Alves Bispo, Fábio Henrique; Silva, Alexandre Christofaro; Vidal Torrado, Pablo; de Souza Junior, Valdomiro Severino

HIGHLANDS OF THE UPPER JEQUITINHONHA VALLEY, BRAZIL. II - MINERALOGY, MICROMORPHOLOGY, AND LANDSCAPE EVOLUTION

Revista Brasileira de Ciência do Solo, vol. 35, núm. 4, 2011, pp. 1081-1091
Sociedade Brasileira de Ciência do Solo
Viçosa, Brasil

HIGHLANDS OF THE UPPER JEQUITINHONHA VALLEY, BRAZIL. II – MINERALOGY, MICROMORPHOLOGY, AND LANDSCAPE EVOLUTION[1]

Fábio Henrique Alves Bispo[2], Alexandre Christofaro Silva[3], Pablo Vidal Torrado[4] & Valdomiro Severino de Souza Junior[5]

SUMMARY

Palm swanp formations, the so-called veredas, typically occur in the Brazilian biome known as "Cerrado" (savanna-like vegetation), especially on flattened areas or tablelands (chapadas). The aim of this study was to characterize the mineralogy and micromorphology of soil materials from a representative toposequence of the watershed of the vereda Lagoa do Leandro, located in Minas Novas, state of Minas Gerais, Brazil, on plains in the region of the upper Jequitinhonha valley, emphasizing essential aspects of their genesis and landscape evolution. The toposequence is underlain by rocks of the Macaúbas group and covered with detrital and metamorphic rocks (schists of Proterozoic diamictites). The soil profiles were first pedologically described; samples of the disturbed and undisturbed soils were collected from all horizons for further micromorphological and mineralogical analyses. The mineralogical analysis was mainly based on powder X ray diffractometry (XRD) and micromorphological descriptions of thin sections under a petrographic microscope. The soils from the bottom to the top of this toposequence were classified as: Typic Albaquult (GXbd), Xanthic Haplustox, gray color, here called "Gray Haplustox" ("LAC"), Xanthic Haplustox (LA) and Typic Haplustox (LVA). The clay mineralogy of all soils was found to be dominated by kaolinite. In soil of LA and LVA, the occurrence of goethite, gibbsite, and anatase was evidenced; "LAC" also contained anatase and the GXbd, illite, anatase, and traces of vermiculite. The micromorphological analyses of the LVA, LA and "LAC" soils showed the prevalence of a microaggregate-like or granular microstructure,

(1) Part of the dissertation of first author, presented to the Master's degree in Produção Vegetal of the Universidade Federal dos Vales do Jequitinhonha e Mucuri – UFVJM. Received for publication in October 28, 2010 and approved in May 6, 2011.

(2) Fellow ship of the Núcleo de Inovação Tecnológica – UFVJM. Rodovia MGT 367, Km 583, CEP 39100-000 Diamantina (MG). E-mail: fabiobispo_agro@yahoo.com.br

(3) Associate Professor, Departamento de Engenharia Florestal, UFVJM. E-mail: alexandre.christo@ufvjm.edu.br

(4) Full Professor, Departamento de Ciência do Solo of the Escola Superior de Agricultura Luiz de Queiroz – ESALQ/USP. PO Box 09, Avenue Pádua Dias 11, CEP 13418-900 Piracicaba (SP). E-mail: pablo@esalq.usp.br

(5) Adjunct Professor, Departamento de Agronomia, Universidade Federal Rural de Pernambuco – UFRPE. E-mail: valdomiro@depa.ufrpe.br

and aggregate porosity has a stacked/packed structure, which is typical of Oxisols. A massive structure was observed in GXbd material, with the presence of illuviation cutans of clay minerals and iron compounds. Paleogleissolos, which are strongly weathered, due to the action of the excavating fauna , and resulted in the present "LAC". The GXbd at the base of the vereda preserved the physical, mineralogical and micromorphological properties that are typical of a pedogenesis with a strong influence of long dry periods.

Index terms: microaggregates, pedogenesis, haplustox, albaquult.

RESUMO: *CHAPADAS DO ALTO VALE DO JEQUITINHONHA, MG. II – MINERALOGIA, MICROMORFOLOGIA E EVOLUÇÃO DA PAISAGEM*

As veredas são formações típicas que ocorrem no Cerrado brasileiro, principalmente nas áreas aplainadas denominadas chapadas. O objetivo deste trabalho foi caracterizar mineralógica e micromorfologicamente os solos de uma topossequência representativa da microbacia da Vereda Lagoa do Leandro, localizada no município de Minas Novas - MG, situada nas chapadas do Alto Vale do Jequitinhonha, enfatizando aspectos de suas gêneses e da evolução da paisagem. A topossequência está embasada em rochas do Grupo Macaúbas, com cobertura detrítica e rochas metamórficas (xistos diamictitos do Proterozoico). Os solos foram descritos em trincheiras, e amostras deformadas e indeformadas foram coletadas em todos os horizontes, para análises mineralógicas e micromorfológicas. As análises mineralógicas da fração argila foram determinadas pela técnica de difração de raios X (DRX), e as micromorfológicas, por descrições de lâminas delgadas em microscópio petrográfico. Os solos caracterizados da base da vereda para o topo foram Gleissolo Háplico (GXbd), Latossolo Amarelo, de cor cinzenta, aqui denominado "Latossolo Acinzentado" ("LAC"), Latossolo Amarelo (LA) e Latossolo Vermelho-Amarelo (LVA). A mineralogia da fração argila em todos os solos é dominada pela caulinita. Nos LVA e LA foram identificadas goethita, gibbsita e anatásio; no "LAC", anatásio; e no GXbd, ilita, anatásio e traços de vermiculita. A micromorfologia do LVA, LA e "LAC" é dominada pela microestrutura do tipo granular ou microagregados e porosidade do tipo empilhamento/empacotamento, típicos de Latossolos. No GXbd predomina a estrutura maciça, com a presença de cutãs de iluviação e ferri-argilãs. Paleogleissolos foram latolizados pela ação da fauna escavadora e deram origem aos atuais "LAC". Os GXbd da base da vereda preservaram atributos físicos, mineralógicos e micromorfológicos que tiveram suas gêneses em períodos secos.

Termos de indexação: microagregados, pedogênese, Latossolos, Gleissolos.

INTRODUCTION

Chapadas (highlands) predominate on the Jequitinhonha plateau, in Northeastern Minas Gerais (MG); these are extensive areas of flattened terrain (at about 900 m asl). The original biome was the Cerrado vegetation and the area was separated by the Jequitinhonha and Araçuaí River and their affluents. Some of these chapadas, which cover over 10,000 ha, are drained by streams with swamps (veredas) at their source.

