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Soils of the Brazilian Amazon

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The Brazilian Amazon represents two-thirds of the total territory of the nation. The major extent of Amazon territory is still covered with exuberant humid equatorial forest which is in biological equilibrium between plant and soil. Recent construction of highways such as the Trans-Amazonian, the Belém-Brasília, the Santarém-Cuiabá, the Cuiabá–Porto Velho, and others of less extension have opened up new horizons for scholars from various fields of the natural sciences to study this immense region. Earlier exploratory soil studies have been made by eminent naturalists who visited the Amazon and presented an idea, though somewhat controversial, of the soils of the area. The Great Soviet Atlas of the World shows the Amazon as an immense cover of laterite with a strip of alluvial soil along the Amazon River. The work of Marbut and Manifold (1926), the references of Mohr and Van Buren (1954), reports by Felisberto Cardoso Camargo (1941) regarding the old quaternary soils of Bragantina region, soil analyses of the Federal Territory of Guaporé and the State of Pará by Silva Carneiro (1955), citations in Pendleton and Prescott (1952), and a few others make up what was known until recently of Amazonian soils.

Specialists from FAO, such as Sombroek and Day, brought to the Amazon a modern methodology of pedologic research, allowing for the establishment of means of soil classification for the region as well as providing orientation for the regional technicians. In 1959, the pedologist Thomas Day published works on the classification of soils of certain areas of the Amazon (Day, 1959a, 1959b); and later S. G. Sombroek contributed important pedologic studies (Sombroek, 1962, 1966). Beginning in 1956, technicians from the Department of Soils of IPEAN[1] initially with the cooperation of the FAO pedologists, began a program of pedologic study in the Amazon region; to date, they have surveyed about 580,000 square kilometers in the field.

In 1956, the Ministry of Agriculture of Brazil, in accord with USAID, published the *Mapa Esquematico de Solos das Regiões Norte, Meio Norte e Centro Oeste do Brasil*[2] with a scale of 1:1,500,000. This map was prepared through extrapolation of data from geologic, geomorphologic, vegetative cover, and local soil genesis maps, which used cartographic units associated with great soil groups and suborders. The pedogenetic types of the most frequent occurrence in the region are: yellow latosols, red latosols, dark red latosols, red and yellow dystrophic and eutrophic quartzilic sands, dystrophic and eutrophic lateritic concretions, dystrophic and eutrophic red yellow podsols, *Terra Preta do Indio, Terras Roxas,* grumosols, ground water laterites, dystrophic and eutrophic low humic gleys, humic gleys, alluvial soil, *salinos–salonchak* soils, alkaline solonetic soils, and finally organic soils (Igapós).

Latosols

Latosols are formed by the process of leaching and eluviations of silica resulting in the concentration of sesquioxides of iron and aluminum (Lemos, 1966a). These soils represent the greatest soil occurrence in the Brazilian Amazon, estimated at about 70 per cent of the total area.

The profile presents the sequence of horizons A, B, and C, with the absence of horizon A_2, being deep, strongly eroded, well drained, permeable, friable, and strongly acidic; in the B horizon, it is difficult to differentiate the genetic horizons. The texture can vary from sandy to very clayey, and textural classes of light to very heavy, respectively, are constituted. The structure of horizon A is almost always weak to moderate, small to average, blocky subangular or granular. Horizon B

1. Instituto de Pesquisa Agropecuaria do Norte (Research Institute of Agriculture and Animal Husbandry of the North).

2. "Schematic Map of the Soils of the Northern, Semi-North, and Central-Western Regions of Brazil."

is yellow or red and has a thickness of about 160 cm. and a texture always heavier than in overlying horizon A. The structure is more developed in the soils that have more clay.

The latosols have low chemical fertility, a consequence of their formation, for in the Amazon region they are derived principally from diagenetic evolution of Kaolinitic clay-sands belonging to the Tertiary-Series *Barreiras*. As they are soils resulting from this genetic formation, they undergo intense leaching as a consequence of local climatic conditions and possess very little reserve of vaporable minerals.

The values of the sum of the bases, the capacity for cation exchange, and basic saturation are always low, as is the assimilable phosphorus. Organic material content varies from average to high in the A horizon, decreasing considerably with depth in the profile.

The latosols are found in the Amazon region on level, slightly rolling terrain, and in some locations such as the areas situated between Manaus and Itacoatiara, Cacau Pirera–Manacapuru, and along the Belém-Brasília Highway, where the topography is very rolling (Brazil, IPEAN, 1969; Silva, 1970; Sombroek, 1962). Normally the vegetative cover on latosols is humid equatorial forest or Amazon Rain Forest; however, vegetative coverings of semidecidual equatorial forest, *cerradão, cerrado,* and *campo cerrao* can be observed. The soils where the semidecidual equatorial forests grow are found in the states of Mato Grosso, Goiás, and southeastern Pará. In accord with the clay horizon B, latosols are classified in distinct textural classes of average, heavy, and very heavy. Average has a clay content in horizon B varying between 15 and 35 per cent, heavy between 35 and 70 per cent, and very heavy greater than 70 per cent (Brazil, IPEAN, 1969; Sombroek, 1962). The latosols form a suborder in which there are several great groups which will be described below:

Yellow latosols.—This great group presents those fundamental characteristics of the suborder of latosol identified by yellow coloration with a hue of 10 YR and 7.5 YR (Munsell Color Chart, 1954), with values and chroma almost always higher and less friable than red yellow, red, and dark red latosols. Occurring principally in the Tertiary Amazon belt, they are distributed throughout the region constituting the pedogenetic type of greatest geographic representation in the Brazilian Amazon.

Red yellow latosols.—This great group, appearing much like the yellow latosol, differs with a hue of 5 YR (Munsell Color Chart, 1954), and therefore is redder in color and is more friable in the B horizon. Red yellow latosols are almost always associated with the yellow latosol but occupy areas more elevated and better drained.

Red latosols.—It is characterized by a hue of 2.5 YR or 10 YR, values of 4 and 5, chromas of 6 and 8 (Munsell Color Chart, 1954), being normally deeper, more friable, and having greater amounts of sesquioxides of iron when compared to the above mentioned groups. This great group occurs in association with the dark red latosol and is located principally in northern Mato Grosso. It has been found along the Belém-Brasília Highway near the town of Acailandia and in the states of Maranhão and Goias.

Dark red latosols.—The dark red latosol is the pedogenetic type having a dark red coloration with a hue of 2.5 YR and 10 YR, and with a value between the red yellow latosol and *latosol roxo* (purple latosol). It is similar to the red yellow latosol in origin but also is derived from parent material poor in minerals, and because of this, it has low fertility. There is very little textural difference between the A and the B horizons (Brazil IPEAN, 1970; Brazil, 1960). The dark red latosol is similar to the *latosol roxo* in that they have in common the tonal qualities of red color and a dense structure with a slightly porous consistency; they are different in that the *latosol roxo* is formed from parent rock basically richer in ferro-magnesium minerals and higher in quality in terms of iron and titanium mineralogic composition. The *latosol roxo* also differs from the dark red latosol in having effervescence with oxygenated water when fine, dry particles are treated with the reactant (Brazil, 1960).

Sandy Quartzous Soil

Red and yellow sandy quartzous soil.—This taxonomic type is composed of soils which have a deep profile, heavily eroded, very strongly acidic, excessively sandy, very porous, loose and at times friable, and difficult to differentiate between the horizons. The profile is excessively drained and almost always presents the sequence of horizons A, B, and C where horizon A is normally very dark gray brown (10 YR 3/2) to dark yellow (10 YR 4/4), and the B horizon can be dark gray brown (10 YR 4/2), yellow brown (10 YR 7/6), dark red (2.5 YR 3/6), or red (2.5 YR 5/8 and 4/8) (Munsell Color Chart, 1954).

