



IRON CONSTITUENTS OF THE LATOSOLIC COVER IN NORTHEAST BRAZIL

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ABSTRACT

The latosolic soils (Oxisols) are distributed all over the Brazilian Northeast. They occupy different geomorphological levels and are found either in humid or in semiarid environment. Their mineralogical composition is simple: they are all constituted of quartz, kaolinite, iron and aluminium oxides. The total iron values range from 5 to little more than 10% of Fe_2O_3 . The main forms of iron oxides are goethite and hematite. These are associated to the clay fraction.

The ferric components had been studied by X-ray diffraction on concentrate obtained by dissolution of kaolinite mineral in 2N NaOH on clay soil fraction. The results on fifty Northeastern soils show a zonality in the distribution of goethite/hematite rate; but it is the Al-substitution, and mainly the division state of goethite, estimated by X-ray diffraction line shifts, that indicate the most interesting geographical variations.

The latosolic soils of the intern oldest geomorphologic levels contain highly substituted and finely divided goethite; in these soils there are also occurrences of hematite and gibbsite. Al-substitution and microdivision in goethite become more pronounced when we go from the driest zones to the more humid ones; at the same time there is a remarkable increase of the gibbsite rates. The Al-substitution and division state of goethite of latosolic soils of semiarid plains are lower. In these soils goethite is associated with hematite; there is no gibbsite. In the latosolic soils of coastal plains, generally only goethite occurs; there is not either hematite or gibbsite. The Al-substitution and microdivision in goethite are moderated, but they increase under more humid climate.

Therefore, it seems there is a significant correlation between the characteristics of the ferric components of the soils, the climate environment and the age of the latosolized materials.

INTRODUCTION

The "Nordeste", between the 4th and the 16th parallels, is clearly distinct from the rest of Brazil due to its semiarid characteristics. It receives, in the main, less than 1,000 mm of annual precipitation. Furthermore the rainfall regime is much irregular with long drought seasons. The adapted vegetation to this climate is a brushwood formation (locally called "caatinga") quite different from savannah ("cerrado") of Central Brazil and the coastal dense forests.

The "Nordeste" soils are varied (Brazil 1970, 1971, 1972, 1973a, 1973b, 1973c, 1973d, 1975a, 1975b, 1976, 1977). The latosols are frequently present and in the states of

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Piauī, Bahia, Minas Gerais, they are found in great extensions. These latosols (Brazil, 1980), like ferral soils (FAO/UNESCO, 1971) and oxisols (Soil Survey Staff, 1975), are perfectly drained soils, ranging from 1 to 3 m depths, formed by quartz, kaolinite plus variable proportions of iron oxide and sometimes of gibbsite; they do not present textural gradient and are characterized by a specific constituents organization which gives them a high porosity and friability. The latosols on the Northeast generally occupy plane or little undulated topography. They are associated with plateaus, and like the latter are regularly distributed over consecutive surfaces (Feio, 1954, King, 1956, Dresh, 1957, Ab'Saber, 1969); it is easy to regroup them according to their geomorphological locations. We can then distinguish (Fig. 2):

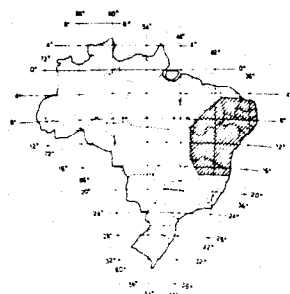


FIG. 1. Brazil map showing the location of the study zone (hachured area).

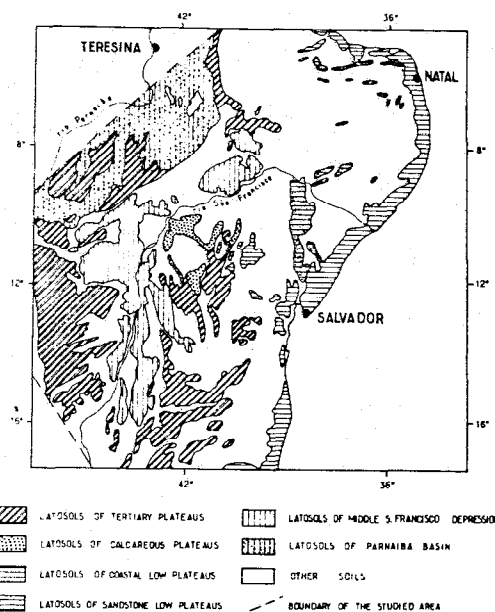


FIG. 2. Simplified map of the latosol distribution in the Northeastern Brazil.

