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Sedimentation of the Cretaceous Bauru Group in São Paulo, Paraná Basin, Brazil

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ABSTRACT

The post-basaltic sediments of the Cretaceous Bauru Group in the Paraná Basin cover an area of 117,000 km^2 in São Paulo State, and are subdivided into the Caiuá, Pirapozinho, Santo Anastácio, Birigüi, Araçatuba, Adamantina and Marília formations. The sedimentation of Bauru Group was controlled by a combination of post-basaltic tectonism (responsible for the migration of the depocenters), erosion and climatic changes. Three main depositional phases are separated by two erosive/non-depositional phases defining depositional sequences. The fluvial-lacustrine deposition represented by the Caiuá/Pirapozinho formations (first sequence), initially filled the basaltic substratum troughs. After an erosional interval, the Santo Anastácio Formation was deposited and overlapped (eastward) underlying beds (second sequence). Renewed erosion and tectonism initiated the last depositional sequence, with the migration of the depocenter to the Queiroz depression. High topographic gradients initially favored the accumulation of fluvial deposits of braided systems of the Birigüi Formation. With the enlarging of the depositional area, a lacustrine system was formed (Araçatuba Formation) and overlapped by a fluvial system with progradation of lacustrine deltas (Adamantina Formation). The sedimentation of the Bauru Group ceased with deposition of marginal fans of Marília Formation.

ARTICLE INFO

Palavras-chave:
Grupo bauru
Sedimentação
Sistema deposicional
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RESUMO

Os sedimentos cretáceos suprabasálticos da Bacia do Paraná, reunidos no Grupo Bauru, ocupam área de 117.000 km^2 no Estado de São Paulo, sendo subdivididos nas formações Caiuá, Pirapozinho, Santo Anastácio, Birigüi, Araçatuba, Adamantina e Marília. Essas unidades encontram-se enfeixadas por superfícies de discordância regionais; sua sedimentação foi controlada pela combinação de tectonismo pós-basáltico (responsável pela migração dos depocentros), processos erosivos e mudanças climáticas. Três fases deposicionais principais, separadas por superfícies erosivas/não-deposicionais regionais marcaram a sedimentação do Grupo Bauru, definindo três seqüências deposicionais. A deposição flúvio-lacustre, representada pelas formações Caiuá/Pirapozinho (primeira seqüência), preencheu inicialmente calhas deprimidas do substrato basáltico. Após ciclo erosivo, a sedimentação foi retomada pela Formação Santo Anastácio que ampliou o sítio deposicional, avançando na direção leste (segunda seqüência). Após novo ciclo erosivo e rearranjo tectônico da bacia, teve início a deposição da seqüência mais jovem, com a migração do depocentro para a Depressão de Queiroz. Gradientes topográficos elevados favoreceram, inicialmente, a acumulação de depósitos fluviais de sistemas entrelaçados da Formação Birigüi. Com a ampliação da área deposicional, instalou-se sistema lacustre (Formação Araçatuba), recoberto pelo avanço de sistema fluvial meandrante marginal com progradação de deltas lacustres (Formação Adamantina). A sedimentação do Grupo Bauru se encerra com a deposição dos leques marginais da Formação Marília.

1. Introduction

The last significant sedimentation episode of the Paraná Basin, a large intracratonic basin in the central-south portion of the South American Platform, with about 7,000 m of sedimentary and volca-

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nic rocks, is the predominantly siliciclastic continental sequence of the Bauru Group. This Cretaceous unit is limited by regional unconformities and called Bauru Supersequence by Milani (1997). The basal unconformity separates the Bauru deposits from the Gondwanic successions of the Paraná Basin, and the upper unconformity corresponds to the South American geomorphological surface (King, 1956) separating the Cenozoic layers deposited above.

The Bauru Group sediments are distributed over approximately 370,000 km^2 of Brazilian territory (Fig. 1), covering western Minas Gerais, northwestern Paraná, southeastern Mato Grosso do Sul, southwestern Goiás and central-western São Paulo states. These deposits have maximum preserved thickness slightly larger than 300 m and average around 100 m. Most are fine- to coarse-grained sandstones, slightly to highly clayey, sparsely conglomeratic, and have variable content of calcite cements. There are also some intercalations of siltstones, shales, mudstones and sandy limestones (DAEE, 1976). Small bodies of analcimite rocks (less than 30 m), intercalated in the upper portion of the unit in São Paulo State, represent contemporary alkaline volcanic activity (Coimbra et al., 1981).

The substratum of the Bauru Group is formed mainly of volcanic rocks of the Serra Geral Formation, and locally some aeolian sediments of the Pirambóia and Botucatu formations, all of which belong to the São Bento Group (Suguio et al., 1977; Paula e Silva and Cavaguti, 1994). The depocenter of Pirambóia and Botucatu formations occupies the same position as the greatest thicknesses of lavas of the Serra Geral Formation. The limits of Bauru deposition were controlled by tectonic elements, that largely influenced the geometry of the sedimentary deposits; for example the Rondonópolis high to the northwest (Coimbra, 1991), the Paranaíba high to the northeast (Hasui and Haralyi, 1991), the Serra do Mar mountains to the east (Almeida, 1976), the Ponta Grossa arch to the southeast and the Piqueri River lineament to the southwest (Ferreira, 1982; Riccomini, 1997) (Fig. 1).

The age of the Bauru Group is still a controversial subject, due to the shortage of paleontological data of chronostratigraphic value. According to Freitas (1973), Soares et al. (1980), Fúlfaro and Barcelos (1993) and Dias-Brito et al. (2001), the lower limit of the Bauru unit should be placed in the Early to Middle Cretaceous and its upper limit in the Late Cretaceous. Many authors suggest a Late Cretaceous age for the unit (Fernandes and Coimbra, 1994, 1996; Gobbo and Petri, 1999), based on vertebrate fossils content (Huene, 1939 *apud* Fernandes, 1998) and on the minimum age of volcanic alkaline rocks (around 61 Ma) intercalated in the sedimentary rock succession. The deposition of these Cretaceous deposits may be correlated to the evolution stages of the Santos Basin, at the Brazilian Atlantic margin (Pereira et al., 1986).

In São Paulo State (Fig. 1), the Bauru Group covers an area of approximately 117,000 km^2 and comprises the Caiuá, Pirapozinho, Santo Anastácio, Birigüi, Araçatuba, Adamantina and Marília formations. These lithostratigraphic units were recently proposed by Paula e Silva (2003) and Paula e Silva et al. (2003, 2005) (Fig. 2), based on subsurface data, mainly from well logs and cuttings data, and are broadly similar to that of Soares et al. (1980). These lithostratigraphic units are bounded by two regional unconformity surfaces: surface S1 separates the underlying sediments of the Caiuá and Pirapozinho formations from the overlying deposits of the Santo Anastácio Formation; unconformity surface S2 separates the Santo Anastácio Formation below and the Birigüi, Araçatuba and Adamantina formations above (Fig. 3). Subsurface alkaline rocks called Taiúva Analcimites by Coimbra et al. (1981) are interbedded with sandstones of the Adamantina Formation, in a small area in the northeastern portion of the study area, close to Jaboticabal (Figs. 1 and 2).

The substratum of the Bauru sediments in São Paulo State is represented mainly by volcanic rocks of the Serra Geral Formation, and dips regionally westward to the Paraná River valley. Dips are steeper close to the outcrop area and gentler away from it.

Bauru deposits are separated into internal depressions and highs inherited from the basaltic substratum, which influenced the migration of the depocenters (Paula e Silva, 2003). Erosion on both regional and local scales, which is largely influenced by climatic conditions, dictated the preservation of a large amount of sediments deposited in the basin. Superimposed deformational events (uplift and subsidence) related to neotectonic processes (Riccomini, 1997) largely modified the volcanic substratum after the deposition of the entire unit. The interpretations presented in this paper are based mainly on geophysical logs and data extracted from water wells (Fig. 4).

2. Structural configuration of the substratum of the Bauru Group

The accommodation space of the Bauru Group developed over a time span of some 40 Ma, since the cessation of the Serra Geral magmatism, by a combination of continuous thermal subsidence (Fernandes et al., 1993) and marginal uplift of the basin (Rondonópolis high to the northwest; Paranaíba high to the northeast; Serra do Mar mountains to the east; Ponta Grossa arch to the southeast). The largest preserved thicknesses of the Bauru Group and its most complete stratigraphic section are located in the southwest region of São Paulo State. Here too is the largest thickness of Serra Geral lavas, suggesting a genetic link between this deposition and the crustal thinning related to the basaltic plateau in the central region of the Paraná Basin (Zalán et al., 1990).

The basement configuration of the Bauru Group in São Paulo State mainly represents the morphologic expression of the basaltic substratum, modeled by the combined action of erosive and tectonic processes during the Early Cretaceous. Frangipani (1964, *apud* Vieira, 1981) argued that both structural and morphological landforms were present and considered that the aspects presented by the surface of the basalts derived from both. Zalán et al. (1990) considered that the most common events were erosive in response to uplift at the basin borders, although the eroded thickness of the Serra Geral Formation is unknown.

From a structural point of view, the linear tectonic elements of the Paraná Basin are oriented along three main trends: NW–SE, NE–SW and E–W. The first two represent ancient weakness zones in the crystalline basement that controlled the entire sedimentation of the Paraná Basin. These old structures were responsible for the control of the depocenters and intrabasin highs in the Paraná basin (Zalán et al., 1987, 1990). Reactivation of these ancient structural directions associated with the rifting process of the Santos Basin, would have caused the compartmentalization of the northern area of the Paraná Basin, chiefly in São Paulo State, forming a depressed region in the area of Pontal do Paranapanema (Presidente Bernardes depression), where the initial deposition of the Bauru Group took place.

The relief on the Bauru-Serra Geral contact has been mapped mainly from ground water studies (Arid, 1966; Mezzalira, 1974; Suguio et al., 1977; Brandt Neto et al., 1978; Barcha, 1980, 1985; Paula e Silva, 2003). Irregularities on this contact surface are attributed to differential resistance to erosion or tectonic causes. Barcha (1980, 1985) emphasized the presence of a 2-m-thick breccia of basaltic fragments just below the deposits of the Bauru Group.

