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GEOMORPHOLOGICAL OBSERVATIONS CONCERNING STONE-LINES

BY

Hanna BREMER and Heinz SPÄTH (†) *

SUMMARY. – There are stone-lines of allochthonous origin on river terraces, footslopes, morphological positions where one can expect accumulations. Many stone-lines, however, seem to be of autochthonous origin, the stones being projected more or less vertically downwards. The main processes are (1) bioturbation whereby fine material is brought to the surface ; (2) subterraneous removal of material. This process is especially active at the level of interflow, i.e. 1-2 m below the surface.

RÉSUMÉ. – *Observations géomorphologiques au sujet des stone-lines.* – Il existe des stone-lines d'origine allochtone dans les terrasses fluviatiles et au pied des versants, sites morphologiques dans lesquels les accumulations présentent une grande probabilité. Toutefois, la plupart des stone-lines semblent être d'origine autochtone, les cailloux migrant plus ou moins verticalement vers le bas. Les processus en cause sont essentiellement (1) la bioturbation par laquelle des produits fins sont apportés en surface ; (2) le déplacement souterrain de matériel. Ce processus est particulièrement actif au niveau d'échange c'est-à-dire vers 1 ou 2 m sous la surface.

SAMENVATTING. – *Geomorfologische waarnemingen in verband met de stone-lines.* – Er bestaan stone-lines van allochtone oorsprong in de fluviatiele terrassen en aan de voet van de hellingen, morfologische plaatsen waar men accumulatie kan verwachten. Nochtans schijnen het merendeel van de stone-lines een autochtone oorsprong te hebben, waarbij de grove elementen zich min of meer vertikaal naar beneden verplaatsen. De processen waarvan sprake zijn hoofdzakelijk (1) de bioturbatie waarbij fijn materiaal aan de oppervlakte gebracht wordt ; (2) ondergrondse verplaatsing van materiaal. Dit proces is bijzonder aktief op het niveau waar bodemwater geconcentreerd vloeit, namelijk op 1 à 2 m onder de oppervlakte.

Introduction

There are several explanations of stone-lines, mainly: 1. colluvium, 2. bioturbation, 3. creep and slips, 4. concretion, 5. weathered veins

* Geographisches Institut der Universität zu Köln, Albertus-Magnus-Platz, D-5000 Köln 41 (Fed. Rep. Germany).

(especially quartz), dykes, or more resistant parts of banded gneiss, 6. chemical denudation.

All except the last one are extensively described in the literature. We could add examples from own experience from different tropical regions, e.g. southern Sri Lanka, Nigeria, Kenya, and eastern Amazonia.

There seems to be no doubt that these explanations are correct, though they imply very different processes. Thus, the main problem is the distinction of the different types of stone-lines before further conclusions can be drawn concerning climatic change, morphogenesis and pedogenesis.

One of the main problems of stone-lines as well as soils in the tropics is their allochthonous or autochthonous character. Stone-lines are clearly allochthonous in stratified sediments (e.g. STOCKING 1978), especially if they contain stones and heavy minerals not related to the bedrock. The stratification may not be visible macroscopically but in thin sections, which according to SEMMEL (1982, p. 137) is rather often the case in examples from southern Brazil. In our own experience of about 1000 thin sections of tropical soils from other areas this case rarely occurs.

Analysis of profiles and processes

Stone-lines are autochthonous if they are closely connected with quartz veins or other rock structures, whose broken up particles are only more or less vertically redistributed over short distances of some centimeters or maximal a few meters. STOOPS (1988) demonstrated that the gradual enrichment of iron compounds in soil profiles is indicative of an in situ formation of stone-lines. THOMAS *et al.* (1985, p. 799) considered a thickening of stone-lines over more or less vertically striking quartz veins as indication of an in situ origin. SEMMEL (1982, p. 137) mentioned a stone-line which originated by breaking up of a small more or less horizontal basalt flow.

Clasts of original rock or sediment structure in weathering profiles are almost the only indisputable observations which can be made from profiles for an in situ origin. Different soil attributes above and below stone-lines like grain size, colour, structure, amount of sesquioxides, spectra of heavy minerals, and the content of quartz pebbles cannot be conclusively interpreted as indicative of transported material, but may also be attributed to autochthonous soil development. Even sharp changes in colour or textures (Fig. 1, 2) which look like strong discordances, may occur in autochthonous profiles.

