THE CAMAQUÃ EXTENSIONAL BASIN: NEOPROTEROZOIC TO EARLY CAMBRIAN SEQUENCES IN SOUTHERNMOST BRAZIL

ANTONIO ROMALINO SANTOS FRAGOSO CESAR[1], GELSON LUÍS FAMBRINI [1,2], RENATO PAES DE ALMEIDA[1,2], ANA PAULA MEIRELES REIS PELOSI[1,2], LILIANE JANIKIAN[1,2], CLAUDIO RICCOMINI[1,3], RÔMULO MACHADO[1,3], AFONSO CÉSAR RODRIGUES NOGUEIRA[1,4] AND GERSON SOUZA SAES[5]

ABSTRACT The Camaquã Basin is an extensional post-orogenic and pre-cratonic rift system of Neoproterozoic-Early Cambrian age located in the Gaúcho Shield, Rio Grande do Sul, southernmost Brazil. The basin is divided into a series of small sub-basins which were filled with the Camaquã Group, a thick (>9,000 m) unit composed of three formations: (i) the siliciclastic Maricá Formation, (ii) the volcano-sedimentary Crespos Formation and (iii) the siliciclastic Santa Bárbara Formation. These units correspond to three major stratigraphic sequences, and are divided into higher order sequences. Provenance and paleocurrent analysis of the siliciclastic deposits show a close relationship of the source-area with the lithologies that occur today in the neighborhood of these deposits, suggesting that no important lateral transport took place along the border faults. Paleocurrent measurements indicate a northern position for the marine body that cyclically invaded the basin.

Keywords: Camaquã Basin, Sequence Stratigraphy, Late Neoproterozoic-Early Cambrian, Provenance, Paleocurrents.

INTRODUCTION In southeastern South America, namely in southern and southeastern Brazil and in Uruguay, the late Neoproterozoic to early Cambrian record is represented by thick post-orogenic and pre-cratonic sedimentary deposits and volcanic rocks. These deposits are non-metamorphic, tilted, locally folded and preserved in small basins bounded by major fault zones, which limit the suspect terranes situated between the São Francisco and Rio de La Plata cratons (Fragoso Cesar *et al.* 1998). Following Almeida (1969), these basins have been interpreted as extensional molassic structures of the end of Precambrian and the beginning of Paleozoic. The Camaquã Basin in Rio Grande do Sul is the best exposed and most studied of these basins. In the present article we summarize its most important features, such as the facies associations, the stratigraphy, the paleocurrents and the provenance. An extensional model for the basin evolution is proposed.

GEOLOGICAL SETTING The Camaquã Basin (Fig. 1) is divided into residual sub-basins that are bounded by the basement highlands of Caçapava do Sul and Serra das Encantadas. The sub-basins are partially covered by Paleozoic deposits of the Paraná Basin. The basin deposits rest on Precambrian suspect terranes of the Gaúcho Shield (Rio Vacacaí, Valentines, Serra das Encantadas, Serra dos Pereira, Cerro da Árvore and Pelotas terranes *sensu* Fragoso Cesar 1991 and Fragoso Cesar *et al.* 1998) which were the source-areas for the clastic deposits, and whose tectonic boundaries are the main sites of preservation of these deposits.

LITHOSTRATIGRAPHY The Camaquã Basin encompasses the deposits of the Camaquã Group. In the present paper this group is redefined and divided into three formations: (i) the basal siliciclastic Maricá Formation, (ii) the intermediate volcano-sedimentary Crespos Formation and (iii) the upper siliciclastic Santa Bárbara Formation.

The age of the Camaquã Group is deduced from the available radiometric data of the metamorphic basement, the Crespos Formation and its comagmatic granitic rocks (*e.g.* Almeida *et al.* 1996, Lima and Nardi 1998), as well as from paleoichnological evidence. The radiometric age of the Acampamento Velho Member (top of the Crespos Formation) is ± 545 Ma (Almeida *et al.* 1996), and furnishes a minimum age for both the Maricá and the Crespos formations, and a maximum age for the Santa Bárbara Formation. The paleoichnological content of the Maricá Formation suggests an upper Vendian age, and that of the Santa Bárbara Formation to an age between upper Vendian and early Cambrian (Netto *et al.* 1992).

