PETROGRAPHY AND DIAGENESIS OF THE CAMBAMBE BASIN, CHAPADA DOS GUIMARÃES, MATO GROSSO STATE, BRAZIL

PETROGRAFIA E DIAGÊNESE DA BACIA CAMBAMBE, CHAPADA DOS GUIMARÃES, ESTADO DO MATO GROSSO, BRASIL

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ABSTRACT: This work presents unpublished information on the petrography and diagenesis of the Cambambe Basin. The deposition of the Cambambe Basin started at 84 Ma ago. This basin consists of a Cretaceous volcanic-sedimentary sequence cropping out in the municipalities of Chapada dos Guimarães and Nova Brasilândia. The volcanic-sedimentary sequence starts with the magmatism of the Paredão Grande Formation at the bottom, followed by the sedimentary units Quilombinho and Cachoeira do Bom Jardim formations, which are part of the Ribeirão Boiadeiro Group and, finally, the Cambambe Formation at the top of this Cretaceous sedimentary package. This is the first detailed work on the petrography of these rocks approaching the description of litharenites, quartzarenites, sublitharenites, chert, and carbonates. The predominant cement phases are related to eodiagenesis. This work also allowed us to better understand the role tectonics has played in the deposition of the Ribeirão Boiadeiro Group and the Cambambe Formation.
Keywords: Petrography, Cambambe Basin, Diagenesis.

RESUMO: São apresentadas informações inéditas sobre a petrografia e diagênese da Bacia do Cambambe. Com início da deposição em aproximadamente 84 milhões de anos, a Bacia do Cambambe é constituída por uma sequência vulcano-sedimentar cretácea, aflorante nos municípios de Chapada dos Guimarães e Nova Brasilândia. O início da sequência se deu com o magmatismo da Formação Paredão Grande, seguido pela sedimentação das formações Quilombinho e Cachoeira do Bom Jardim, pertencentes ao Grupo Ribeirão Boiadeiro e, por fim, a Formação Cambembe que encerra o pacote sedimentar cretáceo. Este é o primeiro trabalho detalhado sobre a petrografia destes sedimentos e apresenta a descrição de lâminas de litarenito, quartzoarenitos, sub-litarenitos, silexito e carbonatos. As fases de cimentações predominantes estão relacionadas à eodiagênese. Este trabalho permitiu também compreender melhor a influência da tectônica na deposição das rochas do Grupo Ribeirão Boiadeiro e da Formação Cambambe.
Palavras-chave: Petrografia, Bacia Cambambe, Diagênese.

INTRODUCTION

The Cretaceous sediments cropping out in the municipality of Chapada dos Guimarães have been studied since the XIX century when Derby (1890) described dinosaur fossils in that same region. Later works have provided important contributions to the lithostratigraphic understanding of the Cambambe basin, such as Weska (1987), Coimbra (1991), Weska (1996), Gibson et al. (1997) and Kuhn (2014).

This paper presents the partial results of the study carried out for the master dissertation of the first author at the Postgraduate Program in Geosciences of the Federal University of Mato Grosso. This is the first detailed petrographic analysis of the Cambambe basin (Figure 1) and aims to understand the diagenetic and tectonic evolution of the basin. Therefore, rocks from both Ribeirão Boiadeiro Group and Cambambe Formation were studied.

The study area includes the Communities of Jão Carro, Gleba Jangada Roncador, Fazenda Rancho Queimado, Cachoeira Rica (Peba) and Morro do Cambambe, which is located in the municipality of Chapada dos Guimarães, 61 km from Cuiabá, the capital of the Brazilian state of Mato Grosso.

THE CAMBAMBE BASIN

The Cambambe Basin (Coimbra, 1991) is related to tectonic forces that over the Cretaceous gave rise to structural highs and basins throughout the region known as the Alto

Garças Platform as well as the installation of several basins. This basin is a tectonic oval depression located in the south-central portion of Mato Grosso, with approximately an extension area of 7,000 km² and almost 300 meters in depth. This area is located between the municipalities of Chapada dos Guimarães and Nova Brasilândia.

The basement consists of rocks of the Cuiabá Group on the north and of rocks of the Paraná Basin on the south, especially the Botucatu Formation.

