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Some factors affecting regional differentiation of  
the soils in the Republic of Benin ( West Africa )

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Papers within any one of the above topics are welcome provided they are of sufficiently wide interest and relevance.

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## Some factors affecting regional differentiation of the soils in the Republic of Benin ( West Africa)

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### Abstract

Spatial distribution of the parent materials, color, clay-eluviated horizon thickness, textural profile type, presence and position of the ferruginous nodules and ferricretes in the profile are analyzed at a small scale using the thematic information content of the published 1:200,000 soil map of Benin. Analyses indicate that there is a regional differentiation of the soil cover which is first drawn on that of the geological provinces, sedimentary basins, great morpho-structural units, and then determined by the factors that control the preservation or the transformation and erosion of an ancient lateritic mantle. These factors are directly influenced by differential changes of the local base levels. © 1998 Elsevier Science B.V. All rights reserved.

*Keywords:* Soil geography; Map analysis; Regionalization; Benin; West Africa

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### 1. Introduction

In West Africa, the 'sudano-guinean' zone between the Sahel and the tropical rain forest is characterized by annual precipitation ranging from 900 to 1400 mm with alternating wet and very dry season (Fig. 1). In this zone 'leached' Ferruginous Tropical Soils (Aubert and Duchaufour, 1956; Maignien, 1964; CPCS, 1967) are the main soil group (Boulet et al., 1971; Ségalen, 1995), while Ferrallitic Soils occur on the wetter southern areas. According to FAO-UNESCO (1977), these soils are Ferric Luvisols and Ferric Lixisols, Ferralsols, Nitosols and Ferric Acrisols, respectively. Ferricretes are

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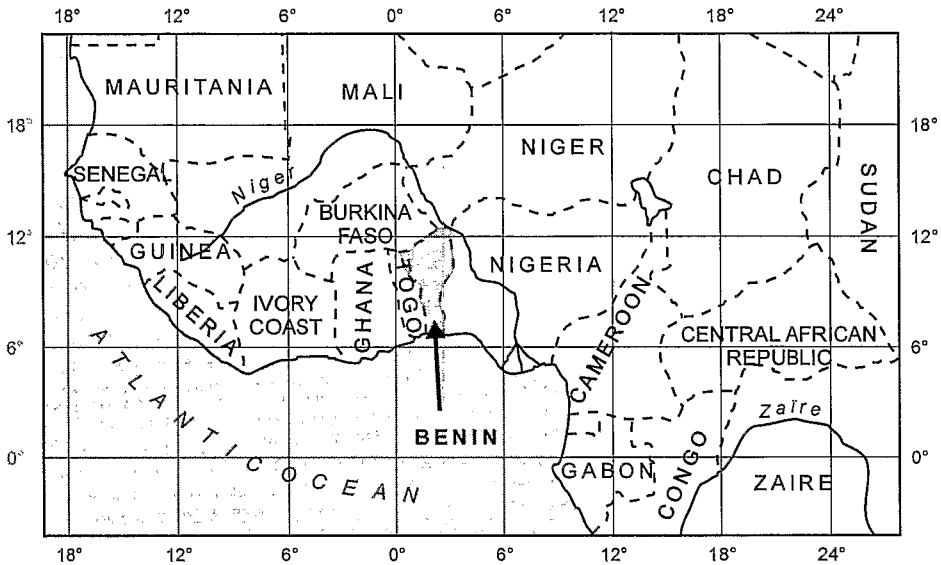


Fig. 1. Location map.

widespread through the zone (Maignien, 1958; Grandin, 1976; Gavaud, 1977; Michel, 1978; Rognon, 1978; Leprun, 1979; Grandin and Thiry, 1983).

All the defined Ferruginous Tropical soil sub-groups (CPCS, 1967) are everywhere present and closely associated, implying that criteria used for soil sub-group definition, weathering intensity, textural differentiation, iron segregation or occurrence of nodules and/or ferricretes, do not allow to discriminate spatial soil entities at the regional scale. However, in the Popular Republic of Benin (previously Dahomey), a small scale synthesis of pedologic maps at the 1/200,000 scale has revealed a marked regional zonation of the soil units (Faure and Volkoff, 1996).

Therefore, a detailed spatial analysis was carried out on the whole set of the 1/200,000 available maps of the country to determine the basic nature of this regional soil differentiation. It was expected that the analysis of soil distribution might allow (i) to detect the connections between the attributes used to differentiate the soil mapping units, (ii) to have information about the spatial changes of these attributes on definite parent rocks and (iii) finally to relate the spatial differentiation to the geology, the geomorphology, the climate or any other factor.

## 2. Environmental setting, background and method

### 2.1. Bioclimatic zones

Benin is divided into four bioclimatic zones: (i) a littoral humid tropical zone (1200 to 1400 mm of annual rainfall) (Fig. 2); (ii) a littoral and inland subhumid zone (900 to

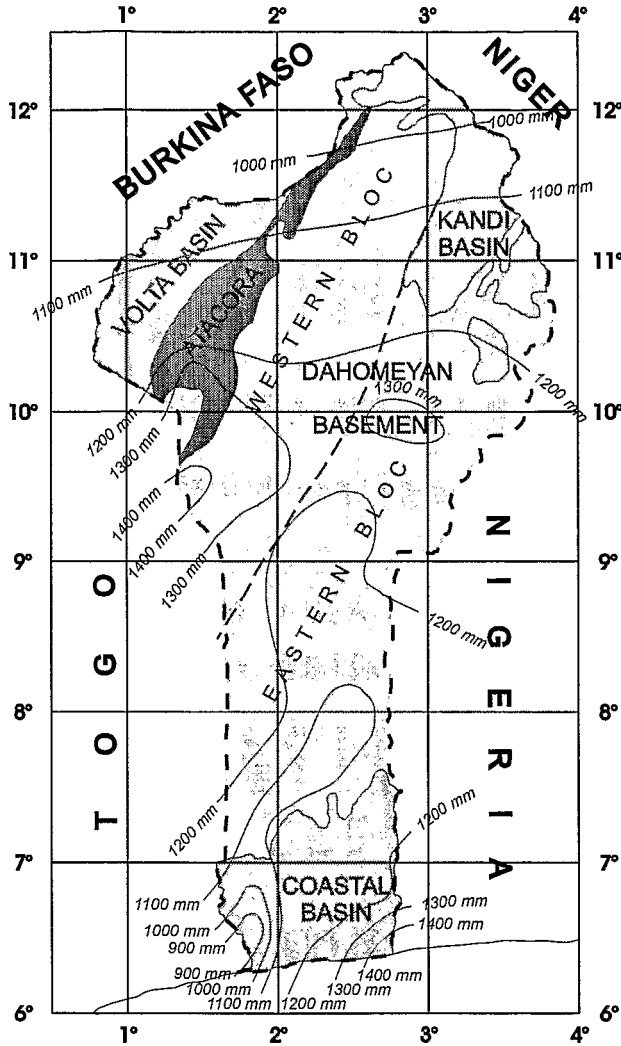


Fig. 2. Schematic map of major geological units of Benin and precipitation.

1200 mm of annual rainfall) with wooded savannas in the low basin of the Ouémé river and the low basin of the Mono river near the Togo border; (iii) a wetter inland zone (1200 to 1400 mm of annual rainfall) with woodlands and savannas corresponding to the central dorsal of Nikki-Djougou; and (iv) a continental dry northern zone (1200 to 900 mm of annual rainfall) with dry bushes and savannas.

In the south, the rainfall regime is bimodal with two wet and two dry seasons, a short dry season during August and a longer dry season from November to March. In the North, there is only one pronounced dry season ranging from October to March. During the dry season, dust is carried by a northeast wind, known locally as the Harmattan.

## 2.2. Geology

The geology of Benin consists of two main rock types: (1) sedimentary rocks distributed in three basins: the coastal basin, the Kandi Basin (in the north-east), and part of the Volta Basin, and (2) metamorphic and crystalline rocks forming the Dahomeyan basement (Fig. 2).

The coastal sedimentary basin is formed by Cretaceous-Tertiary series made up of clays, sands, gravel, ferruginous sandstone overlain by clayey sands and fluvial deposits (Continental Terminal) in which the 'Terre de Barre' is differentiated (Slansky, 1962; Houessou and Lang, 1978).

The Kandi Basin comprises a Cambrian base-conglomerate, Paleozoic sandstones and clays, Cretaceous sandstones and a Continental Terminal cover with ferruginous sandstones (Alidou et al., 1991).

The Precambrian Volta Basin is composed of siltstones and sandstones with interlayered limestones, tillites, limestones and silexites, phosphates of the Buem unit and quartzite sandstones that are gradually metamorphosed toward the east; the metamorphic equivalents of these sandstones constitute the Atacora unit that forms the highest relief line of the area (Affaton, 1973; Caen Vachette et al., 1979; Trompette, 1979).

The Dahomeyan crystalline basement is divided into two differentiated units: a granite gneissic unit in the east and a granulitic and aluminous gneissic unit westward. The latter unit contains several Late- or Post-Panafrican granitic intrusions (Aicard, 1957; Pougnet, 1957).

The eastern granite gneissic unit is composed of rocks corresponding to a medium metamorphic gradient: amphibole-gneiss, biotite-gneiss and some basic rocks as amphibolites embedded in folded granite gneiss-syntectonic granites that form the main lithologic component. The western granulitic unit comprises rocks corresponding to a high metamorphic gradient: aluminous gneiss with hypersthene, biotite-gneiss, and gneiss with pyroxenes. It includes igneous series such as the Kabrais group, Banikoara group, etc.

The map of soil parent rocks (Plate 1a) extracted from the pedological exploration map at 1/200,000 (Volkoff, 1976; Volkoff and Willaime, 1976; Dubroeuq, 1977a,b; Faure, 1977a,b; Viennot, 1978a,b) summarizes the formerly published geological maps (Aicard, 1957; Pougnet, 1957; Slansky, 1962). Ferricretes from the residual hills identified on the original pedologic map were added as a unit on the map of the parent rocks.

## 2.3. Hydrography and landscape

Besides the Atacora, which is the main relief of Benin, and the quartzitic long crest in the east, in the Kandi-Bimbéréké alignment (Fig. 3), three major geomorphologic units can be recognized on the sedimentary plateaus and seven on the crystalline basement.

