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Pedodiagenetic Characterization of Cretaceous Paleosols in Southwest Minas Gerais, Brazil

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ABSTRACT: The influence of post-burial geological processes on preserving pedogenic properties has great importance in identifying ancient paleosols both in the field and in a laboratory. However there are not many publications that focus on characterizing paleosol diagenesis. As temperature and pressure progressively increase, evidence of pedogenesis is modified and destroyed, hindering paleoenvironment characterization and interpretation. This paper discusses diagenetic evidence and its relation to strictly pedogenic features, like structure, cements, nodules, and neoformation of clay minerals using the carbonate paleosols of the Marília Formation in the upper unit of the Bauru Basin as a case study. Despite the long geotectonic and thermal history of the Marília Fomation, paleosols bring us pedogenic evidence that can undergo micromorphological analyses, such as cementation, clay illuviation, bioturbation, and ped structures. The results of analyses in 25 paleopedogenic horizons indicate that the paleotopographic features were responsible for distribution of the diagenetic processes and preservation of the paleosol properties. The maturity of those paleosols controls lithification. In mature paleosols that developed in more stable portions of the landscape, characteristics such as carbonate cementation and development of pedogenic structures are the main factors that inhibit diagenesis. However diagenetic processes that influence poorly-developed paleosols are controlled by depositional characteristics and by changes in the water table, enabling more advanced diagenetic processes, compared to mature paleosols.

Keywords: Marília Formation, pedogenesis, diagenesis.

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INTRODUCTION

There have been an increasing number of papers on paleosols in Brazil in recent years (Dal'Bó and Ladeira, 2006; Fernandes, 2010; Ladeira, 2010; Batezelli and Ladeira, 2016). However, the role of diagenesis in preserving and altering paleosols has not received proper attention, which hinders dialogue between soil scientists, paleosol scientists, and sedimentologists.

Through post-burial diagenetic evolution, pedogenic features are progressively altered and even destroyed, especially in pre-Quaternary paleosols. Such evolution makes characterizing and recognizing pedogenetic features more difficult, both in macromorphological and in micromorphological analysis. In spite of the difficulties imposed by diagenesis on pedological characterization, there are few studies on the effects of diagenesis on paleosols, in regard to individualization and the ranking of processes.

Most effort has been directed to understanding paleosol evolution in different climatic, tectonic, and stratigraphic contexts (McCarthy and Plint, 1998; Kraus, 1999; Retallack, 2001; Alonso-Zarza, 2003; Alonso-Zarza and Wright, 2010; Driese and Nordt, 2013; Batezelli and Ladeira, 2016). Few studies are devoted to the diagenetic processes that paleosols underwent (Retallack and Wright, 1990; Retallack, 1991; Pimentel, 2002; Alonso-Zarza, 2003; Srivastava and Sauer, 2014; Silva et al., 2017), mainly in order to understand the relations between development of the soil and its degree of preservation, leaving a gap concerning the overlapping of diagenetic processes under strict soil features.

The Marília Formation, part of Bauru Sedimentary Basin (which is part of the Paraná Sedimentary Basin), exhibits paleosol sequences developed in floodplains during the Maastrichtian Stage/Age, constituting pedocomplexes (Catt, 1998) that allow us to analyze the diagenetic influence in ancient pedogenic calcretes.

Closed continental basins, such as the Bauru Basin, are suitable for studying the influence of diagenesis on pedogenesis. That is possible because the processes constantly overlap, due to variation in the water table and to the geochemistry of water (Bustillo and Alonso-Zarza, 2007). This causes significant changes in the landscape, resulting in varying pedogenetic and diagenetic trends.

The hypothesis of this paper is that post-burial diagenetic processes are conditioned by the degree of paleosol development in response to the former position of the paleosol in the landscape. The main objectives of this paper are to evaluate the influence of the maturity of paleosols and their effects on diagenetic processes; and reconstitute the pedodiagenetic sequence (as done by Klappa, 1983) for the Marília Formation paleosols, sorting pedogenetic and diagenetic processes in a sequential mode.

MATERIALS AND METHODS

The paleosols analyzed in this paper occur in the Marília Formation, the upper unit of the Bauru Basin, located in southeastern Brazil. The origin of the Bauru Basin (Fernandes, 1998) (Figure 1) is related to tectonic processes of the South American plate during fragmentation of the paleocontinent Gondwana (Upper Jurassic - Lower Cretaceous), and occupies roughly 330,000 km^2 in southeastern Brazil, sheltering sedimentary rocks up to 300 m thick.

The stratigraphy of the Bauru Basin has been studied and reviewed by several authors (Suguio and Barcelos, 1983; Fernandes, 1998; Batezelli, 2003). From paleontological and stratigraphic data, as well as from its correlation to magmatic and volcanic events in the northeast and northern portions of the Bauru Basin, sedimentation would have occurred during the Late Cretaceous Epoch, between the Campanian and the Maastrichtian Age (Batezelli, 2015).

The Marília Formation consists of conglomerates, sandstones, and pelites associated with the distal portions of alluvial fans, accumulated by flows in the water table. The rock types have a massive and strongly-cemented character, carbonate-rich nodules, and vertebrate fossils. The sandstones are intercalated with conglomeratic facies composed of carbonate-rich intraclasts and reworked clasts from older units.

The paleosols of the Marília Formation developed on deposits associated with proximal/intermediate sections of prograding alluvial fans dominated by lenses of conglomerates and sandstones with fining-upward patterns. Batezelli (2015) interpreted this environment as an alluvial fan system dominated by braided rivers with mixed cargo that came from the erosion of adjacent structural highs.

Twenty-five paleosol horizons of the Marília Formation that integrate pedocomplexes were described. Macro- and micromorphological features were described in order to identify and interpret the pedogenetic and diagenetic features. Paleosols were described in the field following the recommendations of the Soil Survey Manual (Soil Survey Staff, 1999) regarding the identification and contact of horizons, color, abundance and nodes, in addition to redoximorphic features and bioturbation patterns (rhizoliths and burrows), such as size and thickness.

