

# Granitic-Gneiss Derived Soils in Humid Forest Tropical Southwestern Nigeria I: Genesis and Classification

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## Abstract

The genesis of granitic gneiss derived soils in the upland well drained areas of humid tropical southwestern Nigeria was studied. The soils have thick (0-20cm) dark brown (7.5YR - 10YR) coarse sandy loam to sandy clay loam - surface horizon, grading into sandy clay or clay in the subsoils. Presence of sesquioxidic concretions seems to reflect cyclic change of climate. The solum is acidic, low in organic carbon, exchangeable bases and cation exchange capacity.

Hydrolytic weathering appears to be the predominant pedogenetic process. The high rainfall, high soil temperature, acidic precipitation and the siliceous parent rock perhaps encouraged this weathering process, resulting in ferrallitic pedogenesis. Free internal drainage as conditioned by topography, geomorphic stability over a considerable geologic period, lessivation, braunification, induration, floral and faunal pedoturbation, mobilization and subsequent immobilization of iron during redox cycles in soils and cyclic change of climate were considered as other dominant pedogenetic processes in the soils. The soils of Iwo series are classified as clayey, kaolinitic, isohyperthermic typic haplustults and Ondo series as clayey, kaolinitic, isohyperthermic, typic kanhaplustults.

## Introduction

Previous efforts at understanding the genesis, chemical and mineralogical properties of soils formed in the Basement Complex of SW-Nigeria have been directed at the study of a veneer of pedisediment over saprolite. Nye (1955) postulated a biogeneous pedogenesis but Ojanuga (1978) noted that this hypothesis no doubt stemmed from improper recognition of the soil parent material. Ojanuga (1978), suggested that a consideration of the interaction of episodic landscape erosion and pedogenesis was required to explain the soil genesis. Earlier, a concept of cyclic soil-landscape development which permits the recognition of lithologic discontinuities (Ojanuga and Writh, 1976) was proposed for the genetic interpretation while Folster *et al.* (1971) suggested ferrallitic pedogenesis.

The views expressed by these workers may be due in part to their approach. Investigations were centred within the solum whereas epimorphic process begins at the rock -saprolite interface. Bryant and Dixon (1964) and Chesworth (1977) had indicated that close proximity to the rock is not necessarily an indication of a low intensity of weathering, and that early weathering stages may be more complex than the later stages. It was suggested that the genesis of soil begins with the physical and chemical alteration of minerals at the rock-saprolite interface. This study therefore examines the genesis of soils resulting from in-situ weathering of granite gneiss under humid tropical climate and attempts at classifying the soils.

## Materials and Methods

**Description of the Study area:** The location (7° 10' and 7° 37'N; 4°30' and 5° 00'E) is a region within the forest central southwestern (SW) Nigeria. (Fig.1). This area is generally gently undulating (2-8% slope) with occasional steeply sloping (>30% slope) rock outcrops (inselberg). Two periods of folding were recorded in the region. The first folding produced an anticline and the second re-folded the structures to produce an approximate North-South strike (the prevalent regional strike) that imposes the stream flow direction (Ojo-Atere *et al.*, 1987). A major town in the area, Ile-Ife, is 800-m above mean sea level.

The granitic-gneiss bedrock forms part of the Precambrian Basement Complex in Nigeria. Isotopic evidence indicated that its emplacement dates back to the Pan-African orogeny about 600± 150 m.a. (Kennedy, 1964), and had remained stable since ca. 1800 m.a. ago. The rock is deep-seated, often concordant or semi-concordant and medium to coarse textured. The area (humid tropical SW-Nigeria) is characterized with distinct dry (November to early March) and wet (mid March-October) seasons. The climatic water balance (Fig. 2) more clearly shows the duration and extent of the seasons. Rainfall pattern is bimodal with peak periods in June and September, mean annual rainfall is about 1300mm. Mean monthly atmospheric and soil temperature at 50 cm depth is moderately high, 27.1–30.4°C and 27.1–31.0°C respectively throughout the year. The climax vegetation has been described as tropical high forest with a dominant tree vegetation which have some recognisable layers of foliage (Keay, 1949). Thomas and Thorp (1985) based on a comparison of sedimentary, pollen and C-14 data from several sources in West Africa observed that the period from 11,000-7,500 B.P. probably was wetter than at present and indicated that a primary rainforest was present. Intensive agriculture in the area had given way to agricultural crops, thickets and bush regrowth.