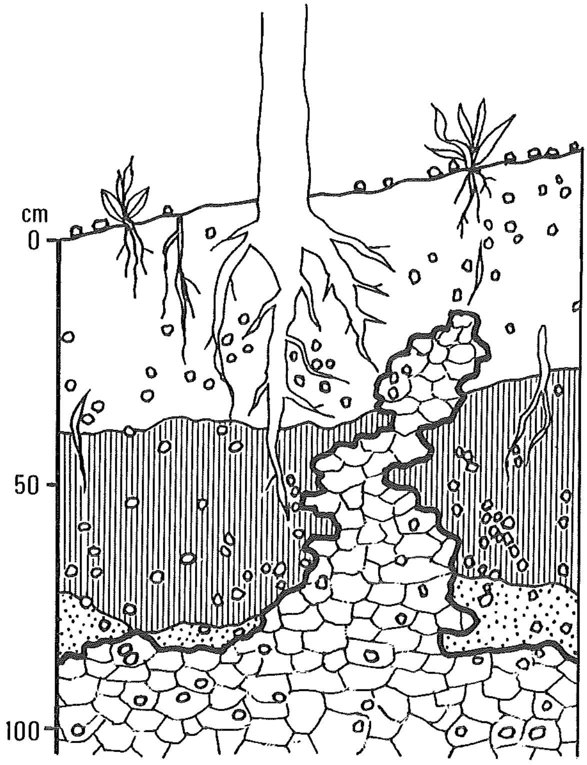

Fig. 1. – In situ profile of a shallow yellow/red earth/latosol near Sleisbeck/Northern Territory/Australia. The decomposed bedrock is extending in part into the topsoil.

Rounded stones, especially quartz pebbles may be due to weathering as can be shown in thin sections by precipitation of secondary silica around quartz particles (Fig. 3) or etching of sharp edges. Rounding of quartz pebbles by transport needs several kilometers in a river with mutual grinding of different stones (SPOERER 1980), it is unlikely by transport on slopes. Roundness of stones in stone-lines is a clue of transport only if there is a whole lense of rounded pebbles and a fluvial origin may be derived.

On the other hand the same soil above and below a stone-line is not unequivocal for an in situ profile. In old intensively weathered soils the material is anyway quite often from top to bottom very similar e.g. a red loam. With redistribution one could not expect distinctions. Especially in the tropics slow sedimentation is hard to prove anyhow as bioturbation may

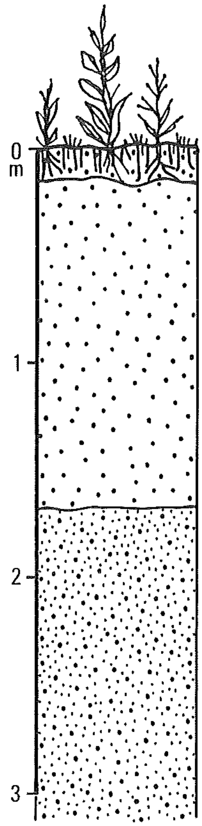

Fig. 2. – Soil profile under Amazonian low caatinga near San Carlos, SW Venezuela. The in situ development can be proven by an isolated occurrence of monazite in the sand, which must have originated from a geode in the granitic bedrock (after SCHNÜTGEN & BREMER 1985).

destroy stratification. Rather conclusive for an accumulation seems to be a mixture of strongly weathered and fresh minerals (MÜLLER 1987) and/or similarly friable stones and worn concretions together with fresh material (THOMAS *et al.* 1985).

Some rather fresh minerals like small mica particles may be seen in soils rather close to the surface, even if the surrounding matrix consists of secondary Fe-, Al-, SiO_2-compounds, clay minerals and some quartz grains only. These few easily weatherable minerals seem to be resistant once they