According to Campos (1998), the drainage system of the upper Jequitinhonha valley is immensely important for the soil and landscape evolution because structural, tectonic, and lithological factors induced changes in this environment. Veredas may occur under varied hypsometric, lithostratigraphic, pedologic, and pluviometric conditions (Melo, 1992). Red, Red Yellow, Yellow, and gray-colored Latosols predominate on the chapadas of the upper Jequitinhonha; and Gleysols and Plinthosols are found in the valleys (Ferreira et al., 2010).

The mineral material of the dominant soils in the Cerrado biome is clayey, composed mainly of kaolinite, iron oxides, gibbsite, and also Ti and quartz oxides (Moura Filho & Buol, 1972; Weaver, 1974; Curi & Franzmeier, 1984); these in turn reflect the soil genesis and weathering stages, related with the landscape evolution. Ferreira et al. (2010) characterized the mineralogy of the Latosols on the Jequitinhonha plateau, which contain mostly kaolinite and gibbsite with significant crystallinity in the clay fraction.

Detailed micromorphological studies deepen the understanding of the origin of soils (Brewer, 1976). Such studies have demonstrated clay illuviation/eluviation, microaggregation, and pore quantity and size distribution as soil forming processes (Bullock et al., 1985), which are also related with the landscape evolution.

The purpose of this paper was to study the micromorphology and identify the mineral material of the clay fraction of soils in a representative toposequence of a highland swamp (vereda located on a chapada) of the upper Jequitinhonha valley, MG, focused on the genesis and relation with the landscape evolution.

MATERIAL AND METHODS

Location, geomorphology, and geology

The studied soils are part of a toposequence in the Vereda Lagoa do Leandro, in the municipality of Minas Novas, Alto Vale do Jequitinhonha, Minas Gerais State, Brazil (latitude 17 ° 19 ' to 17 ° 20 ' South, longitude 42 ° 28 ' to 42 ° 29 ' West).

The region around Minas Novas is drained by the Araçuaí, Fanado, Capivari, and Setubal rivers. There are two hydrogeological domains: Cenozoic dendritic cover, and Neoproterozoic metamorphic rocks (CPRM, 2005).

The planation surface on the Jequitinhonha plateau was formed in the Lower or Middle Tertiary Period, and originated the current chapadas, which are underlain by lithologies of the Macaúbas group; the summits are flattened and were fragmented by intense dissection of the landscape. There are Cenozoic dendritic-lateritic sediments in these dissected areas, converging to the Fanado and Capivari river basins (Minas Gerais, 1982; Campos, 1998).

A deep pedologic cover on the chapadas facilitates water infiltration; part of this water supplies deep regional water tables, and another part rises to the surface as localized surface flow in the lower portions of the chapadas; the headwaters are commonly named "veredas" (Projeto RADAMMINAS, 1977).

The planation surfaces of the Lower or Middle Tertiary Periods overlay Proterozoic diamictite schists (Minas Gerais, 1982; Campos, 1998). This author also claims that this region defines the beginning of the caatinga vegetation in the State of Minas Gerais.

The Macaúbas lithology is a pre-Cambrian Neoproterozoic sedimentary sequence consisting of quartz-biotite-schists with interbedded quartzite, conglomerates, philites, limestone lenses, amphibolites and green schists, underlying the evolution of the regional terrain (Pedrosa Soares, 1996).

Field work

Based on the Brazilian Soil Classification System (Embrapa, 2006), four profiles representing the landscape (top, mid-slope, foot slope, and bottom of the vereda) were described in a toposequence on the hillside of the Lagoa do Leandro microbasin in the upper Jequitinhonha valley: top – typical dystrophic Red Yellow Latosol (LVA); mid-slope – typical dystrophic Yellow Latosol (LA); foot slope – grayish colored dystrophic Yellow Latosol, here named dystrophic "Grayish Latosol" ("LAC"); and the base of the vereda – argisol dystrophic tb Haplic Gleysol (GXbd). Based on the Soil Taxonomy (United States, 1975) the same soil profiles were classified, respectively, as: Typic Haplustox (LVA), Xanthic Haplustox (LA), Xanthic Haplustox, gray color, here called "Gray Haplustox" ("LAC") and Typic Albaquult (GXbd).

The soils sampled in trenches in horizons were described morphologically, according to Santos et al. (2005). Disturbed samples were collected for mineral material analysis of B horizons, since there was no mineralogical variation across the layers, and non-disturbed samples preferably of the A and B or transition horizons for micromorphological analyses. The aim was to sample a surface layer (affected by organic matter) and a subsurface (diagnostic) horizon.

Laboratory work

Mineralogical analyses

The mineral material of the clay fraction was analyzed by X ray diffraction (XRD). Samples were prepared and the mineral material of the clay fraction detremined according to Jackson (1975). Samples were treated according to Kämpf & Schwertmann, (1982), using a method modified by Singh & Gilkes (1991) for concentrates to identify iron oxides.

Diffraction X ray was carried out using a Shimadzu XRD 6000 diffractometer with a copper anode and coupled graphite crystal monochromator, operating at 40 kv and 20 mA. Samples were diffracted in the form of aggregates on slides, scanned in 3–35 °2θ intervals at a speed of 1.5 °2θ min^{-1} in continuous mode. Natural clay and oxide concentrates were analyzed as non-oriented dust scanned in 3–70 °2θ intervals, also at 1.5 °2θ min^{-1} in continuous mode.

The criteria for interpreting diffractograms and identifying the mineral material of the clay fraction were based on interplanar (d) spacing and the diffraction peaks following thermal and saturation treatments, as described by Jackson (1975), Brown & Brindley (1980), and Moore & Reynolds (1989).

Micromorphological analyses

Non-disturbed samples were collected on card paper covered with film paper to maintain the structural integrity. The samples were then impregnated with a 1.0 # 08 crystal resin + styrene monomer + fluorescent pigment and catalyzer, after which the sections were polished, glued onto glass slides, and again sectioned and polished to the ideal thickness for micromorphological analysis, as recommended by Murphy (1986). The thin sections were analyzed under a Zeiss petrographic microscope and described according to Bullock et al. (1985), Brewer (1976), and Stoops & Jongerius (1975).

RESULTS AND DISCUSSION

Characterizing the mineralogy

The mineral material of the clay fraction in all study soils consisted mostly of kaolinite (K), with some titanium oxide occurrences (Anatase - An), as often observed in regions with latosols (Curi & Franzmeier, 1984) (Figures 1 to 4). Goethite (Gh) and gibbsite (Gb) may be found in LA and LVA (Figures 3 and 4). Illite (I) and a low intensity diffraction peak corresponding to the basal spacing of vermiculite (V) was found in the Btg_2 horizon of the GXbd (Figure 1).

