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# TEXTURAL VARIATION IN A SOIL CATENA ON GRANITE UNDER A SAVANNA CLIMATE, NORTHERN NIGERIA

Variations dans la texture des sols le long d'une catena sur granite sous climat de Savane (Northern Nigeria)

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*RESUME*

*Cet article analyse la granulométrie, la lithologie des cailloux et la micromorphologie des sols sableux pris le long d'une catena près de Zaria. Dans presque tous les profils, l'horizon superficiel est plus sableux et les sols deviennent plus lourds avec la profondeur. Des cutanes et des luvanes qu'on y trouve suggèrent des processus d'éluviation, d'illuviation et de colluvation. Le degré d'altératon des cailloux indique que le caractère résiduel de la roche-mère.*

*Un modèle de l'évolution progressive de la catena est présenté.*

*ABSTRACT*

*The paper describes a soil catena near Zaria in terms of soil particle-size, lithology of the gravel fraction and micromorphology. In nearly all samples the particle-size size distribution reveals the presence of a maximum of sand and minima of silt and clay. Sandy top soil overlies heavier subsoil in nearly all the profiles studied. Both cutans and luvans are present and this suggests that processes of eluviation, illuviation and colluviation have been active. The indices of weathering intensity obtained from the study of the lithology of the gravel fraction suggests that the subsoil is a relict feature.*

*Finally, a model of the evolution of the soil catena is attempted.*

## INTRODUCTION

This is a study of the variation in texture within a soil catena, together with associated features of mineralogy and micromorphology. Its

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aim is to elucidate the weathering and physical translocation of the mineral constituents of the soil. Rather than considering individual profiles, the unit of study taken is the soil catena. This enables us to give attention to both the nature of the variation in textural properties from the crest to the base of the slope and the extent to which processes acting laterally down the slope have contributed to their formation.

Previous studies of soil evolution in the context of the catena have been competently reviewed by WATSON (1965), OLLIER (1976) and YOUNG (1976). Most of these studies have either been broad accounts of all aspects of the catena or have concentrated on chemical relationships whilst relatively few have given particular attention to physical aspects.

## STUDY AREA

A catena was selected for study, which is approximately 5 km away from Zaria, which is located on the undulating High Plains of Hausaland. The climate of the area has been described as Tropical Savanna, with distinct wet and dry seasons (HORE, 1970). Total rainfall is, however, not high, with an average of approximately 1100 mm per annum. This is concentrated in the wet season between May and October. According to Thornthwaite's moisture index, the climate of Zaria can be classified as "dry sub-humid". But it is a climate within which high intensities of weathering and leaching, together with high rates of erosion are to be expected. Also in this area, the climate has alternated between wetter and drier conditions during and since the Pleistocene (GROVE & PULLAN, 1963). Pedological processes active at the present time have combined with soil properties inherited from different climates in the past to produce features of great interest for the study of soil.

The catena is developed on porphyroblastic biotite granite, which consists mainly of quartz, microcline and plagioclase feldspars and biotite; with zircon, epidote, garnet and apatite as the major accessory minerals (Tab. I).

| | |
|---|---|
| Quartz | 44.0 % |
| Plagioclase | 24.5 % |
| Microcline | 27.5 % |
| Other (mainly biotite) | 4.0 % |

Tab. I : Mineral composition of porphyroblastic biotite granite. Source : WRIGHT & McCURRY (1970).

The slope supports a dispersed cover of low trees and shrubs, such as *Isoberlinia doka*, *Isoberlinia tomentosa*, *Uapaca togoensis*, together with a grass layer of tufted *Andropogoneae*.

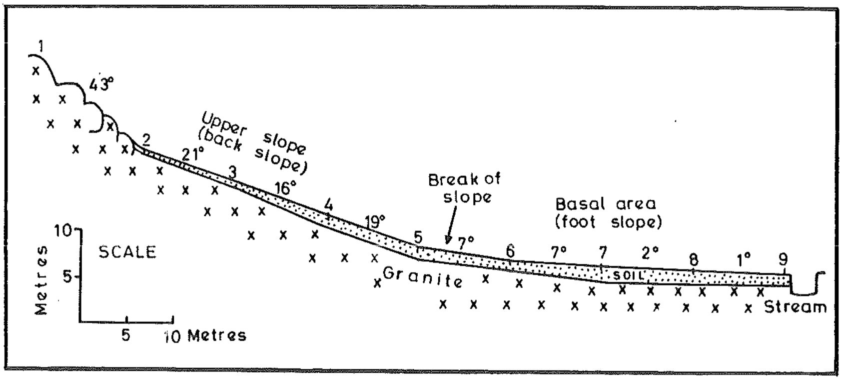


Fig. 1 : Slope profile of the catena, showing the slope gradients, the sampling sites soil profile numbers, and the soil thickness of each soil profile.