- the latosols on the tertiary plateaus that occupy an altitude level from 600 to 1,000 m. These are generally deep soils, of clayed texture and with very low base saturation. They are in all types of substrates (crystalline rocks, quartzites, sandstones and schists);
- the latosols on the calcareous plateaus. These are soils of clay-sandy or sand-clayed textures and with high base saturation;
- the latosols on the coastal low plateaus and on the low sandstone plateaus. The latosols on the coastal low plateaus are clay-sandy and clayed, with low base saturation. On the low sandstone plateaus of the inland, the latosols are much sandy and with medium base saturation;

- the latosols of the Middle São Francisco Depression that are sand-clayed and clay-sandy, medium unsaturated, eutrophic in some cases soils;
- at last, the latosols of the Parnaíba Basin that occupy the 200 to 400 m altitude zones on the Northwest, and directly derived from sandstone. These soils are medium textured, with low base saturation.

The ferrous constituents of Brazilian northeast latosols have not been much studied. Field studies on the State of Bahia (Volkoff and Cesar, 1977) showed significant differences among latosols of the State and an ordered geographical distribution if we consider the nature and the crystallinity of their iron oxides.

The iron oxide nature in the soil, as well as its crystallinity, are ruled by the physico-chemical environment (Lewis and Schwertmann, 1979, Melfi et al., 1979). This straitly depends on the climate conditions, chiefly on the amount of rainfalls and on its annual distribution. Therefore it is interesting to verify, on the entire "Nordeste" region, if the constitution of soil units with the same iron oxide mineralogy is possible and if their geographical distribution can be explained by the natural environment variations. The purpose of this paper is the study of iron oxides constituents of the Brazilian northeast latosols, and the analyse of their iron mineralogy according to the environment data.

The chosen region is bordered (1) on North by a parallel passing a little North of Mossorô (Rio Grande do Norte State), (2) on South by the parallel of Teófilo Otoni (Minas Gerais State) and (3) on East by a broken line linking Floriano (Piauī State) on the Parnaíba River, to Pirapora (Minas Gerais) on the São Francisco River (Fig. 1).

MATERIALS AND METHODS

Samples of B2 horizon of 50 latosol profiles distributed all over the "Nordeste" were analyzed. Each sample was submitted to the granulometric analysis: $\text{pH}_{\text{H}_2\text{O}}$ and pH_{HCl} , exchangeable cations and cationic exchange capacity by ammonium acetate pH 7 method, were determined. The total iron was dissolved by $\text{HCl-H}_3\text{ClO}_4$ and analyzed by atomic absorption.

The iron oxides were only studied on the fine fraction, inferior to 2μ , because the observation of the granulometric fractioning products has shown that the sands have not been formed but by quartz and some residual opaque minerals, and that fine silt fraction was not expressive. This fine fraction was obtained by siphoning suspensions of soil dispersed by soda at pH 9 after mechanic agitation. The collected fraction was flocculated by MgCl_2 , and then, washed and dried at 60°C . Then it was boiled for 30 minutes, by a soda 2N solution (0.4 g of material for each soda litre: Perinet, 1974). The residue of the attack was washed out, dried and fixed with CCl_4 drops on a glass plate for X-ray diffraction analysis ($\text{K}\alpha$ copper radiation; goniometer speed: $1/4^\circ/\text{min}$.; 2,000 CPS; time constant: 4 seconds).

The hematite was identified for the (104) spectrum line at 2.69 \AA and (110) at 2.52 \AA , and the goethite by (130) line at 2.69 \AA and (111) line at 2.45 \AA . The position of the goethite (111) line was precisely located, using (311) lead nitrate line at 2.370 \AA

(Norish and Taylor, 1961) and its deviation (ΔA) with $d(111)$ of pure goethite (at 2.447 Å: ASTM) was calculated. This deviation is directly related to the substitution of iron for aluminium and to oxide crystallinity (Norish and Taylor, 1961).

To precise and confirm the results of X-ray diffraction, samples of < 2 μ fraction, not attacked by soda, of 5 selected latosols were analyzed by Mossbauer spectrometry (Janot and Gibert, 1970, Lamouroux et al., 1977).