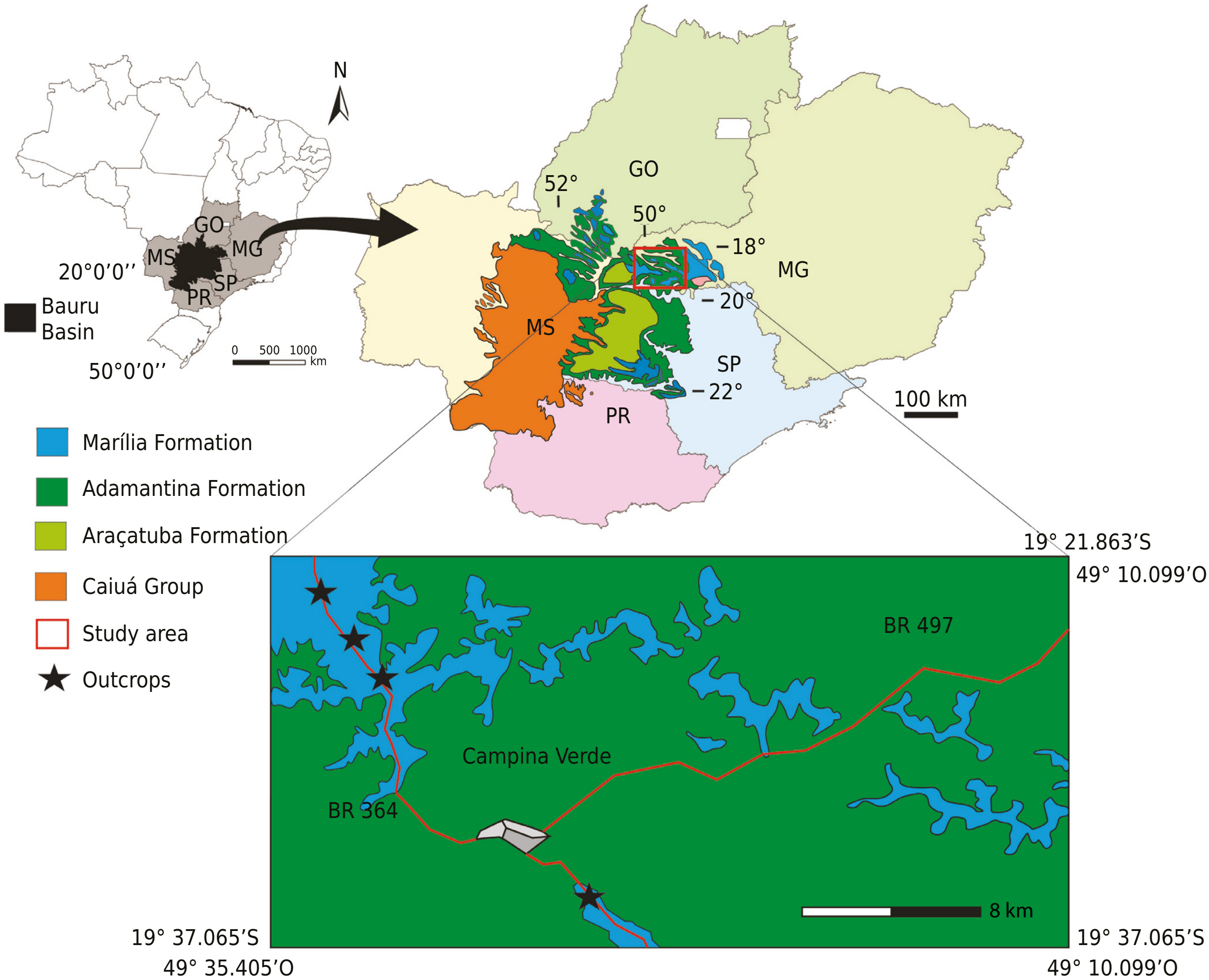

Figure 1. Location of the Bauru Basin and the area studied. Modified from Batezelli (2003).

The degree of paleopedogenetic development was estimated based on Retallack's conception (Retallack, 2001), which uses macromorphological characteristics associated with the development of soils, such as the degree of soil structuring, the presence of pedogenetic carbonate, and the development and thickness of the Bk and Bt horizons. Calcretization degrees were measured from Alonso-Zarza and Wright (2010).

Micromorphological descriptions were conducted with a petrographic microscope, following the recommendations of Stoops et al. (2010). Analysis of the overlap of diagenesis under pedogenesis was based on Nesbitt and Young (1989), Retallack (2001), and Srivastava and Sauer (2014).

RESULTS AND DISCUSSION

In the sections described, the deposits are mostly sandy and conglomeratic, indicating a depositional environment with high energy, except for a few deposits of pelitic overbank. These are somewhat thick and intercalate with amalgamated sandy bars. Based on the different degrees of maturity of paleosols, the influence of the water table, and the position in the stratigraphic record (Figures 2, 3, and 4), we chose to classify them into two different maturities: a poorly-developed pedotype and a well-developed pedotype. This helps understanding of the pedogenetic aspects and their relation to post-burial processes (Tables 1 and 2).

Poorly-developed pedotype

The poorly-developed pedotype groups are horizons C, Cg, and Ck, without pedological structure; they are massive and have poorly differentiated horizons. The C horizons are colored in reddish tones (10R 7/6) with incipient cross stratification; obliterated by pedogenetic processes, rare carbonate nodules with dimensions from 0.03 to 0.05 m isolated along the horizon and cylindrical root marks with diameters from 0.01 to 0.015 m; and filled with sandy material.

The Cg horizons exhibit 2.5Y 8/8, 2.5Y 8/1, and 2.5Y 7/8 colors, with mottling and yellowish-brown halos (2.5Y 8/8) associated with Fe mobilization. Bioturbation is rare, 0.03 m wide and 0.5 m long, as evidenced by redox, resulting in halos of Fe depletion near bioturbation and its distant reprecipitation.

The Ck horizons have variegated reddish (10R 8/4) and whitish (10R 8/1) coloration and are hard, with high levels of calcium carbonate nodules. Such nodules are subspherical, with white and ocher color tones, undifferentiated internal structure, and dimensions from 0.50 to 4.00 cm, and spread over a massive sandy matrix. Nodules are concentrated in the middle and at the base of horizons, characterizing 'per descensum' processes, as conceived by Goudie (1983). Roots marks on Ck horizons range from 0.01 to 0.03 m in diameter and from 0.10 to 0.15 m in length, cemented with $CaCO_3$.

Micromorphological analyses indicate that the coarse fraction (the skeleton) of this pedotype consists of monocrystalline quartz (80 %) and polycrystalline feldspars (15 %, orthoclase), in addition to heavy minerals and lithic fragments of volcanic rocks (5 %).

The grain size of the coarse fraction (skeleton) ranges from fine to medium sand. Grains are sub-round and have a low degree of selection. The relative distribution of the components of this fraction have monic disjunction organization, according to Stoops and Jongerius (1975), a conception also adopted by Stoops et al. (2010). Quartz grains show dissolution marks, and pores are mostly intergranular and stacked in portions where there is plasma concentration (orthopores), showing a "loose" arrangement of grains in some portions of the microscope slide. This pedotype is weakly structured (Figure 5a).

The fine fraction (plasma) has no preferred extinction orientation and is stained with speckled b-fabric microstructures associated with the neoformation and transformation of primary minerals (Figures 5b, 5c, and 5d). These profiles were under direct influence of the water table and have redox features (Figure 5e) and $CaCO_3$ Alpha type cementation (Wright, 2007) from a non-pedogenic origin. Dissolution and recrystallization processes are visible due to the optical discontinuity of crystals (Figures 5f and 5g).

Due to its low degree of evolution and little cementation, this pedotype shows the late post-burial diagenetic processes more clearly, and is evidenced because pedogenetic processes are incipient, being easily obliterated by purely diagenetic processes.