The catena studied is a valley-side slope 80 m long (Fig. 1), starting at the foot of a low inselberg, the slope is clearly divisible into two : a generally steeper back slope (or upper slope) above a gentler footslope with a break of slope separating them. The former is almost rectilinear and angles ranging form 16° to 21° with a convexity on the crest. The footslope (or basal area) is nearly flat (below 2°), except at the top where the gradient is 7°.

## METHODS

In order to permit the objective study of soil layers and their catenary variation, soil inspection sites were chosen at regular 10 m intervals and samples taken at the following standard depths (± 5 cm) : 10, 20, 30, 45, 60, 75, 90, 120, 150 and 200 cms (at most sites the soil depth was less than 200 cm). The word "layer" is used here deliberately the mean zone at a specific depth and must not be confused with the term "horizon", which has a different meaning. A total of 55 samples were collected at 8 soil profile sites. In four of the profiles (profiles 4, 5, 6, 7) undisturbed samples for making thin sections were collected at 20 and 75 cm.

Laboratory analysis included granulometric analysis, lithological analysis of the gravel fraction and micromorphological examination.

Granulometric analysis was carried out by the sieve and hydrometer methods. The gravel fraction (bigger than 2 mm) collected from this analysis was used for lithological analysis. To do this, the gravel samples were washed in an ultra-sonic bath, and examined under both binocular and petrographic microscopes. Minerals were divided into quartz, feldspar, rock fragment and iron minerals, and weighted. For the micromorphological study, undisturbed samples (7.5 x 6.0 x 3.8 cm in size) were dried very slowly and impregnated with vestopal resin. The impregnated blocks were sectioned, ground, polished, cleaned and mounted. The mounting blocks were then cut off and the slides ground down to a thickness of 30-40 µm. Quantitative micromorphological data were obtained by the point-count method, about 2000 points being counted per thin section (7.5 x 6.0 cm).

## RESULTS

### Textural variation

The main feature of the particle-size distribution in nearly all samples is the presence of maximum of sand and minima of silt and clay fractions. The average sand, silt and clay contents of all layers in the catena are close to 60 %, 20 % and 20 % respectively. Silt content remains relatively constant, ranging between 12 and 20 percent in the upper slope. Therefore variation in particle-size distribution in the upper slope is mostly due to changes in the relative proportion of sand and clay. In the basal area, however, there is greater variation in silt content ranging from 10 % to 28 %, but there is no systematic variation with depth.

The maximum sand and minimum clay contents occur in the uppermost layers throughout the catena. Sand content in these layers is usually over 70 percent, while clay is less than 15 percent. There is a decrease of the sand fraction but an increase of clay with depths throughtout the catena. The maximum clay content occurs between 60-90 cm, below which clay generally decreases again. Generally speaking, the subsoils in the basal area contain more clay than the subsoils in the upper slope (Fig. 2).

A textural B horizon will be defined here as any layer which has 8 percent more clay than that found at 10 cm depth. On the basis of this definition, a textural B horizon exists in all profiles, except in profile n° 1, which is only 10 cm deep. The depth at which the textural B horizon begins is generally 30 cm on the upper slope, and 45 cm in the basal area (except profile n° 8). The decrease in clay from the more sandy surface layers to the textural B horizon is usually abrupt, especially in the basal area, where the decrease is more than 10 % per 10 cm depth. The textural B horizon extends downwards to or near to the unweathered rock. The decrease in clay within the textural B horizon from maximum clay layers to less clayey soil layers near the unweathered rock is usually very slow, less than 2 percent per 10 cm depth.

Another way to describe the degree of textural differentiation in a soil profile is by using the index of textural differentiation ($I_T$)

$$\text{where } I_T = \frac{\text{Percentage clay in the layer with maximum clay}}{\text{Percentage clay in the top 10 cm layer}}$$

The index of textural differentiation for the catena is fairly high, ranging between 1.9 and 3.0 in the upper slope, and 2.8 and 4.3 in the basal area (Fig. 2).