## Field Studies

**Petrographic study of rock samples from several quarries preceded profile location.** This served as field check on the geological map and assisted in establishing areas underlain by granitic gneiss. Four representative deep profiles were located at the mid-slope portion of the topography. There were two profiles on each rock type - coarse and medium grained granitic gneiss. The classification is based on the crystal size of the constituents' minerals. Iwo and Ondo soil series are developed from coarse - and medium - textured granitic gneiss respectively (Smyth and Montgomery, 1962). Detailed morphological descriptions of the profiles were carried out as described in the F.A.O. guidelines for soil profile description (FAO, 1977). Multiple subsampling of horizon techniques (Smeck and Wilding, 1980) was used in taking soil samples, while undisturbed soil samples were taken with core samplers for bulk density determination. The addition of chemical elements to soils through rain was monitored by collecting rain water for a period of two years.

**Laboratory Studies:** The pH of rain water were determined soon after collection.

The basic cations, Si, Al and Fe contents of the rain water were determined after concentration by boiling. The Na and K content were determined by flame photometry. Ca, Mg, Al and Fe by atomic absorption spectrophotometre, and Si colorimetrically by the ammonium molybdate blue method (Kilmer, 1965). Soil samples were air-dried, gently crushed and passed through a 2-mm sieve. Percentage gravel (2-75mm) contents were computed. The fine earth (<2mm) was retained for analysis. Particle size distribution analysis was carried out by modified hydrometer method (Bouyoucos, 1962) with 0.2M-NaOH as

dispersing agent and overnight shaking on reciprocating shaker. A 25g soil and saprolitic material were each treated with 30%  $H_2O_2$  to remove the organic matters followed by 0.2M-NaOH overnight shaking prior to fractionation into clay (<2 $\mu$ m), silt (2-50 $\mu$ m) and sand (.50-2,000 $\mu$ m) fractions by the wet sieving, sedimentation and decantation procedure of Jackson (1956). Percentage Clay free sand adjusted for the bulk density (Mbagwu, *et al.*, 1983) was computed, and clay translocation was quantitatively assessed as in Ojo-Atere and Ogunwale (1982). Soil pH was potentiometrically determined in 1M- KCL and water at 1:1 soil-solution ratio, and organic carbon determined by the Walkley-Black (1934) procedure. Available phosphorus (P) was estimated by the Bray and Kurtz (1945) method. Total elemental analysis of rocks, saprolite, soil (<2 $\mu$ m), sand (50-2000 $\mu$ m) and silt (2-50 $\mu$ m) fractions was by  $Na_2CO_3$  fusion technique (Kanehiro and Sherman, 1965). The K, Mg, Ca, Si, Al and Fe content of the dissolved fusates were determined as earlier indicated. Exchangeable bases were measured in 1M-ammonium acetate ( $NH_4OAc$ ) extracts, and exchangeable acidity in both the normal KCl, and  $BaCl_2$ -TEA pH 8.2 extracts. Effective cation ECEC obtained as the sum of exchangeable bases plus 1MKCl exchangeable acidity; and cation exchange capacity by sum of cations (CEC-sum) representing sum of exchangeable bases plus  $BaCl_2$ -TEA, pH 8.2 exchangeable acidity were calculated. Percentage base saturation values based on ECEC and CEC-sum were also calculated. The potential evapotranspiration (PET) for the area was computed as 75% of the open-pan evaporation value (Virmani, 1976) and the climatic water balance was also estimated according to the method of Cocheme and Franquin (1967). Free iron and aluminum oxides were determined by the method described by Mehra and Jackson (1960). The amorphous Fe and Al oxides were extracted with an ammonium oxalate-oxalic acid buffer (Tamm's reagent) adjusted to pH 3.0 with HCl (Mckeague and Day, 1966). Active iron (Blume and Schwertmann, 1969) was calculated as:  $(Fe_2Q_3 - oxalate/Fe_2Q_3 - dithionite) \times 100$ , and was similarly computed for Al.