On sedimentary materials, the hydrographic network is widely spaced, but well-marked. Plateau-leveled surfaces are important compared to those occupied by slopes and lowlands. An inverted relief is developed on sandstone layers resistant to weathering and erosion. As a result, the *coastal sedimentary basin and Kandi Basin* exhibit tabular

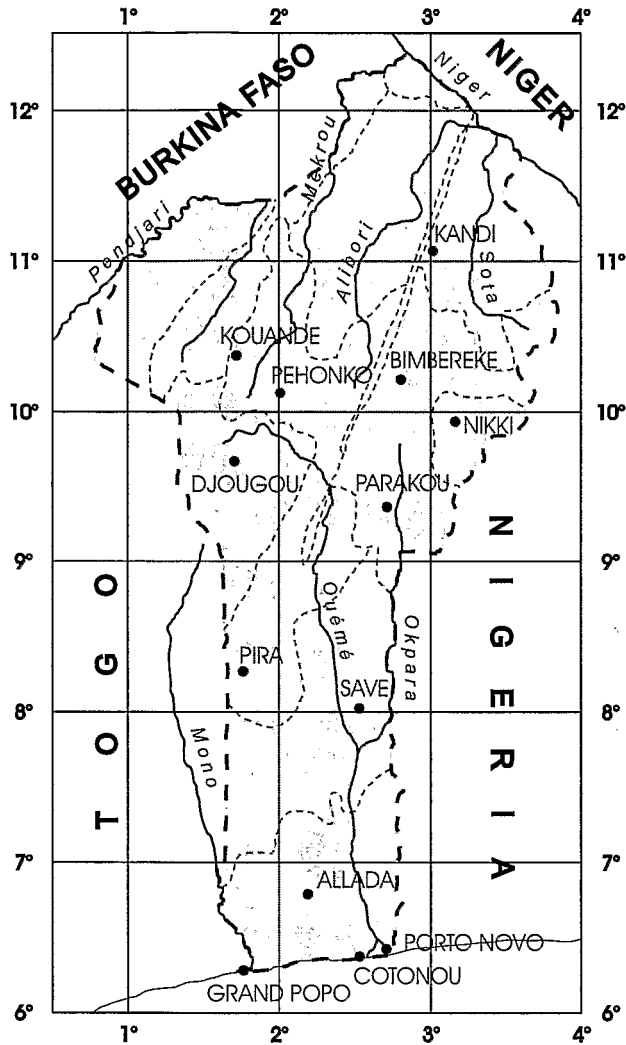


Fig. 3. Main rivers of Benin and boundaries of the main geomorphic units.

landscapes with low plateaus. Erosion and flood plains as that of the Pendjari river, are other characteristic features of the *sedimentary Volta Basin*.

Two major drainage orientations are observed on the crystalline basement (Fig. 3): that of the Ouémé river in the south and that of rivers flowing to the Niger River in the north (Mékrou, Alibori, Sota). The water divide between these two basins roughly follows the 10th parallel (Nikki–Djourou dorsal line). This zone of the Atlantic–Niger interfluvium constitutes a high peneplain adjoining the chain of the Atakora and whose highest points approach 450 m in elevation. As can be recognized in topographic maps, it comprises several morphological units.

Westward, the raised and slightly undulating central *penneplain of Kouandé–Péhonco* forms a large dorsal of the interfluvium on granitic and gneissic substrata. In the north, the *plain of the Alibori* connects gradually with the slightly undulated penneplain of Péhonco on the right bank of the Niger River. The substratum rocks of this region are granitic in its southern part, and basic in the north. The general topography is almost level, with a slightly lowered drainage system, but it is dominated by a set of small plateaus and hills of several tens of meters in elevation that are remnants of the Cretaceous northern plateau. In the south, the *plateau of Djougou* is contiguous with the high penneplain of the regional divide. The substratum rocks are dominantly gneissic and variable in basicity. The lowering of the base levels is more important than in the North. The strongly dissected *penneplain of Pira* is the southern prolongation of the plateau of Djougou in the lower Basin of the Ouémé River. In this area, due to the lithologic orientation of the Dahomeyan the substratum rocks are still granitic and migmatitic. The topography is characterized by convex steep slopes and a general lowering of the thalwegs.

In the east, the gentle hilly *Parakou plateau* is protected by the Cretaceous Kandi Plateau northwards and by the quartzitic crest of Kandi eastwards. It occurs on a dominantly granitic substratum and has undergone slight rejuvenation. The inselberg *penneplain of Nikki* is more rejuvenated by the proximity of the Nigerian drainage basins, and extends on the same granitic basement. In the south, the low erosion-*plain of the lower Ouémé* forms the base surface of the Precambrian basement of southern Benin. The substratum here is a succession of granite and migmatites variable in basicity.

#### 2.4. Soils

Ferrallitic soils ('Sols ferrallitiques moyennement désaturés' and 'Sols ferrallitiques faiblement désaturés' according to CPCS, 1967) are present on the coastal sedimentary basin as 'Terre de Barre' and inland on some parts of the Dahomeyan crystalline basement. They are highly weathered, sesquioxide rich, mainly kaolinitic and characterized by small textural changes within the soil profile. Many soils are shallow and are underlain by ferricretes. Ferricretes outcrops are found on the Djougou plateau and on residual hills, particularly in the north of the 10th parallel. They belong to a differentiated and crusted topography, that can be seen from Senegal to Niger (Beaudet et al., 1981) and are everywhere degraded and reduced to a state of unevenly perched remnants (Boulangé et al., 1973; Michel, 1978; Boulangé, 1984). It is assumed that most of the ferricretes are relict material formed during a long period from the Miocene to at least the Early Quaternary.

The present soils were formed after the original land surface with ferricretes was eroded away. There, the main soil type is the '*ferrugineux tropical lessivé*' soil (CPCS, 1967) where clay translocation and iron segregation lead to great horizon differentiation. At the regional scale, certain soil characteristics are ubiquitous while others exhibit regional trends.

Everywhere soils are characterized by a clear textural change with coarse textured surface horizon, a neutral soil reaction and a clay fraction composed of kaolinite with

variable proportions of illite and smectite. Residual iron nodules are found in the top soil or concentrated within a 'stone-line' where quartz gravel is also widespread. Secondary pedogenic ironstone occurs widely in various forms, at various depths and with various thickness within a mottled clay layer.

On the crystalline basement, mainly in the central plateau, the peneplain of Kouandé and the plateau of Djougou, most of soils are polycyclic and formed on a thick kaolinitic mantle similar to that underlying the ferricretes. They consist of upper clay-poor horizons overlying a hard or a soft ferricrete developed in the subjacent kaolinitic mantle. The upper clay-poor horizons, either partially or totally gravelly, contain quartz gravel and iron nodules. Most of them is residual and the result from 'in situ' accumulation. Soil pH varies from neutral to slightly acid. Similar soils over kaolinitic material are also found in the eastern undulating hilly landscapes but they are restricted to summits and upper slopes.

Where erosion has removed the previous kaolinitic mantle down to the rock, soils are formed in relatively shallow, non-exclusively kaolinitic but mixed 2:1 clay saprolite. Clayey smectitic weathering layers develop into the lower parts of the topography while kaolinite-rich saprolite is confined to the summits (Bocquier, 1973; Boulet, 1978; Lévêque, 1979a; Kaloga, 1983; Pion, 1979). The textural differentiation resulting from vertical clay eluviation and from pediplanation processes is amplified by lateral movement of the water, when the impermeability of the smectitic weathering layers increases the lateral hydrodynamic water flow through the overlying soil material. The normal consequence on higher gradient sites is the removal of fine particles from both the upper and middle horizons (Lévêque, 1979a), that implies a wider spread of thick and very coarse textured soil profiles. These soils overly the weathered smectite-rich material and are linked downslope with planosols. A large variability of textural contrasts characterizes the soil. The pH is neutral on the top soil and slightly basic in the subsoil. A large number of these soils display a marked iron segregation and concretionary development. Part of their ferruginous nodules likely has the same origin as that developing over the kaolinitic material by 'in situ' degradation of previously formed ferruginous layers within the soil (Nahon, 1976; McFarlane, 1991).

The genesis of all these soils, including ferrallitic soils, may have been marked by deposition of dust carried by the Harmattan from the Sahara. At a continental scale, particle-size distribution, mineralogy, chemistry and isotopic signatures indicate that the upper soil of most of West African soils have to be considered as a mixture of long-distance eolian deposits from the Sahara with variable contribution from local sources (Bennet, 1980; McTainsh, 1984; Tiessen et al., 1991; Drees et al., 1993; Mizota et al., 1996). However, how much dust has been deposited in soils was not clearly established. Measures in Benin have verified that present Harmattan dust fallout decreases from north to south and that it is not insignificant in the coastal zone (Herrmann, 1996). Therefore, in Republic of Benin, the dusty accretion may explain some general properties of the soils such as their relative neutrality (Simonson, 1995) but it is not known how it may interact with the pattern of the spatial soil differentiation, and there is no evidence on how much eolian deposits may have contributed to the kaolinitic weathered mantle formation (Vine, 1987) and to the ferricretes genesis (Pye, 1988).