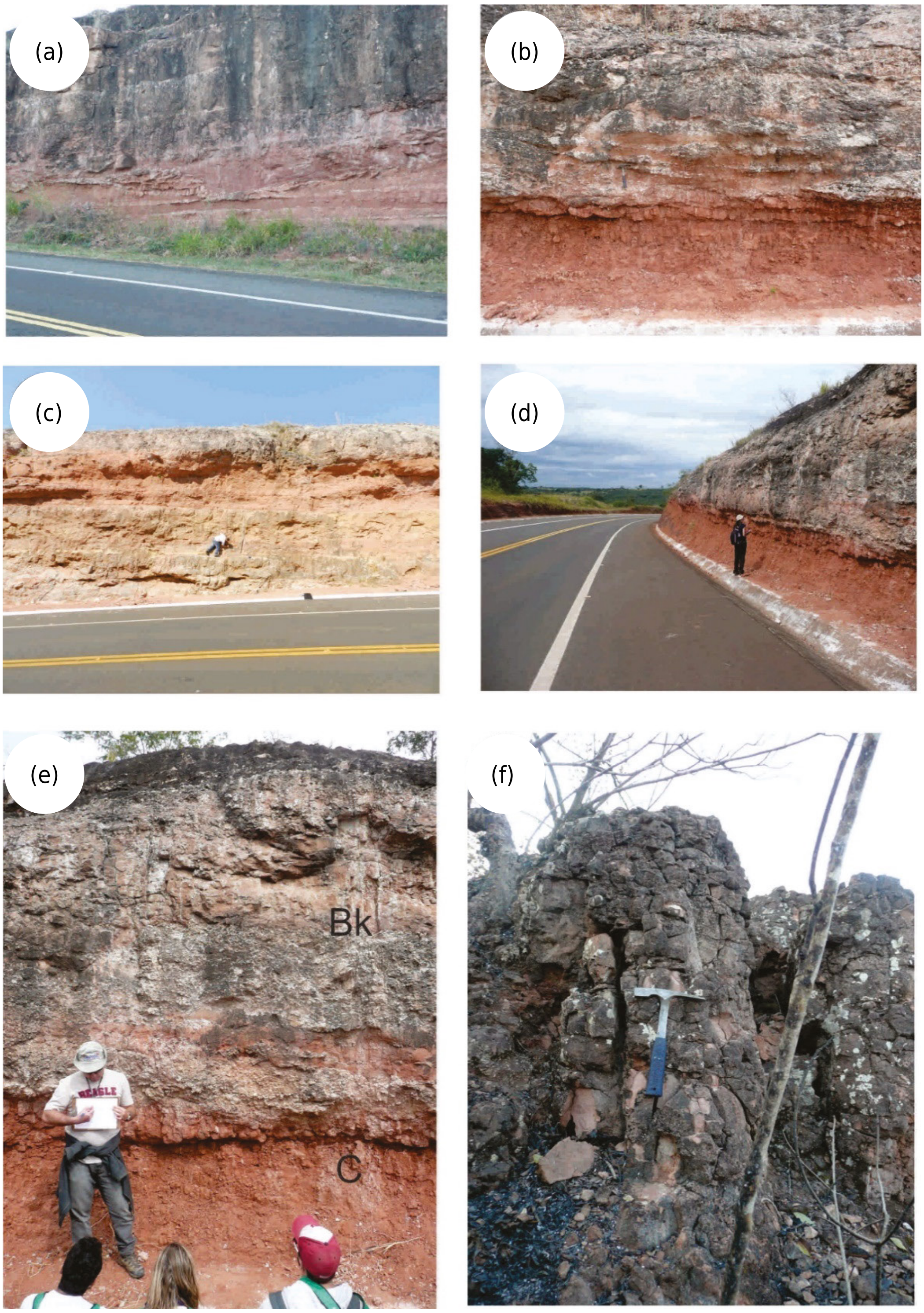

Figure 2. Overview of the outcrops described. (a) and (b) Channel feature truncating poorly-developed paleosols. (c) Amalgamated bar features that truncate paleosols. (d) (e) Top of the pedocomplex - notice the thickness of the carbonate horizon. (f) Btk Horizon structures in well-developed prisms.

On these paleosols, diagenesis printed features of reorganization of the framework, disorganization of the fine fraction, detrital mica fragmentation of the cement, and suture and dissolution of grains, resulting in the escape of fluids due to compaction. The presence of calcite cementation (sparry calcite), hematite, and diagenetic silica are more expressive in these poorly-developed horizons.

Well-developed pedotype

This pedotype features well-developed soils (Figures 5a and 5f), corresponding to Btk and Bk horizons which have mostly macro and micromorphologic soil structures (Tables 1 and 2) with moderate to strong structure in prisms and blocks. Carbonate nodules (Figure 3) usually develop in the horizon base with undifferentiated internal structure, distributed

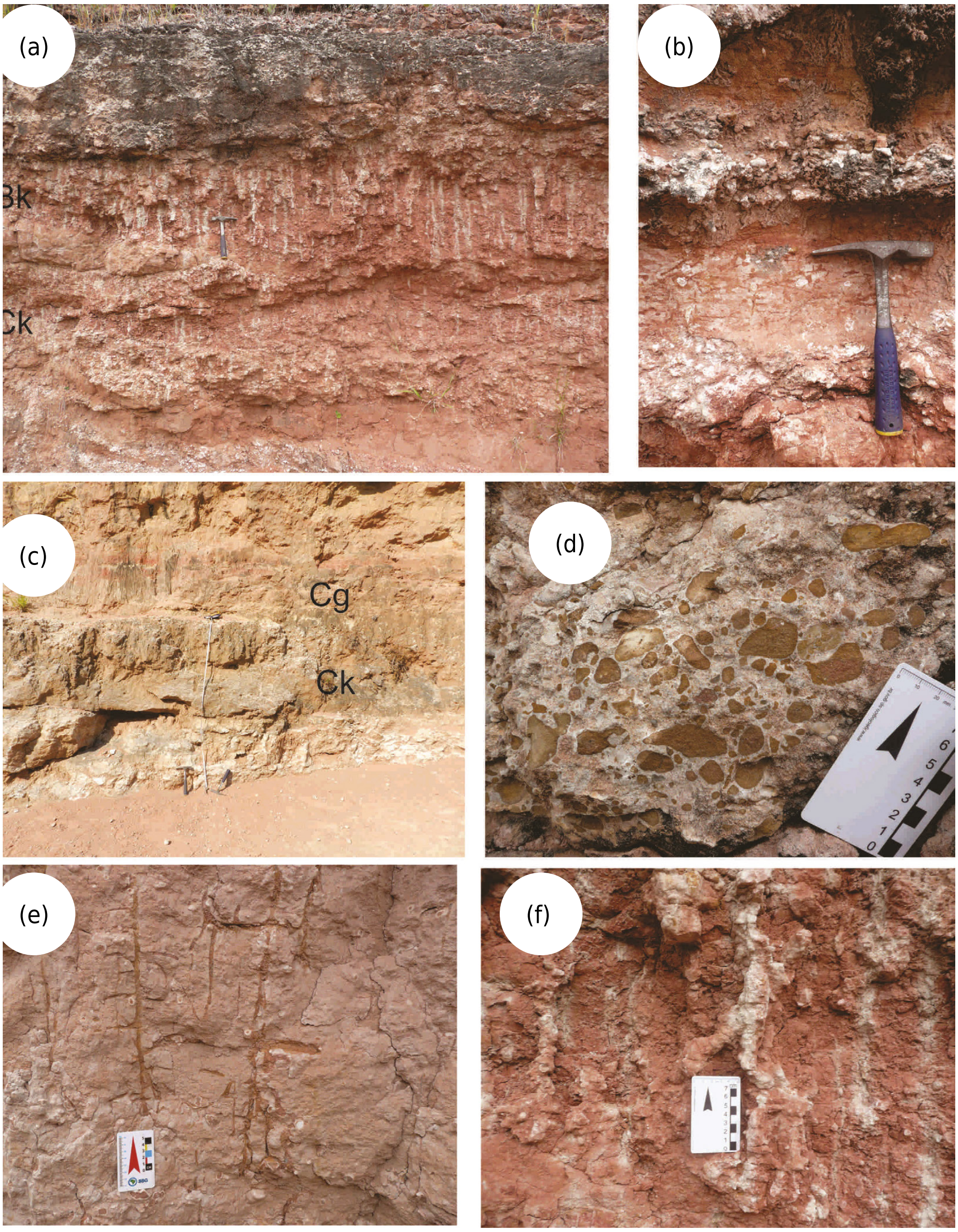

Figure 3. Detail of the pedocomplexes analyzed. (a) Contact between the well-developed pedotype (Bk) and the poorly-developed pedotype. Notice root marks cemented by $CaCO_3$. (b) Nodular $CaCO_3$ level. (c) Contact between paleosols Cg and Ck. (d) Detail of the carbonate nodules. (e) Root marks filled with coarse sand. (f) Roots present in the Ck horizon, cemented by $CaCO_3$.

in a massive sandy matrix that indicates per descensum processes, as proposed by Goudie (1983).

This pedotype has pedogenetic horizons with 4 and 5 evolution levels, according to Alonso-Zarza and Wright (2010), with strongly cemented $CaCO_3$ horizons where the carbonate nodules are embedded in a hardened carbonate matrix. Btk and Bkm horizons in well-developed pedotypes show a prism and block structure, ranging from 2.0 to 10.0 cm, and are strongly cemented by calcium carbonate, which is difficult to disaggregate even after hammer blows.

