Evolution of sin-tectonic alluvial successions in a late Neoproterozoic basin: sedimentary response to the uplift of an inner highland in the Santa Bárbara Group, southern Brazil.

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Abstract

Current models for the tectono-sedimentary evolution of extensional basins consider that tectonic reactivation results in instantaneous increase of subsidence rates, which in turn results in the deposition of finer-grained facies, followed by latter progradation of coarser clastic wedges due to the denudation of the reactivated topographic highs. These models are based on the tectonic activity of structural highs adjacent to the sedimentary basins, and thus do not take into account the particularities of the reactivation of intra-basinal structural highs. The Santa Bárbara Group in the Camaquã Basin (Ediacaran of the southern Brazil) shows evidence of the uplift of an internal structural high contemporaneous to the deposition of the unit. The Santa Bárbara Group comprises a more than 2,000 m thick succession of conglomerates, sandstones and siltstones deposited in continental environments, composing a initial finning-upward cycle followed by two coarsening-upward cycles. Provenance studies in the coarser deposits of the Santa Bárbara Group, combined with detailed facies and paleocurrents analyses, indicates a major shift in the provenance and paleoflow patterns during the first coarsening upward cycle, in a stratigraphic level correlated to the uplift of the Caçapava do Sul high, which divided the Camaquã Basin into a western and a central sub-basins. The identification of progradational deposits as the response to the uplift of the structural high implies in particularities concerning the activity of inner structural highs that have been neglected in the current tectonic models, such as the possible increase in sedimentary input due to the erosion of unlithified sediments previously deposited on the uplifting area and a fall in the subsidence rates as consequence of doming in the early stages uplift.

Introduction

The relation between facies variation, particularly alluvial conglomerates, and the reactivation of sedimentary basin border faults is one of the most debated aspects concerning the tectonic influence to sedimentation. The traditional interpretation of conglomerates as a direct result of fault reactivation events was challenged by Blair & Bilodeau (1988) and Heller et al. (1988), which related the border fault activity to increments in subsidence rates, so recognizing starved basin facies as indicative of tectonic reactivation. Such interpretation follows the principles of sequence stratigraphy, which considers retrogradational patterns of basin infilling as a result of the increment in subsidence rates (Posamentier et al. 1988, Jervey 1988), resulting in higher preservation of flood plains and fine grained deposits of alluvial systems (Wright & Marriot 1993, Shanley & McCabe 1994). On the other hand, simulations based on mathematical models show that the presence of coarse grained facies in distal regions of alluvial systems corresponds to tectonic quiescent periods following uplift of the adjoining highs (Marr et al. 2000, Paola 1988, Paola et al. 1992). The assessment of these models through studies of sedimentary successions related to contemporaneous fault activity has a fundamental role in achieving a better understanding of the interplay among uplift of source areas, varying sediment yield and increments in basin accommodation, and their controls on the sedimentary architecture of syn-depositional successions.

The Santa Bárbara Group was first described as a sedimentary unit by Robertson (1966) and later detailed by Ribeiro et al. (1966) by means of geologic mapping. Sequence stratigraphy concepts were applied for the successions comprised in the Santa Bárbara Group by Paim (1994) and Paim et al. (1995), who described the depositional systems as alluvial and lacustrine, thus interpreting them as deposited in continental settings. Based on observations from the eastern border of the Santa Bárbara Group in the Western Camaquã Sub-Basin Almeida (2001) suggests that the Caçapava do Sul High uplift took place during the basin infilling, while Borba & Mizusaki (2003) consider the presence of the structural high since the beginning of the basin deposition. Borba et al. (2008) following Almeida (2001, 2005) suggests the beginning of contribution of the Structural High during the basin infilling based in petrographic and Sm-Nd isotopic data, however without any considerations on the possible time of onset of the structural high evolution and its effects on the sedimentation.

The present work presents the results of studies in the Santa Bárbara Group (Ediacaran, southern Brazil) in the Western Camaquã Sub-Basin (Fragoso-Cesar et al. 2000) focused on the assessment of the influence of the uplift of the Caçapava do Sul Structural High (Fig. 02) during the deposition of the sedimentary succession.

The evidence of uplift during the continuous deposition of the basin and the characterization of the main border fault movement as normal makes the case study extremely relevant to the identification of sedimentary response to the uplift of an inner structural high in a distensional basin, in that way testing the existent models of sedimentary response to border fault reactivation events (e.g. Blair & Bilodeau 1988, Heller et al. 1988).

Geological setting

The precambrian outcrop belt comprising Uruguay and southern to southeastern Brazil hosts numerous occurrences of basins related to basement faulting with a predominant ENE to NNE strike, filled by sedimentary and volcanic deposits and settled in the interval between the assembling of Gondwana and the setting of wide Paleozoic intracratonic basins (e.g. Paraná Basin), thus recording the Gondwana early stabilization stages (Almeida et al. 2010). The most complete of these basins is the Camaquã Basin, located in southern Brazil and recording sedimentation from the Neoproterozoic to the Eopaleozoic.

The Camaquã Basin (Fig. 01) infilling successions compose the Camaquã Supergroup, a more than 10,000 meters thick succession distributed in three sub-basins separated by the Caçapava do Sul and the Serra das Encantadas highs (Fragoso-Cesar et al. 2000). The Santa Bárbara Group is found in the three sub-basins, overlaying deposits of the Maricá Group (siliciclastic successions), Bom Jardim Group (volcano-sedimentary successions), Acampamento Velho Formation (volcanic succession) and being covered by the Guaritas Group (siliciclastic successions).

In the Western Camaquã Sub-Basin the Camaquã Supergroup strata is tilted predominantly eastwards and, to a lesser degree, northwards, with its older units cropping out in the west and south of the area. The contacts with its underlaying stratigraphical units are mainly tectonic. Erosive contacts are locally found with the Bom Jardim Group and Acampamento Velho Formation volcanics in the western border of the basin. The eastern border is characterized by tectonic contacts with Rio Vacancy Terran and Caçapava do Sul Granite, as well as the Guaritas Group.

Based on radiometric ages obtained in volcanic rocks around 600~580 Ma from the Bom Jardim Group and of 574 Ma for the Acampamento Velho Formation (U-Pb and Ar-Ar ages by Janitorial et al. 2008), as well as ages obtained for plutonism related to volcanism (Soliani Jr. et al. 2002), a maximum age of 549 Ma for the onset of the sedimentation of the

Santa Bárbara Group is considered. Additionally, an age of 535 Ma for the Rodeio Velho Intrusive Suite in the Guaritas Group (Almeida et al. 2010), that ultimately covers the Santa Bárbara Group, defines the minimum age of this unit. Therefore, the deposition of the lower interval of the Santa Bárbara Group is close to the age of crystallization of the Caçapava do Sul Granite, occurred between 555 Ma and 550 Ma (Sartori & Kawashita 1985, Nardi & Bitencourt 1989, Leite 1995).

The Santa Bárbara Group comprises successions formed in continental alluvial sedimentary environments and is divided in the study area in five sedimentary units (Almeida 2005) as follows: The Estância Santa Fé Formation is composed mainly of conglomerates and sandstones, with minor siltstones and fine sandstones related to alluvial fans, braided rivers and ephemeral rivers deposits; Seival Formation includes interlayered siltstones and fine sandstones with minor mudstone related to ephemeral rivers deposits; the Serra dos Lanceiros Formation comprises sandstones and conglomeratic sandstones interpreted as bedload ephemeral braided river deposits; the Arroio Umbu Formation presents mainly siltstones and sandstones, related to ephemeral river deposits, and minor conglomerates related to alluvial fan deposits; the Serra do Segredo is the uppermost unit and comprises sandstones and conglomerates interpreted as braided river and alluvial fan deposits.

Depositional systems and stratigraphic evolution

Sedimentary facies analysis and interpretation of depositional geometries in outcrop enabled the recognitions of five facies associations in the studied succession, following unpublished data and interpretations by Almeida (2005), each representing a particular depositional environment and occurring in more than one stratigraphic level (Fig. 02). These were interpreted as Alluvial Fan Deposits (FA1), Pebbly Fluvial Deposits (FA2), Sandy Fluvial Deposits (FA3), Fluvial Flood-Plains (FA4) and Lacustrine Deposits (FA5). The description and interpretation of the sedimentary facies is summarized in Table 01, and a synthesis of the description and interpretation of the facies associations is given in Table 02.

This facies associations are organized in thousands of meters thick cycles, which reflect the depositional systems evolution of the basin as a response to its external controls (mainly the tectonic subsidence rates and the sedimentary input). Alluvial fan deposits (FA1) are found in the western and southwestern basin borders in the lower stratigraphic levels of the Santa Bárbara Group, and on the opposed (eastern) basin border in the middle and upper levels of the unit. More distal deposits can be described as composing one finning upward cycles, followed by two coarsening-upward cycles. The first one is characterized by the passage from the sandy fluvial deposits (FA3) of the upper part of the Estância Santa Fé Formation to the the successions dominated by FA4 of the Seival Formation. This trend marks a possible increment in the tectonic subsidence rates, allowing the preservation of a greater proportion of distal flood-plains (Wright & Marriot 1993, Shanley & McCabe 1994), culminating with the formation of a major lacustrine body (FA5). Above this level, the first coarsening-upward cycles begins with the abrupt passage from the lacustrine deposits to a succession dominated by distal flood-plains (FA4) in the upper part of the Seival Formation, and then the progressive passage to sandy fluvial systems (FA3) and finally pebbly fluvial systems (FA2) of the Serra dos Lanceiros Formation. This cycle is abruptly ended by a regional surface above which another succession dominated by distal flood-plains (FA4) was deposited (Arroio Umbu Formation), marking the installation of the second coarsening-upward cycle. This second cycle also presents the gradual passage to sandy fluvial systems (FA3) and then pebbly fluvial systems (FA2), and is laterally equivalent to a succession dominated by alluvial fans fed from the Caçapava do Sul Highland to the East.

