REVIEW OF BOOK BY GERARD BOCQUIER ON

ORIGIN AND EVOLUTION OF TWO CHADIAN TROPICAL SOIL TOPOSEQUENCES

BIOGEODYNAMIC INTERPRETATION

by

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Review of Book by Gerard Bocquier on Origin and Evolution of Two Chadian Tropical Soil Toposequences Biogeodynamic Interpretation[1]

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[1]A summary of a thesis presented October 7, 1971 at "La Faculté des Sciences de l'Université Louis Pasteur de Strasbourg" to obtain the degree of "Docteur ès Sciences Naturelles." Thesis published as a "Memoire ORSTOM n° 62," Paris, 1973.

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NOTE: This seminar was presented with a series of excellent slides which illustrated the points discussed here.

In tropical climatic regions with contrasting seasons--like in the central part of the Chadian Basin--several types of soils can be distributed in a regular manner in the landscape, although the parent rocks are the same. These orderly and systematic soil sequences in relation to topographic position are called toposequences. The subject of this seminar is the development of such toposequences.

1. Morphologic organization of the toposequences.

The two toposequences chosen for this seminar differ in their location and their parent material:

(a) One toposequence in Kosselili is only 150 meters in length at the foot of a granitic inselberg. Regionally, it is part of the granitic piedmont of the Chadian Basin. The mean yearly rainfall is 850 mm with a four-month rainy season.

(b) The other toposequence, in Mindera, is derived from quaternary river deposits and is in the sedimentary Chadian Basin. It is about 120 meters long. Minimum yearly rainfall is 975 mm with a five to six-month rainy season.

1.1. Pedological composition.

In the first toposequence, called Kosselili, granitic inselbergs rise to varying heights from broad, very gently sloping piedmont slopes. The vegetation is a grass steppe. Between the inselberg and the lower lying main piedmont slope, a transitional zone, about 100 m long, is

located. In this zone, the vegetation is more dense and varied. The toposequence was studied within the transitional zone. A thorny wooded savannah with Acacia Seyal grows on the lower-lying piedmont, and the soil surface has a "gilgai" microrelief.

Let us now see the various kinds of soils which comprise the Kosselili toposequence, starting from the foot of the inselbert. On the highest part the soils are shallow, colored and leached throughout the profile, and especially at the bottom. They are gray ferruginous leached soils or Haplustalfs. Seven meters downslope, the soils are entirely leached, deeper, and lighter colored. B horizons appear below the leached hydromorphic horizons. Twenty meters downslope, these B horizons are nearer the surface, extending upward at the leached horizon's expense. The B horizons have a fragmentary structure. These soils are called planosolic soils or Albaqualfs.

Finally, in the lower part of the transitional zone, as well as on the whole of the lower-lying piedmont slope, the soil profiles are characteristic of solodized solonetz (Natraqualfs), with columnar structure in the B horizons and very thin leached horizons.

Let us now see the Mindera sequence, which is located in the plains of the sedimentary Chadian Basin. This toposequence is also about one-hundred meters and is on very gentle slopes, less than 7 percent. Vegetation is a wooded savannah on the upper part of the slope, becoming a bushy patchy savannah downslope. The toposequence ends at a floodable grass plain with a gilgai microrelief on the lowland. On the upper part of the slope, the soil profiles are leached to a great depth; at the bottom is a thin B

horizon. In the next profile, about ten meters downslope, B horizons are nearer the surface and vary in character. Farther downslope, the contrast between the A_2 and B horizons increases and the profiles become leached hydromorphic soils (Aqualfs). Still farther down the slope, B horizons are nearer the surface and are more and more accentuated in the planosolic soils (Albaqualfs). A few meters farther downslope, leached horizons are reduced still more and columnar structure appears as in solodized solonetz (Natraqualfs). Finally, the leached horizons disappear near the bottom of the slope, and the last profile of this toposequence is that of a Vertisol with broadly spaced cracks.

1.2. Vertical and lateral organizations of the horizons.

This describes the "morphologic organization" of soil profiles in relation to topographic position in these sequences. We can, immediately, draw two conclusions from the evidence:

(1) Both the Kosselili and Mindera sequences have the same pedologic composition, that is the same orderly succession of kinds of soil from the upper part to the lower part of the toposequence. Leached soils (Haplutalfs), leached hydromorphic soils (Aqualfs), planosols (Albaqualfs), solodized solonetz (Natraqualfs), Vertisols. This important variation of pedologic formation, over a short distance, corresponds to a variation of vegetative associations, which are necessarily tree savannahs, then shrub savannahs and then steppe-like associations down the slope.