## Results and Discussion

### *Morphological and physical characteristics:*

The important morphological characteristics of the soils are given in Table 1. Prominent quartz veins which continue through the saprolite into the soils were observed close to two of the profile pits (Plate 1). In all the locations, the fabric structure of the saprolite closely resembles that of the underlying bed rock. These possibly suggest that the soils, saprolite and bed rock are geologically related and residual. Calvert *et al.* (1980) similarly observed continuous soil - saprolite -rock profile. Presence of residual quartz and or feldspar veins through mottled clay layer into upper horizons of soils were recognised to establish lithologic relationship between soil and the underlying bed rock (Smyth and Montgomery, 1962). The soils are generally well drained and deeply weathered. Depth of solum in all the four representative profiles ranges from 180-240 cm while weathered rock (saprolite) extends beyond 4-metres in most of the profile locations (Table 1). De Swardt and Oliver as reported by Ojanuga (1978) observed the occurrence of deep substratum of saprolite, about 30-m deep, in some SW-Nigeria Basement Complex areas. These were thought to have been formed by marked Tertiary geochemical weathering of bedrock throughout the intertropical regions of Africa. The soils have relatively thick (0-20cm) dark A-horizon ranging from dark brown (7.5 YR. - 10YR.) as in profiles 1-IC and 4-EI, to dark reddish brown (5 YR.) in others. Subsoil matrix colour in the solum is reddish, brownish, or yellowish with occasional strong brown, yellowish brown or red mottles. Reddening of upland subsoils is considered due to

**mobilization and subsequent immobilization of iron during redox-cycles in soils (Buol *et al.*, 1980), causing dispersion with progressive oxidation of iron. Folster *et al.* (1971) postulated a biogenetic process for the colouration, due to mechanical mixing by plant roots and soil fauna (termites mainly). Ojanuga (1978) observed that organic acids from organic matter decomposition and root exudates also encouraged subsoil homogenization in this area. The bright subsoil colour is perhaps also indicative of the good internal drainage. The lower part of the profiles are highly mottled possibly due to lack of mechanical mixing by plant roots and soil fauna.**

**Surface soils are generally coarse sandy loam to sandy clay loam, grading into sandy clay to clay in the B-horizons (Table 2). In terms of quantity and pattern of distribution, there is no sharp break in the total sand content or in any of the various sand size fractions within the solum. This is more clearly reflected by the fairly constant values of clay free sand adjusted for its bulk density with profile depth (Fig. 3). This does not clearly reflect the pedimentation in these soils. In the C-horizons, percentage clay shows a slight decrease thereby revealing the presence of a clay bulge in the B-horizons. The distinct clay skins and Bt/A-horizon clay ratio of greater than 1.2 (Soil Survey Staff, 1987) justify the recognition of argillic horizons. A quantitative assessment of clay translocation on a volume percent basis (Ojo-Atere and Ogunwale, 1982) indicated a net loss of clay (negative clay balance) in the A-horizon and a positive clay balance in all recognised Bt-horizons (Table 3). The clay budget for the entire solum shows that total clay gained is higher than the total lost. This suggests in-situ formation of clay possibly through the weathering of residual silicates (Ojanuga, 1978). Ojanuga (1975) observed that marked weathering and argillation of bedrock to saprolite had taken place in the Basement Complex of SW-Nigeria. Sesquioxidic concretions (Okusami and Oyediran, 1985), ferruginous skeleton (Folster *et al.*, 1971), iron nodules and concretions (Ojanuga, 1978), petroplinthites (Sys, 1968) and quartz materials are dominant in the gravelly horizons of the solum. These are indicative of different climatic or bioclimatic regimes. Dijkerman and Miedema (1988) noted that the presence of iron stone gravels in-situ in residual upland soils suggests that there had at one time been conditions favourable for the segregations of iron possibly in the form of plinthites. This process requires an adequate supply of iron, alternating wet and dry seasons, a relatively flat land surface with seasonally wet soils such as occur in the study area. Thomas and Thorp (1985) remarked that cyclic change of climate occurred during soil formation in West Africa.**

