/or chemically have not occurred. Critical applications of the scheme have been reported by McAlister and Smith (1997) and Widdowson and Gunnell (1999), where the mineralogical transformations have occurred by isovoluminous weathering. Widdowson and Gunnell (1999) were also able to distinguish in situ and undoubted allochthonous profiles. However, there are inherent dangers if the scheme is applied uncritically, and it may be extremely difficult to demonstrate isovoluminous weathering in cases where minerals have been introduced in solution. Even where the system works, the only outcome is a classification of ‘weak, moderate or strong lateritisation’.

Some weathering profiles have been interpreted as stratigraphic sequences. An observed profile may consist of a series of geological materials, horizons in a soil profile or zones in a weathering profile. The first thing to determine is the relative contributions of geological layering and subsequent weathering tranformations.

Many workers emphasise the important role of lateral transport in explanations of ferricrete genesis. Examples come from Africa (e.g. d’Hoore, 1954; Maignien, 1966; de Swardt, 1964; Pullan, 1967), Australia (e.g. Milnes et al., 1985; Bourman et al., 1987; Ollier and Galloway, 1990; Ollier, 1991, 1994; Bourman, 1996), India (Widdowson and Gunnell, 1999) and USA (Phillips, 1999; Phillips et al., 1997).

Ferricretes may form in various ways; they may not be genetically related to the underlying bedrock, and they do not simply reflect the intensity of weathering. The chemical classification of Schellmann may be only appropriate to a small subset of potential ‘laterites’, where the whole profile is of bedrock and saprolite, and where there has been no lateral movement of solids or solutions. Given these restrictions, it may have little value as a universal classification and definition of ‘laterites. In order to understand the origin of regolith materials (preferred to ‘lateritic’ materials), chemical analysis alone is insufficient. Even to interpret the analyses, there is first a need for a detailed understanding of geology, stratigraphy and geomorphic evolution as well as descriptive and analytical information on mineralogy and micromorphology. Perhaps the best way to use the Schellmann triangle is to apply it after other investigations are complete. Even though the scheme is based on chemical analysis only, Schellmann acknowledged the need for information about other characteristics of the ‘lateritic’ materials analysed to gain a more comprehensive understanding of their development.

The formation of ferruginous crusts appears to comprise a continuum between those clearly transported and those formed by weathering in place, and it is important that a set of criteria be established which will allow the delineation of the whole range of ferruginous duricrusts (Bourman, 1996).

‘Laterite’ is still a vague term. It is used to describe soils, ferruginous materials (notably ferricrete), weathering profiles, and Schellmann chemical assemblages. ‘Lateritic’ as an adjective is used to describe a wide range of processes including aspects of weathering, of soil formation, of ferricrete formation and even kaolin formation. The range of applications is, in fact, so broad that it has become meaningless, and one can only strive to guess what a particular author means when that term is applied. Unfortunately, the Schellmann approach does nothing to rectify this situation, and confounds the argument by grouping together a wide range of materials, and producing a system of classification and definition based only on chemical analyses. A morphological classification of ferruginous/aluminous crusts, such as that developed by Pullan (1967) may be a more useful approach to pursue. This allows classification in the field and provides opportunities for new categories to be added. Subsequent chemical and mineralogical analyses (e.g. Bourman, 1993, 1996) can then provide more detailed information about the origin of the materials and their environments of formation.

Acknowledgements

We are grateful for the inputs of the referees, Bernie Smith and Graham Taylor, and those of the editor, Mike Thomas. Chris Crothers drafted the diagrams.

References

Aleva, G.J.J., 1994. Laterites. Concepts, Geology, Morphology and Chemistry. ISRIC, Wageningen.

Bourman, R.P., 1993. Perennial problems in the study of laterite: a review. Aust. J. Earth Sci. 4, 387–401.

Bourman, R.P., 1996. Towards distinguishing transported and in situ ferricretes: data from southern Australia. AGSO J. Aust. Geol. Geophys. 16, 231–241.

Bourman, R.P., Milnes, A.R., Oades, J.M., 1987. Investigations of ferricretes and related surficial ferruginous materials in parts of southern and eastern Australia. Z. Geomorphol. N.F., Suppl.-Bd. 64, 1–24.

Bourman, R.P., Fitzpatrick, R.W., Self, P.G., 1995. Character and origin of ferruginous voidal concretions in weathered Triassic sediments of the Telford Basin, South Australia. In: Churchman, G.J., Fitzpatrick, R.W., Eggleton, R.A. (Eds.), Clays Controlling the Environment: Proceedings 10th International Clays Conference, Adelaide. CSIRO Publishing, Melbourne, Australia, pp. 346–354.

Bowden, D.J., 1997. The geochemistry and development of lateritized footslope benches: the Kasewe Hills, Sierra Leone. In: Widdowson, M. (Ed.), Palaeosurfaces: Recognition, Reconstruction and Palaeoenvironmental Interpretation. Geological Society Special Publication, Geological Society, London, vol. 120, pp. 295–305.

Brimhall, G.H., Lewis, C.J., Ford, C., Bratt, J., Taylor, G., Warin, O., 1991. Quantitative geochemical approach to pedogenesis: importance of parent material reduction, volumetric expansion and aeolian influx in lateritization. Geoderma 51, 51–91.