Kaolinite was found by the presence of diffraction peaks at basal spacings of 0.722 nm (12.24 °2θ d_{001}) and 0.359 nm (24.74 °2θ d_{002}), which collapsed after heating to 550 ºC. Heating the sample to 550 °C causes destruction of Al oxides and collapse of this mineral. The presence of 1.026 nm (8.61 °2θ d_{001}), 0.505 nm (17.52 °2θ d_{001}), and 0.336 nm (26.48 °2θ d_{001}) diffraction peaks indicated the presence of illite (Figure 1). Anatase was found at a 0.351 nm (25.3 °2θ d_{101}) diffraction peak, which becomes clear after heating the oxide concentrate to 550 ºC (Figures 1 to 4). Vermiculite was found in the GXbd because of a weak 1.4 nm (6.3 °2θ d_{001}) diffraction peak that was not displaced after treatment with glycerol, and which

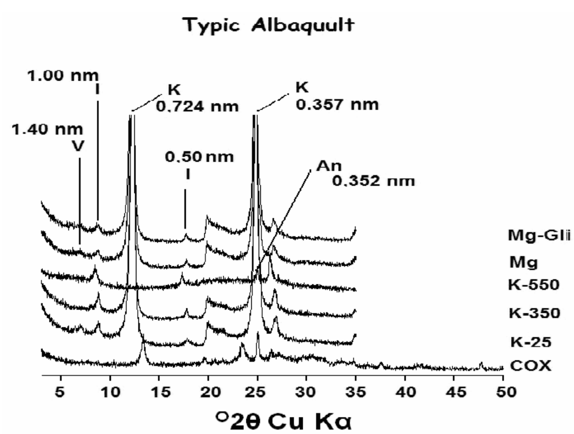


Figure 1. X ray diffractograms of the deferrified clay fraction and oxide concentrations in the Btg_2 horizon of the typic Albaquult (GXbd). K: Kaolinite, I: Illite, An: Anatase, and V: Vermiculite (traces).

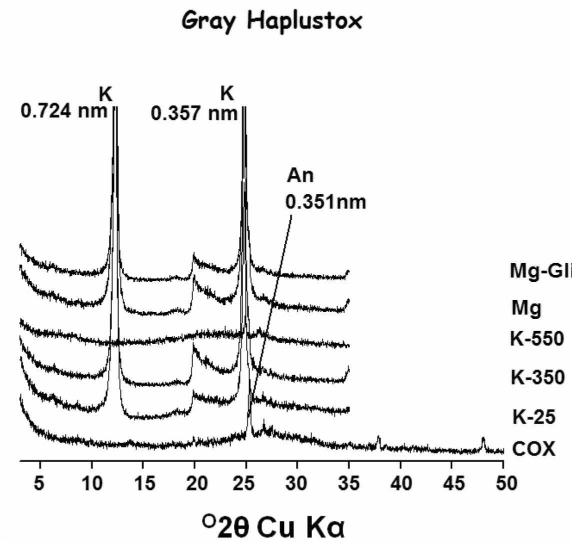


Figure 2. X ray diffractograms of the deferrified clay fraction and oxide concentrations in the Bw_2 horizon of the "Gray Haplustox" ("LAC"). K: Kaolinite and An: Anatase.

collapsed after heating to 550 ºC (Figure 1). Diffraction peaks at 0.483 nm (18.35 °2θ d_{001}) and 0.437 nm (20.3 °2θ d_{001}) indicated the presence of gibbsite. Goethite was found because of 0.416 nm (21.34 °2θ d_{001}) and 0.269 nm (33.25 °2θ d_{001}) diffraction peaks, which collapsed after thermal treatment at 350 ºC (Figures 3 and 4).

Kaolinite was predominant in the Btg_2 horizon of the GXbd; there were occurrences of illite and traces of vermiculite. This material was concordant with the Ki < 2.0 and pH < 5.0 values for all horizons of this soil type (Melo, 1992; Bispo, 2010) also found 2:1 traces of minerals at the bottom of veredas on a plateau in northwestern Minas Gerais.

According to Mala (2002), vermiculite formation may be associated with alteration in micaceous or feldspathic minerals. According to Ramos (2000), the occurrence of vermiculite traces in waterlogged soils of the vereda may be explained by stagnant water that results in less intense weathering and neoformation of these minerals under the effect of silica and bases.

Horizons Bw in LA and LVA consist essentially of kaolinite, goethite, and gibbsite, which are typical clay minerals formed under intense weathering conditions and excellent drainage. Low Ki values and a low Fe_o/Fe_d ratio support these results. Iron oxides were not found in the "LAC", which is supported by a low content of Fe_o and Fe_d and a much higher Fe_o/Fe_d ratio than in the LA and LVA, and at a lower ratio than that of GXbd (Bispo, 2010).

Kämpf & Schwertmann (1983) have suggested that increased moisture and lower pH values in LA and

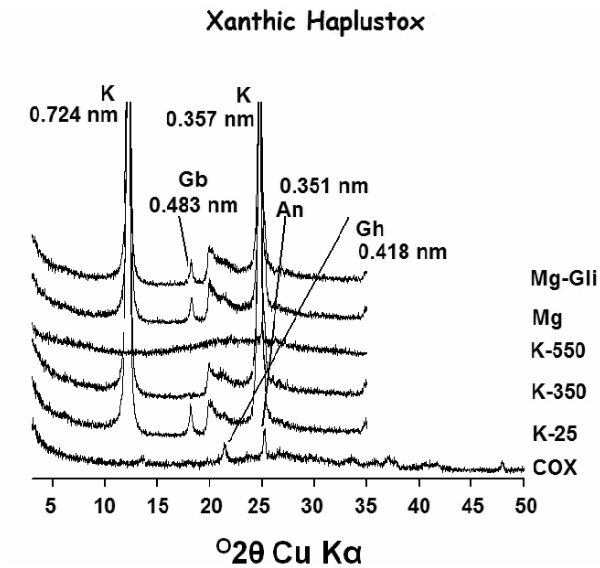


Figure 3. X ray diffractograms of the deferrified clay fraction of the Bw horizon of the Xanthic Haplustox (LA). K: Kaolinite, Gb: Gibbsite, Gh: Goethite, and An: Anatase.

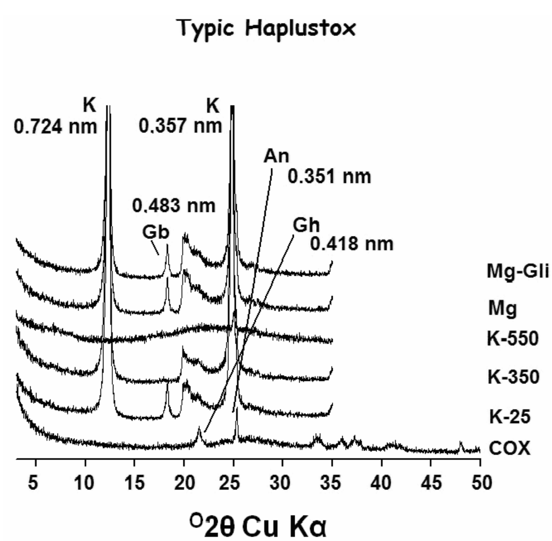


Figure 4. X ray diffractograms of the deferrified clay fraction and oxide concentrations in the Bw$_2$ horizon of the Red Yellow Latosol (LVA). K: Kaolinite, Gb: Gibbsite, Gh: Goethite, and An: Anatase.

