WHAT'S IN A NAME: LATERITE, PLINTHITE, FERRICRETE, PEDOCRETE, GEOCRETE AND DURICRUST ─ IS THERE ANY DIFFERENCE, AND IS IT OF ANY ENGINEERING SIGNIFICANCE?

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ABSTRACT

Some of the English terminology used to describe the secondary, near-surface, ferruginous nodules, concretions, gravels and hardpans often found in the soil profile and used in pavement construction in southern Africa and elsewhere is briefly reviewed. Although the term 'laterite' (Latin: *later,* brick) has chronological priority and is globally the most common, it has become so widely used and misused as to be almost meaningless and has been replaced in pedology by the closely defined term 'plinthite' (Greek: *plinthos*, brick). For pavement and geotechnical purposes, the term 'laterite' should therefore be restricted to materials which comply with pavement material specifications specifically for laterite such as those of Brazil, which include the chemical and/or mineralogical criteria defining the materials from which the specifications were derived, and/or which possess self-hardening properties such as the laterites used for centuries as building blocks in India and adjacent countries. For pavement and geotechnical purposes, the term 'ferricrete' (i.e. soil particles cemented by iron oxide) most aptly describes these materials, which are apparently not usually self- hardening. Ferricrete is a member of the family of pedocretes or geocretes such as calcrete (soil particles cemented by calcite), silcrete (cemented by silica), etc., also called duricrusts. Pedocretes are formed by soil-forming processes in the pedological sense and geocretes by what some pedologists regard as geological processes. The origin and chemical and mineralogical composition of these ferruginous materials are briefly reviewed and their engineering significance discussed.

Keywords: Laterite, Plinthite, Ferricrete.

1. INTRODUCTION

Ferruginous materials ranging from reddish, yellowish and brown sands through gravels to rock-like hardpans and boulders occur in many countries and are widely used as construction materials for road and other pavements (e.g. Gidigasu,1976; Charman,1988). Although generally thought of as being restricted to tropical and subtropical climates they also occur in temperate and mediterranean climates such as much of South Africa, where the terms 'laterite' and 'ferricrete' tend to be used synonymously.

The terminology of engineering versus geological and pedological soils and of pedocretes is often confusing and even conflicting and only the simpler and wider meanings will generally be intended. It is the purpose of this paper briefly to discuss the most common English terms in use worldwide and the differences between them of engineering significance, if any.

Good sources of information including colour photos are Aleva (1994) on laterites (also with analyses), Beinroth et al, (1996) on oxisols and plinthite and for South Africa MacVicar et al (1991), Le Roux et al (2013) and Fey (2010, including analyses). Reviews of the engineering and engineering geological aspects include Netterberg (1969, 1985, 1994), Gidigasu (1976), Morin & Todor (1976), Charman (1988), Queiroz et al (1991), Infra Africa et al. (2014), Paige-Green et al (2015) and Paige-Green & Netterberg (2025), geological Du Toit (1954), and pedological Van der Merwe (1962) and Fey (2010); both of the latter including photographs, test results and maps.

2. SOILS

The term 'soil' in this paper is generally intended in its loosest engineering sense (i.e. it does not require blasting for excavation) unless prefixed by a pedological or engineering consistency descriptor. It would therefore include both the **solum** (the upper part of the soil profile affected by pedogenesis) and the **saprolite** (decomposed rock) of geology and the old term **regolith** for the entire cover over coherent bedrock.

In pedology the term 'soil' refers to the **whole soil profile** affected by pedogenesis, i.e., the solum in geology which is usually only the top 1-2 m of the engineering soil profile) and **not** to individual layers (**'horizons'** in pedology) or materials or soils in the engineering sense. Thus, as pointed out by Van der Merwe (1962), the geologist and engineer use the term 'laterite' to refer to a rock or gravel, whilst to a pedologist it means the whole profile which he or she might call ferruginous lateritic soils, in which the geologist's and engineer's laterite is only a horizon.

3. PEDOCRETES, GEOCRETES AND DURICRUSTS

During pedogenesis – and some processes which some pedologists would regard as geological rather than pedological, segregations of minerals may accumulate to form horizons dominated by nodules, concretions, hardpans (or boulders and cobbles representing fragments of hardpan formed by weathering and/or erosion) which have variously been turmed **duricrusts** (Woolnough, 1927) in Australia, although the term '**ferricrete**' is also used there (Aitchison & Grant, 1967).

In South Africa, in the traditional genetic grouping of engineering soils as residual, transported or **pedogenic soils**, in deference to pedology (Loxton, 1968) the latter was renamed **pedogenic materials** at the Fourth Regional Conference in Cape Town (Donaldson, 1968) and later accepted by Jennings et al (1973). The four major types were listed as silcretes, calcretes, ferricretes and laterites; silcretes do **not** possess self-stabilizing properties, calcretes, ferricretes and laterites **may**, but laterites are **always** self-hardening.