Maricá Formation The Maricá Formation, exposed in the westernmost part of the Camaquã Basin (Figs. 1 and 2), is a siliciclastic succession more than 2,000 meters thick. This unit rests upon metamorphic rocks of the Rio Vacacaí terrane and is overlain by the Crespos Formation above a regional erosion surface.

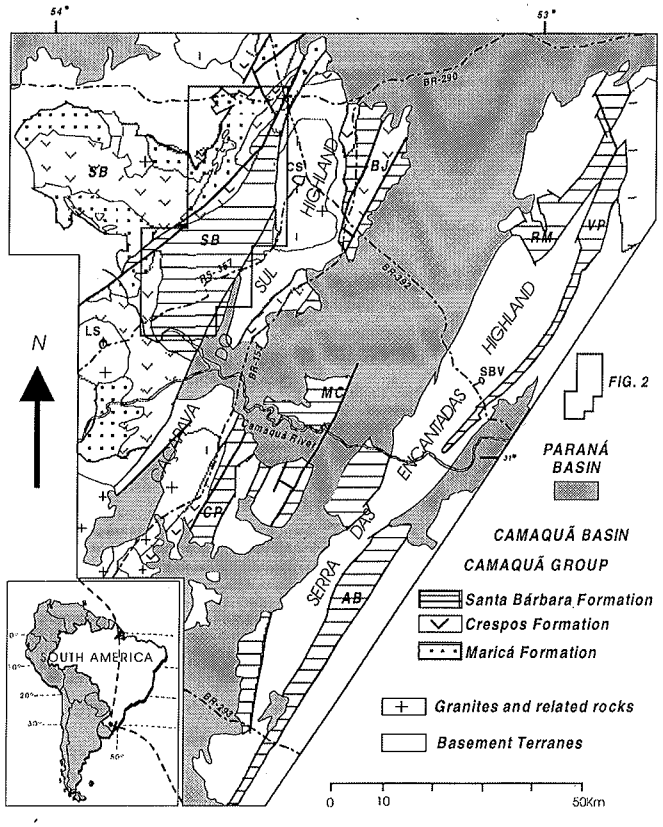

Figure 1 - Schematic map of the Lavras do Sul (LS), Caçapava do Sul (CS) and Santana da Boa Vista (SBV) region in Rio Grande do Sul, southern Brazil, showing the sub-basins which compose the Camaquã Basin: SB- Santa Bárbara; BJ- Bom Jardim; CP- Casa de Pedra; MC- Minas do Camaquã; RM- Rincão dos Mouras; VP-Vale do Piquiri; AB- Arroio Boici

The Maricá Formation consists of arkosic sandstones and rhythmites divided into three members. The lower and upper members are composed of coarse to medium-grained sandstones with pebbles, trough cross-stratification and subordinate massive bedding. The intermediate member comprises fine to medium-grained massive, parallel bedding and wave-ripple cross-laminated sandstones interbedded with minor laminated siltstones. The facies associations of these units suggest a braided fluvial depositional environment for the lower and upper members. The intermediate member is interpreted as

1 - Instituto de Geociências, Universidade de São Paulo, Caixa Postal 11.348, CEP 05422-970, São Paulo, Brazil, FAX: 55 (011) 818-4207
2 - Scholarship of FAPESP
3 - Research fellow of CNPq
4 - Fundação Universidade do Amazonas, Manaus, Brazil
5 - Instituto de Geociências/UFMT, Cuiabá, Brazil