LVA profiles result in (hydrated) goethite rather than (dehydrated) hematite formation. Ferreira et al. (2010) found no Fe oxides either in a gray latosol profile in the upper Jequitinhonha region.

The Latosols of the Lagoa do Leandro swamp are formed by pre-weathered materials (in prior weathering cycles) which, in association with the current terrain and climate, are at an advanced weathering stage; thus they are essentially kaolinitic and oxidic.

Micromorphology

The A horizon of GXbd is homogeneous; it contains a single porphyric-enaulic zone. The microstructure consists of subangular, prismatic, and microgranulated blocks (Figure 5a). The plasma is black-reddish and isoptic, probably because of organic matter. The predominantly inter-aggregate porosity has a stacked/packed structure, with some filled biological cavities, channels, and microfissures (Figure 5b). Pedologic features such as quartz-containing orthotubules, organic matter, micro-aggregates, and empty pedotubules may be found. There are also many roots along this horizon.

The Btg$_2$ horizon of the GXbd is homogeneous. There is a dense porphyric zone with a microstructure of prismatic and subangular polyhedral aggregates (subangular blocks), confirming the morphological description of its structure. The plasma is gray isoptic and predominant cavity porosity (inter-aggregates); there are also chambers and microfissures. The microstructure of these soils is typically prismatic. There are also illuvial ferriargillan and cutans (Figure 5c) composed of illuvial clay and unfilled pedotubules in small quantities. These cutans and ferriargillans are evidence of the occurrence of argilluviation in the GXbd, as proposed by Ranst & Coninck (2002), and help explain the high B/A texture gradient found in these soils.

According to Cooper & Vidal-Torrado (2000), the main processes that form textural B horizons are clay translocation and deposition in pores as illuvial cutans. Fedoroff & Eswaran (1985) also suggested that illuvial cutans are the main feature for classifying textural B horizons.

The Bw$_2$ horizon of the "LAC" is homogeneous and contains a single porphyric-enaulic zone, which consists mostly of a dense microgranulated microstructure with a granular substructure (Figure 6b). The inter-aggregate porosity consists of cavities and chambers, and the plasma is isoptic gray-yellow. Iron compound-filled orthotubules were found as well as a few rounded elongated iron nodules in regions of mottling. Coal fragments are found constantly in this horizon (Figure 6a), showing that the plant cover of this soil had been burned, with the likelihood of root carbonization. These fires probably occurred following landscape dissection because of improved drainage conditions in the current position of the foot of the slope. The microgranulated microstructure suggests an effect of the fauna and demonstrated the latosolic nature of this horizon. Ferreira et al. (2010) published similar descriptions for a gray latosol in the region of Itamarandiba (MG).

The granular microstructure described by Bullock et al. (1985) may be observed in the "LAC", and indicates a typical latosol structure, especially in more weathered soils (Buol & Eswaran, 1978). Another feature of latosols found in the "LAC" is isoptic plasma (Brewer, 1976).

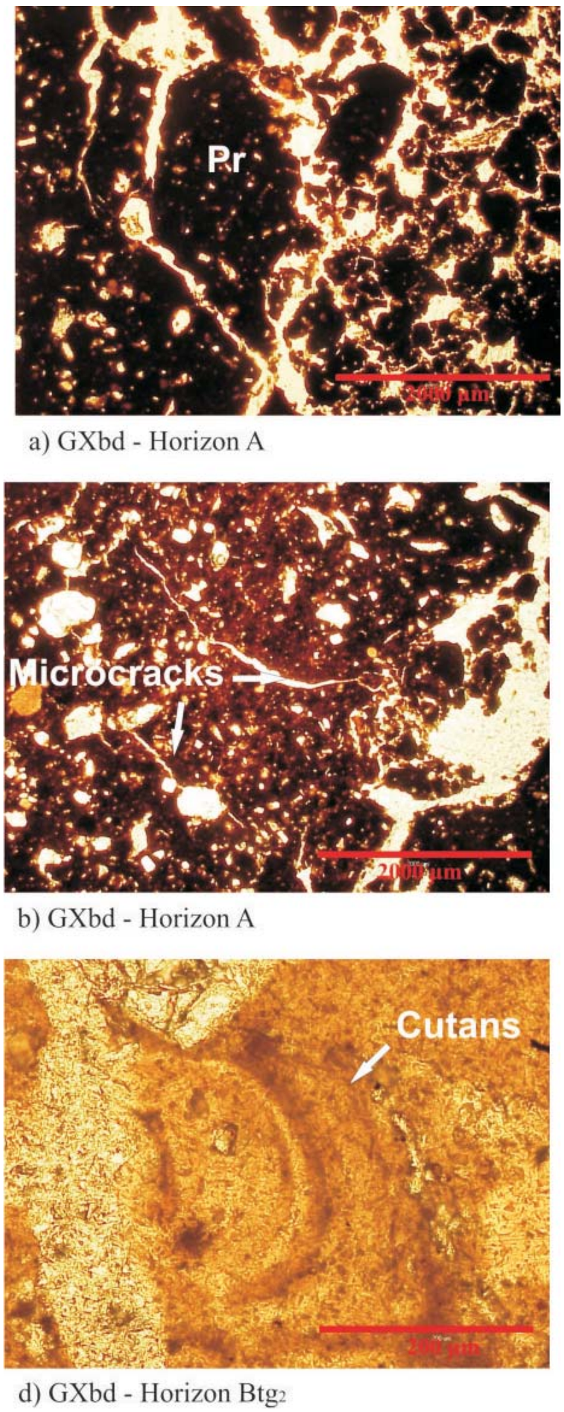


Figure 5. Photomicrographs under ambient light of GXbd horizons: (a) A horizon of the GXbd with prismatic microstruture (Pr); (b) presence of microfissures in the A horizon of the GXbd; (c) illuvial cutans in the Btg$_2$ horizon of the GXbd.