The configuration of the basaltic substratum in São Paulo State (Fig. 5) shows a compartmentalized basin with internal highs and depressions. There are two main depocenters striking NE–SW (dip-

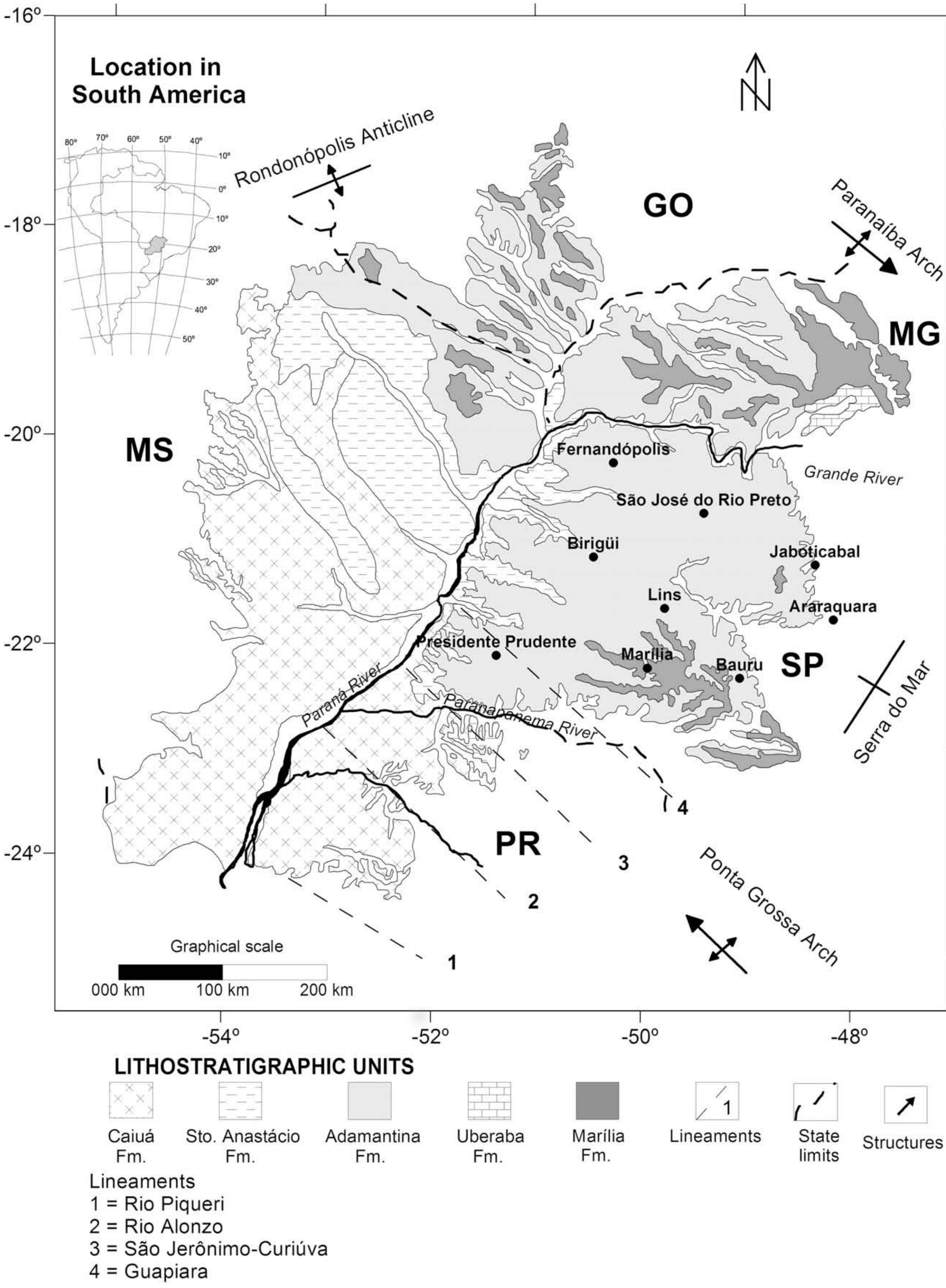

Fig. 1. Distribution of the lithostratigraphic units and main structural-control elements on Bauru Group deposition in the Paraná Basin. Linear structures: 1, Piqueri River Lineament; 2, Alonzo River Lineament; 3, São Jerônimo-Curiúva Lineament; 4, Guapiara Lineament. GO, Goiás; MG, Minas Gerais; MS, Mato Grosso do Sul; PR, Paraná; SP, São Paulo states. Unadorned area is the São Bento Group substratum.

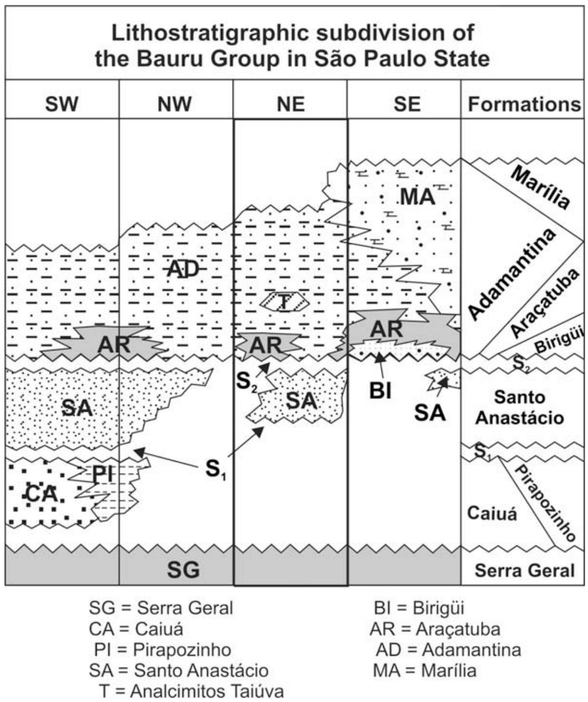

Fig. 2. Stratigraphic relationships between the suprabasaltic Cretaceous formations in the different compartments of the Bauru Group in São Paulo State (modified from Paula e Silva (2003)). S1 and S2: regional unconformity surfaces.

ping SW). These depressions are separated by a structural high, also striking NE–SW (also dipping SW), and another one stiking NW–SE (dipping NW); they clearly show the importance of the tectonic elements noted by Zalán et al. (1987, 1990) in controlling the structural framework of Bauru deposition. The principal structures identified were the Presidente Bernardes, Dracena, Sud Menucci, Queiroz and Rio Preto depressions and the internal highs of Tanabi, Pereira Barreto and Paraguaçu Paulista (Paula e Silva, 2003; Paula e Silva et al., 2005) (Fig. 5), which suggest the greater influence of the northeastern trends in relation to the northwestern trends.

2.1. Presidente Bernardes depression

The Presidente Bernardes depression (Fig. 5) forms a roughly circular trough, limited by the Paraná River to the west, the extension of the Guapiara lineament to the north and the São Jerônimo-Curiúva lineament to the south. This trough accommodates a sedimentary succession over 270 m thick (Paula e Silva et al., 1994, 1999). Based on field mapping, Santoro and Massoli (1985) suggested that in this region the basalt surface has a synclinal form with a NE–SW axis.

2.2. Dracena depression

The Dracena depression forms an oval trough with long axis in NW direction. It is located in a polygon composed of the Peixe, Aguapeí and Paraná rivers and is separated from the Presidente Bernardes depression by the extension of the Paraguaçu Paulista high (Fig. 5). All the wells drilled in this depression reached the basalt at depths greater than 260 m.

2.3. Sud Menucci depression

The Sud Menucci depression also forms an elongated trough with its longer axis in the NE direction, integrating the regional structural low along with the Presidente Bernardes and Dracena depressions (Fig. 5). It is limited to the north by the uplift of the basaltic surface near the Grande River, to the south by the Dracena depression, to the west by the Pereira Barreto high, and to the east by the Tanabi high. Compared to adjacent depressions, it occupies the most elevated structural position. This structure was mentioned in the work of DAEE (1976) and Santoro and Massoli (1985).

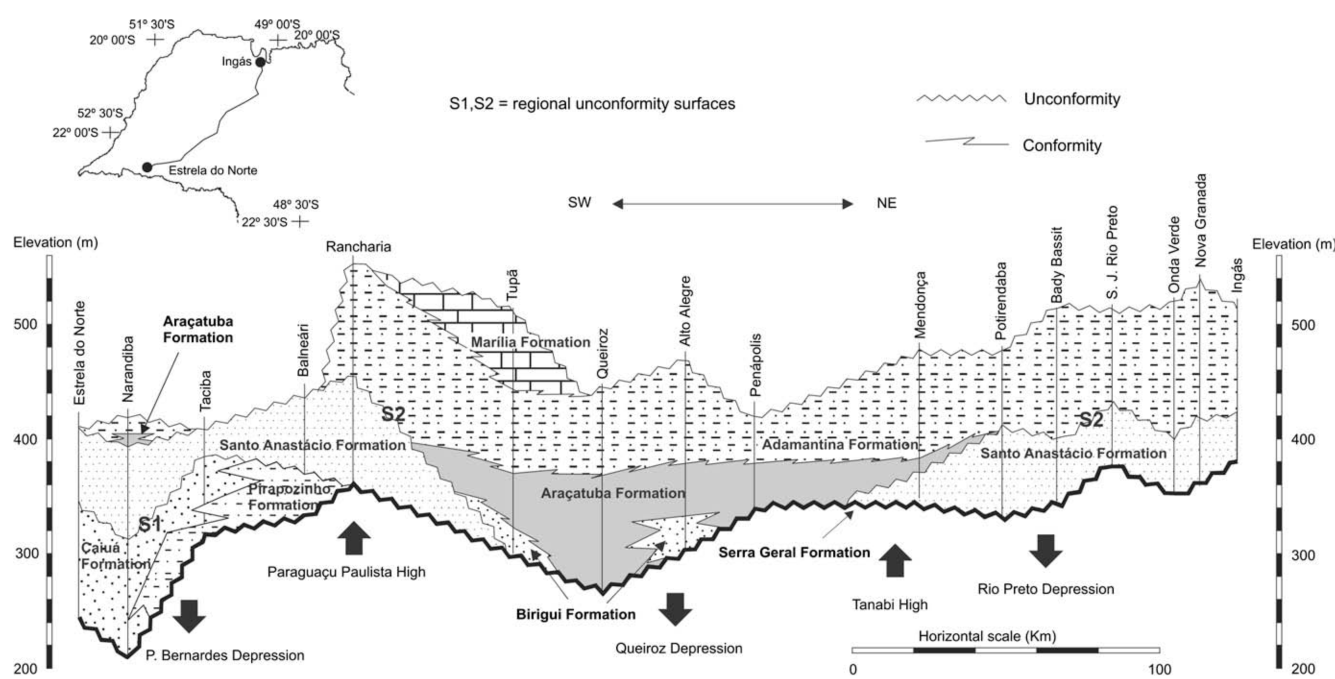

Fig. 3. Regional NW–SE cross-section through the Bauru Group in the São Paulo State.

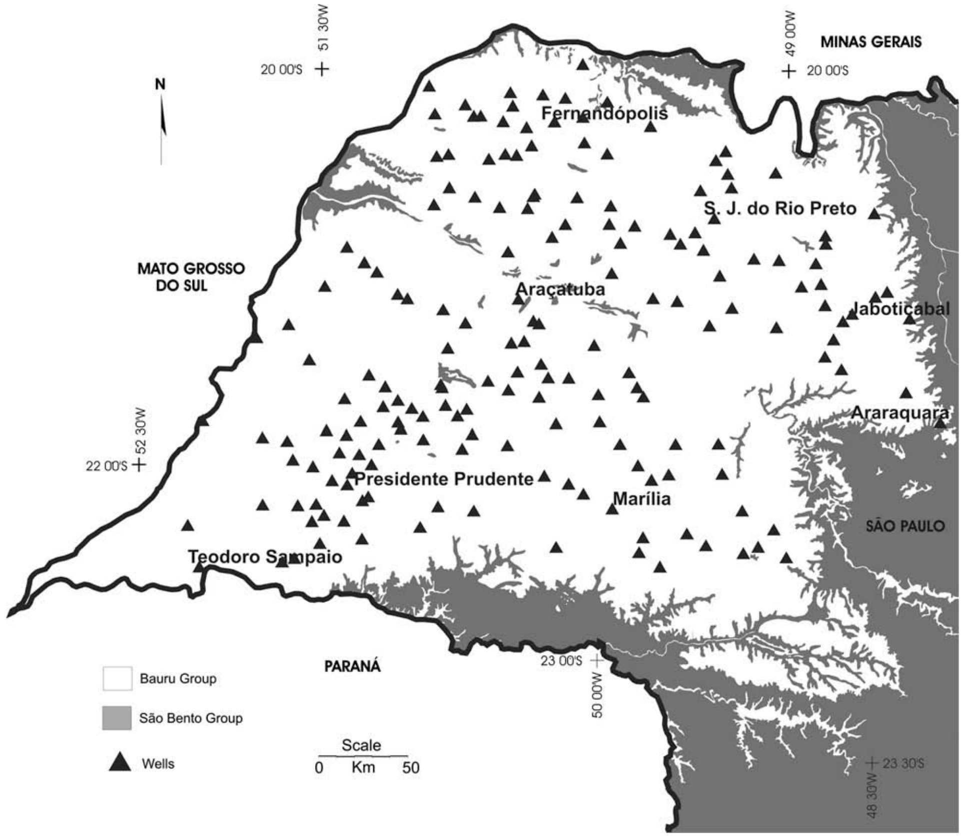

Fig. 4. Location map of wells in São Paulo State.