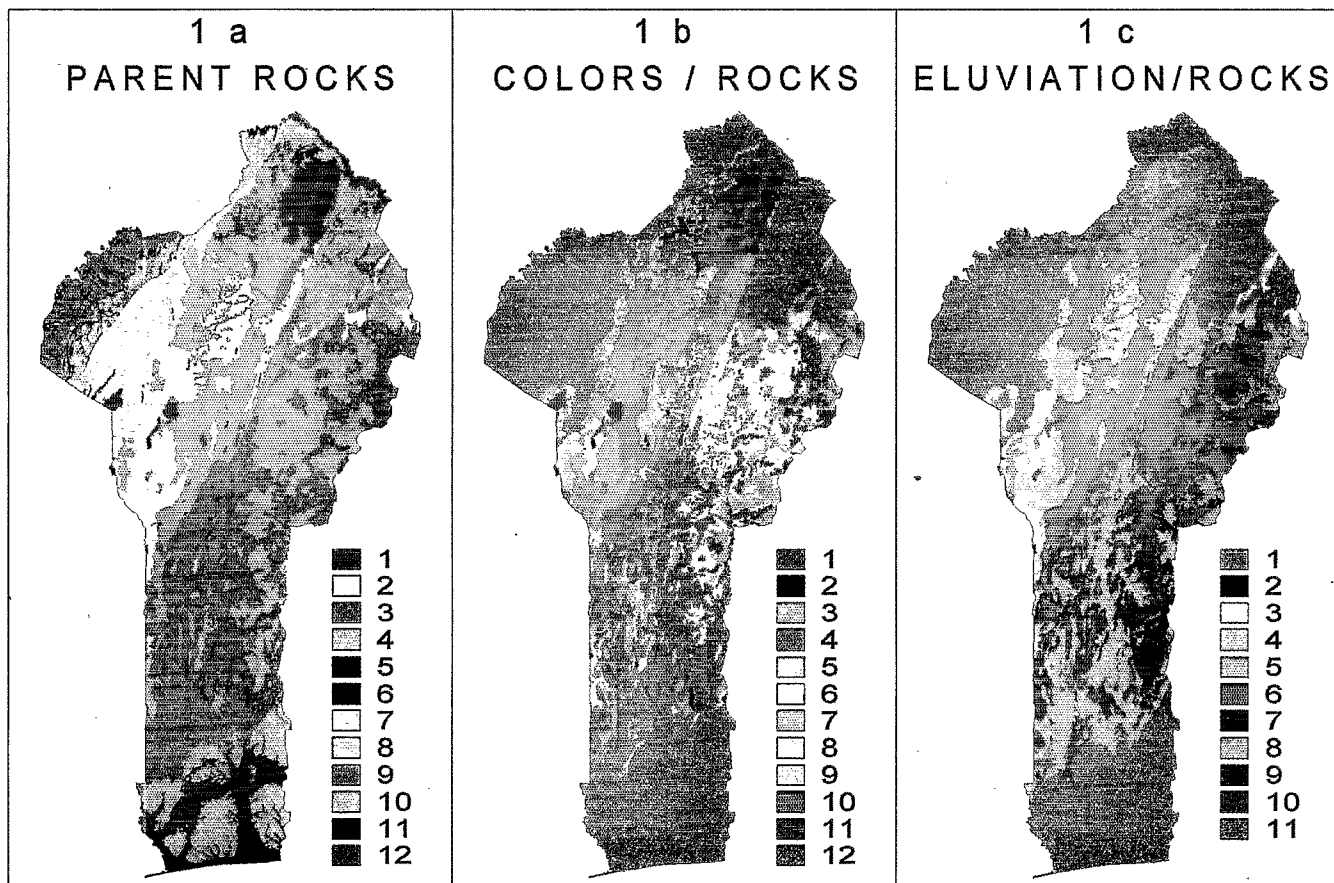


Plate 1.

1a	1b	1c
<p><b>Geographical distribution of the parent rocks</b></p> <p><b>Benin Nigeria Shield (Dahomeyan)</b></p> <ol style="list-style-type: none"> <li>1. Micaschists and quartzites</li> <li>2. Gneisses</li> <li>3. Migmatites</li> <li>4. Granites and granitoids</li> <li>5. Basic rocks</li> <li>6. Undifferentiated rocks</li> </ol> <p><b>Precambrian Volta basin</b></p> <ol style="list-style-type: none"> <li>7. Micaschists and quartzites (Atacora unit)</li> <li>8. Quartzo-micaschists and jasper (Buem unit)</li> <li>9. Schists (Oti unit)</li> </ol> <p><b>Meso-Cenozoic basins and recent sediments</b></p> <ol style="list-style-type: none"> <li>10. Sandstones and unconsolidated continental deposits</li> <li>11. Sedimentary clay and Alluvial deposits</li> <li>12. Residual ferricrete-capped hills</li> </ol>	<p><b>Geographical distribution of the soil units according to the color of the B horizons and the lithology on the Dahomeyan basement</b></p> <p><b>Soils on basic rocks</b></p> <ol style="list-style-type: none"> <li>1. With red B horizons</li> <li>2. With dull-colored B horizons</li> </ol> <p><b>Soils on migmatites</b></p> <ol style="list-style-type: none"> <li>3. With red B horizons</li> <li>4. With dull-colored B horizons</li> </ol> <p><b>Soils on gneisses and micaschists</b></p> <ol style="list-style-type: none"> <li>5. With red B horizons</li> <li>6. With yellow B horizons</li> <li>7. With dull-colored B horizons</li> </ol> <p><b>Soils on granites and granitoids</b></p> <ol style="list-style-type: none"> <li>8. With red B horizons</li> <li>9. With yellow B horizons</li> <li>10. With dull-colored B horizons</li> </ol> <p><b>Soils on residual hills capped by ferricrete</b></p> <ol style="list-style-type: none"> <li>11. With dull-colored B horizons</li> </ol> <p><b>Soils on other rocks</b></p> <ol style="list-style-type: none"> <li>12. Undifferentiated color of the B horizons</li> </ol>	<p><b>Geographical distribution of the soil units according to the thickness of the clay-eluviated horizons and the lithology on the Dahomeyan basement</b></p> <p><b>Soils on basic rocks</b></p> <ol style="list-style-type: none"> <li>1. With thin clay-eluviated horizons</li> <li>2. With moderately thick clay-eluviated horizons</li> </ol> <p><b>Soils on gneisses and micaschists</b></p> <ol style="list-style-type: none"> <li>3. With thin clay-eluviated horizons</li> <li>4. With moderately thick clay-eluviated horizons</li> </ol> <p><b>Soils on granites and granitoids</b></p> <ol style="list-style-type: none"> <li>5. With thin clay-eluviated horizons</li> <li>6. With moderately thick clay-eluviated horizons</li> <li>7. With thick clay-eluviated horizons</li> </ol> <p><b>Soils on migmatites</b></p> <ol style="list-style-type: none"> <li>8. With moderately thick clay-eluviated horizons</li> <li>9. With thick clay-eluviated horizons</li> </ol> <p><b>Soils on residual hills capped by ferricrete</b></p> <ol style="list-style-type: none"> <li>10. With moderately thick clay-eluviated horizons</li> </ol> <p><b>Soils on other rocks</b></p> <ol style="list-style-type: none"> <li>11. Undifferentiated thickness of the clay-eluviated horizons</li> </ol>

Plate 1 (continued).

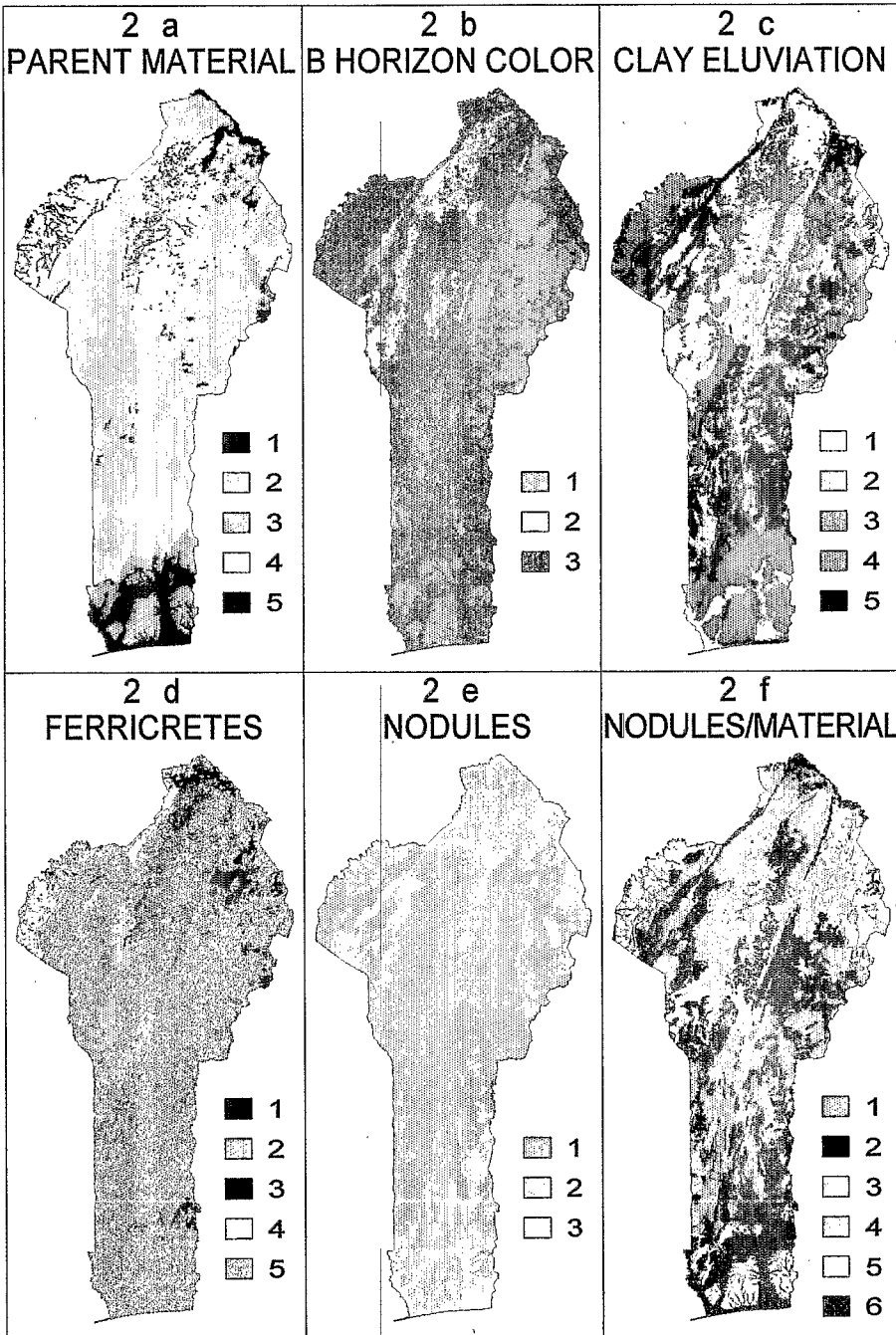


Plate 2.