The texture is sandy throughout the profile, being heavier in the B horizon, of light loamy sand and loamy sand. The principal characteristic of this soil is that it possesses a clay content under 15 per cent in the profile horizons. The structure is very weak and slightly blocky subangular and crumbles easily into fine particles. The consistency determined from humid soils is loose and friable, and with wet soil it is neither plastic nor sticky. The pores and channels are very well distributed through the profile, and the percentage of fine and medium size roots are greater in the A horizon; as a consequence, the organic material is higher. The organic horizon is almost always very thick and can reach 20 centimeters. The values of the sum of the bases, capacity of cation exchange, and saturation of exchangeable bases are low, except in some profiles located on the Carolina-Mirador Highway, kilometer 18, in the State of Maranhão, where these values are very high and are therefore considered eutrophic.

This type of soil occurs under two pedogenetic conditions; one, the most common, has a profile with a latosol B horizon, the other with a textural B horizon. In these cases they are called *Areias Quartzosas Vermelhas e Amarelas Latossólicas* and the other *Areias Quartzosas Vermelhas e Amarelas Podzolizadas,* respectively (red quartzous sand and yellow latosol, and red quartzous sand and yellow podzol).

The red and yellow quartzous sands occupy large extensions of northern Mato Grosso, principally in the areas of the rivers, Suiá Missú, Culuene, Jatobá, Steinein, Arraias, and the headwaters of the Xingú. In the lower Amazon, these soils have been found in some locations, such as Santarém, Alenquer, Monte Alegre, Almerim, etc., on the first terrace of *terra firme* (stable land in respect to the Amazon River). In the State of Maranhão, the occurrence of these soils is located principally in the area between the Turiaçu River and the Atlantic Coast in northwestern Maranhão (Brazil IPEAN, 1971a) named by Day as *Latosol Arenoso* (sandy latosol) (Day, 1959a). When sands occur in association with latosols, they occupy the higher ground.

The red and yellow quartzous sands in Pará and Mato Grosso are derived from the diagenetic evolution of sandy sediments of the Pleistocene, and those sands of Maranhão are derived possibly from the sediments of the Cretaceous period, brick red schists, and green and red shales belonging to the formation *Motuca* of the Triassic (Brazil IPEAN, 1970; Guimarães, 1964).

The vegetation which covers these soils varies in accordance with the ecological situation. In Mato Grosso, it is semideciduous equatorial forest, in Maranhão (Turiaçu River) and Pará, it is Amazon forest or humid equatorial forest, and in the area between Colinas and Mirador in Maranhão, it is babaçu-palm forest.

Lateritic Soils

Lateritic concretions.—In the Amazon, in almost all geologic formations, but principally in those from the Pleistocene and Tertiary periods, are found areas of soil which have in their profiles hard nodules, normally colored red, yellow, or violet, which are called lateritic concretions or commonly known as *picarra* (Falesi, 1970). These concretions vary in diameter from less than 2 millimeters to greater than 6 centimeters. The shapes are also very diverse, appearing rounded, flat, or with sharp points and edges formed by various factors. In the chemical composition of these concretions, there is a dominance of iron and hydrated aluminum oxides, the iron oxides occurring with greater frequency (Falesi, 1970).

This pedogenetic type includes all the soils which have lateritic concretions in the profile (regardless of whether the parent material is basic, sandy, schist, Quaternary or Tertiary sediments, etc.) but which have undergone intense action of laterization. Because of this, these soils are included in one large group called lateritic concretions.

The profile of this pedogenetic type follows the sequence of horizons A, B, and C, with B being textural, or latosolic, formed by the mixture of mineralogic particles and concretions of a ferruginous sand of various diameters and sometimes occupying the whole profile (Falesi, 1970; Vieira, 1967). These soils are strongly eroded, moderately deep, extremely acidic (depending on the parent material), of variable texture from medium to heavy, and of coloration varying from yellow through red yellow to dark red. The sum of the exchangeable bases, cation exchange capacity, base saturation, and assimilable phosphorus usually is low in value, except when the parent rock is basic, as is the case with some laterite concretions found at Monte Alegre and along the Trans-Amazonian Highway.

Such soils occur indiscriminately throughout the whole Amazon region in small areas almost always associated with latosols. In the State of Acre, these soils are hardly representative while in the Federal Territory of Amapá they occupy extensive areas.

Podzolic Soils

The podzolic soils have the characteristics of podzoliation, or the diagenetic process which is the downward migration of clay minerals by the removal of the clays in the A horizon and their concentration in the B horizon; in other words, podzoliation leads to the formation of clay properties in the alluvial horizon. Given the formation of the diagnostic B horizon, B is then textural or clayey (Lemos, 1966a). The general concept of these soils can be summed up thus: there are A, B, and C horizons, with or without A_2, with a medium deep profile, moderately to well drained, friable to firm, average to heavy texture, well-developed structure (block-subangular) in the B horizon, having a covering of filmy colloidal material between the structural units and along the root channels which are called "clay skins."

Red yellow podzols.—The red yellow podzols found in the Amazon can be divided into various groups according to the origin of parent material. These are: the *Podzólico Vermelho Amarelo Plinthico* (which has a plinthite layer at the base of horizon B), the *Podzólico Vermelho Amarelo da Serie Barreiras* (originating from the diagenetic evolution of the sediments of the Barreiras series geologic formation), *Podzólico Vermelho Amarelo substrato filitoxisto* (found near Marabá-Tocantins, originating from the weathering of the schist phyllite substratum), the *Podzólico Vermelho Amarelo Eutrófico* (of Cretaceous origin found in the State of Maranhão), the *Podzólico Vermelho Amarelo Eutrófico substrato folhelho* (Monte Alegre), the *Podzólico Vermelho Amarelo Eutrófico* (in Altamira), and the *Podzólico Vermelho Amarelo Eutrófico intermediário par cambisol Eutrófico* (found along the Trans-Amazonian Highway) (Almeida, 1967; Brazil IPEAN, 1971a; Falesi, 1967a, 1970; Lima, 1965; Silva, 1970).

The red yellow podzols, depending on the values of base saturation, are separated into eutrophic and dystrophic, according to the respective base saturation of high or low. *Podzólicos Distróficos* (dystrophic podzols) occur with greater frequency throughout the Amazon. The eutrophic type is found in Maranhão, in the Lower Amazonas, in Southern Pará (in the *município* of Conceicão do Araguaia), and Altamira on the Xingú River (Almeida, 1967; Falesi, 1967a, 1970). The red yellow podzols normally occur in more broken topography than the latosols, almost always forming a sequence of knolls and/or long sloping hills. The forest cover is largely Amazon forest; however, in some areas, the babaçu-palm forest dominates, e.g., in Maranhão, and semi-deciduous equatorial forest dominates in such areas as *Conceicão do Araguaia.*

Terras Roxas[3]

The expression *Terra Roxa* is used in the states of São Paulo, Paraná, Minas Gerais, and others to designate soils of basic origin, of high fertility, red color, violet tonal quality, and almost always of a clayey texture. After studying a mixture of original material, Professor Setzer of the Instituto Agronomico de Campinas was the one who first classified the *Terras Roxas.* He identified three types: *Terra Roxa legitima* (true Terra Roxa), *Terra Roxa misturada,* and *Terra Roxa de Campo* (Terra Roxa of the Savanna) (Setzer, 1949).