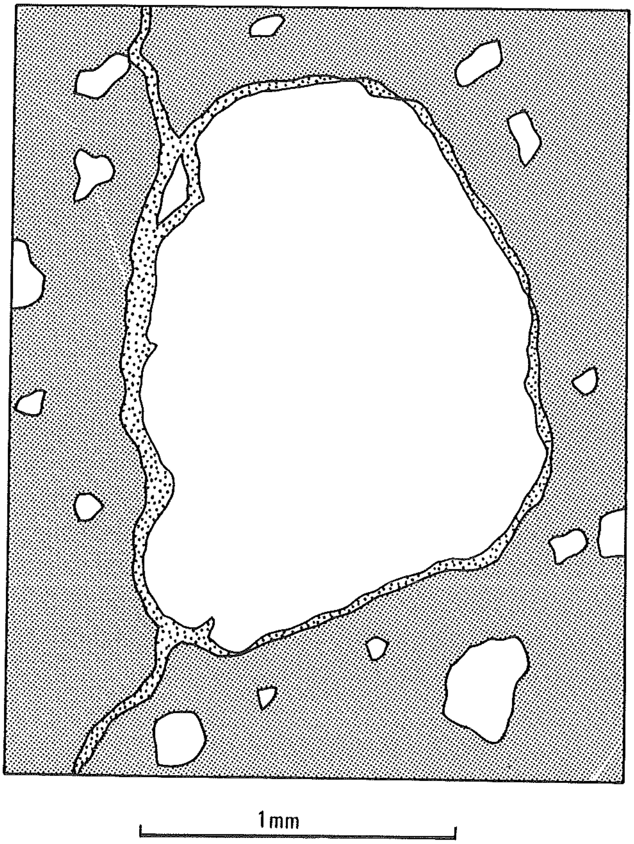

Fig. 3. – Thin section of a topsoil of a latosol, Province Rondonia/NW Brazil : quartz grain coated by secondary silica (dotted) in a dense clayey-loamy matrix (hatched) including small quartz splinters.

are isolated : either close moisture contact is lacking ("divergent weathering" at the micro-scale : SPÄTH 1981, p. 191) or they are protected by a skin of indurated gel (KUBINIOK 1987). Thus very fresh minerals can occur in an in situ profile as well as in an allochthonous one. Probably a distinction is possible with transport there should be still welded original minerals like the connection of one quartz and one feldspar grain. In situ weathered profiles show only isolated minerals.

Advancing from the profile to the areal distribution three pitfalls should be pointed out : quite often a continuous stone-line is postulated though only short sections of 10-20 m are observable. It is assumed that the missing part has been eroded. But the principle of continuity valid for many features in geology, soil science, geomorphology cannot be applied without further proofs to stone-lines or lateritic crusts (plinthite). At least one must ask where the eroded material has gone to. The second difficulty is the vicious type of reasoning for quite often geomorphic or pedologic processes have been deduced from stone-lines which they are supposed to explain. Thirdly they are no obvious examples of recent stone-lines development except in river accumulations and perhaps in arid climates (ROHDENBURG 1969, 1982). Therefore the principle of actualism is not very helpful.

There are geomorphological positions where an accumulation of material is easily perceptible, e.g. footslopes, river terraces, small valleys and/or dambos. For these positions stone-lines have been reported and rightly explained by accumulation. THOMAS *et al.* (1985) and TEEUW (1986) described stone-lines in relation to diamond placers. SEMMEL & ROHDENBURG (1979) observed several stone-lines interbedded with humus horizons, ^{14}C dated 11-46,000 B.P. Such cases are very interesting to study postsedimentary pedogenetic processes (soil welding in the sense of RUHE & OLSON 1980). These cases are undisputably allochthonous. But this conclusion may not be transferred to other morphological positions.

Spatial distribution of stone-lines

Concerning the spatial distribution of other than definitely allochthonous stone-lines there are three main relevant observations :

1. stone-lines occur on divides, on steep or flat slopes, and on plains,
2. stone-lines are more or less parallel to the surface, 1-2 m below,
3. stone-lines follow more or less the recent relief. This holds true, too, in areas with a palaeorelief.

A sheetlike transport of stones on divides is hard to visualize. Even on slopes the velocity of overland flow is not high enough to erode and transport stones, which needs to be more than 1 m/s (according to HJULSTRÖM 1932). If there is a transport one should expect a sorting or at least a compilation in rills or lenses. Even if one thinks of the movement of single stones there should be an increase of stones downslope. A stone pavement on slopes from 10° to 30° in semi-humid areas like the northern part of the Northern Territory/Australia or in semi-arid to arid countries like Israel or Morocco usually consists of one layer only. Rarely can one observe a running on of stones above obstacles like trees or boulders. To summarize : there seem to be no indications except stratification for areal transport. This applies especially to divides and steep slopes.

Transport of stones on slopes is possible by landslips, mudflows and all kinds of mass movement. Creep seems to be less important in the tropics, at least in those parts with an older landscape evolution. The soils there show a rather stable texture as can be seen from macropores (Fig. 4) with iron-silica-clay coatings, e.g. samples from a 40° slope in the rain forest of Sri Lanka (SPÄTH 1981). Material transported by mass movement might be stored on the slope itself or at the foot. It has the structure of the diamicton. The segregation into stones and fines is not possible by these processes.

At the foot of inselbergs in semi-arid to semi-humid countries a rock bench is quite often partly exposed from a relict red loam and small pieces of detritus are transported from the steeply rising slope into the bench. The problem here is how to cover such a "stone-line" with fine material as this obviously is a position where the fines have been removed. But as has been pointed out, these morphological positions may have accumulation stone-lines.