<p style="text-align: center;"><b>2a</b></p> <p style="text-align: center;"><b>Geographical distribution of the soil parent materials</b></p> <ol style="list-style-type: none"> <li>1. Lateritic material underlying ferricrete from residual hills on undifferentiated rocks</li> <li>2. Lateritic material, saprolite from the Precambrian basement (Dahomeyan and Atacora unit)</li> <li>3. Lateritic material from sedimentary deposits (Meso-Cenozoic and Continental Terminal sediments)</li> <li>4. Non-lateritic material, saprolite from the Precambrian basement (Dahomeyan and Atacora unit)</li> <li>5. Non-lateritic material from sedimentary deposits (Meso-Cenozoic and recent sediments)</li> </ol>	<p style="text-align: center;"><b>2b</b></p> <p style="text-align: center;"><b>Geographical distribution of the soils according to the color of their B horizon</b></p> <ol style="list-style-type: none"> <li>1. With red B horizons</li> <li>2. With yellow B horizons</li> <li>3. With dull-colored B horizons</li> </ol>	<p style="text-align: center;"><b>2c</b></p> <p style="text-align: center;"><b>Geographical distribution of the soils according to the thickness of the clay-eluviated horizons</b></p> <p><b>Soils with gradual textural change between eluviated and underlying horizons</b></p> <ol style="list-style-type: none"> <li>1. With clay-eluviated horizons</li> <li>2. With moderately thick clay-eluviated horizons</li> <li>3. With thick clay-eluviated horizons</li> </ol> <p><b>Soils with abrupt transition between eluviated and underlying horizons</b></p> <ol style="list-style-type: none"> <li>4. With moderately thick clay-eluviated horizons</li> <li>5. With thick clay-eluviated horizons</li> </ol>
<p style="text-align: center;"><b>2d</b></p> <p style="text-align: center;"><b>Geographical distribution of the ferricretes</b></p> <ol style="list-style-type: none"> <li>1. Ferricretes capping residual hills on lateritic materials from undifferentiated rocks</li> <li>2. Ferricretes on lateritic saprolite from the Precambrian basement (Dahomeyan and Atacora unit)</li> <li>3. Ferricretes on non-lateritic saprolite from the Precambrian basement (Dahomeyan and Atacora unit)</li> <li>4. Ferricretes on lateritic materials from sedimentary deposits (Meso-Cenozoic and Continental Terminal sediments)</li> <li>5. Soils without ferricrete</li> </ol>	<p style="text-align: center;"><b>2e</b></p> <p style="text-align: center;"><b>Geographical occurrence of the ferruginous nodules and of their location in the soil profiles</b></p> <ol style="list-style-type: none"> <li>1. With nodules up to the top soil</li> <li>2. With nodules only in the lower horizons (top soil without nodules)</li> <li>3. Soils without nodules</li> </ol>	<p style="text-align: center;"><b>2f</b></p> <p style="text-align: center;"><b>Occurrence of the ferruginous nodules and of their location in the soil profiles according to the soil parent materials</b></p> <p><b>Soils on lateritic parent materials</b></p> <ol style="list-style-type: none"> <li>1. With nodules up to the top soil</li> <li>2. With nodules only in the lower horizons (top soil without nodules)</li> <li>3. Soils without nodules</li> </ol> <p><b>Soils on non-lateritic parent materials</b></p> <ol style="list-style-type: none"> <li>4. With nodules up to the top soil</li> <li>5. With nodules only in the lower horizons (top soil without nodules)</li> <li>6. Soils without nodules</li> </ol>

Plate 2 (continued).

Ferruginous Tropical soils are classified as Ferric and Plinthic Acrisols, Haplic Ferric and Plinthic Lixisols, Chromic Luvisols, and some of them as Mollic and Eutric Leptosols (FAO-UNESCO, 1990).

Furthermore, locally restricted Vertisols (Eutric Vertisols) and 'sols bruns eutrophes' (Chromic Cambisols) are developed on basic rocks (gabbro and amphibolite intrusions) and are distributed in the whole country.

Large areas with Hydromorphic soils (Dystric, Mollic and Umbric Fluvisols) are found on the alluvial plains of Mono and Ouémé rivers on the south.

## 2.5. Methods

The pedological exploration map at 1:200,000 scale of Benin consists of 10 sheets and 107 cartographic units (Volkoff, 1976; Volkoff and Willaime, 1976; Dubroeuq, 1977a,b; Faure, 1977a,b; Viennot, 1978a,b). Most of the cartographic units are related to the dominant soil of soil associations rather than pure soil units. They were defined according to the French soil classification system (CPCS, 1967), i.e., classes, subclasses, groups and subgroups that refer to distinct typological soil characters. Soil families are defined according to the parent material, i.e., the underlying supposed parent rock or its derived saprolite. The digitized map, with equivalent 20 m spatial resolution, was processed by information computer analysis (FORBAN System, Faure and Benizri, 1988; Faure, 1989) and prepared as small scale thematic synthesis maps. Some of these are presented at 1:6,000,000 (Plate 1) and at 1:8,000,000 (Plate 2) and discussed in this paper. They show the distribution of a variety of parameters including parent material, soil color, the thickness of the clay-eluviated horizons, the ferricretes and ferruginous nodules occurrence.

Soil parent materials were grouped in four categories: (i) Lateritic material derived from kaolinitic/lateritic sedimentary Meso-Cenozoic and Continental Terminal deposits; (ii) lateritic saprolites of the basement crystalline rocks (Dahomeyan basement and Atacora units), (iii) non-lateritic saprolite (arenaceous, illitic, smectic) of the Precambrian basement (Dahomeyan and Atacora unit) and (iv) recent sedimentary non-lateritic deposits (alluvium, colluvium). Materials underlying ferricretes on residual hills were all considered as lateritic materials, but they were placed in a separate fifth class (Plate 2a).

Two classes of soils with bright colored B horizons (soils with red B horizons and soils with yellow B horizons) were separated from a single class of soils having dull colored B horizons (beige, gray, white, ...) (Plate 2b).

Ferricretes from the residual hills that appear on the pedologic map were included as a distinct class. The other ferricretes correspond to hardened soils of the pedologic map (Plate 2d).

For ferruginous nodules, parameters such as their origin, their form and their abundance were not taken into account. Only the criteria presence or absence, and position in the profiles (up to the surface, i.e., up to the A horizons, or at depth, i.e., absence in the A horizons) were used (Plate 2e).

Three soil classes were considered according to the thickness of the clay-eluviated horizon: (i) soils with thin clay-eluviated horizons (less than 20 cm); (ii) soils with moderately thick clay-eluviated horizons (20 to 100 cm) and (iii) soils with thick

clay-eluviated horizons (more than 100 cm). Moreover, two textural types of soil profiles were defined: (i) profiles with a gradual textural change between clay-eluviated and underlying B horizons; (ii) profiles with a strong textural contrast and abrupt transition between clay-poor upper horizons and underlying B or BC horizons. In the soil legend of the initial map, soils corresponding to the first type were called 'clay-leached soils' (sols lessivés) and soils corresponding to the second type 'clay-depleted soils' (sols appauvris) (Plate 2c).

New maps were drawn by computer from combinations of the thematic maps. They show the distribution of a variety of parameters including the color of soils according to the parent rocks (Plate 1b), the thickness of the clay-eluviated horizons according to the parent rocks (Plate 1c), the ferricretes occurrence according to the parent materials (Plate 2d), and the ferruginous nodules occurrence according to the parent materials (Plate 2f).

### 3. Results

#### 3.1. *Distribution of the pedologic characteristics*

A regional distribution of some soil characters and their relationship to the broad geological divisions are clearly revealed by comparing the map of the parent rocks (Plate 1a) to those of soil parent materials (Plate 2a), color of B horizons (Plate 2b), clay eluviation (Plate 2c), and occurrence of ferricretes (Plate 2d) and ferruginous nodules distribution (Plate 2e), respectively.

##### 3.1.1. *Distribution of soil parent materials*

Lateritic materials are predominant in south and north sedimentary basins (Plate 2a). They actually represent the totality of the Continental Terminal deposits and most of the materials derived by weathering from the sandstones of these two basins.

They account for nearly a third of the soil parent material cover on the basement. They are scarce, but not totally absent in the south eastern part of the Dahomeyan eastern bloc, and in the north-west Volta unit. Elsewhere, they are almost regularly distributed with a greater frequency in the regions of the Atlantic–Niger ridge (peneplain of Péhonco, plateaus of Parakou and Djougou).

Non-lateritic materials are present in all the territory with greater frequency in northern and south-western regions (plain of the Ouémé River, the Pendjari and the Alibori).

##### 3.1.2. *Variation of color*

There is a clear regional grouping of soil B horizon colors (Plate 2b). Red colors dominate largely in the southern and northern sedimentary basins and on the eastern bloc of the basement, specially on its northern half (plateau of Parakou). Dull colors dominate on the western bloc, on the Atacora unit, the Volta unit and on the southeastern border of the eastern bloc (plain of the Ouémé River). Yellow colors are found exclusively on the western bloc and the Atacora unit. They appear alone, associated with dull colors in some sectors of the west and north (plateau of Djougou

and plain of the Alibori), or mixed with red colors in others sectors of the center of this bloc (Péhonco penneplain).

### 3.1.3. *Textural patterns*

As the color, the thickness of the clay-eluviated horizons and of the textural profile type (clay-leached or clay-depleted soils) follow a regional pattern (Plate 2c).

*3.1.3.1. Thickness of clay-eluviated horizons.* Except for hydromorphic soils developed on recent deposits of the southern sedimentary basin, soils with thin clay eluviated horizons are located essentially north of the 9th parallel and mainly on the Atakora and the western bloc of the basement. Very few are found in the north of the Kandi Basin. Soils with thick clay-eluviated horizons are concentrated on the eastern bloc of the basement, the Kandi Basin, the Atakora unit and the Volta unit and are not present on the western bloc of the basement. Only soils with moderately thick clay-eluviated horizons are common in all the territory.