This stratigraphic evolution is therefore marked by abrupt flooding surfaces (or their subaerial equivalents) and the progressive advance of proximal depositional systems over the distal ones. This can be explained by rapid episodes of increase of the accommodation space, most probably caused by tectonic subsidence, followed by declining rates of accommodation generation and / or progressive increase in the sedimentary input.

Provenance

Provenance studies conducted in the Santa Bárbara Group aimed to understand the relations between source areas and sedimentary deposits in order the reconstruct the provenance story of the basin and as consequence the effects of the uplift of an inner high during the basin deposition. To reach these objectives paleocurrent data was systematically collected in sandstones of each sedimentary unit and macroscopic provenance data were obtained in conglomeratic sandstones and conglomerates over the basin. In addition, microscopic provenance data were collected in sandstones and conglomerate sandstones of a specific stratigraphic interval in the Serra dos Lanceiros Formation in order to identify the onset of clastic contribution from the Caçapava do Sul High into the basin.

Paleocurrents

Trough and tabular cross stratification orientation data where collected, as well as cross lamination data, in order to reconstruct the sedimentary transport patterns in different stratigraphic levels of the Santa Bárbara Group in its type area, which eventually revealed changes that would be related to the reactivation event responsible by the Caçapava do Sul High uplift (Fig. 03).

Except for the deposits related to western border denudation, particularly the Estância Santa Fé Formation, the units below the first conglomeratic level of Serra dos Lanceiros Formation show northward paleocurrents (Fig. 03), interpreted as resulting from the development of alluvial plains with transport parallel to the basin axis, common to hemi-grabens (Leeder & Gawthorpe 1987, Gawthorpe & Leeder 2000).

After the first conglomeratic level of Serra dos Lanceiros Formation, a westward transport component related to the east structural high denudation is recognizable (Fig. 03). Although the Arroio Umbu Formation has a lateral facies variation that suggests the presence of a structural high to the east, with alluvial deposits neighboring the Caçapava do Sul High, it also shows northward paleocurrent transport in its distal facies (Fig. 03), pointing to the continuity of axial sedimentary transport simultaneously to alluvial fan transversal progradation. The Pedra do Segredo Formation records an increase in the paleocurrent dispersal and a significant change in the basin transport patterns with south to southeastward paleocurrents in the distal facies (FA3) and west or northwestward in the proximal facies exposed in the top of the unit (FA2 and FA1) (Fig. 03). Hence, the paleocurrent data suggests the presence of the Caçapava do Sul High since the upper part of the Serra dos Lanceiros Formation, responsible by the increase in dispersal and establishment of an westward transport component (Fig. 03).

Macroscopic provenance

Provenance analysis in conglomerates are usually performed by checking the frequency of different lithotype classes (e.g. Jones 2000, Roberts et al. 2008) or by measurements of the volume expression of each lithotype category defined by the author (e.g. Ibbeken & Schleyer 1991, Dürr 1996), the later presenting more reliable data, since it might avoid any bias effect caused by correlation of size and lithology (e.g. overestimation of lithotypes that are richer in smaller clasts). However, in lithified conglomerates it is not possible to assess the volume of each clast, so the proposed procedure is to measure their area expression. In this work we present provenance data obtained in 27 sites located in conglomeratic deposits of the Santa Barbara Group. The data was obtained by measuring clasts bigger than 0.5x0.5 cm and classifying their form, in order to obtain the area expression of the identified lithologies, of a total amount of at least 300 clasts in each site.

The collected data was further classified into 13 classes in order to permit the comparison between the different provenance sites (see table). Following the lithology classification, the zero values found in the compositional data were substituted using a Multiplicative Replacement Strategy (Martin-Fernandez et al. 2003) for each provenance site, since such strategy has the advantage of preserving the covariance structure of the replaced data set. However, instead of substituting the zero values for a value equivalent to 65% of the detection limit (equivalent to a 0.25 cm^2 clast in our work), as proposed by Martín-Fernandez et al. (2003) and Palarea-Albaladejo et al. (2007), the zero values were replaced by the greatest value statistically indistinguishable from zero, given the sample error for each site. Such approach returned a replacement value that was different for each provenance site and was small enough to avoid spurious effects. Provided the nonzero compositional data, the data sets were then submitted to the Centered Log-Ratio transformation (Pawlowsky-Glanh & Egozcue 2006), stretching the compositional data to an unclosed data range, thus allowing further multivariate analysis.

The source areas that crop out to the south and west of the Santa Bárbara Group in the Western Camaquã Sub-Basin includes acid, intermediate and basic volcanic rocks from the Acampamento Velho Formation and the Bom Jardim Group, besides siliciclastic sedimentary rocks from the Maricá Group and granitoids from the Lavras do Sul, Jaguari and Santo Afonso stocks, distinguished from the Caçapava do Sul granite by a coarser graining, massive texture and local occurrence of rapakivi texture. South of the basin, basement rocks are characterized as phyllites, metavolcanic and metavolcano-sedimentary rocks and gneiss from the Rio Vacacaí Terrane, as well as paleoproterozoic basement gneiss (Rio de La Plata

Craton).

The provenance data obtained for the Estância Santa Fé Formation shows a distinct dominance of volcanic fragments (Fig. 05), with an appreciable amount of granitic clasts and a minor contribution of phyllites and other metamorphic rocks. The Seival Formation and the lower part of the Serra dos Lanceiros Formation do not have any appropriate conglomerate level, thus lacking any sort of macroscopic provenance data, although granules of granite and volcanic rocks can be found in sandstones. The upper part of the Serra dos Lanceiros Formation (Fig. 05) has most of its provenance represented by granitic and volcanic fragments, albeit an noticeable component of metamorphic origin can be found. Upwards in the columnar section (Fig. 05) the Arroio Umbu Formation shows, in a provenance site in proximal deposits, an almost exclusive provenance of volcanic rocks, with minor phyllite contribution, whereas other localities show a prevalence of low grade metamorphics (Almeida, 2005). The uppermost unit, the Serra do Segredo Formation, presents a progressive increase in granitic contribution, which can be nearly exclusive in proximal deposits in the top of the unit. However, there is a remarkable variation in the provenance along the basin border near the Caçapava do Sul High, which will be discussed below.

As a significant part of the provenance data was obtained in alluvial fan conglomerates, special attention was given to the Estância Santa Fé and the Pedra do Segredo formations, since both units comprises proximal deposits. In order to assess the lateral similarity in provenance between different sites of analysis, one dendogram was constructed for each unit, and then the diagrams were confronted with the local geological map for a better visualization of the spacial variation of provenance (Fig. 06).

The Estância Santa Fé Formation dendogram has two main clusters that could be fairly correlated to the local geology (Fig. 06). The northern cluster has most of its sites located right north of the limits between the Bom Jardim Group volcanic rocks and the Acampamento Velho Formation outcrops, exception made to one site. The main factor controlling the similarity between these sites is the strong contribution of rhyolite and acid volcaniclastic rocks. The separation of the northern cluster into two minor clusters is related to the granitic contribution of the two southern sites, which may be a product of a wider catchment area, as granites do not occur in the nearby basement. On the other hand, the southern cluster covers nearly only provenance sites that lay near to the expositions of the Bom Jardim Group volcanic rocks, represented mainly by andesites, suggesting that the main component that distinguishes this cluster is the presence of andesite lithoclasts, although the diminished granitic contribution of these sites could have some role in the grouping of these deposits, suggesting minor contribution from farther areas.

The Pedra do Segredo Formation in its turn shows a more complex distribution of the clusters, but still with a good correspondence with the local geology (Fig. 06). Again the provenance sites were divided in two main clusters, and the southern cluster shows that the similarity is influenced by the granitic lithoclast abundance, although the nearly inexistent contribution of metamorphic lithoclasts may be also an important similarity factor. The abundance of granitic fragments in this cluster may be directly correlated to Caçapava do Sul Granite outcrops east of the counting sites. Although the southernmost site shows a far more important provenance of acid volcanic rocks, it still may be correlated to the Caçapava do Sul High, but in this case this provenance site would represent a moment prior to a fully exposition of the granite, since this point is lower in stratigraphy than the other two. In turn the northern cluster shows a more complex distribution of the samples, with the provenance sites likely to have a higher similarity to nearby sites. The main controlling factor in the similarity seems to be the variable proportion between granitic and metamorphic fragments. Such control can be attributed to the geology of the milonitic shear zone adjacent to the basin, where complex interfingering of metamorphic and granitic lenses can be found.

The mainly proximal character of the deposits found in the Estância Santa Fé and Pedra do Segredo formations together with the strong correlation between the provenance sites and the adjacent outcrops of basement rocks and the coincidence between clusters separations and contact between source areas (Fig. 06), indicates that none or minor lateral displacement took place between the source areas and their related deposits. Such evidence implies in the absence of major strike-slip movement of the basin border faults during the basin deposition, favoring the interpretation of the extensional basin instead a strike-slip basin interpretation.

Another approach to assess the effects of provenance through depositional systems is the use of principal components (PCs) in order to check trends and which variables best describes the provenance data. The first (PC1), second (PC2) and third (PC3) components for the provenance data accounts for, respectively, 20.7%, 18.7% and 12.6% of the total variability, in such case, the PC1 and PC2 are responsible for 39.5% of the total variance and are represented by the equations:

$PC1 = -0.297and - 0.230acv + 0.242san + 0.469qtz + 0.365qml + 0.366gne - 0.180met + 0.038mlg - 0.303apl - 0.227gdi - 0.218mgr + 0.269igr + 0.130sgr$

$PC2 = 0.327and + 0.158acv + 0.470san - 0.108qtz - 0.232qml + 0.334gne + 0.090met - 0.425mlg - 0.287apl - 0.349gdi + 0.140mgr - 0.190igr + 0.168sgr$

The scatterplot of PC1 and PC2 is organized in one single cluster (Fig. 07), but it still can be separated in two domains of points separated by the the origin of the PC1, with some overlapping around the PC1 origin and right below the PC2 origin. The identified domains represent different depositional systems, with the black filled points representing data collected in alluvial fan deposits in the Estância Santa Fé, Arroio Umbu and Pedra do Segredo formations and white filled points corresponding to data collected in fluvial deposits of the Estância Santa Fé, Serra dos Lanceiros and Pedra do Segredo formations. Besides the grouping related to the depositional setting, there is no clear individualization concerning the stratigraphic units, leading to the interpretation that the main factor that differentiates the provenance data is whether the source area is proximal (as in the alluvial deposits) or distal (as in the axial fluvial deposits with broader catchment areas).