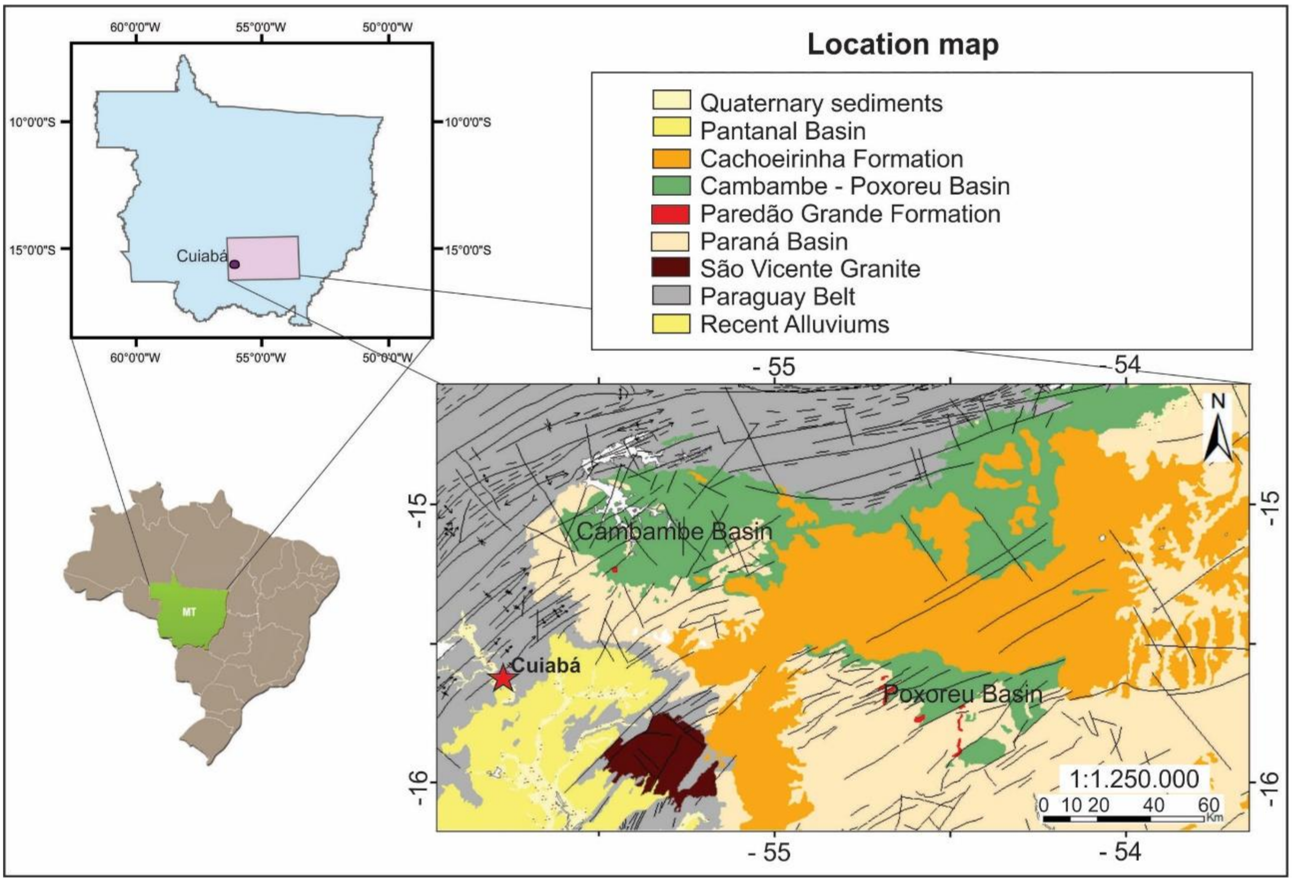


Figure 1 - Location map of the Cambambe Basin (modified from Lacerda Filho et al., 2004).

The bottom portion of the Cambambe Basin is represented by magmatic rocks of the Paredão Grande Formation dated 83.9 ± Ma by Gibson et al. (1997) using $^{40}Ar/^{39}Ar$ method. The overlying Ribeirão Boiadeiro Group consists of the Quilombinho and Cachoeira do Bom Jardim formations. At the top of the sequence, the Cambambe Formation occurs in disconformity with the underlying units. These Cretaceous units were deposited in an alluvial fan system. The sediments of the Cambambe basin are, in places, overlaid by unconsolidated sediments named the Cachoeirinha Formation.

The Paredão Grande Formation was proposed by Weska et al. (1996) in order to group coarse- and fine-grained pyroclastic rocks, lava flows and associated dikes that occur in the municipalities of Chapada dos Guimarães, Dom Aquino, Paranatinga, Poxoréu, Paredão Grande district and Meruri Indian Colony. These rocks are mainly hosted by the Cuiabá Group and the Aquidauana and Botucatu formations as well as by rocks of the Ribeirão Boiadeiro Group. According to Gibson et al. (1997), these rocks are classified as basaltic-trachyandesites and trachyandesites with an approximate age of 83.9 ± 0.4 Ma ($^{40}Ar/^{39}Ar$ method). There are two distinct proposals on the origin of the magmatism: Gibson et al. (1997) and Weska (2006) propose that the Paredão Grande Formation is related to the first brittle phase of Rio das Mortes Rift and that the source of the magmatism would be associated with the Trindade mantle plume. However, De-Min et al. (2013) has recently dated ultramafic alkaline rocks in the municipality of Planalto da Serra and found an age of 600 Ma ($^{40}Ar/^{39}Ar$ method) amongst alkaline intrusions very similar in chemical composition to those of the Paredão Grande Formation. Owing to the similarity of magma characteristics between the magmatic events of 600 Ma and 84 Ma, De-Min et al. (2013) suggests that the plume-related hypothesis is unlikely as previously proposed by Gibson et al. (1997) once both magmatic events have many geochemical similarities. Thus, this magmatism is more likely to be related to the remelting of Neoproterozoic magmatic rocks.

Coimbra (1991) includes into the Ribeirão Boiadeiro Formation, the Quilombinho and Cachoeira facies as previously described by Weska (1987). Weska (1996), however, has raised both facies to formation rank. Based on field data, this work approaches a new lithostratigraphy in order to unify the proposals of Coimbra (1991) and Weska (1996) and raises in rank the Ribeirão Boiadeiro Formation to Ribeirão Boiadeiro Group, which comprises two formations: Quilombinho and Cachoeira do Bom Jardim. These formations were deposited in an alluvial fan system developed under semi-arid climatic conditions in which the Quilombinho Formation represents the proximal portion, while the Cachoeira do Bom Jardim Formation represents the intermediate to distal portion (Weska, 1987).

Heavy minerals from the Ribeirão Boiadeiro Group suggest the influence of volcanism on sedimentation given the presence of unaltered mineral phases, such as subhedral hornblende (Kuhn, 2014). The cement is mainly carbonate. The primary structures are plane-parallel laminations and cross-laminations, trough cross-bedding to tangential tabular cross-bedding. Thick calcretes interdigitate with sandstones, argillites, and conglomerates. The colors of the sedimentary beds are red, pink and white (Weska, 1987, 2006).

The existing facies correspond to an alluvial fan system deposited in a semi-arid climate (Weska, 1987). Under the microscope, the sandstones of the Ribeirão Boiadeiro Group are characterized as litharenites, rich in volcanic rock fragments. The calcretes are mudstone to wackestones presenting different stages of a paleosol series (Kuhn, 2014).

The relationship between sedimentation and volcanism allow us to say that the deposition of this formation took place between the late Santonian stage and the early Campanian stage (Kuhn, 2014).

The Cambambe Formation shows disconformity along the contact with the Ribeirão Boiadeiro Group and the Botucatu Formation. This formation consists of predominantly white, red, cream and gray sandstones including rare polymictic conglomerates (Weska, 2006; Kuhn, 2014). In thin section, these rocks are classified as quartzarenites and rare sublitharenites, which are very distinct from the Ribeirão Boiadeiro Group (Kuhn, 2014). The deposits were interpreted by Weska (1996) as distal portions of an alluvial fan system developed under semi-arid to extremely dry climatic conditions. Owing to the stratigraphic relationships with the older formations and given the occurrence of dinosaur fossils (Souza et al., 2011), it is possible to establish that the deposition of this formation occurred between the Campanian-Maastrichtian boundary.

MATERIALS AND METHODS

Rock sampling was carried out in the Cambambe Basin in the municipality of Chapada dos Guimarães. Optical sedimentary petrography was performed on standard-size thin sections and described according to Pettijohn et al. (1987) regarding fabric, grain-size, roundness, sorting, cement characteristics, texture, and crystal shape and size. Characteristics of the matrix, grain contact and packing are also described. The description and classification of carbonate rocks follow the previously established by Dunham (1962) and Folk (1968), later complemented by Flügel (1982). The laboratory analysis was developed in the Sciences Faculty of the University of Lisbon during the academic internship of the first author between September and December of 2013.

PETROGRAPHIC ANALYSIS

The thin sections described (Table 1) were classified as quartzarenite, litharenite, sublith-arenite, limestone and chert. The samples were collected from several distinct points of the basin in terms of stratigraphic position and spatial distribution.

