Journée d'étude – Studiedag
«Stone-lines»
(Bruxelles, 24.III.1987, Brussel)
Académie royale des Sciences d'Outre-Mer
Koninklijke Academie voor Overzeese Wetenschappen
pp. 139-149 (1989)

Geo-Eco-Trop.
11 (1987, n° 1-4) : 139-149
publ. 1989

CONTRIBUTION OF *IN SITU* TRANSFORMATIONS TO THE FORMATION OF STONE-LAYER COMPLEXES IN CENTRAL AFRICA

BY

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SUMMARY. – In the soils of the western part of Central Africa (e.g. Lower Zaire, Congo Republic) complex stone-layers are commonly observed. Two main sublayers can be distinguished from which the lower one, consisting mainly of iron oxyhydrate nodules, is considered to be formed *in situ* by hardening of plinthite mottles and relative accumulation of the coarser constituents. Arguments for the *in situ* formation are discussed, e.g. a close relation existing between composition of this layer and the underlying bedrock, and features such as quartz veins and chert bands continuous throughout this layer, practically excluding a detrital origin. Some processes, possibly responsible for the relative accumulation of the coarse elements are mentioned : vertical descent, chemical weathering, or termite activity. The upper part of the stone-layer complex is supposed to be, at least partially, of allochthonous origin. In large areas, only this part of the stone-line is present.

RÉSUMÉ. – *La contribution de transformations in situ à la genèse de nappes de gravats complexes en Afrique Centrale.* – Des nappes de gravats complexes sont observées fréquemment dans les sols de l'Afrique Centrale (par exemple, le Bas-Zaïre, la République du Congo). Elles consistent essentiellement en une couche supérieure, partiellement détritique, et une couche inférieure, constituée essentiellement de nodules d'oxyhydrate de fer, probablement formés *in situ* par durcissement des taches plinthitiques, et une accumulation relative des constituants grossiers. Les arguments en faveur d'une formation *in situ* sont discutés : le rapport étroit entre la composition de cette couche et la roche-mère sousjacente, et la continuité des veines de quartz et des bancs de chert, ce qui exclut pratiquement une origine détritique. Les processus, qui pourraient être responsables de l'accumulation relative des constituants grossiers sont mentionnés, tels qu'une descente verticale, l'altération chimique ou l'activité des termites. La partie supérieure de la nappe est, au moins partiellement, d'origine allochtone. Parfois, cette partie seulement est présente.

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SAMENVATTING. – *Bijdrage van in situ omzettingen tot de vorming van "stone-layer" complexen in Midden Afrika.* – Complexe "stone-layers" komen veelvuldig voor in de bodems van westelijk Midden-Afrika (bv. Beneden-Zaïre, Congo Republiek). Ze zijn opgebouwd uit een bovenste, ten dele detritische laag, en een onderste laag die hoofdzakelijk uit ijzer oxyhydraat nodules bestaat en verondersteld wordt *in situ* gevormd te zijn door verharding van plinthietnodules en een relatieve accumulatie van de grovere bestanddelen. Argumenten voor een vorming *in situ* worden besproken, o.a. het nauwe verband dat bestaat tussen de samenstelling van deze laag en het onderliggend moedergesteente, en het continu doorlopen van kwarts aders en chert banken, waardoor een detritische oorsprong praktisch uitgesloten wordt. Enkele processen, mogelijk verantwoordelijk voor de relatieve accumulatie van de grovere bestanddelen worden aangehaald : vertikale uitzakking, chemische verwering en termieten aktiviteit. Het bovenste deel van het "stone-layer complex" is, althans gedeeltelijk, van allochtone oorsprong. In grote gebieden is alleen dit deel van de "stone-layer" aanwezig.

Introduction

Since pedological studies started in Central Africa, soil scientists, geologists and geomorphologists were puzzled by the presence of layers of stones or ferruginous gravel, following more or less the topographic surface in most profiles. Several interpretations were given to this phenomenon.

