# THE BRAZILIAN SYSTEM OF SOIL CLASSIFICATION

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Contents



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## 1. INTRODUCTION

Brazilian soil science is in its infancy. In studies before 1947 soils were mainly classified in relation to parent material or geomorphological units. In 1947 a national soil science society and survey institution were founded. A programme of reconnaissance soil surveys of Brazil started with the survey of the state of Rio de Janeiro in 1954.

At present the entire country has been mapped at the exploratory level, with about 20% at exploratory-reconnaissance level, plus 15% at reconnaissance level and a rather small percentage at more detailed levels.

The former USA soil classification system has been used for the soil map legend and the definition of soil classes (Baldwin et al., 1938; Thorp and Smith, 1949). The great group level was used to refer to the major soils of cartographic units, however, depending on soil variability and distribution patterns also higher or lower taxonomic classes were used.

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## 2. NATURE OF THE SYSTEM

From the inception of soil surveys in Brazil the concepts of soil classes, their distinction and definition, have been drawn up to serve primarily as units in soil-mapping legends. There has never been a consolidated soil classification system developed for Brazil except for an outline of soil classification elements in the descriptions of soils of mapping units, published in various soil survey reports.

By and large, central concepts adopted from the former USA system (Baldwin et al., 1938; Thorp and Smith, 1949) constitute the basis of the soil classification in Brazil. Nevertheless, arising from the needs of soil surveys, in which taxonomic units are tested on their suitability for legend and mapping units, changes in the original reference system have taken place. During the numerous soil surveys criteria have been modified, subdivisions created and intergrades recognized. Since the late 1950s, use has been made of principles from the approximations preceeding Soil Taxonomy (Soil Survey Staff, 1975).

The National Soil Survey and Conservation Service (SNLCS-EMBRAPA) is at present coordinating the elaboration of a Brazilian system of soil classification. The prevailing scheme is undergoing thorough reformulation and a formally explicit and organized system is under development. Although a 2nd approximation of the system has been completed, it is not suitable for reproduction or transcription, as it is a working document. The system is designed to include all known soils of Brazil, but remaining an incomplete and open system, in which new classes may be incorporated. A multi-categorical and descending system is being developed. Its base is morphogenetic, since its organization is keyed to the characteristics which result from pedogenetic processes. For this purpose, morphological, physical, chemical and mineralogical properties are used.

At the present time an orderly arrangement is sought, to provide a provisional reference base. Such an interim reference base is the scope of this paper.

# 3. DIAGNOSTIC HORIZONS AND DIAGNOSTIC PROPERTIES

Criteria currently applied to soil classification in Brazil largely conform with those commonly used by soil scientists in many other countries. They have been drawn from the 7th Approximation (Soil Survey Staff, 1960), from the legend of the Soil Map of the World (FAO-Unesco, 1974) and Soil Taxonomy (Soil Survey Staff, 1975).

From the criteria contained in a monograph report (Carvalho et al., 1986), excerpts of the major features are given in the following summary.

## 3.1 Diagnostic horizons

The relative stable B-horizon was sought as a distinctive criterion. The adherence to surface and subsurface diagnostic horizons occurred in the early sixties, based on the 7th Approximation of the USA soil classification system (Soil Survey Staff, 1960). However, some of the concepts used in the Brazilian scheme were modified and improved to suit local conditions. The diagnostic horizons currently used in Brazil are compared with the equivalent horizons of the FAO-Unesco Legend (1974) and Soil Taxonomy (Soil Survey Staff, 1975) in Table 1.

## 3.2 Diagnostic properties

Soil colour correlated with mineral components

In Latosols particularly, the colour of the B horizon was used as an important criterion to distinguish soil classes. At a regional scale colour is linked with other properties, such as iron oxides/hydroxides in the less than 2 mm fraction and the magnetic susceptibility of dry crushed material. It is also associated with behaviour pertaining to agricultural use, and related to soil climatic conditions. At a national scale, soil colour per se does not correlate well with mineral components of soils.

