Enregistrement scientifique n° : 172
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Organisation and dynamic of a soil mantel in tropical southeastern brazil (Serra do Mar) - Relation with landslide processes

Organisation et dynamique d'une couverture pédologique dans le Sud Est Brésilien (Serra do Mar). Relations avec les mouvements de masse

FURIAN Sonia (1), BARBIERO Laurent (2), BOULET René (3)

1 - Depto de Geografia – USP-FFLCH, Cidade universitaria C.P. 8105, Cep: 05508-900 Sao Paulo – SP, Brasil
2 - ORSTOM, Centre de Hann, B.P. 1386 Dakar, Sénégal.
3 - ORSTOM - Instituto de geociencias - DGG – USP, C.P. 11 348, Cep: 05 422-970 Sao Paulo – SP, Brasil

As the Serra do Mar region exhibits a high probability of landslides, the 3-D organisation of the soil mantle was studied out in a 56 ha small catchment, representative of the region. The study allows to reproduce certains steps of the landscape development, and helps to understand the behaviour of the pedological cover. Upslope, in situ material that develops from the parent rock has been distinguished whereas the downslope domain is composed of a material arising from a landslide process. The soil mantle observed upslope is mainly caracterized by various hardly permeable kaolinitic horizons within a thick gibbsitic weathering horizon and disposed like tiles of a roof. Various observations of the contact between the kaolinitic horizon and the gibbsitic-weathering horizon show that the kaolinitic horizon evolves upslope at the expanse of the gibbsitic material. Kaolinitic horizons are compact and overlaid by microaggregated horizon. The contrast in porosity between these two horizons, estimated by density measurments, Hg porosimetry and images processing and the water behaviour estimated by water retention and shrinkage curves, indicate that the water can be stocked transiently and briefly within the microaggregated horizon during rainfall. Moreover, due to the inclination of the kaolinitic horizon, the water flows laterally downslope in the subsurface and can create an overload at the third part downslope. This overload depends on the surface drained by the kaolinitic horizon, which increases with the development of the soil. Organisation and dynamic of the soil cover are related to landslide processes.

Keywords : Gibbsite, Kaolinite, Landslides, Landform, Brazil
Mots Clés : Gibbsite, Kaolinite, glissements de terrain, Brésil

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1. Introduction

Landslide processes are very frequent in the Southeastern region of Brazil. Up to now, the majority of the studies concerns statistical datas to estimate the occurence of landsides with regard to location, climatic conditions, bedrock, slope steepness, vegetal cover and human occupation. The results show that landslides occures principally at the end of the rainy season when the more intensive rainfall are observed. GUIDICINI and IWASA (1976) show that the probability of landslide processes is high over a threshold value of 250mm/24hr, regardless to the recent anterior rainfall. CRUZ (1974) underlines that dips over 40% are propicious for landslides processes, regardless to vegetal cover and human occupation. Although the quasi totality of water infiltrates during rainfall the flow of the water in the soil mantel is unknown (FURIAN, 1994). The soil and its organisation is also unknown excepted some isolated observations. DE PLOEY and CRUZ (1979) have conclued that more attention should be paid to the hydrology of the slopes.

The aim of this paper is to present the organisation of the soil mantle and the dynamic of soil genesis and to show that both can be relationed to landslides processes.

2. Site

The studied area is located in the Brazilian humid tropical zone, 23°S latitude, in the eastern part of the Sao Paulo state. The fieldwork was concentrated in a 56-ha small catchment of the river Paraibuna, district of Cunha (fig.1). The chemical weathering of the crystalline Precambrian basement has resulted in the formation of sandy loamy regoliths with a maximum thickness of 15 m. Actual and subrecent evolution of slopes in the Serra do Mar appears to be largely controlled by mass movements: slumping and planar slides in the regoliths combined with rockfall and rockslides (DE PLOEY and CRUZ, 1979). The climate belongs to the type « Cwa » of Köppen with orographic influences. Annual precipitation in the region varies from 2000 and 2500 mm. The vegetation is the « Atlantic forest ».