Only few authors recognized initially the complex structure of the so called "stone-line" or "stone-layer" in some areas (e.g. LAPORTE 1962, STOOPS 1967), and little attention was given to the, probably systematic, variations in aspect from one area to another.

Right from the beginning, a controversy arose between "allochthonists", explaining the stone-layer as an accumulation of transported material, and "authochthonists", suggesting that the stone-layer is formed by in situ weathering and transformation of the parent rock. In this paper the arguments of the authochthonists, for in situ formation of at least part of some stone-layers are summarized. This does not mean, however, that the author intends to extend these arguments to all stone-layers in the tropics.

One of the earliest definitions of a stone-line was formulated by SHARPE (1938), mentioned by RUHE (1959) : "a line of angular to subangular fragments which parallels a sloping surface at a depth of several feet". This definition used by several authors, might be applicable to some stone-lines in the equatorial zone, but does not define accurately most of the impressive layers of coarse elements found in many African soils, reaching thicknesses of a meter or more, and, at least partly, composed of rounded sesquioxidic nodules. The term stone-line itself is not the most appropriate one, as it depicts only the cross-sectional appearance of a three dimensional body, which may even seem rather a broad band than a line. Therefore the term stone-layer is prefered in this paper. The term carpedolith, proposed by PARIZEK & WOODRUFF (1957), mentioned by RUHE 1959, would be more suitable, but was never generally accepted.

The weathering profile and the stone-layer complex concept

In the region of the Lower Zaire, where the author was working several years, and in the neighbouring Congo Republic, complex stone-layers, consisting of sublayers with a different fabric and/or composition, succeeding each other according to a specific scheme, occur (LAPORTE 1962, STOOPS 1966, 1967).

According to STOOPS (1967), the "weathering profile", i.e. the zone between the soil surface and the unweathered rock, can be subdivided into three major units : the cover or α-layer, the stone-layer or β-layer and the weathered rock or γ-layer (Fig. 1). This $\alpha\beta\gamma$-terminology was prefered, rather than using A, B and C, as was done by LAPORTE (1962), in order to avoid confusion with the pedological horizon nomenclature.

The α-layer : This is generally a few centimeter to a few meters thick. It consists of loose but structured material, of sandy to clayey texture, practically devoid of elements coarser than 4 mm. There are no traces of stratification. The color and grain size distribution is frequently related to that of the γ-layer.

The lower boundary of the α-layer roughly follows the topographic surface, except for a more wavy path and local introversions. The amplitude of these waves varies between 2 and 4 m, and the height-differences seldom reach 50 cm. The base of the α-layer may be somewhat coarser than the rest : fragments up to 1 cm were noticed.

The β-layer : It consists mainly of gravel sized material. In contrast to the cover, the β-layer can be characterized by a striking vertical zonation ; two important sublayers can be identified :

The β_1-layer corresponds to a detrital stone-layer. It contains angular to subangular fragments of rock or saprock or of its more resistent components such as veinquartz or chert. Rounded alluvial pebbles may be observed near river terraces. Prehistoric implements locally occur. Ferruginous gravels, when present are rounded, have a smooth surface, and are commonly covered by a thin concentric dark coating (so called patina) of iron oxyhydrate and clay. Hard laterite fragments may also occur. Generally the β_1-layer is only a few centimetres thick, but locally layers of a few meters were