*3.1.3.2. Distribution of the textural profile types.* The character 'textural type' displays less regional localization than that of the character 'thickness of clay-eluviated horizons'. It is apparent that all soils with thin clay-eluviated horizons exhibit a textural profile with gradual transitions between the clay-eluviated horizons and the underlying horizons and that, except for the sedimentary Kandi Basin, soils with thick clay-eluviated horizons show abrupt transitions between these horizons. Soils with moderately thick clay-eluviated horizons belong indistinctly to one type or the other.

### 3.1.4. *Ferricretes distribution*

Ferricretes are found, in variable proportions, throughout the territory (Plate 2d). There are few ferricretes in the south sedimentary basin, in the north sedimentary basin, and on the Atakora unit. Ferricretes are widespread in the Volta Basin on schist and sandstones of the Oti unit. On the Dahomeyan basement, they are regularly distributed in the western bloc, but very irregularly in the eastern bloc.

Residual hills capped with ferricretes are essentially localized on the western bloc of the basement (Plate 1aPlate 2d), but are absent in the extreme south of this bloc. In the eastern bloc, a few residual hills are found in the north-east and the south-west near the Nigerian and the Togo borders, respectively.

### 3.1.5. *Distribution of the ferruginous nodules*

Although almost all of the soils contain ferruginous nodules, soils without nodules do exist. These 'nodule-free' soils are scattered throughout the territory (Plate 2e), but are particularly well-represented in sedimentary basins, on the Atakora unit and in the southern part of the eastern bloc of the crystalline basement (lower Ouémé plain). Two types of 'nodular soils' are observed. In the first, the nodules are present in all the horizons, and reach the surface. In the second, nodules are only seen in the lower horizons. On the crystalline basement, the two soil types are normally found in equal proportions throughout the western bloc and in the northern part of the eastern bloc while there is a distinct predominance of the first type in the southern part of this bloc.

### 3.2. *Distribution of parent material types according to the lithologic factors*

If sandstone and Continental Terminal deposits of sedimentary basins that consist essentially of kaolinitic materials are not taken into account, one can see (Plate 1a and Plate 2a) that the presence or the absence of the lateritic materials is not linked to any rock type, even though lateritic materials and non-lateritic materials are associated in variable proportions.

### 3.3. *Variation of B horizons color according to the lithologic factors*

Soils are red or dull on sandstone and continental deposits of both the northern and southern sedimentary basins. They have essentially dull colors on the quartzo-micaschists and the schists of the Volta Basin, and they are yellow, red or dull colored on the Atacora unit (Plate 1a and Plate 2b).

On the western bloc of the Dahomeyan basement, yellow soils are found on granite as well as on gneiss (Plate 1b). Red soils, dominating in the northern part of the eastern bloc (Parakou plateau), are essentially found on granite. Dull colored soils occur mainly on the southern part of this bloc and are distributed on migmatites as well as on granite. The same distribution occurs for the red soils that are in lesser proportions in this part of eastern bloc.

Red soils, dull colored soils and some yellow soils are found on granite but the dull and the red soils are found on the entire basement while the yellow soils are specific to the western bloc. It is also observed that dull soils are dominant on granites of the western bloc and that red soils are more frequent than dull ones in the eastern bloc.

Soils on gneiss and micaschists are dull colored or yellow, more rarely red. The three colors are found in the western bloc, but only red soils and dull soils are found on the eastern bloc. Again, yellow soils on gneiss appear to be limited to the western bloc.

Soils on migmatite are only found in the eastern bloc. There, dull and red soils are associated, but a predominance of dull soils is noted in the southern part of the bloc in the lower plain of the Ouémé river.

Therefore, regional color differentiation is not strictly related to the nature of the substratum. Indeed, regardless of the parent rock (gneiss or granite), soils in the western bloc are particularly dull, sometimes yellow and rarely red. They are red and associated with dull soils in the north of the eastern bloc (Parakou plateau); they are dominantly dull and associated with red soils in the south of the eastern bloc in the lower plain of the Ouémé.

### 3.4. *Relationships between the thickness of the clay-eluviated horizons and the lithology*

Soils on sandstone of the northern sedimentary basin have thick clay-eluviated horizon materials and are considered to be deeply eluviated with gradual textural changes within the profile. Soils on Continental Terminal of the southern basin are moderately eluviated. Those of Volta units have moderately thick clay-eluviated horizons (Plate 1a and Plate 2c).

In the western bloc of the Dahomeyan basement, soils on gneiss have thin or moderately thick clay-eluviated horizons (Plate 1c). Soils with thick clay-eluviated horizons are not found on gneiss.

In both the western bloc and the eastern bloc, the most frequent soils have moderately thick clay-eluviated horizons on granites. Soils with thick clay-eluviated horizons are only found in the eastern bloc and they are clearly more abundant in the south than in the north. Soils with thin clay-eluviated horizons are strictly limited to the western bloc where soils with thick clay-eluviated horizons no longer exist.

There are no soils with thin clay-eluviated horizons on migmatite. Soils on migmatite are dominantly soils with moderately thick clay-eluviated horizons. The proportions of soils with thick clay-eluviated horizons is variable; they are absent on the northern part of the eastern bloc of the basement and are mainly found in the center and the south of this bloc (lower plain of the Ouémé).

Thus, the lithology seems to determine some textural characters but not systematically, as shown by soils on granites in which the intensity of the clay-eluviation is partly linked to the geographical location inside the bloc; clay-eluviated horizons are thinner in the north than in the south of the eastern bloc.

### 3.5. Ferricretes, parent material and lithology

Ferricretes cover ~ 30% of the lateritic materials on the crystalline basement (Plate 2a and d). Ferricretes are particularly well represented in the northern region of the western bloc of the basement, where all lateritic materials, developed from gneiss or granites, are capped with ferricretes (Alibori plain). In the central regions of the two blocs, ferricretes are less common, and there are no more ferricretes on granites in the eastern bloc (Plate 1a and Plate 2a and 2d). Ferricretes capping residual hills are always on lateritic materials and are distributed on all rocks including granites of the western bloc and migmatites of the eastern bloc at the Nigerian border.

The ferricretes also occurs on the non-lateritic materials in the center-west and in the north-west (Plate 2a and 2d). Ferricretes are common on gneiss whereas they are not found on granite except in the north of the western bloc.

Ferricretes are widespread on the northern sedimentary Cretaceous and Tertiary deposits (Kandi Basin) but not in the south (Coastal Basin) (Plate 2d). They occur on non-lateritic materials on the plain of the Pendjari on schists of the Volta Precambrian units, where lateritic remnants, equally hardened, are extremely sparse.

### 3.6. Relationships between the occurrence of ferruginous nodules and the parent material

#### 3.6.1. Soils on lateritic materials

With the exception of sedimentary basins, nodules are ubiquitous in most of soils on lateritic materials.

In the coastal sedimentary basin (Plate 2a and 2f), soils with nodules up to the surface form a fine fringe at the plateau periphery or are found on the inner plateaus overlying ferricretes. In this area, soils with nodules in the subsurface horizons occur only on sandstone.

In the Kandi Basin, all hardened soils have nodules up to the surface (Plate 2d and 2f), while all other soils lack nodules; soils with nodules only in lower horizons are very scarce.

On the Dahomeyan basement, soils from lateritic materials normally have nodules up to the surface, except in the central regions of the Atlantic–Niger interfluve (Plate 2f), where soils with surface nodules and soils with deeper nodules (top soil without nodules) coexist. Soils without nodules are found only on migmatite in the central part of the eastern bloc (Parakou plateau). The central part of the crystalline basement on both sides of the 9th parallel is characterized by the presence of soils on lateritic materials with no nodules at the surface, while in the other places, nodules appear the most frequently up to the surface.

### 3.6.2. *Soils on non-lateritic materials*

Soils on non-lateritic parent materials of the coastal sedimentary basin do not have nodules; they are essentially hydromorphic soils and Vertisols. In contrast, on the whole sedimentary Volta Basin, soils on the non-lateritic materials contain very high proportions of nodules.

On the basement, though nodules may be present or absent in the soils and their position in the profile is varied, it can be noted that: (i) in the western bloc, soils normally have nodules that are mainly in the subsurface horizons, while in the eastern bloc, soils may or may not contain nodules; if soils are nodular, nodules are usually seen up to the surface; (ii) soils with nodules at depth exist on migmatites in the north and in the south of the eastern bloc; (iii) soils without nodules are rare in the western bloc as they are limited to granites; they are more frequent in the southern part of the eastern bloc on both granites and migmatites (low plain of the Ouémé river).

### 3.7. *Relationships between ferruginous nodules position within the profile and textural characters*

On the Atlantic–Niger divide and *on the lateritic mantle*, nodules are found in lower soil horizons, either on gneiss or on granite, where soils have thin superficial clay-eluviated horizons (Plate 2c and 2f). Elsewhere on the basement, towards the north and south soils have nodules up to the surface and have thicker clay-eluviated horizons.

In soils formed *from non-lateritic materials*, it was observed that, when present, nodules are systematically found in the lower part of the profiles, below thin or moderately thick clay-eluviated horizons on gneiss, and up to the soil surface, in profiles having thick clay-eluviated horizons on granites. On migmatites, nodules are next to the surface, more rarely at depth, and the profiles have moderately or thick clay-eluviated horizons.

## 4. Discussion and interpretation

Neither the geographical distribution of the lateritic or non-lateritic parent materials, nor the occurrence and the position of the ferruginous nodules in profiles from lateritic

materials, can be strictly related to the lithologic nature of the parent rocks. However, characters such as the thickness of the clay-eluviated horizons, the position of the nodules in the profiles from non-lateritic materials, the preferential development of some colors of B horizons, and, to a certain extent, the ferricretes occurrence, are linked to the lithology.

#### *4.1. Distribution of soil parent materials*

Non-lateritic materials are distributed in all geographical zones, throughout Benin. These materials whose mineralogical composition depends, locally, on the basicity of the rock are saprolites resulting from a weathering process intermediate between bisiallitisisation and monosiallitisisation (Pédro, 1964).

