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Contributions of modern pedological analysis to the history of soils and landscapes

Application to the study of soils derived from the Continental Terminal in Casamance, Senegal

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Abstract - The study of the evolution of the soils formed on Continental Terminal in Casamance (Senegal) during the Quaternary shows how modern concepts in structural soil science can be used to understand the history of the morphopedological landscapes.

Résumé - L'étude de la distribution des sols développés sur le Continental Terminal de la moyenne Casamance (Sénégal) représente une contribution intéressante de l'analyse pédologique «structurale» à la connaissance et à la mise en place des paysages caractérisant cette région. L'analyse de la transformation enregistrée à la suite de l'arrivée d'une phase aride a conduit à situer dans le passé les différents stades de l'évolution et à proposer une vision de la structure future de ce milieu morpho-pédologique.

INTRODUCTION

Current trends in pedology, which emphasize space and time, are quite different from classical concepts found in most texts devoted to the study of soils. Until recently, soil science was based upon principles that corresponded to a strict interpretation of pedology, particularly to strict relations between parent rock (substratum) and soil based upon a very local approach to pedological phenomena.

This classical concept meant:

- the significance of **external** bioclimatic factors (atmosphere-biosphere) was paramount, rather than including internal factors;
- only relatively **short** periods of evolution were considered, rather than geologic time periods;
- only **vertical** dynamics of evolutionary processes (major role of gravity) was considered, rather than lateral dynamics within the landscape.

Therefore, a soil type corresponded to limited environmental conditions, which implies the following consequences:

1. a spatial extrapolation (soil maps) was made on the basis of strictly local data;
2. the existence of a given soil involved a given climate during the whole period of its formation.

Before showing that such a conception is quite inadequate and even, in a number of cases, quite wrong, one must recognize that it can occasionally be applied, particularly when the above mentioned requirements are met, such as in the case of recent volcanic zones (Andes, Pacific,...).

In regions where soil genesis is ancient, such as the intertropical zones of Africa, it is necessary to use a wider interpretation of pedology, which means incorporating **time** (geological duration) into the equation in order to understand these soils. Therefore, it is also obvious that at one time or another climatic modifications (arid or humid) or base level modifications linked to neotectonic movements (uplift or depression) would occur, thus leading to a new equilibrium of the pedologic cover.

It is clear that the classical relation between lithosphere and atmosphere is not the most important. In its place is the general, dynamic relation between pedosphere and atmosphere. Two recent studies (Boulet *et al.*, 1982; Fritsch *et al.*, 1986) of this dynamic equilibrium have made evident two facts:

1. any soil is undergoing transformation (structurally and mineralogically) at any moment under any conditions, whether the climatic conditions become arid or humid;
2. these transformations do not affect simultaneously and uniformly the original soil mantle, but affect specific sites from which the transformation spreads laterally to the whole surface. For example, in an interfluve it is observed from downstream to upstream and in a plateau it is observed from the centre to the edges.

These transformations are accompanied by the evolution of the relief (Millot, 1977).

This means that:

1. under a given climate, several types of soils may be distributed in space along a well defined sequence. Therefore, there can be no simple relation between current climate and soil type (Fig. 1);
2. if the soil sequence remains the same during the course of these transformations, the proportion of space occupied by each soil varies with the duration of the evolutionary process (Fig. 2):
   - if a transformation has just begun, the initial soil sequence and proportion of each soil is still prevailing;
   - if on the contrary, a transformation has been under gone for some time, the proportion of each soil changes but the soil sequence remains the same.

Therefore, it seems obvious that structural soil and landscape analysis can contribute to revealing the environmental variations (climatic, eustatic, neotectonic) which occur in the course of soil formation and, in a number of cases, to evaluate the duration of the phenomena envolved.