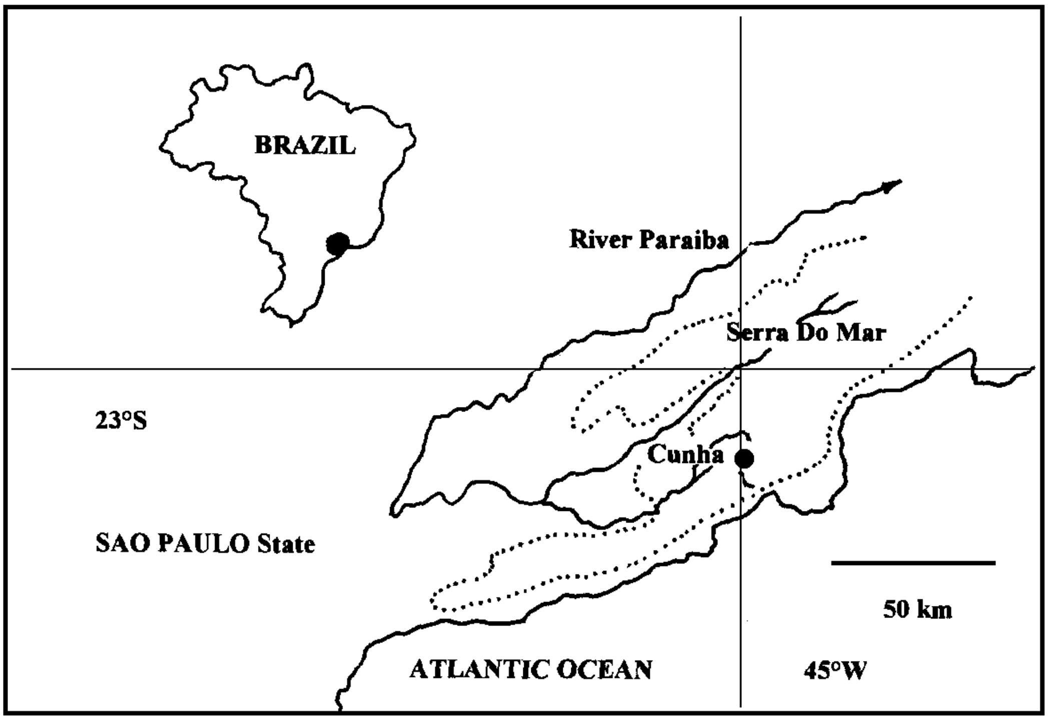

Fig. 1. Location of the study site in the southeastern Brazil.

3. Methods

The pedological cover organisation has been reconstituted from 47 borers with a hand auger and 24 pits generally located on lateral soil transition zones organised along four sequences. Blocks were collected and impregnated with a polyesther resin for thin sections confections. In order to visualize the macroporosity, a fluorescent dye was added to the resin. Samples were collected for SEM observations and analyses. Particle density was measured using a water picnometer. The bulk density of soil was measured on calibrated cylindrical samples. The pore size distribution, between 0.0037 and 100µm equivalent radii, was studied by mercury porosimetry. Images were captured by reflected UV light on thin sections (HALLAIRE and CURMI, 1994). The identification of the pores was performed by a simple partition thresholding on digitalized images with a spectral resolution of 256 grey levels. The water retention curves were obtained by ultrafiltration according to TESSIER and BERRIER (1979) for low suction range (pF 1 to 3) and using pressure membrane equipment (TESSIER, 1978) for higher suctions. The shrinkage curves were estimated from the apparent volume at pF 2 and 6, determined by the kerosene method (MONNIER *et al.*, 1973).

4. Catena organisation, material and origin

The soil organisation and constituants are presented through the T2 sequence, which can be divided in 2 domains, here called upslope and downslope domains (Fig. 2). The upslope domain consists of a 12m thick ferrallitic soil. The pseudo-morphoses by gibbsitic septa insure the preservation of the parent-rock structure and results in a box-work organisation. The polysynthetic twin of plagioclases and the losangic cleavage of amphibole is also preserved, indicating that the gibbsitic weathering correspond to the first weathering of the parent-rock. Only quartz and muscovite appear spared by this gibbsitic weathering. The structure of the parent-rock is also observed as millimetric gibbsitic veins. It is also still preserved in many blocks, which present all the same orientation, similar to that of the parent-rock. Although the soil fauna burrows the superficial horizons, it is possible to identify relicts of the millimetric gibbsitic veins, which also globally preserve the parent-rock orientation. All these observations show that the upslope soil cover arise from the in situ gibbsitic weathering of the bedrock.