Quartzarenite: twelve thin sections were described (92, 124-A, 114-A, 24-A, 103-B, 106, 86-A, 85, 53, M 49, 119-A and 119-B) (Figure 2), whose granulometry varied from fine- to medium-grained sand.

A subordinate fraction of the fabric is represented by lithoclast fragments (variation of up to 4.5%) of siltstone, graywacke, phyllite, chert, polycrystalline quartz, and quartzite. The mineraloclasts are composed of opaque mineral grains, albite, tourmaline, rutile, microcline, zircon and chlorite. Quartz grains show, in places, undulatory extinction or inclusions of rutile, chlorite, and tourmaline.

Table 1 - Location of collection points of the samples studied.

Sections	Geographical coordinates	
92	-55,419262	-14,931364
103-A, B e C	-55,294879	-15,185143
111 A	-55,277612	-15,170760
86	-55,465433	-14,987671
630-1	-55,288920	-15,165876
632-1	-55,295803	-15,183669
631-1, 2 e 3/ SN	-55,294969	-15,185632
115-A	-55,271804	-15,177728
49-29 e M 49	-55,637798	-15,212701
633-1, 3 e 2	-55,363260	-15,148872
124-A - 24-A	-55,277938	-15,164951
114-A	-55,272570	-15,176243
106	-55,314402	-15,167712
85	-55,459496	-14,991012
53	-55,5809	-15,27305
119-A e B	-55,270877	-15,180803

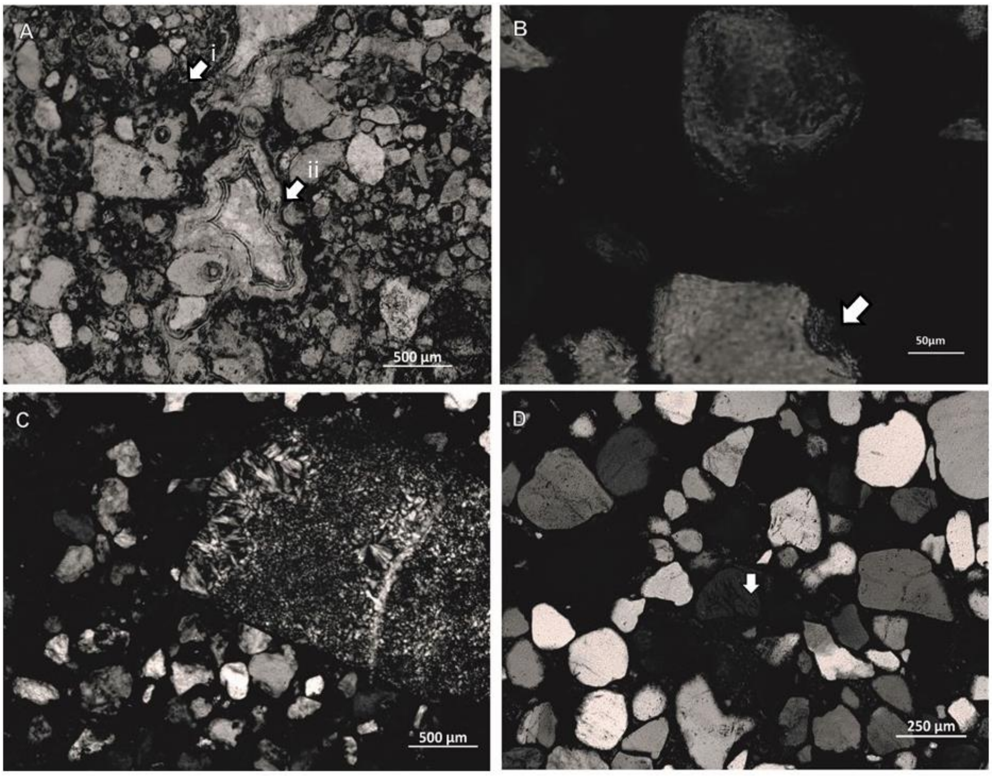


Figure 2 - (A) Litharenite exhibiting pores filled (II) with siliceous cement as well as iron oxide (I) cement, which either form halos inside pores or occurs disseminated; parallel polarizers, objective lens of 5x. (B) Corroded quartz grains; crossed polarizers, objective lens of 40x. (C) Granule of silexite composed of chalcedony and micro-cristalline quartz as well as quartz grains cemented with iron oxide; crossed polarizers, objective lens of 5x. (D) Tourmaline grain with rutile inclusions (arrow); parallel polarizers, objective lens of 10x.

Quartzarenites contain a matrix average of 4% that can vary up to 15%; well- to moderately well-sorted grains as well as rounded to well-rounded grains are predominant.

The punctual and sutured contacts are commonly shown in quartzarenites. The degree of roundness varies from predominantly rounded to well rounded.

The percentage of cement (Figure 3) usually ranges from 3% to 15%, however it can reach up to 30%. Some thin sections allow observing grain-size distribution. These sandstones are massive, with rare slightly-oriented laminae, the matrix is usually absent. In places, the matrix is quartzous and silty, clayey or clay-carbonate (Figure 4).

