FACIOLOGY OF THE ACAMPAMENTO VELHO FORMATION VOLCANIC ROCKS (CAMAQUÃ BASIN) IN THE REGION OF SERRA DE SANTA BÁRBARA, CERRO DO PERAU AND CERRO DO BUGIO (MUNICIPALITY OF CAÇAPAVA DO SUL – RS)

HENRIQUE ZERFASS[1], DELIA DEL PILAR M. DE ALMEIDA[2] AND CRISTIANE H. GOMES[3]

ABSTRACT In the Santa Bárbara Sub-Basin (Camaquã Basin), Acampamento Velho Formation (Late Vendian to Early Cambrian) presents two associations of volcanic facies, one at the base and another at the top. The basal association is constituted by (1) andesites, andesitic basalts and (2) basaltic to andesitic breccias. The upper association, with a rhyolitic composition, includes (3) lapillites, (4) tuff, (5) welded tuffs and (6) rhyolitic flows. Facies 1 is interpreted as flows and Facies 2 as basal or frontal clastic accumulations associated with the flows of Facies 1. Facies 3, 4 and 5 are associated with pyroclastic flows, a product of the collapse of the eruptive column, and the lateral variation occurs as a result of the grain size and degree of welding. The rhyolitic flows (Facies 6) cover the previously mentioned facies. The geochemical results (REE and immobile traces) suggest that the rocks are cogenetic, characterizing bimodal volcanism. In the stratigraphic view, the lithological discontinuity existing between the base and the top of Acampamento Velho Formacion allows the postulation of the presence of a hiatus between the two facies associations.

INTRODUCTION The Acampamento Velho Formation (AVF, *sensu* Ribeiro & Fantinel 1978) represents one of the main volcanic events in the volcanic-sedimentary sequence of Camaquã Basin, generated during the final phases of the Brasiliano Cycle. In the Santa Bárbara Sub-Basin of Camaquã Basin (*sensu* Paim *et al* 1995), the volcanic rocks of AVF crop out as a long, narrow strip standing out in the relief, constituting a number of elevations with altitudes of up to 500m. The area studied includes *Cerro do Bugio*, *Cerro do Perau* and *Serra de Santa Bárbara*, located in the municipality of Caçapava do Sul, approximately 15 km west from the town (Fig. 1).

Rb/Sr ages of 545.1± 12.7 M a. (Almeida *et al.* 1996) and U/Pb ages in zircons of 573 ±18 (Chemale Jr. *et al*. in prep.) are presented for the AVF in the area studied. Two associations of volcanic facies were recognized, one in the lower part of the unit (basaltic/andesitic composition) and another in the upper part (rhyolitic composition).

An approach in terms of volcanic facies is needed in order to understand the type of volcanism. Furthermore, it is essential to understand the spatial and temporal relationships between the different facies to enable the definition of the stratigraphic architecture.

METHODOS The area studied is considered a type-area due to the good exposure of the rocks and facies variation. Thus, geological mapping was performed on the 1:25.000 scale (Zerfass & Almeida 1997).

The description of the different volcanic facies was one of the mapping activities. Every volcanic package with its own geometrical, structural and textural aspects is considered to be a distinct volcanic facies. Among the geometrical aspects, were fundamental the definition of the thickness of the package as constant or variable, and its extent. Structural aspects refer here to the primary structures within the packages. Among the textural aspects are mainly grain size, nature of clasts, nature of the matrix and texture *stricto sensu*, whenever a specific term exit for

the arrangement of the grains. The different facies are defined independent of the map scale.

Petrographic studies of hand samples and thin sections complement the field information. Mineral chemistry data obtained by electronic microprobe analysis (Instituto de Geociências, UFRGS) also complement the description.

Once the different facies are individualized, the relationships between them were established. Thus, the paleoenvironmental interpretation and the meaning of each facies association in the evolution of the whole volcanic event are obtained. This study contributes to the proposition of the stratigraphic architecture of AVF. Geochemical data (REE and immobile trace elements, Activation Laboratories) are used to test the stratigraphic model.