#### **Chemical Characteristics:**

The soils of Ondo series (Profiles 3-IM and 4-EI) are neutral to slightly acid in the surface horizon whereas Iwo series (Profiles 1-IC and 2-IT) are strongly acidic. Iwo series are more strongly acidic in the subsoil than soils of Ondo series (Table 4). Factors suggested to be responsible for the acidic solum include heavy rainfall, the acidic nature of the parent rock and the acidic precipitation. Annual rainfall is about 1300mm and most of this fall within six to seven months in the year (Fig. 2). At this period, rainfall is greater than 0.8PET which is considered the lower threshold value of moisture adequacy for leaching and colloid translocation. Precipitation in this region is acidic, pH 5.14-6.45 (Table 5), and is believed to enhance the soil acidity. Further more, the siliceous nature of the parent rock encourages the acidic nature of the soils and the pH of the saprolite (Table 4) confirms this. For instance, elemental analysis of the bedrock indicates (table 6) that Si and Al accounted for greater than 85% while the alkaline and alkali metals make up less than 7% of the total. In the surface horizon, the exchangeable Mg and Ca are slightly lower in soils of Iwo series than those of

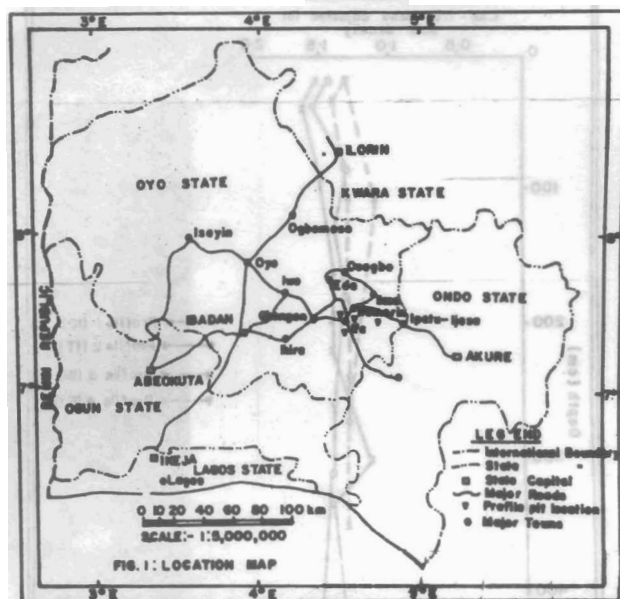


Fig. 1: Location of the study area.

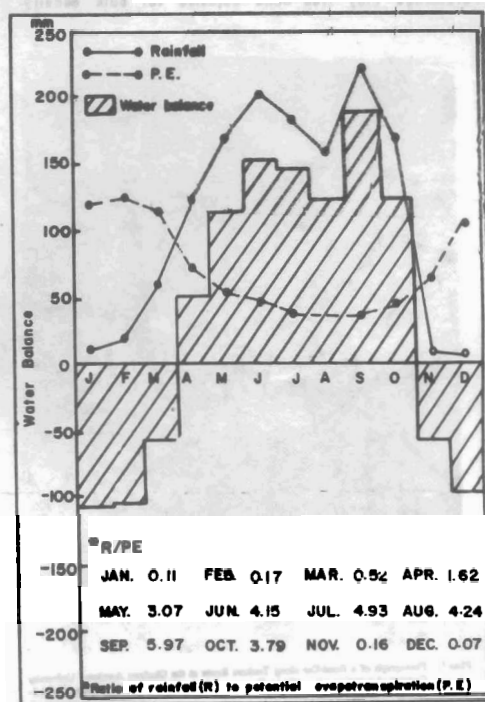


Fig. 2: Rainfall, P.E. and climatic water balance, Obafemi Awolowo University teaching and research farm, Ile-Ife.