(2) If the horizon limits between the different profiles are followed laterally, it is evident that the leached, sandy A_2 horizons are strongly expressed on the upper part of the toposequence (sometimes to the exclusion of B horizons), and decrease downslope, while the clayey B horizons of accumulation increase down the slope until they merge with the Vertisolic profiles at the bottom. The unbroken boundary, between the leached A_2 horizons and the B horizons of accumulation looks like the steps of a staircase which approach the surface downslope. Each step itself has a slope which is steeper than that of the soil surface. Each

step corresponds to a kind of soil. This regular horizon geometry shows that the morphologic organizations is both vertical in each profile and lateral between the different successive profiles.

1.3. The three basic organizations of the horizons.

Now, at the scale of horizons, micromorphologic analyses enable one to distinguish three basic organizations:

(1) The eluvial organization, that is, that of the A_2 horizons. It is characterized by three patterns:

(a) In the first pattern, that of the A_{2g} horizons, the skeleton dominates and is organized in laminar features, consisting of fine grains deposited on the top of one or several coarse grains. Laminar voids, horizontally oriented, are thus created underneath.

(b) In the second pattern, the plasma is limited to discontinuous illuvial bodies which are in the laminar voids. They were formed, therefore, much later than these voids. They are the A_{2gb} horizons.

(c) Finally, these plasmic illuvial bodies are themselves the origin of ferruginous nodules, by segregation and diffusion of the hydroxides through the adjacent skeleton. The ferruginous nodules acquire, in turn, a cap of fine skeleton. The horizon is called A_{2g} cn.

(2) The illuvial organization, that of the B_t horizons. Unbroken illuvial bodies of plasma have invaded the skeleton, which maintains a laminar arrangement like that described for eluvial horizons.

In the same way, specific pedologic features of A_{2g} horizons, like the capped nodules, are to be found also in the laterally adjacent B_t horizons. These B horizons thus have formed in the A_2 horizons. Illuviation follows eluviation.

(3) The transformation organization: These are the structural B horizons. The illuviated or neoformed constituents (mainly clay minerals) mechanically transform an antecendent illuvial organization and even destroy the skeleton arrangement which was formerly an eluvial type.

(A series of photomicrographs were shown to illustrate these features.)

1.4. Sequential evolution of horizons and profiles.

These three organizations, which have just been shown: Eluvial, illuvial and transformation are successively distributed.

(1) In space: Vertically and laterally, from the upper part towards the lower part of the toposequence.

(2) In time: They follow each other, on the spot, by successive development from each other, through removal, definition and transformation of matter. The eluvial environment becomes illuvial and then transformation environment.

Thus, there would be a sequence of horizon evolution:

$$A_{2g} - A_{2gb} - A_{2g\ cn} - B_{tg} - \text{B structured}$$

In time, the B horizons, which invade the A_2 horizons, grow upward in the profiles, and grow laterally toward the upper part of the toposequences. In a parallel direction, there is a sequence of evolution of profiles. The profiles of the accumulative type of the lower part of the toposequence, like the solodized solonetz and the Vertisols tend to invade the eluvial

soils of the upper part. Thus, in these toposequences, the pedologic evolution appears to occur laterally and upwards on the slope. It occurs also on the scale of basic organization, as well as on that of the horizons and of the profiles.

2. The significance of analytic data.

Let us now consider analytic data, that quantify these relationships and substantiate the foregoing conclusions.

2.1. From particle size analysis, three observations can be made:

(a) Granulometric clay is not the only fraction able to migrate. When the loss of intermediate fractions is added to the loss of clay, there is an important relative concentration of the coarse elements in the A_{2g} horizons. In the A_2 horizons the increase of coarse fraction is higher than the decrease of clay.

(b) The particle size profiles show that concentrations of coarse fraction are also found in the illuvial B_t horizons. Histograms show a particle size distribution analogy between A_{2g} and B_t. This confirms the possibility of the formation of a B_t horizon through clay illuviation in a particle size distribution of A_{2g} type.