Burgess, A., Beadle, N.C.W., 1952. The laterites of the Sydney district. Aust. J. Sci. 14, 161–162.

de Swardt, A.M.J., 1964. Lateritisation and landscape development in parts of equatorial Africa. Z. Geomorphol. 8, 313–333.

d'Hoore, J., 1954. Essai de classification des zones d'accumulation de sesquioxydes libres sur de bases genetiques. Sols Afr. 3, 66–80.

Eggleton, R.A., Taylor, G., 1999. Selected thoughts on "laterite". In: Taylor, G., Pain, C.F. (Eds.), Regolith '98. Cooperative Research Centre for Landscape Evolution and Mineral Exploration, Perth, pp. 209–226.

Herbillon, A.J., Nahon, D., 1987. Laterization processes: Chap. 22. Iron in Soil and Clay Minerals. Reidel, Dordrecht.

Hunt, P.A., 1985. The mobility of silicon and iron in the near-surface zone: a re-evaluation of the concept of duricrust in central and eastern New South Wale. PhD thesis, Macquarie University, 343 pp.

Hunt, P.A., Mitchell, P.B., Paton, T.R., 1977. “Laterite profiles” and “lateritic ironstones” on the Hawkesbury Sandstone Australia. Geoderma 19, 105–121.

Maignien, R., 1966. Review of research on laterites. UNESCO Natural Resources Research IV. UNESCO, Paris, 148 pp.

McAlister, J.J., Smith, B.J., 1997. Geochemical trends in Early Tertiary palaeosols from northeast Ireland: a statistical approach to assess element behaviour during weathering. In: Widdowson, M. (Ed.), Palaeosurfaces: Recognition, Reconstruction and Palaeoenvironmental Interpretation. Geological Society Special Publication, Geological Society, London, vol. 120, pp. 57–65.

Millot, G., 1970. Geology of Clays. Masson, Paris.

Milnes, A.R., Bourman, R.P., Northcote, K.H., 1985. Field relationships of ferricretes and weathered zones in southern South Australia: a contribution to ‘laterite’ studies in Australia. Aust. J. Soil Res. 23, 441–465.

Ollier, C.D., 1959. A two-cycle theory of tropical pedology. J. Soil Sci. 10, 137–148.

Ollier, C.D., 1991. Laterite profiles, ferricrete and landscape evolution. Z. Geomorphol., N.F. 35, 165–173.

Ollier, C.D., 1994. Exploration concepts in lateritic terrains. Bull. Aust. Inst. Min. Metall. 3, 22–27.

Ollier, C.D., Galloway, R.W., 1990. The laterite profile, ferricrete and unconformity. Catena 17, 97–109.

Pain, C.F., Ollier, C.D., 1992. Ferricrete in Cape York Peninsula, North Queensland. BMR J. Aust. Geol. Geophys. 13, 207–212.

Pain, C.F., Ollier, C.D., 1995. Inversion of relief—a component of landscape evolution. Geomorphology 12, 151–165.

Phillips, J.D., 1999. Edge effects in geomorphology. Phys. Geogr. 20, 53–66.

Phillips, J.D., Lampe, M., King, T., Cedillow, M., Beachley, R., Grantham, C., 1997. Ferricrete formation in the North Carolina Coastal Plain. Z. Geomorphol., N.F. 41, 67–79.

Pullan, R.A., 1967. A morphological classification of lateritic ironstones and ferruginized rocks in Northern Nigeria. Niger. J. Sci. 1, 161–174.

Schellmann, W., 1981. Considerations on the definition and classification of laterites. Proceedings of the International Seminar on Lateritisation Processes, Trivandrum, India. A.A. Balkema, Rotterdam, pp. 1–10.

Schellmann, W., 1983. A new definition of laterite. Nat. Resour. Dev. 18, 7–21.

Schellmann, W., 1986. A new definition of laterite. Geol. Surv. India, Mem. 120, 1–7.

Taylor, G., Eggleton, R.A., Holzhauer, C.C., Maconachie, L.A., Gordon, M., Brown, M.C., McQueen, K.G., 1992. Cool climate lateritic and bauxitic weathering. J. Geol. 100, 669–677.

Trendall, A.F., 1962. The formation of apparent peneplains by a process of combined lateritisation and surface wash. Z. Geomorphol., N.F. 6, 183–197.

Twidale, C.R., Horwitz, R.C., Campbell, E.M., 1985. Hamersley landscapes of the northwest of Western Australia. Rev. Geol. Dyn. Geogr. Phys. 26 (3), 173–186.

Walther, J., 1915. Laterit in Westaustralien. Z. Geol. Ges. 67B, 113–140.

Widdowson, M., Gunnell, Y., 1999. Lateritization, geomorphology and geodynamics of a passive continental margin: the Konkan and Kunara coastal lowlands of western peninsular India. In: Thiry, M., Simon-Coincon, R. (Eds.), Palaeoweathering, Palaeosurfaces and Related Continental Deposits. Special Publication Number 27 of The International Association of Sedimentologists. Blackwell, Oxford, pp. 245–274.