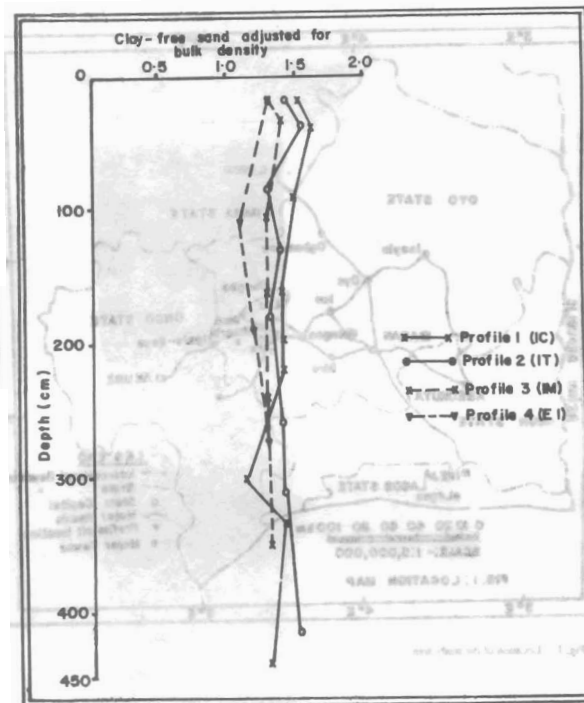


Fig.3: Percentage clay-free sand adjusted for bulk density



Plate 1: Photograph of a Road-Cut along Tombari Road at the Obafemi Awolowo University Campus, showing prominent Quartz Veins from the Saprolite into the soil Solon (Profile 1 IC) 15 M away)

Ondo, whereas Iwo series is higher in exchangeable K than in Ondo series. In Profiles 1-IC and 2-IT, exchangeable K, Mg and Ca are 0.45-0.51, 0.51-1.0 and 2.28-2.46 me/100g soil respectively in the 0-20cm depth. At similar depths in profiles 3-IM and 4-EI, exchangeable K, Mg and Ca are 0.25-0.4, 1.75 and 2.34-7.70 me/100g soil respectively. The trend is similar in the subsoil. Surface horizon CEC-sum in Iwo series ranges from 18.37 - 18.47 me/100g soil, and in Ondo series, the range is 16.51 - 22.54 me/100g soil. Solum subsoil CEC-sum ranges from 16.14 - 26.06 me/100g soil in Iwo and 13.68-17.14 me/100g soil in Ondo series. However, percentage base saturations by sum of cations' method are higher in the soils of Ondo series than in Iwo. Probable reason is the higher content of  $\text{BaCl}_2$ -TEA extractable acidity in Iwo than Ondo soil series. Also, the higher values of active iron obtained for profiles 3-IM and 4-EI further indicate that the soils of Iwo series are probably more intensively weathered than those of Ondo (Table 7). Higher active Fe ratios are believed to show predominance of amorphous form of iron which are product of recent weathering or less intensively weathered horizon (McKeague and Day, 1966).

In all the profiles, the exchangeable bases, CEC and percentage base saturation are slightly higher in the surface horizons than subsoils in general. Probable reason is that the surface horizons, although the most exposed to leaching and runoff, are indeed continuously recharged by phytocycling.

