UDC 553.492.1:553.06:502.76

RELATION BETWEEN LATERITIC BAUXITIZATION AND EVOLUTION OF LANDSCAPE

B. Boulangé

ORSTOM, Pétrologie de la surface, Bondy, France

In previous papers we have shown the mechanisms of aluminous concentration during the formation of isalteritic bauxite from granite, and the mechanisms of structural, mineralogical, and geochemical transformation of this gibbsitic and hematitic bauxite into boehmitic and hematitic pisolitic bauxite.

In this paper, considering an example from Lakota area (Ivory Coast), we put in evidence the influence of the external geomorphological factors in the origin of these transformation.

In the landscape, facies are arranged into a lateral sequence and one can find the following succession in a massif from upstream to downstream: isalteritic or alloteritic bauxites, pisolitic bauxite and clay ferruginous hardpan. The evolution of this sequence of facies corresponds to the permanent settling of a sequence of geochemical environments on a relief.

The development and permanence will depend on the dynamics of the water table and therefore on the local base water level. Given an original bauxitic formation, three cases of evolution can be considered.

1. The continuous geochemical evolution in the absence of incision leads to a double geochemical planation of reliefs: a first geochemical planation with pisolitic bauxite, and a second planation with a new clay-ferruginous hardpan.

2. The geochemical evolution in the presence of a gradual and moderate incision: profiles become thicker and alloteritic bauxites are formed. The area pisolitization which follows the gradual incision of the surface relief is moving downstream; the pisolitic bauxite and the clay-ferruginous hardpan can give rise to slope hardpans.

3. The geochemical evolution in the presence of a sharp and deep incision: at each moment, the continuous or gradual evolution can be upset by a sudden and deep depression of the base level. Profiles become thicker and isalteritic bauxites are formed.

* * *

ODNOS IZMEĐU LATERITSKE BOKSITIZACIJE I KRAJOLIKA

U ranijim radovima prikazali smo mehanizam aluminijske koncentracije za vrijeme nastanka izalteritičnih boksita od granita i mehanizam strukturne, mineraloške i geokemijske transformacije tog gipsitičnog i hematitskog boksita u bemitski i hematitski pizolitski boksit.

U ovom radu prikazujemo, na primjeru iz područja Lakota (Obala Slonokosti), utjecaj vanjskih geomorfoloških faktora na prapočetak tih transformacija.

U krajoliku, facije su poredane u lateralni redoslijed, pa se u nekom masivu može naći slijedeći niz odozgo nizvodno: izalteritični ili aloteritični boksiti, pizolitski boksit te glinasto-željezovit hardpan (tvrd, »cementiran« sloj tla — op. prev.). Evolucija facijalnog niza odgovara trajnom ustaljenju niza geokemijskih ambijenata na nekom reljefu.

Razvoj i trajnost zavisit će od dinamike podzemne vode, tj. od lokalne razine podzemne vode. U slučaju izvorne boksitne formacije mogu se razlikovati tri slučaja evolucijskog razvoja.

1. Kontinuirana geokemijska evolucija u odsustvu usjeka dovodi do dvostruke geokemijske planacije reljefa: prve geokemijske planacije s pizolitskim boksitom i druge planacije s novim glinasto-željezovitim hardpanom.

2. Geokemijska evolucija uz postojanje postepenog i umjerenog usjeka: profili postaju deblji i nastaju aloteritični boksiti. Područje pizolitizacije koje slijedi postepenom usijecanju površinskog reljefa kreće se nizvodno; pizolitski boksit i glinasto-željezoviti hardpan mogu prouzrokovati hardpane na kosini.

3. Geokemijska evolucija uz postojanje oštrog i dubokog usjeka: u svakom trenutku, kontinuirana ili postepena evolucija može se poremetiti naglim i dubokim potiskivanjem osnovne ravnine. Profili postaju deblji i nastaju izalteritični boksiti.

(R. M.)

In previous papers, we have shown the mechanisms of aluminous concentration during the formation of isalteritic bauxite by granite weathering [2] and the mechanisms of structural, mineralogical and geochemical transformations of this gibbsitic and hematitic bauxite into boehmitic and hematitic pisolitic bauxite [3]. In this paper, considering the same example from Lakota area (Ivory Coast), we shall put in evidence the relations between the genesis of these bauxite deposits and the evolution of relief.