The gibbsite, with quantitative evaluation on richer samples, was investigated by Differential Thermic Analysis (DTA) on total soil crushed samples.

RESULTS

The iron content of the studied latosols varies from less than 1% of total Fe_2O_3 to more than 10% (Tables 1, 2 and 3). The most frequent values are around 2-3%.

TABLE 1. ANALYTICAL DATA OF LATOSOLS OF THE COASTAL LOW PLATEAUS AND THE SANDSTONE LOW PLATEAUS (GI = GIBBSITE; HE = HEMATITE; GO = GOETHITE).

Sample	Location	Clay %	pH		V %	Fe_2O_3 %	Gi	He	Go	ΔA
			H ₂ O	HCl						
Latosols of the coastal low plateaus										
VFF 23	Belmonte, BA	60	5.2	4.4	38	2.9	-	-	+	0.0285
VFF 3	Salvador, BA	61	5.0	4.3	20	4.4	-	-	+	0.0285
DBA 8	Esplanada, BA	27	4.8	4.2	52	2.1	-	-	+	0.0253
DAL 1	Arapiraca, AL	38	5.1	4.8	68	3.5	-	-	+	0.0238
DRN 3	Mossoró, RN	22	4.6	4.0	62	0.9	-	-	+	0.0175
Latosols of the sandstone low plateaus										
DPE 6	Ibimirim, PE	nd	4.6	4.3	nd	nd	-	-	+	0.0175
DRN 4	Açu, RN	25	5.5	4.7	nd	2.2	-	+	tr	0.0128

nd = not determined; tr = trace; + = detected; - = not detected

X-RAY DIFFRACTION STUDIES

Tables 1, 2 and 3 indicate that the hematite is not identified but in half of analyzed samples, while the goethite, with rare exception, is always present. It can be perceived that the fact of the hematite being present, does not interfere on the goethite parameter ΔA values. This goethite ΔA parameter presents a large interval of variations since it can take on any value between 0.0112 and 0.0395.

If we observe for the spacial distribution of the goethitic soils, of the goethitic and hematitic soils, and for the spacial distribution of ΔA values, no ordering is found.

TABLE 2. ANALYTICAL DATA OF LATOSOLS OF THE MIDDLE SÃO FRANCISCO DEPRESSION, THE PARNAIBA BASIN AND THE CALCAREOUS PLATEAUS (GI = GIBBSITE; HE = HEMATITE; GO = GOETHITE).

Sample	Location	Clay %	pH		V %	Fe_2O_3 %	Gi	He	Go	ΔA
			H ₂ O	HCl						
Latosols of the Middle São Francisco Depression										
DPE 1	Petrolina, PE	19	4.8	4.0	40	1.6	-	tr	+	0.0175
DPE 2	Rajada, PE	30	4.9	3.9	43	2.9	-	tr	+	0.0206
DBA 6	Remanso, BA	23	5.2	4.4	82	1.6	-	-	+	0.0175
ABD 1	Ibitiara, BA	36	5.2	4.2	nd	3.2	-	-	+	0.0175
DBA 33	O.dos Brejinhos, BA	31	5.7	4.9	nd	2.9	-	-	+	0.0206
DBA 10	Boquira, BA	28	5.1	4.4	85	2.2	-	+	+	0.0206
DBA 32	Macaubas, BA	26	5.3	4.6	nd	3.2	-	tr	+	0.0175
DBA 12	Livramento, BA	28	4.6	4.0	22	2.3	-	tr	+	0.0206
DBA 23	Brumado, BA	26	5.8	5.0	80	4.1	-	+	+	0.0175
DBA 27	Guanambi, BA	28	5.6	4.4	62	2.2	-	tr	+	0.0206
DBA 28	Urandi, BA	27	5.7	5.0	91	5.5	-	+	+	0.0206
DMC 10	Monte Azul, MG	32	5.2	4.5	84	2.5	-	-	+	0.0206
DBA 5	Formoso, BA	32	4.7	4.2	55	4.7	-	tr	+	0.0238
Latosols of the Parnaiba Basin										
DPI 2	Gilbues, PI	21	4.9	4.1	8	1.0	-	+	tr	nd
DPI 8	Picos, PI	28	4.4	4.1	10	2.6	-	-	+	0.0144
DPI 3	Cristino Castro, PI	39	4.4	4.2	9	2.4	-	tr	+	0.0206
Latosols of the Calcareous Plateaus										
DBA 2	Irecê, BA	35	5.3	4.8	76		-	+	tr	nd
DBA 25	Souto Soares, BA	15	7.3	6.6	60		-	+	+	0.0112

nd = not determined; tr = trace; + = detected; - = not detected

But if we analyse separately the latosols of the low plateaus, those of the Middle São Francisco Depression, Parnaiba Basin and Tertiary plateaus, the results will show some coherent relationships.

