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Old landscapes, pre-weathered materials, and pedogenesis in tropical Africa: How can the time factor of soil formation be assessed in these regions?

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ABSTRACT

The present paper is an overview of tropical West Africa soils with the aim to compile soil characteristics and identify research gaps in respect to rates of soil forming processes. Compilation of morphological, mineralogical and chemical data on soil development has distinguished several types of soils. The major soils identified and described include ferrallitic soils, ferruginous tropical soils, vertisols, semi-arid tropical soils, and hydromorphic soils. Their formation and their evolution depend on climate and paleoclimate actions, parent materials, vegetation, and geomorphology. Most of these soils have been mapped using FAO, CPS classification, and Worldwide Reference Base (WRB).

Some aspects of the pedogenesis process are also discussed. Three new methods of investigation used by researchers: Potassium–argon, gold mineralogy, and cosmogenic beryllium-10 allow dating chemical and weathering processes and also led to a quantification of geochemical and mechanical processes in this area. The modern climate has an impact on soils. All these types of soils are experiencing secondary pedogenic processes such as rejuvenation, and especially reworking to some extent by water or wind erosion, giving rise to younger soils. Rapid disturbance through reworking leads to induration and armouring.

Soil dating data in this area are very scarce. Some approaches (e.g. mass balance, relative chronology, chronostratigraphic, archaeological, luminescence, paleobiological, radiocarbon, OSL, and termite activity) have been implemented to assess the time factors of soil formation. Finally, this work highlights some gaps about soil research, particularly the need to define soil parameters which can be related to soil age.

1. Introduction

West Africa, with an area of 6 million km^2, covers one fifth of Africa between 4°N and 28°N, and 15°E and 16°W (Fig. 1). The Gulf of Guinea is the southern boundary; the norther is the northern boundary of Mauritania, Mali and Niger; the Mount Cameroon/Adamawa Highlands and the Atlantic Ocean form the eastern and western limits. West Africa includes 17 countries: Mauritania, Senegal, Cape Verde, Gambia, Guinea, Guinea-Bissau, Sierra Leone, Liberia, Côte d'Ivoire, Ghana, Togo, Benin, Nigeria, Cameroun, Mali, Burkina Faso, and Niger.

Soil research in West Africa started in 1948 and was carried out mainly by French Institute of research (IRD, formerly ORSTOM), African universities, and national research institutes, or was financed by international organizations (FAO, FAO-UNDP-OMVG). Research focused mainly on rock weathering and soil formation (Maignien 1965; Kaloga, 1966; Chauvel, 1967; Fauck, 1968), soil mineralogy, geochemistry and physical–chemical properties (Maignien, 1965; Kaloga, 1968; Boulet, 1970, 1978; Gavaud, 1977; Faure, 1978, 1985, 1987; Leprun, 1979; Levêque, 1979a, 1979b; Eschenbrenner 1988), soil surveys and soil fertility, and soil erosion and land conservation (Jenny, 1941; Ahn, 1961; Brammer, 1962; Volkoff and Willaime, 1963).

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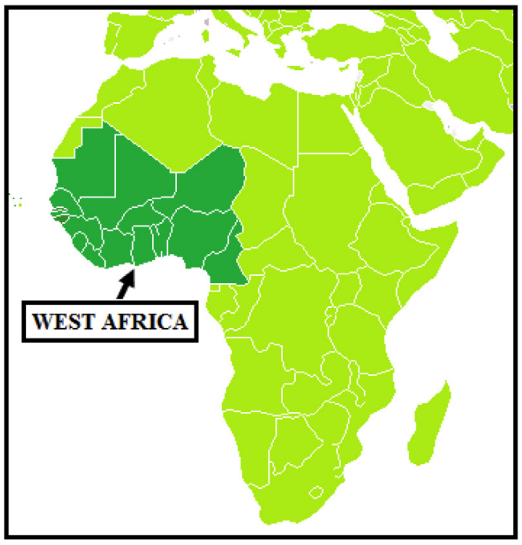

Fig. 1. Location of the investigated area.

Numerous data on soil development and soil properties exist in tropical Africa, but they have been rarely related to soil age in this region. A few studies, based on mass balance, have estimated the formation rates of those soils (Leneuf, 1959; Hervieu, 1968; Gac and Pinta, 1973; Trescases, 1975; Nahon and Lappartient, 1977; Boulangé, 1984). They estimated the rate of the weathering front as between 30 and 290 cm per 100 000 years.

This research has provided data on West African soils. Nowadays, investigated methods turn essentially on rates of soil-forming. It is necessary to adapt older information in order to harmonize soil data and get a soils database. This is very important because knowledge on rates of soil-forming processes can provide a good base to interpret paleosols in terms of duration and environmental conditions of soil development, and hence land surface stability. However, this is not particularly easy in tropical Africa where soil formation has operated over very long time intervals, since the Palaeocene or earlier.