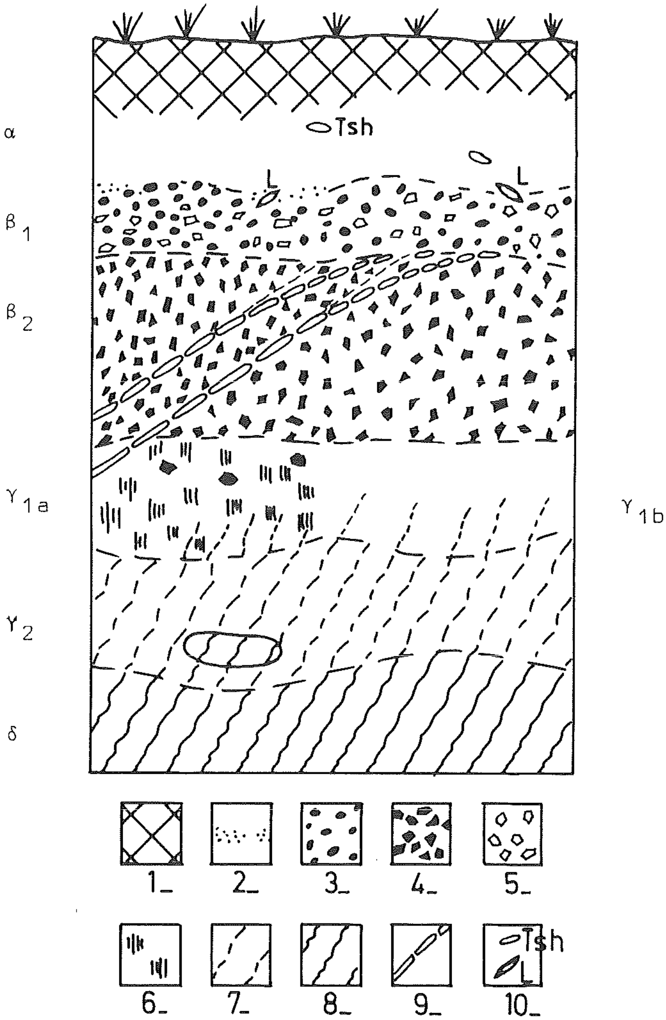

Fig. 1. – Weathering profile with stone-layer complex. 1 : humiferous horizon ; 2 : loose fine material, coarser towards the base ; 3 : rounded iron oxyhydrate nodules, commonly with patina ; 4 : (sub)angular iron oxyhydrate nodules ; 5 : detrital rock fragments (mainly quartz or chert) ; 6 : mottled clay ; 7 : weathered rock (saprolite) ; 8 : fresh rock ; 9 : chert band or quartz vein ; 10 : stone implements of Lupembian (L) or Tshitolian (Tsh) age. After STOOPS 1967.

observed. If there is an underlying β_2-layer, the transition is gradual, although it occurs over a relatively short vertical distance (about 5 cm maximum).

The β_2-layer consists essentially of subangular to angular rough ferruginous fragments, without coating. In several cases they become more angular and less hard with depth. Only detrital material derived from the profile is present, e.g. quartz veins and chert bands *in situ*. They can be followed up to the contact with the β_1-layer, but show from bottom to top a progressive downward vertical displacement.

An agglomeration of the ferruginous fragments by ironoxyhydrates gives rise to large *in situ* laterite boulders. They seem to be relatively soft in the soil, as they are easily cut by scrapers, but soon harden after exposure.

Micromorphologically an evolution could be noticed in the ferrugineous nodules (STOOPS 1968), as iron separation and incrustation becomes more evident in the higher parts of the β_2-layer. The β_2-layer is generally a few decimetres to two meters thick.

The γ-layer. This is the zone of weathered rock, occurring between the fresh bedrock or the saprock and the β-layer. Two sublayers may be distinguished : the γ_2-layer, or saprolite, where the rock structure is still conserved, and the γ_1-layer which has been homogenized by pedoplasmation. The limit between the γ_1-layer and the γ_2-layer corresponds thus to the pedoplasmation front.

In the γ_1-layer two facies are distinguished : the γ_{1a}-layer and the γ_{1b}-layer. The γ_{1a}-layer is an homogeneous loose structureless material with a grain size distribution depending upon the parent material. Its upper boundary, with the β-layer, is generally sharp. The material is mostly very incoherent and subject to erosion, as can be seen in road sections.

The γ_{1b}-layer shows a red and white or red and brown flecked pattern. The white or brown parts mostly form a continuous phase, in which the roots penetrate and pores occur. The reddish flecks are much more coherent and harder. A gradual transition towards the β_2-layer is evident : the flecks get harder and tend to individualize until they form isolated nodules. If the red zones form the continuous phase, a kind of vesicular laterite is formed after hardening.