Lateritic saprolitic materials, in which kaolinite is the major clay mineral, are also present all over the territory. They are juxtaposed to the non-lateritic materials in the same places and on the same parent rocks, and in the wettest regions as well as in the driest regions. It is assumed that most are inherited materials, although part of them could also be formed currently in some areas where the mean annual rainfall exceeds 1400 mm. Their systematic presence indicates that lateritic materials may have mantled all the territory of Benin. Geomorphic processes that have molded the current landscape have stripped a large portion of this old kaolinitic cover (Churchward and Gunn, 1983; Thomas, 1994) and it could, thus, be presumed, that the less weathered non-lateritic materials have been formed further on the stripped places.

The lateritic mantle is well preserved only on the southern and northern sedimentary plateaus. Nevertheless, important remnants exist in peneplain and plateau regions of the Atlantic–Niger divide. Their importance decreases from this divide toward the north and the south, and, locally, downward the main drainage axes, the north Niger base level, the north-west Pendjari base level and the south Atlantic base level. They are particularly rare in the low plain of the Ouémé River and in the plain of the Pendjari River.

#### *4.2. Ferricretes distribution*

##### *4.2.1. Ferricretes on lateritic materials*

In the coastal sedimentary basin ferricretes overlay Tertiary and Cretaceous deposits and are anterior to the overlying Mio-Pliocène detrital materials in which the 'Terres de Barre' have developed (Houessou and Lang, 1978). Those of the Kandi sedimentary basin are represented by ferruginous sandstone layers and residual hills and plateaus capped with Continental Terminal deposits. These ferricretes are considered to be Pliocene northward in the Niger Republic (Gavaud, 1977; Grandin and Thiry, 1983).

The ferricretes-capped residual hills found on the Precambrian basement are considered to be Pleistocene (Michel, 1978) or Late-Tertiary (Poss and Rossi, 1987) in the neighboring countries of Togo, Burkina Faso and Niger. Information provided by pedologic maps do not allow to establish a precise correspondence between these ferricretes found on both sides of the Atlantic–Niger divide, especially on the western bloc, and those of the Djougou central plateau areas. However, ferricretes of the plateaus

and those of the residual hills appear in topographic concordance on the highest parts of the landscape and therefore would certainly be contemporaneous.

This large distribution would indicate that ancient ferricretes have developed, as the lateritic mantle, on the totality of the territory of Benin. However, on the Atlantic–Niger divide of the eastern bloc (Parakou plateau), residual ferricretes are sparse, while ferruginous nodules are found in large amounts—which can lead to the assumption that presumably ancient ferricretes were there more easily dismantled or were less developed for lithologic reasons.

Not all ferricretes on lateritic material are comparable to those capping the plateaus and the residual hills. Indeed, other ferricretes found on the slopes of the plateau and hills were developed only after valley incision and are therefore posterior to the highest ones (Tardy, 1993). Ferricretes on kaolinitic material thus constitute a complex unit composed of several generations of ferricretes that were not differentiated on the initial pedologic map.

#### 4.2.2. *Ferricretes on the other materials*

In the landscape, ferricretes overlying smectitic or micaceous saprolites are located below ferricretes on lateritic materials. They are never exposed in the form of ferricretes capping residual hills. They are found on all rock types in the western bloc of the granito-gneissic basement, but exclusively on migmatites, not on granites, in the eastern bloc. In the Pendjari plain, where lateritic remnants capped by ferricretes are extremely rare, they form an almost continuous cover. It can be assumed that most of these ferricretes formed downslope are younger than the ferricretes on lateritic materials.

One observes finally: (i) that two ferricretes types are easily differentiated: ferricretes on lateritic material and ferricretes on non-lateritic saprolites. Most of the former result from a relative iron accumulation in the lateritic saprolite (D'Hoore, 1954; Maignien, 1966; McFarlane, 1976; Nahon and Bocquier, 1983; Nahon, 1986; Bardossy and Aleva, 1990; Tardy, 1993), the latter are formed by absolute accumulation within the nodular B horizons of the soils (Maignien, 1958; McFarlane, 1976; Faure, 1985); (ii) that the ferricretes formation is still occurring and has probably been taking place all over the territory of Benin since the Tertiary; (iii) that the geochemical environment at a regional scale is, and has always been, more favorable for ferricretes development westward on any the parent rocks, because rocks of the western bloc are generally more mesocratic than those of the eastern bloc.

#### 4.3. *Spatial distribution of soils according to the occurrence of ferruginous nodules*

Soils with ferruginous nodular horizons largely overlie the ferricretes zones in all regions and on any rock type. However, nodules are absent on some rocks, such as quartzites of the Atacora and continental deposits and close to the base levels on the crystalline basement.

The nodules are either nodules formed 'in situ' in the kaolinitic (Bocquier et al., 1984; McFarlane, 1991) or non-kaolinitic matrix, or resistant nodules derived from a 'stone line' existing in most soils (Ruhe, 1959; Fölster and Ladeinde, 1967; Ségalen,

1969; Burke and Durotoye, 1971; Thomas, 1994). The two types of nodules often coexist in soils (Lévêque, 1979a; Faure, 1986, 1987).

The communality of nodules occurrence in the soils may be related either to concretions formation by iron leaching and accumulation, that is especially noticed on ferromagnesian rocks and more rarely on leucocratic rocks, or to an inheritance consecutive to the morpho-pedologic evolution of slopes and the preservation of the nodules of profiles of former landscapes. The absence of nodules in the lower hydrographic basins, not only in the basin of the Ouémé River, but also of the Alibori River, is indicative of a complete rejuvenation and consequently the removal of both the old lateritic cover and the nodules that constitute the last remnants of this cover.

#### 4.4. *Clay eluviation*

The thickness of the clay-eluviated horizons is linked to the nature of the parent rock. Thin clay-eluviated horizons observed in soils on gneiss may be explained by the fine texture of these rocks that provides little sandy skeleton, and a proportionally high amount of clayey soil plasma. Therefore, soils on gneiss are less affected by the clay eluviation. On the contrary, the thicker clay-eluviated horizons of soils on granites and migmatite may be explained by their greater content of sands.

However, it is noteworthy that soils of the western bloc of the basement are, as a whole, relatively less eluviated than those of the eastern bloc. This may be interpreted considering the regional pattern of the topography. The western bloc is barely incised by the hydrographic system and its topography is composed of gently inclined and extended slopes. This character is shared by gneiss zones and granite zones of the western bloc. Such a topography induces a slow general-drainage and clay eluviation that is weaker than that in the dominantly granitic eastern bloc. In that bloc, both the high permeability of the soil surface and the hilly incised landscape, typical of the granitic plateau of Parakou promote clay eluviation, lateral elimination of fine particles, and relative accumulation of residual coarse elements in the surface horizons of the soils on the steeper slopes. The thickness of the clay-eluviated horizon is, thus, linked partly to the lithology and partly to geographical location in longitude (western bloc or eastern bloc).

Besides, soils with thick clay-eluviated horizons, and strong textural contrasted profile, are widespread on granites, migmatites, including schists, near southern regional base levels and the north-west plain of the Pendjari while they are exceptional either on granite or on gneiss near the Niger base level. In addition, identical soils have been observed on gneiss in Togo in the lower basin of the Mono River (Lévêque, 1979b), in geographical and geomorphologic positions equivalent to those of the southern part of the western bloc. Excluding continental and sandstone-like sedimentary rocks it can be then stated that whatever the parent rock, soils with thick clay-eluviated horizons prevail among other soils on the whole southern part of the Togo–Benin crystalline basement.

Therefore, at a regional scale the distribution of the soils according to textural characteristics does not depend exclusively on the nature of the parent rock. It is clearly related to geographical areas which pattern cannot be superposed to a climatic zonation or to any orientation corresponding to Harmattan wind blow direction. That means that neither the existing range of rainfall regimes and rainfall totals that might have

controlled clay eluviation nor the dust deposition (Herrmann, 1996) that might have brought some textural change have led to perceptible regional variations.

In this context, differentiation of soils with thick clay-eluviated horizons might have been induced by differences in the processes of the recent landscape development in the hydrographic basins draining directly towards Atlantic Ocean (central and southern parts of the crystalline basement and the north-west plain of the Pendjari) and in the northern basins which drain towards the Niger bases level (plain of the Alibori river).

Stripping of the lateritic mantle, that is linked to the development of the current topographic surface, had relatively little effect in the Atlantic–Niger divide but was more and more effective near the regional base levels. It was most active and has almost completely reduced the lateritic mantle in the low regions in the south and the north-west allowing the posterior development of common, short and relatively steep slopes of litho-dependent saprolites from the different fresh rocks. There, topography and the poorly drained soil parent materials have both led to a lateral elimination of the clay.

As a conclusion, the soil cover of the northern parts of the basement seems to have been partly preserved from recent transformation because the Niger River level, far from its mouth, has not undergone important changes, and also because of the protection by the barrier formed by the plateaus of the sedimentary Basin of Kandi and the Atacora. The southern and the north-western parts have been more clearly rejuvenated by the lowering of the Atlantic bases level and the rivers flowing directly into the Atlantic (Ouémé, Mono, Pendjari–Volta).

#### *4.5. Textural characters and ferruginous nodules position in the profile*

The results illustrate the relationships between clay eluviation, the position of the ferruginous nodules in the profile and erosion.

Nodular soils on granites and migmatite of the eastern bloc exhibit both thick clay-eluviated horizons and a nodule accumulation from the top soil. These characters indicate that most of the nodules are residual and that the soils are submitted to physical erosion.

In contrast, soils on gneiss and granites of the western bloc have thin clay-eluviated horizons and nodules are found only at depth, part of these being formed in situ (Faure, 1975). That is indication that the superficial erosion processes are limited and that the soils have developed vertically under relatively stable conditions.

It can then be assumed that slope dynamics and the balance of erosion-profile development are quite different in the two blocs. In the east, on granite, the permeability of the surface horizons is not sufficient to restrict the erosion that contributes to a superficial selective sorting of the coarsest components of the soil. Westward, on gneissic rocks, the slight inclination of the slopes limits erosion despite the weak penetration of the water.