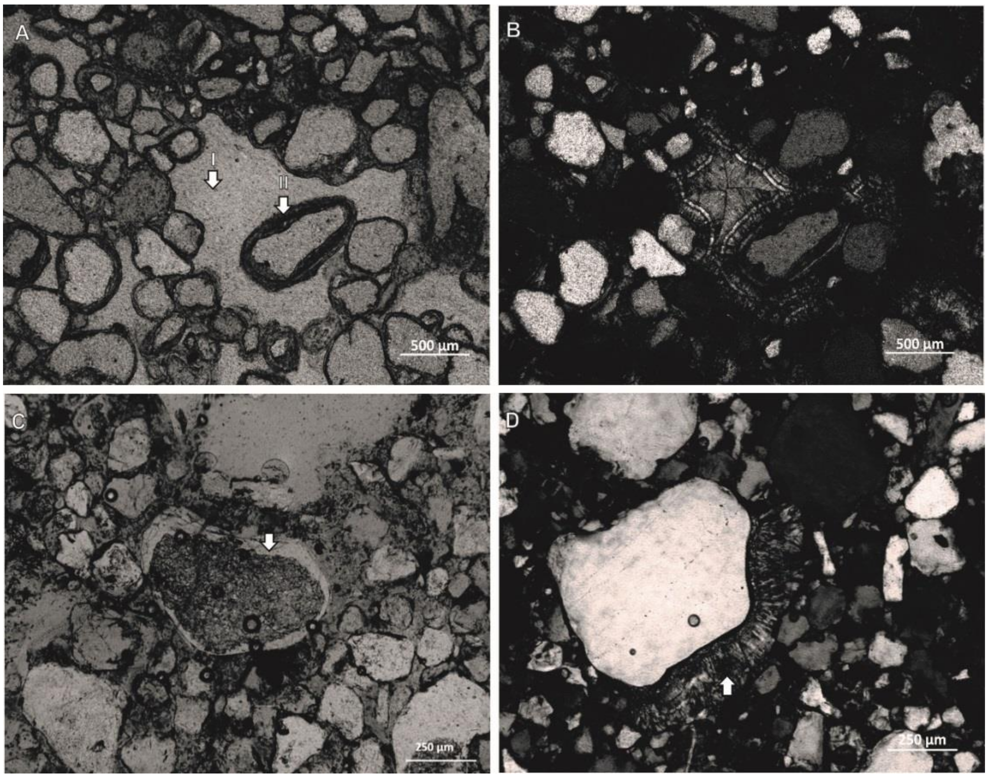


Figure 3 - (A) I – Detail of carbonate cementation, II – distinct phases of siliceous cementation; parallel polarizers, objective lens of 5x. (B) Pore filled with chalcedony, grains surrounded by envelopes of clay-carbonate cement characterizing ooids; crossed polarizers, objective lens of 5x. (C) Clay-carbonate cement coating silexite; parallel polarizers, objective lens of 10x. (D) Quartz grain partialy surrounded by chalcedony cement which shows gravitational morphology, typical of vadose environments, crossed polarizers, objective lens of 10x.

Sandstones may contain siltstone granules up to 10 mm. Nine different types of cement are observed in thin section: 1) ferruginous-clay cement disseminated or with oolitic grains characterized by the formation of rings around the grains; 2) chalcedony cement occurs filling pores and, in places, only on one side of grains; 3) fringe-shaped prismatic quartz cement inside the pores; 4) microcrystalline quartz cement disseminated or filling pores showing local partial replacement of chalcedony cement by the microcrystalline quartz cement; 5) meso-crystalline quartz cement; 6) iron-oxide cement disseminated; 7) spathic calcite cement; 8) mosaic calcite cement; and 9) opal cement. In addition, some grains may be overgrown by quartz cement. The distribution of cement is heterogeneous due to grain-size distribution in zones of mechanical or chemical compaction. Thus, the cement is poorly distributed in some thin sections. Quartzarenite were collected from rocks of the Cambambe Formation.

Sublitharenite: One of the thin sections was classified as medium-sand sized sublitharenite (633-3), with dispersed granules. It consists of mineraloclasts (89%) of quartz, opaque minerals, tourmaline, rutile, albite, microcline, and garnet as well as lithoclasts (11%) of polycrystalline quartz, chert, quartzite, siltstone, graywacke, phyllite, and quartz showing undulating extinction and opaque mineral inclusions.

The fabric has mainly punctual and sutured contacts. Grain usually vary from rounded to well-rounded. Grain size ranges from 0.05 to 3.50 mm. The matrix is silty and the cementation consists of 1) clay-carbonate cement filling pores and forming rings around the grains; and 2) microcrystalline quartz cement surrounding grains and, in places, inside pores. The cement makes up 6% of the total rock, and the matrix makes up 12%. These samples were collected from the Branco Hill where rocks from the Cambambe Formation are exposed.

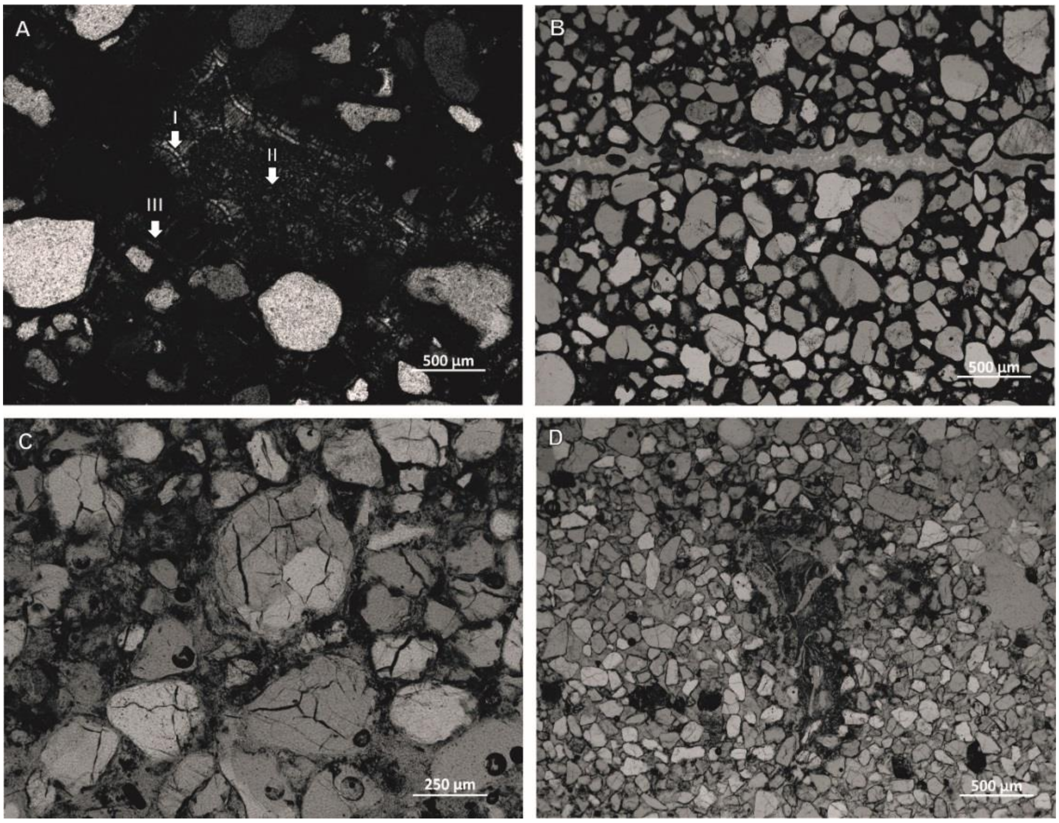


Figure 4 - (A) Overview of the giant pore exhibiting the relationship among different phases of cementation: clay-carbonate cement (I) surrounding grains, chalcedony cement (II) corroded by micro-crystalline quartz cement (III), crossed polarizers, objective lens of 5x. (B) Fabric essentialy formed by quartz grains covered by clay-ferruginous and siliceous cements which form a linear structure with main orientation of siliceous cement, parallel polarizers, objective lens of 5x. (C) Fractured quartz grains coated by iron oxide and cemented both with clay-carbonate and siliceous cements, parallel polarizers, objective lens of 10x. (D) Mosaic spathic calcite cement and silteous-iron cement filling fractures and pores, parallel polarizers, objective lens of 5x.