In the γ_2-layer traces of the original rockstructure are evident, and density is lower than in the γ_1-layer ; its lowest part corresponds to the zone of isovolumetric weathering. Not only the macroscopic, but also the microscopic rock fabric is conserved. The fabric, composition and grain size distribution of the γ_2-layer is therefore immediately related to the characteristics of the parent material.

The δ-layer corresponds to the unweathered bedrock, or to the saprock, which may extend till a depth of several metres.

The combination of these different layers, which are genetically interrelated, determines the type of weathering profile present. The most characteristic and differentiating layer is the β-layer. Only when a complete weathering profile on a relatively old geomorphological surface is present, both the β_1- and β_2-layers are present. Tentatively the term "stone-layer complex" is proposed to designate a stone-layer composed of a β_1- and β_2-sublayer.

The essential difference between the stone-layer complex and a stone-layer resulting from pedimentation (FÖLSTER 1969, ROHDENBURG 1969, DE DAPPER 1981, DE BAVEYE 1987), is thus that in the latter the real stone-line, sense SHARPE (1938) is situated below the gravel layer, whereas the opposite situation is found in the former (Fig. 2).

In practically all soils of the Lower Zaire a β_1-layer is present. The β_2-layer is not observed in relatively young geomorphological units, and does never occur without overlying β_1-layer, except in recently eroded spots where it reaches the surface.

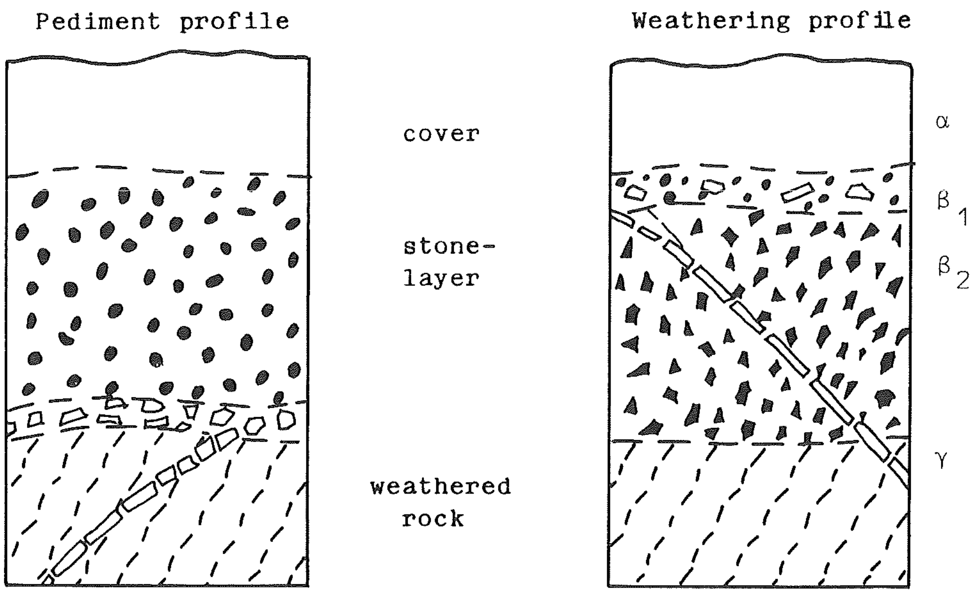

Fig. 2. – Comparison between a pediment profile and a weathering profile (symbols as in Fig. 1).