#### *4.6. Regional differentiation of B horizon colors*

On Continental Terminal deposits soils are uniformly red while on the basement various bright and dull colored soils are associated. Dull colored soils are uniformly

distributed in the eastern and western blocs and are not linked to the rock type. Bright colored soils are normally red on the eastern bloc and are yellow on the western bloc regardless to the rock type, which indicate a connection of the geographical differentiation of soil color to geomorphology, since red soils develop preferentially in a hilly regional landscape, whereas yellow soils are preferentially associated with a regional smooth landscape with long and slightly inclined slopes.

The color of the soil is then correlated to the hydrological regime on slopes: red to rapid drainage, yellow to slow drainage and dull color to poorly drained slopes. Color also depends on the mode of iron individualization in the soil material either in the clayey plasma for yellow and red soils, or under the form of nodules for dull soils but this is also related to the soil hydrological regime.

Another factor of geographical color differentiation is the distance from the regional base level, which is connected to the stripping of the lateritic mantle. Red soils and yellow soils are mainly found on the upper portion of the great basins in which ancient lateritic cover are better preserved while dull colored soils are found in the lower basins in the most rejuvenated zones.

Finally, soil color, thickness of clay-eluviated horizons and presence and position of nodules in the profile are interconnected and are closely dependent on the landscape.

## **5. Conclusion**

The main morphological soil characteristics, color, texture and forms of individualization of the iron in the profile are closely linked to the landscape and consequently to the lithology of the major geological units. They are also closely related to the nature of parent materials. The materials belong to two major types: an ancient lateritic mantle which has been unequally stripped by the current landscape genesis and a non-lateritic weathering saprolite.

Sedimentary plateaus are well-delimited spatial units where the preserved ancient mantle is uniformly covered by soils whose characteristics are directly linked to the quartzo-kaolinitic nature of the parent material.

On the crystalline basement there is a clear correspondence between the soils characteristics, landscape and lithology, pattern and occurrence of the ancient lateritic mantle.

In the mainly gneissic western bloc, yellow and dull-colored soil development, slight clay eluviation, nodule concentrations, and sometimes ferricretes development at depth can be attributed to specific hydrodynamics of the rather planate landscape exhibiting long and straight slopes with very low-gradient plans. In the mainly granitic eastern bloc, red soil develop in which clay eluviation and relatively small nodule concentration are probably due to the hydrodynamics of the short convex slopes of the hilly landscape.

As for the soil zonation involving the ancient lateritic mantle it can be seen that in the zone of the Atlantic–Niger divide, where the ancient lateritic mantle is well-preserved in both the eastern and the western blocs, ferricretes do not exist in the east whereas they occur widely in the west, and in the east, the upper soil is thickly clay-eluviated and iron nodules are concentrated in the top-soil.

In the area between the Atlantic–Niger divide and the Niger River, marked by a variable but never pronounced reduction of the lateritic mantle, the two blocs are again differentiated. In the western bloc where ancient ferricretes are abundant, soils with nodules up to the surface in lateritic materials contrast with soils on non-lateritic saprolites because in these soils ferruginous nodules are only found in sub-surface horizons. The current topographic surface therefore appears to be embedded in the ancient surface that is outlined by its remnants in the form of residual hills capped with ferricretes. In the hilly landscape of the eastern bloc, where the ferricretes are very scarce, the drainage incision and progressive slope adjustment by erosion have exposed the nodular layers of soils both on lateritic material and on non-lateritic saprolites. This differentiation suggests varied ferricretes development during the time of the lateritisation and distinct modern landscape evolution of the two blocs.

Between the Atlantic–Niger divide and the Atlantic ocean, particularly in the low plain of the Ouémé River where most of the lateritic mantle was removed, the dominant soils on non-lateritic saprolites have experienced an additional differentiation of intense and deep clay eluviation. Indeed, the strong and deep clay eluviation characterizes soils of this low-basin. This reflects, and may be linked to, a certain magnitude of the base level depression. Analogous processes are observed in soils of the plain of the Pendjari river in the northwest.

In summary, regional differences in the soil cover are clearly revealed. Soil provinces roughly correspond to the known geomorphologic units of Benin. This differentiation can be directly connected to characteristics of the geomorphologic evolution in terms of intensity of the valley incisions and removal of the ancient lateritic mantle and to the nature of geological units on which such evolution has taken place. Probably because the inadequacy of the criteria used, the results could not account for any effect of the regional climate, particularly the rainfall, and for any contribution of present or past eolian depositions on spatial differentiation of the soils at regional scale.

This small scale analysis allowed us to clarify the typological variability and the soil distribution in Benin and demonstrated: (i) the extent of an ancient lateritic mantle on the sedimentary basins and on the quasi-totality of the Precambrian substratum. The extent of the preserved remnants of this mantle is closely related to conditions of specific geomorphologic evolution of each of these regions, which are themselves a function of their location on the Atlantic–Niger divide and their distance from the Atlantic and Niger base levels; (ii) the commonality of soils with a more or less marked textural differentiation and with ferruginous nodules as in Tropical Ferruginous Soils that have developed on all types of parent materials, as well as on lateritic and non-lateritic saprolites; (iii) the existence, despite the typological diversity of these soils, of a clear regional compartmentalization that is directly connected to the geomorphologic factors and the lithologic nature of each of the great geological provinces of Benin.

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Erratum

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(West Africa)’ [CATENA 32(1998) 281–306] <sup>1</sup>

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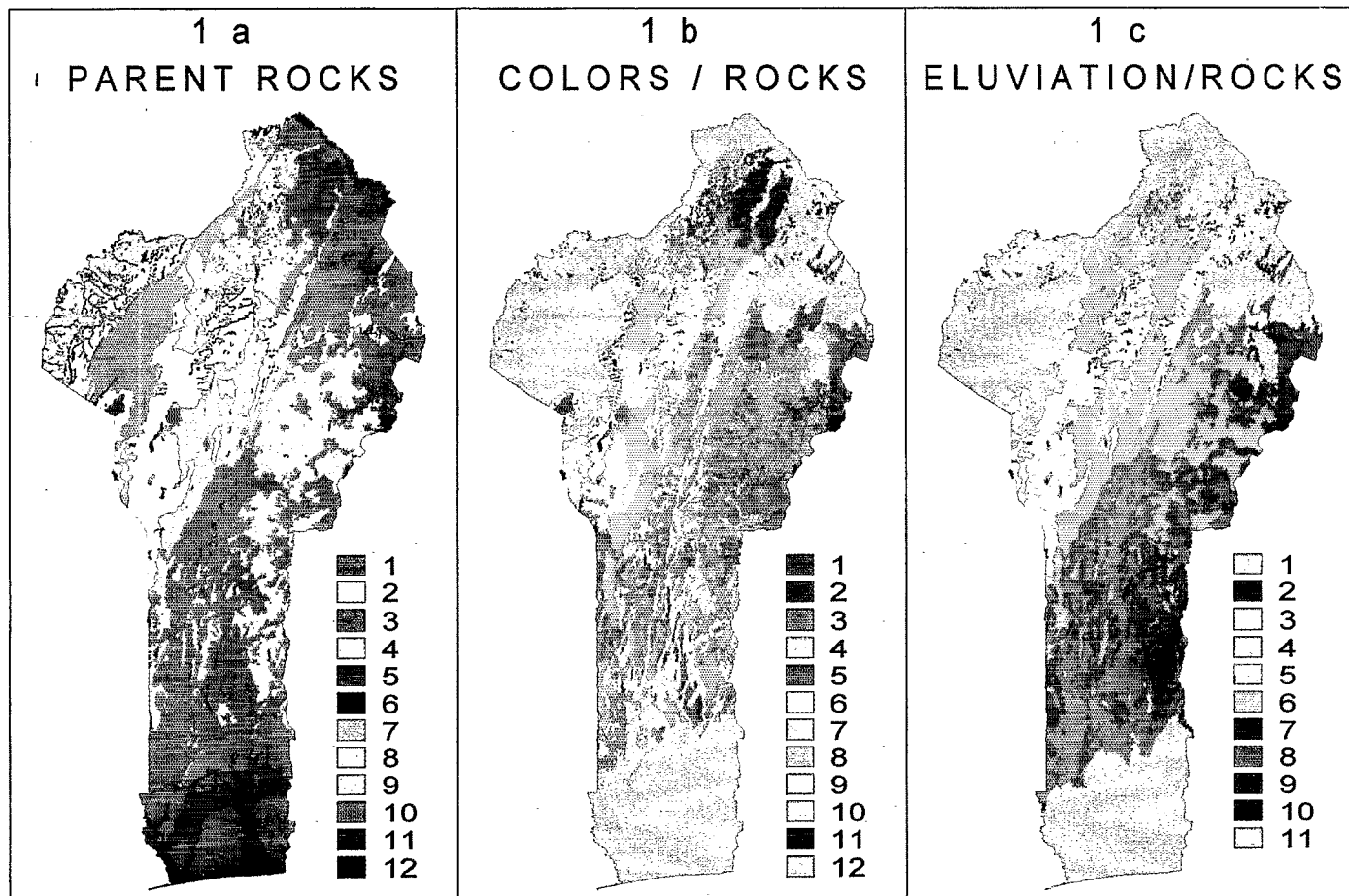