APPLICATION TO THE AFRICAN INTERTROPICAL ZONES - SOILS FORMED ON THE CONTINENTAL TERMINAL IN CASAMANCE, SENEGAL

In Africa there are numerous examples of this type of complex evolution, where a local classical analysis (with extrapolation) is not sufficient, but a spatial analysis allows us to understand the soil structure and its history. The studies carried out by ORSTOM (Bocquier, 1971; Boulet, 1974; Chauvel, 1976; Leprun, 1979; Brabant and Gavaud, 1985) are quite significant from this point of view. As it is not possible to discuss all of them, we will focus on an example that concerns the soil dynamics in Middle Casamance during the Quaternary (Chauvel, 1976).

Through a study of the soils of this region and an analysis of their distribution, Chauvel showed that:

1. there are two principal types of soil: ferrallitic red soils (sols rouges) and ferruginous beige soils (sols beiges) and they are not distributed randomly:
   - at a regional level, the extension of these soils varies with latitude, red soils prevailing in the south and beige soils prevailing in the north (Fig. 3);
   - in the landscape, red and beige soils are always associated in the same toposequence: beige soils are found in the centre and on the downhill slopes of the plateaus and red soils are found on the raised plateau edges; the area occupied by beige soils within toposequences increases from south to north (Fig. 4);
2. red soils are unstable and are in the process of transformation into beige soils. This transformation was revealed both:
   - **in space**: the transition from one type of soil to the other is made through a strip of specific transitional soils about 200 m in width (Fig. 5);
   - **in time**: land reclamation after deforestation leads, within 100 years (results obtained from previous surveys), to a degradation of red soils to transitional soils and to the individualization of soils which are quite similar to natural

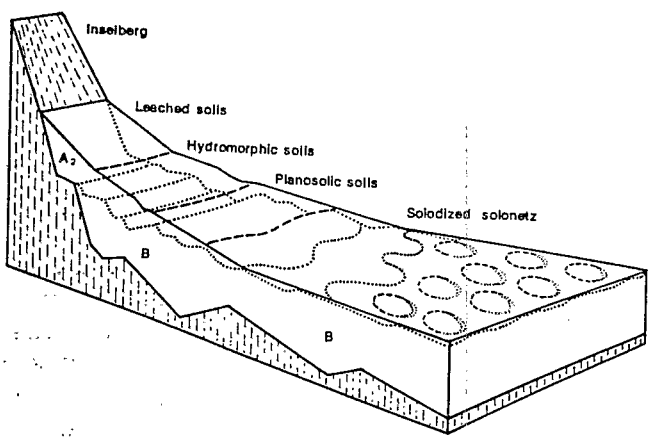


Fig. 1. Classical soil toposequence in the Sudano-Sahelian zones, Kosselili, Chad, from Bocquier (1971).

Fig. 1. Toposéquence représentative de la zone soudanosahélienne en Afrique: Kosselili (Tchad). d'après G. Bocquier (1971).

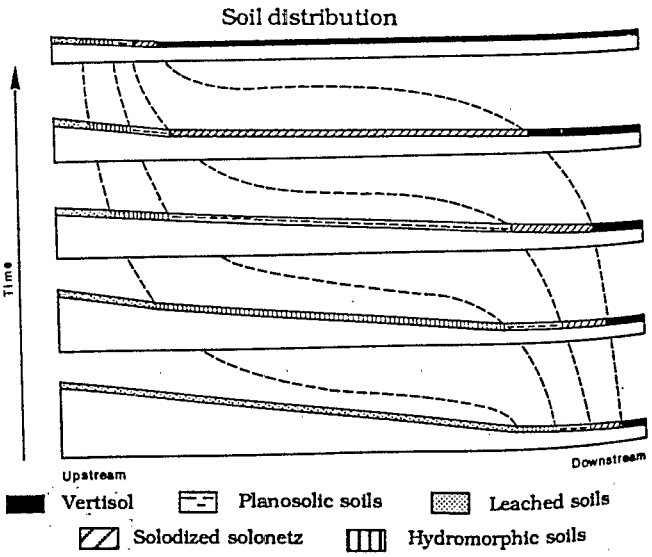
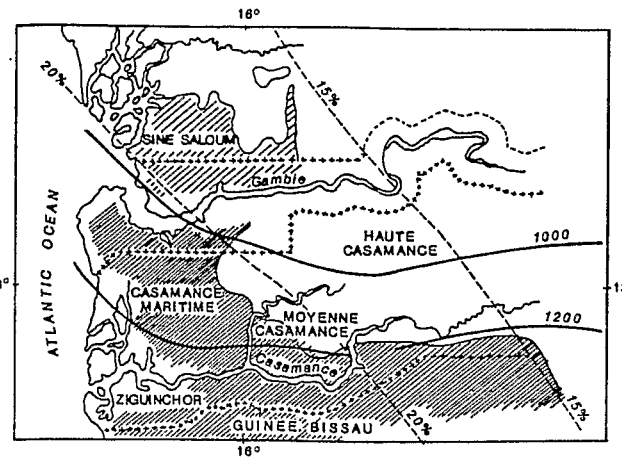