Litharenites: Nine litharenite thin sections have been described (103-A, SN-1, 633-1, 631-1, 103-C, 631-3, 115-A, 49-29, 632-1). Litharenite consists of 65% to 35% lithoclasts and of 65% to 35% mineraloclasts. Some sections show dispersed granules larger than 15 mm. The lithoclasts (Figure 5) found are composed of tuff, polycrystalline quartz, quartzarenite, chert, siltstone, phyllite, and ignimbrite. The mineraloclasts observed are quartz, perthite, opaque minerals, albite, microcline, tourmaline, and chlorite. The quartz grains contain chlorite or rutile inclusions and may show undulating extinction.

Regarding textural maturity, litharenite contains on average less 2% matrix although this value can reach up to 7%. Sorting varies from moderate to poorly-sorted (none of the thin sections were well-sorted); and grains are rounded to subrounded (if only quartz grains are considered, they range from rounded to angular grains). The irregular and punctual contacts predominate in litharenites. Brecciated zones are also observed.

Six different types of cement were identified: 1) iron-oxide cement that occurs disseminated or forming films and halos around the grains; 2) clay-carbonate cement; 3) fringe- calcite cement surrounding grains; 4) spathic calcite cement forming macrocrystalline to microcrystalline mosaics; 5) opal cement coating some grains and filling fractures; and 6) silica cement. The calcite cement has undergone partial dolomitization as observed in some thin sections. The matrix is present in the form of micrite and clastic matrix. These samples come from the Ribeirão Boiadeiro Group.

Limestones: Four thin sections (111 A, 86, 631-2, 630-1) were described for hybrid rocks between limestone and sandstone (Figure 6). From 60% to 99% of the content on thin sections consists of the binding phase whose distribution occurs between 55% to 5% of sparite, 70% to 15% of microsparite, and 70% to 17% of micrite.

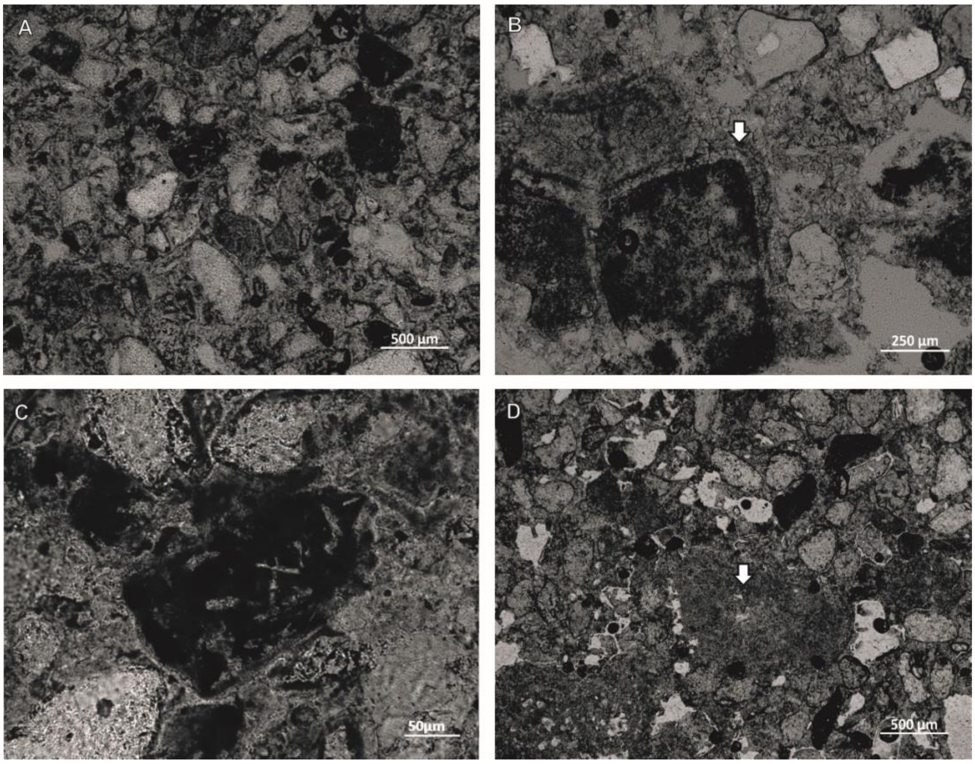


Figure 5 - (A) framework formed by lithoclasts and mineraloclasts, grains coated by iron oxide and spathic calcite cement filling pores, parallel polarizers, objective lens of 5x. (B) lithoclasts surrounded by envelopes of clay-carbonate cement (arrow), parallel polarizers, objective lens of 10x. (C) Lithoclasts of volcanic rock coated with iron oxide, parallel polarizers, objective lens of 40x. (D) Tuff fragment (arrow), surrounded by fringe calcite cement and mosaic spathic calcite cement, parallel polarizers, objective lens of 5x.