2.4. Rio Preto depression

The Rio Preto depression was mentioned by Santoro and Massoli (1985) and Campos et al. (1992). It constitutes a NNE trough dipping SSW, limited to the north by the basalt uplift in the region of Grande River, to the west by the Tanabi high, to the east by the rise in volcanic substratum and to the south by the Queiroz depression, close to the Tietê River valley (Fig. 5). The Santo Anastácio Formation deposits are preserved in this depression, isolated from their main area of occurrence by the Tanabi high.

2.5. Queiroz depression

The Queiroz depression forms a NE–SW trough, with the axis located almost in the central part of the occurrence area of the Bauru sediments in São Paulo State. This trough corresponds to the southern extension of the Rio Preto depression (Fig. 5). It is limited to the north by the Tietê River valley, to the south by the Paraguaçu Paulista high, to the west by the Tanabi high extension and to the east by the basaltic substratum uplift. Santoro and Massoli (1985) described this depression as an elongated structural low with a NE–SW axis. Fernandes (1998) referred to this structure as a depressed zone where the totality of the Araçatuba Formation was accumulated. According to Paula e Silva (2003), this was the main depocenter of Araçatuba Formation and can be correlated to other lacustrine deposits in the basin.

2.6. Pereira Barreto high

The Pereira Barreto high is a structure on the west bordering the Sud Menucci depression; it is disposed parallel to the Paraná River in the northwestern region of the São Paulo State (Fig. 5). It has a NE–SW longitudinal axis and dips to the SW. It was recognized by DAEE (1976) as "a structural high alongside the Paraná River". Santoro and Massoli (1985) informally designated this prominent feature as Andradina high. Due to its location and elevated position in relation to the Sud Menucci depression, it could have constituted a geographic barrier during the deposition of the Caiuá and Santo Anastácio formations (Paula e Silva, 2003).

2.7. Tanabi high

The Tanabi high represents a prominent structural feature in the basaltic basement topography, which separates the Rio Preto depression to the east and the Sud Menucci depression to the west (Fig. 5). It emerges on the northern Grande River valley and continues in a NE–SW orientation with a SW dipping direction until crossing the Tietê River. It was first mentioned by DAEE (1976) as the Tanabi-Votuporanga high; by Santoro and Massoli (1985) as the Bálsamo high. Barcha (1985) recognized this structure as responsible for the non-deposition of the Santo Anastácio Formation in the vicinities.

2.8. Paraguaçu Paulista high

The Paraguaçu Paulista high is the only NW–SE prominent structural feature of the basaltic substratum in São Paulo State territory (Fig. 5). Its southern limit is the Paranapanema River and dips to the NW, in the direction of the Paraná River. Its northwestern extension was probably responsible for the individualization of the Presidente Bernardes depression to the south and the Dracena depression to the north, prior to the pre-Bauru erosional surface. This structural feature is genetically linked to the Guapiara fault zone, constituting its northwest end portion. The Guapiara, São Jerônimo – Curiúva, Alonzo River, and Piqueri River lineaments

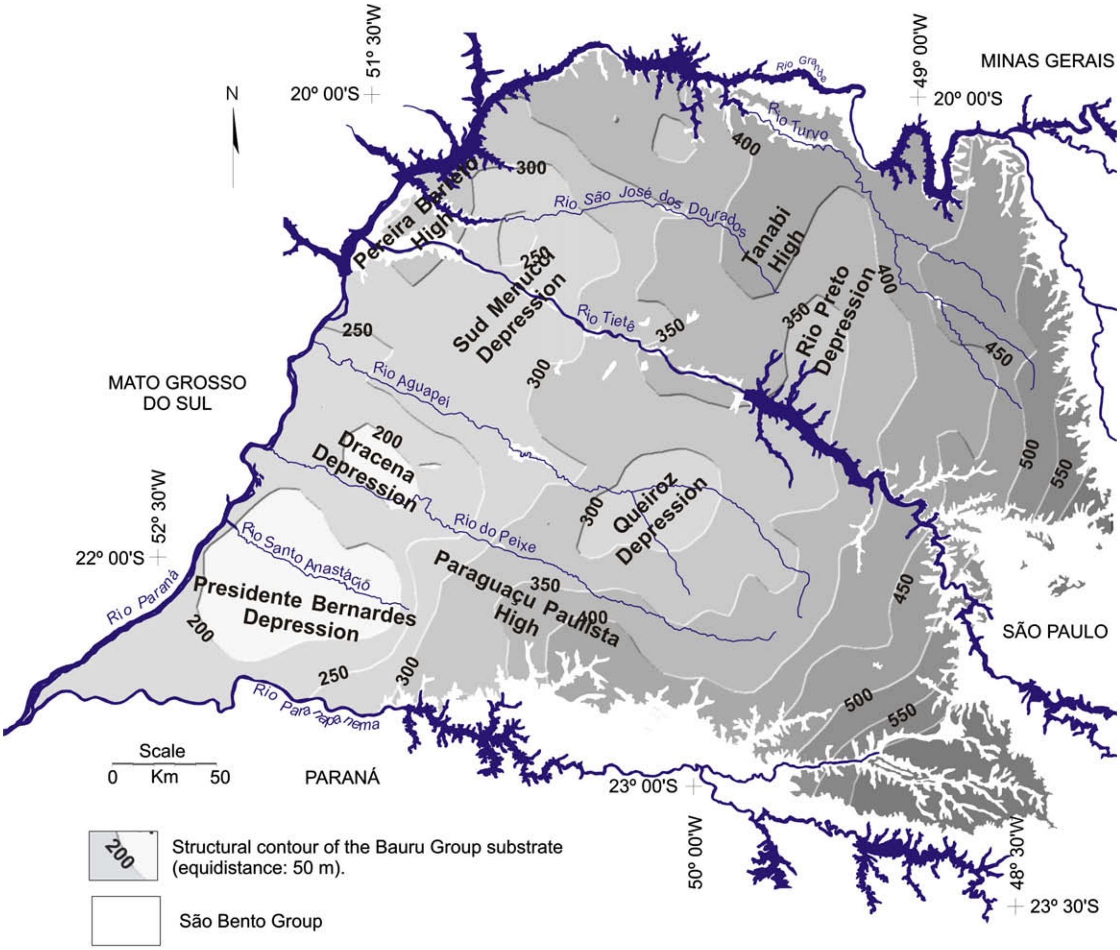

Fig. 5. Current configuration of the basaltic substratum of the Bauru Group in São Paulo State (modified from Paula e Silva (2003)). Dark areas are dams.

were identified by Ferreira (1982), using aeromagnetic data. Ferreira (1982), Zalán et al. (1987, 1990) and Milani (1997) considered that these deep structural features of NW–SE trend are responsible for the Serra Geral lava flow, the alkaline magmatism and the generation of minor structures in the Paraná Basin.

3. Sedimentation of Bauru Group

The Bauru Group sedimentation took place after the most remarkable tectonic phase of the Paraná Basin evolution, when an enormous volume of basaltic lava covered almost its entire area, as a consequence of the Gondwana break-up and the opening of the South Atlantic Ocean during the Jurassic–Cretaceous (Zalán et al., 1990). The igneous events occurred between 137 and 127 Ma (Turner et al., 1994), leaving a very thick pile of basalt flows and an intricate net of dikes and sills. This tectonic mega-event reactivated ancient weakness zones in the basement along the main NE–SW and NW–SE trends (Ferreira, 1982; Zalán et al., 1987; Milani, 1997), constraining the intrusive and extrusive mafic bodies. It caused the last phase of important basin subsidence, as a result of the weight exerted by the lavas on the crust, and is responsible for establishing a third structural trend with E–W direction (Zalán et al., 1987). This complex tectonic and magmatic event in the South American Platform was named Wealdenian Reactivation (Almeida, 1967).

For Milani (1997), the depocenter of the Bauru Group overlaps the largest thicknesses of the Serra Geral Formation, and suggests that the subsidence of the basin, at this time, was due to negative flexural adjustments of the lithosphere after cooling and mechanical accommodation of the volcanic rocks. Development of the sedimentation was conditioned by the Guapiara fault zone in São Paulo State, and by the São Sebastião high in Paraná State (Zalán et al., 1987). Considering the end of the basaltic volcanism between 137 and 127 Ma (Early Cretaceous) and the Senonian age (89 Ma – Late Cretaceous) of the Bauru Group sediments (Fernandes and Coimbra, 2000), around 40 Ma would have passed until proper accumulation conditions occurred for the first Late Cretaceous deposits. Soares et al. (1980) and Dias-Brito et al. (2001) assumed Aptian age for these sediments; then only 6 Ma would have passed, suggesting a relatively short erosion cycle.

The beginning of the Bauru sedimentation is still a controversial issue, which lacks detailed biostratigraphic studies. In spite of the uncertain beginning, whether in the Early or Late Cretaceous, the Bauru succession was deposited over an extremely irregular basaltic substratum, as often referred to in the literature (e.g., Arid, 1966; Mezzalira, 1974; Suguio et al., 1977; Brandt Neto et al., 1978; Soares et al., 1979; Barcha, 1980, 1985). These irregularities have been attributed to differential erosion or tectonic causes. The presence of basalt breccias and basal conglomerates at the contact between basalts and Bauru deposits (Salamuni et al., 1981; Riccomini et al., 1981; Sobreiro Neto et al., 1981; Brandt Neto, 1984; Barcha, 1985; Fernandes and Coimbra, 1994) suggests that the irregularities of an erosive nature would have been generated by the fluvial currents over a tectonically irregular basaltic substratum.