Table 1 - Equivalences between diagnostic horizons of FAO, Soil Taxonomy and Brazilian system of soil classification and specific criterion used in Brazil

| Systems of classification: FAO | Soil Taxonomy | Brazilian | Specific or additional criterion used in Brazilian system |
|---|---|---|---|
| - Surface Diagnostic Horizon - | | | |
| Mollic A | Mollic Epipedon | Chernozemic A | equivalent definitions |
| Umbric A | Umbric Epipedon | Proeminent A | corresponds with a weakly developed umbric epipedon (thinner and/or less organic carbon content) |
| --- | Anthropic Epipedon | Anthropic A | equivalent definitions |
| Histic A | Histic Epipedon | Turfoso A | equivalent definitions |
| Ochric A ( weak ochric A) | Ochric Epipedon | Moderate A | corresponds with a well-developed ochric epipedon |
| Ochric A ( very weak ochric A) | --- | Weak A | surface horizon with $<$ 0.58% organic carbon, light colours with moist values $>$ 5 and without development of structure or weak structure; corresponds to a weakly developed ochric epipedon |
| --- | --- | Humic A | corresponds with a well developed umbric epipedon (thicker and/or higher organic carbon content) |
| - Subsurface diagnostic horizons - | | | |
| Argillic B | Argillic horizon | textural B | similar definitions, but textural gradient (ratio of average clay content of B horizon/A horizon excluding BC) is: $>$ 1.5 if A horizon has $>$ 40% clay; $>$ 1.7 if A horizon has 15 to 40% clay; $>$ 1.8 if A horizon has $<$ 15% clay. When the B horizon presents blocky or prismatic structure with associated clay skins which exceed few and weak, the former textural gradient is not required |

Table 1 - (cont.)

| Systems of classification | | | Specific or additional criterion used in Brazilian system |
|---|---|---|---|
| FAO | Soil Taxonomy | Brazilian | |
| - Surface Diagnostic Horizon - | | | |
| Natric B | Natric horizon | Natric B | equivalent definitions |
| Spodic B | Spodic horizon | Spodic B | equivalent definitions |
| Cambic B | Cambic horizon | Incipient B | similar definitions, but a) to distinguish from latosolic B, should meet one or more of the requirements: have in the 0.05-2 mm fraction $\geqslant$ 4% weatherable minerals on basis of total fraction $<$ 2 mm; or CEC of clay $\geqslant$ 13 me/100 g after correction for organic carbon; or silt/clay ratio $\geqslant$ 0.7; or $SiO_2/Al_2O_3$ ratio $\geqslant$ 2.2; or $\geqslant$ 5% by volume of rock fragments or saprolite; and b) excluding characteristics from reduction processes and from plinthitization, referred respectivelly to gley horizon and plinthic horizon |
| Oxic B | Oxic horizon | Latosolic B | similar definitions, but exclusive of A or AB horizons, and a) meeting all the following requirements; thickness $\geqslant$ 50 cm; CEC after deduction of the contribution of organic carbon $\leqslant$ 13 meq/100 g of clay; $SiO_2/Al_2O_3$ ratio (Ki index value) of the clay fraction $\leqslant$ 2.2; silt/clay ratio $<$ 0.7; if present in the 0.05-2 mm fraction, $<$ 4% weatherable minerals on basis of total fraction $<$ 2 mm; $<$ 5% by volume of rock fragments or saprolite; strong very fine to moderate subangular blocky structure; b) always with clay gradient in the solum unsatisfactory for textural B; and c) additional exclusion of characteristics from reduction processes and from plinthitization, referred respectivelly to glei horizon and plinthic horizon |

Table 1 - (cont.)

| Systems of classification | | | Specific or additional criterion used in Brazilian system |
|---|---|---|---|
| FAO | Soil Taxonomy | Brazilian | |
| - Surface Diagnostic Horizon - | | | |
| --- | --- | Plinthic horizon | horizon with thickness of 15 cm and containing $\geqslant$15% by volume of plinthite, as defined in Soil Taxonomy |
| --- | --- | Glei horizon | derivative of hydromorphic properties of FAO system, concerning horizon with gleyic properties, as: 1) dominant neutral (N) hues or bluer than 10Y; and/or 2) saturation of water at some period of the year, or artificially drained, with evidence of reduction processes or of reduction and processes or of reduction and segregation of iron reflected by $\geqslant$20% of mottles of chromas of $\leqslant$2, otherwise if not mottled, the value being $>$4, the chroma is $<$1 and if the value is $\geqslant$4 or more, chroma $\leqslant$1 |
| Albic E | Albic horizon | Albic horizon | equivalent definitions |
| Calcic horizon | Calcic horizon | Calcic horizon | equivalent definitions |
| --- | Petrocalcic horizon | Petrocalcic horizon | equivalent definitions |
| Sulfuric horizon | Sulfuric horizon | Sulfuric horizon | equivalent definitions |
| --- | Salic horizon | Salic horizon | equivalent definitions |
| --- | Fragipan | Fragipan | equivalent definitions |
| --- | Duripan | Duripan | equivalent definitions |

## Activity of Clay

This is expressed by the cation exchange capacity (CEC) as determined at pH 7.0, and refered to the fraction less than 0.002 mm. It is considered after subtraction of the contribution to the CEC by organic carbon.