Especially difficult is the covering up of stone-lines on steeper slopes. Sometimes the author says : "the origin of the material is unknown". But this is no rigorous scientific reasoning. A process of micro-pedimentation proposed by FÖLSTER (1969, 1979) – the retreat of 1-2 m high steps – is rarely seen in rather undisturbed landscapes like the savannahs of northern Australia, the rain forest of southern Venezuela, western Amazonia. According to our observations such forms in Nigeria are eclectically distributed, which suggests an artificial influence. Anyhow it is difficult for hydrodynamic reasons to imagine a deposition of fine material just below an erosional form, where there is no change in amount of rainfall, slope angle, etc.

The second remarkable observation stressed by many colleagues is the position of stone-lines always more or less at 1-2 m below the surface. This is hardly compatible with accumulation for one would expect a thinner or an increasing sedimentary cover above in relation to slope length, angle etc. But it is a strong argument for bioturbation, especially most termites are working mainly down to the depth of 2 m. The tremendous amount of material moved by them has been pointed out by WILLIAMS (1968, 1973), LEE & WOOD (1971a, 1971b) and NYE (1955). There is one difficulty though, termitaries are rather rare on steeper slopes, but perhaps in long time spans fine material might be brought up by termites even on slopes. In the rain forest termites quite often build their nests on stems of trees or work the dead wood. This pertains to slopes as well as to flat areas.

The third point stressed by several investigators, too, is the arrangement of stone-lines more or less parallel to the recent surface. A fast conclusion would be that they are a feature of recent origin. This is contradicted by their occurrence in old relict soils impoverished in weathered material like the red loams southeast of Nairobi. They are connected with landforms dated as Tertiary (DIXEY 1955, SPÖNEMANN 1974, 1984). Similarly FAIRBRIDGE & FINKL (1984) reported old stone-lines from Western Australia. FANIRAN & JEJE (1983) argued against a recent or subrecent origin of stone-lines in Nigeria for sometimes they are underlain by several meters of in situ red soils. These have been formed in long times.

This contradiction may be solved by the assumption of an old origin and a more or less continuous activity. The process would be subterraneous removal of material by soil water movement. From the observation of landforms like closed depressions on divides and planar bands ("Flächenstreifen" : BREMER 1981) it has been concluded that these processes of chemical denudation (Fig. 5, 6) are much more important in the tropics than in the temperate zone (BREMER 1973, 1986, THOMAS 1974, 1978, WIRTHMANN 1973, 1983).

Figure 6 is an example from southern Sri Lanka with about 3000 mm annual rainfall. Almost vertically striking quartz veins are bending to the left forming a more or less horizontal stone-line near the surface. Because the gradient of the slope is in the opposite direction this case cannot be explained by surficial transport like creep or wash. This stone-line has evolved by subterraneous removal of material. We would like to call this a "stone-line of chemical denudation".

Figure 5 shows closed depressions on divides from the Roraima province/northern Brazil. This is the surficial expression of a subterraneous movement of water and material (BREMER 1973).

The role of interflow

A rather fast movement of water in the soil which is called interflow usually takes place in 1-2 m depth, preferable at a change of soil horizons especially with different texture. Obviously a stone-line is a medium for fast water movement (see THOMAS *et al.* 1985, p. 799). A remarkable example is shown by MOEYERSONS (1989). Soluted material and even particles up to silt size (BREMER 1973) may be transported. A subsurface movement of stones has been proven by artefacts (CAHEN & MOEYERSONS 1977). By this morphologic/pedologic processes stones may be arranged in a line in time.