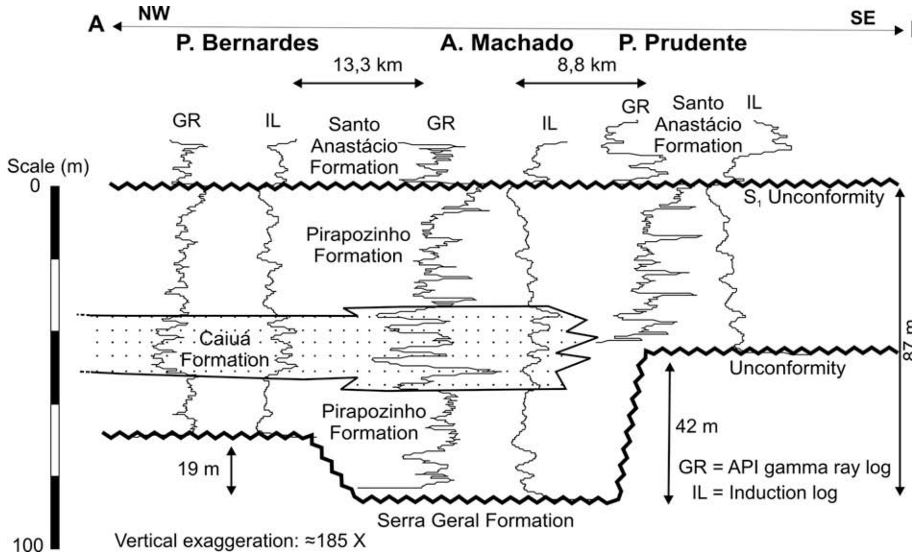

Fig. 6. Stratigraphic correlation with *datum* at the unconformity surface S1, showing the relationships between the Caiuá and Pirapozinho formations of the Presidente Bernardes region. Note the pre-depositional irregularities of the basaltic substratum (modified from Paula e Silva (2003)). Location of the section shown in Fig. 7.

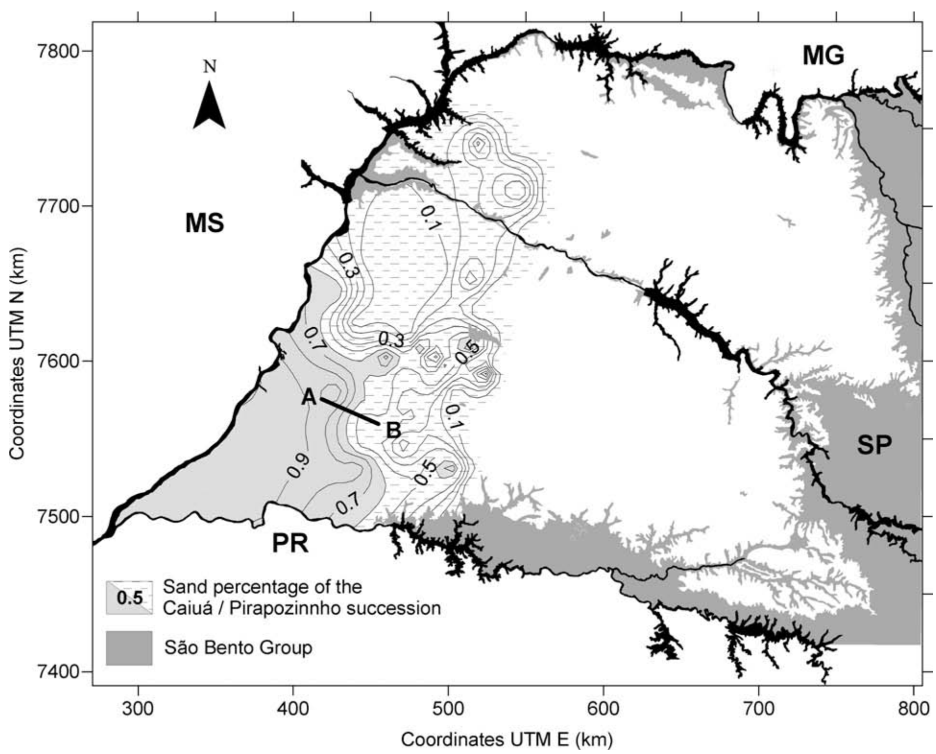

Fig. 7. Sand fractional percentage map of the Caiuá/Pirapozinho succession (modified from Paula e Silva (2003)). Light grey colors represent predominance of sandy facies; broken lines represent predominance of muddy facies. A–B represents the geological section of Fig. 6.

Over this basement, in the most depressed portion of the basin (southwestern region of São Paulo State – Presidente Bernardes Depression – Fig. 5), the first sandy–clayey clastics of the Bauru Group succession were deposited. It comprises the Caiuá and Pirapozinho formations, which initially filled the major irregularities in the basaltic substratum (Fig. 6). These lithostratigraphic units show cyclic inter-tonguing between aeolian-fluvial sandstone and lacustrine mudstone facies, respectively (Paula e Silva et al., 2005).

This first succession was deposited mainly in an endorreic fluvial system, where meandering rivers reach shallow lacustrine bodies. This lacustrine system had probably a reduced extension compared to the fluvial system and appears to have been barred by the intersection of the Tanabi and Paraguaçu Paulista highs. The sediments were better preserved in an elongated area about 3,500 km^2, limited to the east by these highs. The main clastic influx probably came from southwest to northeast (Fig. 7); sandy wedges prograded over the lacustrine sediments, with advances

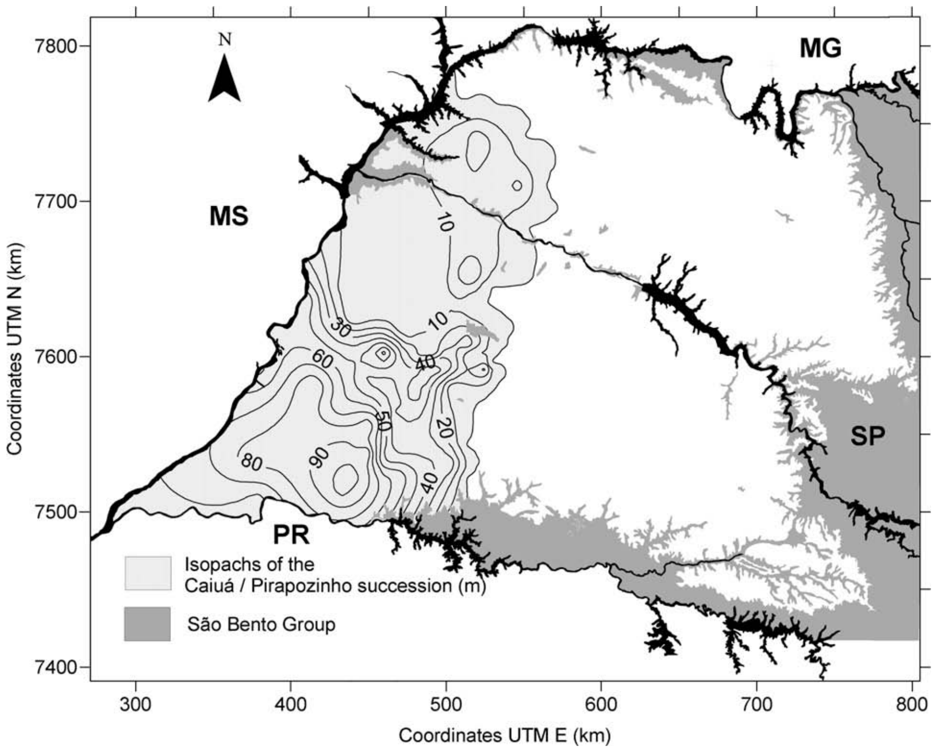

Fig. 8. Isopachs of the Caiuá/Pirapozinho succession (modified from Paula e Silva (2003)).

and retreats controlled by the oscillations of the local base level. Fluvial-aeolian interaction occurred, mainly in the more distal portions of the Pirapozinho lacustrine system in the Pontal do Paranapanema region (Paraná and Paranapanema rivers confluence, Fig. 1).

The Caiuá/Pirapozinho sediments filled the basaltic substratum irregularities to the southwest and expanded its limits to the northeast, occupying the Dracena and Sud Menucci depressions that, along with the Presidente Bernardes depression, form an elongated northeast trough (Fig. 8). The Tanabi and Paraguaçu Paulista highs maintained a slight prominence, just enough to prevent the transgression of the Caiuá/Pirapozinho sedimentation to the eastern portions of the basin. This disposition and localized character of the deposits might have induced Fúlfaro and Barcelos (1993) to consider a rift phase for the deposition of the Caiuá and Santo Anastácio formations.

The basin underwent a period of bypass after the initial phase of sediment deposition, generating a regional unconformity surface (S1). The S1 surface represents a temporal and erosive hiatus, closing this depositional phase and defining the first depositional sequence of the Bauru Group.

With the return of subsidence conditions, the second depositional phase was marked by the fluvial braided system of Santo Anastácio Formation, with dominant sand deposits and little shale. Locally, as in the southwestern region of the state, meandering streams deposited point-bar facies, in the lower and middle portions of the unit. Wind reworking of fluvial bars deposited aeolian dunes over fluvial facies.

Fluvial conditions persisted during this phase and the depositional area grew northward and southeastward, reaching the Rio Preto depression (Fig. 9). In the southeastern portion of the basin, deposits of the Santo Anastácio Formation transgressed over the Paraguaçu Paulista high, accumulating more than 90 m of sediments. Here Soares et al. (1979) recognized fine to very fine sandstones which they called Ubirajara lithofacies.

During deposition of the Santo Anastácio Formation, the volcanic substratum of the Paraguaçu Paulista high was overlapped by alluvial fill, whereas the Tanabi high was not.

There is evidence for an unconformity between the Santo Anastácio and Adamantina formations. This erosional event can be well observed near São José do Rio Preto, where the abrupt contact between the units is clearly marked in geophysical logs. As can be seen in Fig. 10, drilling wells close to this city reached the volcanic basement at approximately the same altitude ($\sim$350 m), indicating that there was no vertical movement in the substratum; also, the top of the Santo Anastácio Formation is unleveled about 30 m in a distance of 10 km. Furthermore, the occurrence of Santo Anastácio Formation in the western and southern portions of the basin and in the Rio Preto depression in the east, suggests that it overlapped the Tanabi high. Thus it may be that the Santo Anastácio Formation had a much wider lateral extent, occupying a greater area than that seen in the isopach map (Fig. 9).

At the end of the deposition of the Santo Anastácio Formation, the basin entered a bypass/erosional process that persisted until new tectonic adjustments and climatic changes occurred, such as border elevation, displacement of the internal structures of the basin, followed by an increase in water drainage. These events were responsible for the erosion of underlying sediments (Santo Anastácio Formation) and volcanic rocks exposed on the Tanabi high (unconformity surface S2). The Queiroz depression was initiated at this time and constitutes a remarkable example of erosive processes cutting through prior deposited sediments and substratum (Fig. 3). The Santo Anastácio Formation deposits constitute the second depositional sequence of the Bauru Group in São Paulo.