The loading plot of PC1 and PC2 shows the importance of each of the provenance components in the data structure (Fig. 07). The provenance domain with positive PC1 values, related to fluvial deposits, is controlled mainly by lithotypes that have minor contribution in the total amount of data, like gneiss, vein quartz and quartz milonite. Such characteristic suggests that the main factor that differentiates fluvial provenance data is the variability of the provenance assemblage in each provenance site. Additionally, it can be said that the importance of lithotypes like gneiss and vein quartz is useful to illustrate the importance of distant source areas in the bulk provenance of fluvial deposits, given that gneiss sources, generally related to Don Feliciano Belt and Rio Vacacaí Terrane, do not crop out in the vicinity of the studied deposits. On the other hand, the provenance domain with negative PC1 values, related to alluvial fan deposits, has its importance represented by more representative lithoclasts, like andesite, rhyolite and metamorphic rocks, which in turn are more common lithotypes in the provenance assemblage, as a result of the mainly local source areas, and the less variable provenance, with minor or none of the lithoclasts related to more distant source areas.

The overlapping of the two mentioned domains may be explained as an effect of the reworking of alluvial deposits by the fluvial deposits, or simply by the fact that although the fluvial deposits have wider catchment areas, they still have the same common lithoclasts that act as source areas for the alluvial fan deposits.

Microscopic provenance

Provenance analysis in sandstones and conglomeratic sandstones were performed in samples collected throughout two columnar sections between the top of the Seival Formation and the first conglomerate levels of the Serra dos Lanceiros Formation. This specific stratigraphic interval has its importance stated by a major shift in the paleocurrents dispersion patterns between the Estância Santa Fé Formation and the top of the Serra dos Lanceiros Formation (Fig. 03), as well as the prominent change in the conglomerate provenance (Fig. 05), both suggesting the activation of a structural high to the east. The detailed character of this analysis aimed to determine the stratigraphic level corresponding to the beginning of the denudation of the Caçapava do Sul High, and its sedimentary contribution to the basin.

Thin sections of sandstones were analyzed following the Gazzi-Dickinson method (Ingersoll et al. 1988), through the counting of 300 points in 20 thin sections. In order to allow a better visualization of the results, a selected combination of components is represented in a line diagram adjacent to the columnar sections in Fig. 08.

The column "A " (Fig. 08) presents a sharp decrease in the proportion of volcanic lithoclasts and plagiarize in its intermediate interval accompanied by an important increase in the contribution of granitic lithoclasts and potassium feldspar, specially microcline, and some increment in metamorphic and sedimentary lithoclasts. Despite that, the column "B" do not present such sharp transition but shows a nearly continuous increase of granitic clasts until the point "B 10" (Fig. 08), where the granitic proportion jumps from nearly 20% to 30%, microcline fragments become more common, coinciding and there is an expressive fall in the contribution of volcanic lithoclasts and plagioclase, resembling the level corresponding to the increase in granitic contribution on column "A".

The granitic lithoclasts identified above such level were correlated directly to the Caçapava do Sul Granite, with the appearance of microcline and microcline bearing plutonic fragments, specially in the column "A", as determinant factors for the correlation with the granitic pluton. Therefore, the stratigraphic level that records the increment in granitic contribution in both sections is identified as equivalent to the start of contribution of the Caçapava do Sul High to the basin.

The differences in the provenance data between the two samples may be related to some differences in the catchment area for the deposits in each section. As long as the contribution of microcline or fragments that would be readily correlated to the Caçapava do Sul Granite is difficult to identify in the provenance of column "B", it can be said that another granitic source was feeding some parts of the basin by that time, probably one of the volcanic related plutons, like the Ramada stock. As the column "A" sandstones received few granitic clasts from such source areas, it is natural that the eventual input of the Caçapava do Sul Granite lithoclasts would be better noticed in the deposits of column "A" than in column "B".

Discussion

The here presented data strongly suggests that the onset of the denudation of the Caçapava do Sul High occurred during the deposition of the Serra dos Lanceiros Formation. The hypothesis of activity of the Caçapava do Sul High during the entire basin evolution, as suggested by Borba & Mizusaki (2003), is refuted by the provenance data and paleoflow patterns of the Estância Santa Fé Formation (Figs. 03 and 06), which do not include any eastward source rocks and suggests the absence of an structural high in the area that today encompasses the Caçapava do Sul High. Moreover, the paleocurrents found in the Seival Formation and in the lower Serra dos Lanceiros Formation do not show any important westward flow direction, as would be expected if a structural high was present to the east (Fig. 03). The appearance of lithoclasts that could be correlated to the rocks of the Caçapava do Sul High in thin sections from the upper part of the Serra dos Lanceiros Formation, as well as pebble lithologies identified in the first conglomerate level above this sandstones, is interpreted as evidence for the beginning of the contribution of the Caçapava do Sul High to the basin fill (Fig. 08). Such event can be attested by other evidences of an active high to the east, like the westward component in the paleocurrent pattern in the same stratigraphic level of the Serra dos Lanceiros Formation and latter on the Pedra do Segredo Formation (Fig. 03), and the progressive increase in Caçapava do Sul High lithoclasts content in the subsequent sedimentary units, specially in the Pedra do Segredo Formation (Fig. 05), that might have experienced a period of higher denudation of the structural high. The proposed hypothesis of the activation of a structural high that is internal to the basin during deposition brings a different perspective to the problem of the effects of tectonic activation in the sedimentary record of tectonically controlled basins.

The model proposed by Blair & Bilodeau (1988) that describes the instantaneous increase in the rate of subsidence during tectonic activation events for distensional, strike-slip and foreland basins, with a delayed increase in sedimentary input due to highlands denudation, points to the interpretation of coarse clastic wedges as a later consequence of the tectonic activity, whereas finer facies would be the imediate record of tectonism. This model has been widely applied in the interpretation of stratigraphic surfaces and stacking patterns in tectonically controlled basins (e.g. Heller *et al.* 1988, Hartley 1993, Castle 2001, Martins-Neto et al. 2001, Jo 2003, Capuzzo & Wetzel 2004).

Following the descriptions by Almeida et al. (2005) the basal surface of the Arroio Umbu Formation would be the period of higher accommodation generation of the upper succession of the Santa Bárbara Group, equivalent to the marine flooding surfaces in coastal systems proposed by Wagoner et al. (1988). In this way the basal surface of the Arroio Umbu Formation would be the most suitable level to represent the record of the onset of uplift of the Caçapava do Sul High according to the model by Blair & Bilodeau (1988), with the coarsening upward Pedra do Segredo Formation representing the later progradation of clastic wedges. However, the evidence of detritic contribution from the Caçapava do Sul high below this level and the coincidence of the beginning of such contribution with a coarse-grained level (Fig. 08) accompanied by the shift of the paleocurrent pattern (Fig. 03) reveals that particularities concerning a tectonic reactivation event may challenge the theoretic model.

The response to the Caçapava do Sul High activation is, therefore, a coarsening upward succession of pebbly sandstones. This can be explained by a possible decrease in the subsidence rates in the basin during the first phase of uplift of the Caçapava do Sul High, considering the thermal effect of the emplacement of the Caçapava do Sul pluton over a wider area than the occupied by the fault-bounded structural high of the latter stages. Consequently, as the subsidence rate decreases, the accommodation rates also fall and the coarser particles are able to reach greater distances (Marr et al. 2000, Paola 1988, Paola et al. 1992). The coarsening upward pattern observed through the Seival Formation and the Serra dos

Lanceiros Formation can thus be thought of as a result of incipient doming prior to the nucleation of the master fault, when an increase in the subsidence rates, such as predicted by the model by Blair & Bilodeau (1988), would finally occur. That increased subsidence interval would correspond to the Arroio Umbu Formation, and the following slow decrease in the subsidence rates, with greater tectonic stability and progradation of the clastic wedge basinwards, would be represented by the coarsening pattern of the Pedra do Segredo Formation.

Additionally, another early effect of the uplift of the Caçapava do Sul High could be an increase in the local sedimentary input, caused by the capture of the drainage system that feed the entire Camaquã Basin to the restricted Western Camaquã Sub-Basin or by the effect of the erosion of sediments previously deposited on the structural high, what would result in an sensible increase in the sediment input due the great erodibility of unlithified sediment.

Hence, it can be concluded that there is a straight relation between the uplift event of the Caçapava do Sul High and the changes in provenance and paleocurrent data, as well as the modifications in the depositional systems. Moreover, the data and interpretations here presented indicate that particularities in the tectonic events responsible for the uplift of structural highs could result in misinterpretations of the tectonic record of stratigraphic surfaces as a consequence of unpredicted effect, such as the uplift or the decrease in subsidence of different areas of the basin at different moments. It is worth to state that the model proposed by Blair & Bilodeau (1988) accounts for the reactivation of basin border faults, and not of inner structural highs, and thus do not consider changes in the sedimentary input that may result from local geographic changes, especially the increase in sedimentary input resulting from the erosion of unlithified sediments.