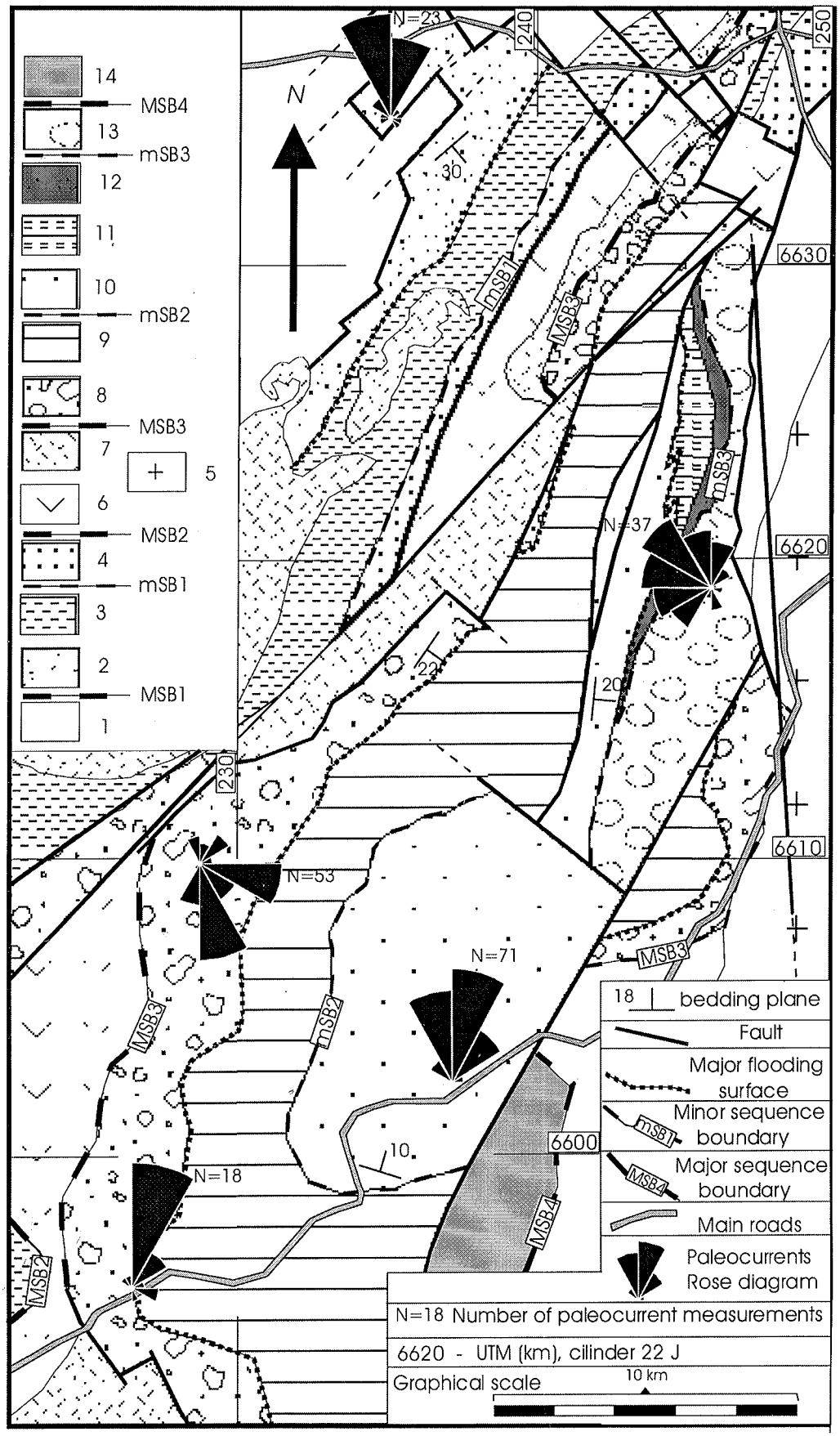

Figure 2 - Schematic map of the Santa Bárbara sub-basin: 1- Metamorphic basement (Rio Vacacaí Terrane); 2 to 13 Camaquã Group (except for 5); 2 to 4 Maricá Formation; 2- Lower fluvial sandstones; 3- Marine sandstones; 4- Upper fluvial sandstones; 5- Caçapava do Sul Granite; 6 and 7- Crespos Formation; 6- Hilario Member; 7- Acampamento Velho Member; 8 to 13- Santa Bárbara Formation; 8- Alluvial conglomerates and sandstones; 9-Marine and coastal rhythmites and sandstones; 10-Fluvial sandstones; 11- Lagoonal sandstones and rhythmites; 12-Shoreface sandstones; 13-Fan-delta conglomerates;14- Early Paleozoic deposits of the Paraná Basin.