When favorable conditions for sedimentation were restored, the troughs left by the erosive cuttings were initially filled by fluvial braided deposits of the Birigüi Formation. This unit, found only in subsurface in the central region of the basin (Fig. 11), is characterized by the succession of sand bodies with predominantly cylinder-shaped GR (gamma ray) logs and rare intercalations of clayey

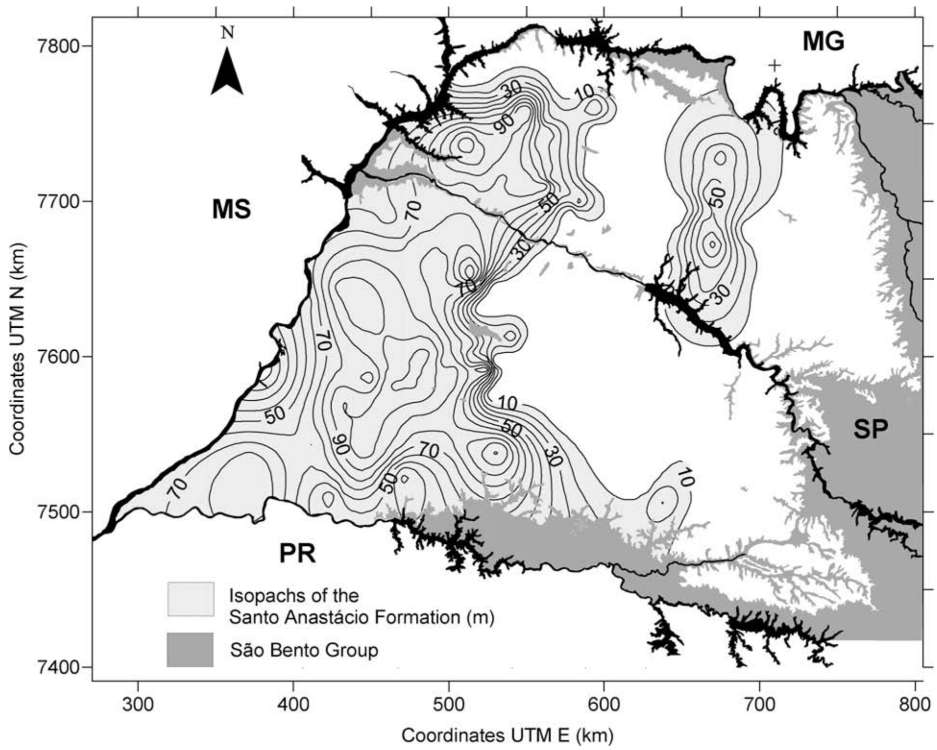

Fig. 9. Isopachs of the Santo Anastácio Formation (modified from Paula e Silva (2003)).

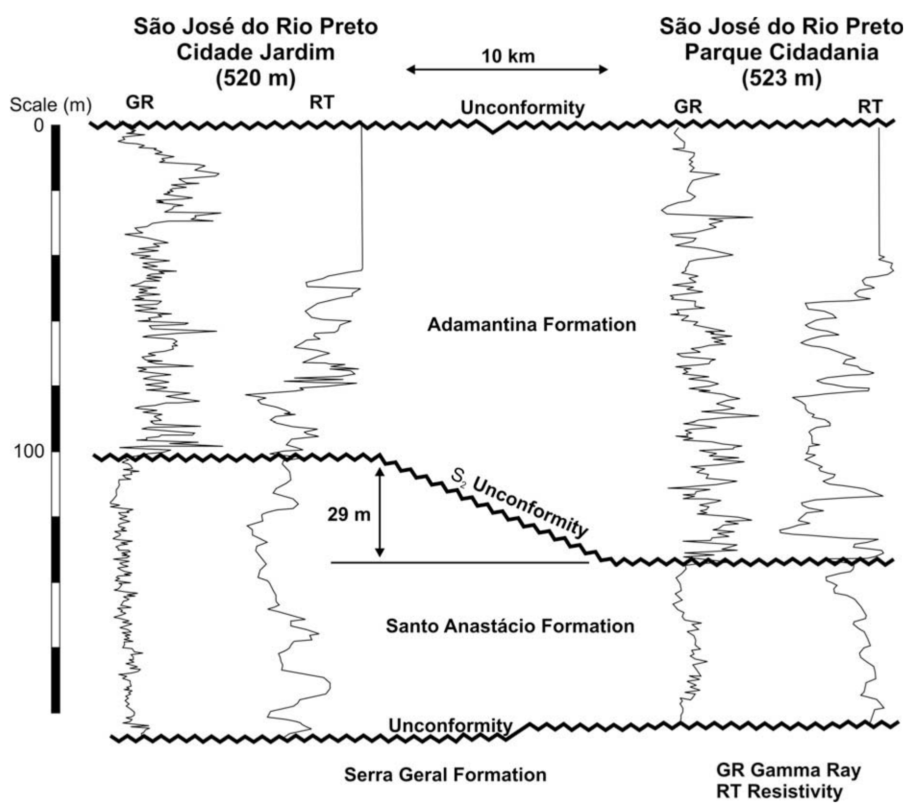

Fig. 10. Correlation between two wells in the city of São José do Rio Preto (modified from Paula e Silva (2003)). Location of the city is shown in Fig. 1.

bodies and low mud content (Fig. 12). The depositional area was enlarged mainly by the installation of a shallow lacustrine system which worked as regional base level, and was associated with a meandering fluvial system. The lacustrine and fluvial deposits correspond to the Araçatuba and Adamantina formations, respectively.

The depocenter of the Araçatuba Formation is located in the Queiroz depression and covers the whole central and southwestern

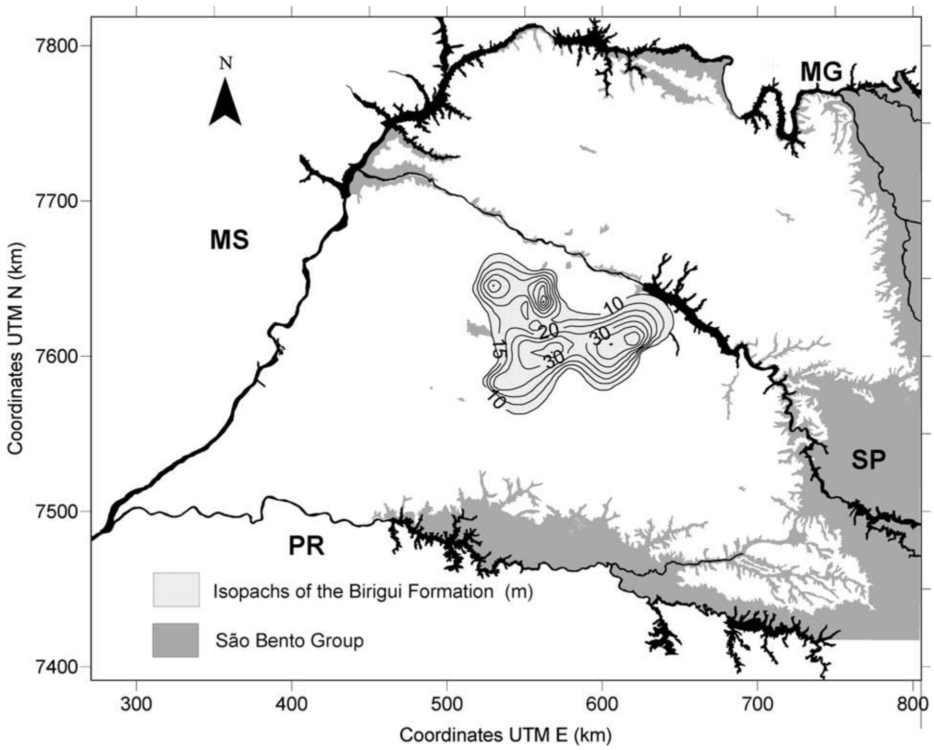

Fig. 11. Isopachs of the Birigüi Formation (modified from Paula e Silva (2003)).

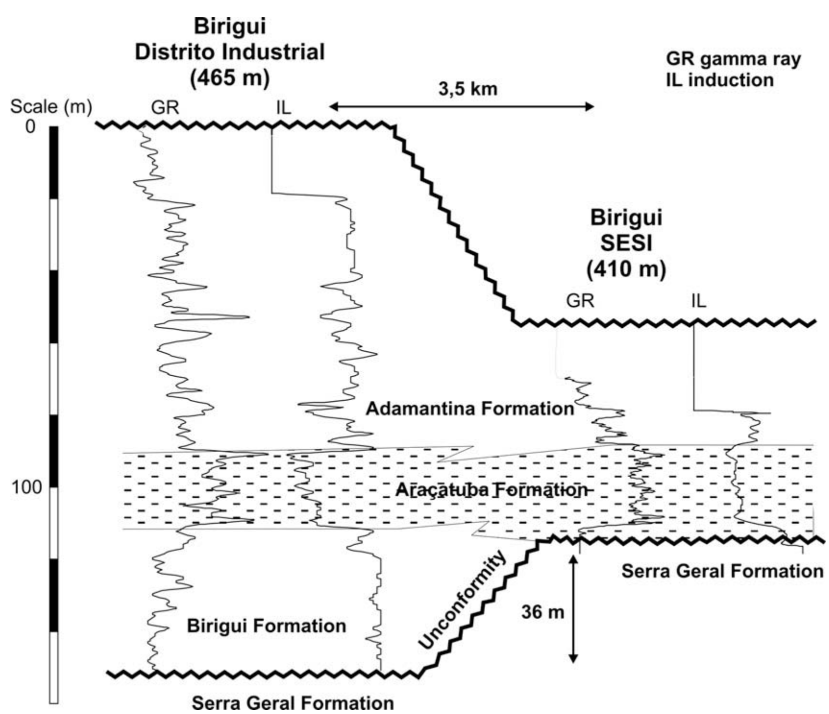

Fig. 12. Correlation between two wells drilled in the city of Birigüi (modified from Paula e Silva (2003)). Location of the city is shown in Fig. 1.

portions, and many other restricted areas in São Paulo State (Fig. 13). It is probable that the lakes of the central and southwestern portions were separated from smaller lakes spread over the basin. Thus, the Araçatuba Formation represents a time interval of mainly humid conditions, favoring the accumulation of water in the most depressed areas. The clastic influx was multidirectional and marked the major phase of endorreism of the basin.

At the first step of the final stage of basin infilling, the Adamantina fluvial system overlapped the Santo Anastácio Formation to the west (preserved in the marginal portions of the lacustrine system), the basalts to the east, and finally the clay-rich deposits of the Araçatuba Formation in the central area. The fluvial depositional system of the Adamantina Formation advanced over the lacustrine system of the Araçatuba Formation, determining a major

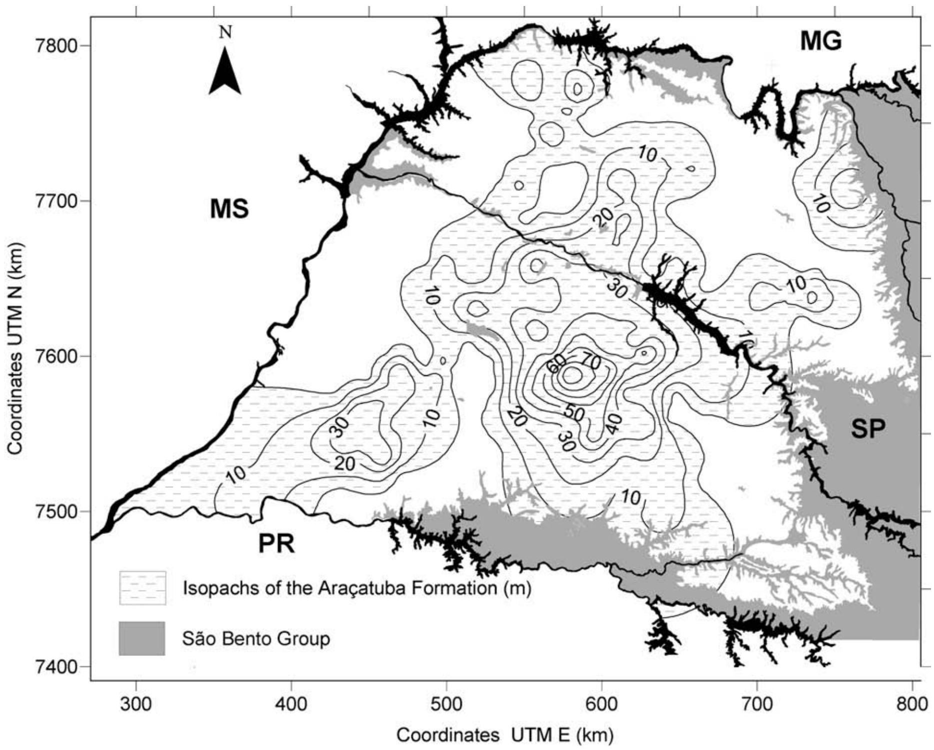

Fig. 13. Isopachs of the Araçatuba Formation (modified from Paula e Silva (2003)).

succession of coarsening-upward pattern composed of smaller fining and coarsening-upward cycles. The successive stacking of single sand bodies increasing in thickness and grain size upwards, just overlying Araçatuba clay-rich beds, suggests the deposition of small lacustrine deltas in the lower portion of the Adamantina Formation (Paula e Silva et al., 2006). Sedimentation proceeded with the accumulation of cyclic sand deposits showing both fining and coarsening-upward patterns, suggesting deposition on point-bars and longitudinal sandbars, respectively. The meandering fluvial system dominates at the upper portion of the Adamantina Formation, following braided fluvial deposits, which overly the basal deltaic deposits (Fig. 14). The deltaic deposition was controlled by the expansion and retraction of the lacustrine system of Araçatuba Formation due to climatic and/or tectonic variations (Paula e Silva et al., 2005).