Terra Roxa legitima.—*Terra Roxa legitima,* belonging to Group 13 of Setzer's classification, has for its basic material essentially extrusive

3. Editor's note: *Terra Roxa,* literally purple land, is not translated from the Portuguese as the term should be used in context.

rocks. Particles of quartz are almost absent, but there is much shiny black sand from the presence of ilmenite and magentite.

Terra Roxa misturada.—*Terra Roxa misturada,* Group 14 of Setzer's classification, originates from the decomposition of basic rocks and also from sands which are interspersed in horizontal beds of variable thicknesses. The weathering of these rocks results in a soil of mixed composition with mineralogic characteristics of basic and sandstone rocks. The mixture of these minerals is not proportional as there is always a predominance of one of the original materials in the different soils. These soils are clayey and fertile when the sediments of the basic rocks predominate and sandy and low in fertility when the parent material is sandstone. In this (latter) case the soil receives the name *Terra Roxa de Campo,* which corresponds to Group 12 of Setzer's classification.

Actually, according to a second criterion of the Soil Survey of the Brazilian Ministry of Agriculture, the *Terras Roxas* are classified as *Terra Roxa estruturada* (structured *Terra Roxa*), which has a textural and *Latosolo Roxo* B horizon because the B horizon is latosolic. In the Amazon, the *Terra Roxa estruturada* is very extensive, having been found in various locations while the *Latosolo Roxo* is located only in the *município* of Alenquer on the road, *Lauro Sodré,* kilometers 31 and 32 (Brazil IPEAN, 1970).

The *Terra Roxa* has its origin in the weathering of basic rocks. These rocks in Brazil appeared principally during the Retic period by Paraná diastrophism and were accompanied by basic lava flows which covered great areas. In fact, these lava flows covered extensive regions of the Paraná River Basin. O. A. Derby, cited by Oliveira and Leonardos, named this lava flow the *Trapp do Paraná* (Paraná Trap) (Oliveira and Leonardos, 1943). It has been shown that the lava flows of Paraná and southern Brazil were not limited to that region since they also reached other areas in the Amazon as well as Venezuela and the Guianas.

In the Brazilian Amazon, various occurrences of basic magmatic material are perfectly recognizable. In the State of Pará, *Terras Roxas* have been identified in the *municípios* of Alerim, Alenquer, and Monte Alegre in the lower Amazon, Conceicão do Araguaia in the south, and Altamira along the Trans-Amazonian Highway. In the Federal Territories of Rondônia and Roraima, there also exist significant occurrences of this soil. In northern Goiás, in the *município* of Araguaia, there also has been recorded the presence of *Terra Roxa* (Agriamazonia, 1969; Beek and Bennema, 1966; Almeida, 1967; Brazil IPEAN, 1970; Falesi, 1967a, 1970). Certainly there are extensive areas of *Terra Roxa* as yet unknown because of the difficulty of access to immense areas of the Amazon which are waiting to disclose their plentitude. These soils should provide the most valuable potential of the great valley. Nevertheless, of the areas studied by means of actual penetration, we can only estimate that *Terra Roxa* covers 1,030,000 hectares in the Brazilian Amazon. The pedogenetic characteristics of the *Terras Roxas* are outstanding among Brazilian soils, when compared, not so much for their physical or chemical properties, but above all for the high productivity (agricultural) which they possess.

"Structured eutrophic" Terra Roxa.— This pedogenetic type, already mentioned, is formed of fertile soils originating from basic rocks and has a low content of quartz in its mineralogic composition and a high content of iron (Falesi, 1970; Setzer, 1948). These soils possess an average thickness of 150 centimeters, considering the A and B horizons. They are well drained with dark brownish red coloration which turns purple when observed at determined angles of incidence of the sun's rays. Differentiation between the horizons is very difficult because of the small variation in color, which presents a diffuse and gradual transition between them.

The "structured eutrophic" *Terra Roxa* has a moderate to heavy waxiness and very abundantly endows the soil structure with its aggregate components. The consistency determined by wet soil is plastic and sticky, the number of fine pores is abundant, and the number of roots diminishes with depth of profile. When dry, the soil particles are strongly attracted by a magnet because of the presence of heavy minerals in the mineralogic composition of the soil. On the surface, it is very common to observe the accumulation of these minerals of dark color determined as being ilmenite (Falesi, 1970).

The structure of horizon A is generally weak and moderate, small and in subangular block form, and in horizon B it is moderate, average, and subangular, sometimes being slightly prismatic. Chemically, the soils, owing to their genesis, are high in nutrients, particularly in the bases of calcium and magnesium, low in acidity (nearly neutral), and, as a consequence, possess high indices of saturation since they are eutrophic soils. The *Terras Roxas* in the Amazon are geologically attributed to the Retic period occurring on a slightly undulating topography with a vegetative cover principally represented by humid equatorial forest or Amazon Rain Forest.

Eutrophic latosol roxa.—The eutrophic latosol *roxa* is a deep soil, well drained, with a latosol B horizon; friable; porous, dark brown yellowish or dark red in color, with a color hue 2.5 YR, it becomes purple when observed with solar rays falling on the profile. Morphologically, it is similar to the dark red latosol, differing, however, in origin. The eutrophic latosol *roxo* is formed from the weathering of basic rocks which results in high iron content and high base saturation while the dark red latosol has parent material principally made of sediments attributed to the Tertiary, and, as a consequence, low iron content and low base saturation.

The profile is of type A, B, and C with a depth of about 2.5 meters, with the presence of concretions called *chumbinho de caça,* which are much like magnetic minerals. It has much aggregate stability in horizon A (Brazil, 1960). The texture of this horizon is loamy clay, being normally of moderate structure, and is small and average in subangular blocky form. The consistency determined by dry soil is hard, by humid soil, friable, and by wet soil, plastic and sticky. The transition between the horizons is plain and diffuse. Horizon B has a thickness of about 1.6 meters, a coloration of dark yellowish brown and dark red; the texture is heavy clayey and light clayey; it has a structure of subangular and granular, small and average, weakly developed. It is hard, very friable, plastic and sticky, having a diffuse transition into horizon C.

Chemically they are soils which possess high base saturation with values between 66 and 96 per cent. There is medium capacity of cation exchange in horizon A, which varies from 18.55 mE/100 grams of soil to 16.20 mE/100 grams of soil, these values falling abruptly in the B horizon. The sum of the exchangeable bases is also high in the A horizon and decreases towards the alluvial horizon. The pH varies through the profile from 5.8 to 6.9, from moderately acid to neutral. Assimilable phosphorus is low in these soils; this is common in the Brazilian *Terras Roxas.* The eutrophic latosol *roxo* originates from the weathering of basic rocks where the process of laterization predominates, developing as a consequence a latosolic profile of high fertility. It occurs on level and slightly rolling relief, having been found until now in the *município* of Alenquer in *Pães de carvalho* agricultural colony, at kilometers 31 and 32 on the Lauro Sodré Road, located at Emilia Ezequiel and Villa Nova (Brazil IPEAN, 1970), and along the Trans-Amazonian Highway. The primitive vegetative cover is humid equatorial forest, and in various places, the soil is already covered with crops or secondary growth.