In the downslope direction, a clay loam kaolinitic compact horizon (here called K-horizon) is observed in the gibbsitic horizon (G-horizon). It presents a form of tongue. The organisation of this K-horizon is intersected with the superficial horizons and with the actual slope topography. It is overlaid by two very porous microaggregated horizons. A second clay loam kaolinitic horizon (K-horizon) appears downslope and at depth, also in the sandy gibbsitic weathering horizon (G-horizon) under the first K-horizon.

The downslope domain is composed of superficial horizons overlaying a clay horizon with many blocks randomly oriented. This horizon is directely and abruptly in contact with the hard bedrock. Remnants of the gibbsitic boxworks are observed, but frequently associated with unweathered mineral such as hornblende, amphiboles, microcline and biotite, i.e., a mixing of material of very different weathering degrees. Such minerals cannot result from the same weathering history. We can advance that the downslope material is colluvia and results from a landslide process.

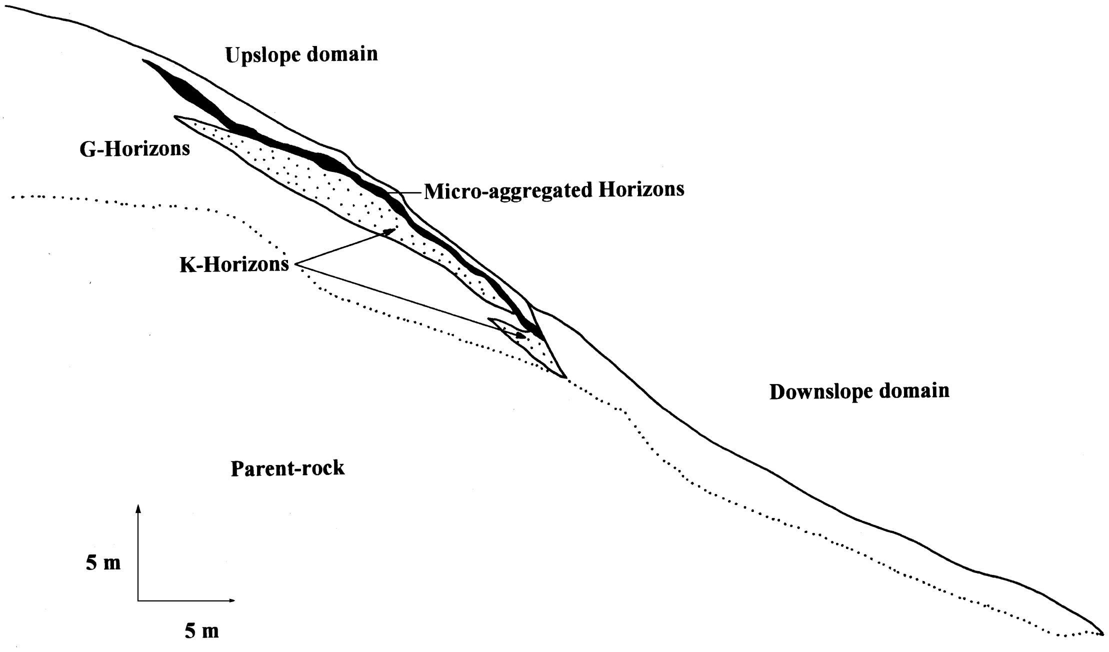

Fig. 2. Distribution of the main horizons along the T2 toposequence.

The organisation of the upslope soil cover clearly differs from that of the downslope. The contact between the two domains is abrupt. At the middle part of the slope, the upslope soil cover is intersected, down to the bedrock, by the material of the downslope one (fig. 2). The upslope soil cover, which is intersected and not overlaid by the colluvia, is the type of cover that undergoes the landslide process. Therefore, the dynamic of this soil catena and its relationships with the flows of water will be presented in detail.