These variations in the depositional systems reflect the climatic changes imposed to the basin that initially had a more humid climate, which gradually passed to a more arid climate. For example, the kaolinite clay-rich sediments occur at the base, and are replaced by montomorillonite-rich sediments at the top of Adamantina Formation (Brandt Neto, 1984; Petri, 1998).

The sedimentation of the Adamantina Formation extended throughout the whole area of Bauru deposition (Fig. 15). While the older units occupied well-delineated compartments, strongly controlled by internal highs and depressions, the Adamantina Formation was deposited over a smoothed surface and overlapped the limits of preexisting units, advancing over the basalts, and greatly expanding the basinal depositional area. This phase is marked by increased uplift of the basin borders, such as those defined by important tectonic highs (Fig. 1).

The alkaline volcanic rocks of Taiúva Analcimites are interbeded with the Adamantina Formation in the northeastern portion of the basin. Their origin is related to the alkaline rocks of the Poços de Caldas Massif (Minas Gerais State), formed between 87 and 60 Ma, that is, between the Coniacian and Paleocene (Almeida,

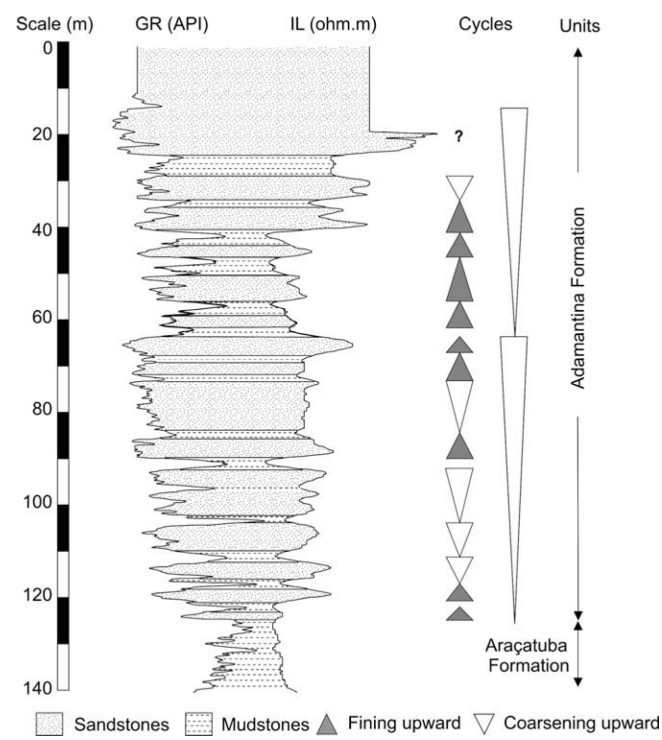

Fig. 14. Sedimentation cyclicity of the Adamantina Formation as shown in the geophysical log of a well located in the Presidente Prudente region. Location of the city is shown in Fig. 1.

1983). Paula e Silva et al. (2002) related gamma-ray anomalies of geophysical logs nearby São José do Rio Preto (Fig. 16) to the contribution of volcanic materials to Adamantina Formation. The authors suggested a possible chronological correspondence with

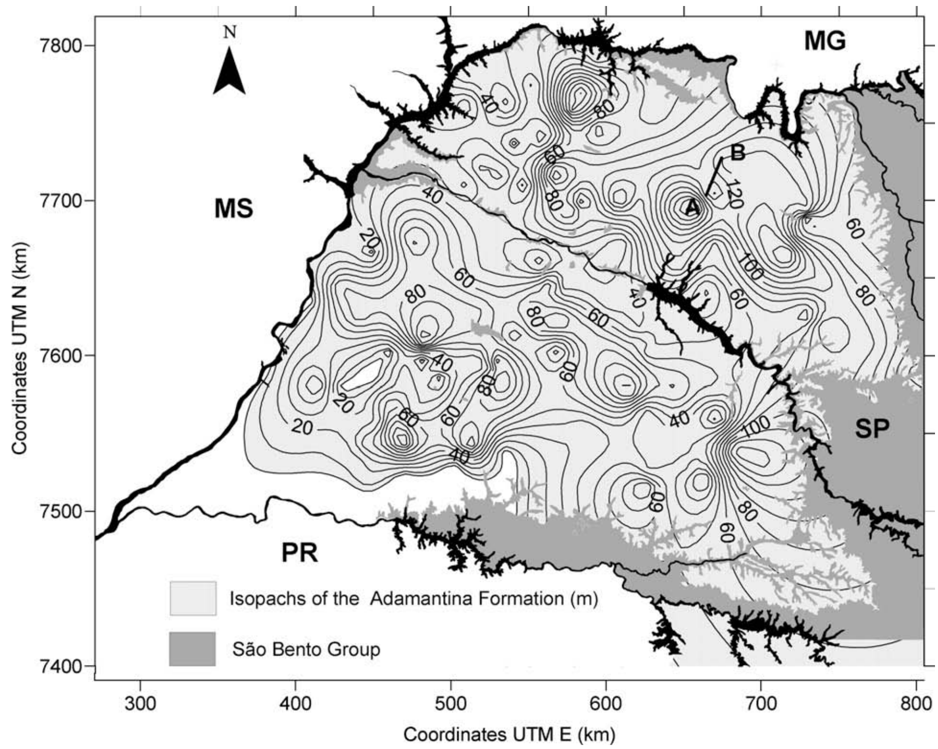

Fig. 15. Isopachs of the Adamantina Formation (modified from Paula e Silva (2003)). A–B geological section is shown in Fig. 16.

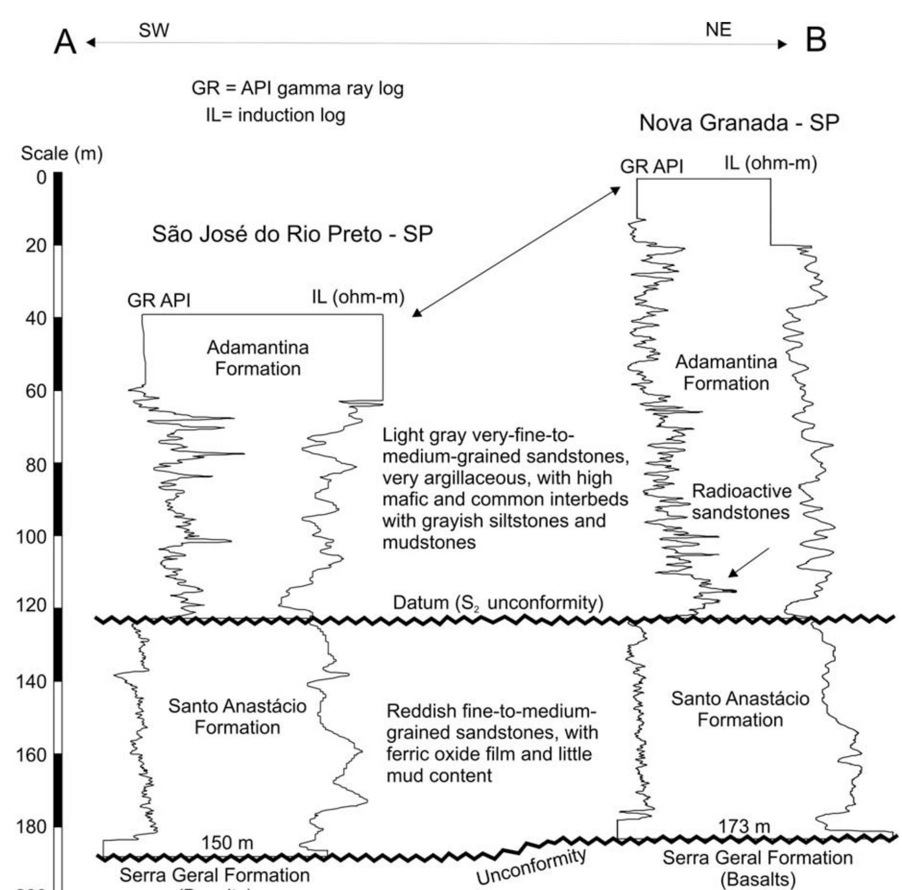

Fig. 16. Radioactivity anomalies as shown by gamma ray logs of the Adamantina Formation in the São José do Rio Preto region (modified from Paula e Silva (2003)). Location of the section is shown in Fig. 15.

the Uberaba Formation, the occurrence of which is restricted to Minas Gerais.

At the end of the Cretaceous, the continuous uplift of the basin borders exposed the Precambrian and Paleozoic basement rocks, providing clastics for the deposition of marginal fans of the Marília Formation (Fernandes and Coimbra, 1996). These fans must have occupied a much larger area than current geologic maps show, considering their overlap over the older formations. However, the Cenozoic erosion dissected most of the Bauru sediments, chiefly along the basin axis. In fact, only a small outcropping area was preserved due to intense calcite cementation of its sandstones. The isopach map for this unit is shown in Fig. 17, except for the occurrences recorded in the Monte Alto region which are not represented due to scarce data.

The Marília sedimentation is considered to be the climax of the basin infilling, and the majority of researchers agree on sedimentation by alluvial fans under semi-arid climate conditions for the unit (e.g. Soares et al., 1980; Barcelos and Suguio, 1987; Fernandes, 1998). Evidence of dry paleoclimate are provided by the presence of calcretes and palygorskite, as well as textural and mineralogical immature sediments (Petri, 1998).

Unconformity between Marília and Adamantina formations as presented by Dias-Brito et al. (2001) is debatable. Besides the fact that the studied samples came from distinct outcrop areas in the basin (Adamantina sediments were sampled in the central and southwest regions of São Paulo and the Marília equivalent sediments were sampled close to Ponte Alta, in Minas Gerais), samples of Adamantina Formation were collected in areas where the unit is extensively eroded. In the present study only six wells cutting through Marília and Adamantina Formations have been logged, preventing a more detailed analysis and interpretation of the contact between these units.