Terra Preta do Indio[4]

In the Amazon, latosols constitute the soil of greatest geographic distribution. They are deep soils, yellow or red, of low chemical fertility, having been endowed, however, with good physical properties. Contrast-

4. Literally, "black soils of the Indian."

ing with these soils, however, there occur on higher level land, numerous spots of land which usually form circular layers but do not occupy great extensions (Brazil IPEAN, 1970; Franco, 1962; Gourou, 1949). They are soils of natural fertility and have black alluvial horizons which explain the high content of organic material. In addition to these chemical characteristics, they contain a high content of assimilable phosphorus and exchangeable magnesium. Another characteristic of these soils is the notable presence of fragments of indigenous ceramics within them; these are principally located in the anthropic horizon (Etchevehere, 1962), which has stimulated many interesting hypotheses in respect to their origin (Camargo, 1941; Falesi, 1967a; Gourou, 1949). The *Terras Pretas do Indio* already studied present the sequence of horizons A, B, and C, with the exception of one profile observed in Monte Alegre (located in Major Barata Colony) where there was an absence of the alluvial horizon. The black A horizon was sitting on top of rocky material (Falesi, 1970).

The black soil has as its most evident characteristic a prominent A horizon, anthropic, black, friable, humic, normally with a high content of clay, very acidic, rich in exchangeable bases, principally calcium and magnesium, and a very high content of assimilable phosphorus. Normally the horizon is deep, varying from 30 centimeters to 150 centimeters. The latter depth was found in the *município* of Oriximiná, State of Pará (Falesi, 1965, 1967a). The average, however, is about 55 centimeters, since this horizon is deeper in the center of the circular spot than in the areas which border the neighboring soils. The B horizon, on the contrary, is of yellow or red yellow coloration, clayey, friable to firm with or without waxiness, subangular structure, moderately developed but can be of coherent porous mass which disintegrates in fine soil since it is plastic and sticky or very sticky.

The content in terms of chemical elements is always lower than that found in the A horizon; however, if compared with the latosols of the region, the values are much higher. Phosphorus maintains a high level in the B horizon even though the value decreases as the profile deepens. The nutrient P_2O_5 varies in the A horizon from 66.00 mE/100 grams of soil to 21.40 mE/100 grams of soil and in the B horizon from 93.16 mE/100 grams of soil to 3.8 mE/100 grams of soil. Normally the values in the B horizon are above 20 mE/100 grams of soil.

The exchangeable calcium, like the exchangeable magnesium, is high in content in the *Terras Pretas do Indio.* Organic material values, determined by calculating the carbon content in the A horizon, vary from 9.55 to 1.5 per cent, since they have lower values in the transition to horizon B. Organic material in the alluvial horizon is much lower, varying from 1.99 to 0.44 per cent, having a decrease in value as the profile deepens. Exchangeable base saturation determined by value V per cent is high in the A horizon. In this horizon, the index "V" varies from 87 to 46 per cent, and in B from 71 to 32 per cent. It is considered a soil of high base saturation and therefore is eutrophic.

Cation exchange capacity, or the basic contents to the point of saturation expressed in milligram equivalents, presents much higher values in horizon A owing to the notable presence of high organic material. These values vary from 61.82 mE/100 grams of soil to 13.11 mE/100 grams of soil in horizon A, and in horizon B, from 12.24 mE/100 grams of soil to 3.7 mE/100 grams of soil.

Cunha Franco (1962) is of the opinion that the *Terras Pretas* had their origin starting from closed depressions which are a characteristic of the Santarém *planalto.* These depressions coincide almost always with the size of the spots of *Terras Pretas* already formed. During the rainy period, the depressions fill with water and create small shallow lakes whose subsoil has an impermeable clay layer and can retain water for a long period of time. According to Cunha Franco, the Indian inhabiting the margins of the Amazon and Tapajós rivers realized that because of the low productivity of the harvests, the marginal *terras firmes* were of low fertility. When planting was done on higher land and further from the river where there was more clay content, the fertility was higher, permitting better harvests. In the dry season in the higher lands, it was possible to find water in the depressions. Water was indispensable for sustenance and for the preparation of manioc flour, the basic food. Cunha Franco explained further that when the rains started, the Indian migrated from the river margin to the higher land and settled beside these lakes or natural basins, setting up provisional villages and remaining for the duration of the rainy season (December to June).

The wastes of these villages were gradually thrown into these ponds, as well as the broken utensils and pottery which today are found in great numbers. The floods contributed to the buildup of silt deposits in the depression by washing in the remains of plants and animals. When the rains ended and the ponds started to dry up, the Indian returned to the river margin where he lived from fishing during the dry season. Continuing the cycle of coming and going, prolonged over many years, allowed for the formation of the soil found in horizon A. This soil is black and rich in organic material as well as in the phosphorus, calcium, and magnesium resulting from the remains of plants and animals such as the skeletons of humans and animals.

Countering the archaeological hypothesis, Pierre Gourou (1949) questions the existence of indigenous settlements so large and of such long duration that they can account for the accumulation of calcium and phosphorus (originating from animals and human skeletons) in such quantities as to be sufficient to form the spots of black soil. The modern Indians inhabit villages so modest and unstable that they could not be responsible for having created lands with such a thick anthropic horizon. Gourou cites the geologic theory of the black soils and thinks they have originated from sediments deposited in the depths of lakes or else from the weathering of volcanic rocks. He argues that, in the first case, the high content of calcium and phosphorus cannot be explained, which would not be true if the soil had a turf origin, leaving human occupation responsible for the accumulation of calcium and phosphorus. Felisberto Camargo (1941) admits that no geologic formation could be responsible for the richness of mineral elements found in the *Terra Preta;* he has in mind that these deposits are found in the lower Amazon at altitudes of 170 meters to 180 meters and 70 kilometers from Santarém. He says that transport in the horizontal sense does not justify the presence of the high parts, principally on the borders of the Belterra Plain, because if horizontal transport were the cause, then deposits would have been found at lower altitudes. In this manner Camargo does not find a justification for the transport in the horizontal sense, attributing the richness of phosphorus and calcium to vertical transport and suggesting the hypothesis that the origin of the *Terras Pretas* started with volcanic ash.

Gourou (1949), combating the volcanic hypothesis, asks, "How is it possible, the presence of numerous spots of these soils in various places?" "Would it be necessary that the volcanic elements are very recent so they could be found in the most varied morphological positions?" He continued: "How do you explain the absence of all the elements not decomposed?" The opinion today is that the *Terra Preta do Indio,* already having been reasonably studied morphologically and chemically, has mixed origin, that is, geologic and anthropogenetic.

The Amazon region today is a vast area covered by exuberant humid equatorial forest; nevertheless, from the Pre-Silurian until the Carboniferous, a large gulf occupied this region, constituting an authentic mediterranean sea which was connected with the west or Pacific Ocean. The east did not connect with the Atlantic, being limited in the north by the Guiana Highlands and in the south by the Central Brazilian Massive. At the end of the Carboniferous period, the sea dried up, draining all of the area which today constitutes the Amazon basin, the drainage at this time toward the Pacific. At the end of the Cretaceous, the rise of the Andes began and blocked the outlet of rivers to the Pacific. In this manner water was dammed and formed an immense fresh water lake which existed during the whole Tertiary. As time passed, organic and mineral sediments constituting hundreds of thousands of meters of thickness were deposited in the depths of this lake.

The Andes continued to emerge, and at the end of the Tertiary, possibly with the help of vertical movements of the continent, the eastern part of the great lake opened and gave passage to the water so that it could flow into the Atlantic. This exposed the dry lake bottom which became covered with new vegetation, the Amazon forest of today. Obviously the bottom of the great lake had level, raised, and depressed areas. With the departure of the water, the depressions remained filled with water, imprisoning the animals who inhabited the waters of that region as well as the aquatic vegetation. With time, this water dried up; existing life ceased to be which resulted in the death and decomposition of the animals and plants. The noted presence of phosphorus and calcium in the *Terras Pretas* was caused by the bones of the animals that lived in the closed depressions. Even today, ribs of considerable size, jawbones, etc., can be found in some locations of the *Terra Preta.* The Indian contributed to these water holes when he inhabited them.