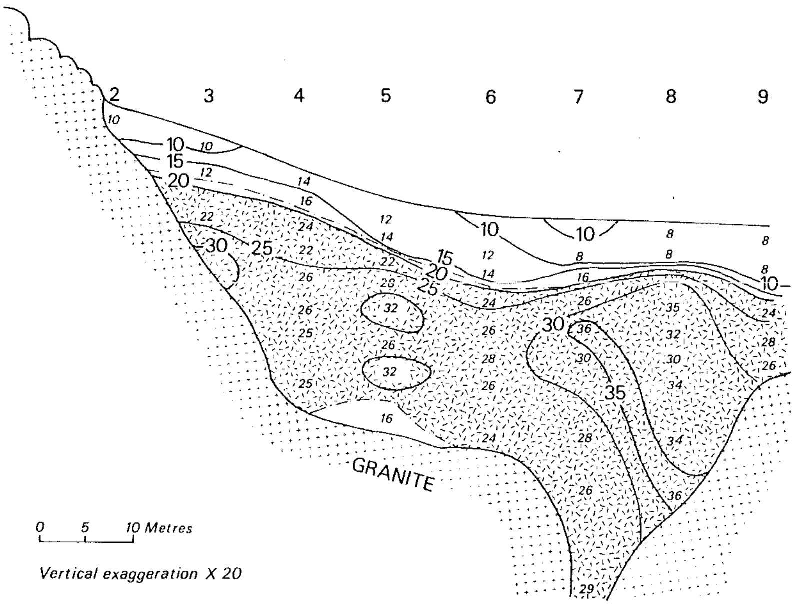


Fig. 2 : Isopleth diagram of clay percentage an the $I_T$ value of each soil profile. The shaded area is the textural B horizon.

## Lithology of gravel fraction

The amount of gravel expressed as a percentage of the fine earth (less than 2 mm) content ranges from 157 % to only 1 %. The surface layers have the highest gravel contents. The gravel content in these layers is consistently over 20 % and is mostly overs 60 %. The gravel content also tends to decrease with depth. But in profiles 4, 5, 6 and 7 the gravel contents increase again in layers near the unweathered rock. The gravel contents of the sub-soil in the basal area are very low, being less than 20 % in all cases (Fig. 3).

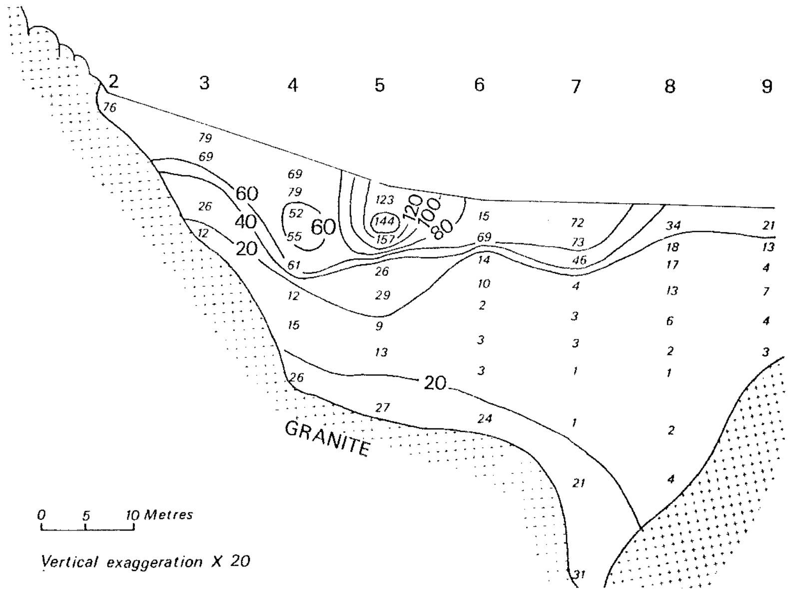


Fig. 3 : Isopleth diagram of gravel fraction, expressed as percentage of fine earth content.

The gravels encountered in the area can be classified into four types : pure quartz, feldspar, iron minerals and rock fragments. The latter contain quartz, feldspar and biotite.

The amount of iron minerals is very low in all layers and never exceeds 2 percent of the total amount of gravels in each layer.

The other three types of gravel can be grouped into two according to their resistance to weathering. The pure quartz is a very resistant mineral, while the feldspar and the rock fragment gravels are more readily weatherable.