The term '**pedocretes**' (Brink et al, 1982; Netterberg, 1985), was later offered as a group term for all the 'cretes' and the term '**geocrete'** is offered here as a descriptor for those formed by geological processes. Although pedocretes are usually relatively thin (1-2 m at most) and may cap a geocrete which are usually thicker (metres), they are not always easily distinguished and for engineering purposes the terms can be regarded as synonymous unless shown otherwise.

Pedocretes, geocretes and duricrusts are simply soils in the engineering sense which have been variously cemented and/or replaced in-situ by calcite (calcrete), iron oxides (ferricrete, laterite or plinthite), silica (silcrete), gypsum (gypcrete), etc. (Netterberg, 1985, 1994). Their engineering properties therefore depend upon the nature of the host soil (e.g. clay, sand, etc.), the degree of such cementation and replacement, and on the nature of the cement (Netterberg 1985, 1994).

The apt term 'calcrete' (Latin: *calx,* lime and (Latin: *crescere,* grow)-Netterberg,1967) and some of the other 'cretes' such as ferricrete are due to Lamplugh (1902, 1907) in order to avoid descriptions involving "long and awkward circumlocutions".

In Australia, the term '**duricrust**' (Woolnough, 1927) is commonly applied to a "case-hardened crust of soil formed in semi-acid climates by the precipitation of salts at the surface of the ground as the ground water evaporates."[In this context the term 'salts' does not refer to highly water-soluble salts such as NaCl, but rather to the only slightly soluble salts such as those of Fe and Ca]. Although apparently originally intended to apply to laterite it has globally been extended to include other 'cretes'(e.g., Goudie, 1973; Fookes, 1997) and for engineering purposes can be regarded as synonymous with pedocrete and geocrete.

In South Africa the term '**pedocrete'** is the most popular and is recommended.

4. LATERITE, PLINTHITE AND FERRICRETE

The term '**laterite**' is often used for reddish tropical soils varying from loose or soft soils to rock which have been produced by advanced weathering accompanied by a relative enrichment in iron and aluminum sesquioxides (mostly Fe and Al) due to the decomposition of primary minerals and the removal of bases and silica. Some such soils are indurated, and some are capable of induration on exposure.

As originally described, **Buchanan's laterite** was simply a soft, reddish or mottled clayey soil rich in sesquioxides which could be cut and shaped with hand tools into blocks and would harden irreversibly on exposure (Buchanan, 1807; e.g., Maignien, 1966; Aleva, 1994). The type area is at Angadipuram in Kerala State in India where the Geological Survey built a monument of hardened laterite in 1979 to acknowledge Buchanan's contribution (photo in Beinroth et al., 1986).

The use of laterite as durable masonry building blocks for structures ranging from single storey dwelling houses to churches, temples, bridges and forts has been well documented (e.g., Kasthurba et al., 2014), and continues to this day. The soaked compressive strength of such blocks is very variable, those in India ranging mostly between about 1 and 5 MPa, in comparison with the Bureau of Indian Standards IS 3620 (2017) of a minimum of 3,5 MPa. The general requirements for such blocks are that "they shall be without any soft veins, cracks, cavities, flaws and similar imperfections and "shall be exposed preferably for a period of three months before being used…. to ensure stabilization. However, exposure to rains should be avoided."

No mention is made of any necessity for wetting and drying cycles.

However, the terms '**laterite'** and '**lateritic soils'** have been globally so widely used and misused as to be almost meaningless and have been **abandoned** by pedologists and some geologists and engineers. Indeed, no "subject has been more actively discussed and investigated during the past thirty years than the laterite problem" (Hall & Robinson, 1945), and there is still no consensus about laterites and what they represent, etc. (Aleva, 1994;

Fey, 2010), except that **the terms should be abandoned** (e.g., Van der Merwe, (1962), Mitchell & Sitar, (1982), who include a good discussion; Von Moltitz Harmse, 1976).

In Aleva's (1994) view the correct use of the term 'laterite' is that of Schellmann (1983): "Laterites are products of intense subaerial rock weathering. They consist of predominantly geothite, hematite, aluminum hydroxides, kaolinite minerals and quartz. The SiO_2 / (Al_2O_3 + Fe_2O_3) ratio of a laterite must be lower than that of kaolinized parent rock in which all the alumina of the parent rock is present in the form of iron oxides and which contain no more silica than is fixed in the kaolinite plus the primary quartz."