This is only a hypothesis. A more scientific clarification of the formation of these soils would require more research in the field and in the laboratory by specialists from various scientific disciplines. Such a group would include archeologists, anthropologists, pedologists, geologists, geomorphologists, and paleobotanists, working together with the same objective. In a short time, these scientists could solve the problem of the genesis of the *Terra Preta do Indio.* Such soils are widespread in the Brazilian Amazon. They have been found near Santarém; southwest of Manaus between the Solimões and the Rio Negro; on the margin of lakes in the Rio Trombetas–Uaupes region; near Altamira on the Xingú River; at the Indian post Diavarun higher up the Xingú; and on Marajo Island (Gourou, 1949; Silva, 1970).

Developing Soils

Grumosols.—Grumosols are soils included among the vertisols which present typical characteristics of high clay content, more than 30 mE exchange capacity in all horizons below 5 centimeters, presence of "gilgai," occurrence of "slickensides" (structural aggregates in the form of wedges or paving stones inclined between 10 and 60 degrees with the horizontal), and the presence of calcic horizons (Etchevehere, 1962; Falesi, 1970).

The montmorillonite material can be derived from calcarius, basic, and sometimes from granitic rock. In the Amazon region, grumosols were studied beginning with the decomposition of limestone and basic igneous, since they have not yet been observed among granitic rocks (Falesi, 1970). During the rainy period, grumosols remain very wet; in the dry season, they become very dry and form cracks up to various centimeters below the surface.

Grumosols with limestone substratum.—The grumosols with calcarious substratum constitute a soil type which is derived from the decomposition of Carboniferous or Pre-Cambrian limestone rocks. A consequence of horizons A, C, and R is present in the profile with an absence of horizon B. Horizon A is normally very thick, of black color, has a high clay content, and a high base saturation. The texture of horizon A is heavy clay or clay, having a strong structure, small and average blocky subangular in form. Prismatic and columnar structure also occur, and a colloidal filmy material called "slickensides" is observed between the structural elements between the soil masses. The degree of consistency of the soil is plastic and sticky when wet and is hard to very hard when dry.

Horizon C can be divided into C_1, C_2, C_3, etc., having a high content of soluable salts, principally calcium carbonate, where an abundance of concretions is formed by salt precipitation. The color of this horizon can be dark grayish brown, clear olive brown, or of grayish tone. These soils are normally low in organic material content but have high values in the sum of the exchangeable bases, exchange capacity, and base saturation. The acidic index determined by pH can vary in horizon A from 6.0 to 6.8, therefore being slightly acidic; in the C horizon, it is much higher, varying from 7.5 to 7.9, owing such high values to the presence of exchangeable bases, principally calcium and magnesium.

The grumosol with limestone substratum occurs in the Amazon region in these places: Município of Conceição do Araguaia and Município of Monte Alegre (State of Pará), Município of Imperatriz (State of Maranhão), and in the Federal District of Roraima (Falesi, 1970).

The vegetative cover is varied; it can be dry forest as in Maranhão, *cerrado* as in Roraima, semideciduous equatorial forest as in Conceição do Araguaia, and Amazon forest as found in Monte Alegre. These soils occur on level relief in valley bottoms and in Maranhão; on the President Dutra Highway in *Barra do Corda,* they occur on slightly rolling relief in the uplands.

Grumosols with basic rock substratum.—This pedogenetic type is similar to the preceding type, differing principally in these three characteristics (Falesi, 1970). (1) Calcium content, exchange capacity, sum of the exchangeable bases, as well as base saturation, are lower in these soils derived from diabase. (2) Magnesium content is higher in the grumosols originating from diabase, resulting from the presence of ferromagnesium minerals in the mineralogic composition of the rock matrix. (3) Morphologically, the soils derived from limestone have the thickness of horizon A much more developed, as the presence of "slickensides" is more evident.

The grumosol with basic rock substratum occurs on level relief and sometimes in areas slightly sloping, as in the road which links Dourado to Pilão at Jari Indústria e Comércio.[5] It occurs in the Brazilian Amazon in the State of Pará: in the *município* of Alenquer (Campo do DEMA), in the *município* of Almerim (Jari Indústria e Comércio), and in the State of Goiás along the Trans-Amazonian Highway.

Lithosols.—The lithosols are azonal soils, poorly developed, shallow, with a sequence of horizons A, R, or sometimes A, C, and R depending upon the performance of the soil forming factors, principally time and relief. Horizon A, normally with 25 to 30 centimeters of thickness, is found sitting on top of a rock matrix, the characteristics of the profile poorly developed. The fertility of these soils is based upon the rock matrix of origin. They are fertile if the parent rock is basic limestone, limestone shale, etc., and of low fertility if originating from sandstone, siltstone, or other rock poor in mineralogic composition. Lithosols studied in the Amazon region originate from the following rock materials: diabase, gneiss, sandstone, and siltstone.

These soils are found in the State of Pará: in the *municípios* of Alenquer and Monte Alegre; in *Serra de Tumucumaque* in the extreme north on the border with Guyana; in *Serra do Acaraí* on the border with French Guiana; and in *Serra de Gorotire e Carajás.* They are also found in several areas in the State of Maranhão, in the State of Amazonas near the border with Colombia, in the Federal Territory of Amapá in *Serra de Tumucumaque* near the border with French Guiana, and in the Federal Territory of Roraima in *Serra de Parima e Paracaima* near the border with Venezuela. They occur in areas where the relief is undulating or mountainous and almost always where rock outcrops can be observed. The vegetation which covers these soils is well characterized, normally *campina-rana,*[6] but it can be mountain forest.

Regosol.—Regosols are azonal soils (Brazil IPEAN, 1969; Day, 1959b; Falesi, 1967a; Robinson, 1960; Silva, 1970) characterized by being very deep, very sandy, loose, extremely well drained, and with a sequence of horizons A, C. They originate from the diagenetic evolution of sandy

5. This company plants *Gmelina arborea* on a large scale in the region of the Jari River in the *município* of Almerim, Pará.

6. Translator's note: *campina-rana* is typical Amazonia grassland with woody vegetation.

sediments belonging to the Pleistocene (Sakamoto, 1957) and have a very low natural fertility. The organic layer O, formed principally by a network of fine diameter roots and also by vegetative remains, has a variable thickness of 8 centimeters to 12 centimeters and a dark brown color which at times is black.

The mineral horizon A, situated below the organic layer, has a thickness on the order of 15 centimeters and a color of clear gray 10 YR 7/2 or pink-brown, corresponding to the hue of 5 YR. The texture is sandy, and the structure is of simple noncoherent grains, having a consistency when the soil is humid of loose and very friable and when wet of not plastic or sticky. The fine and average roots are abundant in this horizon because of the high content of organic material derived from the decomposition of the remains of plants and animals deposited on the soil surface.

Horizon C is deep, excessively sandy (quartzic sand), the color (when humid) varying from neutral N/8 to clear gray with hues 2.5 Y to 2.5 YR. There is no structure in this horizon since it is a determined consistency with wet soil, neither plastic nor sticky.

Potential and fertility of these soils are very low according to the values of the sum of the exchangeable bases and exchange capacity (Brazil IPEAN, 1969; Day, 1959b; Silva, 1970). These soils occur in level areas with typical vegetation of rickety forest called *campina* or *umirizal* (Silva, 1970) or even "caatinga" (Brazil IPEAN, 1969; Vieira and O. Filho, 1962).