Fig. 2. Variation in the proportion of different soils in the Sudano-Sahelian zone during the evolution of this region (bottom is oldest, top most recent), from Bocquier (1971).

Fig. 2. Variation de l'extension des différents sols de la zone soudano-sahélienne en fonction de la durée de l'évolution. d'après Bocquier (1971).



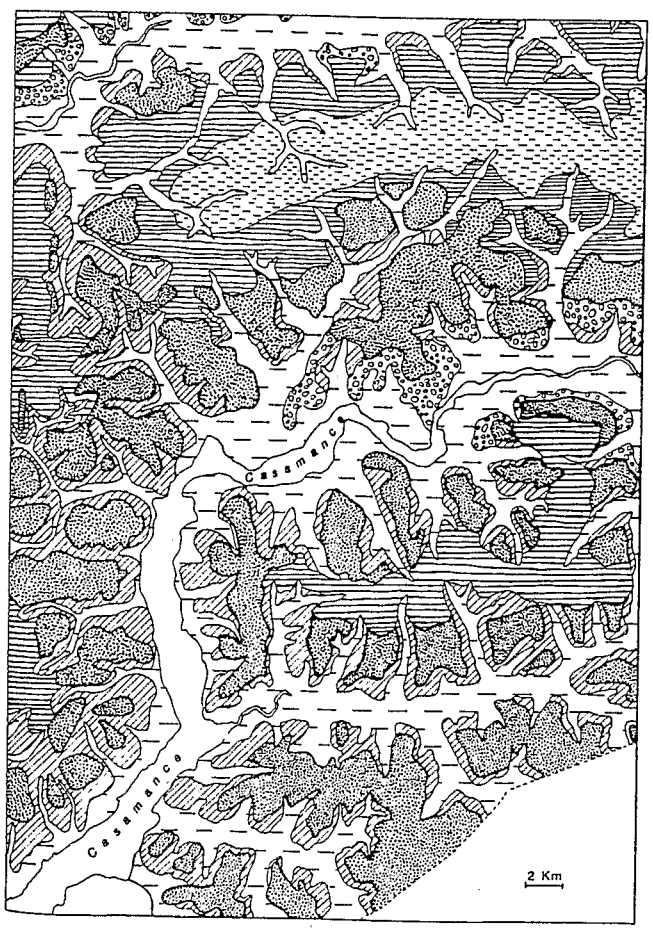
Preponderance of typic red soils
Preponderance of pale red soils
Preponderance of beige soils
1000 Isohyet
++++ Senegal frontier
15% Relative air humidity (average of minim in mars)

Fig. 3. Schematic map of the distribution of red and beige soils in south-west Senegal, modified from Maignien (1965).
Fig. 3. Répartition schématique des sols rouges et des sols beiges dans le Sud-Ouest du Sénégal. d'après R. Maignien (1965) modifié.