The following equation can be used:

$$\text{CEC (100 g clay)} = [\text{CEC (100 g soil)} - (4.5 \times \%C)] \times 100/\% \text{ of clay}$$

For more precise procedure and specially for Latosols, the graphic method proposed by Bennema (1966) should be used. Two main classes of activity of clay are used:

High activity - soils with CEC $>$ 24 meq/100 g clay, and

Low activity - soils with CEC $<$ 24 meq/100 g clay.

Further subdivisions of importance, particularly concerning the Latosols are indicated by CEC $<$ 13 meq, meant as requisite for Latosols, and CEC $\leq$ 6.5 to separate the mature typical Latosols. A comparison of threshold values of CEC used in Brazil, with those of Soil Taxonomy (Soil Survey Staff, 1975) is presented in Table 2 according to the correlation developed by Olmos & Paolinelli (1982).

Table 2 - Equivalences pertaining to CEC limits used in the Brazilian system and Soil Taxonomy

| Brazilian* | CEC values meq/100 g of clay | | | Soil Taxonomy** |
|---|---|---|---|---|
| | Brazilian° | | Soil Taxonomy°° | |
| | - Org. C | + Org. C | + Org. C | |
| High activity/low activity clay | 24 | 27 | 42 | nihil |
| Limit latossolic B horizon | 13 | 16 | 24 | Limit oxic subgroups |
| Limit latossolic B horizon highly weathered kinds | 6.5 | 10 | 16 | Limit oxic horizon |

*Distinction intended by the Brazilian system
°CEC values determined according to SNLCS method
°°CEC values determined according to Soil Taxonomy method
**Distinction intended by the Soil Taxonomy system
- Org. C = Organic Carbon contribution is subtracted from CEC values
+ Org. C = CEC values are not corrected for organic carbon

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Appendix I

PHASES OF ORIGINAL NATURAL VEGETATION

Since the early 1960s, the main types of primary vegetation have been introduced as phases criteria, applied to general soil survey classification in Brazil (Camargo et al., 1962).

The reasoning behind this procedure, has been further explained in a soil workshop sponsored by SNLCS-EMBRAPA (Reuniao de Classificaçao Correlaçao e Interpretaçao de Aptidao Agricola de Solos, 1979) and lately reiterated by Carvalho et al. (1986).

The nature of major types of primary vegetation is influenced by climatic and/or edaphic conditions, which control the kinds of phytogeographic formations and affect their physiologic-physiognomic behaviour. Areal comparisons of climatic divisions with phytogeographic divisions (thermic and hydric indexes versus nature of primary vegetation) show relationships between vegetation and climatic conditions, principally the thermic and hydric regimes, inclusive the soil hydric regime. Moreover, soil oligotrophic or eutrophic status influences the primary vegetation.

Field observations on soil climate and especially the soil hydric regime are scarce. However, phases of primary vegetation are resorted to, which allow inferences on climatic conditions and the soil moisture regime.

Certainly, besides the pedological meaning, the subdivisions carry a broader ecological implication, giving further knowledge of relationships between soil classes, land units and their agricultural capabilities, enhancing the utilitarian scope of soil surveys.

The main types of original natural vegetation that have been recognized as phases, indicative for pedoclimatic conditions, or sometimes of soil oligotrophy or eutrophy (Carvalho et al., 1986), are presented in the following Table. Correlations with calculated soil moisture and temperature regimes (Van Wambeke, 1981), as used in Soil Taxonomy (Soil Survey Staff, 1975), are given by checking the calculated regimes from about 250 meteorological stations against the identified primary vegetation type or co-existing types (e.g. forest and cerrado; grassland and forest) in the region near the station location. The number of locations referred to each primary vegetation type and corresponding calculated soil moisture and temperature regimes (op. cit.) is given between brackets in the table.