(c) Finally, the particle size profiles with depth show ancient concentrations of coarse fractions which bear out successive and reascending clayey illuviations.

2.2. From the mineralogical viewpoint, the outstanding fact is the contrast between the environments of the upper and lower parts of these toposequences.

- In the environment of the upper part of the toposequences, weatherable primary minerals predominate. Some weather but some have accumulated relatively.
- On the other hand, in the lower part of the toposequences, the secondary minerals dominate, which form and accumulate there.

Let us discuss two particular items:

(a) The relative accumulation of some primary minerals in the upper part. These are mainly alkaline feldspars, which have been concentrated (relatively more than quartz) in the A_{2g} horizons. This concentration is also found in the illuvial B_t horizons. Thus, in the process of formation of the A_2 horizons, these B_t horizons inherit the mineralogic composition, as well as the particle size distribution of the A_{2g} horizon. The skeleton arrangement and the pedologic features, are typical of the A_2 horizons. Thus, we have there a series of pieces of evidence that the B horizons form <u>in</u> the A_2 horizons and <u>after</u> them.

(b) The distribution of clay minerals in a sequence, like the Kosselili one (on granite).

Three mineralogic associations succeed each other downslope:

Biotite-Kaolinite

Biotite-Kaolinite-Interstratified or mixed layer minerals

Montmorillonite-Kaolinite-Biotite.

This succession is arranged like a four-term mineralogic series: Biotite-Kaolinite-Mixed layers-Montmorillonite. It can be

interpreted as follows:

- Biotite is inherited and is residual or detrital. It disappears downslope.

- Kaolinite is neoformed from biotite and plagioclase. It migrates, accumulates, and remains downslope.

- Mixed layer minerals are a transient and localized stage of the transformation of biotite.

- Montmorillonite, absent in the upper part of the toposequences, suggests by its sudden appearance and its accumulation downslope that transformation and neoformations are its source: Transformation from mixed layers; neoformations from plagioclases and ions in the process of migration. Montmorillonite thus remains downslope, like the previously formed kaolinite and the inherited biotite.

This distribution would suggest two conclusions:

- At any given point of the toposequence or landscape, the formation of the secondary clay minerals and the constitution of a stock would follow each other in time.

- The sequence would also be exhibited in space; the montmorillonite formation initiated downslope would tend to progress on the landscape upslope.

2.3. From the <u>geochemical viewpoint</u>, we should consider three items:

- The contrast of physico-chemical conditions between the upper and lower parts of the toposequences can be seen from pH curves in the two sequences. Indeed, we can distinguish an acid upper zone and an alkaline lower zone, which becomes very alkaline in the surface horizons.

- Variations for many geochemical elements have distinct gradients from the upper to the lower part of the toposequences. Variable intensity of these gradients indicates some differences in behavior and mobility of the various geochemical elements and

even from their different form, which may be more or less mobile. For instance consider silica and alumina; they increase by steps downslope. Iron and manganese accumulate at the upper part of the sloping steps, and concentration of them originate in these places, in the A_2 horizons. The distribution of exchangeable sodium strongly suggests later migration and accumulation stepwise downslope.

- These lateral and differential migrations and accumulations are more forcefully illustrated by comparing the vertical distributions of some elements. Thus, in the A_2 horizons, on a downward sloping step above an impermeable B horizons, iron is low in the upper part, while it accumulates a few meters downwards. By comparing these variations of iron to those of the iron/clay ratio, one finds that iron migrates vertically when it is bound to clay minerals, while it migrates laterally in hydromorphic environments, where it is in an ionic or organo-metallic complex state.

3. The biogeodynamic interpretation.

Thus, we reach the general biogeodynamic interpretation. These sequences can be considered as biogeochemical systems in which the lateral and differential migrations of elements link the different kinds of soils, join the upslope eluvial system to the downslope accumulation environment and differentiate a biogeochemical landscape.

3.1. Interdependence of upslope and downslope environments

But these two upslope and downslope environments are interdependent. In fact, once the accumulations have occurred downslope, they affect, in

their turn, the upslope weathering and migrations by modifying the hydrodynamic and physico-chemical conditions. The accumulations are arranged in the B horizons inversely to the order of migration. Accumulation in the B horizons begins, in fact, downslope and at depth, consisting first of the less mobile constituents: The fine skeleton, followed by kaolinitic clays, hydroxides, montmorillonite, carbonates, and then, sodium.