This area, situated at 250 km to Abidjan north-west, is entirely on granitic basement. Its form, not strongly marked, is a serie of hills, with altitudes including between 384 m on the Mont Tato to 215 m near of Lakota, which dominate long ridges, low sloped to the cuts of the present drainage pattern (Fig. 1).

Four morphological unit so can be characterized, according to their relative altitude and superficial deposits (Fig. 2).

a) *Bauxitic hills:* except Mont Tato, with isalteritic bauxitic deposit, all the other outliers with alumino-ferruginous crust are hills of which the altitudes decrease regularly to drainage axis and which are overlain with pisolitic bauxite.

b) *Middle hills,* according to the definition established in West Africa [7, 8, 11], are strewn with argilo-ferruginous crust fragments and form either residual plateaus, all lower than the nearest pisolitic bauxitic hills, or benches which occur on the sides of these hills with a dislevelment of about twenty meters.

c) *Long ridges* with convex-concave sides diverge down from these hills. Their superficial deposits are formed from top to the bottom by a unhardened clay horizon, a globular horizon (ferruginous nodules) and an

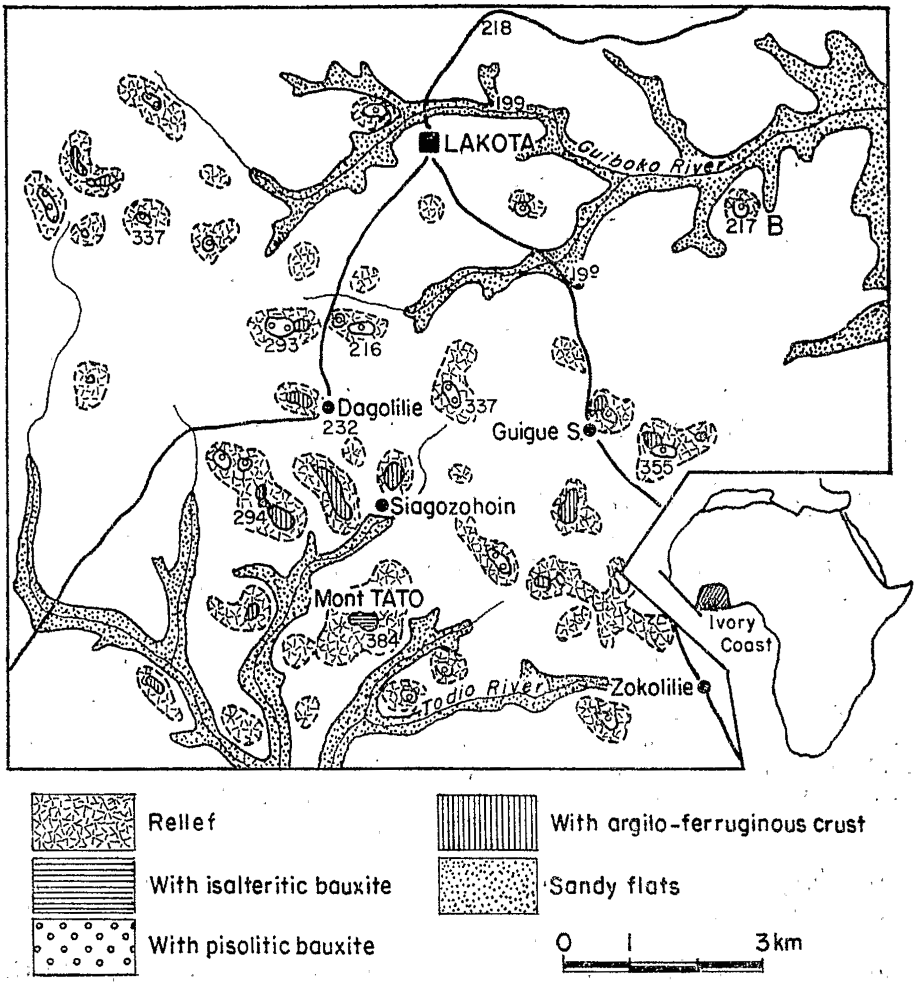

Fig 1. Bauxitic and middle hills in the Lakota area

alloteritic spotted clay horizon. No pisolitic bauxitic and argilo-ferruginous crust fragments are reworked in the globular horizon.

d) The low-sloped (0,4 %) *drainage pattern* (190 m) is taking place between this long ridges. The transition to the sandy flats (white sands) is a narrow area between two inflections of the slope with ocher sands and ferruginous nodules [7].