Equivalences concerning main phases of primary vegetation* as applied in general soil surveys in Brazil versus calculated soil moisture and temperature regimes and classes of tentative subdivisions of moisture regimes (Van Wambeke, 1981).

| Primary vegetation phases | | Calculated soil moisture and temperature regimes | Tentative subdivisions of moisture regimes |
|---|---|---|---|
| 1. Floresta equatorial (Tropical forest) | | | |
| 1.1 Perúmida (Perhumid evergreen rain forest) | (7) | Perudic Isohyperthermic (7) | Perudic (7) |
| 1.2 Perenifólia (Evergreen rain forest) | (12) | Udic Isohyperthermic (9)<br>Ustic Isohyperthermic (3) | Typic Udic (6) Udic Tropust (3) Dry Tropudic (3) |
| 1.3 Subperenifólia (Semi-evergreen) | (9) | Ustic Isohyperthermic (7)<br>Udic Isohyperthermic (2) | Typic Tropust (4) Udic Tropust (3) Dry Tropudic (2) |
| 1.4 Subcaducifólia (Semi-deciduous) | (4) | Ustic Isohyperthermic (4) | Udic Tropust (4) |
| 1.5 Higrófila de várzea (Hygrophilous riverine) | | Aquic *at least pro parte* | |
| 1.6 Hidrófila de várzea (Hydrophilous riverine) | | Aquic | |
| 2. Floresta tropical (Tropical forest) | | | |
| 2.1 Perúmida (Perhumid evergreen rain forest) | (5) | Perudic Isohyperthermic (5) | Perudic (5) |
| 2.2 Perenifólia (Evergreen rain forest) | (31) | Udic Isothermic (14)<br>Udic Isohyperthermic (8)<br>Perudic Isohyperthermic (4)<br>Perudic Hyperthermic (3)<br>Perudic Isothermic (1) Udic Hyperthermic (1) | Typic Udic (23) Perudic (8) |
| 2.3 Subperenifólia (Semi-evergreen) | (55) | Udic Isohyperthermic (33)<br>Ustic Isohyperthermic (15)<br>Udic Isothermic (6)<br>Ustic Isothermic (1) | Typic Udic (26) Dry Tropudic (13) Udic Tropust (11) Typic Tropust (5) |
| 2.4 Subcaducifólia (Semi-deciduous) | (31) | Ustic Isohyperthermic (18)<br>Udic Isohyperthermic (12)<br>Ustic Isothermic (1) | Typic Tropust (10) Udic Tropust (9) Dry Tropudic (8) Typic Udic (4) |
| 2,5 Caducifólia (Deciduous) | (19) | Ustic Isohyperthermic (19) | Typic Tropust (10) Udic Tropust (9) |
| 2.6 Higrófila de várzea (Hygrophilous riverine) | | Aquic *at least pro parte* | Aquic |
| 2.7 Hidrófila de várzea (Hydrophilous riverine) | | Aquic | |

*A few formation-types of minor extent are omitted in the table given.

(con't)

| Primary vegetation phases | Calculated soil moisture and temperature regimes | Tentative subdivisions of moisture regimes |
|---|---|---|
| 3. Floresta subtropical (Warm temperate forest) | | |
| 3.1 Perúmida (2) (Perhumid evergreen rain forest) | Perudic Isothermic (2) | Perudic (2) |
| 3.2 Perenifólia (8) (Evergreen rain forest) | Perudic thermic (6) Perudic Isothermic (1) Udic Isothermic (1) | Perudic (7) Typic Udic (1) |
| 3.3 Subperenifólia (3) (Semi-evergreen) | Udic Thermic (2) Udic Isothermic (1) | Typic Udic (3) |
| 3.4 Subcaducifólia (2) (Semi-deciduous woodland) | Udic Thermic (2) | Typic Udic (2) |
| 3.5 Higrófila de várzea (Hygrophilous riverine woodland) | Aquic *at least pro parte* | |
| 3.6 Hidrófila de várzea (Hydrophilous riverine woodland | Aquic | |
| 4. Vegetação de restinga (Sand bar and coastal sand plains psammophilous vegetation) | | |
| 4.1 Floresta mesófila (15) (Mesophyllous forest) | Udic Isohyperthermic (6) Ustic Isohyperthermic (4) Perudic Isohyperthermic (3) Udic Thermic (2) | Typic Udic (6) Perudic (3) Dry Tropudic (2) Udic Tropust (2) Typic Tropust (2) |
| 4.2 Floresta hidrófila (Hydrophilous forest) | Aquic | |
| 4.3 Formação herbácea-arbustiva (Shrub-grassland) | Same conditions as in 4.1 | |
| 5. Cerrado - *lato sensu* (variously savanna woodland, tree and/or shrub savannas, savanna grassland whichever oligotrophic and scleromorphous nature) | | |
| 5.1 Cerrado equatorial subperenifólio (4) (Tropical semi-evergreen tree and/or shrub savannas) | Ustic Isohyperthermic (4) | Dry Tropudic (2) Udic Tropust (2) |
| 5.2 Campo cerrado equatorial (2) (Tropical savanna grassland) | Udic Isohyperthermic (1) Ustic Isohyperthermic (1) | Dry Tropudic (1) Udic Tropust (1) |