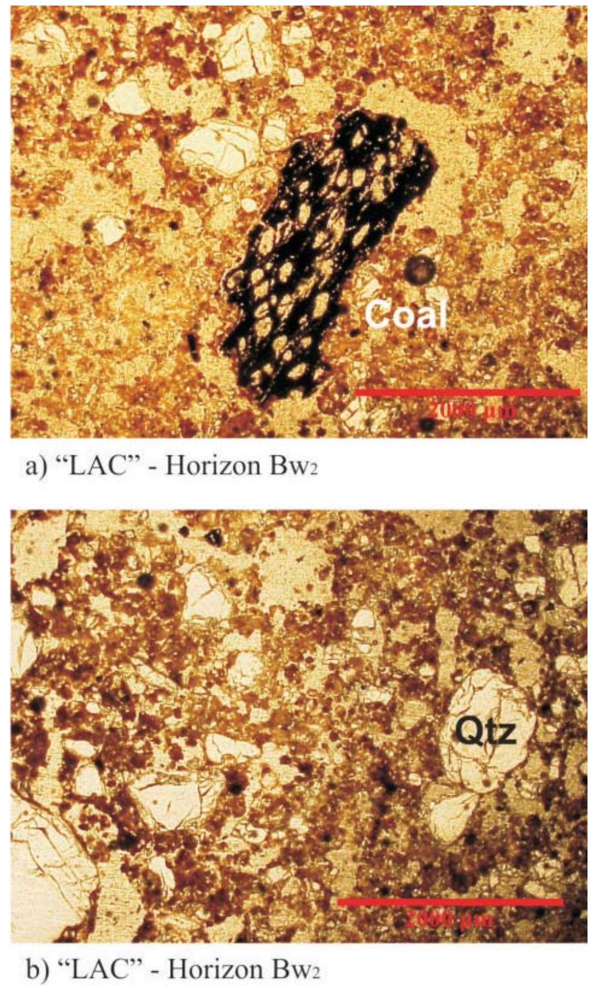
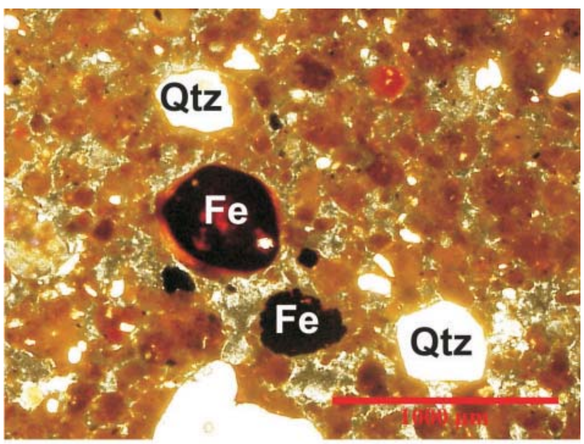


Figure 6. Photomicrographs (under ambient light) of "LAC" horizons: (a) Bw horizon of the LAC, with coal; (b) porphyric-enaulic zone with a dense microgranulated microstructure and granulated substructure.

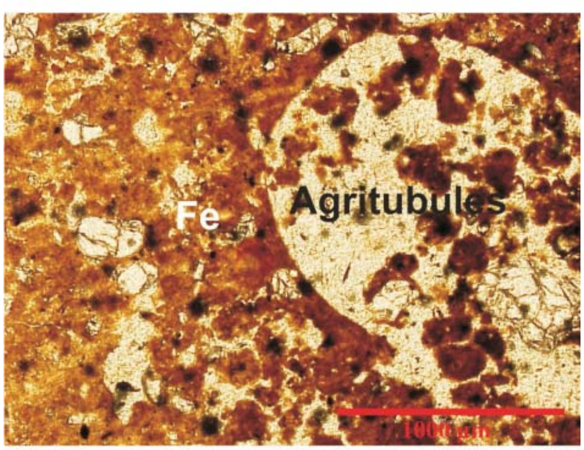
The A horizon in the LA contains two zones – a prophyric zone (zone A) and a porphyric-enaulic zone (zone B). Zone A contained subrounded microaggregates, subangular polyhedral aggregates, and aggregate agglomerates; zone B also consists of subrounded microaggregates and subangular aggregates. The plasma in both regions is isoptic, and contains clay and Fe oxides; yellow is its prevailing color. In Zone A, porosity was predominantly structured by complex inter-aggregate stacking; there were also filled biological cavities, channels, and microfissures. The porosity of Zone B was predominantly structured by complex inter-aggregate stacking. Pedological features included rounded iron nodules, unfilled pedotubules, iron oxide-filled agrotubules, quartz, and clay; biological activity was evidencecd by excrements and roots filled with microaggregates and quartz.

The Bw horizon of the LA contained a single homogeneous porphyric-enaulic zone, with a predominantly coalesced microaggregate microstructure, subangular microaggregates, and aggregate agglomerates. The plasma was yellow red isoptic, and interaggregate porosity was predominantly structured by stacking with a few biological cavities and microfissures. Pedological features include Fe nodules (Figure 7a) and Fe oxide and clay-filled agrotubules (Figure 7b); roots were also common.

The A horizon of the LVA contains a homogeneous porphyric-enaulic zone, which consists of a microstructure with predominantly coalesced microaggregates, subangular aggregates, and aggregate agglomerates. Porosity was predominantly structured by stacking, biological cavities, channels, and microfissures, and the plasma is red isoptic. There are rounded Fe nodules and agrotubules filled with iron oxides, quartz, and clay; coal that contains microaggregates is common (Figure 8a).

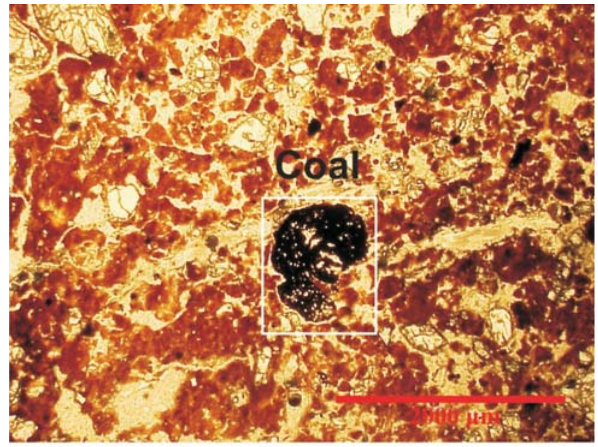


a) LA - Horizon Bw

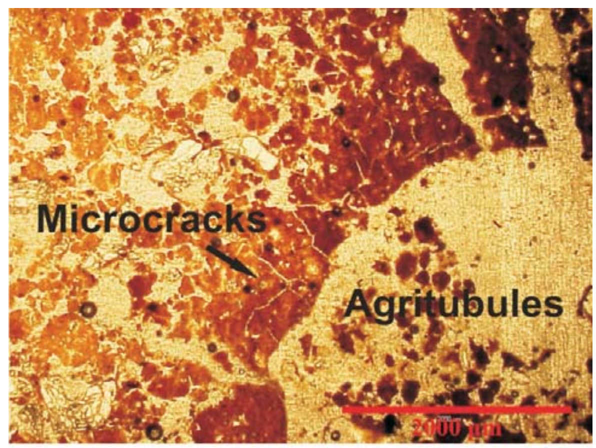


b) LA - Horizon Bw

Figure 7. Photomicrographs of the Bw horizon of the LA: (a) quartz and iron nodules, predominantly stacking porosity throughout the photo-micrograph, taken under polarized light; (b) agrotubules filled with clay and iron oxides, taken under ambient light.



a) LVA - Horizon A



b) LVA - Horizon BA

Figure 8. Photomicrographs (under ambient light) of LVA horizons: (a) porphyric-enaulic zone and coal with microaggregates in the A horizon of the LVA; (b) microfissures and agrotubules filled with clay, quartz, and iron oxides composing the BA horizon of the LVA.