In situ origin of the β_2-layer

Whereas the β_1-layer contains in many cases elements clearly of allochthonous origin, this is not the case for the β_2-layer. Several arguments can be given to demonstrate that at least the β_2-sublayer of the stone-layer complex is the result of an in situ weathering and a relative accumulation of coarser materials. The most important ones are discussed below :

(i) No allochthonous elements, such as rock fragments, alluvial material or stone implements were observed in the β_2-layer ;
(ii) Quartz veins or chert layers, which are relatively more resistent to weathering than the surrounding rocks, can be followed continuously throughout the β_2-layer, although mostly partly fragmented (especially in the upper part). This contradicts an elementary transport of the material. As mentioned earlier, they also show a progressive relative downward displacement the more they come near to the top of the β_2-layer. This relationship could only be observed in those cases where the β_2-layer is overlying a γ_{1b}-layer. In γ_{1a} materials, no quartz veins or chert layers were observed.

It is interesting to notice that some authors consider such quartz veins as newformations, resulting from deposition of silica released during weathering (De Craene & Sorochinsky 1954, Mayor 1961). Recent studies on this subject seem missing.
(iii) Where the β_2-layer is overlying a γ_{1b}-layer (mottled clay), a gradual transition from mottles to nodules is observed, proving their genetic relationship and their in situ formation. Even when overlying a γ_{1a}-layer, a gradual morphological and mineralogical evolution can be recognized. The nodules in the lower part of the β_2-layer are rather angular and become more rounded and harder towards the top. A systematic micromorphological and mineralogical study of this evolution is necessary.
(iv) The composition of the β_2-layer reflects that of the underlying γ-layer and the bedrock ; the gravel has the same microfabric and mineralogy as the γ-layer, except for its free iron content ; the interstitial fine material is comparable to that of the γ-layer, and frequently also to that of the α-layer. In the profiles studied by the author, no mineralogical or chemical differences were noticed between β_2- and γ_1-layers, other than those due to weathering and laterization.

Laporte (1963) mentions several examples of "coupes mixtes", i.a. sections situated above the contact of different lithological units. According to his experience, the nature of the bedrock is reflected in the overlying material, and only a small zone (a few metres) of mixed composition is observed above the contact. The examples illustrated in his study however are not that straightforward, as they are dealing with subhorizontal contacts. During the CCTA/CSA-excursion (1963) a more striking example was shown of a garnet bearing vein, which, they pretend, could be detected in the surface layer.

From the arguments mentioned above, it seems clear that the β_2-layer consists entirely of autochthonous elements. The coarse elements are or inherited from the parent material (e.g. quartz veins), or formed by selective hardening of some parts of this material (e.g. iron nodules). It is also evident that a relative accumulation of these coarse elements in the β_2-layer has taken place. This can be deduced from the higher proportion of resistent coarse elements found in the β_2-layer, compared to the γ-layer, and from the progressive inclination of quartz veins and chert bands. The gradual decrease (towards the top of the β_2-layer) in distance between two or more originally parallel distributed chert bands points to the same phenomenon.

A deposition by pedimentation of the β_2-layer on the γ-layer seems also doubtful, in view of the very friable character of the latter, as can be observed in many road sections, where the β-layer, and frequently even the α-layer stay in relief compared to the γ-layer. The presence of the complete sequence (α, β and γ) on the hilltops, as described by many authors, is also difficult to explain by pedimentation processes.

It is however not yet clear which processes have contributed to this accumulation. More quantitative studies are necessary. A vertical descent of the coarse material, as proposed by LAPORTE (1962) and explained later by CAHEN & MOEYERSON (1977) could be partially responsible, but does not explain the sudden disappearance of quartz veins when they reach the β_1-layer. Also the substraction of fine material by termites, as suggested by several authors (e.g. DE HEINZELIN 1955, NYE 1955, STOOPS 1967) can be defended. Chemical weathering, combined with a loss of elements could be invoked too, but seems less realistic in these cases as most of the weatherable minerals have disappeared in the γ_2-layer, and a restructuration with increase of density (i.e. loss of volume) took already place in the γ_1-layer. Moreover, weathering in the β_2-layer concerns essentially phyllosilicates, whereby no important volume decrease is to be expected. Several authors (e.g. COLLINET 1969, LEVÊQUE 1969) defend an *in situ* accumulation of the coarse material by extraction of soil material and weathering. LEVEQUE calculated that the coarse material (> 1 cm) is 12 times more concentrated in the stone-line than in the underlying saprolite.