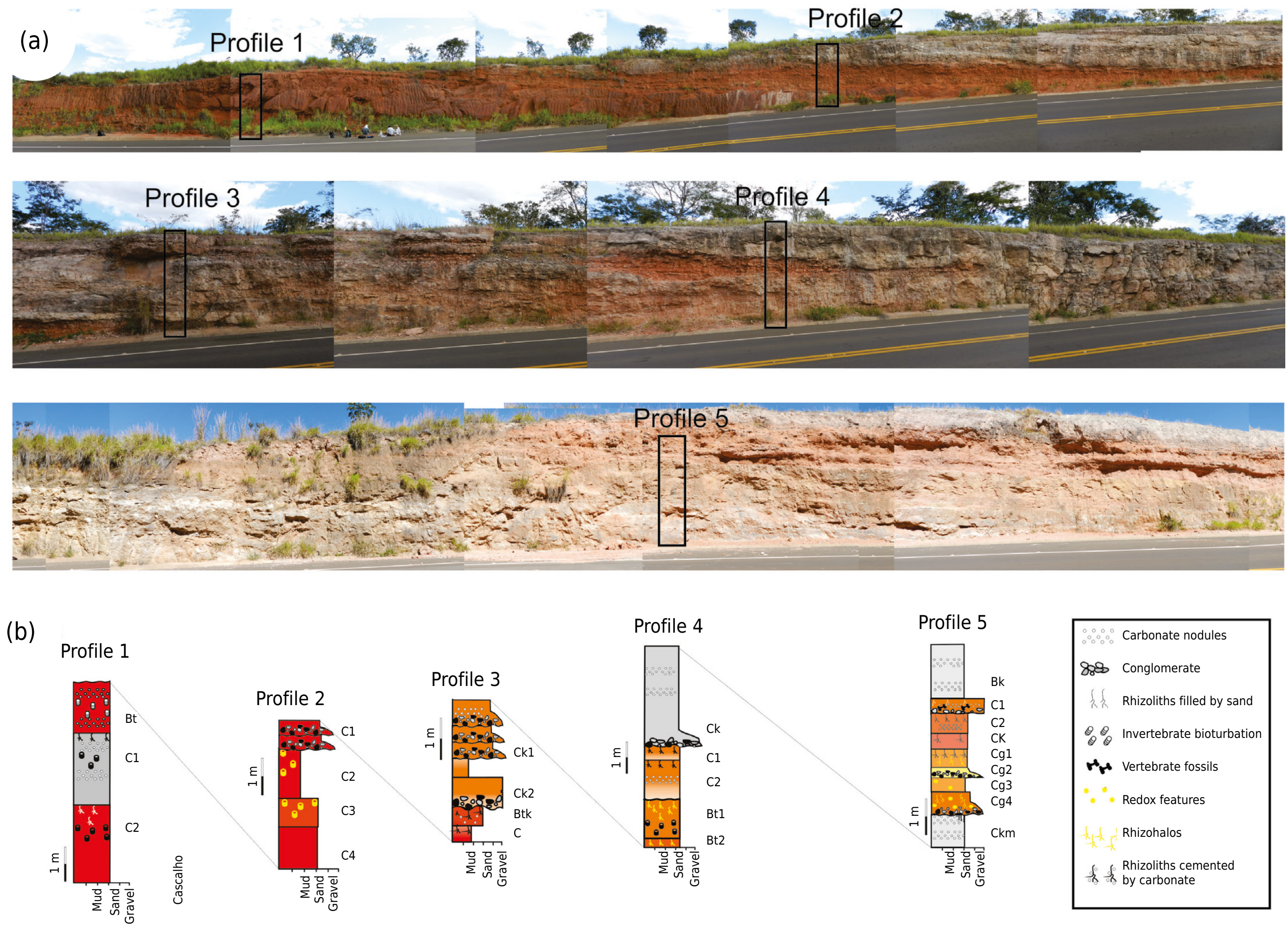

Figure 4. (a) Sections and location of profiles. (b) Columns described.

Table 1. Macromorphological characterization of the pedotypes described

Pedotype	Horizons	Texture	Color	Structure	Reactive to HCl 10 %	Nodules of $CaCO_3$	Redox evidence	Bioturbation
Well developed	Bt, Bk, and Btk	Sandy/ conglomeratic	10R 7/6, 10R 8/4, 10R 7/8	Prismatic to blocky	Strongly reactive	Abundant	Only associated with biotubation	Common 5-10 mm
Poorly developed	Ck	Sandy	10R 8/4, 10R 8/1	Massive	Reactive	Rare	Only associated with biotubation	Common 5-10 mm
Poorly developed	C and Cg	Sandy/ conglomeratic	2,5Y 8/8, 2,5Y 8/1, 2,5Y 7/8, 10R 7/6	Massive	Non reactive	Common	Common depletion features and mottles; Fe and Mn concentration in matrix; rhizohalos.	Rare root traces

The well-developed pedotype has a coarse fraction consisting primarily of quartz (85 %), followed by feldspar (10 %), heavy minerals and lithic fragments (5 %). Grains mostly vary from an angular to a sub-round shape, and quartz grains with a knurled surface are common, due to dissolution of calcium carbonate. Relative distribution is configured as gefuric/quitonic. Relations between coarse and fine fractions are characterized by conjunction and association in the portions where bridges and thin pellicles prevail, as well as strong $CaCO_3$ cementation.

$CaCO_3$ coatings appear as calcium carbonate layers surrounding the grains of the coarse fraction in the form of pendants (Figures 6d, 6e, and 6f), typical of the vadose zone of the soil (Freytet and Plaziat, 1982). Due to intense pedogenetic cementation (Figure 6g), the presence of $CaCO_3$ nodules in association with spastic calcite can be noticed in some slides, due to recrystallization processes.

The following eodiagenetic features can be perceived: groundmass compaction and reorganization (to a lesser extent compared to the poorly-developed pedotype), recrystallization of the micritic cement, spastic calcite cementation and cementation by Fe oxides, and the presence of palygorskite.

Pedodiagenetic cycle

Due to the difficulty in establishing interface between pedogenesis and diagenesis, Klappa (1983) coined the term "pedodiagenesis" to refer to both cases. However, he pointed out that diagenetic development is wider, considering that which refers to active processes ranging from the deposition of sediments to low-grade metamorphism, with the exception of biological influence.

Given that biological activity is a factor in soil evolution, a purely diagenetic environment would be one in which living organisms would not exercise a physical or chemical influence. Thus, pre-burial conditions, including degree of maturity and position in the landscape, in association with depth of burial, are determining factors for establishment of a border between diagenesis and pedogenesis.

Table 2. Micromorphological and diagenetic characterization of the pedotypes described

Pedotype	Horizons	Microstructure	Ground mass (coarse/fine)	b-fabric	Coating	PC[(1)]	NPC[(2)]	Iron oxide	Rhizolith	Diagenetic feature
Well developed	Bt and Btk,	Granular/blocky	70/30	Crystallitic/ stipple-speckled striated	Common thick continuous or non-oriented	30 %	<5 %	Rare	Common rhizoliths	Compaction and disorganization of peds and the matrix by compression, coating fragmentation, diagenetic cementation, dissolution and recrystallization of pedogenetic carbonate cementation by iron oxide.
Poorly developed	Ck	Massive or undifferentiated	80/20	stipple-speckled/ single grain	Common thick continuous or non-oriented	15 %	<10 %	Few	Rare rhizoliths	Compaction and groundmass (c/f) disorganization by compaction, diagenetic cementation, dissolution and recrystallization of pedogenetic calcite, grain fragmentation and also cementation.
Poorly developed	C, Cg	Massive or undifferentiated	80/20	Undifferentiated	Undifferentiated	-	-	Common	Rare rhizoliths	Reorganization of the groundmass, liquefaction and suturing of grains by compaction, infiltrated mica fragmentation, oxide coatings, quartz overgrowth and diagenetic cementation by silica

[(1)] PC: pedogenetic $CaCO_3$. [(2)] NPC: nonpedogenetic $CaCO_3$).

With the increase in temperature and pressure during burial, soil features are progressively destroyed, and, thus, part of soil memory is lost (Targulian and Goryachkin, 2004). However, under certain conditions, such as calcretization, biogenic and pedological features are preserved (even partially), which allow us to establish the pedodiagenetic sequence (pre- and post-burial processes).