From the engineering point of view the most important aspect is that the dominant **clay mineral** in such a laterite is **kaolinite** and not the highly deleterious smectite and that the **molecular silica/sesquioxide ratio (S/R)** can be used to identify the material as laterite. The use of the S/R ratio dates from the time before x-ray diffraction (XRD) analysis became available and it has been supplanted by other chemical tests and XRD analysis and is no longer used in pedology. However, it is still used as an essential identifier of laterite in some specifications, notably LNEC, et al (1959, 1969) developed mostly in Angola and Mocambique, and DNIT (2007) in Brazil (see Paige-Green et al., 2024; Paige-Green & Netterberg, 2025).

Whilst better information is now available on the mineralogy, the current classification and works on South African soils (MacVicar et al, 1991; Fey, 2010; Le Roux, 2013) do not include silica/sesquioxide ratios and the most convenient source of such information is Van der Merwe (1965) and his **grey ferruginous lateritic soils**, also formerly known as **groundwater lateritic soils**, but classified as fersiallitic soils for the soil map of Africa (D'Hoore, 1964) is taken as an example. These typically have a B horizon of ferruginous concretions and/or brown, ferruginous, concretionary, well-cemented hardpan called **ouklip (**Afrikaans: old stone). This is what is currently generally called **ferricrete gravel or concretions** and **hardpan ferricrete**.

These typically have about 15-60% "stones" (i.e. particles coarser than 2,00 mm) and 10-20% "clay" (passing 2 µm), about 5-25% Fe_2O_3, and S/R ratios of the "soil" (i.e. particles finer than 2,00 mm) all well in excess of 2,0 (about 4-15). However, the S/R ratios of the colloids passing 2 µm are typically **less** than 2,0 (1,5-2,2) and the clay minerals present are **kaolinite** with a little illite.

These horizons would therefore classify as **laterites** according to the LNEC et al (1959, 1969) criteria which specify the S/R ratio of the colloids, but possibly **not** that of DNIT (2007) in which the S/R ratio of the fraction passing 2,00 mm is used. The S/R ratio of the passing 2 µm fraction was initially used in Brazil, but the use of the passing 2,00 mm fraction was adopted as it was much quicker and cheaper and was also found to be satisfactory (Instituto de Pesquisas Rodoviarias, Rio de Janeiro, 1975; pers. comm.) and the relaxed Brazilian specification DNIT-098 for unstabilized laterite bases for up to 5 MESA should be applicable.

Although there are also other soils described by Van der Merwe (1965) with a S/R ratio of less than 2,0, they are not dealt with here.

Ideally, the terms 'laterite' and 'lateritic soils' should be totally abandoned in all disciplines in favour of plinthite and appropriate pedological names.. However, they so entrenched that this is unlikely to happen anytime soon, and as a start it is **recommended** that for engineering purposes the term 'laterite' should be restricted to materials which are self-hardening as in Buchanan's laterite as well-described by Soares de Carvalho (1967), and/or comply with specifications developed specifically for laterite such as the above. This definition would include soft plinthites as in Soil Taxonomy (1975, 2002) and FAO (1997) but **not** the soft plinthite in the South African pedological classification (MacVicar,1991).

In an attempt to overcome this confusion, the term **'plinthite'** (Greek: *plinthos,* brick) was introduced in the United States as a synonym for Buchanan's laterite (Soil Survey Staff, 1975) and is still in use (2022). "**Plinthite** is an iron-rich, humus-poor mixture of clay with quartz and other diluents. It commonly occurs as dark red redox concentrations which usually form platy, polygonal or reticulate patterns. Plinthite changes irreversibly to an **ironstone hardpan** or to irregular **aggregates** on exposure to repeated wetting and drying, especially if it is exposed to the sun. It generally forms in a horizon that is saturated for some time during the year. Plinthite does not harden irreversibly as a result of a single cycle of drying and wetting; after a single drying it will remoisten and can then be dispersed in large part by shaking in water with a dispersing agent. In moist soil, plinthite is soft enough to be cut with a spade. After irreversible hardening it is no longer considered plinthite but is called **ironstone**." (Soil Survey Staff, 1975, 2002).

On the question of hardening on exposure, the degradation of agricultural lands due to the rapid hardening of plinthite after deforestation has apparently been well-documented (e.g. Morin & Todor, 1976; Asiamah & Dedzoe, 1999). Whilst such exposure would involve natural wetting and drying cycles, even hardening reversible by wetting as in hard-setting soils (e.g. Sumner, 1999) is detrimental to agriculture and it is not always clear whether or not such hardening is irreversible. According to Fey (2010) hardening of plinthite upon exposure is a property largely based on myth.

In the South African binomial pedological soil classification system the terms '**soft** and **hard**' plinthite are used, but plinthite is **not** required to possess self-hardening properties (MacVicar et al*.,* 1977, 1991; Fey, 2010).