The bauxitic hills have a flat top; the borders have no scarps and are emphasized by mere alterations of a slope, which are strewn with bauxitic fragments. The steep sides (40 % on Mont Tato) are convex from the summit to the benches that are associated to »midle hills«, and they become clearly concave in the upper part of the long ridges.

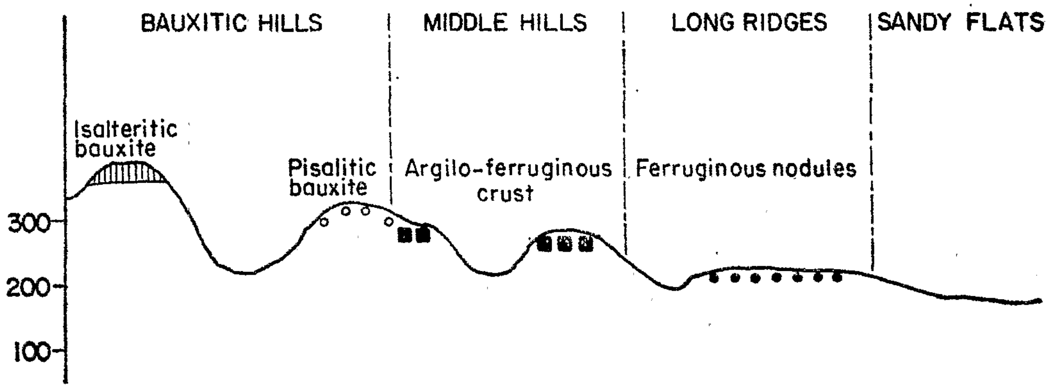

Fig. 2. Diagrammatic section in the Lakota area

1. *THE GENESIS OF THE ISALTERITIC BAUXITE*

From the summit of a hill in its initial stage to the nearest thalweg, three zones can be pointed out: an initial *upstream zone* [5], and an *accumulation downstream zone* [1, 6] which lie on a *weathering zone* [9], Fig. 3a.

On the summits and on the sides, gibbsitic isalterite is forming at the *weathering front.* In the initial upstream zone, at the top of the water-table, this isalterite, enriched by absolute accumulations of aluminous and ferruginous oxihydroxides, indurates and changes into an isalteritic gibbsitic bauxite (or aluminous isalteritic crust). The profile is becoming thick by the *going down* of the *two weathering and induration fronts* at the same time.

2. *THE TRANSFORMATION OF THE ISALTERITIC BAUXITE INTO BOEHMITIC BAUXITE*

A part of the iron, which is kept on the move in the water-table, is carried along and sets on the side because the oxydation increases when the water table oscillates near of the surface. This oscillation, which dries up periodically the crust, causes the transformation of gibbsite into boehmite. Thus, on an interfluve where is forming an isalteritic bauxite, between the initial zone and the accumulation zone, a *transformation zone* sets, in which the initial gibbsitic hematitic crust changes into a boehmitic hematitic crust, enriched in iron (Fig. 3a).