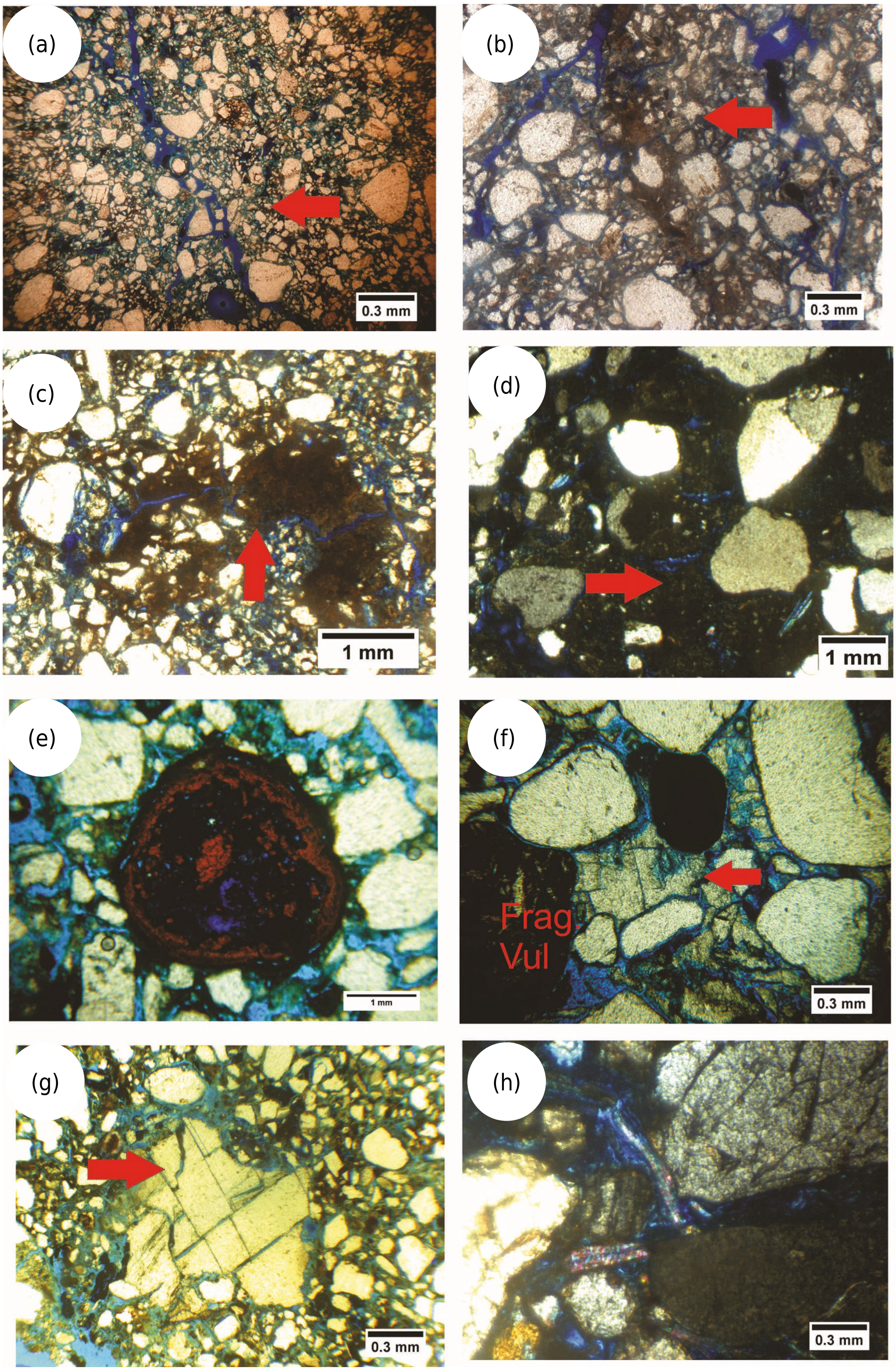

Figure 5. Micromorphological features of the poorly-developed pedotype. (a) Photomicrograph showing the weak structuration. (b) Clay illuviation without a preferential orientation. (c) Arrow draws attention to the distorted coating. (d) Speckled structure without preferential orientation. (e) Iron oxide nodule corresponding to Cg4 profile. (f) and (g) Carbonate-rich cementation of non-pedogenic origin. (h) Fragmented mica due to the compression of the poorly-developed pedotype (crossed polarizers).

Diagenetic processes acting on the burial of paleosols are indicated by means of neoformation and recrystallization of calcite, neoformation of clay minerals, coating distortion, and the cementing of hematite and silica, in addition to mechanical compression, which results in the distortion of soil structures and in the dissolution of grains.

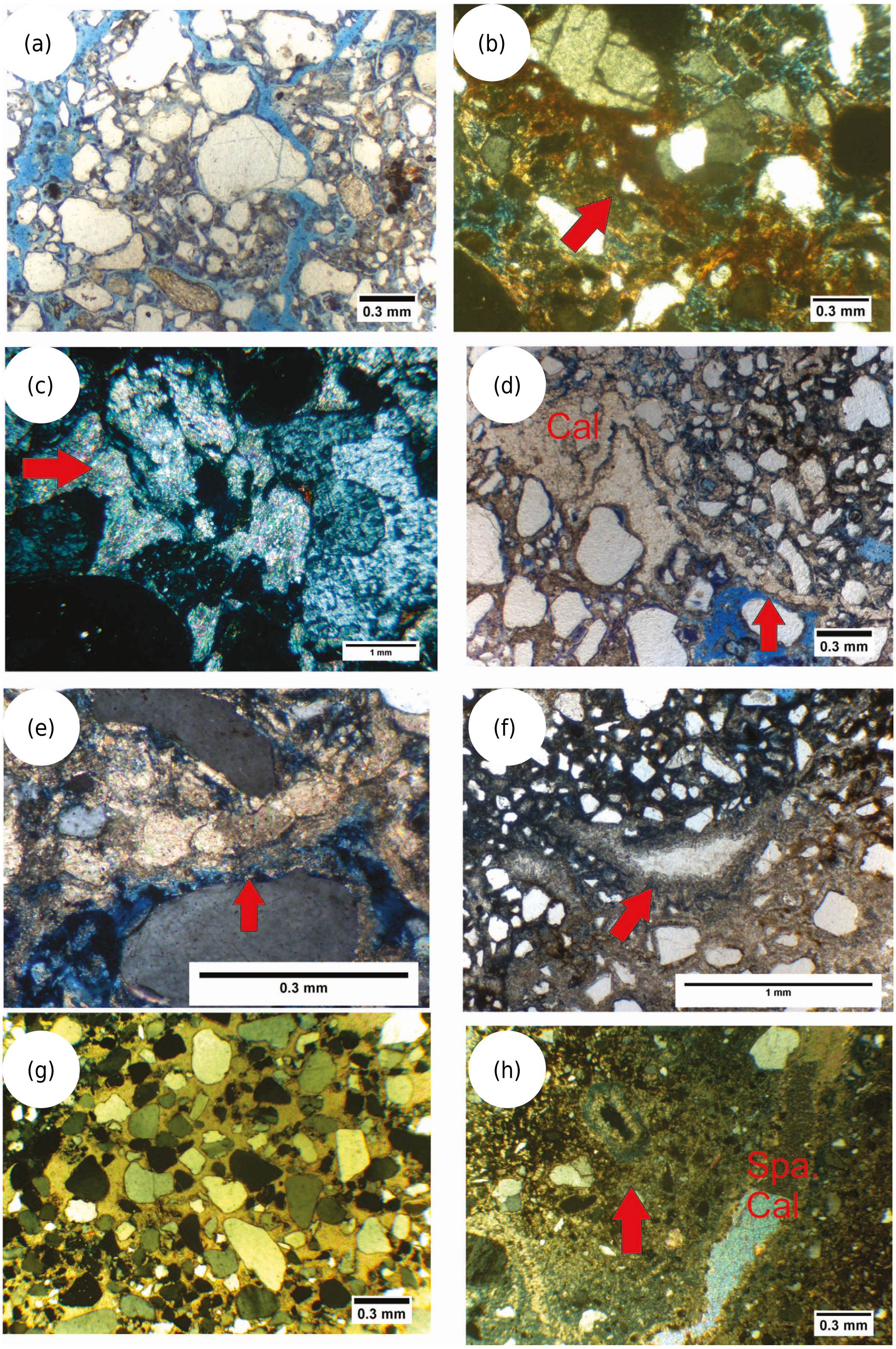

Figure 6. Micromorphological features of the well-developed pedotype. (a) Pedological microstructure partially accommodated. (b) Poorly oriented filling porosity illuvial clay. (c) Calcite coating. (d) and (e) Carbonate mobilization in the form of pendants along the profile. (f) Arrow indicates feature of calcite recrystallization. (g) Intense cementation from pedogenetic $CaCO_3$. (h) Arrow indicates carbonate nodule. Pictures (c), (e), (g), and (h) - crossed polarizers.