Relative weathering intensities of the soils may be estimated by using the principles that higher relative amounts of very resistant minerals (i.e. pure quartz) and lower absolute amounts of weatherable minerals (here feldspar and rock fragments) indicate more intense weathering.

| Profile n° Depth cm | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|
| 10 | 5 | 3 | 13 | 15 | 8 | 9 | 26 | 53 |
| 20 | - | 11 | 5 | 11 | 15 | 16 | 27 | 73 |
| 30 | - | 32 | 7 | 4 | 74 | 31 | 82 | 88 |
| 45 | - | 11 | 5 | 32 | 68 | 75 | 83 | 70 |
| 60 | - | 13 | 12 | 58 | 68 | 91 | 90 | 80 |
| 75 | - | - | 47 | 66 | 72 | 81 | 78 | 90 |
| 90 | - | - | 36 | 51 | 94 | 88 | 95 | - |
| 120 | - | - | 19 | 27 | 75 | 87 | 78 | - |
| 150 | - | - | - | - | - | 50 | 37 | - |
| 200 | - | - | - | - | - | 39 | - | - |

Tab. II : Percentage of quartz in the gravel fraction.

The relatively low amounts of the pure quartz (Tab. II) and high absolute amounts of rock fragment plus feldspar (Fig. 4) in the upper slope and the surface areas of the adjacent profile of the basal break of slope indicate less intense weathering in these areas. Based on the same principles, the weathering intensities increase with depth, and also with the distance away form the slope crest. In some of the layers near the underlying rocks, the relative amounts of pure quartz (Tab. II) is lower, and this together with the higher absolute amounts of weatherable minerals found here indicate that weathering intensities decrease again. This is rather curious and is further discussed below.

Evidence of illuvial clay

It is not intended to discuss in full, the details of the micromorphological characteristics of the soils here, but only those features related to textural variation.

The two most important microphological features related to textural variation are cutans and luvans. Cutans are deposited materials on the surface of peds, pore spaces, rock fragments and detrital grains. Clay

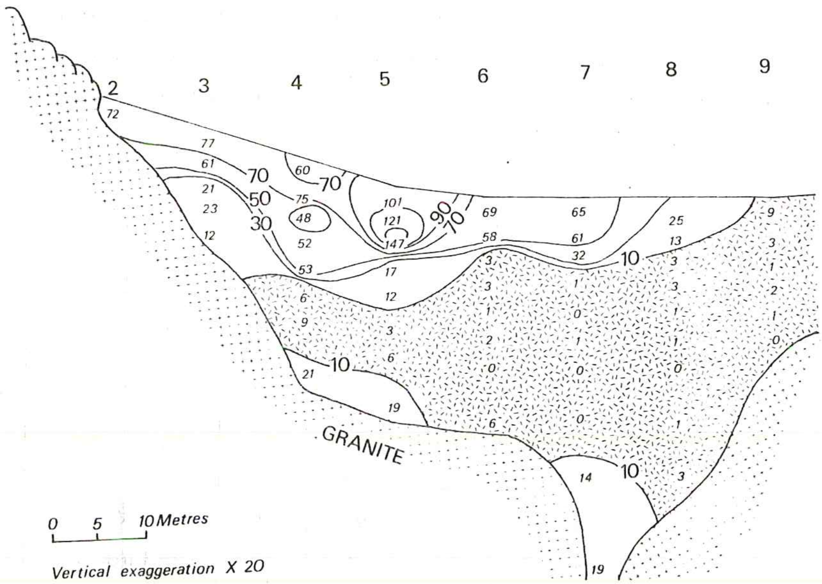


Fig. 4 : Isopleth diagram of absolute amount of weatherable mineral (felspar plus rock fragment) in the gravel fraction, expressed as g per 100 g of fine earth.

cutans are probably the most common type of cutan and are recognised in plane polarised light by their layered structure and absence of coarse material, while in crossed polarised light they are most often anisotropic. They are usually formed by eluviation of fine material and deposition of the same in a deeper horizon. Luvans occur on the outer surface anu contain less clay than the ped interior; they are formed by the differential removal of material by percolating water.

The percentages of illuviated cutans present in the three profiles are shown in table III. The average amounts of cutans are about 1.5 % in the surface layers of the upper slope, and between 3.0 and 3.6 % in the subsoils. In the basal area, the amounts of cutans are very low in the surface layer (less than .5 %) but fairly high in the subsoils (between 4.1 and 4.5 %). The variation of illuviated cutans is quite clearly associated with the amount of clay in these layers.

| Profile n° | 4 | 5 | 6 | 7 |
|---|---|---|---|---|
| 20 cm | 1.6 | 1.3 | 0.4 | 0.3 |
| 75 cm | 3.0 | 3.6 | 4.5 | 4.1 |

Tab. III : Percentage of illuvial clay cutans.