Allochthonous origin of the β_1-layer

In contrast to the β_2-layer, the β_1-layer contains mostly many allochthonous elements, its composition is not always related to that of the underlying bedrock, and no continuous structures (e.g. quartz veins) starting from the bedrock are conserved. Lateritic gravels from the β_1-layer frequently show an internal microfabric different from that of the bedrock (e.g. other grain size distribution). This means that, although part of the β_1-material may be derived from in situ weathering, at least a local reorganization at the earth surface, together with an admixture of allochthonous material, took place. Soils with a complete stone-layer complex are found mainly in the regions characterized by older geomorphological surfaces. In younger relief (e.g. the Crystal Mountains) only β_1-layers were observed by the author.

In the case of the superposition of two or more stone lines, one generally observes the presence of younger β_1-layers in the cover. The possibility of a superposition of two or more complete stone-layer complexes should not be ruled out however.

Stone-layer formation by mineralogical transformations

As mentioned above, COLLINET proposed in 1969 a scheme to explain the formation of stone-layers in Gabon based on weathering ("chemical erosion") and a gradual deepening of the profile, combined with a lowering of the topographic surface. The dissolution products are supposed to be evacuated by lateral drainage. This hypothesis however was not supported by mineralogical or geochemical data.

Recently more evidences for chemical deepening of the profile were presented by several French authors, mainly based on ORSTOM-research in Brazil and Africa (CHAUVEL *et al.* 1983, BOUDEULLE & MÜLLER, 1987).

CHAUVEL *et al.* (1983) describe the formation and destruction of a nodular layer in a soil on Tertiary sediments in the Amazon basin. In the lower part of the profile a ferruginization of the plasma takes place, combined with a gradual dissolution of the quartz and a kaolinite neoformation. Between 9 and 4 m depth, diffuse cryptocrystalline gibbsite nodules develop, which become gradually microcrystalline. Between 4 and 2.5 m their boundaries are sharper and they are more individualized by pedoturbation ; at the same time they develop a kaolinite cortex, which is mechanically desintegrated in the upper part of the profile, contributing to the clayey matrix of the B-horizon. The latter process is repeated till the nodule is completely destroyed. In this way a clayey cover is formed over a nodular layer.

This process of formation and destruction of a gravel layer *in situ* is not likely to take place in the soils of the Lower Zaire, which are not that extremely weathered, and generally contain only ferruginous nodules without gibbsite. From the descriptions it is also not clear in how far these layers of gibbsite nodules have the same morphological aspect as the stone-layer complexes in Central Africa.

Conclusions

Several arguments are presented to prove the *in situ* origin of at least part of the stone-layer in the case of stone-layer complexes, as observed in some parts of Central Africa. The processes responsible for this phenomenon however are not fully understood. Geochemical evidences for *in situ* formation of nodular layers in strongly weathered profiles of South America are not necessarily applicable to the situation in the western part of Central Africa.

In order to come to a better understanding of the *in situ* formation of the β_2-layer of the stone-layer complex, more systematic observations and analyses are necessary. Special attention should be given to the study of profiles situated above the contact of two contrasting rock types, or over small, lithologically different intrusions (e.g. pegmatite veins, dikes). On selected profiles precise studies of the geochemical balance at both sides of the lithological discontinuity are necessary, supported by detailed mineralogical, petrographical and micromorphological analyses of the different components (e.g. nodules, mottles) of each layer. A detailed morphological analysis of the stone-layer and the weathering profile as a whole is of course a first requirement.

Much more attention should be given also to the distribution in the field of the different layers and their thickness. Indeed, very few data exist on the presence of stone-layers and their internal morphology on the top of hills and near the valley bottoms. Finally, a large scale mapping of the occurrence of the stone-layer complexes could help explaining their genesis. This means however that one first should come to an agreement on the classification of the different stone-layer types and define them precisely. It is clear that significant results only can be obtained through a multidisciplinary effort.

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