Water-deposited soils.—These soils are found sometimes on the first terrace level from the banks of the white water rivers (Sioli, 1951) subject to inundations, or in low areas situated between higher areas in narrow valleys. They are formed by recently deposited materials (not consolidates of Halocenic origin), having silt as the dominant fraction in the granularmetric composition.

Recent alluvial soils do not have genetic horizons in the profile, but they do have a sequence of mineral layers originating from various deposits of sediments. The deposits are formed by being inundated by the muddy river waters which release the particles from suspension. The color is gray with distinct common specks, principally in the first layers of the profile, and soils are normally of medium to high fertility.

Hydromorphic Soils

In the hydromorphic soils are included the meadow lands, which are level, low, recently formed sediments that border the rivers, having variable extension and reaching in some places several kilometers (lower

Amazon). In accord with the formation of these soils three types can be distinguished: high *várzea* (meadow-like levee), low land (back swamp), and the Igapó (Gapo), all being directly related to the process of sedimentation of the particles in suspension in the river waters (Falesi, 1967b; Lima, 1965; Sioli, 1951). In the high *várzeas,* the larger particles sediment first, being next to the river where the topography is higher. The granularmetric composition of these soils is predominately constituted of the largest particles and, because of this, is better drained. Particles further from the river become finer with distance, and the land topographically is much lower and forms the low *várzeas* and finally the *igapó* (Lima, 1965; Sioli, 1951). The term *igapó* refers to low areas of constantly stagnant waters with semidecomposed organic material in suspension and a very acidic reaction.

The principal *várzeas* of Amazonia are those formed by white water rivers of mud rich in sediments or organic matter. The *várzeas* of the Amazon River and of the estuary are those which are the most important since they are best known and are utilized as much for livestock as for agriculture. Physically the high *várzea* of the Rio Guama (estuary) has a high content of silt fraction and clay, approaching fine sand with thick particles (Lima, 1965; Vieira, 1967). An analysis of the chemical elements shows the presence of calcium and a high content of magnesium. Potassium is low, and sodium is average. The analysis of organic material reveals a high content in the superficial horizons; this decreases considerably with deepness of profile. The pH of these soils is very strongly acidic (pH 4.5 to 5) (U.S. Department of Agriculture, 1951). The potential of the estuarian *várzea* results from the periodic depositions of sediments brought by the river waters, renewing the content of nutrient elements.

The *várzeas* of the Amazon River are morphologically similar to the estuary, but in some places, the soils have high chemical contents. They are soils developed on level relief, flooded by the Amazon River, which deposits the sedimentary material, for a period of approximately six months. Principally this material is made up of fine particles of silt, clay, and other minerals besides organic elements. *Várzeas* of Amazonas were recently formed in the Quaternary in the Halocene period. They are imperfectly to badly drained, of heavy texture (clay) with a high silt fraction percentage. The pH is on the order of 5.5 (Brazil IPEAN, 1969) or even less (Falesi, 1965).

The profile is made up of the organic material of horizon A, followed to a slight depth to the strong gley horizons, abundantly speckled. These conditions of gleyation are caused by the oscillation of the water table which results in oxidation and reduction of the various soil layers.

When these layers or horizons are wet, they lack air and consequently lack oxygen, and the trivalent free iron is reduced. When the water level is low, air and oxygen can enter into the various layers through the pores, oxidizing the iron. This oxidation, however, is not homogeneous. Various spots, especially among roots and cracks, are oxidized while other parts remain reduced. There is, as a consequence, a spotting effect of a gray hue with yellow and red spots. In better drained areas, generally on higher land, the structure is moderately developed and of plastic and sticky consistency which permits a high saturation of water during the winter. These soils, contrary to those of the *Terra Firme,* do not have good physical properties. However, owing to the successive deposits of rich sediments brought by the Amazon River water, they are considered soils of higher than average fertility with a high base saturation (Falesi, 1965). In order to use these soils economically, it would be necessary to prepare a rational drainage system and possibly an irrigation system for the dry season.

The hydromorphic soils found in the Amazon are ground water laterites, eutrophic and dystrophic low humic gleys, humic gleys, and ground water podzols.

Ground water laterites.—Ground water laterite is constituted of hydromorphic soils, strongly eroded, excessively acidic, imperfectly drained owing to its clay nature, compact subsoil, low topographic situation, and developed from recent Quaternary sediments (Brazil IPEAN, 1970; Day, 1959b; Falesi, 1967a; Silva, 1970). The processes for the formation of these soils are podzolization, which gives origin to horizon A, and laterization, which contributes to the presence of plinthite. Plinthite is the most important characteristic of ground water laterite. It consists of clay material, is highly weathered, rich in sesquioxides and poor in humus occurring generally with red and gray white specks, with a polygonal or reticular arrangement. It turns irreversibly into hardpan or concretion under special conditions of being wet and then dry (Etchevehere, 1962).

Ground water presents a sequence of horizons A, B, and C with the presence of A_2. The A horizon has a dark gray coloration with a hue of 10 YR and very variable texture, being of a moderate to strong structure of small to average in blocky subangular form, becoming in horizon B a clear and irregular form or undulating. Horizon B is more clayey, very speckled with a disintegrating structural mass, subangularly large, with a prismatic occurrence. The plinthite layer is located in this horizon.

Ground water laterites are low in fertility, which is evident by low values of the sum of the bases, exchange capacity, and base saturation. They also have a very low content of phosphorus. As the pH is around

4.3, these soils are excessively acidic. As a consequence of the high acidity, a high content of aluminum appears with values above 2.00 mE/100 grams of soil. These soils normally occur in lowland areas and remain very wet during the rainy period because of poor drainage. However, they can be formed in high level areas away from floods. The principal area of occurrence of these soils is the Halocene part of Marajó Island in the State of Pará where the vegetative cover is natural savanna made up of grasses and sedges of low nutrient values (Santos and Falesi, 1964). The ground water laterite has humic, sandy, and low phases (Day, 1959b; Santos and Falesi, 1964; Sombroek, 1966), possibly occurring, however, in moderately and imperfectly drained phases with respect to the variation in the drained area (Brazil IPEAN, 1970; Falesi, 1967a) in addition to its occurrence in truncated and higher elevations.

Humic phase of ground water laterite.—The humic phase of ground water laterite presents all the relative characteristics of the great group, being identified by the presence of the A horizon with a black color with a high content of organic material and a thickness of over 20 centimeters (Santos and Falesi, 1964). On the other hand, it represents a phase with a much impeded drainage because it is always located in the greatest land depressions. Soils of the humic phase are of heavy texture, extremely acidic, inundated by rain water and river floods, and formed by the diagenetic evolution of Halocene fluvial sediments. Horizon A is black, changes quickly toward the low horizon to gray speckled clay of red and white or brownish yellow, which constitutes the plinthite, which in these soils is found very near the surface (Santos and Falesi, 1964). This type of soil has a high content of organic matter in the A horizon which is excessively acidic with a pH varying between 4 and 4.5. These soils occur principally on Marajó Island and are found to form small lakes which appear during the rainy season and last into the dry period.

Sandy phase of ground water laterite.—The sandy phase of ground water laterite is characterized by a profile of excessively sandy texture, very strongly acidic, strongly eroded, developed on sediments from old Quaternary, Pleistocene, and it is generally situated among the old terraces located at higher levels than the inundable lower lands (Day, 1959b; Santos and Falesi, 1964).