In this system both soft and hard plinthite are diagnostic B horizons. Among other requirements **soft plinthite** is characterised by the accumulation of iron and often also manganese oxides in the form of red, brown or black mottles with or without hardening to form sesquioxide concretions in a zone of periodic saturation with water. However, the concretions have **not** coalesced to the extent of forming the continuous, indurated sheet that constitutes hard plinthite**,** and the **horizon** can be cut with a spade when moist. A hard plinthite **horizon** cannot be cut with a spade when moist and may eventually form a continuous, **indurated ironpan**, also known as **hardpan ferricrete**, many of which are obviously relict.

Although soft plinthite is equivalent to the unhardened laterite of Buchanan, in South Africa it is **not** regarded as self-hardening.

In both geology and engineering the term '**ferricrete**' has been widely used in South Africa where it is commonly in the form of individual nodules or concretions, gravel, hardpans or boulders and is restricted to indurated, iron-rich materials. The term 'laterite' is often used loosely both in southern Africa and on a global basis to include what are here called ferricretes. It will be used in this loose sense here. Although the differences in origin and composition implied in the use of many of these terms should not be of overriding concern to the engineer, at the Sixth Regional Conference in Durban in 1975 there was general agreement that it **was** worthwhile distinguishing between laterite and ferricrete for engineering purposes (Netterberg, 1976), and the following recommendations were also made:

“The term ‘**laterite**’ should be restricted to a generally reddish coloured material formed by the relative accumulation of iron and aluminium oxides formed under tropical conditions by the weathering and leaching out of the more soluble constituents including silica, etc.”

“The term ‘**ferricrete’** should be restricted to iron-rich materials formed by the absolute accumulation of iron oxides during the cementation and/or replacement of a pre-existing soil by iron oxide deposited by soil water or ground water.”

It was, also recommended that the terms ‘laterite’ and ferricrete’ should be restricted to minerals containing at least 50% of the cementing sesquioxide minerals and that the terms ‘lateritic’ and ‘ferruginous’ be used for materials with less than 50% of sesquioxides. On the basis of a large number of analyses a minimum of 20% sesquioxides was later recommended for lateritic soils (Madu, 1980).

The simple delta pH test (National Soil Survey Center, 2005) can also be used: if the pH in a KCl solution is higher than the pH in water then the material is aluminium-rich (Von Moltitz Harmse, 1976) and therefore probably a laterite. This test can be carried out both in the field using a pocket pH meter or dyes, as well as in the laboratory and is a routine laboratory test in South African soil science (The Non-affiliated Soil Analysis Work Committee, 1990).

No cases are known of the use of soft plinthite as building blocks in South Africa and the general opinion among South African pedologists seems to be that they are **not** self-hardening, and that many hard plinthites are relict (e.g. MacVicar et al., 1991; Le Roux et al., 2013; Fey, 2010), and that self-hardening is a myth (Fey, 2010).

However, according to Du Toit (1954, p 451), “like the true laterites” what he called **siliceous laterites** and **lateritic loams** “possess the peculiar property of hardening on exposure” “which is particularly valuable when the material is used as road-metal”. There is also evidence of self-hardening in roads of laterites in Angola (LNEC et al, 1959,1969 and ferricrete in South Africa, Namibia, Zimbabwe and Zambia (Netterberg, 1975; & unpublished) and laboratory tests have been developed to predict this potential (LNEC et al., 1959,1969; Nascimento et al., 1969; and Netterberg, unpublished).

On the other hand, although the nearly 2 000 miles (3 000 km) of roads in the then Transvaal with ferricrete bases had generally performed well, the phenomenon of self-stabilization had not been observed (Marais, 1968), and delegates at the Fourth African Regional Conference were of the same opinion with respect to ferricrete/laterite-based roads in the Cape Province and Zimbabwe (also Van der Merwe & Bate, 1971).

In the FAO (1997) soil classification system for the soil map of the world the definition of plinthite is the same as that of Soil Taxonomy (1975) including the requirement that it be self-hardening. Irreversibly hardened plinthite is no longer called plinthite but **hardpan**, **ironstone** or a **petroferic** or **skeletal phase,** although **petroplinthite** is also used. Whilst plinthite also occurs in other soils, **plinthosols** always contain it (FAO, 1997; Fey, 2010).

Whilst Du Toit (1954) stated that “Laterite proper, with hydrated alumina predominant” was then only known “extensively” in northeastern Zimbabwe and in Malawi where bauxite caps the syenite of the Mlanje Mountains and bauxite was being mined just inside

Mocambique, **ferruginous bauxites** were later discovered along the eastern seaboard in South Africa (Fitzpatrick, 1983).

In South Africa ferricretes" have been **derived** [author's embolding] from rocks of the most diverse character, such as granites, sandstones, slates, basic schists, basalts, etc". (Du Toit, 1954). However, as pointed out by Loxton (1968), transportation of the cementing agents takes place in suspension and solution over distances which can vary between millimetres and kilometres.