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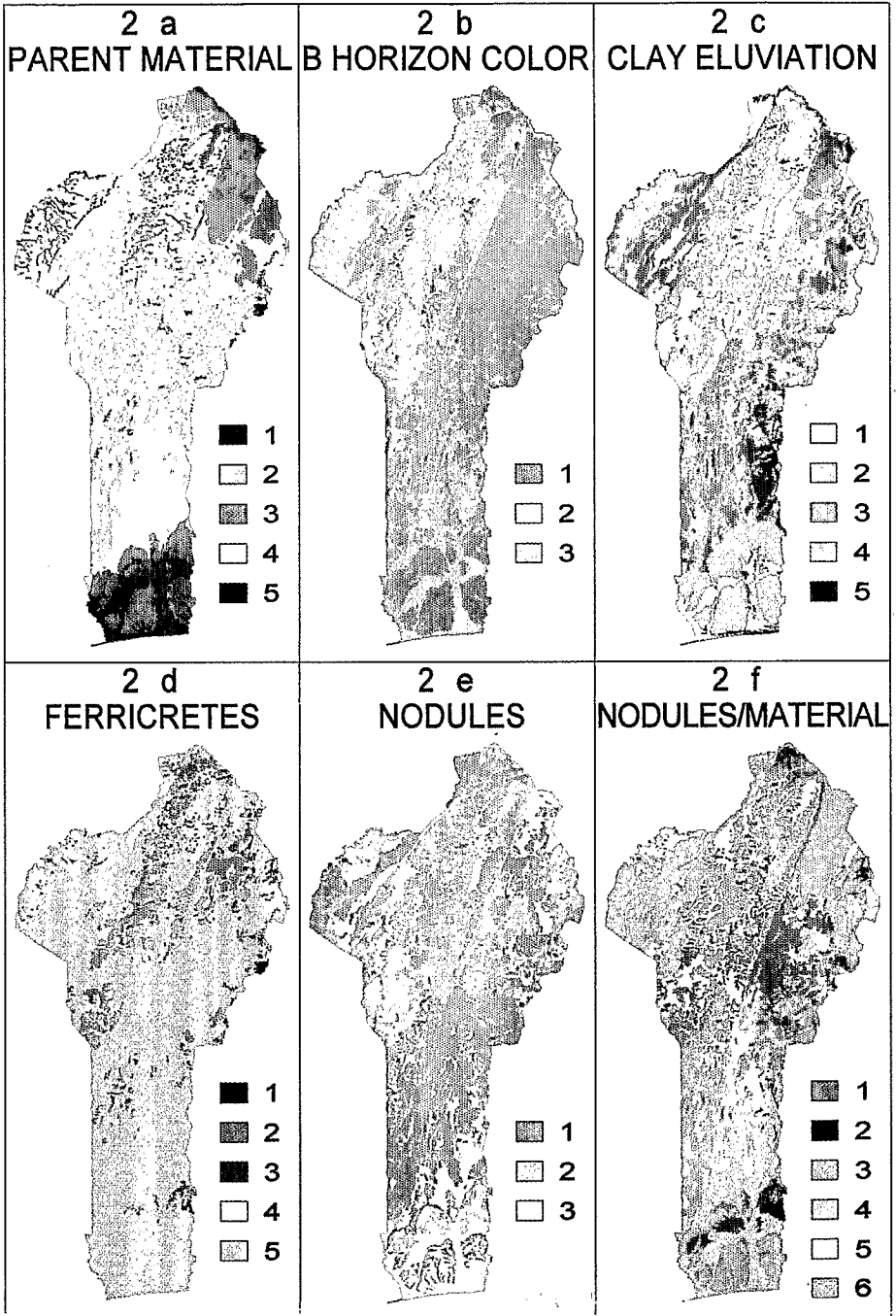
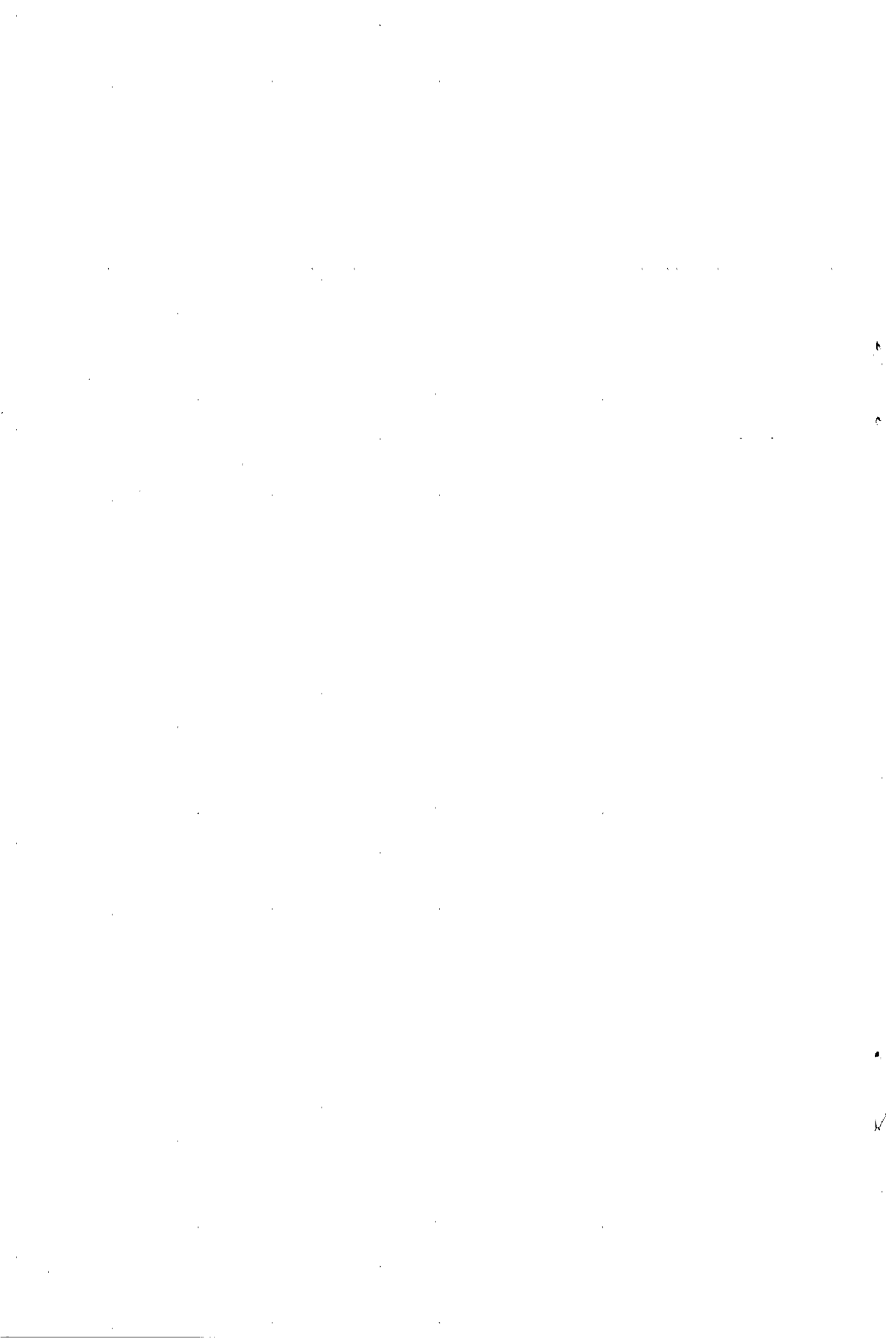


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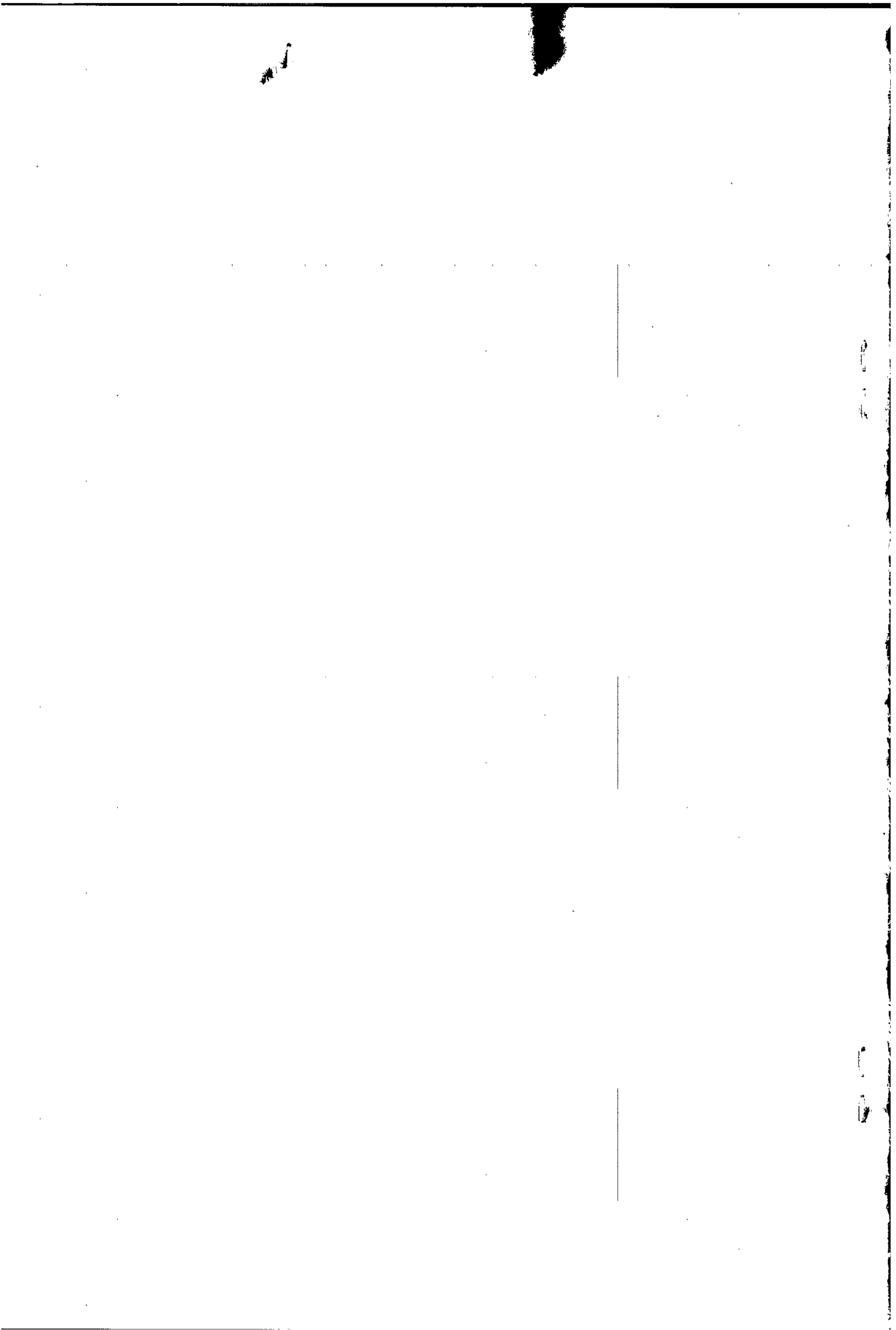
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