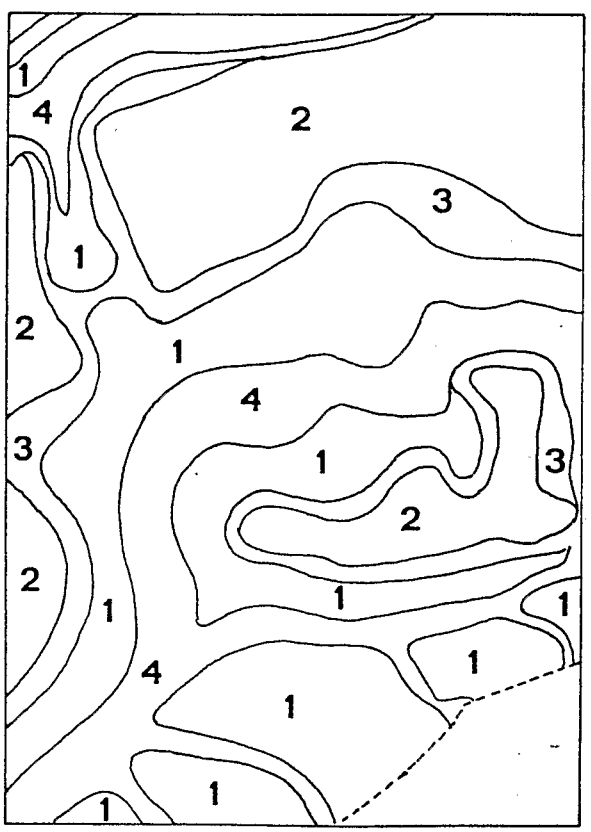
(unaffected by deforestation) transitional soils;

3. This transformation results from the more arid climatic conditions in the Recent Quaternary, which became more and more pronounced (both in length and intensity of the dry season) since this time.

Based upon the above data, Chauvel hypothesized that the transformation from red to beige soils spread laterally at a rate of several cm/year. He also suggested a model for the evolution of soil distribution in space, as related to time: the ferrallitic plateaus vere formed during the humid period from 350 000 to 150 000 B.P. defined by Michel (1970) (Fig. 6, n° 1); during the arid period from 150 000 to 40 000 ergs were formed. This landscape is characterized by the development of beige soils in the centre of the old ferrallitic plateaus which vere also being dissected by deepening valleys (Fig. 6, n° 2); since 40 000 the present landscape has progressively evolved (Fig. 6, n° 3); if current climatic conditions continue, the future (100000 year) evolution of this landscape could be predicted (Fig. 6, n° 4). The



Red soils
Beige soils
Hydromorphic beige soils
Beige slope soils
Desmantling iron crust
Hydromorphic soils



MORPHOLOGIC SCHEME

1 Interfluvials and lateral valley domain
2 Plateau domain
3 Discontinuous peripheric domain
4 Principal valley domain

Fig. 4. Distribution of red and beige soils in the Middle Casamance (scale 1:200 000), from Chauvel (1976).
Fig. 4. Repartition des sols rouges et des sols beiges en Moyenne Casamance (échelle 1/200 000).