Presenting the horizon sequence A, B, and C, all are very sandy with A_2 thick enough sometimes to reach around 100 centimeters of thickness. This horizon also is sandy with a reddish brown tone constituting the plinthite. Soils which are excessively sandy whose origin is from Pleistocene fluvial sediments favor intense leaching and are of very low fertility. Normally the sandy phase occurs in the *tesos*[7] of Marajó Island

7. *Teso* is the name given to the land on the higher sandy remains of old

and the lower Amazon and is associated with the low phase of ground water podzol to which it is very similar. The vegetative cover can be humid equatorial forest which is not too exuberant or else grasses and sedge savannas with sparse bushes.

Low phase ground water laterite.—This pedogenetic type is characterized by a profile sequence of horizons A, B, and C with the presence of thick leached sand in horizon A_2 which changes quickly into a dense B horizon with a much higher clay content than the above permeable layer (Day, 1959a; Santos and Falesi, 1964). The soil is moderately to imperfectly drained because of the presence of a dense plinthite layer in the B horizon which is heavily leached, excessively acidic, and very low in fertility. It has its origin from Pleistocene sand sediments and develops normally on the lateral parts of old terraces (*tesos*) found on Marajó Island. They occur in association with the sandy phase of ground water laterite which is distributed on the higher parts of the *tesos* (Santos and Falesi, 1964).

Moderately drained ground water laterite.—This pedogenetic type presents some common characteristics with the normal ground water laterite having, however, moderate drainage not only because of the clayey nature in horizon B but because of the presence of plinthite at the base of this horizon (Falesi, 1967c). It has an average depth of 150 centimeters down to horizon B_{22Pl} where the plinthite develops. Therefore the layer of greatest oscillation of the water table is located in this laterized layer. This was first studied at the Estação Experimental de Porto Velho where it was found associated with the imperfectly drained ground water laterite but situated at higher levels. Recently they were also identified on Marajó Island.

These soils are found in level, low areas since they are derived from the diagenetic evolution of Halocene sediments. The imperfectly drained phase is located in sites of lower elevation than the moderately drained. The former remains inundated during the rainy season while the moderately drained becomes only waterlogged. The chemical analysis made from samples collected from the profile horizon shows low fertility where the values of the sum of the bases, exchange capacity, and permutable base saturation are always low resembling latosol type of hardly saturated clay (Brazil IPEAN, 1970).

Imperfectly drained ground water laterite.—This soil has morphological characteristics attributed to the great group ground water laterite normally developed in lowlands, but was separated as "imperfectly drained" with the presence of plinthite in horizon B. This impermeable

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Pleistocene terraces, generally covered with forests or natural pastures not inundated by the waters.

or semi-impermeable layer is located close to the profile surface as a consequence of the slow or slightly impeded descent of water through the soil during the rainy season. In the same manner as the moderate phase, this soil develops in low level lands, originating from the diagenetic evolution or recent Quaternary sediments. Soils of this type are also soils of low fertility where the content of exchangeable bases, assimilable phosphorus, exchange capacity, and base saturation are low (Falesi, 1967c).

High land ground water laterite.—Ground water laterite is normally found in low level topographic areas, inundated by flood waters. However, this type of laterite develops in high areas away from river floods. The morphological characteristics are the same in both geomorphic situations, differing only by the type of drainage. The soils of this type are characterized by being moderately deep, very acidic, and almost always developed on medium level terraces of the Tertiary (or Cretaceous in this case). They occur in Maranhão and are not reached by flooding rivers. The profile has horizon sequence of A, B, and C with the almost constant presence of the alluvial horizon A_2; however, this can be absent. This soil is formed from the process of podzolization which gives origin to the A_2 horizon and concomitantly to laterization characterized by the leaching of silica and the concentration of iron sesquioxides (Brazil IPEAN, 1970; Day, 1959b; Santos and Falesi, 1964).

A typical characteristic of this soil is the indispensable presence of plinthite located in the B horizon which is a semi-impermeable layer of consolidated or nonconsolidated clay, rich in sesquioxides and poor in humus. This soil occurs more commonly in the dystrophic phase but occurs also as eutrophic. The latter was found only in the State of Maranhão along the São Luiz–Terezina highway (Falesi, 1967c).

The dystrophic high land ground water laterite possesses low values of the sum of the bases, exchange capacity, and base saturation. The acidity index is between 4.0 and 4.5 and the assimilable phosphorus content is always low. Organic material values are average in the A horizon because of its contact with organic material which accumulates on the surface of the soil. The eutrophic phase studied in Maranhão has high base saturation, pH above 5.5, and a high sum of the bases. The high land ground water laterite occurs in topography slightly undulating to undulating with slight slopes.

In the State of Pará, profiles were studied along highway PA–070 which links the Belém-Brasília Highway (BR–010) to the city of Marabá situated on the right bank of the Tocantins. The vegetative cover is humid equatorial forest. In Amazonas State, profiles were studied in the Cacau Pirera–Manucapuru area (Silva, 1970) which was also covered with Amazon Rain Forest. In Maranhão, the high land ground water laterites studied were eutrophic and were located in several spots along the highway which links São Luiz to Terezina. In the State of Mato Grosso, a profile was also identified in the *municípío* of Chapada dos Guimarães, near the city of that name.

Truncated ground water laterite.—This pedogenetic unit presents the fundamental characteristics assigned by Day (1959b), Sombroek (1966), and Falesi and others (Brazil IPEAN, 1970) in various locations in the Brazilian Amazon. The profile is strongly leached, very strongly acidic (U.S. Department of Agriculture, 1951), and normally heavy in texture. In the superficial horizons there are concretions, and there is visible geologic erosion which has removed horizon A and part of horizon B. The lateritic concretions, initially on the mass of the old B horizon, are dry and hard with the erosion of the granularmetrically finer material. They remain in the fragmented form of hard laterite now located in the superficial layer giving origin to a truncated profile (Day, 1959b). Besides these characteristics, the plinthite appears as an intrinsic property of the profile being observed in the B horizon (Brazil IPEAN, 1970, 1971b; Day, 1959b).

These soils have the horizon sequence of A, B, and C with or without the presence of horizon A_2. They are normally of heavy texture, small, granular, friable, and have concretions and gravels. They are average to low in fertility which is evidenced by medium to low base saturation. Normally they occur on slightly undulating to undulating relief, originating from Tertiary or old Quaternary (Brazil IPEAN, 1970; Day, 1959b). The vegetative cover is humid equatorial forest or second growth in various stages of development.

Low humic gley.—Low humic gley soils belong to the hydromorphic suborder, not only because of morphological characteristics, but because of the processes which condition their formation. They are the result of an accumulation of very recent sediments which were, and continue to be, transported and deposited by the periodic inundations of muddy waters of not only the Amazon but its affluents and the white waters of the estuary region. They are imperfectly drained soils of fine texture where the clay and silt fractions appear as the predominant elements in the granularmetric composition (Lima, 1965).

Low humic gleys are characterized principally by the presence of a surface organic horizon seated over gley horizons. This makes the process of oxidation-reduction, which acts upon the iron compounds, conditioned to temporary or permanent level of the water table next to or at the surface. Horizons A, B_g, and C_g are present with a texture almost always of silty clay or sometimes loamy. The structure of the horizon is weak, moderate, medium to large, subangular and granular, while B_g and C_g can be a coherent mass breaking up as subangular and prismatic. They are normally plastic and sticky or very sticky soils. Roots are concentrated in the surface horizon giving a high organic material content and a lesser amount of waterlogging.