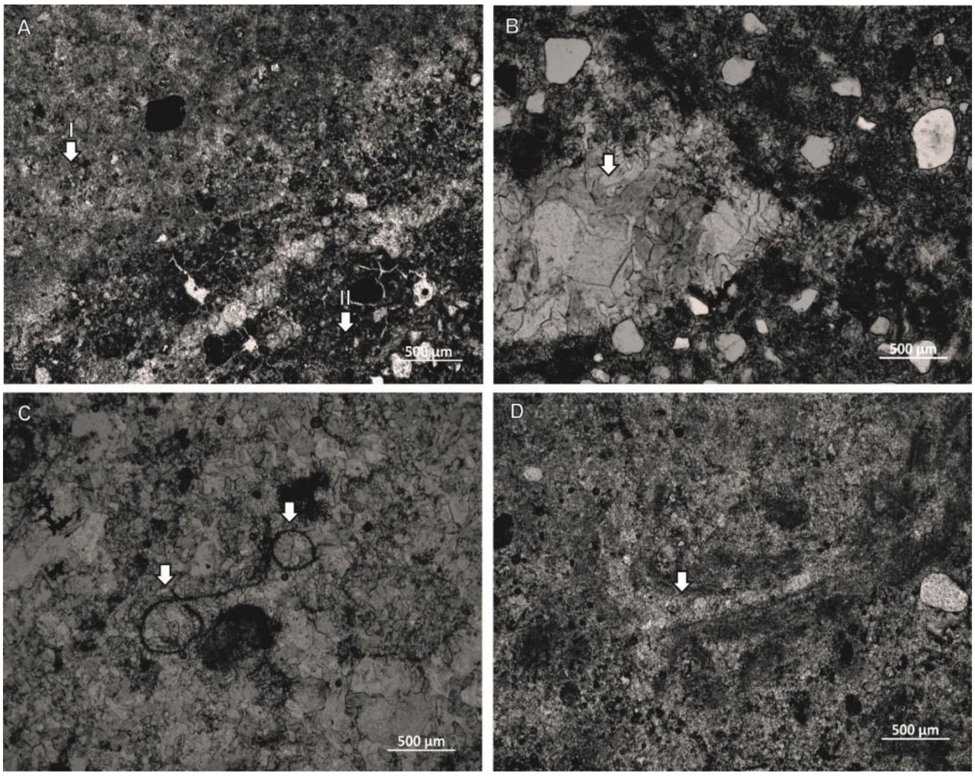


Figure 6 - Microphotographs taken at parallel polarizers, objective lens of 5x. (A) Carbonate brecciation exhibiting two different compositions: I) Carbonate with micritic matrix, binding phase between calcite and spathic calcite; II) brecciated horizon containing siliciclastic lithoclasts cemented by iron oxide. (B) Carbonate filling thin fractures as a result of displacive growth. (C) Paleosol showing well developed calcrete and almost wholly substitution of the rock by carbonate as well as root marks (white arrows) in vertical section. (D) Biogenic structure (arrow, bacteria colony) developed in a calcrete section in the paleosol.

Here, micrite is clearly a depositional phase that exhibits circum-granular cracks, nodules, dark micrite and organic matter with irregular porosity. In addition to variations in the degree of crystallinity of the carbonate cement, there is also silica cement surrounding grains or filling fractures (quartz or opal), and iron-oxide cement. Finally, the binding phase also presents (a) biogenic reliquary structures such as circular cross-sections, (b) fractures filled with fine- to very fine-grained sandstone (consisting of quartz, phyllite, volcanic rock fragments, opaque and perthite) and (c) envelopes of prismatic calcite surrounding some grains.

The grains make up less than 40% of the rocks. They are essentially terrigenous consisting of quartz, chert, rutilated quartz, undulatory quartz, polycrystalline quartz, quartz with inclusions of chlorite, opaque minerals, siltstones, quartzite and volcanic rock fragments. The grains are rounded to subrounded, vary from 0.05 to 7 mm in size, and are distributed heterogeneously. Quartz dissolution is observed at the edges of grains.

Chert: A single thin section (633-2) of chert (Figure 7) was described in which four generations of cement totally replace the pre-existing rock: 1) chalcedony cement with crypto- and microcrystalline crystals make up most part of the rock thin section; 2) micro- and mesocrystalline prismatic quartz cement filling pores; 3) iron-oxide cement that occurs coating the grains or disseminated around the prismatic quartz cement; and 4) pore-filling macro-crystalline quartz cement. The rock thin section exhibits vugs highlighted by discontinuities and sharp boundaries, some pores are unfilled. The rock sample was collected in the region of Branco Hill and belongs to the Cambambe Formation.

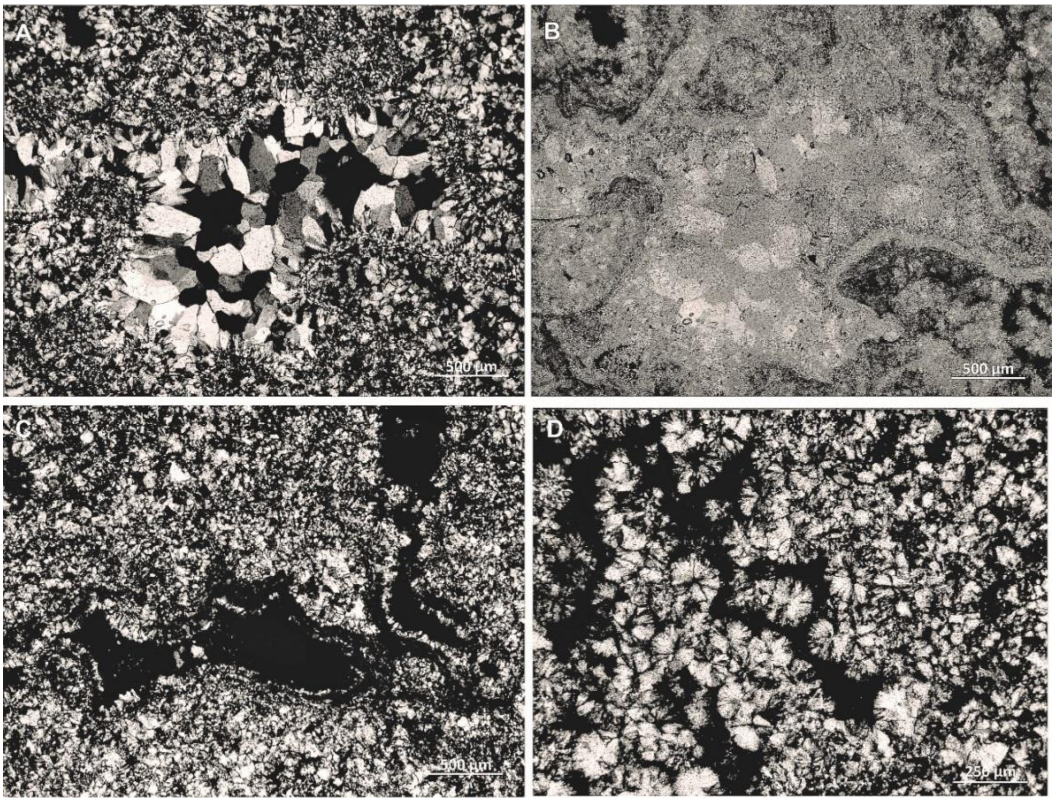


Figure 7 - (A) Giant pores filled with prismatic fringe quartz cement along the pore borders while macrocrystalline quartz fills inside pores, crossed polarizers, objective lens of 5x. (B) Giant pores filled with quartz cement, parallel polarizers, objective lens of 5x. (C) Iron oxide cement coating giant pores, parallel polarizers, objective lens of 5x. (D) Detail of chalcedony cement, crossed polarizers, objective lens of 10x.