Among the primary effects of soil burial are degradation and replacement of organic matter and cementation of biogenic features (roots, for example) for more stable cements. Due to the semi-arid sedimentary environment in the Marília Formation, pedogenetic and biological $CaCO_3$ cementation is the initial sub-aerial pedodiagenetic feature. Cementation replaces grains and fills in primary pore space, resulting in a “loose” arrangement in which grains “float” in a micritic matrix (Figure 6g).

The low degree of compaction of well-developed pedotypes results, however, in preservation of microaggregates after burial. Intense calcretization (soil memory) and predominance of the sand fraction are responsible for preservation of microaggregates (Retallack and Wright, 1990; Retallack, 1991, 2001; Srivastava and Sauer, 2014), preventing intense groundmass reorganization and loss of porosity due to progressive burial.

In well-developed pedotypes, the effect of compaction affects only clay coatings, disorganizing their orientation and fragmenting them (Figure 7a). However poorly-developed horizons in pedocomplexes indicate a higher degree of mechanical and chemical compaction, evidenced by the fragmentation of mica, concave - convex contacts, suturing, and dissolution of quartz grains (Figures 7b and 7c). Due to its high primary porosity, interstitial alkaline water should have favored the dissolution of quartz and subsequent precipitation in the form of microcrystalline silica.

The mechanical compaction effect of the growing of pedogenetic cementation from micritic $CaCO_3$ on the well-developed pedotype resulted in the breaking of coarse fraction grains (Figures 7d and 7e), mainly from polycrystalline grains. That indicates the existence of a carbonate-supersaturated vadose environment, a common situation in the current semi-arid environments (Braithwaite, 1989).

Calcite needles are common in pedogenic calcretes, partially filling the vadose space of the soil (Figure 7f), connected to secondary calcite biomineralization by fungi or roots (Callot et al., 1985; Verrecchia and Verrecchia, 1994). Post-burial mineralogical and morphological modifications alter these features, merging them, which results in microsparitic crystals (Loisy et al., 1999). Due to the diagenetic degree of such paleosols, intact preservation of this feature is rare.

Another significant pedogenetic feature is the presence of cytomorphic calcite (Figure 7g) in response to calcification and decalcification processes associated with impregnation of root tissues. This feature is constituted by equigranular sparitic calcite crystals, filling in channels, and it is common in semi-arid environment soils (Durand et al., 2010).

Poorly-developed pedotype cementation by poikilotopic calcite (Figure 7 – H) indicates the overprint of post-burial diagenetic processes under pedogenesis. Diagenetic cementation shows euhedral and rhombohedral calcite crystals, denominated Alpha, which, according to Wright (2007), characterizes calcretization by underground water.

The sequence of precipitation of secondary calcite in these paleosols allows us to establish the pre- and post-burial pedodiagenetic evolution of the well-developed pedotype. Pedogenetic cementation by micritic calcite occurs in pre-burial conditions influenced by biological activity, followed by poikilotopic calcite precipitation (sparry calcite) among grains, microaggregates, and krotovinas, by underground water saturated in $CaCO_3$, which indicates an initial burial (Figures 8a and 8b).

Pressure and temperature increase pedogenic and diagenetic cementation are submitted to recrystallization, assuming a serrated microsparitic aspect that cuts older cements (Figures 8c and 8d), which is evidenced by optic discontinuity in different types of cements.

With the progressive increase of temperature and pressure, iron oxide diagenetic mobilization occurs, which is expressed by the coatings of grains and microaggregates.

This process is associated with purely diagenetic processes because the oxides are observed integrating calcite hypocoating surfaces and biogenetic structures of

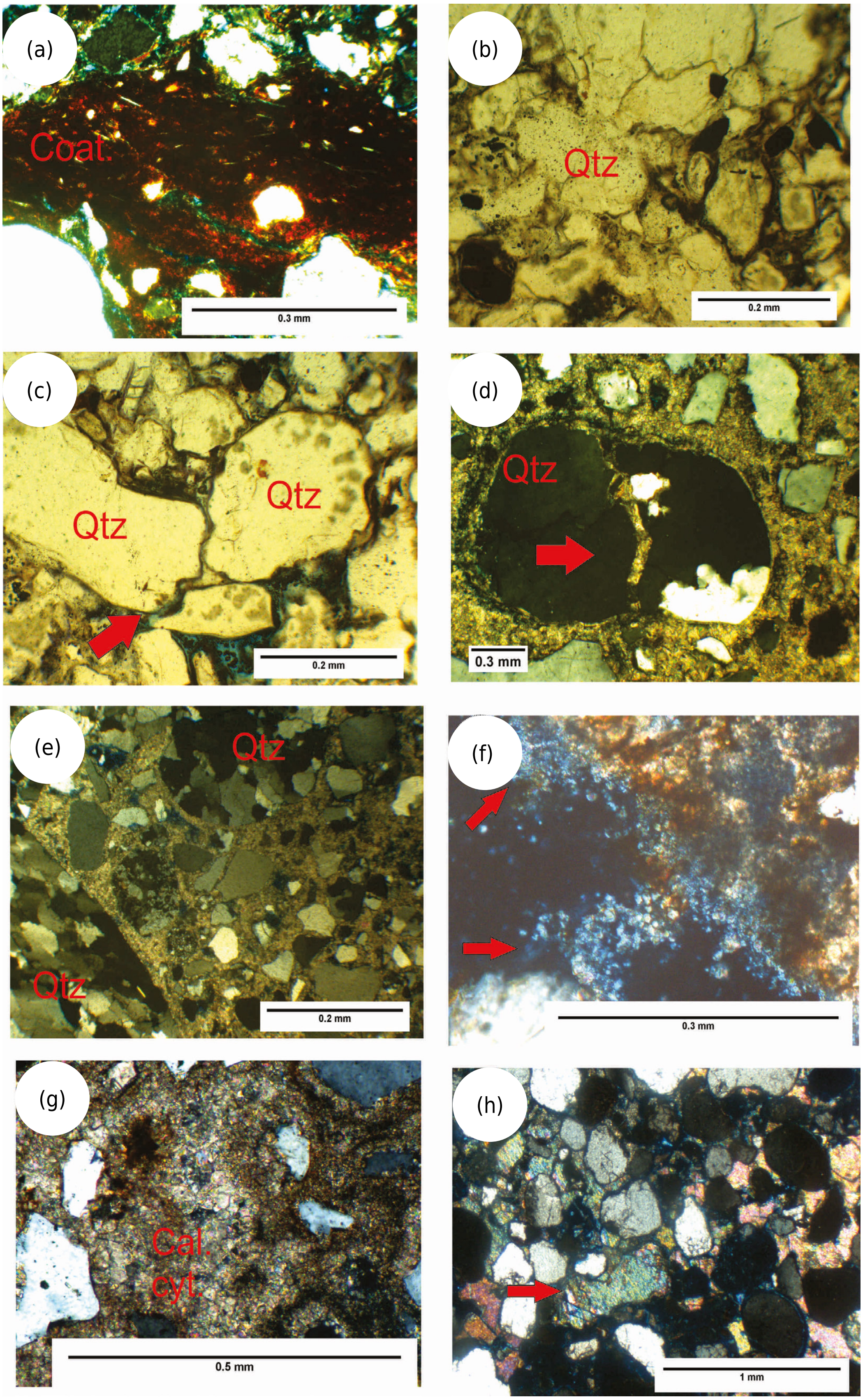

Figure 7. (a) Coating in well-developed profile distorted due to compaction. (b) and (c) Suture and dissolution of quartz grains. (d) and (e) Grain fragmentation due to the displacive effect of cementation. (f) Recrystallized calcite needles. (g) Cytomorphic calcite. (h) Cementation by non-pedogenetic poikilotopic calcite. Pictures (d), (e), (f), (g), and (h) with crossed polarizers.

pedogenic origin (Figure 8c). The source of such iron oxides in the well-developed pedotype is related to the weathering of fragments of basaltic rocks and ferromagnesian minerals (pyroxene).