The BA horizon contains two rather heterogeneous zones. Zone A is enaulic, and zone B is porphyric. The microstructure of both is a coalesced and granulated microstructure. Inter-aggregate porosity in the former consists of stacking, channels, and microfissures; in the latter, of biological cavities and microfissures (Figure 8b). The plasma is red isoptic. Agrotubules are filled with clay, quartz, and Fe oxides; iron nodules are an additional pedological feature.

The micromorphological features of the horizons of these latosols are similar to those reported by Andrade et al. (1997) and Silva & Vidal-Torrado (1999).

Origin of soils in the toposequence

The presence of illite and vermiculite traces in the Btg_2 horizon of the GXbd (Figure 1) is evidence of drier periods, as illite is formed when there is more evaporation (dry seasons) in sedimentary environments (Thompson & Ukrainczyk, 2002). Further evidence is provided by the argisolic nature of the GXbd.

Buol et al. (1980), Vidal-Torrado & Lepsch (1993), and Breemen & Buurman (2002) have suggested that one of the main B/A texture differentiating processes in soil profiles is the movement of suspended clays from surface to subsurface horizons. To make clay migrate downwards across profiles, aggregates must break apart by a sudden entry of water into the aggregate pores, resulting in explosion of the aggregates by the air leaving the pores. Rupture is more common when seasonality is significant, with well-defined dry periods when soils dry out completely, and short wet periods with intense rains that quickly saturate the soil, thereby "exploding" the aggregates. Thus, argilluviation in the GXbd as shown by the presence of illuviation cutans (Figure 5c) and ferriargilans is strong evidence of a past climate with a pronounced dry season and torrential rains at the beginning of a short wet period (Breemen & Buurman, 2002) in the Lagoa do Leandro swamp region. This structure was preserved because a change to a wetter climate raised the water table in this soil, minimizing the homogenizing effect of biological activity in the profile.

In the current climate, ferrolysis may have further increased the B/A textural differentiation observed in the GXbd. This horizon is water-saturated during the rainy season, and dries out during the dry season. Water saturation reduces Fe^{3+} to Fe^{2+}, which displaces the cations from the exchange complex, thereby reducing the pH. In the dry season, oxidation of Fe^{2+} to Fe^{3+} causes H^+ formation, resulting in a further pH decrease; H^+ then penetrates the surface of silicate clay (K, I, and V – Figure 1), changing positions with the Al in its octahedrons, resulting in their break up (Brinkman, 1970; Breemen & Buurman, 2002; Ranst & Conick, 2002). This soil-forming process may have contributed significantly to the clay destruction in the A horizon of GXbd.

Good drainage in the LVA and the LA favor profile homogenization due to the fauna activity in soils. In the "LAC", landscape dissection the helped improve drainage, and the fauna homogenized the profile. The presence of coal fragments in the Bw_2 horizon of the "LAC" (Figure 6a) suggests that the plant cover of this soil had been affected – and remains exposed to – fires, which carbonized mainly the roots. These fires can only have occurred after landscape dissection and the resulting improved drainage conditions. A microgranulated microstructure suggests the effect of the fauna, and is evidence of the Latosolic nature of this horizon.

Landscape evolution and origin of soils in the Lagoa do Leandro swamp

The chapadas of the upper Jequitinhonha valley extend over 10,000 to 40,000 ha and are separated by dissected areas. In the region of Minas Novas (MG), chapadas contain drained microbasins in oval, pear-shaped, depressed areas named veredas.

Figure 9 presents a model of the evolution of vereda-drained microbasins on the chapadas of the upper Jequitinhonha region. Field work, satellite images, and geomorphological studies (King, 1956; Boaventura, 1978; Saadi, 1995; Campos, 1998; Motta et al., 2002) played important roles in developing the model and understanding the current landscape.

The regional terrain was formed on a uniformly flattened surface during a prolonged period in the Lower Tertiary (Figure 9a); it corresponds to a peneplan resulting from the South American erosion cycle (King, 1956). Chapadas at 800 to 1,000 m asl are evidence of the relief imposed by the South American Surface (Saadi, 1995).

The oval shape of the vereda of the Lagoa do Leandro microbasin may have been originated by "geochemical dissolution" processes (Lima & Queiroz Neto, 1996) associated with erosion (Figure 9b). "Geochemical dissolution" may have occurred due to the presence of less weathering-resistant minerals in the parent material (Macaúbas). A low-grade drainage network dissected the chapadas during the Tertiary period, (Figure 9c).

The chapadas in the region of Minas Novas (MG) are a more recent dissection, compared to those studied by Ferreira et al. (2010). The soil distribution in the

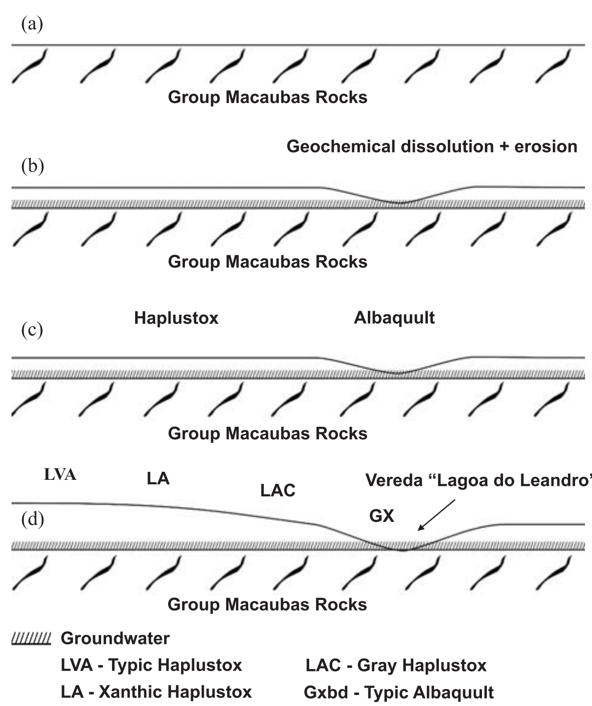


Figure 9. Proposed model of landscape evolution of drained vereda-microbasins on highlands of the Jequitinhonha plateau.