(con't)

| Primary vegetation phases | Calculated soil moisture and temperature regimes | Tentative subdivisions of moisture regimes |
|---|---|---|
| 5.3 Cerrado e cerradão tropical subperenifólio (16) (Tropical semi-evergreen savanna, woodland & tree and/or shrub savannas) | Udic Isohyperthermic (7) Udic Isothermic (7) Ustic Isohyperthermic (2) | Typic Udic (14) Udic Tropust (2) |
| 5.4 Cerrado e cerradão tropical subcaducifólio (31) (ditto though semi-deciduous) | Ustic Isohyperthermic (18) Udic Isohyperthermic (11) Ustic Isothermic (1) Udic Isothermic (1) | Udic Tropust (14) Dry Tropudic (12) Typic Tropust (5) |
| 5.5 Cerrado e cerradão tropical caducifólio (6) (ditto though deciduous) | Ustic Isohyperthermic (6) | Typic Tropust (4) Udic Tropust (2) |
| 5.6 Campo cerrado tropical (3) (Tropical savanna grassland) | Udic Isohyperthermic (2) Udic Isothermic (1) | Typic Udic (3) |
| 6. Caatinga (Thorn scrub) | | |
| 6.1 Hipoxerófila (9) (Hypoxerophilous) | Ustic Isohyperthermic (8) Aridic Isohyperthermic (1) | Aridic Tropust (5) Typic Tropust (3) Weak Aridic (1) |
| 6.2 Hiperxerófila (8) (Hyperxerophilous) | Ustic Isohyperthermic (5) Aridic Isohyperthermic (3) | Aridic Tropust (5) Typic Aridic (2) Weak Aridic (1) |
| 7. Vegetação Campestre (Grasslands) | | |
| 7.1 Campo tropical higrófilo de várzea (Tropical meadow) | Aquic | |
| 7.2 Campo tropical hidrófilo de várzea (Tropical swamp grassland) | Aquic | |
| 7.3 Campo subtropical perúmido - *vegetação altimontana* (2) (Subtropical montane grassland - *perhumid*) | Perudic Isothermic (1) Perudic Isomesic (1) | Perudic (2) |
| 7.4 Campo subtropical úmido (11) (Subtropical mesophyllous grassland) | Perudic Isothermic (5) Perudic Thermic (4) Udic Isothermic (2) | Perudic (9) Typic Udic (2) |

(con't)

| Primary vegetation phases | Calculated soil moisture and temperature regimes | Tentative subdivisions of moisture regimes |
|---|---|---|
| 7.5 Campo subtropical subū mido (4) (Subtropical subhumid grassland - *pampas*) | Udic Thermic (4) | Typic Udic (4) |
| 7.6 Campo subtropical hi- grōfilo de vārzea (Subtropical meadow) | Aquic | |
| 7.7 Campo subtropical hi- drōfilo de vārzea (Subtropical swamp grassland) | Aquic | |

Appendix II

ANALYTICAL METHODS USED BY THE BRAZILIAN SOIL SURVEY SERVICE - SNLCS

Analytical methods are referred to codes according to Manual de metodos de analise de solo (Empresa Brasileira de Pesquisa Agropecuaria - SNLCS, 1979).

Fraction $<$ 2 mm (gravel and cobbles) and $<$ 2 mm (fine earth) - air-dried whole samples, wood rolling to break clods and sieving through rounded hole 2 mm sieve; volume percentage determined by volumetric measurement of fractions coarser and finer than 2 mm (Meth. 1,2,2); weight percentage by gravimetric determination (Meth. 1,2,1).

Particle size distribution - determined in the $<$ 2 mm fraction dispersed in water with NaOH or occasionally calgon, high speed stirring, sedimentation; clay measured in supernatant by modified hydrometer method, sands by sieving and silt by difference; no pretreatment to destroy organic matter (Meth. 1,16,2).

Water dispersible clay - same as above, except no dispersing agent used (Meth. 1,17,2).