Latosols of sandstone and coastal low plateaus

These are iron-poor soils (always less than 5% of total Fe_2O_3) and soils without gibbsite (Table 1). The goethite is systematically present.

The latosols of the low coastal plateaus are sand clayed and clayed soils. Only goethite is found. The ΔA of this goethite is 0.0175 northwards, close to Mossoró (Rio Grande do Norte State), in a zone where the annual pluviometry is of the order of 750 mm. It is 0.0285 on the south of Salvador (Bahia State) where the annual pluviometry is over 1,500 mm. It takes intermediary values between Natal and Salvador, in intermediary pluviometric conditions (Fig. 3).

In the latosols of the sandstone low plateaus, goethite is only present. Hematite was found on a single case, which indicate that latosols derived from sandstone could also be hematitic.

TABLE 3. ANALYTICAL DATA OF LATOSOLS OF THE TERTIARY PLATEAU
(GI = GIBBSITE; HE = HEMATITE; GO = GOETHITE).

Sample	Location	Clay %	pH		V %	Fe ₂ O ₃ %	Gi	He	Go	ΔA
			H ₂ O	HCl						
DBA 9	Poções, BA	44	4.6	4.0	20	2.9	-	-	+	0.0206
DBA 20	Maracás, BA	39	4.5	4.4	35	7.4	-	-	+	0.0206
DRN 5	Cerro Corá, RN	30	4.6	4.0	19	0.7	-	-	+	0.0206
DCE 1	Campos Sales, CE	39	4.6	4.0	12	2.1	-	-	+	0.0206
DBA 30	Itaberaba, BA	53	5.1	4.8	nd	5.0	-	tr	+	0.0238
DRN 1	Martim, RN	60	4.9	4.1	77	3.5	-	-	+	0.0238
DPI 4	Eliseu Martin, PI	39	4.3	3.9	18	3.0	-	-	+	0.0253
DRN 6	Jaçaná, RN	41	4.7	4.0	8	2.3	-	-	+	0.0253
MPI 1	S.R. Nonato, PI	20	4.6	4.3	6	2.6	-	tr	+	0.0270
DBA 37	Mundo Novo, BA	37	5.3	4.1	nd	6.3	-	tr	+	0.0270
DBA 26	Cacitã, BA	21	5.2	4.5	14	2.3	-	-	+	0.0285
DCE 3	Crato, CE	39	5.1	4.3	3	3.8	-	-	+	0.0285
VFF 21	Barra da Estiva, BA	64	4.9	4.2	7	10.0	+	+	+	0.0285
DBA 36	Morro do Chapêu, BA	18	5.7	5.1	nd	2.4	tr	tr	+	0.0300
DBA 34	Seabra, BA	50	5.0	4.9	nd	5.1	-	-	+	0.0300
DMG 11	Salinas, MG	55	5.0	4.4	2	8.8	+	+	+	0.0300
VFF 15	Barreiras, BA	36	4.9	5.6	2	6.0	+	+	+	0.0316
DPE 5	Garanhuns, PE	32	4.9	4.3	18	2.7	-	-	+	0.0332
VFF 19	Seabra, BA	42	5.1	5.6	10	7.5	-	tr	+	0.0332
DMG 13	Montes Claros, MG	14	4.9	5.3	7	9.6	+	+	+	0.0332
DMG 15	Montes Claros, MG	41	4.4	4.5	21	2.6	+	+	+	0.0332
DMG 7	Pedra Azul, MG	46	5.3	5.1	9	5.0	-	+	+	0.0395
DMG 20	Montes Claros, MG	61	4.5	4.8	2	15.6	+	+	tr	nd
DMG 21	Turmalina, MG	69	4.9	4.6	2	12.4	+	+	tr	nd

nd = not determinated; tr = trace; + = detected; - = not detected.