shallow marine turbidites slightly reworked by wave processes. The fluvial paleocurrent data indicate a northward transport pattern.

Crespos Formation Volcanic rocks of the Camaquã Basin, exposed mainly in the western sub-basins, are grouped in the Crespos Formation (Ribeiro *et al.* 1966). This unit comprises the basal Hilário Member (mainly andesite, volcaniclastic and sedimentary rocks) and the upper Acampamento Velho Member (rhyolite and acid volcaniclastic deposits), reaching up to 3,000 m in thickness.
The most common sedimentary rocks of the Hilário Member are tabular sandy rhythmites and conglomerates, and massive mudstones and siltstones interbedded with fine laminated sandstones. The volcaniclastic deposits include tuff, lapilli tuff and pyroclastic and autoclastic breccias, as well as a series of reworked (epiclastic) facies. The volcaniclastics of the Acampamento Velho Member include ignimbrite and minor pyroclastic breccias.

The depositional environments of the Hilário Member are deduced from the facies associations of the sedimentary and volcaniclastic successions. Part of the volcaniclastic deposits are subaerial deposition (*e.g.* pyroclastic fall deposits, surge deposits, pyroclastic flows and *lahaars*), as noted by Wildner *et al.* (1997) and Lima and Nardi (1998). However, other volcaniclastic facies, such as fining upward breccias and lapilli tuffs with juvenile andesitic fragments, may be subaqueous (Fambrini *et al.* 1999). Most of the sedimentary facies, attributed to turbidity currents and offshore suspension deposits, also suggest subaqueous environments and occur interbedded with the volcanic rocks in most of the stratigraphic column. The Acampamento Velho Member is considered to represent subaerial volcanic activity.

Santa Bárbara Formation The Santa Bárbara Formation (Robertson, 1966) is the best known unit of the Camaquã Group (Fig. 2). It occurs in a series of isolated sub-basins that are preserved preferentially along the NNE-SSW basement limiting faults, in a belt almost 100 km wide. The thickness of this unit reaches more than 4,000 meters in the Rincão dos Mouras/Vale do Piquiri sub-basin. The lower limit of this unit is an erosional unconformity with the Crespos Formation, and the upper limit is an angular unconformity with the Paleozoic sequences of the Paraná Basin. Dips of the bedding range from a few degrees to sub-vertical as a result of rotational normal and oblique faulting, drag and regional open folding.

The most common lithofacies of this unit are: (i) massive and stratified clast-supported conglomerates, (ii) tabular sandy rhythmites with wave and/or current ripple cross-lamination and hummocky cross-stratification, (iii) coarse to fine-grained arkosic sandstones with trough cross-stratification, (iv) fine-grained rhythmites with mud cracks and heterolithic stratification and (v) classical turbidites.

The depositional systems of the Santa Bárbara Formation are not uniform in all sub-basins: continental and shallow marine environments prevailing in the western sub-basins, and alluvial and deep-water marine environments in the eastern sub-basins. The western sub-basins include (i) fan-delta and alluvial braided deposits; (ii) shallow marine turbidites and tempestites; (iii) minor tidal influenced delta and lagoon facies. The eastern sub-basins include (i) deep-water submarine fan facies; (ii) fan-delta and alluvial fan; (iii) distal braided river deposits. The typical distribution of these associations in most of the sub-basins shows an alluvial-marine-alluvial succession. Locally (*e.g.* Minas do Camaquã/Bom Jardim sub-basin) an upper marine transgression is recorded.