DISCUSSION

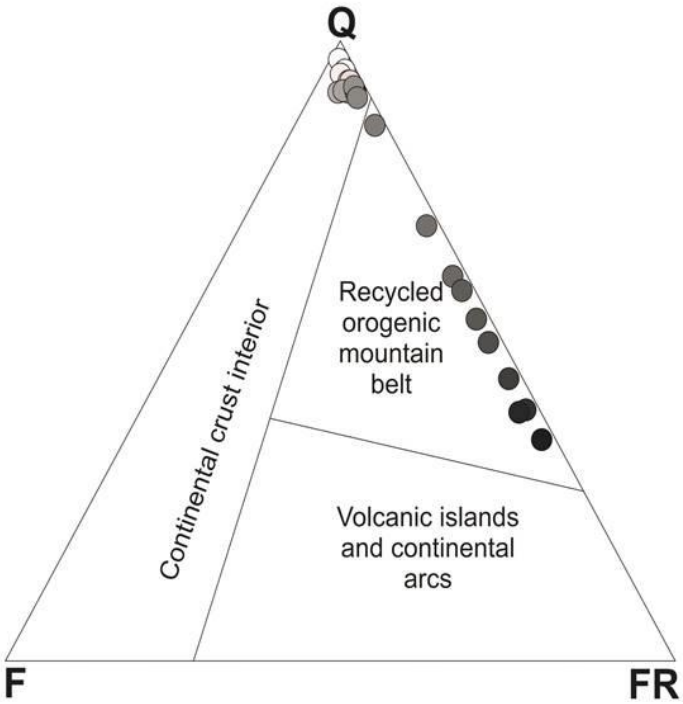
The description of rock thin sections has unraveled some of the processes that led to the deposition (Figure 8) and diagenesis (Table 2) of rocks of the Ribeirão Boiadeiro Group and the Cambambe Formation as described below.

Petrography of the Ribeirão Boiadeiro Group

The litharenite is virtually composed of mineraloclasts, which suggests rapid deposition in a tectonically active environment (Figure 9). The presence of unstable minerals (e.g., albite)

Table 2 - Cementation phases of the Cambambe Basin

Cement type	Eodiagenesis	Mesodiagenesis	Telodiagenesis
Clay-carbonate	X		
Clay-ferruginous	X		
Iron oxide	X		
Chalcedony	X		
Prismatic quartz	X		
Micro and macro crystalline quartz		X	
Fringe calcite	X		
Sphatic calcite		X	
Opal			X



sections	quartz	lithoclasts
53	1	99
M 49	1	99
103 - B	2	98
106	2	98
119 - A	3	97
124 - A	4	96
24 - A	4	96
119 B	4	96
86 - A	4	96
92	4	96
114 - A	4,5	95,5
85	4,5	95,5
633 - 3	11	89
49 - 29	35	65
631 - 3	41	59
632 - 1	42	58
631-1	45	55
633-1	49	51
103 - C	55	45
SN-1	60	40
115 A	60	40
103-A	65	35

Figure 8 - Classification of rock thin sections according to the tectonic environment of Dickinson & Suczek (1979).

in the fabric indicates that these rocks were rapidly deposited as well as that the processes and percolating fluids present during diagenesis have not influenced the mineral composition of grains. The phyllite clasts point out to a metamorphic source area linked to the Cuiabá Group. The presence of perthite grains and volcanic fragments (such as tuffs and ignimbrites) may indicate an igneous-related source area. However, there are no nearby volcanic sources to confirm this assumption. These grains prove instead that this unit is penecontemporaneous with the volcanism of 84 Ma. Tourmaline grains are among the ultrastable minerals commonly found in polycyclic sedimentary rocks.

The parameters analyzed to understand the textural maturity (i.e., matrix content, sorting and roundness) show that the litharenite maturity is not compatible with a simple evolutionary path. In this analysis, moderate to poorly-sorted grains would be an indication of submature sandstones (cf. Folk, 1968). Roundness, on the other hand, has pointed to supermature sandstones. This incongruence has been referred to as textural inversion and its occurrence is attributed to different possibilities (cf. Folk, 1968). In the study area, the reason for textural inversion was the incorporation of more-rounded (and older) and polycyclic extraclasts reworked in the depositional environment since the source area of the litharenite would come from the Cuiabá Group and Botucatu Formation as well as from cherts and sandstones.

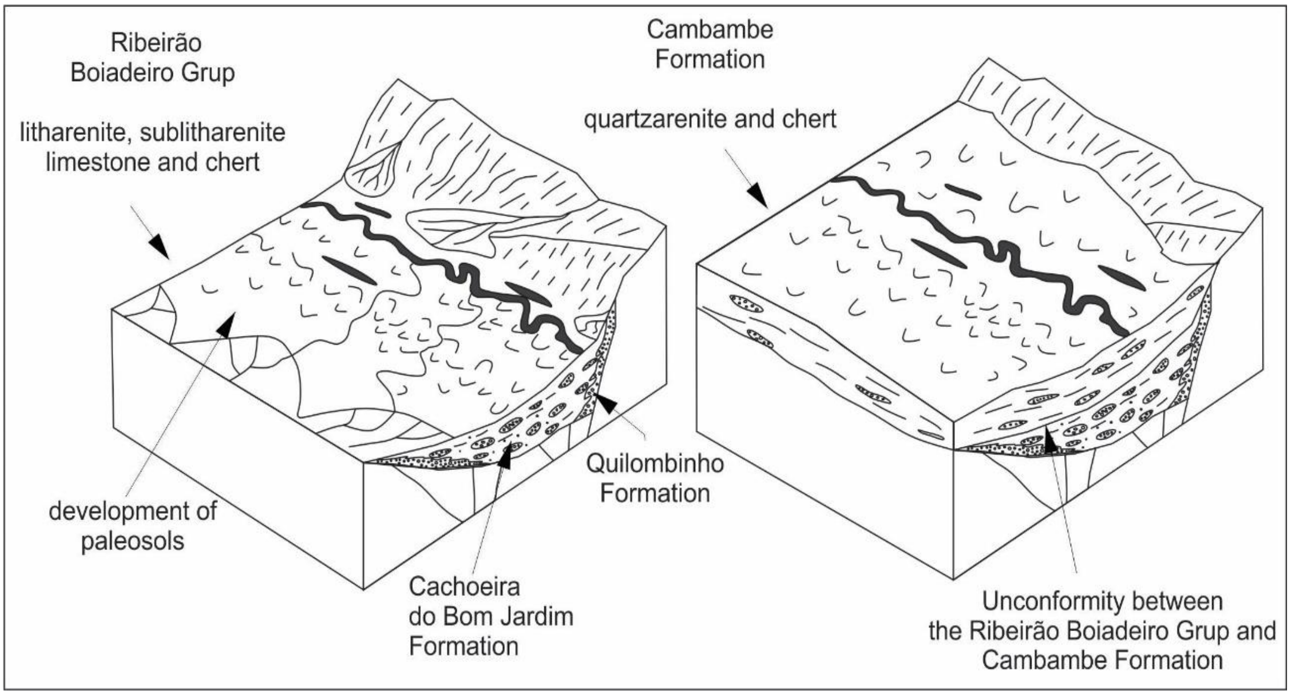


Figure 9 - Depositional and petrographical model of the Cambambe Basin.

Most rounded to subrounded grains are likely inherited from a source area in which particles have undergone several sedimentary cycles as suggested above and by Williams et al. (1970). Therefore, it is suggested that about 60% of these grains are derived from the erosion of the Paraná Basin given the fact this is the polycyclic tectonic province that overlies with unconformity the Cambambe basin in its southern portion.