In conclusion, **in South Africa** although there are also other requirements in pedology, for engineering purposes ferricretes can be regarded as soft or hard plinthite depending upon whether they can or cannot be dug with a hand spade when moist, but the soft plinthite is **not** expected to be self-hardening, and more use should be made of the vast amount of information available in pedology on South African soils.

The term 'lateritic material' can be used when short, general 'blanket' terms with no genetic connotations are needed to cover laterites, plinthites, ferricretes and lateritic soils (Paige-Green et al., 2015) and 'ferruginous soil' when only fine-grained materials such as sands are intended.

The descriptions of laterites in Angola and elsewhere (LNEC et al., 1959; 1969) could equally well apply to many Southern African "ferricretes" as seen by the author in South Africa, Malawi, Zambia, Zimbabwe, Australia and Brazil.

5. PROPERTIES DEPENDENT UPON ORIGIN

As well-described by Fey (2010), there are two different kinds of plinthite-forming processes: **Residual iron enrichment** (the **relative accumulations** of D'Hoore, (1964) and the primary laterites of the LNEC et al., 1969) and **imported iron enrichment** (D'Hoore's **absolute accumulations** and the secondary laterites of the LNEC et al., 1969). Although both processes can take place within the same profile, one is usually dormant in a particular horizon, and absolute accumulation appears necessary for induration (Netterberg, 1994).

Relative accumulations of sesquioxides are concentrated by removal of the more soluble constituents such as bases and silica under conditions of intense weathering and resistant oxides of aluminium, titanium and zirconium are co-enriched with iron, giving rise to what is generally referred to as **laterite** (Fey, 2010). The ultimate end-product of this process is **bauxite,** which is an ore-grade, aluminous laterite. The clay minerals present are normally only of the kaolinite group and a maximum molecular/silica sesquioxide ratio of 2,0 is used as part of some specifications (LNEC et al., 1959, 1969; DNIT, 2007), discussed further by Paige-Green, et al. (2024) and Paige-Green and Netterberg (2025).

Most of the **ferricretes** in Zimbabwe represent absolute accumulations and relative accumulations are only found in the eastern highlands (JG Thompson, compiler of the soil map of the then Rhodesia,1960; pers. comm.), and most plinthitic soils in South Africa also represent absolute accumulations (Fey, 2010). The materials in South Africa are **ferricretes** and not laterites, which only occur north of the Zambezi, where ferricretes only occur in low-lying areas (Von Moltitz Harmse, 1968).

Relative accumulations are generally found in old land surfaces, while absolute accumulations usually occur in gentle, usually concave slopes accepting seepage of Fe-rich water from surrounding areas (Fey, 2010), where the only other element which may exhibit significant co-accumulation with iron is manganese.

As might be expected, relative accumulations with an S/R of less than 2,0 containing only kaolinite as a clay mineral will be less plastic and troublesome than absolute accumulations which have S/R ratios in excess of 2,0, may contain smectite, and are **not potentially** self-stabilizing.

The **classic laterite weathering profile** consisting of "laterite" gravel grading downwards into a mottled zone and then into a whitish, kaolinitic, decomposed rock can be observed at many sites in South Africa, including Gauteng, KwaZulu-Natal and the southwestern Cape, and especially in the early Tertiary African land surface.

6. ORTSTEIN

In podzol soils the B horizon has become enriched in organic matter and sesquioxides by illuviation (MacVicar et al., 1991) and not by relative accumulation during intense weathering as in plinthites. Such horizons may be soft and mottled in colour with or without concretions or a dark, vesicular hardpan, called **ortstein** to distinguish it from **hard plinthite**. Such horizons do not qualify as plinthite but for engineering purposes could simply be called ferricrete. However, it is unlikely that such horizons have ever been worked separately as a pavement material in South Africa from Van der Merwe (1967) they are usually thin, clayey, fine-grained and have S/R ratios well in excess of 2.0 both in the soil and the colloids and, although kaolinite is usually present, illite and/or illite-smectite is usually dominant.

An exception are the soils of the sugar belt, which are brown in colour, contain small "buckshot" ferruginous concentrations, may have S/R ratios of both the soil and the colloids of about 2,0 and kaolinite as the prominent clay mineral, but are very clayey. The reddish soils developed from dolerite have lateritic characteristics with a high percentage of sesquioxides throughout the profile and are related to the red ferrallitic Soils (Van der Merwe, 1965), although D'Hoore (1964) classified them as pseudo-podzolic.

Podzolic soils occur mostly in the western and southeastern Cape (Fey, 2010).