Paleocurrent analysis of the Santa Bárbara Formation reveals net axial transport to the north, with minor transverse systems from east and west. This pattern suggests the presence of a major marine body to the north of the studied occurrences, as well as the presence of inner highlands that might have isolated the sub-basins from each other, at least at the time of the deposition of the upper units. The provenance of the upper units confirms this hypothesis, revealing an important contribution of the typical rocks of the inner highlands, as well as reworked sedimentary rocks of the lower units of the Santa Bárbara Formation. It is important to note that the coarse-grained deposits reveal provenance of units that are still found in the vicinity today, suggesting little or no lateral transport at the border faults.

SEQUENCE STRATIGRAPHY The three lithostratigraphic units of the Camaquã Group are closely related to low order stratigraphic sequences analogous to those proposed by Paim *et al.* (1995). Although volcanic clasts were recognized in the Maricá Formation, indicative of a volcanic event prior to the Camaquã Group, we will hereafter refer to the three major sequences as pre-volcanic, syn-volcanic and post-volcanic sequences, identified with the Maricá, Crespos, and Santa Bárbara formations, respectively. These are bounded by major erosion surfaces (MSB1, MSB2, MSB3, MSB4), which may represent important tectonic events that promoted partial rearrangement of the Camaquã Basin configuration.

The pre-volcanic sequence (MSB1) rests on an erosional contact with the metamorphic basement, and is composed of two higher order sequences. The first begins with aggradational fluvial deposits covered by marine transgressive facies. Sea-level fall and subaerial exposure generated the erosional unconformity (MSB1) that limits this first stratigraphic sequence. A subsequent base-level rise is represented by aggradation of the upper fluvial unit, marking the beginning of the second sequence. Some restricted fine-grained facies that occur above the upper fluvial deposits may represent another marine transgression, characterizing cyclically recurring lowstand-trangressive system tracts.

The boundary between the pre-volcanic and the syn-volcanic sequences (MSB2) is marked by an abrupt facies change from alluvial to deep marine deposits, clear decrease of lithification of the lithotypes and beginning of volcanic activity. The subdivision of the syn-volcanic sequence is not established yet. Some locally recognized erosion surfaces, as well as abrupt facies changes, may represent higher order sequence boundaries, but their regional importance must be tested before any assumption is made.

The post-volcanic sequence rests on a regional erosion surface (MSB3) above which no more volcanic activity is recorded in the Camaquã Group. It is divided into three higher order sequences related to base-level fluctuations. The first one (mSB1) is composed of lowstand, transgressive and highstand system tracts, and begins with alluvial fan and braided fluvial deposits with an aggradational pattern (LST), covered by transgressive shallow water rhythmites (TST), which progressively pass to progradational delta front and tidal plain deposits (HST). Although no major erosion surface could be recognized, the passage from this tidal plain facies to a thick (over 150 m) fluvial succession is interpreted as a sequence boundary (mSB2). The second sequence begins with this aggradational fluvial unit (LST), which is covered by transgressive lagoonal-barrier and shoreface facies (TST). The third sequence rests on a surface (mSB3) which is marked by coarse-grained clastic influx of progradational fan-delta deposits (LST), probably related to increased tectonic activity at the border faults, rather than eustatic sea-level fluctuations.

TECTONIC AND SEDIMENTARY EVOLUTION The tectonic and sedimentary evolution of the Camaquã Group may be divided into three stages related to the major stratigraphic sequences. The first stage, represented by the pre-volcanic sequence and equivalent to the Maricá Formation, characterizes deposition in a broad basin whose remaining exposures are of distal and well-sorted facies. Although there are no preserved coarse-grained deposits showing a clear relationship with active tectonism, the great thickness of the successions and the similarity of the paleogeographic configuration with the overlying units suggest that this first moment was the initial phase of the evolution of the Camaquã Basin rift system. The second stage, represented by the syn-volcanic sequence, is interpreted as the maximum extensional event of the basin, revealed by the voluminous volcanic deposits of the Crespos Formation. The third stage, represented by the post-volcanic sequence, is characterized by the subdivision of the Camaquã Basin into small sub-basins trough the rise of inner highlands, and the growth of the depositional area to the east. All stages seem to be related to extensional tectonics, with no evidence of transtensional processes.