Generally they are soils of medium to high fertility and, as a consequence, have relatively high contents of calcium, magnesium, and potassium. Aluminum is low and the pH is above 6 as is the case in some areas along the banks of the Amazon River. Aluminum, however, in other profiles, as in the estuary of the Solimões River and other locations, has a high content correlating perfectly with low pH indices. The low humic gleys which make up the *várzeas* of the lower Amazon and estuary are eutrophic as a result of their high base saturation values.

These soils bordering the Amazon River and some of its affluents and the estuary region constitute excellent fertile areas as a result of the annual and periodic inundations of muddy water which leave behind rich deposits (Falesi, 1967b; Lima, 1965; Sioli, 1951). The high and low *várzeas*, which generally correspond with the low humic gley soils, with drainage variations cover, it is estimated, areas of the Amazon estuary alone of about 15,000 square kilometers—the high *várzea* about 3,000 square kilometers and the low *várzea* about 12,000 square kilometers (Lima, 1965). The total area of *várzeas* bordering the Amazon River, considering its complete extent from west to east in Brazilian territory, is about 60,000 square kilometers (Oliveira and Leonardos, 1943).

These areas after being drained are excellent soils for whatever kind of agriculture is adapted to the local ecological conditions. The low humic gley can be covered with humid equatorial forest of the *várzea* or by natural savanna, constituting in this latter case excellent pastures for extensive livestock raising as is done in the lower Amazon. These soils are developed from the evolution of organic mineral sediments from the Halocene and have level topography in the areas of occurrence.

Humic gley.—Humic gley is the soil type constituted by poorly drained hydromorphic soils of recent formation and sedimentation which are very strongly acidic and have a thick black A horizon with high organic content. It has the horizon sequence of A, B_g, and C_g with strong reduction zones of many specks as a result of an oscillating water table and consequent oxidation-reduction of iron. Differing from the previous soil type by having a deeper A horizon and a higher organic material content, it is even more poorly drained, appearing similar to the humic phase of ground water laterite. Humic gley soils have low chemical fertility and are located at less elevated topographic sites than are the low humic gley. These soils form in small, temporarily inundated depressions. Geographically, this type has little representation and is utilized for raising cattle when the land is covered by natural pasture.

Ground water podzol.—Grouped with the denomination of ground water podzols are soils with the evident characteristics of podzolization, acidic humus in their superficial profiles, leached A_2 horizons, and an alluvial B horizon of accumulated iron oxides or humus and iron oxides (Klinge, 1968). The profile is excessively sandy with a dark A horizon owing to the presence of organic material dissolved in quartzous material. This is followed by a white, clear gray, or brownish gray A_2 horizon which is normally thick and made up of exclusively quartzous sand. The B_{hiR} horizon is rich in iron oxide and humus, compact, cemented, and called "Ortstein" or "hardpan" (Brazil IPEAN, 1969; Falesi, 1967b; Robinson, 1960; Silva, 1970). The profile depth of the ground water podzol found in the Amazon region varies from 80 centimeters to 220 centimeters and where the A_2 predominates, the thickness over the other horizon reaches 148 centimeters (Sioli, 1951). The name "ground water" given to these podzols comes from the presence of a high water table during the rainy period, oscillating in the profile, reaching principally horizon B_{hiR}.

Ground water podzol is an excessively acidic soil, very low in exchangeable bases and with a low cation exchange capacity. Its principle use has been to furnish white sand from the A_2 horizon for civil construction. It originates from quartzous sandy sediments from the Pleistocene and develops under conditions of poor drainage. The vegetative cover is characterized by humid equatorial forest which is the least exuberant or when the vegetation is secondary, by arenicolous forest (Brazil IPEAN, 1969; Silva, 1970) with the presence of the plant species *Samambaia* with the big leaf. These soils occur in the middle of Amazon forest and in the vicinities of watercourses. They were found in the states of Pará and Amazonas in various places (Brazil IPEAN, 1969; Day, 1959b; Silva, 1970; Vieira, 1962) and can be associated with the regosol. When this happens, the regosol is located in higher ground and the podzol on lower ground.

Organic and Partly Organic Soils (Igapós)

The areas of occurrence of these soils are known in Amazonia by the name *Igapós*. The *Igapó*, according to Sioli (1951), occurs in the depths of low valleys where the area is almost permanently inundated, very acidic, and covered with forest characterized by flooding. Rivers which occur in these areas are of black water. They are poor in sediments and are dark in color because of the presence on the ground (in the *Igapó*) of decomposing organic material which is transformed partially into dissolved humus or humus colloidally dissolved (Sioli, 1951). The *Igapó* constitutes a land more stable than a *várzea,* older in formation than the Halocene and created by erosion rather than by sedimentation.

The *Igapó* soil profile, technically named for the surface layer, is dark, very acidic, formed by decomposition of organic material and almost always anaerobic because of an excess of water during the greater part of the year. An analysis of a sample from the horizons of an *Igapó* located at IPEAN indicated the organic material content to be very high, on the order of 47 per cent. The content for calcium is 3.57 mE/100 grams of soil, magnesium 1.91 mE/100 grams of soil, and potassium 0.44 mE/100 grams of soil. The assimilable phosphorus is high with a content of 9.95 mE/100 grams of soil and nitrogen with 2.08 per cent. The granularmetric analysis showed a predominance of silt and clay fractions corresponding respectively to values of 65 per cent and 33 per cent. Gross sand is 1 per cent and fine sand also 1 per cent.

Halomorphic Soils (Salinos and Alcalinos)

Halomorphic soils owe their characteristics not only to the presence of an excess of sodium salts but also to the predominance of this element among the exchangeable bases. The saline or white alkaline soils, or *solonchak* soils from the Russian school, are made up of an excess of sodium salts (with chlorides and sulfates being the most common) and have a flocular structure. During the dry season, white efflorescence of sodium chloride or sodium sulfate appears. In the rainy period, these salts are dissolved and temporarily taken down into the soil to the water table. Alkaline or Solonetz soils are characterized by the presence of sodium carbonate with a strong alkaline reaction and are in a disflacculated state (Alison et al., 1954). These are still morphologically identified by the strong, well-developed columnar or prismatic structure with rounded extremities where white salts normally accumulate. This structure is a consequence of the state of disfloculation of clay colloids.

In the Amazon region, these soils are found on the Atlantic coast on Marajó Island (principally Solonetz), in the State of Maranhão, in the *Campos Perizes* (Solonchak), in the *município* of Alenquer, and lower Amazon (Solonchak). Unrepresented, however, are considerable extensions of area not in the proximity of the Atlantic coast (Brazil IPEAN, 1970; Falesi, 1967c).

Conclusions

The Amazon region includes an area approximately 42 per cent of the Brazilian territory. Two landscapes are distinguishable in the Amazon:

the *terra firme* and the *várzea*. The soils of *terra firme* are, in general, well drained, porous, deep, of variable texture, and with low or average fertility. The only exceptions are the soils of basic origin, calcareous soils and the so-called *Terra Preta do Indio* with above average natural fertility. Latosols, usually resulting from Tertiary sedimentation processes, have good agricultural potential when rationally used. These soils, however, should not be used for more than two years in food production without the application of fertilizers. The use of fertilizers is, at this point, noneconomical in Amazonia due to high costs. Latosols, when used in the cultivation of perennials, for pastures, or in reforestation projects, have given good results. Areas having soils of high fertility should be studied more as to their full usage in subsistence and commercial production. The *várzea* regions, though having above average chemical potential, have limited usefulness for agriculture due to seasonal flooding and bad drainage resulting from their low elevations. The potential of the *várzeas* can be realized either through government initiative or through large corporations able to overcome through massive investment the difficulties of agricultural production in this environment.

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