5. Dynamic of the pedogenesis

The detailed study of the contact between K and G observed in the field shows that the structure of the K-horizon intersect those of the G material indicating that the latter developed first and subsequently changed in a kaolinitic material. At this contact, the gibbsite lost its optical properties under the petrographic microscope and many dissolution patterns of the quartz and of the gibbsite are observed using the SEM. Therefore, silica and Aluminium necessary for kaolinite formation are supplied by these in situ dissolutions. The destruction of gibbsite was already described by DELVIGNE (1965), ESWARAN and DAUD (1980) and KELLER and CLARCK (1984). In our case, the dissolution of gibbsite and quartz, and formation of kaolinite generate tongues disposed like tiles of a roof, which are suspected to be hardly permeable and to influence water flows in the slope.

6. Water circulation in the catena

During the fieldwork, water logging was observed after rainfall in the microaggregated horizon overlaying the K-horizons. It suggests a severe decrease in the vertical infiltration at this contact.

Horizon	**Gibbsitic** **G-Horizon**	**Kaolinitic** **K-Horizon**	**Micro aggregated**
Total porosity	40%	51%	64%
Hg - porosity (0,001µm-100µm)	bimodal	unimodal	bimodal
Mode 1	0,23µm - 49%	0,28µm - 90%	0,032µm - 41,3%
Mode 2	>100µm - 51%		43µm - 59 %
Image Processing Macroporosity	24,50%	9,30%	31,60%
Connection	medium	low	high
pF3 saturation	48%	87%	50%
pF2 saturation	50%	92%	66%

Table 1 Porosity and water retention at pF 2 and 3 of the gibbsitic, kaolinitic and microaggregated horizons.