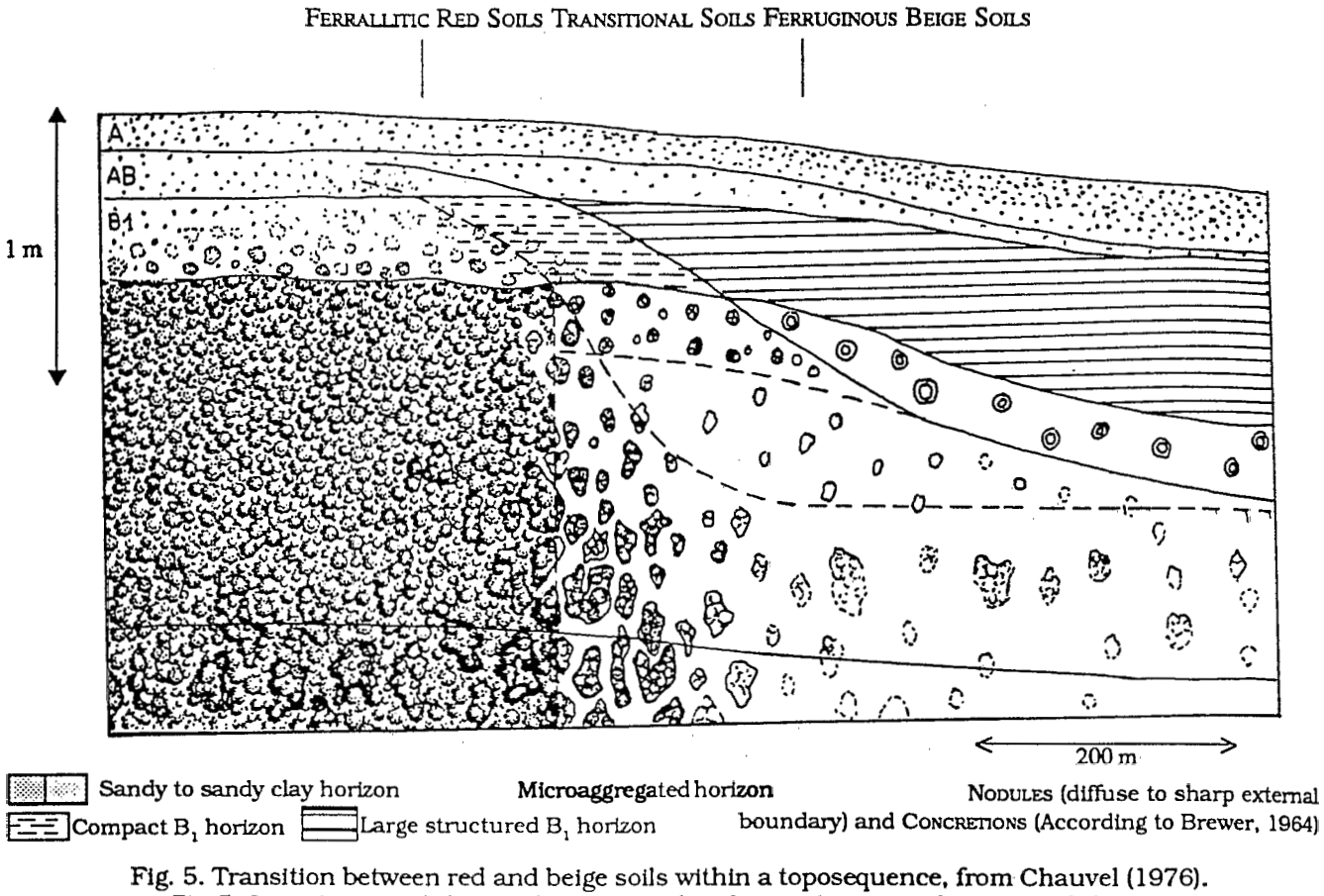


Fig. 5. Transition between red and beige soils within a toposequence, from Chauvel (1976).
Fig. 5. Caractérisation de la zone de transition dans la toposéquence: sols rouges-sols beiges.