This paper is a synthesis of soil data in tropical West Africa from bibliographic documents including theses, reports, articles, and maps relating to soil surveys in each country of the studied area. The main goals of this article are to present an overview of West African soil, discuss pedogenetic process, assess time factors of soil formation, and identify research gaps.

2. Geographic and geologic setting of West Africa

Most of West Africa consists of an undulating low plateau below 500 m, fringed on the west and south by a coastal plain which is widest in Senegal, the southern Côte d'Ivoire, the Niger Delta, and the lower valleys of the Volta and Niger rivers. There are some isolated highland areas above 500 m, and some peaks exceed 1000 m. The most important are Fouta Djallon (1537 m), Guinea Highlands (1656 m), Sierra Leone Mountains (1948 m), Jos Plateau (1690 m), and Adamawa Highlands (2042 m). Currently, along the Atlantic Ocean, the coastline is characterized by lagoons, mangrove swamps, and river-deposited sandbars.

The climate in this region (Michel, 2004) is controlled by the annual north and south migration of the intertropical convergence zone (ITCZ) which follows the apparent movement of the sun (Fig. 2). The lowland climates of West Africa are characterized by uniformly high sunshine and high temperatures throughout the year: mean annual temperatures are usually above 18 °C. The annual distribution of daily rainfall per year in West Africa shows two seasonal cycles, the "Guinean system" characterized by a bimodal shape due to the double passage of the ITCZ, and the "monsoon system" with a single season in summer (Nicholson, 1988). This highlights the zonal character of precipitation in West Africa (Fig. 2). Strong zonation results in rainfall on West Africa, particularly noteworthy north of the 1000 mm hysoyet, generally considered as the southern limit of the Sahel (De Felice, 1999). There are two maxima centered on Guinea and Cameroon related to orogenic influences of the Fouta Djallon mountain in the west and Mount Cameroon in the east. Mount Cameroon rises 4070 m above the neighbouring warm sea and receives the full force of the humid air, resulting in the highest rainfall of the continent (averaging 10 000 mm annually at Debundja). Between these two areas there is a uniformity of rainfall, except in Togo and Ghana which have the minimum rainfall. This area of low rainfall is designated "V Baoulé". This is because the coastline runs parallel to the direction of the rain-bearing southeasterly winds and the cold Benguela Current, which impinges on the coast and reduces the rainfall in amount and duration.

West Africa, because of the change in vegetation cover, orography, and its position in the tropics with a surplus radiation balance, consists of four climatic zones (Fig. 3): arid zone, semi-arid zone, tropical dry zone (or subhumid zone), and tropical humid equatorial zone. The heterogeneity of climate in these regions influences the vegetation distribution (Fig. 4).

- The arid zone (Sahel or Sahelian zone) has up to 750 mm of rain in a single short rainy season, not exceeding three months, with an extended dry season of up to 10 months. This zone includes northern parts of Senegal, parts of Mali, Burkina Faso, Niger, and Cameroon. The vegetation is mostly grassland.
- The semi-arid zone roughly includes the Sahelo-Sudan zone which covers the southern parts of Senegal, Gambia, Mali, Burkina Faso, Niger, Chad and northern Guinea-Bissau, Guinea, Togo, Benin, Nigeria, Cameroon, and the Central African Republic. The average annual rainfall, 750 mm–1250 mm, falls in one season followed by a long dry season. The vegetation is mainly grassland with some shrubs.
- The tropical dry zone (or subhumid zone) includes Guinea-Bissau, upper parts of Guinea, the southernmost parts of Mali and Burkina Faso, and the northern parts of Ghana, Côte d'Ivoire, Cameroon, Sierra Leone, and Benin, and the central parts of Nigeria. The average annual rainfall is between 1250 mm and 1500 mm in one season with a basically grass and shrub vegetation. Forests are confined to the river valleys in the southern parts of the zone.
- The tropical humid zone includes the Guinea or derived savannah zone with an annual rainfall of between 1500 mm and 1800 mm, divided into two wet seasons which alternate with two dry seasons. The natural vegetation is generally grassland and woody transitional forests. This sub-zone includes parts of southeast Guinea, northern Liberia, Côte d'Ivoire, Ghana, Togo, Nigeria, and southern Cameroon. A coastal savannah with about 730 mm annual rainfall extends from the middle of the Ghana coast to the extreme southwestern corner of Nigeria. The equatorial zone is essentially localized along the Gulf of Guinea, with annual rainfall above 2000 mm, which falls in two wet seasons alternating with two dry seasons. The vegetation is dense tropical forest.

The geology of this region (Fig. 5) includes the Archean to Paleoproterozoic West Africa Craton, Neoproterozoic to Paleozoic