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New hypotheses and results about the origin of stonelines and subsurface structured horizons in ferrallitic soils of Misiones, Argentina.

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INTRODUCTION

Ferrallitic soils, mainly Ultisols and in lower proportion Oxisols, are found in the Province of Misiones, in northeastern Argentina. These soils have been traditionally considered derived from in situ weathering of the tholeiitic Cretaceous basalt of the Serra Geral Formation (Sanesi, 1965). This ferrallitic material is usually 3 to 7 m thick above the weathered basalt. Frequently a "stone line', many times lying on a thin structured layer, appears in its lower part, close to the transition with the saprolite.

The origin of "stonelines", which are a frequent feature in tropical and subtropical soils, is a controversial matter that has deserved numerous interpretations. Segalen (1994) indicates that among the different hypotheses currently admitted the following should be mentioned: 1) erosion of laterites and slope development; 2) downslope movement; 3) autochtony or in situ sinking of fragmented laterites; 4) soil fauna activity. Among the older explanations, relevant only for local application, he mentions a two stages process made up by a first stage of deflation and surface exposure of pebbles, and a second one of burial of pebbles by sedimentation. Segalen also mentions that several authors have also presented general explanations that involve the simultaneous effect of different processes. For instance, Johnson (1993) proposed a general explanation combining different theories and principles of geomorphology, pedology and hydrology that he named "the dynamic denudation theory", and in which the dynamic processes and conditions are driven by gravity, water and biotic agents.

In its turn, Iriondo and Kröhling (1997) and Iriondo et al (1997) referring specifically to the area of Misiones and to neighbouring regions in Brazil and Paraguay, postulated that the material that covers the basaltic rock and in which the red soils have developed is an eolian sediment deflated from the alluvial plains of the Paraná and Uruguay rivers: the authors consider this material a “tropical loess” of upper Pleistocene age and formally named it “Oberá Formation”. According to these authors, the main characteristics to consider it as an eolian sediment are the following ones: 1) it covers the landscape as a mantle; 2) a stoneline, constituted by platy gravel-sized silica, occurs in numerous places; iron concretions also appear locally; 3) less frequently, a buried soil represented by a moderately structured B horizon and crowned by the stoneline, is conserved in the middle section of the profile; 4) the clay fraction is composed of kaolinite and quartz, with hematite and gibbsite as minor components; besides, 70% of the heavy minerals is represented by magnetite and hematite; this mineralogy coincides with that of the sediments transported by the neighbouring big rivers; 5) the granulometric composition is dominated by the clay fraction, also similar to that of the suspended load transported by the Paraná River; 6) a TL dating of a sample taken in the lower section (below the stone line) indicates 18.560+-1.340 years BP and the upper section was TL-dated in 3740+-150 years BP.

Lichte and Behling (1999) referring to the Quaternary landscape evolution in south-eastern Brazil, also consider that the stonelines have developed on a now fossil surface that was subsequently covered by a sediment. For these authors the quartz pebbles come from quartz veins included in the Precambrian crystalline rocks, which were distributed by strong rains across the slopes, and later on covered by a fine eolian sediments deriving at least partly from the lateritic cover of the Sudamericana plain.

Regarding the structured horizon that usually appears below the stonelines, it has been interpreted by Iriondo et al (op.cit.) as a B horizon of a moderately developed Ultisol, and therefore as an evidence of a palaeosurface.

Consequently, taking into account the diversity of hypotheses concerning the origin of the soil´s parent materials, the origin of stonelines and of subsurface structured layers, and due to the interest it has for the interpretation of landscape evolution, a study is currently carried out along the area covered by ferrallitic soils in the province of Misiones.

RESULTS

A) According to the field and laboratory work done up to now, different types of stonelines have been observed, the most extended and typical ones being the following two:

1) The first type that we characterise as ¨nodules line¨, is observed in the southern part of Misiones. It consists of ferrugineous nodules of approximately 15 mm diameter, that can be differentiated in three kinds: some of them are hematitic, smaller, dark red in color and with bright surface, others are goethitic, larger, yellowish red in color and opaque, and a third group has intermediate aspect and composition. The first type of nodules is observed in low proportion along the profile with a maximum in the stoneline, while the other two types are almost exclusively present in that level.

In some profiles of southern Misiones it was found that this type of ¨nodular¨ stoneline develops in situ from a more resistant rock layer of particular structure and composition intruded into the basalt. In some locations we observed a lateral transition of different weathering stages, from a conserved and homogeneous rock body, through a “fragmental” stage, up to a relictic level with sparse small goethitic fragments; these fragments may appear stained by iron and mixed with dark iron nodules.