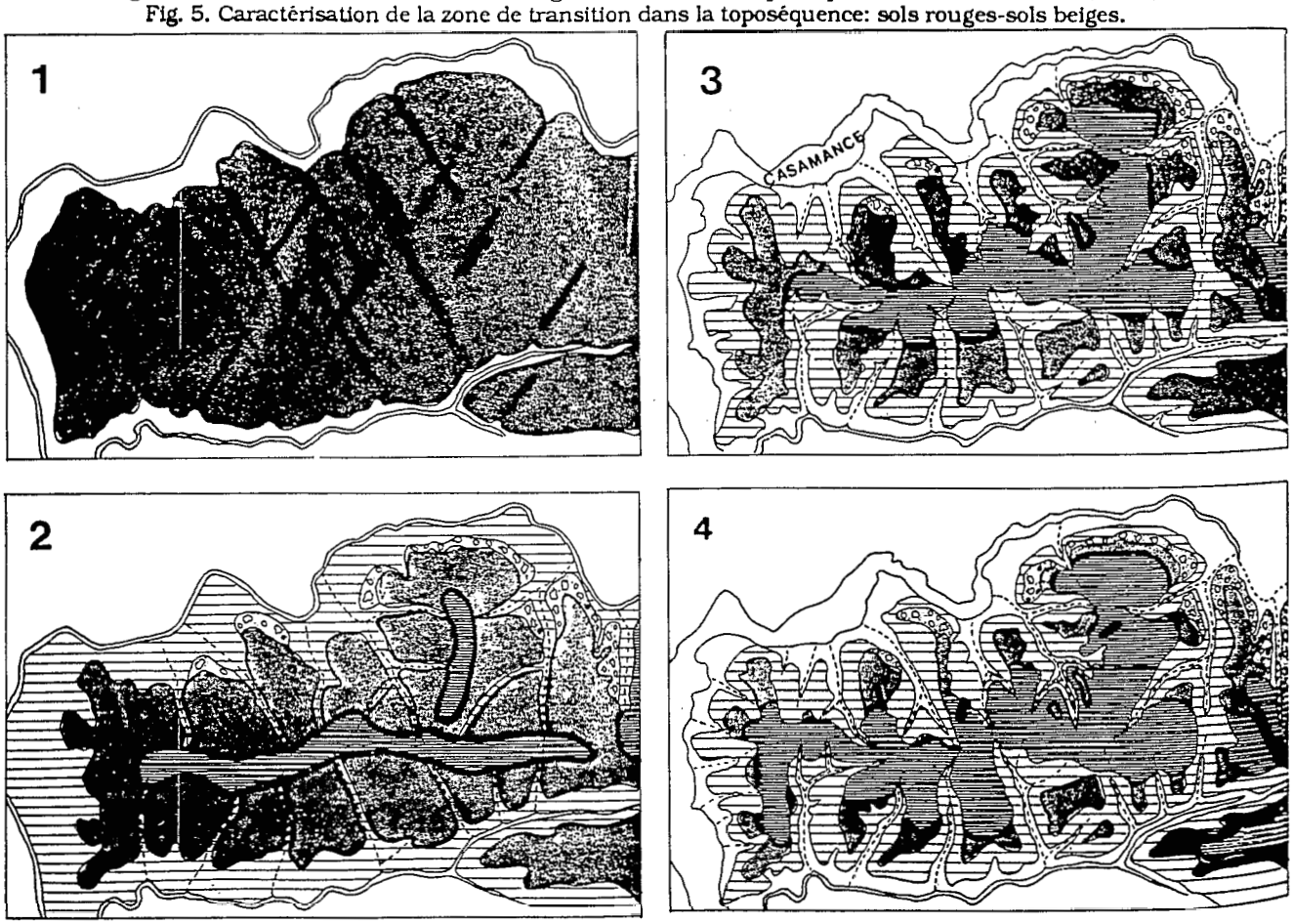


Fig. 6. Transformation phases of a typical plateau in Casamance since the Quaternary (n° 1 through n° 3) and projected into the future (n° 4), from Chauvel (1976).
Fig. 6. Evolution de la couverture pédologique en Casamance durant le Quaternaire: Passé-Présent-Futur.

red soils will survive only as "relicts" on the plateau periphery, while along the valleys the beige plateau soils would be progressively eroded and give rise to the beige slope soils.

CONCLUSIONS

This study of the evolution of the soils formed on the Continental Terminal in Casamance is a good example of how modern concepts in pedology can be used to understand the history of modern landscapes. The transformations discussed can be more or less rapid, depending upon the geography of the area under study and the climatic conditions to which it is subjected Moreover, the process can be accelerated by human intervention.

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