3. *THE GENESIS OF THE PISOLITIC BAUXITE*

While the weathering front moves down, at the lower part of the sides the clayed accumulations progress from downstream to upstream and connect the crust which is thus set in conditions of instability. The hematitic boehmitic side crust is so in the near upstream of a less draining envi-

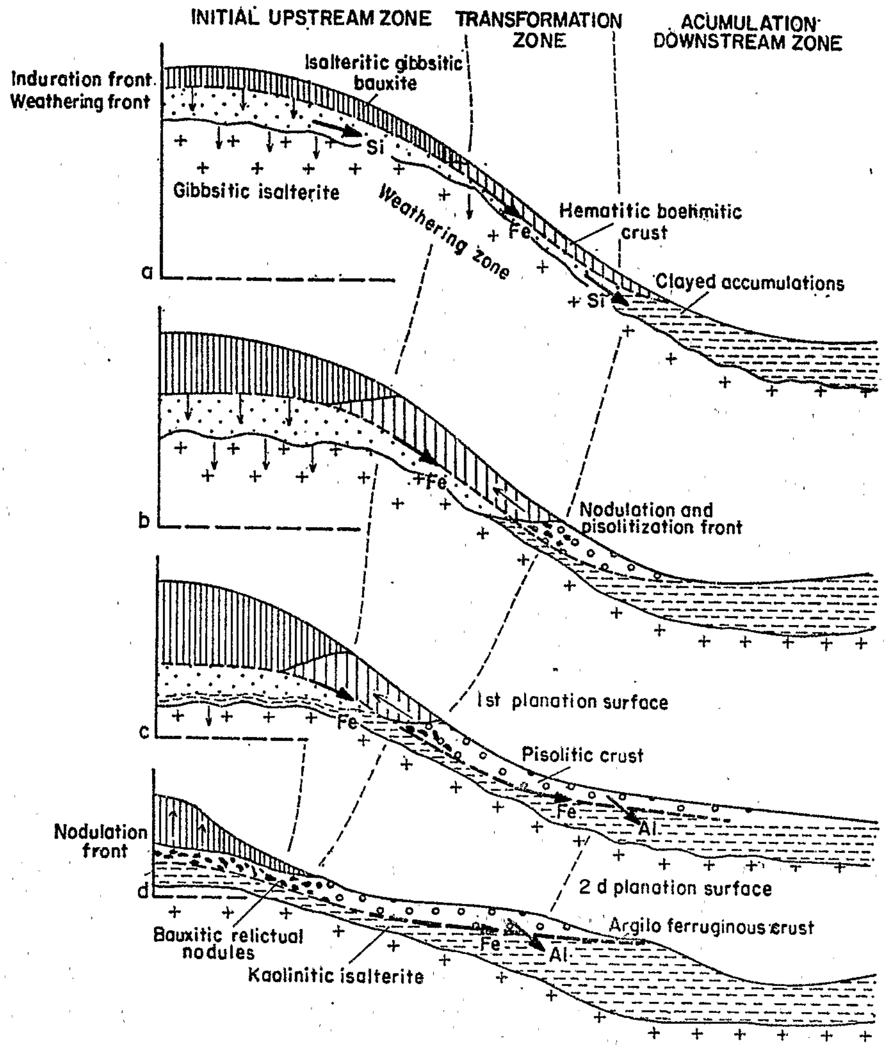

Fig. 3. Diagram of crust forming and relief evolutions of a side in the Lakota area

ronment. In this zone the alternation of oxidation and reduction conditions is to determine *globular evolutions* which are at the origin of *relictual nodules* at first, and then pisolites (Fig. 3b).

The diminution in porosity (estimated of about 20 to 30 %) which goes with the pisolitization involves an important reduction in the volume of the crust. The pisolitization is beginning at the foot of the sides, and so leads to a weaker slope than the slope of the initial side; this slope decrease stretches to upstream, following the general recess of the sides. The pisolitization front so advances to upstream freeing *an aplanation surface* with pisolitic crust deposit (Fig. 3c). The unit of relief is then formed by a plateau with an isalteritic bauxite in its center and pisolitic bauxite in borders (Fig. 3d).

It is not out of the question that the pisolitization zone should extend to the whole plateau below the initial bauxite. But the latter, which has not undergone the first transformation (ferruginization and gibbsite-boehmite change), will advance to nothing but *relictual nodules.*

Frequently in this area we observe the proximity of two small pisolitic outliers, separated of about 100 or 200 m by a col without crust. The outliers can represent the aplanation of an initial interfluve sides, without the pisolitization having extended to the center. An increase in mechanical erosion, after the bauxitization, has eroded the less indurated central part of the interfluve.