7. DORBANKS

South African **dorbanks (Afrik:** *dor,* dry *bank* layer) are indurated, usually reddish brown, massive or platy horizons up to about 1-2 m thick which are cemented by silica and often some calcium carbonate and/or iron oxides, to produce a consistency up to that of hard rock (Ellis and Schloms 1981, 1984). They are equivalent to the **duripans** of Soil Taxonomy and the **red and brown hardpans** of Australia and represent a form of pedocrete intermediate between silcrete, calcrete and ferricrete. Dorbanks do not slake if soaked only in water or acid (MacVicar et al., 1991).

Dorbanks have been used as road construction materials up to subbase level and have been the subject of a recent study (Fouche & Blignaut, 2020).

8. CONCLUSIONS

- The terms 'laterite' and 'lateritic soils' have been so widely used as to become almost meaningless and should ideally be abandoned as in pedology and replaced by the term 'plinthite' and appropriate well-defined pedological terminology.
- In the interim, for pavement and geotechnical purposes the term 'laterite' should be restricted to materials which comply with material specifications developed specifically for laterites such as those of Brazil which include the chemical and/or mineralogical criteria which define the materials from which the specifications were derived, and/or which possess self-hardening properties such as the laterites used for building blocks in India and adjacent countries.
- For pavement and geotechnical purposes the general term 'ferricrete' should be used for all other concretions, hardpans, boulders and cobbles visibly cemented by sesquioxides, together with the appropriate engineering descriptions such as gravel, etc.
- For pavement and geotechnical purposes the term 'lateritic soils' should be abandoned and the general term 'ferruginous soils' i.e. with no genetic connotations used, until appropriate pedological terms become accepted.
- The general term 'ferruginous materials', i.e. also with no genetic or other connotations, should be used when a short blanket term such as in titles is necessary to cover laterites, plinthites, ferricretes, ortstein and lateritic soils of whatever origin and consistency.
- As the engineering properties of laterites and ferricretes as defined here can differ substantially it is desirable to distinguish between the two.
- Methods of distinguishing them include visual appraisal, chemical and mineral tests and, as confirmation, the appropriate engineering tests.
- Some South African laterites apparently qualify as laterites for the application of the relaxed Brazilian specifications.

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10. REFERENCES

Aitchison, GD & Grant K. 1967. A preliminary appraisal of the engineering significance of silcretes and ferricretes in Australia, Proc. 4th Reg. Conf. Afri. Soil Mech. Fndn Eng, Cape Town, 1,53-56.

Aleva, GJJ. 1994. Laterites: Concepts, geology, morphology and chemistry. Int. Soil Ref. Info. Centre, Wageningen, Europ. Comm., Brussels, 169 pp.

Asiamah, RD & Dedzoe, CD. 1999. Plinthization – A threat to agricultural production. *Ghana J. Agric. Sci*, 32:223-227.

Beinroth FH, Eswaran, H, Palmieri, F & Reich, PF. 1996. Properties, classification, and management of oxisols: The Guy D Smith memorial slide set. US Dept Agric. Natural Resources Conservation Service, Washington DC. Available at:
www.iec.cat/mpasols/docuInteres/PDF/Libre08.7pdf

Brink, ABA, Partridge, TC & Williams, AAB. 1982. Soil survey for engineering Clarenden Press, Oxford., 378 pp.

Buchanan, F. 1807. A journey from Madras through the countries of Mysore, Canara and Malabar. East India Coy, London, 440-441.

Bureau of Indian Standards 1998. IS: 3620-1979 (Reaffirmed 2017: Indian Standard Specification) for laterite stone block for masonry. BIS, New Delhi, 6pp.

Charman, JM. 1988. Laterite in road pavements. CIRIA Spec. Publ. 47, London, 71pp.

Crown Agents, UKaid, Asanra, AFCAP final report May 2014, London. Available at:
http://r4d.dfid.gov.uk/pdf/outputs/AfCap/Laterite-Final-AFCAPgen124-v140525.pdf

Departemento Nacional de Infraestrutura de Transportes 2007. Pavimentacao – Base estabilizada granulometricamente com utilizacao de solo lateritico – Especificacao de service. Norma DNIT-098/2007-ES.

D'Hoore, J. 1954. Proposed classification of the accumulation zones of free sesquioxides on a genetic basis. *Afr. Soils*, 3:66-81.

D'Hoore, J. 1964. Soil map of Africa scale 1 to 5 000 000 with explanatory monograph. Commission for Technical Co-operation in Africa, Publ. No. 93, Joint Project No. 11, Lagos, 126 pp.

Donaldson GW. 1968. Summary of discussions on pedogenic soils. Proc. 4th reg. Conf. Afr. Soil Mech. Fndn Eng, Cape Town, 2 ,341-342.

Du Toit, AL. 1954. The geology of South Africa. Oliver & Boyd, Edinburgh, 611 pp.