Conclusions

Depositional systems analysis integrated to paleocurrent measurements and provenance studies were performed in the expositions of the Santa Bárbara Group (Late Neoproterozoic, Southern Brazil), in the Western Camaquã Sub-basin, enabling the recognition of lateral and vertical depositinal systems variations attributable to the influence of tectonic activity during sedimentation. Continuous successions of alluvial fans indicate the presence of fault scarps at the western border of the basin since the onset of sedimentation, but the eastern border presents evidence of active faulting only in the upper succession. Further away from the basin borders, sedimentation was dominated by axial fluvial systems of intermittent or ephemeral nature, with evidence for highly variable discharges and periodic abandonment, as well as localized lacustrine deposition. Different proportions of coarse grained facies and of preservation of flood-plain fines define a initial retrograding cycle followed by two thousand-meter-scale progradational cycles bounded by a major flooding surface.

The hypothesis of uplift of the Caçapava do Sul High simultaneously to deposition of the Santa Bárbara Group in the Western Camaquã Sub-basin (Almeida 2001, 2005, Borba et al. 2008) was confirmed by means of systematic provenance analysis, both at the outcrop and microscope scales, which revealed the presence of lithoclasts derived from the structural high, such as low grade metassedimentary rocks and lithotypes related to the Caçapava do Sul granitic stock.

The normal character of the border fault responsible for the uplift of the structural high east of the basin, as well as of the post sedimentary fault that bounds the basin to the west, is attested by the lateral variation in the provenance data obtained in alluvial fan deposits, well illustrated by means of multivariate analysis, which ultimately demonstrates the direct correlation between the lithoclasts and lithotypes outcropping in adjacent areas (Fig. 06). These correlation is indicative of the absence of any significant lateral displacement between source areas and sedimentary deposits, thus indicating the absence of strike-slip movement of the border faults during and after sedimentation.

The stratigraphic level that records the onset of the detritic contribution of the Caçapava do Sul High is recognized in a coarsening upward succession of Serra dos Lanceiros Formation, below a regional flooding surface that would be the best candidate for the stratigraphic response to a event of tectonic activation according to current models. Such divergence from the model allows the recognition of particularities in the structural high uplift that resulted in progradation in the basin, thereby increasing the sedimentary input rate relative to the accommodation rate almost instantaneously.

The central position of the Caçapava do Sul granitic stock in its homonyms structural high together with its crystallization age, around 555-550 My (Sartori & Kawashita 1985, Nardi & Bitencourt 1989, Leite 1995), close to the estimated age for the beginning of the Santa Bárbara Group deposition, suggests that the granite placement is related to the uplift event.

The recognized progradation during the uplift of the structural high can be explained by a decrease in the subsidence rates caused by the doming of an area wider than the area limited by the further brittle faulting, by an increase in the sedimentary input during the first stages of the uplift caused by erosion of unlithified sediments deposited on the highland or by the capture of a major drainage system to the restricted area of the Camaquã Western Sub-Basin. A combination of some or all of these factors may also be considered.

All these hypotheses consider the particularities of the uplift of an inner structural high in a extensional basin, which contrasts with the existing models of sedimentary response of reactivation of basin-margin structural highs. However the possibility of increase in the sedimentary input due the erosion of sediments deposited over the structural high prior to the reactivation has implications even for basin-border faults, especially in situations of reactivation after the onset of thermal subsidence, which according to McKenzie (1978), imply an increase of the distensional basin area and deposition beyond the master fault responsible for mechanic subsidence.

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References

Almeida R.P. 2001. *Evolução tectono-sedimentar da Formação Santa Bárbara na Sub-bacia Camaquã Ocidental, RS*. Ms.C. thesis, Instituto de Geociências, Universidade de São Paulo, 160 p.

Almeida, R.P. 2005. *Tectônica e sedimentação do Ediacarano ao Ordoviciano: exemplos do Supergrupo Camaquã (RS) e do Grupo Caacupé (Paraguai Oriental)*. Ph.D. thesis, Instituto de Geociências, Universidade de São Paulo, 203p.

Almeida R.P., Janikian L., Fragoso-Cesar A.R.S., Fambrini G.L. 2010. The Ediacaran to Cambrian rift system of Southeastern South America: tectonic implications. *The Journal of Geology*. **118**: 145-161.

Blair T.C. 1999. Sedimentary processes and facies of the waterlaid Amil Spring Canyon Alluvial Fan, death Valley, California. *Sedimentology*, **46**: 913-940.

Blair T.C. & Bilodeau W. 1988. Development of tectonic cyclothems in rift, pull-apart and foreland basins: sedimentary response to episodic tectonism. *Geology*, **16**: 517-520

Borba A.W. & Mizusaki A.M.P. 2003. Santa Bárbara Formation (Caçapava do Sul, southern Brasil): depositional sequences and evolutin of an Early Paleozoic postcollisional basin. *Journal of South American Earth Sciences*, **16**: 365-380.

Borba A.W., Mizusaki A.M.P., Maraschin A.J. & Silva D.R.A. 2008. Santa Bárbara Formation (Early Paleozoic, Caçapava do Sul, southern Brazil): Petrographic and Sm–Nd isotopic provenance parameters. *Journal of South American Earth Sciences*, **26**: 485–497.

Capuzzo N. & Wetzel A. 2004. Facies and basin architecture of the Late Carboniferous Salvan-Dorénaz continental basin (Western Alps, Switzerland/France). *Sedimentology,* **51**: 675-697.

Castle 2001. Appalachian basin stratigraphic response to convergent-margin structural evolution. *Basin Research*. **13**: 397-418.

Dürr S. B. 1996. Provenance of Xigaze fore-arc basin clastic rocks (Cretaceous, south Tibet). *GSA Bulletin*. **108**(6): 669-684.

Fragoso-Cesar A.R.S., Fambrini G.L., Almeida R.P., Pelosi A.P.M.R., Janikian L., Riccomini C., Machado R., Nogueira A.C.R. & Saes G.S. 2000. The Camaquã extensional basin: Neoproterozoic to early Cambrian sequences in southernmost Brazil. *Revista*

Brasileira de Geociências, **30**(3): 438-441.

Gawthorpe R.L., Leeder M.R. 2000. Tectono-sedimentary evolution of active extensional basins. *Basin Research,* **12**: 195-218.

Hartley A.J. 1993. Sedimentological response of alluvial systems to source area tectonism: the Seilao Member of the Late Cretaceous to Eocene Purilactis Formation of northern Chile. In: M. Marzo & C. Puigdefábregas (eds.). *Alluvial Sedimentation, International Association of Sedimentologists Special Publication,* **17:** 489-500.

Heller P.L., Angevine C.L., Winslow N.S. & Paola C. 1988. Two-phase stratigraphic model of foreland-basin sequences. *Geology*, **16**: 501-504.

Ibbeken H. & Schleyer R. 1991. *Source and Sediment – A case study of provenance and mass balance at an active plate margin (Calabria, southern Italy)*. Springer-Verlag, Berlin-Heidelberg, 286 pp.

Ingersoll R.V., Bullard T.F., Ford R.L., Grimm J.P., Pickle J.D. 1988. The effect of grain size on detrital modes: a test on the Gazzi-Dickinson point-counting method. *Journal of Sedimentary Petrology*. **54**: 103-116

Janikian L., Almeida R.P., Trindade R.I.F., Fragoso-Cesar, A.R.S., D'Agrella-Filho M.S.. Dantas E.L. & Tohver E. 2008. The continental record of Ediacaran volcano-sedimentary successions in southern Brazil and their global implications. Terra Nova **20**(4): 259–266.

Jervey M. T. 1988. Quantitative geological modelling of siliciclastic rock sequences and their seismic expression. *In*: Wilgus C.K., Hastings B.S., Kendall C.G.ST.C., Posamentier H.W., Ross C.A. & Van Wagoner J.C.). Sea-level Changes – An Integrated Approach.Society of Economic Paleontologists and Mineralogists Special Publication. **42:** 47-70.

Jo H.R. 2003. Depositional environments, architecture, and controls of Early Cretaceous non-marine successions in the northwestern part of Kyongsang Basin, Korea. *Sedimentary Geology,* **161**: 269-294.

Jones A. P. 2000. Late quaternary sediment sources, storage and transfers within mountain basins using clast lithological analysis: Pineta Basin, central Pyrenees, Spain. Geomorphology. 34:145-161.

Leeder M.R. & Gawthorpe R.L. 1987. Sedimentary models for extensional tilt-block / half-graben basins. In: M.P. Coward, J.F. Dewey, P.L. Hancock. Continental Extensional

Tectonics. Geological Society Special Publication 28, 139-152.

Leite J.A.D. 1995. Datação SHRIMP U/Pb em zircões e o exemplo de dois corpos graníticos contrastantes no Escudo Sul-Riograndense. *In*: SBG, IV Simpósio Sul-Brasileiro de Geologia/I Encontro de Geologia do Cone Sul, Porto Alegre, *Boletim de Resumos*, p.5-12.

Marr J.G., Swenson J.B., Paola C. & Voller V.R. 2000. A two-difusion model of fluvial stratigraphy in closed depositional basins. *Basin Research*, 12: 381-398.

Martín-Fernandez J.A., Braceló-Vidal C. & Pawlowsky-Glahn V. 2003. Dealing With Zeros and Missing Values in Compositional Data Sets Using Nonparametric Imputation. Mathematical *Geology*. **35**(3): 253-278.

Martins-Neto M.A., Pedrosa-Soares A.C., Lima S.A.A. 2001. Tectono-sedimentary evolution of sedimentary basins from Late Paleoproterozoic to Late Neoproterozoic in the São Francisco craton and Araçuaí fold belt, eastern Brazil. *Sedimentary Geology,* **142**: 343-370.

McKenzie D.P. 1978. Some remarks on the development of sedimentary basins. Earth and Planetary Science Letters, **40**: 25-32.

Nardi L.V.S. & Bitencourt M.F. 1989. Geologia, petrologia e geoquímica do Complexo Granítico de Caçapava do Sul. *Revista Brasileira de Geociências*, **19**: 153-169.

Paim P.S.G. 1994. Depositional Systems and Paleogeographical Evolution of the Camaquã and Santa Bárbara Basins, Brazil. Phil. Doctor Thesis, Oxford. v.I, 277 p.

