Neoproterozoic to Early-Cambrian volcano-sedimentary successions of the Camaquã Basin, Rio Grande do Sul State, Brazil

Liliane Janikian*, Renato P. de Almeida*, A. Romalino S. Fragoso-Cesar*, Veridiana T. de S. Martins*, Manoel S. D'Agrella Filho**, Ian McReath*, Elton L. Dantas***

*Instituto de Geociências, Universidade de São Paulo (USP), Rua do Lago, 562, São Paulo-SP, 05508-080, Brazil, lijanikian@yahoo.com.br
; **Instituto de Astronomia, Geofísica e Ciências; Atmosféricas, Universidade de São Paulo (USP); Rua do Matão, 1226, São Paulo, SP, 05508-080, Brazil
***Instituto de Geociências, Universidade Federal de Brasília (UnB), Brasília, DF, 70910-900, Brazil
Supported by FAPESP (Fundação de Amparo à Pesquisa do Estado de São Paulo)

The Camaquã Supergroup is constituted by siliclastic and volcano-sedimentary successions of Neoproterozoic to Early Paleozoic age that crop out in the south-central region of Rio Grande do Sul State (southern Brazil). It comprises five units, from base to top: Maricá Group (marine and fluvial clastic deposits), Bom Jardim Group (basic to acid volcanic rocks and lacustrine clastic successions), Acampamento Velho Formation (mainly acid volcanic and volcaniclastic rocks), Santa Bárbara Group (post-volcanic continental siliclastic successions) and Guaritas Group (aluvial and aeolian successions), intruded by the Rodeio Velho Intrusive Suite. These units are exposed in three sub-basins separated by basement highlands, each one representing a distinct episode of tectonic subsidence with different depocentre and basin configuration.

This paper presents new geochronological data, a revision of the stratigraphy and an interpretation of the paleoenvironmental evolution of the volcano-sedimentary successions of the Camaquã Supergroup: the Bom Jardim Group, the Acampamento Velho Formation and the Rodeio Velho Intrusive Suite.

Bom Jardim Group

Because of the rapid lateral variation of depositional environments typical of small fault-bounded basins, the Bom Jardim Group is characterized by lithologic variation among different regions. As the depocentre and basin area have changed trough time, there is a marked pattern of onlap towards the west in the period of deposition of the Bom Jardim Group and the Acampamento Velho Formation. Thus, the older successions of the Bom Jardim Group occur only in the Central Camaquã Sub-basin, and the younger ones overlay directly the Maricá Group or the basement of the Camaquã Basin in the Western Camaquã Sub-basin. The Bom Jardim Group is divided into three formations, following the stratigraphic column proposed by Janikian *et al.* (2003):

Cerro da Angélica Formation

Having its occurrences restricted to the Central Camaquã Sub-basin, the Cerro da Angélica Formation is approximately 1500m thick at its northernmost exposure (Bom Jardim region) and 1700m thick at the southernmost (Casa de Pedra region). In the Bom Jardim region, the unit is composed of rhythmic centimeter-scale cycles of sandstones, siltstones and mustones locally cut by channel-shaped bodies of pebbly sandstones, interpreted as lobe and channel deposits of sub-lacustrine fans which overlay deltaic fans of the base of the unit. Volcaniclastic rocks formed by the intrusion of basic magma in unlithified sediment (peperite) are also found. In the Casa the Pedra

region, the correlated succession is represented by proximal facies, mostly conglomerates and pebbly sandstones of alluvial fans and fan-deltas.

Provenance analysis of the Cerro da Angélica Formation revel source-areas dominated by granitic lithologies and low-grade metassedimentary rocks of the Dom Feliciano Belt and the Rio Vacacaí terrane. Metacarbonate clasts are found in alluvial fan deposits in the Casa de Pedra region and are relatable to small occurrences of carbonates in the basement located west of the Central Camaquã Sub-basin. As the area of occurrence of carbonate clast bearing alluvial fans is restricted to the vicinity of the basement carbonate exposures, the basin border faults are thought to have been mainly normal, leading to few lateral displacement between the source areas and the corresponding deposits.

The correlation between the two areas is based on the recognition of bounding surfaces, depositional sequences and systems tracts, and is corroborated by a U-Pb age of 593,7±2,8 Ma, obtained in a granitic apophysis that cuts the top of the succession of the Casa de Pedra region, which is close to the crystallization age of the Hilário Formation that overlays the succession of the Bom Jardim region.

Hilário Formation

The Hilário Formation (Ribeiro & Fantinel 1978) is approximately 1000m thick in the Bom Jardim region (northern portion of the Central Camaquã Sub-basin) and over 2500m thick in the Lavras do Sul region (southern portion of the Western Camaquã Sub-basin), at the type-area of the unit. It is constituted by volcanic rocks of basic, intermediate and acid composition (basalts, latite-basalts, latites, andesites and rhyolites) placed in subaquous environments in the Bom Jardim region and subaereous environments in the Lavras do Sul region (Nardi & Lima 2000). Related pyroclastic rocks are also present (lapilli-tuffs and coarse-grained lithic and vitric tuffs), formed by primary pyroclastic flow processes, secondary gravity flows or water settling.

In the Bom Jardim region, those volcanigenic rocks are interbedded with rhythmic successions of pelites and fine-grained sandstones deposited in a lacustrine pro-delta environment.