Fey, M. 2010. Soils of South Africa. Cambridge Univ. Press, Cape Town., 287 pp.

Fitzpatrick, RW. 1983. Occurrence and mineralogy of ferruginous bauxites along the eastern seaboard of South Africa. *Spec. Publ. Geol. Soc. South Afri.*, 7, 87-96.

Food and Agriculture Organization of the United Nations (FAO). 1997. Soil maps of the world, revised legend with corrections and updates ISRIC, Wageningen.

Fookes, PG (ed.). 1997. Tropical residual soils. Geol. Soc. Working Party revised report, Geol. Soc., London, 184 pp.

Fouché, N & Blignaut J. 2020. A preliminary study of the engineering properties of dorbank. *J. South Afr. Instn Civil Eng*, 62(1):22-32.

Gidigasu, MD. 1976. Laterite soil engineering: Pedogenesis and engineering principles. Elsevier, Amsterdam, 525 pp.

Goudie, AS. 1973. Duricrusts in tropical and subtropical landscapes. Clarendon Press, Oxford, 174 pp.

Hall, AP & Robinson, GW. 1945. The soil. John Murray, London, 322pp.

Infra Africa, Frank Netterberg, Council For Scientific & Industrial Research, (2014). Review of specifications for the use of laterite in road pavements.

Jennings, JE, Brink, ABA & Williams, AAB. 1973. Revised guide to soil profiling for civil engineering purposes in Southern Africa. *Civil Engr S. Afr.*, 15(1):3-13.

Kasthurba, AK, Reddy, KR & Reddy, DV. 2014. Use of laterite as a sustainable building material in developing countries. *Internat. J. Earth Sciences & Eng*, 07(04):1251-1258.

Laboratório Nacional de Engenharia Civil, Laboratório de Engenharia de Angola, & Laboratório de Ensaio de Materiais e Mecânica dos Solos 1959. As laterites do Ultramar Português. Lab. Nac. Eng. Civil Mem. 141, Lisbon, 156 pp.

Laboratório Nacional de Engenharia Civil (Lisboa), Laboratório de Engenharia de Angola (Luanda), Laboratório de Ensaio de Materiais e Mecânica dos Solos (Lourenco Marques) & Junta Autonoma de Estradas de Angola (Luanda) 1969. Portuguese studies of engineering properties of lateritic soils. Proc. Spec. Session Eng Prop. Lat. Soils. 2, 85-96, 7th Int. Conf. Soil Mech. Fndn Eng, Mexico City.

Lamplugh, GW. 1902. ‘Calcrete’. Geol. Mag., 9, 575.

Lamplugh, GW. 1907. The geology of the Zambesi Basin around the Batoka Gorge (Rhodesia). *Quart. J. Geol. Soc. London*, 63(249):162-216.

Loxton, RF. 1968. Discussion on pedogenic soils. Proc. 4th Reg. Conf. Afr. Soil Mech. Fndn Eng, Cape Town, 2, 336-337.

Le Roux, PAL, Du Plessis, MJ, Turner, DP, Van der Waals, J & Booysens, HB. 2013. Field book for the classification of South African soils. South African soil Surveyors Assoc., Reach Publ., Wandsbeck,173 pp.

MacVicar, CN & eight others of Soil Classification Working Group, 1977. Soil classification: A binomial system for South Africa. Soil & Irrigation Res. Inst., Dept Agric. Tech. Services Science Bull. 390, Pretoria,150 pp.

MacVicar, CN (Convenor, Soil classification Working Group. 1991. Soil classification: A taxonomic system for South Africa. Soil Irrigation Res. Inst., Dept Agric. Development Mem. 15, Pretoria, 257 pp.

Madu, RM. 1980. The use of the chemical and physiochemical properties of laterites in their identification. Proc. 7th Reg. Conf. Afr. Soil Mech. Fndn Eng, Accra, 1, 105-116.

Maignen, R. 1966. Review of research on laterites. Natural Resources Research, IV, UNESCO, Paris, 1-148.

Marais, GP. 1968. Discussion in pedogenic soils. Proc. 4th Reg. Conf. Afr. Soil Mech. Fndn Eng, Cape Town, 2, 337-338.

Mitchell, JK & Sitar, N. 1982, engineering properties of tropical residual soils. Proc. Conf. Eng Constr. Tropical Residual Soils, Honolulu, 30-57.

Morin, WJ & Todor, PW. 1976. Laterite and lateritic soils and other problem soils of the tropics. Lyon Assoc's Baltimore & Road Research Inst. Rio de Janeiro. United States AID/csd 3682, Washington, DC, 369 pp.