Luvans are found in the surface layers of all profiles (0.8 - 1.2 %) but not in the subsoils. This indicates that some kind of relative removal of fine particles is taking place of surface layers of the upper slope and the basal area.

## DISCUSSION

The frequency distribution of particle-size of the soils is marked by the presence of maximum of sand with minima of silt and clay. This feature together with the presence of fairly large amount of feldspar and partially weathered rock fragments, and the high silt/clay ratio (over 0.75 in most cases) indicates that the soils are in the young stage of development (VAN WAMBEKE, 1962).

The sandy layer overlying the moderately heavy subsoils is observed on both the upper slope and the basal area. This feature may be attributed to strong eluviation and colluviation. Eluviation removes the fine particles in a vertical direction and deposits them in the subsoil as illuviated cutans, whilst colluviation and lateral eluviation remove fine particles in a lateral direction. The presence of luvans in the surface layers, and the high amount of cutans in the subsoils together with the steep nature of the slope support the above theory.

However, the indices of weathering intensity obtained by the lithological analysis of the gravel fraction, shows that other factors may need to be considered. The weathering indices show a clear positive correlation with the textural differentiation in the catena. Less intense weathering is associated with high sand contents, whilst the high weathering intensities are associated with high clay content.

The less weathered sandy surface layers on top of more weathered heavy subsoil layers may be explained in terms of the subsoil being a relict feature, i.e. inherited from past conditions of climate or landforms that differ substantially from those of the present as suggested by OLLIER (1959) in his study of deep regolith formation in East Africa. He suggested that the subsoil may be formed from regolith material weathered during a previous cycle of erosion in the pre-Tertiary time, and the top soil may be formed during the present cycle of soil formation. However, it is not necessary to call upon pre-Tertiary time to achieve the observed depth of weathering in the study area, since the soil depth is seldom over 2 m. Therefore, if it allowed that the weathering front advances by as little as 0.1 mm per year, then a few thousand relatively stable years is sufficient for attainment of the observed depth of weathering penetration.

From the above discussion, it may be possible to conclude that the textural variation in the soil catena on granite in the study area may be due to some relict features inherited from the past, together with the present processes, such as eluviation, illuviation and colluviation acting together.

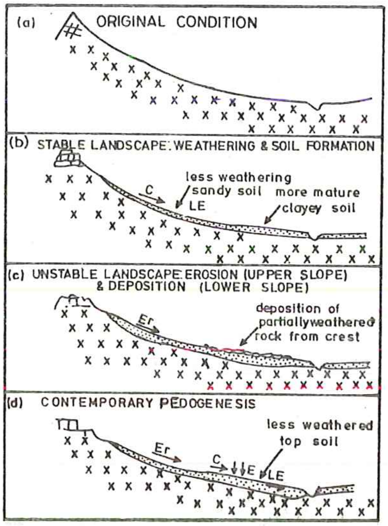


Fig. 5 : Model of soil catena evolution (for detailed explanation, see text). C : colluviation; E : eluviation; LE : lateral eluviation; ER : erosion.

Finally, a model of soil catena evolution may be attempted to explain the genesis of the soil catena. This model postulates a prolonged period, may be a few thousand years long, when the rate at which the weathering front advanced into rock exceeded the rate at which the ground surface was being lowered by natural erosion. A soil cover develops on the catena with sandy, less mature soil on the upper slope and deeper, more mature and finer textured soil in the basal area (Fig. 5 a et b). After this, a period of landscape instability occurs. This may be a long period with lower rainfall and a sparse vegetation cover. More active erosion under such conditions would remove partially weathered rocks from the inselberg and the upper slope down to the basal area (Fig. 5 c). Under contemporary bioclimatic conditions weathering of the regolith and rocks in the basal area has continued and eluviation, both horizontal and vertical together with colluviation have led to the formation of a high amount of cutans in the subsoils and luvans in the surface layers.

This model explains the formation of shallow, sandy soils with less intense weathering at the top of the slope, and in the top layers of the basal area, of heavy, more mature subsoils. The condition for this evolutionary model is relatively simple, the only requirement is the formation of soil previous to the removal of the partially weathered rocks from inselberg and upper slope to the adjacent basal area. Geomorphological studies suggest very strongly that such regolith stripping in fairly recent times have played a major role in fashioning the contemporary landscape of the Zaria area (THORP, 1970; OLOGE, 1971).

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