At the beginning of the Tertiary, the Bauru depositional area lost its subsiding character and positive epeirogenic movements

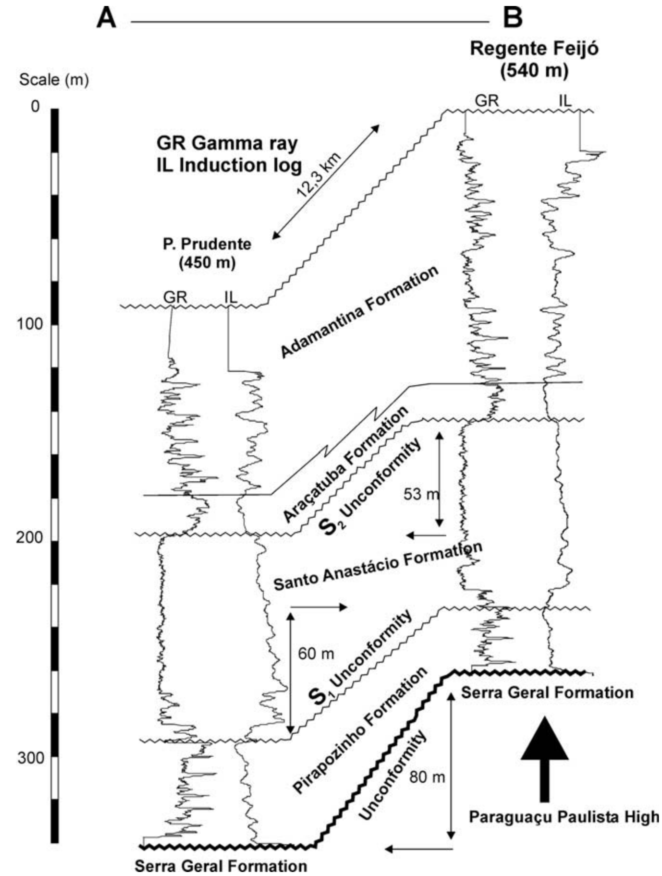

Fig. 18. Well-logs correlation between the cities of Presidente Prudente and Regente Feijó, with *datum* at sea level (modified from Paula e Silva (2003)). Location of the section is shown in Fig. 17.

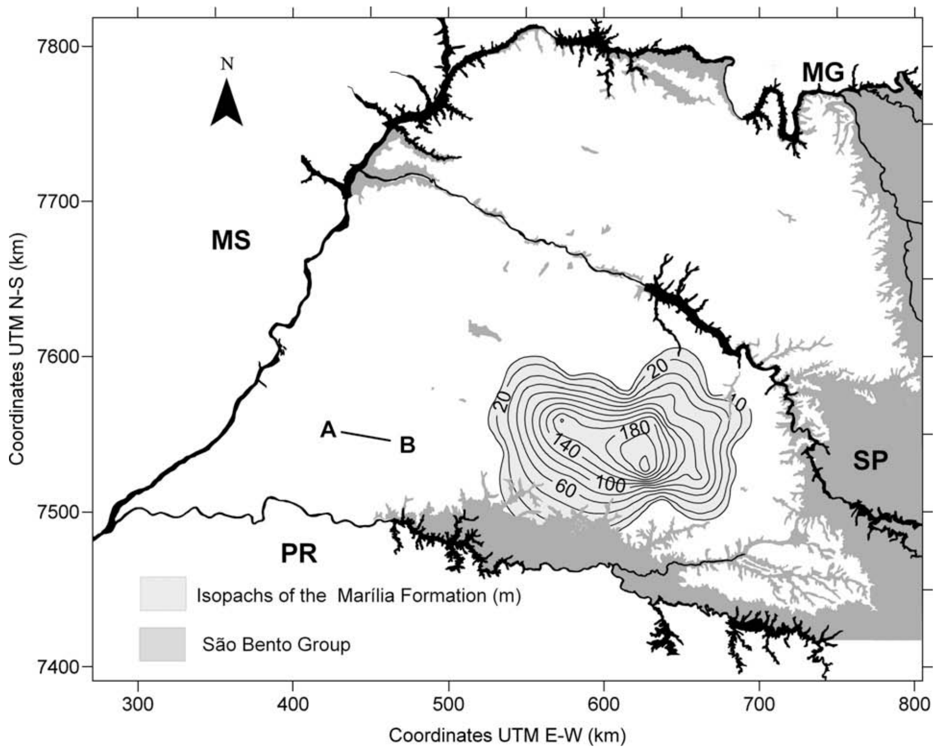

Fig. 17. Isopachs of the Marília Formation (modified from Paula e Silva (2003)). The occurrences in the Monte Alto region are not presented due to insufficient data. A–B geological section is shown in Fig. 18.

started, exposing its deposits to progressive erosion until the present time.

During the Paleocene and the Eocene, the eastern flank of the basin went through an intense erosive phase which resulted in the development of the Japi geomorphological surface (Almeida, 1976). This regional unconformity surface might be correlated to the unconformity surface at the end of the Cretaceous in the Santos Basin (Macedo, 1989). The tectonic activity continued disrupting the Japi surface and creating the taphrogenic basins of southeastern Brazil (Macedo et al., 1991). The continued uplift of the eastern border is corroborated by the deposition of two Tertiary prograding sequences in the Santos Basin (Pereira et al., 1986). Uplift of the Paraná basin during the entire Cenozoic appears to be related to isostatic adjustment. Soares et al. (1979) suggested that the deposition of younger sediments in the basin area occurred in valleys cut into the Mesozoic sediments by fluvial erosion, as a consequence of the pulsation of the marginal ridges.

The Bauru Group substratum underwent modifications in its original form, adjusted to later tectonic events. The main tectonic features, inherited from previous phases, kept their behavior during its evolution. An example is observed in Fig. 18 where the Paraguaçu Paulista high, a western extension of the Guapiara lineament, assumed ascending behavior, offsetting lithostratigraphic units during post-Cretaceous time. This section reveals that an offset already existed in the top of the basalt at the time of the deposition of the Pirapozinho Formation. Almost equal thicknesses of the Santo Anastácio and Araçatuba formations, as shown in well log correlations, indicate that there was no differential movement during the deposition of these units, that is, the tectonic feature remained inactive during this period, as well as during the deposition of the Adamantina Formation. On the other hand, Tertiary epeirogenic movements disrupted the lithostratigraphic units to the current situation. In this example the differences reached around 53 m over 12.3 km, resulting a gradient of 4.3 m/km.

The Cenozoic Era marks the end of the deposition of the Bauru Group and closes the last period of effective subsidence within the Paraná Basin; from there on predominating events of entrenchment and denudation of the previously deposited units with subordinated sedimentation were restricted to small areas.

4. Conclusions

Sedimentation of the Bauru Group possibly started in the Early Cretaceous, shortly after the Serra Geral volcanism. Deposition occurred over a predominantly basaltic substratum, disturbed by tectonic and erosive processes. The main structures in the Bauru substratum are the Presidente Bernardes, Dracena, Sud Menucci, Queiroz and Rio Preto depressions and the internal highs of Tanabi, Pereira Barreto and Paraguaçu Paulista. These structures controlled the accumulation and preservation of the supra-basaltic Cretaceous units.

Bauru sedimentation took place during three main depositional phases separated by unconformities – S1 and S2 – defining three depositional sequences.

The first sequence was dominated by meandering streams reaching shallow lacustrine bodies; a marginal aeolian system interacted with the fluvial deposition. It resulted in the interbedding of sandy deposits of Caiuá Formation and the clay-rich deposits of Pirapozinho Formation. The main sedimentary influx came from southwest to northeast, with sand wedges overlapping the lacustrine sediments. Subsequently, the basin entered a bypass/erosional process responsible for the regional unconformity surface S1.

The second depositional sequence was marked by sandy fluvial sedimentation of the Santo Anastácio Formation, with facies of aeolian reworking. Fluvial conditions persisted with the depositional site enlarging to the north and southeast. In this phase, the Tanabi high remained relatively elevated. At the end of deposition of the Santo Anastácio Formation the basin was subjected to a bypass/erosional process – unconformity surface S2.

The third depositional sequence was preceded by tectonic rearrangement and climate change, such as elevation of the borders, reactivation of internal tectonic structures and increase of water input in the system. Subsidence of the Queiroz depression favored the accumulation of fluvial braided deposits of the Birigui Formation and lacustrine deposits of the Araçatuba Formation in the deepest portions of the basin. The Bauru sedimentation continued with the deltaic and fluvial deposits of the Adamantina Formation, overlapping the Araçatuba and Santo Anastácio formations.

Because of the uncertainty of the nature of the contact between Marília and Adamantina Formations, Marília deposits were not considered in this sequence stratigraphy analysis.

At the beginning of the Tertiary, the Bauru depositional site lost its subsiding character, and positive epeirogenic movements began to dominate, exposing its deposits to progressive erosion.

Acknowledgements

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References

Almeida, F.F.M., 1967. Origem e evolução da plataforma brasileira. Boletim da Divisão de Geologia e Mineralogia, Rio de Janeiro, DNPM 241, 1–36.

Almeida, F.F.M., 1976. The system of continental rifts bordering the Santos Basin, Brazil. Anais da Academia Brasileira de Ciências 48, 15–26.

Almeida, F.F.M., 1983. Relações tectônicas das rochas alcalinas mesozóicas da região meridional da Plataforma Sul-Americana. Revista Brasileira de Geociências 13 (3), 139–158.

Arid, F.M., 1966. A Formação Bauru na região norte-ocidental do Estado de São Paulo. Geociências 1, 1–126.

Barcelos, J.H., Suguio, K., 1987. Correlação e extensão das unidades estratigráficas do Grupo Bauru definidas em território paulista, nos estados de Minas Gerais, Goiás, Mato Grosso do Sul e Paraná. In: Simpósio Regional de Geologia 6, Rio Claro, SP, Atas, pp. 313–321.

Barcha, S.F., 1980. Aspectos geológicos e províncias hidrogeológicas da Formação Bauru na Região norte-ocidental do Estado de São Paulo. Tese de Doutoramento. Instituto de Biociências, Letras e Ciências Exatas, UNESP, São José do Rio Preto, SP, 209pp.

Barcha, S.F., 1985. Condicionamento geológico da água subterrânea em São José do Rio Preto, SP. Revista Geociências, UNESP 4 (1), 57–68.

Brandt Neto, M., 1984. O Grupo Bauru na região centro-norte do Estado de São Paulo. Tese de Doutoramento. Instituto de Geociências da Universidade de São Paulo, 106pp.

Brandt Neto, M., Petri, S., Coimbra, A.M., 1978. Considerações sobre a estratigrafia e ambiente de sedimentação da Formação Bauru. In: Congresso Brasileiro de Geologia 30, Recife, PE, pp. 557–566.

Campos, J.E., Takya, H., Belloni, M.C., Ferreira, L.M.R., 1992. Contorno estrutural do topo da Formação Serra Geral (Bacia do Paraná – Estado de São Paulo). Geociências, UNESP 11 (1), 63–73.

Coimbra, A.M., 1991. Sistematização crítica da obra. São Paulo Tese de Livre-docência, Instituto de Geociências da Universidade de São Paulo, 54pp.