3.2. The geochemical barriers.

Each type of B horizon then constitutes for the vertical and lateral migrations a specific microbarrier, according to its own composition. These different geochemical barriers are either mechanical (impermeability and concentration) or physicochemical (oxido-reduction, acidity, alkalinity, adsorption). They are spread out over the successive steps at the boundary between the A_2 and B horizons, and they transform this accumulation front in the landscape into a complex geochemical filter.

3.3. The lateral development of soils upslope.

The successive accumulations occur on the edge of this filter, and the whole accumulation front progresses toward the upslope eluvial zone; it advances upward to the soil surface at a given place, and it reascends the slope laterally. So, the material migrates from upslope to downslope. But the accumulation advances from downslope to upslope. Caught in the successive biochemical traps, the different constituents of this material accumulate from downslope and in the reverse order of their migration. Thus, the downslope accumulation zone invades the upslope eluvial zone. Therefore, the general development of these biogeodynamic system is lateral and reascending. Moreover, new evidence brings additional confirmation of this data.

By the radioactive carbon isotopic method, accumulation of carbonates in similar horizons but in downslope and upslope positions of the two sequences were dated. In both sequences, the most recent calcium carbonate nodules were clearly localized upslope, which implies that the calcareous accumulation is advancing upslope.

3.4. The self-development of these natural systems.

Finally, an essential characteristic of these biogeodynamic systems should be pointed out: They are endowed with a system for self-development. The soils, or the biogeochemical systems, which constitute these topo-sequences are in fact interdependent in the natural macrosystem where they evolve. This macrosystem processes its own determinism which is the development of accumulative downslope elements at the expense of eluvial upslope elements.

4. Implications of the biogeodynamic interpretation.

Now, we can discuss some consequences and applications of this biogeodynamic interpretation.

4.1. Distribution of soils--Self-development and external factors.

First of all, we have a new concept of soil distribution problems. This concept is based on the auto-development of landscape sequences; it implies that external factors do not act separately on each type of soil, but rather on the whole biogeodynamic system. A basic principle follows: If external factors remain constant, the distribution of kinds of soil in the landscape would only depend on age, as measured in terms of duration of the system of evolution. Thus, the extension of accumulation

soil types in a landscape, like Vertisols in contrasted tropical climates, would depend only on time.

However, if one refers to the two cases studied, where the sequences appear to have the same age, one notices that their relative composition is different: Solonetzes prevail in Kosselili, Vertisols in Mindera. This difference may be attributed to the variation of external factors during the Holocene. The principal variations known during this period, in the Chadian Basin, are the following:

(a) The fact that the climate has become drier has played a part for the two sequences. It may have favored the invasion of the landscape by the montmorillonite soils.

(b) Tectonic actions were opposite in the two regions. The positive tectonic action of the granitic piedmont would favor the development of solonetz by improving the external drainage. The Vertisols would be more likely to develop at the time of the subsidence of the sedimentary basin. Thus, one reveals the action of external factors on self-development, and, in particular, the possible influence of tectonic action on soil distribution. This seems to be confirmed in the Chadian Basin by the fact that the solodized solonetz are extending to the east of the piedmont (Guera) and, in fact, the tectonic deformations are also extending in amplitude in this direction.

Then one can try to reconstruct the paleogeographic history, that is to retrace the soil distribution's evolution. For instance, nowdays, the broad piedmont slopes are occupied by solonetz which are replaced in the

Chadian Basin by plains with Vertisols and then by iron pans. Due to the presence of relict surfaces, it is thought that this vast piedmont had steeper slopes and was occupied by a sequence of ferruginous soils terminating downslope at iron pans. When climatic drying occurred, Vertisols and solodized solonetz formed upslope of the iron pans. Vertisols and, chiefly, solonetz advanced up the slope, invading the leached soils which now remain only in the short toposequences, located--like the Kosselili's--at the inselberges' foot.

This reascending invasion is, therefore, accompanied by an evolution of the slopes.