Mountain, MJ. 1967. Pedogenic materials, their engineering properties and distribution in South Africa & South West Africa. Proc. 4th Reg. Conf. Afr. Soil Mech. Fndn Eng, Cape Town, 1, 65-70.

Nascimento, U, Branco F & De Castro E, 1965. Identification of petrification in soils. Proc. 6th Int. Conf. Soil Mech. Fndn Eng, Montreal, 1,80-81.

National Soil Survey Center. 2005. Use of reaction(pH) in Soil Taxonomy. Soil Survey Tech. Note No. 8, NCRS, Lincoln, 4 pp.

Netterberg, F. 1967. Some roadmaking properties of South African calcretes. Proc. 4th Reg. Conf. Africa Soil Mech. Fndn Engng, Cape Town, 1, 77-81 91.

Netterberg, F. 1969. Pedogenic materials in road construction. Nat. Inst. Road Res. Bit. Surfacing Lecture Course, NIRR Rep. RS/10/69, CSIR, Pretoria, 13 pp.

Netterberg, F. 1975. Self-stabilization of road bases: fact or fiction? Proc. 6th Reg. Conf. Africa Soil Mech. Fndn Engng, Durban 1, 115-119.

Netterberg, F. 1975. Pedogenic Materials. Proc. 6th Reg. Conf. Africa Soil Mech. Fndn Engng, Durban, 1, 291-294.

Netterberg, F. 1976. Convenor's introduction: Some contrasts between pedogenic and traditional materials. Proc. 6th Reg. Conf. Africa Soil Mech. Fndn Engng, Durban, 1975, 2, 195-198; convenor's summary, 211-212.

Netterberg, F. 1985. Pedocretes. Chapter 10 in A B A Brink, (Ed.), Engineering geology of southern Africa, 4, 286-307, Building Publications, Silverton.

Netterberg, F. 1994. Engineering geology of pedocretes and other residual soils. Proc. 7th Congr. Int. Assoc. Engng Geol., Lisbon, Keynote Address, Theme 4, V, XIX-XXXVIII.

Netterberg, F. 2022. Laterites, lateritic soils and ferricretes in civil engineering: A bibliography. Frank Netterberg, Pretoria, unpubl., 79 pp.

Paige-Green, P, Pinard, MI & Netterberg, F. 2015. A review of specifications for lateritic materials for low volume roads. *Transportation Geotechnics*, 5:86-98. Available at: http://dx.doi.org/10.1016/j.trgeo.2015.10.002

Paige-Green, P, Netterberg, F & Pinard, MI. 2024. Testing of lateritic materials for road pavements. Proc. 42nd Southern Afr. Transport Conference, Pretoria, Session 1A, 16 pp.

Paige-Green, P & Netterberg, F. 2025. A review of specifications for lateritic materials for roads. Proc. 43rd Southern Afr. Transp. Conf., Pretoria, Session 2A, 14pp.

Queiroz, C, Carapetis, S, Grace, H & Paterson, WDO. 1991. Observed behaviour of bituminous-surfaced low-volume laterite pavements. Transp. Res. Record 1291, 2, 126-136.

Schellmann, W. 1971. Considerations of the definition and classification of laterites Proc. Int. Sem. Lat. Processes, Trivandrum, 11-14.

Soares de Carvalho, G. 1967. The genesis of “laterites” from the geological point of view. Proc. 4th Reg. Conf Afr. Soil Mech. Fndn Eng, Cape Town, 61-64.

Soil Survey Staff. 1975. Keys to Soil Taxonomy US Dept Agric. Handbook No. 436, Natural Resources Soil Conservation Service, Washington, DC.

Soil Survey Staff. 2002. Keys to Soil Taxonomy, 13th Edn. Natural Resources Soil Conservation Service, Washington, DC.

Summer, ME. (ed.) 1999. Handbook of soil science. CRC Press, Boca Raton.

The Non-Affiliated Soil Analysis Work Committee. 1990. Handbook of standard soil testing methods for advisory purposes. Soil Sci. Soc. S. Afr., Pretoria.

Van der Merwe, CR. 1962. Soil groups and subgroups of South Africa. 2nd & revised edn. of Bull 231. Dept Agric. Tech. Services Chemistry Series 165, Science Bull. 356, Pretoria., 364 pp.

Van der Merwe, CP & Bate, IC. 1971. The properties and use of laterites in Rhodesia. Proc. 5th Reg. Conf. Afr. Soil Mech. Fndn Eng, Luanda, 1, Theme 2, 3-15.

Von Moltitz Harmse, HJ. 1976. Discussion on pedogenic materials. Proc. 6th Reg. Conf. Afr. Soil Mech. Fndn Eng, Durban, 2, 210.

Woolnough, WG. 1918. The physiographic significance of laterite in Western Australia. Geol. Mag., 5, (Dec. VI), 385-393.