Acknowledgements To FAPESP grants (93/03228-7, 98/04510-1, 98/03682-3, 98/11544-0, 99/00552-4, 99/00878-7) for financial support, to Prof. Dr. Ian McReath and two anonymous referees of RBG for reviewing the manuscript.

References

Almeida D. del P.M., Zerfass H., Basei M.A.S. 1996. Mineralogia, geoquímica e novas idades para o vulcanismo ácido da Bacia do Camaquã, RS. In: Congresso Brasileiro de Geologia, 39, Salvador, 1996. *Anais*.... Salvador, SBG, v. 2, p. 19-21.

Almeida F.F.M. 1969. Diferenciação tectônica da Plataforma Brasileira. In: Congresso Brasileiro de Geologia, 23, Salvador, 1969. *Anais*.... Salvador, SBG, v. 1, p. 29-46.

Fambrini G.L., Martin M.A.B., McReath I., Fragoso Cesar A.R.S. 1999. Subaqueous pyroclastic deposits of the Hilário Formation, RS. In: Simpósio Sobre Vulcanismo e Ambientes Associados, 1, Gramado, 1999. *Boletim de Resumos*, Gramado, SBG, p. 34.

Fragoso Cesar A.R.S. 1991. *Tectônica de Placas no Ciclo Brasiliano: as orogenias dos Cinturões Dom Feliciano e Ribeira no Rio Grande do Sul*. São Paulo, 366p (Tese de Doutoramento, Instituto de Geociências da Universidade de São Paulo)

Fragoso Cesar A.R.S., Machado R., Phillip R.P., Mello F.M., Endo I., Nummer A.R., Preciozzi F.P., Fambrini G.L., Sayeg H.S. 1998. Terrenos suspeitos a sul da Placa Sanfranciscana (SE da Plataforma Sul-Americana). In: Congreso Uruguayo de Geologia, 2, Punta del Este, 1998. *Actas*.... Punta del Este, SUG/Facultad de Ciencias, p. 1-6.

Lima E.F. and Nardi L.V.S. 1998. The Lavras do Sul Shoshonitic Association: implications for the origin and evolution of Neoproterozoic shoshonitic magmatism in southernmost Brazil. *Journal of South American Earth Sciences*, **11**:67-77.

Netto R.G., Paim P.S.G., Rosa C.L.M. 1992. Informe preliminar sobre a ocorrência de traços fósseis nos sedimentitos das Bacias do Camaquã e Santa Bárbara. In: Workshop Sobre as Bacias Molássicas Brasilianas, 1, São Leopoldo, 1992. *Boletim de Resumos Expandidos*. São Leopoldo, SBG/UNISINOS, p. 90-96.

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: Simpósio Sul-Brasileiro de Geologia, 6/Encontro de Geologia do Cone Sul,1, Porto Alegre, 1995. *Boletim de Resumos Expandidos*. Porto Alegre, SBG- Núcleo RS, p. 39-50.

Ribeiro M., Bocchi P.R., Figueiredo Filho P.M., Tessari R.I. 1966. Geologia da Quadrícula de Caçapava do Sul. Rio Grande do Sul. *Boletim da Divisão de Fomento Prospecção Mineral do Brasil*, Rio de Janeiro, **127**, pp. 1-232.

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

Wildner W., Lima E.F., Camozzato E., Lopes R.C. 1997. Vulcanismo Neoproterozóico-Cambriano no Rio Grande do Sul: estratigrafia e aspectos texturais. *A Terra em Revista*, **3**:19-27.

Contribution IGC-125
Received March 1, 2000
Accepted for publication April 26, 2000