4.2. Geomorphologic and hydrologic implications.

This leads us to discuss some geomorphologic and hydrologic implications. There is, in fact, a retreat of the slope break upslope, and downslope a levelling. This is the so-called "pedimentation" of geomorphologists. It can be explained by the lateral redistribution of material on the piedmont slope itself, at the slope break, and by the displacement of the accumulation front upslope. At the slope break, there is a loss of material in the eluvial environment, which tends to subside. And there is a gain of material in the adjacent environment of accumulation, of which the density, if not the volume, increases to form, for instance, a gilgai microrelief. The piedmont slopes over granite with solodized solonetz, like those of Guera, would therefore be, landscapes of biogeochemical accumulation and not eroded land forms or sedimentary accumulative land forms.

In addition, the invasion of these landscapes by some accumulation like that of montmorillonite, results in the development of a superficial impermeable screen which modifies the surface water flow in these regions. Deep water tables can no longer be maintained with seasonal rhythms. These levelled surfaces are alternately saturated, if not flooded and then severely dried. This makes human implantation and the agriculture in these regions difficult.

Concerning the soil distribution, one can, at least, compare the soil distribution in the toposequences and the soil distribution across the bioclimatic zones. Thus, in the Chadian Basin, on young land forms and on the same parent rocks, leached ferruginous soils, hydromorphic soils, planosols, solodized solonetz and then Vertisols are successively predominant in relation to the climatic zonation. But, at the landscape scale, in each of these bioclimatic zones, one observes some toposequences where all these elements are represented, and always in the same order. One of these elements, however, becomes successively predominant, according to the climate. In a humid climate, the leached soils prevail in the toposequence; in an arid climate, Vertisols prevail. Thus, the bioclimatic zonation would correspond to the successive predominance of each of the different elements of the same general toposequence.

The climatic gradient, and particularly the rainfall gradient in tropical regions, would therefore play a part similar to time in soil distribution by regulating the distances and the speeds of migration.

4.3. The geochemical association of landscape.

Finally, the biogeodynamic interpretation illuminates some aspects of the surface geochemistry. Polynov defines the landscape geochemistry as follows: "Geochemical elements are distributed laterally in the landscapes according to their mobility and the geochemical barriers which they meet successively in their migration." In addition, one can state that upslope hydrolysis fosters downslope neoformations which correspond to absolute accumulations. But the upslope hydrolysis also gives rise *in situ* to neoformations which are relative accumulations. A biogeodynamic landscape must then be defined by the geochemical association of its relative upslope accumulations and absolute downslope accumulations. Thus, in the two cases studied, the landscapes are defined by the association of kaolinite (in relative upslope accumulation) and montmorillonite (in absolute downslope accumulation).

4.4. The climatic sequence of the tropical geochemical associations.

But these associations vary according to the climate, and in an intertropical zone, a climatic sequence of the geochemical landscape associations may be outlined:

- In an equatorial zone, the allitization accumulates gibbsite upslope, while the products of this strong allitization and those of a superficial degradation give way to downslope neoformations of kaolinite (monosiallitisation). This absolute accumulation of kaolinite limits the drainage and tends to invade the upslope zone. It fixes hydroxides by superimposing itself on allitization, acquiring, thus, all

the major characteristics of ferrallitic soils.

- In a humid tropical zone, the monosiallitization keeps the relative accumulation of kaolinite upslope. At the foot of the slope, kaolinitic illuviation takes place and creates conditions favoring the migration and the absolute accumulation of hydroxides: It is the phenomenon of iron pan formation which is the epigenesis of eluvial structures and progresses by reascending the upper part of the slope.
- In a dry tropical zone, which was studied here, the association is that of the upslope kaolinite and of the downslope montmorillonite which tends to invade the landscape.
- In a more arid climate, the bisiallitization may be generalized in the landscape and absolute accumulations of calcium carbonate take place, first downslope and at depth. The facies of the calcium carbonate encrustations may appear remarkably convergent with those of iron encrustations because both result from the epigenesis of eluvial structures. Then, one can observe the succession of massive, lamellar and nodular features, as in the iron crusts.
- In a still more arid climate, one would observe the formation of attapulgite within calcareous hardpans. Then, in the desert area the last paragenesis appears with the salt concentrations and the neoformation of alkaline silicates.

Thus, as a conclusion, the continental environment is not only that of weathering and migration. It also has in its landscapes its own biogeochemical accumulation which depend on time and climate (for the same parent

rock). These continental accumulations are distributed in a way which is convergent to sedimentary accumulations, from which they would only distinguish themselves by their specific internal structures.