Paim P.S.G., Lopes R.C. & Chemale Jr. F. 1995. Aloestratigrafia, sistemas deposicionais e evolução paleogeográfica da Bacia do Camaquã -Vendiano Superior/ Ordoviciano Inferior do RS. *In*: XIV Simpósio Sul-Brasileiro de Geologia, Encontro Geologia Do Cone Sul,1, Porto Alegre, , SBG. Núcleo RS, *Boletim de Resumos Expandidos* ,p. 39-50.

Palarea-Albaladejo J., Martín-Fernandez J.A., Gomes-Garcia J. 2007. A Parametric Approach for Dealing with Compositional Rounded Zeros. Mathematical Geology. 39: 625–645

Paola C. 1988. Subsidence and gravel trasport in basins, In: Kleinsphen K.L. & Paola C. New perspectives in Basin Analysis. Springer-Verlag, New York. p. 231-243.

Paola C., Heller P.L., Angevine C.L. 1992. The large-scale dynamics of grain-size variations in alluvial basins I – Theory. Basin Research, 4: 73-90.

Pawlowsky-Glahn V. & Egozcue J.J. 2006. Compositional data and their analysis: an introduction. Geological Society of London Special Publications. 264:1-10

Posamentier H.W., Jervey M.T., Vail P.R. 1988. Eustatic controls on clastic deposition I – conceptual framework. In: Sea-level Changes – An Integrated Approach (Ed. by Wilgus C.K., Hastings B.S., Kendall C.G.ST.C., Posamentier H.W., Ross C.A., Van Wagoner J.C.) Society of Economic Paleontologists and Mineralogists Specal Publication, 42:109-124.

Ribeiro M., Bocchi P. R., Figueiredo Filho P. M., Tessari R.I. 1966. Geologia da Quadrícula de Caçapava do Sul, Rio Grande do Sul. Rio de Janeiro,DNPM/DFPM, 232 p. (Boletim 127).

Roberts S.J., Hodgson D. A., Bentley M. J., Smith J. A., Millar I. L., Olive V. & Sugden D. E. 2008. The Holocene history of George VI Ice Shelf, Antarctic Peninsula from clast-provenance analysis of epishelf lake sediments. *Palaeogeography, Palaeoclimatology, Palaeoecology.* **259**: 258-283.

Robertson J.F. 1966. Revision of Stratigraphy and nomenclature of rock units in Caçapava-Lavras Region. *Notas e Estudos*, IG-UFRGS, Porto Alegre, **1**(2): 41-54.

Sartori P.L.P & Kawashita K. 1985. Petrologia e geocronologia do Batólito Granítico de Caçapava do Sul. In: SBG, II Simpósio Sul-Brasileiro de Geologia, Florianópolis, Anais, p.102-115.

Shanley K.W. McCabe P. J. 1994. Perspectives on the sequence stratigraphy of continental strata. *American Association of Petroleum Geologists Bulletin 78* (4): 544-568.

Soliani Jr. E., Koester E., Fernandes L.A.D. 2002. A Geologia Isotópica do Escudo Sul-rio-grandense – Parte II: os dados isotópicos e interpretações petrogenéticas. *In*: Holtz M. & DeRos L.F. (eds.) - Geologia do Rio Grande do Sul. CIGO/UFRGS. P:231-274.

Wagoner J.C., Posamentier H.W., Mitchum R.M., Vail P.R., Sarg J.F., Loutitt T.S. & Handerbol J. 1988. An overview of the fundamentals of sequence stratigraphy and key definitions. In: Sea-level Changes – An Integrated Approach (by Wilgus C.K., Hastings B.S., Kendall C.G.ST.C., Posamentier H.W., Ross C.A., Van Wagoner J.C.) Society of Economic *Paleontologists and Mineralogists Special Publication,* **42***:* 30-45.

Wright V.P. & Marriot S.B. 1993. The sequence stratigraphy of fluvial depositional systems: the role of floodplain sediment storage. *Sedimentary Geology*, **86**: 203-210.

Tables

Code	Facies	Description	Interpretation
C1	Conglomerates interstratified with sandstones	Conglomerates interstratified with coarse sandstones, in centimetric to decimetric pairs. Grains range from coarse sand to cobble, with rare boulders. Clasts are subangulose to subrounded. Layering is due to alternation between sandy and pebbly strata.	Products of the destabilization of upper-flow regime antidunes during sheet-flood events in alluvial fans (Blair & McPherson 1994, Blair 1999).
C2	Stratified conglomerate	Pebble to cobble conglomerates and pebbly sandstones disposed in metric tabular layers, with clasts imbricated parallel to the A-B plane. Stratification is crude, marked by the aligment of larger clasts.	Deposition from plane-bed or low relief bedforms in fluvial streams.
C3	Tabular cross stratified conglomerate	Conglomerates and pebbly coarse sandstones with medium scale tabular cross stratification. Clasts range from 3 to 15 cm, with extreme in 20 cm, and are subangulose to subrounded.	Migration of dunes and bars in bed load dominated fluvial streams.
C4	Massive conglomerate	Massive, clast-supported conglomerates with larger clasts ranging from 20 to 100 cm, and finner fraction of feldspathic coarse, poorly sorted sand. Provenance is local and the clast shape is function of its litotypes (rounded granites and angular low grade metamorphics).	Non-cohesive debris flow with few matrix (sensu Shultz 1984).
D	Massive diamictites	Massive diamictites with clasts ranging from clay to boulder, in lenticular beds with variable amount of coarse fragments. Provenance is mono to oligomitic. Rare occurence, restricted to some locations in the vicinity of the Caçapava do Sul High.	Debris flows.
S1	Trough cross stratified sandstones	Sandstones and conglomeratic sandstones with medium to small scale trough cross stratification and immature composition. Occur in thick homogeneous deposits with few conglomeratic levels. May show deformation due to current shear.	Deposits of migrating subaqueous dunes of sinuous crests
S2	Tabular cross stratified sandstones	Feldspathic sandstones with tabular cross stratification in medium to small scale layers.	Deposits of migrating subaqueous dunes of nearly straight crests.
S3	Planar stratified sandstones	Medium to coarse arkosean sandstones with plane parallel lamination in decimetric tabular layers. Frequently with primary current lineation.	Migration of low-relief ripples in upper-flow conditions (bedload sheets sensu Best and Bridge, 1992) .
S4	Low angle cross stratified sandstones	Fine to medium-grained, well-sorted sandstones with low angle cross stratification in decimetrinc to metric sets. Primary current lineation is a common feature.	Migration bedforms under flows in the transition between lower and upper-stage (Fielding, 2006)
S5	Massive sandstones	Structureless feldspathic sandstones often with sparse granule and pebble. The facies occurs as decimetric and less frequently metric layers, sometimes with remaining contorted lamination marked by mud films.	Liquefaction and obliteration of hidrodynamic structures.
S6	Sandstones with climbing ripples	Medium to fine grained micaceous sandstones with asymmetric climbing ripples.	Migration of current ripples with deposition both from traction and suspension.
S7	Sandstones with ripple marks	Micaceous fine sandstones with preserved assimetric ripple marks, often covered by mud-drapes. Sometimes on top of climbing-ripple sets.	Preservation of bedforms (current ripples) by cessation of current and subsequent covering by settled fine particles.
H	Heterolithic siltstones and sandstones	Intercalation between laminated sandstone and siltstone in milimetric to centimetric layers with tens to hundreds of meters in width. Sandy strata are planar-stratified or show ripple marks and sometimes climbing ripples, with deposition of the muddy siltstones in the ripple troughs.	Alternation between deposition of material from traction and from suspension in stagnant water, revealing intermitent flow
M1	Massive mudstones	Massive sandy mudstones and muddy sandstones, micas and rare granules. Occur in decimetric layers with tens of meters in width.	Cohesive gravitational flows, distal in relation to the diamictite facies or with no available pebbly fraction.
M2	Laminated siltstones and fine sandstones	Fine grained lithotypes, mainly siltstone but also fine to very fine micaceous sandstones and rare mudstones, with planar lamination. This facies occurs in centimetric to decimetric tabular layers, rarely lenticular.	Settling of fine particles from suspension.
M3	Mudcracked siltstones and mudstones	Micaceous siltstones and mudstones in milimetric to centimetric layers with mudcracks filled by medium to coarse sand. Locally the edges of the mudcracks may be curved, forming mud curls.	Subaereal exposition of settling deposits, with consequent desiccation of clay minerals. It suggests short-lived subaerial exposition without significant erosion before deposition of the following layer.

Table 01: Description and interpretation of the sedimentary facies comprised by the Santa Bárbara Group

Code	Facies Association	Description	Interpretation
FA1	Alluvial Fans	Homogeneous successions hundreds of meters thick, dominated by facies C1, with local occurrence of C2 and C3 in scour-based, channelized metric beds. Rare successions dominated by diamictites are found where provenance is mostly of volcanics and metassedimentary rocks.	Recurrence of conglomeratic sheet-floods in alluvial fans and minor reworking of fan-tops by channelized currents after the major floods. Local dominance of debris-flows is controlled by the availability of mud in the sources.
FA2	Pebbly fluvial deposits	Homogeneous successions, hundreds of meters thick, dominated by pebbly sandstones of facies S1 and, to a lesser degree, S2. Isolated, scour-based lenses of C3 may mark the base of decametric finning-upward cycles which sometimes are capped by discontinuous tabular beds of facies S3 and S4.	The dominance of facies formed by migration of pebbly sand-dunes suggests deposition by fluvial streams. Nevertheless, the absence of recognizable macroforms and the presence of finning-upward cycles topped by upper-flow stage facies suggests shallow and broad channels with high discharge variation.
FA3	Sandy fluvial deposits	Tens to hundreds of meters-thick successions composed of metric, scour-based cycles of sandy cross-stratified facies (S1 and minor S2) passing to plane-bedded sandstones (S3) and minor S4.	Finner-grained fluvial systems characterized by high discharge fluctuation, with deposition of lower-stage bedforms during the peak flow (when channels are deeper) and subsequent deposition in transitional to upper-stage flow in fast, poorly confined shallow currents during the wanning of flood.
FA4	Fluvial Flood Plains	Tens of meters thick successions composed of metric to decimetric, scour-based cycles of sandy to pebbly cross-stratified (S1 and S2) and plane-bedded facies (S3 and S4), passing to fine-grained deposits (mostly H) with the frequent occurrence of exposure surfaces (M3) at the top of each cycle. Isolated metric bodies composed mainly of intercalations of M2, S6 and H occur between some cycles. Facies M1 and S7 are also found.	Deposition in intermitent or ephemeral flood-plains, fed by episodic floods and characterized by recurrent abandonment and subaerial exposition of broad areas, and local preservation of small ponds in depressions, where settling of fine particles took place.
FA5	Lacustrine Deposits	Homogeneous successions, tens of meters thick, and atteraly continuous for thousands of meters composed mainly by settling deposits of facies M2 and minor intercalations of tabular, centimeter-thick beds of S6 and S5.	Perennial lacustrine deposits.