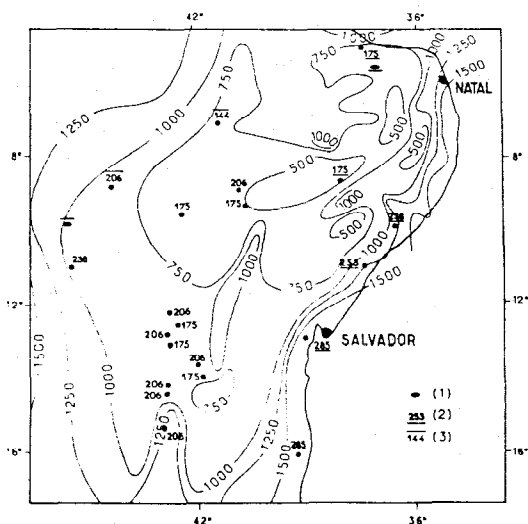


FIGURE 3
Map of annual isohyets (mm of mean annual precipitation) after Nimer (1972) and location of d(111) goethite line deviations ($\Delta A \cdot A^4$) on the Middle São Francisco depression, low plateau and Parnaíba basin latosols. (1) Latosols with many hematite; (2) latosols of the low plateaus; (3) latosols of the Parnaíba basin.

In all sandstone low plateaus latosols, the ΔA goethite parameter is of little high value (Table 1). It will be noted here that all the soils on the low sandy plateaus are located in low pluviometric zones with less than 750 mm of annual rainfall (Fig. 3).

The low plateau latosols are but for rare exceptions soils with goethite only. In these soils there is a clear relation between the pluviometric conditions and the goethite ΔA parameter values.

Latosols of Middle São Francisco Depression

These are equally iron-poor soils: the maximum found is 5.5% of Fe₂O₃ (Table 2). Goethite and hematite are both present, but the hematite is never well characterized by X-ray diffraction. There is no gibbsite in latosols of this depression. The ΔA parameter of the goethite ranges from 0.0175 to 0.0238. The most frequent values, 0.0175 and 0.0206, are aleatory distributed over the Middle São Francisco Depression,

in an area which has an annual precipitation. There are no evidences that the lowest values (0.0175) are preferably located in the dryer zones. It can be only noticed that the highest value (0.0238) was found on the occidental part, close to the moisty region of Central Brazil.

Latosols of the Parnaíba Basin

These are sandstone-associated latosols. They have a poor iron content (Table 2). There is either predominance of hematite or goethite. The ΔA value of the goethite is always less than 0.0206. There is no gibbsite in these soils.

Latosols of the Tertiary Plateaus

These latosols present highly variable iron contents. Some have less than 1% of total Fe₂O₃, others, over than 15%. It looks like, though it is not an absolute general law, that soils with low iron contents will be located in the north plateaus while those with high iron contents, on the south plateaus. We can distinct: the hematite-only latosols, the hematite and goethite latosols and the goethite only latosols.

The hematite only latosols. In some cases, there are traces of goethite. These latosols are found only at the south of the studied zone. Their iron content is high (Table 3). Furthermore they are highly gibbsitic (generally over 30% of gibbsite).

The hematite-goethite latosols. The hematite can be either very well characterized by X-ray diffraction or present only in traces. The goethite is always perfectly identified. Its ΔA parameter ranges from 0.0238 to 0.0395. The higher values correspond to the richer hematite soils, those which are at the same time gibbsitic soils. The low values are correlated with the goethite of the hematite-poor soils, generally lacking gibbsite. The goethite and hematite latosols seem to be preferably extended over the southern half part of the studied zone.

The goethite-only latosols. The ΔA is low (0.0206-0.0300). There is no gibbsite. These

goethite-only latosols are located on north and southeast of the tertiary plateaus zone.

The goethite $\Delta\text{\AA}$ parameter on the whole tertiary plateaus soils range, therefore, from 0.0206 to 0.0395. It was stated that both the hematite and the gibbsite are present when the goethite $\Delta\text{\AA}$ exceeds a certain value. Systematically, there is goethite only when $\Delta\text{\AA}$ is low, and there is hematite + gibbsite following the goethite when $\Delta\text{\AA}$ is very high.