2) The second type of ¨line¨, observed in the central part of Misiones, is characterised by an accumulation of silica which can not be defined as a stoneline but as a ¨silcrete¨. In this case the accumulation appears as horizontal plates of variable thickness, from few millimeters (in this case usually fractured and with the appearance of laminar fragments) to up to 30 cm or more. According to XRD analyses the material is quartz, crystal development being observed quite frequently in situ. In this cases, a certain proportion of dark red nodules are found along the profiles with a maximum at the level of the silcrete; quartz concentrations of different morphology, more abundant than red nodules, are also found along these profiles, increasing abruptly at the silcrete level.

B) Concerning the blocky structured subsurface horizons, field work let assume that they are not buried paleosols and that they may not be considered as an evidence of palaeosurfaces. Two processes may be responsible for the formation of these structured layers: 1) The first one is similar to the stone line development described above, to which sometimes they are associated: in this case a lateral sequence of weathering of basalt, from the fresh rock to a structured and fine textured material can be observed. 2) In a second one, gravel or silcrete layers derived from the above mentioned processes, appear to exert a “protection” effect on the underlying fine textured materials against the weathering front, thus allowing the development or conservation of structural units (blocks and prisms). As a consequence, places are found in which a well defined stoneline covers a continuous structured horizon, as well as places where short discontinuous ¨lines¨ or even isolated gravels preserve structured microhorizons, surrounded by a differently organized material.

Besides the profiles showing one of the above mentioned two types of ¨stonelines¨, other situations have been also observed: ¨lines¨ with dark and bright gravels of laminar morphology; profiles without ¨lines¨; profiles with several superimposed ¨lines¨ of the same type; profiles with different types of ¨lines¨ superimposed at different depths; ¨stonelines¨ appearing above, below as well as inside of structured layers, having no positional relation with structured horizons, lying directly on the saprolite, etc. It is also to be mentioned that besides the horizontal facies, many times stonelines and structured layers show subhorizontal directions and bifurcations.

C) Other results obtained up to the present indicate:

1) The clay fraction shows a gradual mineralogical variation from the saprolite up to the surface given by a decrease of kaolinite and a parallel increase of chloritic minerals; 2) the magnetic susceptibility shows a gradual increase from the saprolite towards the surface. These results suggest that all the material above the saprolite is the result of in situ ferrallitic weathering of the basalt.

3) The granulometric data shows a gradual increase of clay and silt fractions from the surface to the middle part of the soil profiles, and then a progressive decrease towards the base of the saprolite. These results reflect the process of illuviation typical of Ultisols together with a weathering process of the crystalline rock.

4) The gravels are not restricted to the stoneline. In the profiles with a ¨nodular stone line¨, the content of gravels (nodules) increase slowly from the middle part of the soil profiles up to an abrupt maximum in the stone line, decreasing rapidly from there downwards to the saprolite. This fact suggests that the nodules are not related to a palaeosurface.

5) Concerning the siliceous stonelines, field observations suggest that they can derive either from silica solubilized and precipitated during the ferrallitisation of the basalt, or from preexisting quartz veins within the basalt that were preserved from the weathering process.

6) The surface horizons (0-50 cm) of the profiles under study have delta 13C values of ca. –25 permil typical of the existing C3 vegetation. With increasing depth (50- ca. 200 cm) some profiles show C4 signals (ca. –15 permil), which decrease again as a function of depth. These results let assume that the extreme arid climatic conditions during the Last Glacial Maximum (ca. 18-20 ka BP) are “preserved” in the soil layers with the more positive delta 13C values between 50-200 cm. Up to now, no C4 signal could be identified in the vicinity of the stonelines: in other words, from the stable C isotope data there is no evidence of accelerated denudation of fine materials and accumulation of pebbles and stones on a LGM palaeosurface, covered later on by aeolian sediments (¨tropical loess¨).

CONCLUSIONS

According to field and laboratory results, in most part of the studied sites in Misiones it is possible to attribute an autochtonous origin to the elements forming the stonelines: the rounded nodules of goethitic mineralogy evidently derive from differential weathering of layers intruded into the basaltic rock; the hematitic and denser nodules may be concentrated in the stonelines by gravity; the nodules of intermediate composition may result from a secondary concentration of hematite in goethitic nodules; the silica concentrations are quite clearly the result of in situ precipitation giving rise to silcretes, eventually fractured; in some cases they can be in situ relicts from former quartz veins in the basalt. On the other hand, there are evidences that subsurface structured horizons may derive from two processes: one is a differential weathering and organization of some basaltic layers; the other is a protection effect of stonelines on the underlying weathered material. The stable C isotope values in the vicinity of the stonelines never indicate the existence of a C4 grass vegetation, a prerequisite for accelerated denudation and stoneline exposure on LGM palaeoland surfaces.

Consequently, though the eolian origin of a ferrallitic mantle in Misiones can not be completely discarded, the arguments that have been used for its postulation are not corroborated by the results here obtained, appearing on the contrary several arguments to sustain the autochtonous origin of the stonelines, of the subsurface structural horizons as well as of the surface soil material.

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