Table 02: Description and synthesis of the facies association found in the Santa Bárbara Group.

Figures

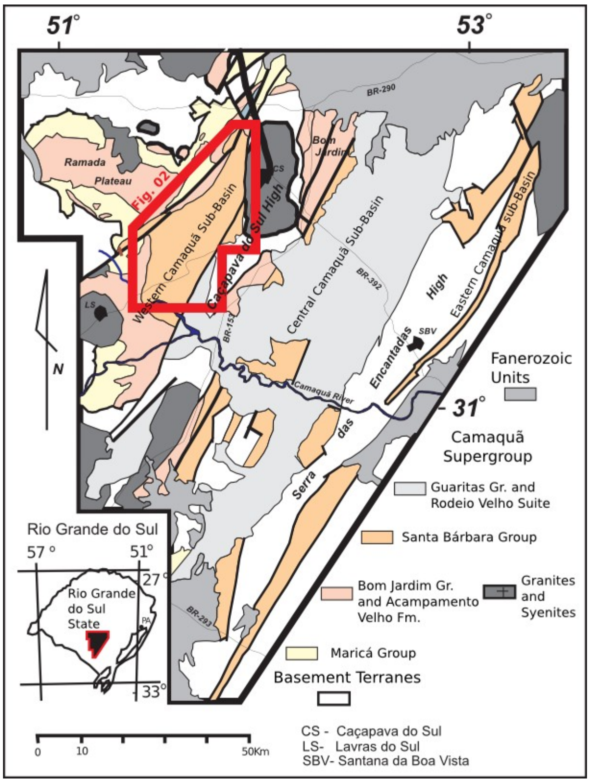

Fig. 01 – Simplified geological setting of the Camaquã Basin and surroundings.

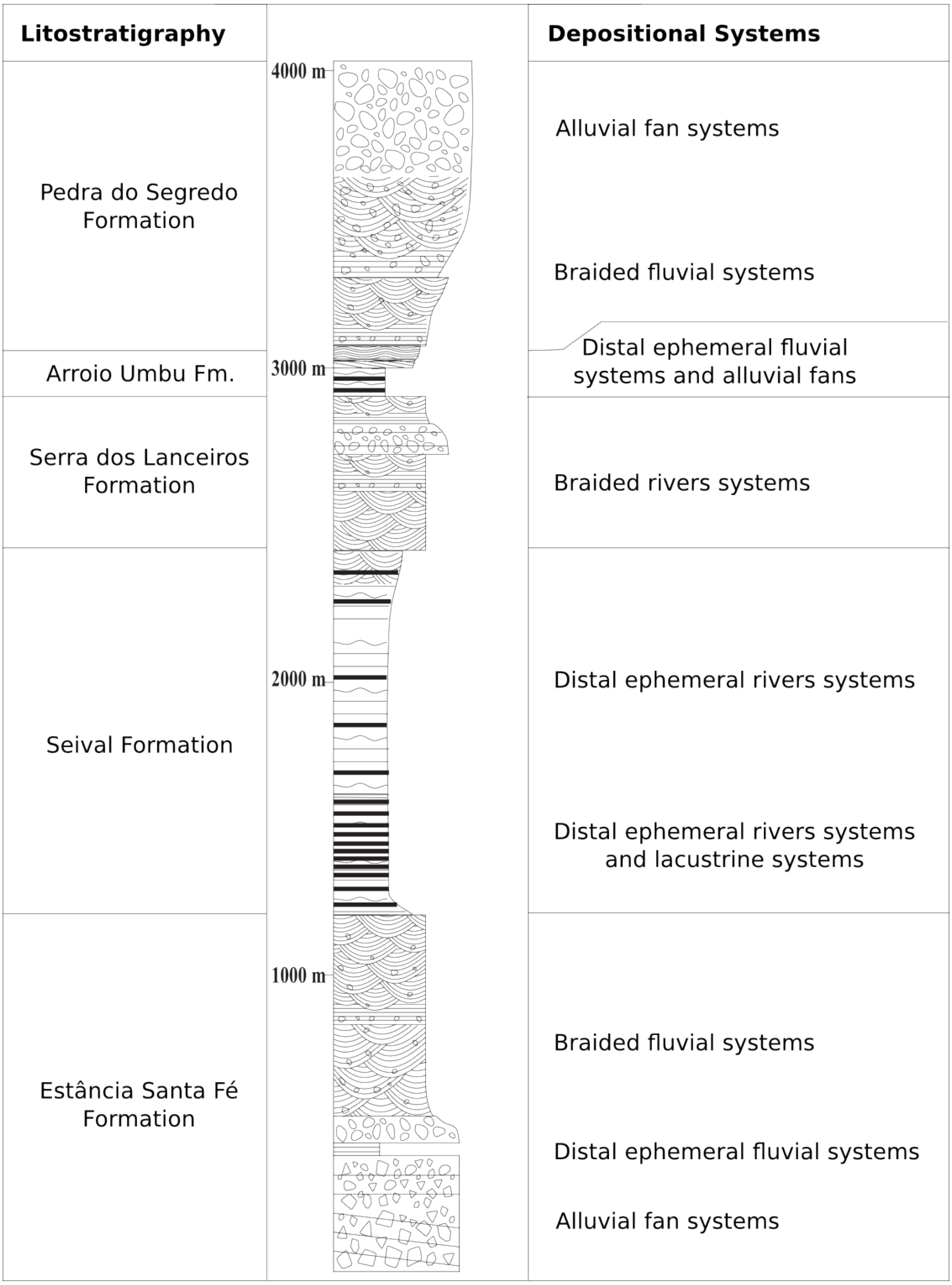

Fig. 02 – Composed columnar section of the Santa Bárbara Group, enumerating the sedimentary units and depositional systems comprised by each sedimentary unit.

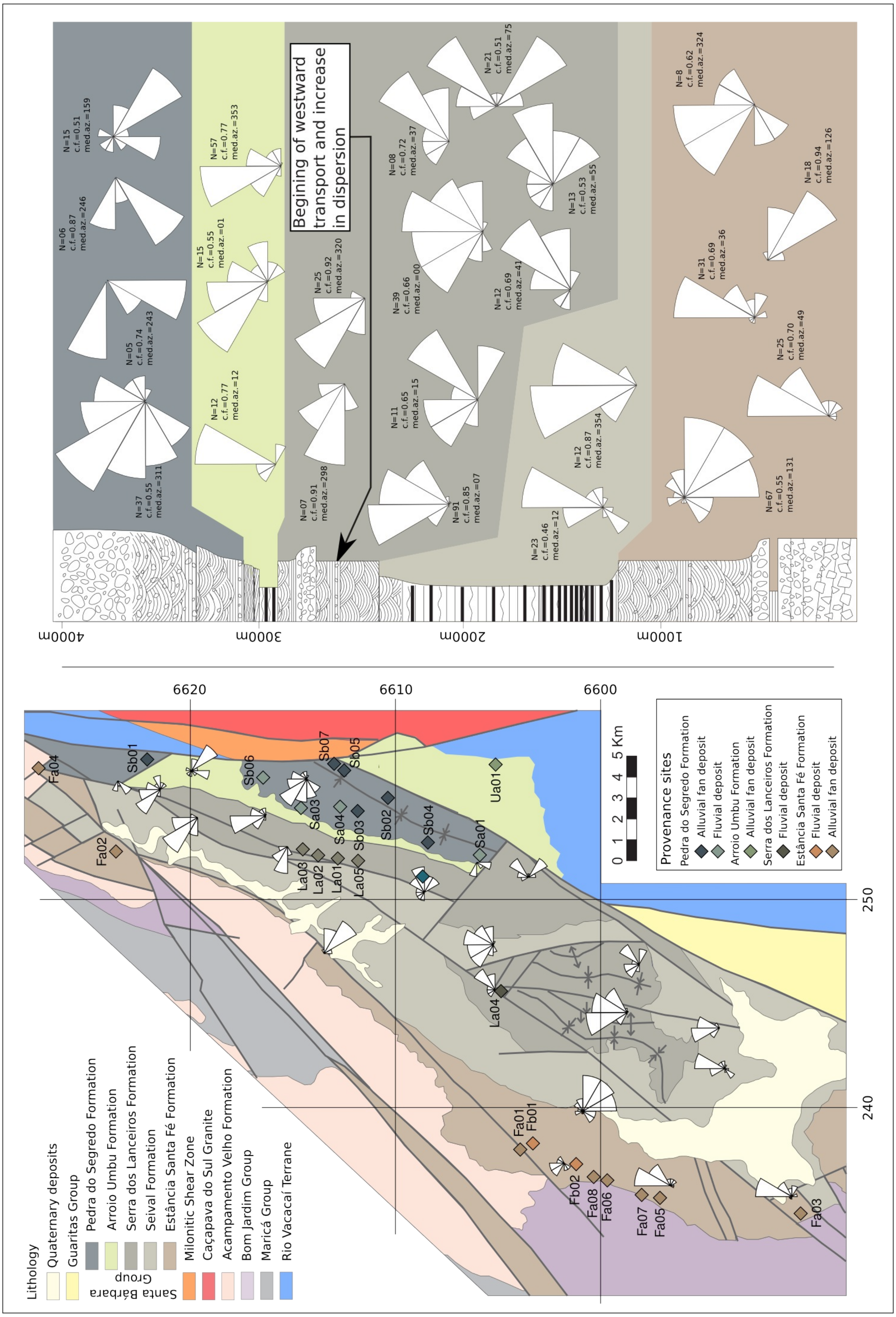

Fig. 03 – Area distribution and stratigraphic position of the paleocurrent data in the Santa Bárbara Group. Special attention must be made for the shift in paleocurrents after top of the Serra dos Lanceiros Formation. Geological map modified from Almeida (2001).