Thus, the initial interfluves appear with a little extension of about one kilometer. Therefore, all the interfluves would form an initial undulated and multiconvexe surface. The decreasing altitude of pisolitic outliers, from Mont Tato (Fig. 1), indicates that this initial surface was meant to have a low slope towards North.

4. *THE GENESIS OF THE ARGILO-FERRUGINOUS CRUST*

Bellow the pisolitic horizon of the low hills, an *argilo ferruginous crust* occurs discontinuously [2]. The latter indicates the phreatic level position which is determinated by local hydrographic base level. Besides, when the pisolites are entirely deferruginised, the boehmite is then destabilized, and the alumina thus released is brought into movement again, and crystallizes in micro-environments into gibbsite. In the zones which are most downstream of the pisolitic aplanation surface, this alumina is likely to go directly in the watertable, and combines again with the silica to give kaolinite and so join with the argilo-ferruginous crust (Fig. 3d).

In this Lakota area, not only the argilo ferruginous crust horizon occurs vertically underneath pisolitic crust, but every bauxitic outlier is flanked with benches (sometimes with hills) which are of lower altitude (about 20 m), on which subsist argilo-ferruginous crust residues. Sometimes, pisolitic crust residues occur in this »middle hills«. The *argilo-ferruginous crust* so looks to be *the last remnant of the pisolitic bauxite deposit.*

5. *THE BAUXITIZATION AND THE APLANATION SURFACES*

We can thus define a sequence of three crust facies, which are distributed in decreasing altitudes: isalteritic bauxite on the higher hill, pisolitic bauxite on the near hills, and argilo-ferruginous crust on the »middle hills« between the bauxitic hills and the more recent »long ridges«. Generally, this sequence looks discontinuous. We cannot consider to extend continously bauxitic crust on more than a hundred km². Each relief, formed by one or two plateaux with pisolitic crust deposit, is outlier of an early interfluve, and the whole of them would form the initial surface.

These three terraced facies do not need, in spite of their discontinuities, the existence of series of mechanic planations and crust episodes. They proceed rather from differenciation of geochemical environments according to an initial relief. Indeed, in relation with the distinction of geochemical zones which is propounded by **Boulet** [6] are successively realized:

— the genesis of isalteritic bauxite in the allitization initial zone,

— the ferruginization and the gibbsite-boehmite change in the transformation zone of sides,

— the pizolitization in the upstream of the accumulation zone,

— and the degradation of pisolites and the genesis of argilo-ferruginous crust in the bottom and the downstream of the pisolitic crust.

The gradual and continued evolution of this system leads to give a complete planation of relief, which is associated with an argilo-ferruginous crust.

During the isalteritic bauxite genesis, while the weathering and induration fronts move down, the aluminous crust undergoes degradations on its top (gibbsite and hematite dissolving). The aluminium and the iron are leached towards the lower part of the profiles, and set in the cutanic deposits of the upper isalterite. The bauxitic crust is made from this isalterite feeded with the absolute accumulations which are due to the aluminium and iron vertical transfers. It so occurs what has already been defined as »the crust geochemical going down« [10] which involves in the landscape a subsidence of the interfluve summits. We can calculate at M. Tato that this subsidence is about 30 m, taking into consideration the evaluation established for this crust which shows that the weathering of 45 m of granite is necessary to form this 18.50 m profile.

At the same time, the iron lixiviation and the porosity decrease, which occur during the pisolitic genesis, involve an important reduction of isalteritic bauxite volume. The progression of the pisolitization front, from the lower part of the side to the interfluve axis, clears a *first planation surface.* As there are not outliers of the initial interfluves which would set in continuity whith the pisolitic bauxite hills, it is difficult to estimate the dislevelment of the planation with regard to the interfluve. The Ti high contents, three times more concentrated in the pisolitic bauxites than in the isalteritic bauxites, indicate the efficiency of these mechanisms which, by reducing the crust volume, would lower again the relief in a ratio of about three for one.

More downstream, the complete degradation of the pisolites frees a *second planation surface,* overlain and protected by the argilo-ferruginous crust, which constitutes the »middle hills«. The sides which join these two planation surfaces are always convex, what corroborates the continuity of the geochemical degradations and their prevalence on the mechanical erosion during their forming.