The observation of the geographic distribution of the goethite $\Delta\text{\AA}$ (Fig. 4) shows that there are 2 zones of low $\Delta\text{\AA}$ values: one on the north borders of the plateaus, and the other on south of Salvador. They are not explained by any climatic evidence; nothing indicates that they are related to specially dry climate zones. On the other hand, the high $\Delta\text{\AA}$ values are regrouped on the south, on a zone where the annual pluviometry ranges from 750 to 1.250 mm. There is, visibly, on the tertiary plateau area, no relation between the $\Delta\text{\AA}$ parameter and the pluviometric data.

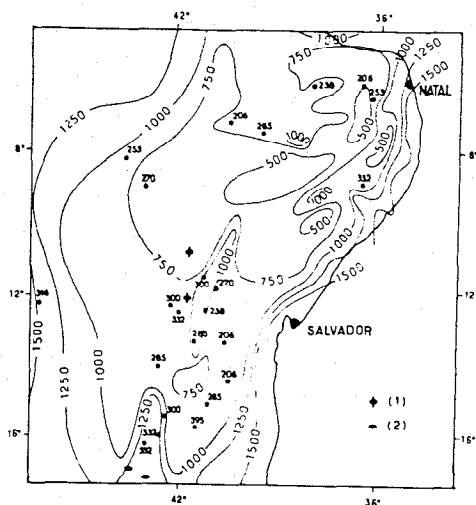


FIG. 4. Map of annual isohyets (mm of the mean annual precipitation) after Nimer (1972) and location of $d(111)$ goethite line deviations ($\Delta\text{\AA} \cdot 10^4$) in the tertiary plateaus; (1) latosols with many hematite on calcareous plateaus; (2) latosols with many hematite on tertiary plateau.

Latosols of the Calcareous Plateaus

These soils are located at the center of the "Nordeste", in a single climatic zone (less than 750 mm of annual rainfall). The hematite is the principal iron oxide. The goethite exists only but in very low amounts. The $\Delta\text{\AA}$ parameter presents very low values (0.0112). Gibbsite is never found (Table 2).

MÖSSBAUER SPECTROMETRY STUDY

The analyses results of 5 samples show there is a very good correlation between the X-ray identifications and Mössbauer Spectrometry. Nevertheless, in ABD 1 sample, the hematite found by Mössbauer Spectrometry (Table 4) is not clearly identified by X-ray diffraction. In fact, on the diffractogrammes (Fig. 5) the 2.52 \AA hematite line does not exist; however, the enlargement to 2.69 \AA of the goethite peak at 2.65 \AA confirms the hematite presence.

TABLE 4. Fe DISTRIBUTION TO NON-FERROUS MINERALS, GOETHITE, HEMATITE AND AMOUNT OF VERY FINELY DIVIDED GOETHITE AND HEMATITE (IN PERCENT OF Fe TOTAL) FROM MÖSSBAUER ANALYSIS OF $< 2\mu$ SOIL FRACTIONS.

Sample	Fe in substitution in non-ferrous minerals	Goethite		Hematite	
		Grain Size		Grain Size	
		$< 100 \text{ \AA}$	100 to 250 \AA	40 to 100 \AA	$> 100 \text{ \AA}$
ABD 1	35	-	45	10	10
DAL 1	10	10	80	-	-
DRN 1	20	10	70	-	-
DPE 5	10	20	70	-	-
DMG 7	10	40	10	30	10

The results of Table 5 point that, on the goethite, iron substitution for aluminium is always important. For high rates of substitution, the goethite $\Delta\text{\AA}$ parameter does not provide exact informations about the iron replacement but it is in close relation with the goethite grain size (Table 4), reflecting very well the soil goethite division. This has already been pointed out (Norish and Taylor, 1961. Bigham et al., 1978). Fig. 6 shows that a same $\Delta\text{\AA}$ variation indicates greater increasing of the goethite state division in the 0.0300/0.0400 interval than on the 0.0100/0.0300 one.

The iron substitution for aluminium in the hematite, when this oxide is present (Table 5) seems to be equal in all the cases, but its division state could be different. The finest hematite is associated with the more divided goethite.

DISCUSSION AND CONCLUSION

Results show that in the Northeast Brazil latosols, the iron oxides associated with the fine soil fraction are the hematite and the goethite. Their relative proportions and their division states are much variable. According to this, we can distinguish: (1) latosols with only hematite, (2) latosols with only Al-substituted goethite, (3) latosols with both Al-substituted goethite and hematite.