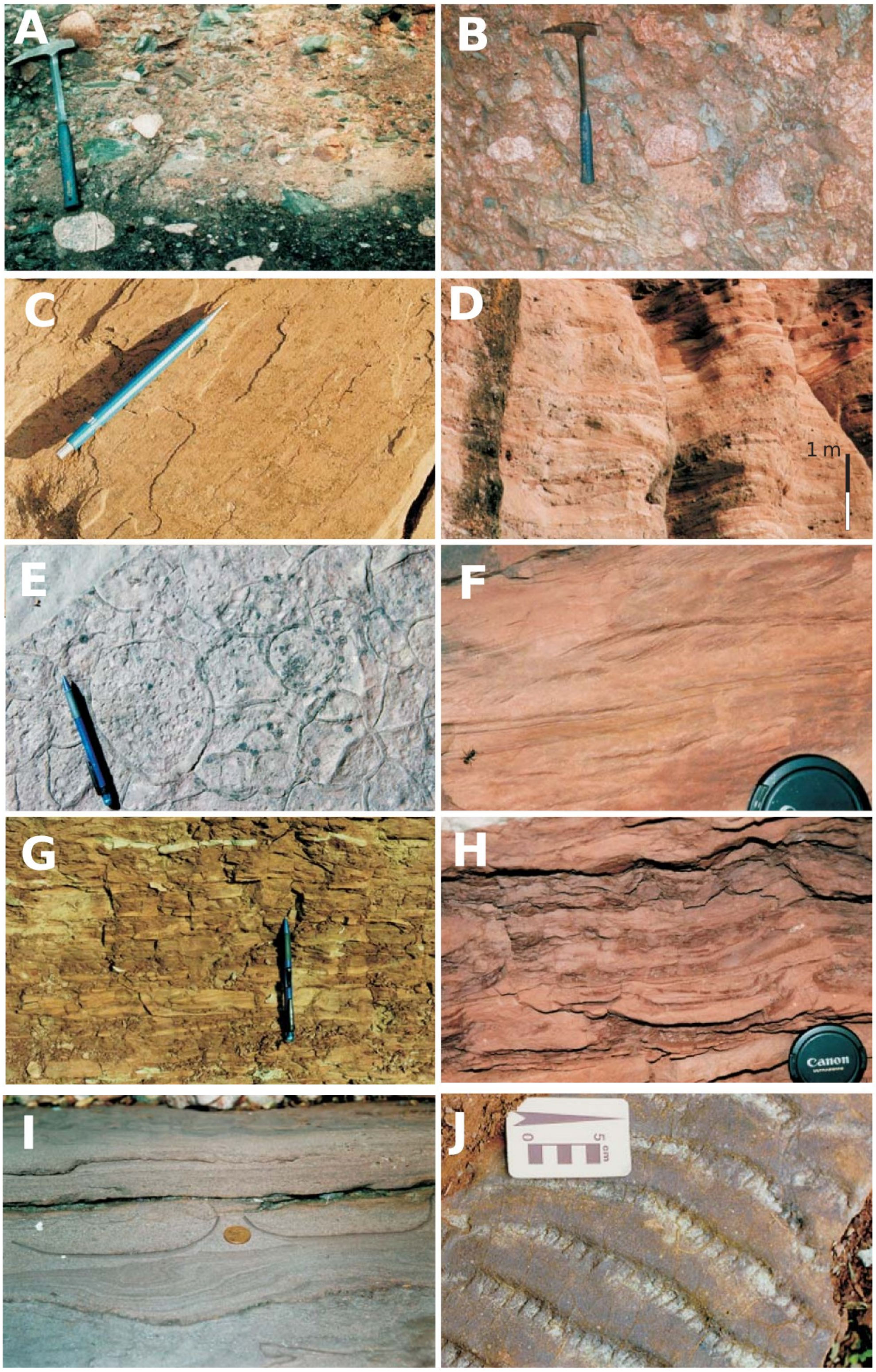

Fig. 04 – Plate with the main sedimentary facies described in the Table 01. A – C1 facies; B - C4 facies, with significant contribution of phyllites and granitic lithoclasts from the Caçapava do Sul High; C - S3 facies with primary current lineation; D – S1 facies; E – Mudcracks (facies M3) with raindrop marks; F – S6 facies; G – M2 facies interlayered with levels of S6; H – Convoluted H facies; I – M3 facies with mud curls; J – S7 facies, with interference of smaller ripplemarks.

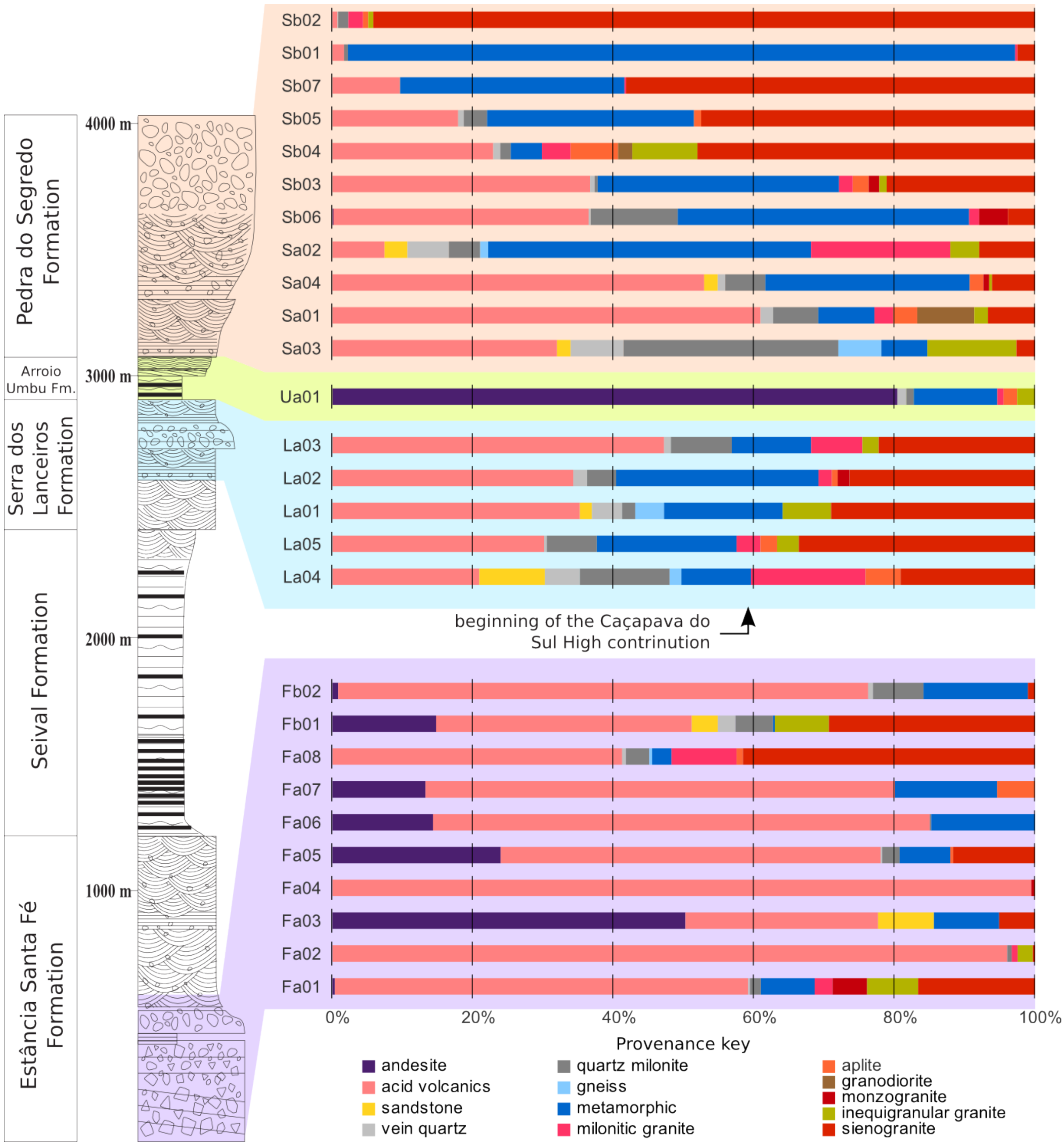

Fig. 05 – Stratigraphic position of the provenance data collected in conglomerates of the Santa Bárbara Group. Special attention has to be made for the progressive increase in granitic lithoclasts in the top units of the Santa Bárbara Group.