Floculated clay ratio - derived value based on percentage of clay fraction and percentage of water dispersible clay (Meth. 1,18).

Bulk density - measured in core samples by volumetric ring (Kopecky) method (Meth. 1,11,1) or paraffin-coated clods (Meth. 1,11,3), when applicable - reported on oven dry base.

Particle density - volumetric flask and ethyl alcohol (Meth. 1,120).

Porosity - derived value based on bulk density and particle density (Meth. 1,13).

Water content $\sim$1/3 bar - determined in presaturated $<$ 2 mm fraction by centrifugation at 2,400 rpm during thirty minutes (Meth. 1,8).

pH H20 and 1N KCl - measured by glass electrode in a soil-water and soil-1N KCl 1:2.5 suspension contact for no less than thirty minutes, stirring immediately before reading (Meth. 2,1,1 and 2,1,2).

Extractable bases - $Ca^{++}$ and $Mg^{++}$ extracted with 1N KCl and titrated with EDTA (Meth. 2,9 and 2,10); $K^+$ and $Na^+$ extracted with 0.05N HCl + 0.025 N $H_2SO_4$ and determined by flame photometer (Meth. 2,12 and 2,13).

Sum of bases - calculated as sum of $Ca^{++}$, $Mg^{++}$, $K^+$ and $Na^+$ determined as above (Meth. 2,14).

Extractable acidity - $Al^{+++}$ extracted with 1N KCl, titration of acidity with 0.025N NaOH and bromthymol blue as indicator (Meth. 2,8); $H^+$ + $Al^{+++}$ extracted with 1N Ca $(OAC)_2$ pH 7.0, titration of acidity with 0.0606N NaOH and phenolphtalein as indicator (Meth. 2,15); $H^+$ calculated by difference from above determinations (Meth. 2,16).

CEC - sum of cations (at about pH 7.0) - calculated by summing extractable bases and extractable acidity as above (Meth. 2,17).

Base saturation - derived valued based on extractable bases and CEC as above, reported as percentage of CEC (Meth. 2,18).

Aluminium "saturation" - derived value based on extractable $Al^{+++}$ and extractable bases reported as percentage of summation of these values (Meth. 2,19).

Extractable P - extracted with 0.05N HCl + 0.025N $H_2SO_4$ and determined colorimetrically (Meth. 2,6).

Total P - H2S04 1:1 digestion - determined colorimetrically using ascorbic acid (Meth. 2,28).

Organic carbon - wet oxidation with 0.4N $K_2Cr_2O_7$ and titration with 0.1N $FeSO_4$ (Meth. 2,2).

Total nitrogen - Kjeldahl - digestion with acid mixture, diffusion and titration of $NH_3$ with 0.01N HCl (Meth. 2,4,1).

Attack by H2SO4 1:1 and NaOH 0.8% - boiling solubilization of < 2 mm size fraction to (1) extract in the filtrate: iron and aluminium - determined complexometrically by titration, reported as $Fe_2O_3$ and $Al_2O_3$ (Meth. 2,24 and 2,25); titanium, manganese and phosphorus - determined colorimetrically, reported as $TiO_2$, and $P_2O_5$ (Meth. 2,26; 2,27; 2,28); (2) in the residue of the sulfuric attack, extraction of silicon with NaOH 0.8% and determined colorimetrically, reported as $SiO_2$ (Meth. 2,23,3).

SiO2/Al2O, SiO2/R2O3, Al2O3/Fe2O3 ratios* - calculation on molecular basis, derived from above determinations (Meth. 2,29 and 2,30).

CBD extractable iron - determined by atomic absorption spectrophotometry, reported as $Fe_2O_3$ Meth. 2,31).

CaCO3 equivalent - reaction with HCl 1:1 and gasometric determination of $CO_2$ evolved (Meth. 2,43,3).

Electric conductivity of the saturtion extract - water extraction of a saturated paste (Meth. 2,32) and conductimetric determination (Meth. 2,33).

Total sulfur - Attack by HCl 1:1, precipitation with $BaCl_2$ and determined gravimetrically (Meth. 2,45).

Mineralogy of sands and fractions > 2 mm - identification of mineral particles by optical methods using binocular microscope and polarizing microscope with occasional complementary chemical microtests; qualitative and semi-quantitative determinations of mineralogical species are made and results expressed in approximate percentage (Meth. 4,3; 4,4,1; 4,5).

Clay mineralogy - X-ray diffraction and differential thermal analysis.

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* Indexes of overall composition of the secondary mineral constituents plus ilmenite.