In the well-developed pedotype, the presence of pedogenic palygorskite is noteworthy. (Figure 9a), indicating the alteration and neoformation of 2:1 clay minerals. Palygorskite is common in semi-arid and arid environments (Khormali and Abtahi, 2003; Daoudi, 2004) where salinity and alkalinity conditions favor its formation in situ from the soil solution.

The fact that palygorskite stands out in well-developed pedotype paleosols is related both to its position in the landscape and to good drainage. A similar situation was

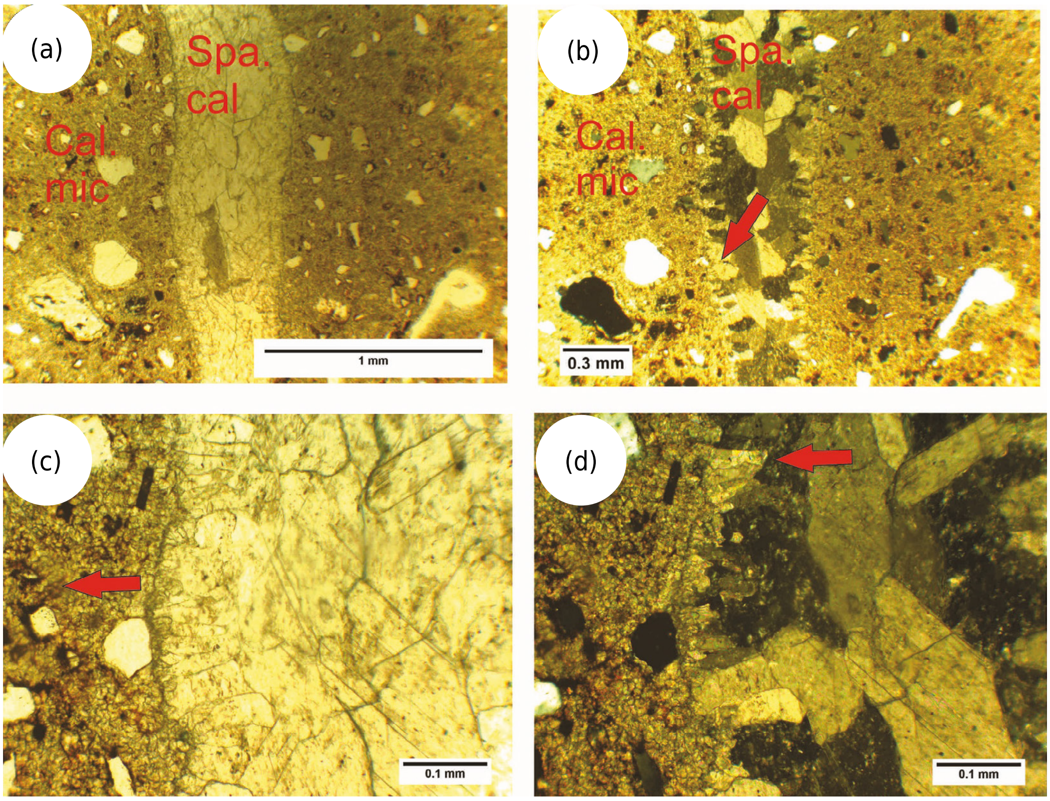

Figure 8. Sequence of pedogenic calcite recrystallization. (a) and (b) Sparitic calcite filling a biopore surrounded by pedogenetic microcrystalline calcite. Arrow draws attention to the diagenetic recrystallization of micritic calcite. (c) Detail of previous pictures. Arrow indicates cementation by iron oxide. (d) Detail (arrow) of pedogenic calcite recrystallization cutting poikilotopic cementation. Pictures (b) and (d) with crossed polarizers.

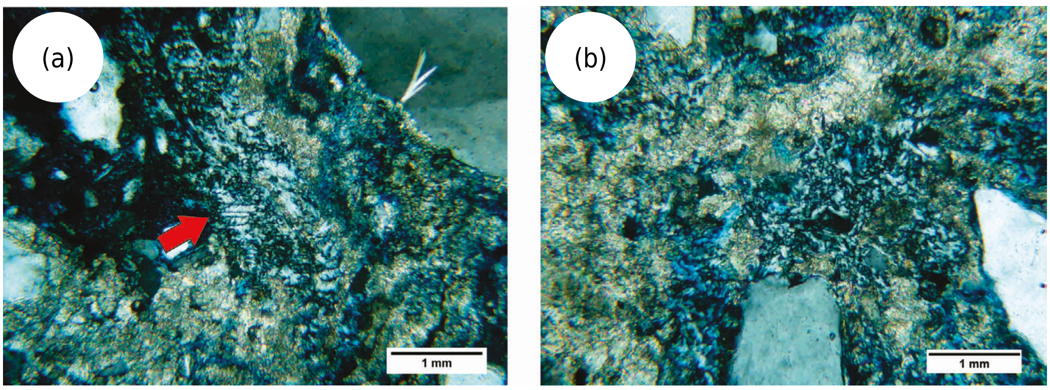

Figure 9. (a) Arrow indicates palygorskite and its fibrous characteristic in the well-developed pedotype. (b) Arrow indicates microcrystalline silica precipitation.

observed by Abtahi and Khormali (2001) in current soils, showing that well-drained soils favored the formation of palygorskite and that illite was dominant in poorly-drained soils.

Authigenesis of silica (Figure 9b) is an advanced diagenetic feature, characterized by cryptocrystalline silica precipitation in the vadose zone. Quartz is the most abundant diagenetic mineral in sandstone (Worden and Morad, 2000) and the progressive increase in temperature, in association with alkaline-predominant interstitial water, propitiated its precipitation in the microcrystalline form, rather than to the coarse fraction grains.

Pedodiagenetic features and paleotopographic conditions

The observed micromorphological characteristics are directly linked to the pre-burial conditions of the described pedotypes. In continental sedimentation environments, paleosols mark depositional or erosional hiatuses. Thus, it is possible to relate the sequence of pre- and post-burial events to the old position of a paleosol in the landscape, which allows reconstruction, though only partially, of the influence of factors and processes throughout its evolution.

The poorly-developed pedotype evolved in the most unstable areas of the landscape (Figure 10), in the lower portions of ancient slopes, under direct influence of the water table. That is evidenced by redox features and by the lack of carbonate cementation of pedogenic origin. Its position in the landscape resulted in the combination of pedodiagenetic processes, strongly influenced by sediment dynamics, as well as by the geochemistry and behavior of the water table. This is clearly shown through its low development level (predominantly with stacked C horizons), cementation by poikilotopic calcite, and the dissolution of quartz grains.

Good primary porosity in the poorly-developed pedotype prevented the mechanical infiltration of clay and mica, in response to the constant presence of the water table, which prevented