#### Soil Genesis:

Pedogenetic study of these soils reveals that hydrolytic weathering plays a significant role. Factors which appear to have encouraged rapid hydrolytic weathering in this environment are high rainfall, high soil temperature, acidic precipitation and geochemical nature of the parent rock. When precipitation is higher than 0.8 PET, leaching of basic cation and silica is encouraged. The acidic precipitation is believed to furnish hydrogen ions ( $\text{H}^+$ ). Rasmussen *et. al.* (1988) observed greater losses of  $\text{Na}^+$ ,  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$  and  $\text{K}^+$  in their study with acidified throughfall. The relatively high soil temperature encourages photolysis of water. Ojanuga (1979) remarked that warm soil temperature causes marked dissociation of soil water, leading to a build-up of hydrogen ions. Siever (1962) reported that high soil temperature and extreme leaching favour rapid desilication and accumulation of iron, immobilized in ferric oxide forms under oxidising conditions. Significant loss of  $\text{SiO}_2$ , alkali and alkaline earth observed in rock-saprolite-soil transformation with relative accumulation of iron and aluminium are considered resultant effects of the interplay of these factors. This is favoured by humid conditions, free internal drainage, geomorphic stability over prolonged period of time and strong weathering intensity (Beinroth, 1982). In the Basement Complex region of SW-Nigeria, the climate is humid as precipitation is greater than ET-for-greater part of the year with continually high temperature. Kennedy (1964) indicated that Nigeria lies within the zone of pan-african reactivation, east of the West African craton which had been stable since ca. 1800 M. a. ago. Iwo and Ondo series are upland, well-drained soils. Therefore, it appears that both the climatic, geologic and physical setting of the region predispose the parent rock to allitization (Henin and Pedro, 1965) or ferrallitization (Tessens and Shamshuddin, 1982) which is the basis for ferrallitic pedogenesis. Tessens and Shamshuddin (1982) noted that ferrallitic weathering is the dominant soil forming process in the humid tropical regions. Lessivation, braunification, induration, floral and faunal pedoturbation, mobilization and subsequent immobilization of iron during redox cycles in soils and cyclic change of climate were considered as other dominant pedogenetic processes in the soils.

## Soil Classification (Soil Taxonomy)

The pedons studied are mineral soils with an ochric epipedon, low in organic matter, high in colour values and chromas. The argillic horizons have recognisable clay skins, solum is acidic and low in base status. Base saturation by sum of cation method at 125cm below the top of the argillic horizon, or 180cm below the soil surface (Soil Survey Staff, 1987) is less than 35% (Table 4). These criteria place the soils in the order ultisols. The soils are dry for more than 90 cumulative days but less than 180 (Fig.2). The uplands of SW-Nigeria are primarily under Ustic moisture regime (Periaswamy and Ashaye, 1982), therefore the soils are in Ustults suborder. Profiles 3-IM and 4-EI have calculated ECEC of 8.13-12.02 me/100g clay, and in profiles 1-IC and 2-IT, the range is 12.26-19.65 me/100g clay in the argillic (Bt) horizons. The ECEC, texture and clay distribution in Profiles 3-IM and 4-EI meet the kandic horizon criteria. The ECEC of the clay however excludes Profiles 1-IC and 2-IT from the kandic horizon. The percentage clay decrease from its maximum is more than 20% within a depth of 150cm from the soil surface in these soils. This therefore places the soils of Ondo series (Profiles 3-IM and 4-EI) in the great group of Kanhaplustults and those of Iwo series as Haplustults. Most of the representative profiles (Table 1) have hue redder than 10YR, in all parts above a depth of 75cm, with ECEC of greater than 1.5me/100g clay to a depth of 150cm. Consequently, the soils of Ondo series are placed in the subgroup Typic Kanhaplustults and Profiles 1-IC and 2-IT as Typic Haplustults. Mean monthly soil temperature at 50cm depth in a typical Iwo series in SW-Nigeria ranges from 27-31°C, indicative of isohyperthermic temperature regime. The companion paper II indicates that the clay is 50-80% kaolinite. In the family placement, Ondo series are clayey, kaolinitic isohyperthermic typic kanhaplustults while Iwo series are clayey, kaolinitic, isohyperthermic typic haplustults.

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