The other sources suggested for these sediments are the igneous rocks of the Paredão Grande Formation, which provided tuff and ignimbrite clasts. The metamorphic mineraloclasts, in turn, are probably derived from rocks of the Cuiabá Group, the regional basement whose contact with the Cambambe Basin defines a discordance on the west and north boundaries. The common irregular and punctual contacts among grains reinforce the idea of rapid deposition and corroborate that there was no time for significant compaction.

The existing matrix demonstrates a relationship either with the development of paleosols or with the deposition in a shallow environment. That is the reason why root marks found in carbonates, filled cracks, and biogenic structures are some of the elements that indicate different stages of a paleosol series. The environment was probably dry due to intense evaporation and partial pressure change of CO_2 leading $CaCO_3$ to accumulate in soils of drier regions (Batezelli et al., 2005).

During this eodiagenetic regime, iron oxide cement was still the infilling of cracks formed during the dry period. Calcite cement present in the form of spathic calcite (with variable crystallinity) and micrite calcite allow suggesting that paleosols underwent different degrees of recrystallization during eodiagenesis (or better, pedogenesis). This process developed through cementation and substitution in saturated $CaCO_3$ solutions (Goudie, 1973).

The poikilotopic texture described for part of the calcite cement existing in paleosols is also observed in the litharenites as well as in the quartzarenites of the Cambambe Basin. Batezelli et al. (2005) have suggested a relationship between cementation and mesodiagenesis. Ribeiro (2001) proposes that calcite results from the rapid precipitation of supersaturated solutions.

Cement of iron oxide, claycarbonate, fringed calcite, and spathic calcite may have originated from rock fragment dissolution (Stradioto et al., 2008), and release of Fe and Ca ions into the formation water. The clay-carbonate cement is related to the initial moments of burial when clay infiltrated among the grains through percolating fluids.

This idea is consistent with the presence of fringe calcite cement, which is characteristic of an eodiagenetic environment, under vadose and even subaerial conditions, where air and water still coexist in the pores of newly deposited sediments (e.g. Flügel, 1982).

The variable crystalline forms of these different stages of cementation occurred due to changes in temperature and water saturation as a function of burial depth. Bjorlykke & Egberg (1993) demonstrate that the solubility of silica is strongly controlled by temperature. Friedmann & Sanders (1978) associate the increase of silica solubility with pH variation. In this way, the variation in cement types may be related to changes in temperature and pH conditions of the formation water during burial.

The silica cement present in the litharenites are related to processes that occurred during telodiagenesis, which resulted in the filling of fractures caused by lithostatic pressure relief during uplift phases.

This is the most recent phase of the basin that probably originated as a consequence of the formation of the Pantanal Basin, which led the region of Chapada dos Guimarães to resemble an abutment (or even a buttress) (e.g., Ussami et al., 1999).

The chert mostly consists of chalcedony cement which is probably a result from replacement and dissolution of grains and matrix of a pre-existing limestone. The large pores indicate that this rock has been exposed in the vadose zone.

The first fluid to percolate through the pores during eodiagenesis was saturated with iron oxide and silica giving rise to iron-oxide cement coatings.

Later, the interaction among time, pressure, pH, temperature and the availability of silica in the environment has generated prismatic quartz and macrocrystalline quartz cement. In some interstices between grains, these cement phases have not formed since there was no percolation of fluids rich in that specific composition amongst pores. We can hence affirm that, at a certain point in its evolution, the Ribeirão Boiadeiro Group has experienced a condition of reduced permeability.

Petrography of the Cambambe Formation

The change from litharenite to quartzarenite unravels tectonic changes in the behavior of the basin whose meaning expresses a significant time lapse between the deposition of the first and second unit.

The fabric contains ultrastable minerals and lithoclasts from metamorphic and sedimentary rocks. The existence of albite and microcline indicates both the probable contribution of igneous sources and dry and warm climatic conditions that would have favored physical weathering.

The predominant amount of punctual and sutured contacts indicates that sorting has taken place during transport and deposition. The increase in the degree of roundness (here, rounded to well-rounded grains predominate) relative to litharenites indicates a higher contribution of polycyclic rocks (Williams et al., 1970), that is, rocks of the Paraná Basin.

The different generations of cement and their cutting and overlapping relationships show that cementation has happened intensely during eodiagenesis, which explains the greater amount of cement ascribed to this phase. This may imply that these rocks have not undergone deep burial. The chalcedony cement is here attributed to the vadose environment because of the partial cementation featuring on only one side of grains (gravitational cement). The source of silica is unknown.

Fringe calcite cement is also typical of vadose zones according to Flüglel (1982). Spathic calcite, on the other hand, is associated with deeper zones. Both of them were observed in thin section and their presence suggests either an evolution from vadose to the phreatic zone or progressive burial of the basin.

The third stage of cementation is represented by recrystallization of silica cement into micro- and macrocrystalline quartz crystals. These different types of cement occur due to temperature (Bjorlykke & Egberg, 1993) and Ph (Friedmann & Sanders, 1998) changes. Owing to such variations, partial replacement of chalcedony cement by the micro- and macrocrystalline quartz occurs. These changes probably happened because of burial. The last stage of cementation consists of opal filling fractures during telodiagenesis.

The two cementation phases observed in sublitharenites represent two different moments. The clay-carbonate cement was formed during eodiagenesis in the vadose zone. Mechanical infiltration of clay may have occurred during episodic floods in which waters carry large amounts of suspended load that are later absorbed by pores because of the very dry climate (Walker et al., 1978 in Batezelli et al., 2005).

CONCLUSIONS

The petrographic analysis carried out on rocks of the Cambambe Basin allows us to draw the following conclusions:

The textural characteristics of rocks of the Ribeirão Boiadeiro Group demonstrate tectonics played a major role at the beginning of the Cambambe Basin deposition. Carbonates are also an evidence of relatively tectonic quiescence that allowed the development of paleosols.

Textural differences between sediments of the Ribeirão Boiadeiro Group and Cambambe Formation reveals the existence of a discordance related to tectonic uplift and a significant period of non-deposition and erosion that resulted in textural changes among sediments of the Cambambe basin. The predominant amount of cement phases related to eodiagenesis in the Cambambe Formation shows that sediments have not undergone deep burial. Grain-size and textural variations also show the role of the Paraná Basin as a sediment source area since some of these characteristics are clearly inherited.

Finally, the data here presented has contributed to the characterization of rocks from the Ribeirão Boiadeiro Group and Cambambe Formation, which allows us to elucidate some of the processes that have influenced deposition and diagenesis in the Cambambe Basin.

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