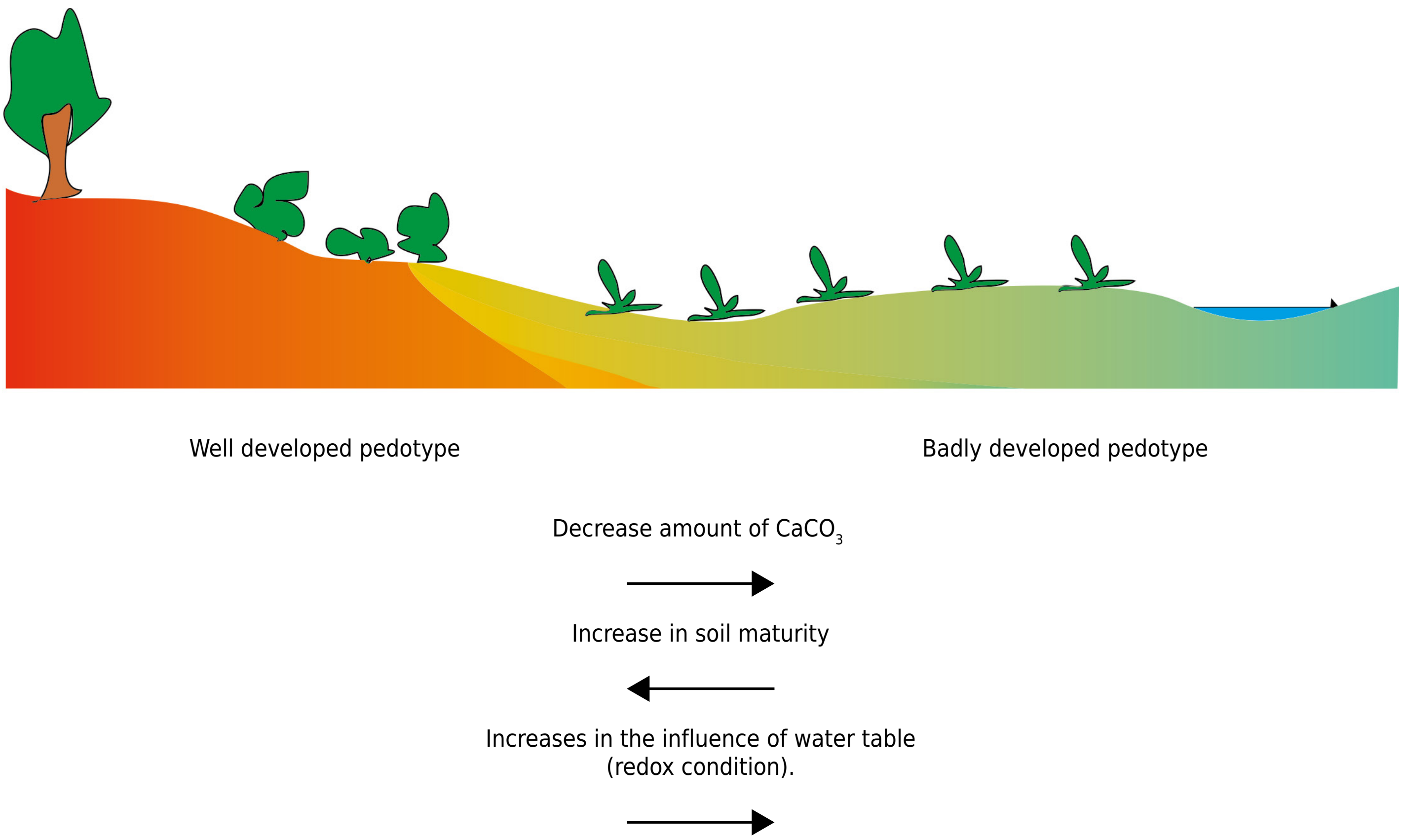

Figure 10. Described pedotypes and their respective positions in the ancient landscape.

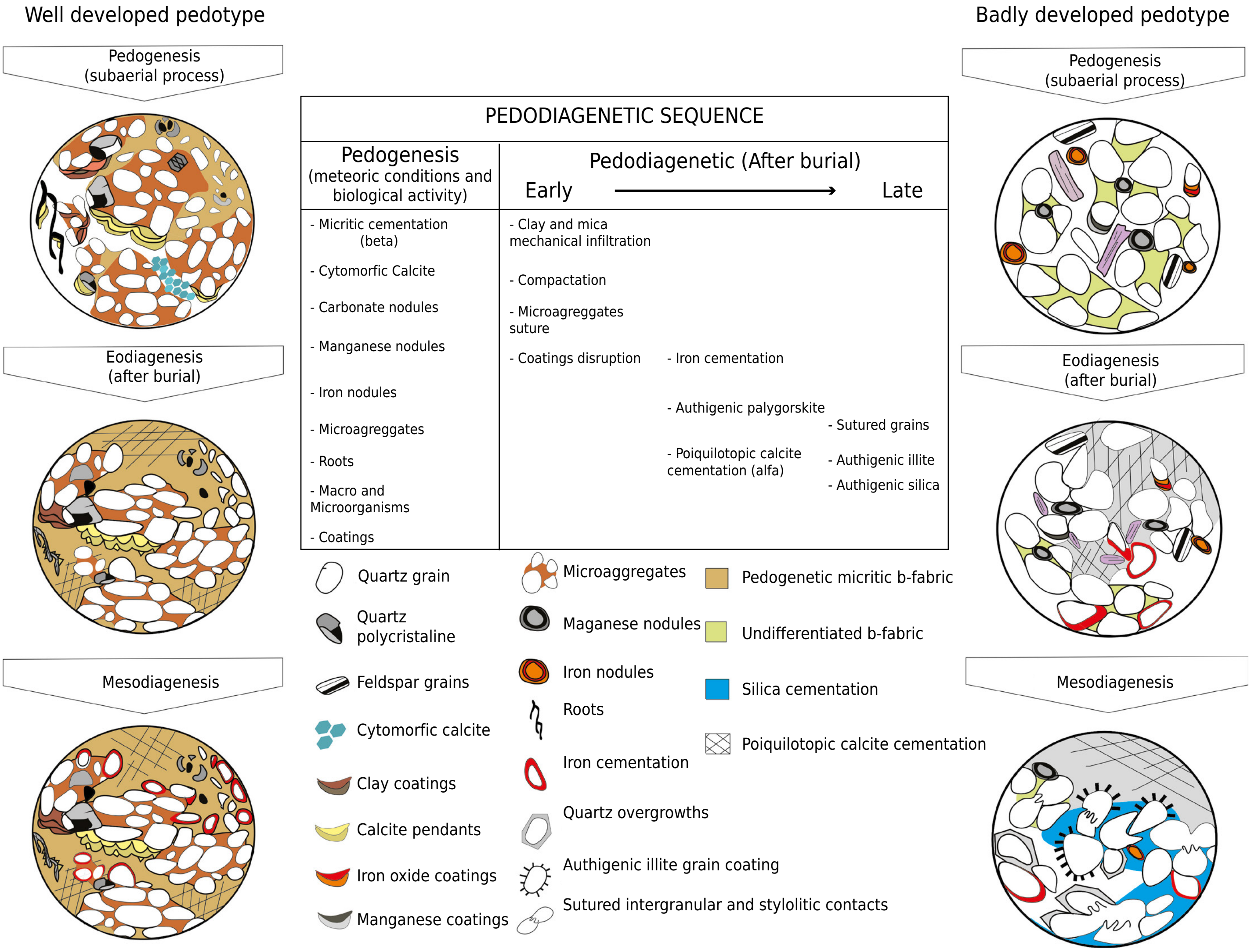

Figure 11. Pedodiagenetic sequence showing the ranking of pre- and post-burial processes in the pedotypes described. Modified from Choquette and Pray (1970).

$CaCO_3$ cementation. The suture of quartz grains and the authigenesis of silica indicate that this pedotype underwent stronger compression than the well-developed pedotype.

The well-developed pedotype evolved in the most stable positions of the landscape where there was the development of mature paleosols (Btk and Bk). Carbonate profiles of pedocomplexes indicate water deficit, not evolving under the direct influence of the water table. The recrystallization of pedogenic calcite and cementation by iron are the main strictly diagenetic processes. Precipitation, dissolution, and recrystallization of localized secondary sparitic calcite (with bioturbation and pores) indicate an increase in pressure and temperature, whereas the cementation of hematite is associated with remobilization of iron oxides that impregnate the grains and microaggregates.

The pedogenic processes affected the three-dimensional permeability of such sand bodies and the diagenetic processes associated with compression and percolation of interstitial water, resulting in the sequence of processes for pedotypes ranked in figure 11.

CONCLUSIONS

Pedogenetic evidences, such as microstructures, clay illuviation, biogenic remnants, and pedogenic carbonate were modified through chemical and mechanical compaction, resulting in the distortion of aggregates and coatings and in a decrease in porosity. Such processes are much more evident in the poorly-developed pedotype, indicating that the degree of maturity affected diagenetic processes.

The progress of diagenetic processes, dissolution and mineral recrystallization, sparitic calcite precipitation, iron and amorphous silica indicate the process of burial and diagenesis. This pedogenetic characterization allows us to sort the processes hierarchically (pre- and post-burial) and to answer questions regarding the origin of the processes acting in paleosols, facilitating communication between scientists.

Elaborating the pedodiagenetic cycle helps us characterize pre-Quaternary paleosols, enabling reconstitution of the factors and processes involved in soil evolution, such as the influence of relief and biological factors, thus facilitating understanding of paleoenvironmental conditions.

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