The geographic distribution of these latosols leads to a schematic division of the Northeast in three domains (Fig. 7):

Domain III, with very finely divided goethite, located on the central part of the tertiary plateau and under a present dry climate.

On the other hand, it has been observed that the hematite occurrence is correlated with high base saturation, or, in acid soils, with a humid tropical climate with contrasting seasons (case of the southwestern soils of the studied zone). There is, indeed, no hematite in unsaturated soils of the coastline zone, under moist and well-distributed rainfall climate. This would indicate, according to Melfi et al. (1979), that a humid tropical climate with dry season, is needed for the hematite formation and that under a humid equatorial climate, with well distributed annual rainfall, only the goethite is present. It was also observed that the microdivision of iron oxides in acid soils is influenced by the rainfall abundance. The microdivision of soil iron oxides could be then subordinated to the rainfall volume while the relationship goethite/hematite is ruled by the pluvial regime, that is, by the length and severity of the dry season. On these conditions the characteristics of the iron oxides of latosols presently under a dry climate should have a paleoclimatic signification.

Thus, the latosols of the Domain II have probably never been under an equatorial climate without dry seasons, since they contain hematite. But, domain III soils have all been marked by such a climate.

A very moist period is necessary to explain the microdivision of the goethite of Domain II and Domain III plateau soils. This period must be previous to the formation of the low plateau, Middle São Francisco Depression and Parnaíba Basin latosols, in which the goethite is less divided.

The low topographic level soils have probably been formed under a moister climate than the present one, but this climate have never been very rainy. Their goethite have not been strongly divided.

In conclusion, this paper shows that the iron oxide mineralogy is a good differentiation criterion of Northeast Brazil latosols and that the knowing of the iron oxides allows the outlining of interesting hypothesis about the formation of these soils. The interpretations made here are much partial ones for they are not supported by a sufficient number of observations. They have been proposed notwithstanding aiming to point out what type of information the studies on the iron constituents of the soils can bring.

REFERENCES

- . Ab'Saber, A.N., 1969. Participação das superfícies aplainadas nas paisagens do Nordeste brasileiro. Instituto de Geografia, Universidade de São Paulo, Geomorfologia, 19: 1-38.
- . Bigham, J.M., Golden, D.C., Bowan, L.H., Buol, S.W. and Weed, S.B., 1978. Iron oxide mineralogy of well-drained Ultisols and Oxisols. I. Characterization of iron oxides in soils clays by Mössbauer spectroscopy, X-ray diffractometry and selected chemical techniques. Soil Sci. Soc. Am. J., 42: 816-825.