The great difference in thickness between the volcanic and pyroclastic successions of the two regions suggest that the Lavras do Sul region was closer to the volcanic centers and the Bom Jardim region was nearer to the basin depocentre, with less contribution of volcanic flows in a lacutrine pro-delta environment.

In the Lavras do Sul region, Ar-Ar plagioclase analysis of the volcanic rocks revel a crystallization age of 590±6 Ma for a sample below the main pyroclastic deposits and ages of 588±7 Ma and 586±8 Ma for two samples of the upper portion of the unit. U-Pb ages of pyroclastic deposits of the Hilário Formation in the Bom Jardim region show compatible results, with crystallization ages of 589±5,3 Ma and 590,5±5,7 Ma.

Picada das Graças Formation

The Picada das Graças Formation overlays the Hilário Formation in the Bom Jardim region, where it is approximately 1800m thick, and was deposited directly over the Maricá Group in the northern portion of the Western Camaquã sub-basin (Serra do Espinilho region), where it is approximately 700m thick.

In both sub-basins, the lower portion of the unit is characterized by rhythmic layers of fine-grained sandstones, siltstones and mudstones, deposited in lacustrine pro-delta environments, overlaid by thick conglomeratic and sandy successions of delta front environment.

The upper portion of the unit shows latteral variation between the sub-basins. In the Central Camaquã Sub-basin, it is constituted by pebbly sandstones and sandstone-siltstone successions of river-dominated deltaic environment. In the Western Camaquã Sub-basin, the same stratigraphic

level is characterized by fluvial conglomerates that gradually pass to fluvio-deltaic sandstones and siltstones.

This upper portion of the Picada das Graças Formation marks the progradation of river-dominated deltas and the cessation of border-fault induced proximal deposits, suggesting a post-rift stage.

Acampamento Velho Formation

With occurrences restricted to the Western Camaquã Sub-basin, the Acampamento Velho Formation (*sensu* Ribeiro & Fantinel 1978) is composed mainly of volcaniclastic and volcanic rocks of acid composition, formed in subaereous environments, and minor andesitic rocks. The unit is approximately 600m thick and is in angular unconformity with the Bom Jardim and Maricá groups.

The lower succession of the Acampamento Velho Formation is composed of approximately 100m thick coarse-grained vitric, lithic and crystal moderately to strongly welded tuffs, formed by pyroclastic flows. Those coarse-grained tuffs are gradually overlaid by 15m of lapilli tuffs in massive tabular beds, some levels being moderately to strongly welded. Tuff-breccias occur above the lapilli tuffs, constituting a succession of approximately 200m dominated by coarse grained pyroclastic deposits composed of lithic fragments (mainly tuffs and acid volcanic rocks).

The upper portion of the Acampamento Velho Formation is characterized by acid volcanic rocks, mainly rhyolites, that reach 150m in the Cerro do Bugio area. Above the main acid volcanic succession, new reworked lapilli tuffs (approximately 50m thick) and andesites occur.

A crystallization age of 574±7 Ma for the Acampamento Velho Formation was obtained by U-Pb analysis of rhyolites.

Rodeio Velho Intrusive Suite

Sub-volcanic rocks of intermediate to basic composition intrude all stratigraphic levels of the Camaquã Supergroup, even the Guaritas Group. These rocks have been mistaken for the Hilário Formation in early works (Robertson 1966) but they register a younger magmatic event related to the subsidence cycle of the Guaritas Group. Ar-Ar whole rock step heating ages of the Rodeio Velho Intrusive Suite at a location where it intrudes the Guaritas Group point a crystallization age of 535±8 Ma (unpublished data of Almeida, R.P), positioning the Guaritas Group in the Early Cambrian.

Conclusions

The volcano-sedimentary successions of the Camaquã Supergroup, included in the Bom Jardim Group and the Acampamento Velho Formation, are one of the most important elements for the understanding of the geological evolution of south-east South America in the Neoproterozoic as they register tectonic and paleogeographical conditions in their various stratigraphic levels and present the possibility of direct dating of volcanic rocks interbedded with the sedimentary successions.

The first unit of the Bom Jardim Group, the Cerro da Angélica Formation, registers the pre-volcanic stage of the basin, when the basin was restricted to the area of the Central Camaquã Sub-basin and limited by normal faults. The southern deposits are dominated by alluvial fans, revealing the presence of nearby basin margin faults, and the northeast deposits are characterized by deep-water lacustrine deposits, related to the basin's depocentre.

The onset of the major volcanic activity was around 590 Ma, represented by the Hilário Formation. At this time the basin expanded to the west, where the volcanic centers probably developed, but the depocentre was still in the Central Camaquã Sub-basin. After the volcanic events, the basin expands even more, with no evidence of proximal border faults in the Picada das Graças Formation, probably related to post-rift thermal subsidence. A younger volcanic event

occurred at approximately 575 Ma, characterized by the dominance of acid rocks (Acampamento Velho Formation).

Those volcanic successions have developed in a lacustrine basin with no evidence of glacial deposits. The last magmatic event registered in the Camaquã Basin is the Rodeio Velho Intrusive Suite, dated of 535 Ma, related to the last subsidence cycle of the Camaquã Basin in the Early Cambrian.

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