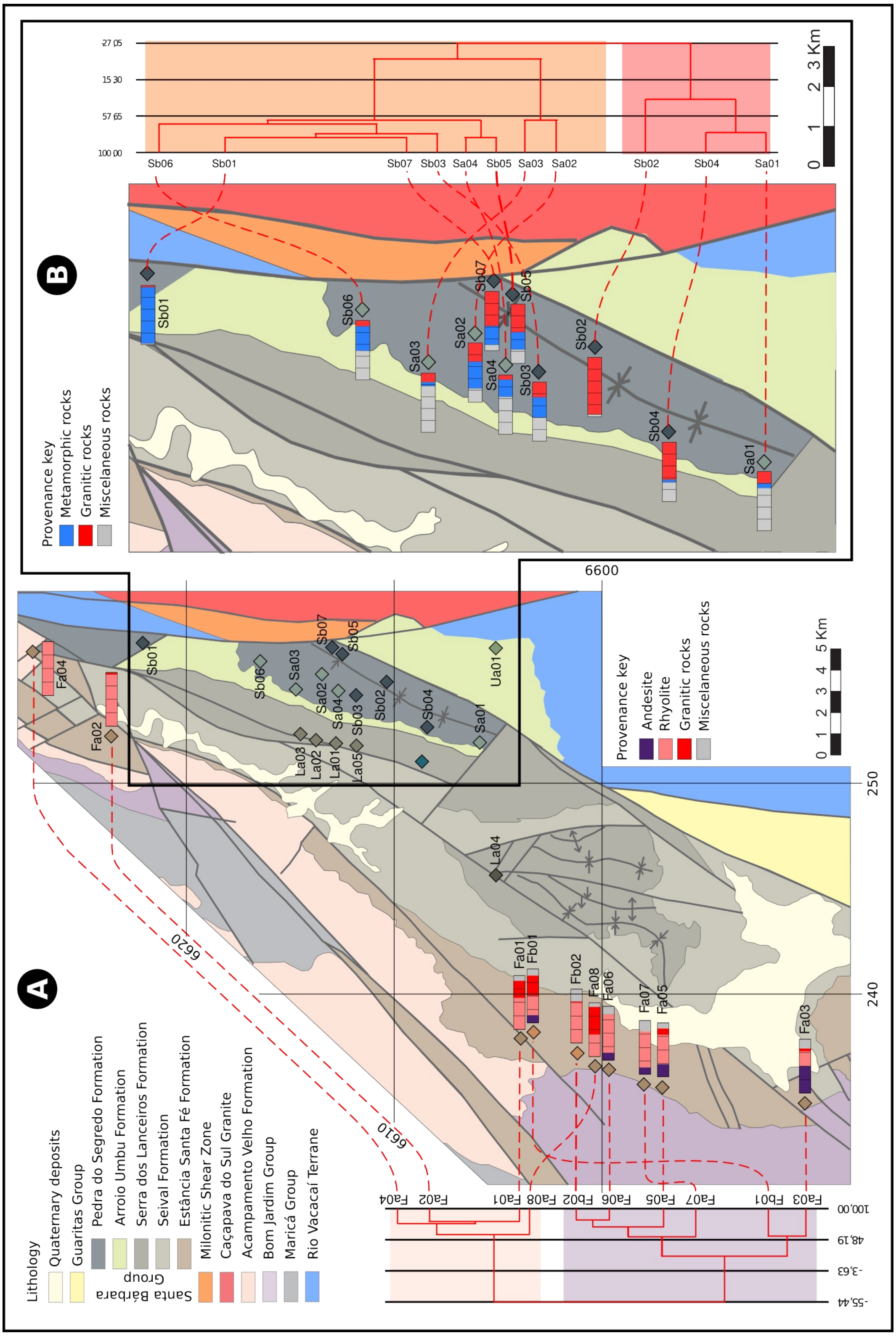

Fig. 06 – Visual resume of the matching between the provenance data and the Santa Bárbara Group nearby source rocks. A: dendogram and site distribution for the Estância Santa Fé Formation; B: dendogram and provenance site distribution for the Pedra do Segredo Formation. The dendograms were constructed using the square euclidean distance measure combined with Ward linkage. Geological map modified from Almeida (2001).

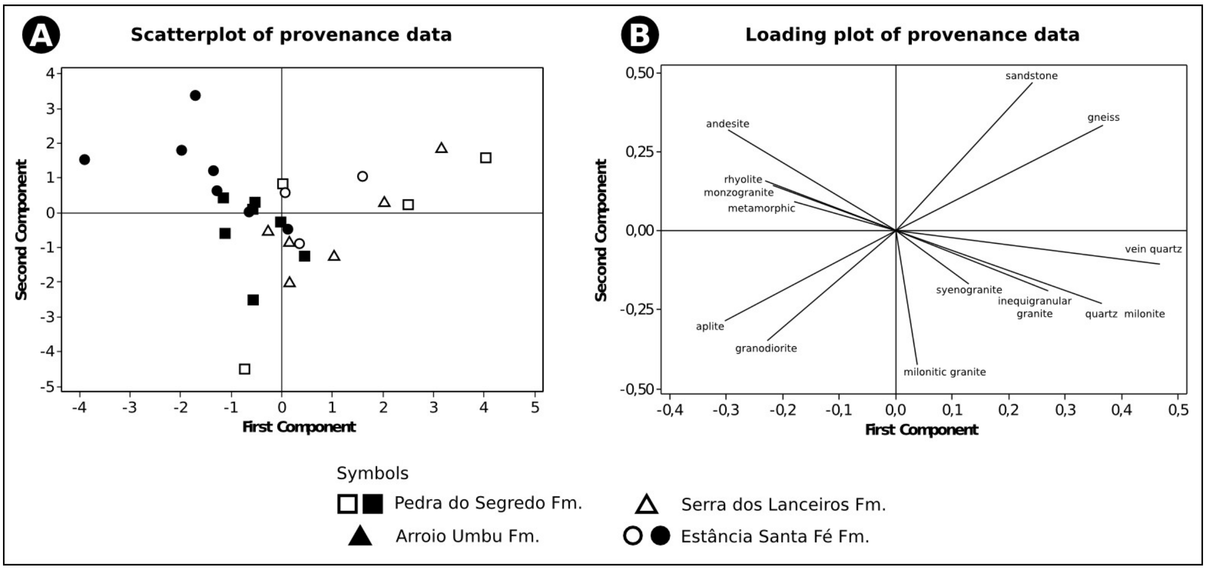

Fig. 07 – Scatterplot and Loading Plot for the macroscopic provenance analyses. Closed symbols represent data collected in alluvial fan deposits and open symbols represent data obtained in fluvial deposits.

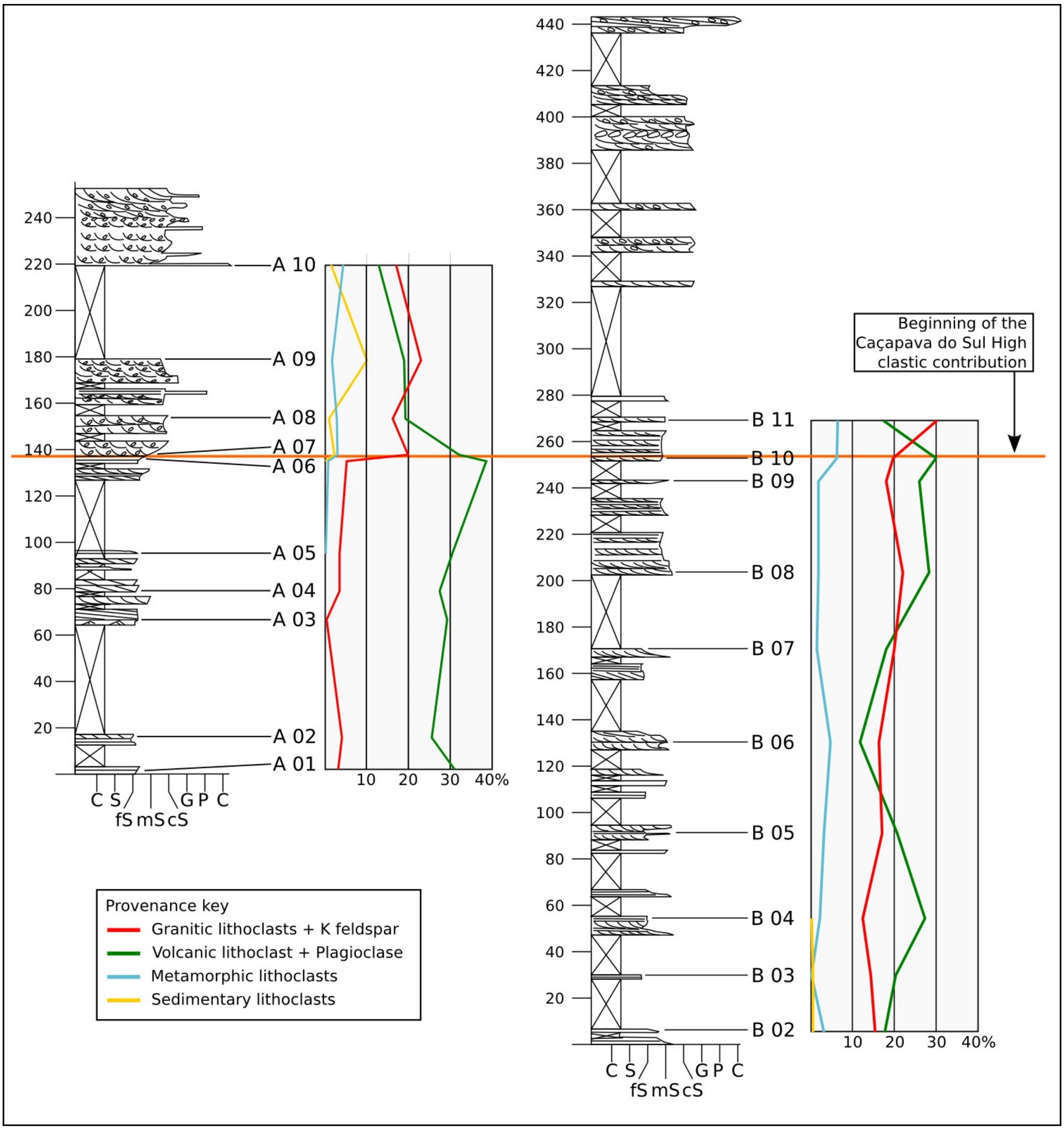

Fig. 08 – Evolution curves of microscopic provenance data for the top of the Serra dos Lanceiros Formation. Special attention must be made for the interval representing the beginning of the structural high contribution. Curves were constructed with selected components from the petrographic provenance analysis.