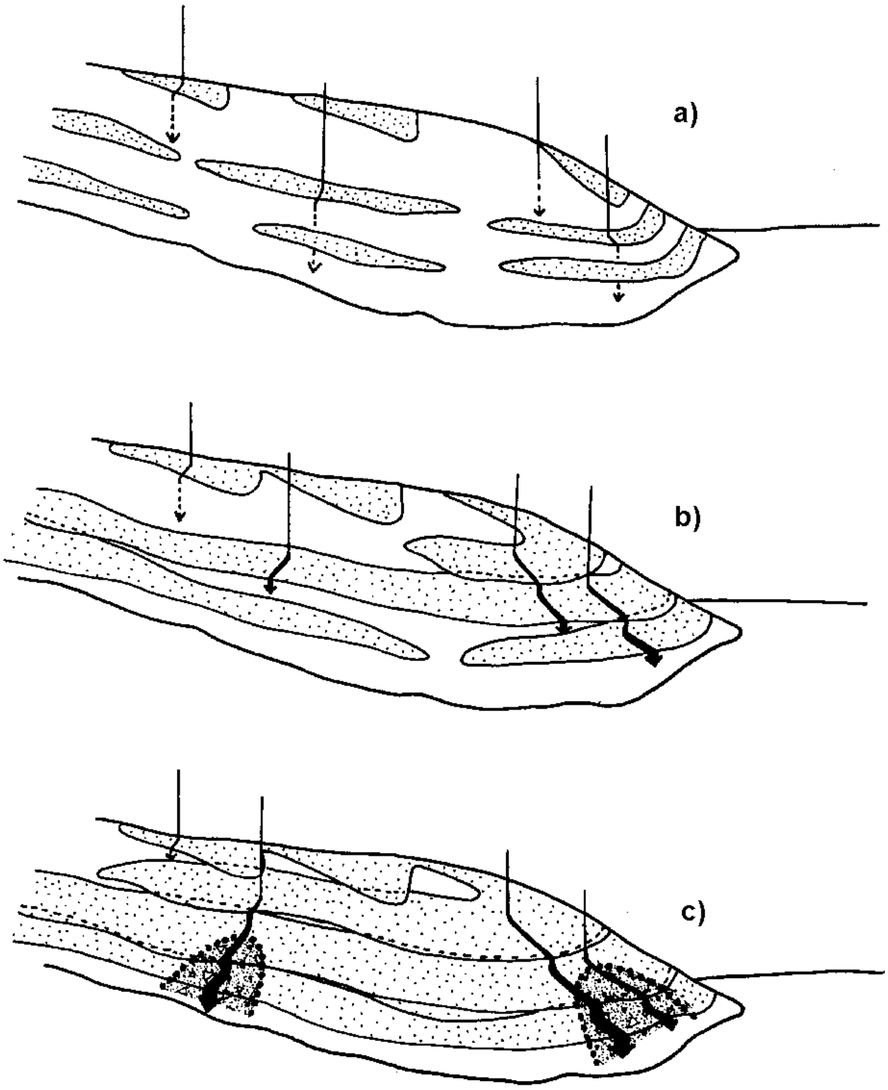

Fig 3.Model proposed for the contribution of the soil system to landslides.

Density measurements (Table 1) indicates that the total porosity increases from G (40%) to K (51%) and M (64%) but the mercury injection curves reveal that the pore size distribution appears significantly different. G and M presents a bimodal distribution of the porosity, similar to many ferrallitic soils (CURMI *et al.*, 1994) whereas that of K is unimodal and only corresponds to microporosity (90% of the porosity prospected by Hg). The macroporosity corresponds to 24.5% of the image superficy with medium connexion in G, 9.3% with low connexion in K, and 31.6% with high connexion in M. A vertical circulation of the water is possible in G, but the contact between M and K correspond to a clear decrease of the soil porosity. K appears hardly permeable due to the low connexion of macropores and will generate a lateral circulation in subsurface into M.

The water retention and shrinkage curves confirm these informations. Under low succion (pF3), the microaggregated horizon retains only 50 % of water whereas the kaolinitic horizon appears quasi saturated (87 %). It traduces that a large proportion of the porosity is still available for water at pF 3 or 2. This porosity can be transiently and briefly occupated by water during intensive rainfall.

A vertical drainage is possible in the gibbsitic material, but the water is oriented laterally and in subsurface over the K-horizons. This is consistent with the field observations.

7. Identification of the landslide risk

Due to the catena organisation, the water flow in the slope can create a sizeable overload downslope during intensive rainfall. This overload increase with the superficy drained by these K-horizons, as proposed on a model on fig. 3, built from the 3-D reconstitution of the soil mantle. In the first case (a), the K-horizons are separated without overlap. The vertical drainage in the sandy gibbsitic weathering material predominates in the slope. The landslide risk induced by the soil system is low. In the second case (b), the K-horizons are more developed and the proportion of lateral drainage in sub surface increases. The risk of landslide also increases. In the third case (c), quasi-all the K-horizons present overlap and the lateral drainage is generalized all over the slope. The overload-generated downslope during rainfall and the risk of landslide are very high.

8. Conclusion

Landslides occure in the Serra do Mar complex, at the end of the rainy season after important rainfall, generally in the third part downslope. DE PLOEY and CRUZ (1979) have suggested that more attention sould be paid in the study of slope organisation and water flows. This is the contribution of our paper.

In the region, the in situ soil cover is mainly caracterised by various clay loam kaolinitic horizons disposed like the tiles of a roof, into a thick sandy gibbsitic-weathering horizon. These K-horizons are overlaid by a very porous microaggregated horizon. This type of soil cover undergoes the landslide processes.

The study of porosity, water retention and shrinkage curves and field observations along the slope indicate that the drainage should be vertical into the gibbsitic weathering material (G-horizon), whereas lateral and sub-superficial over the kaolinitic horizon (K-horizon) into the microaggregated horizon. Which can stock transiently and briefly a large quantity of water during intensive rainfall. An overload is created in the third part downslope and can generate downslope landslides. A hydrological study of water flows on the slope is necessary to bring quantitative data (GRIMALDI and BOULET, 1990).

This study underlines that a better knowledge of the three dimensional distribution of the soil mantle, is generally necessary for a good management of the environment. Understanding the water flow into the soil mantel is necessary for the location of drainage system to remove quickly the excess of water during and directly after rainfall.

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