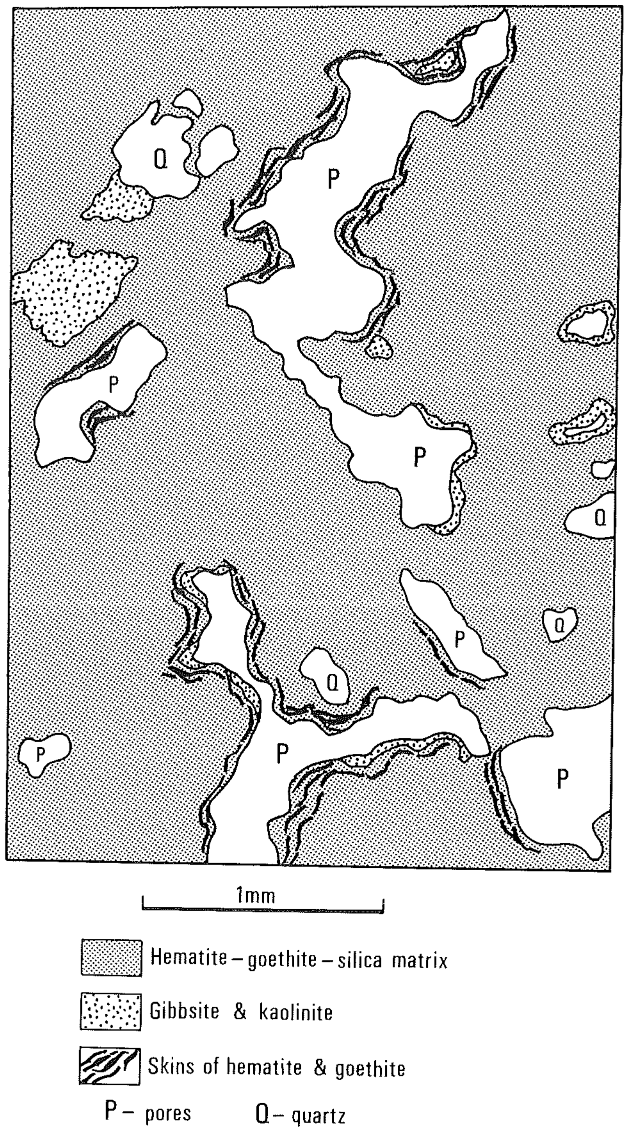

Fig. 4. – The thin section of a muturely weathered crystalline bedrock near Morapitiya/SW Sri Lanka shows cavernous quartz grains with solution features and a few areas of clay minerals and gibbsite in the diffuse matrix consisting mainly of hematite. The large macropores contain several layers of hematite-goethite-skins, in other parts clay-skins, proving the stability of the pores.

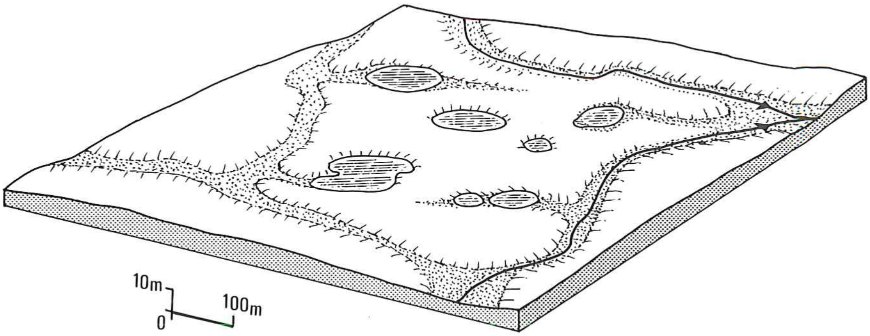

Fig. 5. – Closed depressions on local divides N Boa Vista, Province Roraima/Brazil (after BREMER 1973).

Fig. 6. – Near Madampe, SW Sri Lanka, almost vertically striking quartz veins of a decomposed gneiss are bending to the left (against the slope gradient !) forming a stone-line which has developed mainly by subterraneous removal of material causing subsidence near the surface. The dark holes in the midst of the profile are tubes of former roots. Their clayey filling proves descending transport of material. Length of the scale is 40 cm (from SPÄTH 1981).

In case the top soil is slowly washed off at the surface it may be imagined that the interflow is slowly deepened at the same time.

This hypothesis has some attractiveness :

1. The match with large landforms of chemical denudation
2. The explanation of irregular soil horizons like the "mantle rock" of McCallien *et al.* (1964)
3. The quite often observable wavy appearance of stone-lines. The 50-100 cm wide indentations would be pathways of interflow.

An observation of a stone-line beneath 1-2 m laterite by Bibus (1983, p. 90) is more easily understood by these processes than by very young accumulation due to climatic change. The anyway rather rare occurrence of massive laterite in the Amazon is unlikely to be of Late Quaternary or even Holocene age.

The discontinuous appearance of stone-lines is more easily compatible with processes induced by bioturbation and interflow than by accumulation. A density of termitaria is very irregular. As mentioned before, they are often missing on steeper slopes. The runnels of interflow are interspersed. Both processes seem to require certain soil properties, but these are not known as yet. For alluvial or colluvial origin of stone-lines, on the contrary a more even distribution at least in similar sedimentary positions should be expected.

On the whole there seem to be either plinthites or stone-lines. From own experience we can state that stone-lines are best developed in East Africa, where there are rarely heavy plinthites. In Australia on the other hand where there are many occurrences of plinthites stone-lines are quite rare.

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