Lagoa do Leandro microbasin appears to be significant evidence of the current drainage network. The occurrence of Latosols (Figure 9d) is similar to that found on surface I, as described by Motta et al. (2002), for soils of the Brazilian Central Plateau, which is in turn related with the South American Surface as described by King (1956).

The soils of the vereda underwent an intense deferrification process, resulting in grayish colors; unlike on the chapadas, where reddish or yellowish soils predominate, due to better drainage (UFV, 1980). The color of the B horizon of Latosols in the microbasin under study is yellowish and burnished and can be grayish at the base of the vereda.

On gently undulated areas that correspond to the “LAC”, alternating reduction and oxidation because of water table oscillations in the swamp led to mottling in the subsurface of this soil. Gleysolization of the GXbd probably occurred because of permanent water saturation during most of the Pleistocene, interrupted by dry periods (Salgado-Labouriau et al., 1998).

In the “LAC”, formed in lower and poorly drained areas of the landscape during the Pleistocene (Ferreira et al., 2010), drainage improved gradually, but the grayish colors remained as probably almost all Fe^{3+} was removed during the long period under reducing conditions (Schwertmann & Taylor, 1989; Peterschmitt et al., 1996; Kämpf & Curi, 2000).

As drainage improved, the action of the bioturbating fauna (ants, termites, and annelids) in the pedologic cover may have been intensified, changing the blocky structure of old gleysolized soils into a granulated structure (Figure 6b). These Gleysols were gradually latosolized by biological and chemical processes; however, as the grayish colors were not lost, they originated the gray Latosols, or “LAC” (Ferreira et al., 2010).

Thus, Argisols may have been formed during climates with more pronounced dry seasons and torrential rains at the beginning of short wet seasons, (Breemen & Buurman, 2002). Drainage lines became deeper and soils in higher parts of microbasins that drain to the veredas may have become homogenized by the action of the soil fauna supported by the wet climate during the more humid Pleistocene period. As dissection progressed, soil drainage in lower portions of the past landscape improved, and the fauna caused material to become homogeneous and formed microaggregates – latosolizing the ancient hydromorphic soils.

The current veredas would have formed in the newer, more depressed parts of the landscape, a result of the interconnection of circular depressions (exudation points) located in poorly drained areas on the chapadas. At these sites, Gleysols are currently found, preserving evidence of dry periods or inherited material, such as illite and vermiculite in the clay fraction, and illuvial cutans and ferriargilans in the Btg horizon. Ferrolysis in horizon A would have contributed significantly to a high texture gradient between horizons A and B.

CONCLUSIONS

1. Paleogleysols were latolized by excavating fauna/ bioturbating fauna and gave rise to the current LACs.

2. The past seasonal climate and current ferrolysis are evidence of a high B/A texture gradient in Haplic Gleysols.

3. Haplic Gleysols at the base of the vereda conserve original physical, mineralogical, and micromorphological features of their formation during dry periods.

4. The soils and landscape of the Lagoa do Leandro swamp were formed and developed together with a drainage network that is related with Pleistocene climate changes.

ACKNOWLEDGEMENTS

The authors are indebted to the company ArcelorMittal S.A, the Brazilian Federal Agency for Support and Evaluation of Graduate Education (CAPES), and the Research Foundation of the state of Minas Gerais (FAPEMIG) for funding for this study. In particular, they wish to thank professor Valdomiro Severino da Souza Júnior, lecturer at the Universidade Federal Rural de Pernambuco (UFRPE), for his suggestions for the mineralogical analyses and support in interpreting the results.

LITERATURE CITED

ANDRADE, H.; SCHAEFER, C.E.; DEMATTÊ, J.L.I. & ANDRADE, F.V. Pedogeomorfologia e micropedologia de uma sequência Latossolo – Areia Quartzoza Hidromórfica sobre rochas cristalinas do estado do Amazonas. Geonomos, 5:55-66, 1997.

BISPO, F.H.A. Gênese e classificação de solos em topossequência de veredas das chapadas do Alto Vale do Jequitinhonha, MG. Diamantina, Universidade Federal dos Vales do Jequitinhonha e Mucuri, 2010. 98p. (Tese de Mestrado)

BOAVENTURA, R.S. Contribuição ao estudo sobre a evolução das veredas. In: ENCONTRO NACIONAL DE GEÓGRAFOS, 3., Fortaleza, 1978. Anais... Fortaleza, AGB/UFC, 1978.

BREEMEN, N.V. & BUURMAN, P. Soil formation. 2.ed. Dordrecht, Kluwer Academic, 2002. 404p.

BREWER, R. Fabric and mineral analysis of soil. New York, R. E. Krieger, 1976. 482p.

BRINKMAN, R. Ferrolysis, a hydromorphic soil forming process. Geoderma, 3:199-206, 1970.

BROWN, G. & BRINDLEY, G.W. X ray Diffraction Procedures for clay mineral Identification. In: BRINDLEY, G.W. & BROWN, G. London, Mineralogical Society, 1980. p.305-360.

BULLOCK, P.; FEDOROFF, N.; JONGERIUS, A.; STOOPS, G.; TURSINA, T. & BABEL, U. Handbook for soil thin section description. Wolverhampton, Waine Research Publication, 1985. 152p.

BUOL, S.W.; HOLE, F.D. & McCRACKEN, R.J. Soil genesis and classification. Ames, The Iowa State University Press, 1980. 404p.

BUOL, S.W. & ESWARAN, H. Micromorphology of oxisols. In: INTERNATIONAL WORKING MEETING ON SOIL MICROMORPHOLOGY, Granada, 1977. Proceedings... Granada, Universidade de Granada, 1978. p.325-328.

CAMPOS, J.C.F. Solos, geomorfologia e evolução da paisagem no Alto e Médio Jequitinhonha, Minas Gerais. Viçosa, MG, Universidade Federal de Viçosa, 1998. 207p. (Tese de Mestrado)

COOPER, M. & VIDAL-TORRADO, P. Gênese de ferri-argilãs em horizontes B texturais de uma sequência de solos sobre diabásio em Piracicaba, SP. Sci. Agric., 57:745-750, 2000.

COMPANHIA DE PESQUISA DE RECURSOS MINERAIS - CPRM. Projeto Cadastro de Abastecimento por Águas Subterrâneas, Estados de Minas Gerais e Bahia: diagnóstico do municipio de Minas Novas, MG. Belo Horizonte, 2005.

CURI, N. & FRANZMEIER, D.P. Topossequence of Oxisols from the Central Plateau of Brazil. Soil Sci. Soc. Am. J., 48:341-346, 1984.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA – EMBRAPA. Centro Nacional de Pesquisa de Solos. Sistema brasileiro de classificação de solos. 2.ed. Rio de Janeiro, Embrapa Solos. 2006. 306p.