Thus in absence of any resuming of mechanical erosion, there would be a complete planation of the bauxitic initial interfluve and a forming of an argilo-ferruginous crust.

6. *THE CUTTING OF THESE PLANATION SURFACES*

At the north and near the 217 hill, the Guiboke rivers run now at an altitude of 170 m. We can therefore estimate that the subsidence of the base level should be of about 30 m in this place, followingly at the thrusting of the drainage pattern which comes later than the forming of the argilo-ferruginous crust. A first cutting divides the early surface and separates pisolitic crust and argilo-ferruginous crust outliers.

When the weathering resumes, these outliers become again an initial allitization zone. So, a new isalteritic bauxite may be formed under the remnants of the pisolitic crust.

Simultaneously to this cutting, a »pediplain« forms bounded by the contour line 200. Afterwards, the »pediplain« is divided in »ridges« by two little later cuttings which appear on the borders of the principal rivers.

The geochemical planation surfaces, protected by their owns crusts, are thus put in relief by these three successive cuttings. This change:

— stops the globular evolutions and the pizolitization in the isalteritic bauxite,

— controls a revival of the weathering under the crusts with forming of gibbsitic or kaolinitic isalterite, according to the drainage conditions,

— ensure a revival of the geochemical going down of crusts.

REFERENCES

1. *Bocquier, G.:* — 1971 — Genèse et évolution de deux toposéquences de sols tropicaux du Tchad. Th. Doct. Sci., Strasbourg, Mém. ORSTOM 1973, 62, 350 p.
2. *Boulangé, B.:* — 1983 — Aluminium concentration in a bauxite derived of granite (Ivory Coast): relative and absolute accumulations 5th Int. Congr. ICSOBA, Zagreb 1983. Travaux ICSOBA, 13, 18: 109÷116.
3. *Boulangé, B., Bocquier, G.:* — 1983 — Le rôle du fer dans la formation des pisolites alumineux. Coll. Int. CNRS. Petrologie des altérations et des sols, Paris, Sci. Geol. Mém. 72, 2: 29÷36.
4. *Boulangé, B.:* — 1984 — Les formations bauxitiques latéritiques de Côte d'Ivoire. Th. Doct. Sci, Paris, Trav. et Doc. ORSTOM, 175, 341 p.
5. *Boulet, R.:* — 1974 — Toposéquence de sols tropicaux en Haute Volta. Th. Doct. Sci., Strasbourg, Mém. ORSTOM 1978, 85, 272 p.
6. *Boulet, R., Bocquier, G., Millot, G.:* — 1977 — Géochimie de la surface et forme du relief. Déséquilibre pédobioclimatique dans les couvertures pédologiques de l'Afrique Tropicale de l'Ouest et son rôle dans l'aplanissement des reliefs. Sci. Geol., Strasbourg, 30, 4: 235÷243.
7. *Grandin, G., Delvigne, J.:* — 1969 — Les cuirasses de la région birrimienne volcano-sédimentaire de Toumodi, jalons de l' histoire morphologique de Côte d'Ivoire. C. R. Acad. Sci., Paris, 269, D, 16: 1474÷1477.
8. *Michel, P.:* — 1970 — Les bassins des Fleuves Sénégal et Gambie. Etude Géomorphologique Th. Doct. Sci., Strasbourg. Mém. ORSTOM, 1973. 3 vol., 752 p.
9. *Nahon, D.:* — 1976 — Cuirasses ferrugineuses et encroûtements calcaires du Sénégal Occidental et en Mauritanie. Th. Doct. Sci. Strasbourg, Mém. Sci. Geol., 44, 232 p.
10. *Nahon, D., Millot, G.:* — 1977 — Géochimie de la surface et formes du relief. V. Enfoncement géochimique des cuirasses ferrugineuses par épigénie du manteau d'altération des roches mères gréseuses. Influence sur le paysage. Sci. Geol., Strasbourg, 30, 4: 275÷282.
11. *Vogt, J.:* — 1957 — Rapport provisoire de mission sur le plateau Mandingue (Soudan). Arch. Bur. Rech. Geol. Min., Dakar, 24 p.