- . Brasil, 1970. Levantamento de reconhecimento dos solos da Zona do Médio Jequitinhonha. Ministério da Agricultura. Departamento Nacional de Pesquisa Agropecuária. Divisão de Pesquisa Pedológica. Rio de Janeiro, (Boletim Técnico 9), 340 p.
- . Brasil, 1971. Levantamento exploratório-reconhecimento dos solos do Estado do Rio Grande do Norte. Ministério da Agricultura. Departamento de Pesquisa Agropecuária (Boletim Técnico 21), Rio de Janeiro, 530 p.
- . Brasil, 1972. Levantamento exploratório-reconhecimento de solos do Estado da Paraíba. Ministério da Agricultura. Departamento Nacional de Pesquisa Agropecuária. Divisão de Pesquisa Pedológica (Boletim Técnico 15), Rio de Janeiro, 683 p.
- . Brasil, 1973a. Levantamento exploratório-reconhecimento de solos do Estado de Pernambuco. Ministério da Agricultura. Departamento Nacional de Pesquisa Agropecuária. Divisão de Pesquisa Pedológica (Boletim Técnico 26), Rio de Janeiro, 359 p.
- . Brasil, 1973b. Levantamento exploratório-reconhecimento de solos do Estado do Ceará. Ministério da Agricultura. Departamento Nacional de Pesquisa Agropecuária. Divisão de Pesquisa Pedológica (Boletim Técnico 28), Rio de Janeiro, 301 p.
- . Brasil, 1973c. Projeto Radam: Parte das Folhas SC-23 Rio São Francisco e SC-24 Aracaju. Departamento Nacional de Produção Mineral, vol. 1, Rio de Janeiro.
- . Brasil, 1973d. Projeto Radam: Folha SB-23 Teresina e parte da Folha SB-24 Jaguaribe. Departamento Nacional de Produção Mineral, vol. 2, Rio de Janeiro.
- . Brasil, 1975a. Levantamento exploratório-reconhecimento de solos do Estado de Alagoas. Ministério da Agricultura. Empresa Brasileira de Pesquisa Agropecuária. Centro de Pesquisas Pedológicas (Boletim Técnico 35), Rio de Janeiro, 532 p.
- . Brasil, 1975b. Levantamento exploratório-reconhecimento de solos do Estado de Sergipe. Ministério da Agricultura. Empresa Brasileira de Pesquisa Agropecuária. Centro de Pesquisas Pedológicas (Boletim Técnico 36), Rio de Janeiro, 506 p.
- . Brasil, 1976. Levantamento exploratório-reconhecimento de solos da margem esquerda do Rio São Francisco, Estado da Bahia. Ministério da Agricultura. Empresa Brasileira de Pesquisa Agropecuária. Centro de Pesquisas Pedológicas (Boletim Técnico 38), Recife, 404 p.
- . Brasil, 1977. Levantamento exploratório-reconhecimento de solos da margem direita do Rio São Francisco, Estado da Bahia. Ministério da Agricultura. Empresa Brasileira de Pesquisa Agropecuária. Centro de Pesquisas Pedológicas (Boletim Técnico 52), Recife, 735 p.
- . Brasil, 1980. Sistema brasileiro de classificação de solos (1ª aproximação). Ministério da Agricultura. Empresa Brasileira de Pesquisa Agropecuária. Centro de Pesquisas Pedológicas. Rio de Janeiro, 73 p.
- . Dresch, J., 1957. Les problèmes morphologiques du Nord-Est brésilien. Bull. Ass. Geogr. Franç., 263-264: 48-59.

- . F.A.O./UNESCO, 1971. Definition of soil units for the soil map of the world. Rome. World Soil Resource Report, 72 p.
- . Feio, M., 1954. Notas acerca do relevo da Paraíba e do Rio Grande do Norte. Anuário da Fac. de Filos. da Paraíba, João Pessoa, pp. 131-140.
- . Janot, Ch. and Gibert, H., 1970. Les constituants du fer dans certaines bauxites naturelles étudiées par effect Mössbauer. Bull. Soc. fr. Min. Crist., 93: 213-223.
- . King, L.C., 1956. A geomorfologia do Brasil Oriental. Rev. Bras. de Geografia, 18(2): 147-265.
- . Lamouroux, M., Loyer, J.Y., Bouleau, A. and Janot, Ch., 1977. Formes du fer des sols rouges et bruns ferriallitiques. Application de la spectrometrie Mössbauer. Cah. ORSTOM, série Pédologie, 15(2): 199-210.
- . Lewis, D.G. and Schwertmann, U., 1979. The influence of aluminum on the formation of iron oxides. IV. The influence of (Al), (OH), and temperature. Clays and Clay Minerals, 27(3): 195-200.
- . Melfi, A.J., Pedro, G. and Volkoff, B., 1979. Natureza e distribuição dos compostos ferríferos nos solos do Brasil. Rev. Bras. Ciência do Solo, 3: 47-54.
- . Nimer, E., 1972. Climatologia da Região Nordeste do Brasil: Introdução à Climatologia Dinâmica. Rev. Bras. Geografia, 34(2): 3-51.
- . Norrish, K. and Taylor, R.M., 1961. The isomorph replacement of iron by aluminium in soil goethites. J. Soil Sc., 12: 294-306.
- . Perinet, G., 1974. Contribution à la connaissance mineralogique de formations bauxitiques de Provence. Thèse doc. Univ. de Provence-Aix-Marseille I, 212 p., (mimeog.).
- . Soil Survey Staff, 1975. Soil taxonomy, a basic system of soil classification for making and interpreting soil surveys. U.S. Dep. Agric., Soil Conserv. Serv., Agriculture Handbook 436, U.S. Gov. Print. Off., Washington, D.C., 754 p.
- . Volkoff, B. and Cesar, V.R. da S., 1977. Ferro nos latossolos do Estado da Bahia. Rev. Bras. Ciência do Solo, 1: 85-92.