FEDOROFF, N. & ESWARAN, H. Micromorphology of ultisols. In: DOUGLAS, L.A. & THOMPSON, M.L. Soil micromorphology and soil classification. Madison, Soil Science Society of Agronomy, 1985. p.145-164.

FERREIRA, C.A.; SILVA, A.C.; VIDAL TORRADO, P. & ROCHA, W.W. Genesis and classification of Oxisols in a highland toposequence of the upper Jequitinhonha Valley (MG). R. Bras. Ci. Solo, 34:195-209, 2010.

JACKSON, M.L. Soil chemical analysis: Advance course. 29.ed. Madison, 1975. 895p.

KÄMPF, N. & CURI, N. Óxidos de ferro: Indicadores de ambientes pedogênicos e geoquímicos. In: NOVAIS, F.R.; ALVAREZ V., V.H. & SCHAEFER, C.E.G.R., eds. Tópicos em ciência do solo, Viçosa, MG, Sociedade Brasileira de Ciência do Solo, 2000. v.1. p.107-138.

KÄMPF, N. & SCHWERTMANN, U. Goethite and hematite in a climosequence in southern Brazil and their application in classification of kaolinitic soils. Geoderma, 29:27-39, 1983.

KÄMPF, N. & SCHWERTMANN, U. The 5 M-NaOH concentration treatment for iron oxides in soils. Clays Clay Miner., v.30, p.401-408, 1982.

KING, L.C. Geomorfologia do Brasil Oriental. R. Bras. Geogr., 18:147-265, 1956.

LIMA, S.C. & QUEIROZ NETO, J.P. As veredas e a evolução do relevo. Soc. Natur., 8:481-488, 1996.

MALA, P. Vermiculites. In: DIXON, J.B. & SCHULZE, D.G. Soil mineralogy with environmental applications. Madison, Soil Science Society of America, 2002. p.501-529.

MELO, D.R. As veredas nos planaltos do Noroeste Mineiro: Caracterizações pedológicas e os aspectos morfológicos e evolutivos. Rio Claro, Universidade Estadual de São Paulo, 1992. 218p. (Tese de Mestrado)

MINAS GERAIS. Secretaria de Ciência e Tecnologia. Diagnóstico Ambiental de Minas Gerais. Belo Horizonte, COPAM/CETEC, 1982.

MOORE, D.M. & REYNOLDS, R.C. X ray diffraction and identification and analysis of clay minerals. Oxford, Oxford University Press, 1989. 332p.

MOTTA, P.E.F.; CARVALHO-FILHO, A.; KER, J.C.; PEREIRA, N.R.; CARVALHO JR, W. & BLANCANEAUX, P. Relações solo-superfície geomórfica e evolução da paisagem em uma área do Planalto Central Brasileiro. Pesq. Agropec. Bras., 37:869-878, 2002.

MOURA FILHO, W. & BUOL, S.W. Studies of a Latosol Roxo (Eutrustox) in Brazil: Clay mineralogy. Experientiae, 12:218-234, 1972.

MURPHY, C.P. Thin section preparation of soils and sediments. Berkhamsted, A B Academic Publishers, 1986. 149p.

PEDROSA-SOARES, A.C. Geologia da folha de Araçuai, Minas Gerais. In: PROJETO ESPINHAÇO. Secretaria de Estado de Recursos Minerais, Hídricos e Energéticos/Companhia Mineradora de Minas Gerais (COMIG). Belo Horizonte, 1996.

PETERSCHMITT, E.; FRITSCH, E. & RAJOT, J.L. Yellowing bleaching and ferritisation processes in soil mantle of the Western Ghats, South India. Geoderma, 74:235-253, 1996.

PROJETO RADAMMINAS. Geomorfologia: Mapa geomorfológico – Folha Montes Claros Escala de 1:500.000. Belo Horizonte, 1977.

RAMOS, M.V.V. Veredas do Triângulo Mineiro: Solos, água e uso. Lavras, Universidade Federal de Lavras, 2000. 127p. (Tese de Mestrado)

RANST, E.V. & CONINCK, F. Evaluation of ferrolysis in soil formation. Laboratory of Soil Science, Ghent University. Europ. J. Soil. Sci., 53:513-519, 2002.

SAADI, A.A. Geomorfologia da Serra do Espinhaço em Minas Gerais e de suas margens. Geonomos, 3:40-63, 1995.

SALGADO-LABOURIAU, M. L.; BARBIERI, M.; FERRAZ-VICENTINI, K.R. & PARIZII, M.G. A dry climatic event during the late Quaternary of tropical Brazil. Rev. Palaeobot. Palynol., 99:115-129, 1998.

SANTOS, R.D.; LEMOS, R.C.; SANTOS, H.G.; KER, J.C. & ANJOS, L.H. Manual de descrição e coleta de solos no campo. 5.ed. Viçosa, MG, Sociedade Brasileira de Ciência do Solo, 2005. 100p.

SCHWERTMANN, U. & TAYLOR, R.M. Iron oxides. In: DIXON, J.B., ed. Minerals in environments. Madison, Soil Science Society of America, 1989. p.145-180.

SILVA, A.C. & VIDAL-TORRADO, P. Gênese dos Latossolos Húmicos e sua relação com a evolução da paisagem numa área cratônica do Sul de Minas Gerais. R. Bras.Ci. Solo, 23:327-341, 1999.

SINGH, B. & GILKES, R.J. Concentration of iron oxides from clays by 5 M NaOH: the complete removal of sodalite and kaolin. Clays Miner., v.26, p.463-472, 1991.

STOOPS, G. & JONGERIUS, A. Proposal for a micromorphological classification in soil materials. I. A classification of the related distributions of coarse and fine particles. Geoderma, 13:189-200, 1975.

THOMPSON, M.L. & UKRAINCZYK, L. Micas. In: DIXON, J.B. & SCHULZE, D.G. Soil mineralogy with environment applications. Madison, 2002. p.431-461. (SSSA Book Series, 7)

UNITED STATES. Department of Agriculture. Soil Survey Division. Soil Conservation Service. Soil Survey Staff. Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. Washington, 1975. 754p. (USDA. Agriculture Handbook, 436)

UNIVERSIDADE FEDERAL DE VIÇOSA – UFV. Levantamento de reconhecimento, com detalhes, de solos de chapadas do Alto Jequitinhonha. Viçosa, MG, Sociedade de Investigação Florestal, 1980. 188p.

VIDAL-TORRADO, P. & LEPSCH, I.F. Morfogênese dos solos de uma topossequência com transição B Latossólicos/B textural sobre migmatitos em Mococa (SP). R. Bras. Ci. Solo, 17:109-119, 1993.

WEAVER, R.M. Soils of the Central Plateau of Brazil: Chemical and mineralogical properties. New York, Cornell University, 1974. 45p.