Coimbra, A.M., Coutinho, J.M.V., Brandt Neto, M., Rocha, G.A., 1981. Lavas fonolíticas associadas ao Grupo Bauru no Estado de São Paulo. In: Simpósio Regional de Geologia 3, Curitiba, PR, Atas, pp. 324–327.

Departamento de Águas e Energia Elétrica – DAEE, 1976. Estudo de águas subterrâneas, regiões administrativas 7, 8 e 9, v. 1 e v. 2. Bauru, São José do Rio Preto e Araçatuba, São Paulo, SP.

Dias-Brito, D., Musacchio, E.A., Castro, J.C., Maranhão, M.S.A.S., Suárez, J.M., Rodrigues, R., 2001. Grupo Bauru: uma unidade continental do Cretáceo no Brasil – concepções baseadas em dados micro-paleontológicos, isotópicos e estratigráficos. Revue Paléobiol. Genève 20 (1), 245–304.

Fernandes, L.A., 1998. Estratigrafia e evolução geológica da parte oriental da Bacia Bauru (Ks, Brasil). Universidade de São Paulo, São Paulo, SP, USP, 216pp.

Fernandes, L.A., Coimbra, A.M., 1994. O Grupo Caiuá (Ks): revisão estratigráfica e contexto deposicional. Revista Brasileira de Geociências, São Paulo 24 (3), 164–176.

Fernandes, L.A., Coimbra, A.M., 1996. A Bacia Bauru (Cretáceo Superior, Brasil). Anais da Academia Brasileira de Ciências 68 (2), 195–205.
Fernandes, L.A., Coimbra, A.M., 2000. Revisão estratigráfica da parte oriental da Bacia Bauru (Neocretáceo). Revista Brasileira de Geociências 30 (4), 717–728.
Fernandes, L.A., Coimbra, A.M., Brandt Neto, M., 1993. Silicificação hidrotermal neocretácea na porção meridional da Bacia Bauru. Revista do Instituto Geológico – IG 14 (1), 35–52.
Ferreira, J.F.F., 1982. Alinhamentos estruturais magnéticos da região centro-oriental da Bacia do Paraná e seu significado tectônico. In: Geologia da Bacia do Paraná: reavaliação da potencialidade e prospectividade em hidrocarbonetos. Consórcio CESP/IPT, São Paulo, SP, Paulipetro, pp. 143–166.
Freitas, R.O., 1973. Geologia e petrologia da Formação Caiuá no Estado de São Paulo. In: Boletim do Instituto Geográfico e Geológico – IGG, São Paulo, SP 50, 122pp.
Fúlfaro, V.J., Barcelos, J.H., 1993. Fase rifte na Bacia Sedimentar do Paraná: a Formação Caiuá. Geociências 12 (1), 33–45.
Gobbo, S.R., Petri, S., 1999. *Ilyocypris bertinii*, nova espécie de Ostracoda da Formação Adamantina (Grupo Bauru, Bacia do Paraná). In: Comunicação de Resumos, Rio de Janeiro - RJ. Anais da Academia Brasileira de Ciências. Rio de Janeiro, 71 (1), 145–146.
Hasui, Y., Haralyi, N.L.E., 1991. Aspectos lito-estruturais e geofísicos do soerguimento do Alto Paranaíba. Geociências 10, 57–77.
Huene, F.Von., 1939. Carta de F.Von Huene ao Dr.Euzébio de Oliveira. Mineração e Metalurgia, Rio de Janeiro, 4(22), 190pp.
King, L.C., 1956. A geomorfologia do Brasil oriental. Revista Brasileira de Geografia 2 (18), 147.
Macedo, J.M., 1989. Evolução tectônica da Bacia de Santos e áreas continentais adjacentes. Boletim de Geociências, Petrobrás, Rio de Janeiro 3 (3), 159–173.
Macedo, J.M., Bacoccoli, G., Gamboa, L.A.P. 1991. O tectonismo Meso-Cenonozóico da região sudeste. In: Simpósio de Geologia do Sudeste, 2, São Paulo, Atas, pp. 429–437.
Mezzalira, S., 1974. Contribuição ao conhecimento da estratigrafia e paleontologia do arenito Bauru. In:Boletim do Instituto Geográfico e Geológico – IGG, São Paulo, SP, v. 51, 162pp.
Milani, E.J., 1997. Evolução tectono-estratigráfica da Bacia do Paraná e seu relacionamento com a geodinâmica fanerozóica do Gondwana sul-ocidental. Porto Alegre, RS. Tese de Doutorado, Universidade Federal do Rio Grande do Sul, 255pp.
Paula e Silva, F., 2003. Geologia de subsuperfície e hidroestratigrafia do Grupo Bauru no Estado de São Paulo. Tese de Doutorado, Instituto de Geociências e Ciências Exatas, Universidade Estadual Paulista (UNESP), Rio Claro, 166pp.
Paula e Silva, F., Bianchi Neto, C., Ricaldi, A.E.M., Sapio, A.J., 1994. Estudo estratigráfico do Grupo Bauru na região de Presidente Prudente com base em perfis geofísicos de poços para água. Geociências, UNESP 13 (1), 63–82.
Paula e Silva, F., Cavaguti, N., 1994. Nova caracterização estratigráfica e tectônica do Mesozóico na Cidade de Bauru – SP. In: Geociências, UNESP, pp. 83–99.
Paula e Silva, F., Chang, H.K., Caetano-Chang, M.R., 2002. Caracterização das unidades cretáceas da Bacia do Paraná na região de São José do Rio Preto (SP) com base na análise de perfis geofísicos e suas implicações estratigráficas. In: Boletim do Simpósio sobre o Cretáceo do Brasil, 6 e Simpósio sobre el Cretáceo de America del Sur, 2, São Pedro, SP, pp. 345–349.
Paula e Silva, F., Chang, H.K., Caetano-Chang, M.R., 2003. Perfis de referência do Grupo Bauru (K) no Estado de São Paulo. Geociências 22 (especial), 21–32.
Paula e Silva, F., Chang, H.K., Caetano-Chang, M.R., 2005. Estratigrafia de subsuperfície do Grupo Bauru (K) no Estado de São Paulo. Revista Brasileira de Geociências, São Paulo 35 (1), 77–88.
Paula e Silva, F., Chang, H.K., Caetano-Chang, M.R., Stradioto, M.R., 2006. Sucessão sedimentar do Grupo Bauru na região de Pirapozinho (SP). Geociências, Rio Claro 25 (1), 17–26.
Paula e Silva, F., Saad, A.R., Perinotto, J.A.J., Fulfaro, V.J., 1999. Arquitetura deposicional do Grupo Bauru (Ks) na região sudoeste do Estado de São Paulo. In: Simpósio sobre o Cretáceo do Brasil, 5 e Simpósio sobre el Cretácico de América del Sur, 1, Serra Negra, SP, Boletim, pp. 45–49.
Pereira, M.J., Barbosa, M.C., Agra, J., Gomes, J.B., Aranha, L.G., F., Saito, M., Ramos, M.A., Carvalho, M.D., Stamato, M., Bagni, O., 1986. Estratigrafia da Bacia de Santos: análise das sequências, sistemas deposicionais e revisão litoestratigráfica. In: Congresso Brasileiro de Geologia 34, v. 1, Goiânia, GO, Anais, pp. 65–79.
Petri, S., 1998. Paleoclimas da Era Mesozóica no Brasil: evidências paleontológicas e Sedimentológicas. Revista Universidade de Guarulhos – Geociências 3 (6), 22–38.
Riccomini, C., 1997. Arcabouço estrutural e aspectos do tectonismo gerador e deformador da Bacia Bauru no Estado de São Paulo. Revista Brasileira de Geociências 27 (2), 153–162.
Riccomini, C., Gimenez, A.F., Stein, D.P., Almeida, F.F.M., Pires Neto, A.G., Dehira, L.K., Melo, M.S., Braga, T.O., Ponçano, W.L., 1981. Características da porção basal da Formação Caiuá no noroeste do Paraná. In: Simpósio Regional de Geologia, 3, Curitiba, PR, Atas, pp. 25–33.
Salamuni, R., Landim, P.M.B., Slongo, T.T., Sobreiro Neto, A.F., Paiva Filho, A., 1981. Observações sobre o ambiente de deposição da Formação Caiuá no noroeste do Estado do Paraná. In: Simpósio Regional de Geologia, 3, Curitiba, PR, Atas, pp. 25–33.
Santoro, J., Massoli, M., 1985. Mapa de contorno estrutural do topo do basalto subjacente ao Grupo Bauru no Estado de São Paulo. Revista do Instituto Geológico – IG, São Paulo, SP 6 (1/2), 39–44.
Soares, P.C., Landim, P.M.B., Fúlfaro, V.J., Amaral, G., Suguio, K., Coimbra, A.M., Sobreiro Neto, A.F., Giancursi, F., Correa, W.A.G., Castro, C.G.J., 1979. Geologia da região sudoeste do Estado de São Paulo. In: Simpósio Regional de Geologia, 2, Rio Claro, SP, Botetim de resumos. pp. 307–319.
Soares, P.C., Landim, P.M.B., Fúlfaro, V.J., Sobreiro Neto, A.F., 1980. Ensaio de caracterização estratigráfica do Cretáceo no Estado de São Paulo: Grupo Bauru. Revista Brasileira de Geociências, São Paulo, SP. pp. 177–185.
Sobreiro Neto, A.F., Paiva Filho, A., Araújo, C.H.A., Seignemartin, C., Couto, E.A., Salamuni, R., Slongo, T.T., 1981. Estruturas sedimentares primárias de ambiente flúvio-deltaico da Formação Caiuá. In: Simpósio Regional de Geologia, 3, Curitiba, PR, Atas, pp. 47–59.
Suguio, K., Fulfaro, V.J., Amaral, G., Guidorzi, L.A., 1977. Comportamentos estratigráfico e estrutural da Formação Bauru nas regiões administrativas 7 (Bauru), 8 (São José do Rio Preto) e 9 (Araçatuba) no Estado de São Paulo. In: Simpósio Regional de Geologia, 1, São Paulo, SP, Atas, pp. 231–247.
Turner, S., Regelous, M., Kelley, S., Hawkesworth, C.J., Mantovani, M., 1994. Magmatism and continental break-up in the South Atlantic: high precision ^{40}Ar-^{39}Ar geochronology. Earth and Planetary Science Letters 121, 333–348.
Vieira, P.C., 1981. Sugestões para estudo de captação de água subterrânea no Grupo Bauru: considerações tectônicas. Revista do Instituto Geológico–IG, São Paulo 2 (2), 5–16.
Zalán, P.V., Wolf, S., Conceição, J.C.J., Astolfi, M.A.M., Vieira, I. S., Appi, V.T., Zanotto, O.A., 1987. Tectônica e sedimentação da Bacia do Paraná. In: Simpósio Sul-Brasileiro de Geologia, 3, Curitiba, PR, Atas, pp. 441–477.
Zalán, P.V., Wolf, S., Conceição, J.C.J., Marques, A., Astolfi, M.A.M., Vieira, I.S., Appi, V.T., Zanotto, O.A., 1990. Bacia do Paraná. In: Origem e Evolução de Bacias Sedimentares, Rio de Janeiro, RJ, Publicação Petróleo Brasileiro S.A., pp. 135–168.