STRATIGRAPHIC FRAMEWORK This study deals specifically with AVF internal subdivisions. It is, however, necessary to observe the unit in the context of Camaquã Basin, in terms of its relationship to the lower and upper units. The lithostratigraphic terms are used for reference, as per to the proposal of Ribeiro & Fantinel (1978). Despite this, an attempt is made to approach the succession studied by means of a genetic stratigraphic concept. Thus the units studied are related to the allostratigraphic units proposed by Paim *et al.* (1995).

In the area, the basal unit is the Maricá Allogroup or Formation (MF, Fig. 2), which consists of sandstones and mudstones, that are tilted and commonly folded. An angular unconformity separates this unit from the Vargas Formation (VF) or Bom Jardim Allogroup rhythmites and conglomerates. In certain sectors of the area, VF is absent, and the upper contact of MF occurs directly with the AVF (Fig. 2).

Vargas Formation sedimentary rocks are tilted at a high angles and are often vertical. Over these rocks are seated the volcanic AVF or Alloformation. The low angle tilting of the strata of the latter unit indicates an angular unconformity at its base (Fig. 2).

In the allostratigraphic concept (Paim *et al.* 1995), an erosive unconformity separates the Acampamento Velho Alloformation from Santa Fé Alloformation, constituted by conglomerates which are in turn covered by rhythmites of the Lanceiros Alloformation (Fig. 2).

Classically, AVF is considered to be exclusively constituted by acid volcanics. Recently, however, an andesitic and basaltic-andesitic (A-Abas) layer was recognized and mapped, with a considerable thickness and area extent at the base of the unit (Zerfass & Almeida 1997). Generally, from the base to the top, A-Abas, pyroclastics rocks of rhyolitic composition and rhyolitic flows occur (Zerfass & Almeida 1997). Rhyolitic sills also occur as intrusions in the sedimentary rocks of the MF, which are associated with AVF.

FACIES ASSOCIATIONS AND PALAEOENVIRONMENTAL INTERPRETATION **Lower Association** *FACIES 1 - ANDESITIC AND BASALTIC-ANDESITIC FLOWS* This facies presents as a continuous horizon bed throughout the area studied (Figure 2), with a variable thickness (10m to 350m), lying on an angular unconformity over MF or VF. It occurs as massive or rarely stratified. When stratified strata, it presents a dip of approximately 20^o to E or SE, as the following facies described for AVF. It is gray, and constituted by phenocrysts and a pilotaxitic matrix, with variable grain size. The main phenocrysts are albitized plagioclase (Ab_{100}) and clinopyroxene, the latter substituted by sericite, carbonate, chlorite and opaque minerals. The matrix is composed of plagioclase microcrystals, and probably clinopyroxene substituted by chlorite and carbonate. Chlorite-carbonate vesicles also occur.

FACIES 2 - BASALTIC-ANDESITIC BRECCIAS This facies occurs as gray, metric thick lenses within Facies 1. They have poorly selected basic/intermediate volcanic clasts (up to 50 mm in diameter). The matrix is microcrystalline and pilotaxitic, presenting phenocrysts of plagioclase and probably substituted clinopyroxene.

Facies 1 is interpreted as basaltic-andesitic flows, and Facies 2 as basal or frontal clastic accumulations of the flows, considering also lateral variations.

1 - Pós-Graduação em Estratigrafia/UFRGS - Bolsista CAPES – Av. Bento Gonçalves, 9500 – CEP. 91500-900, Porto Alegre/RS, zerfass@if.ufrgs.br)
2 - Mestrado em Geologia/UNISINOS- Av. Unisinos, 950 – CEP. 93022-000 – São Leopoldo/RS. pilar@euler.unisinos.br)
3 - Graduação em Geologia/UNISINOS - Bolsista PIBIC/CNPq – cris@euler.unisinos.br)

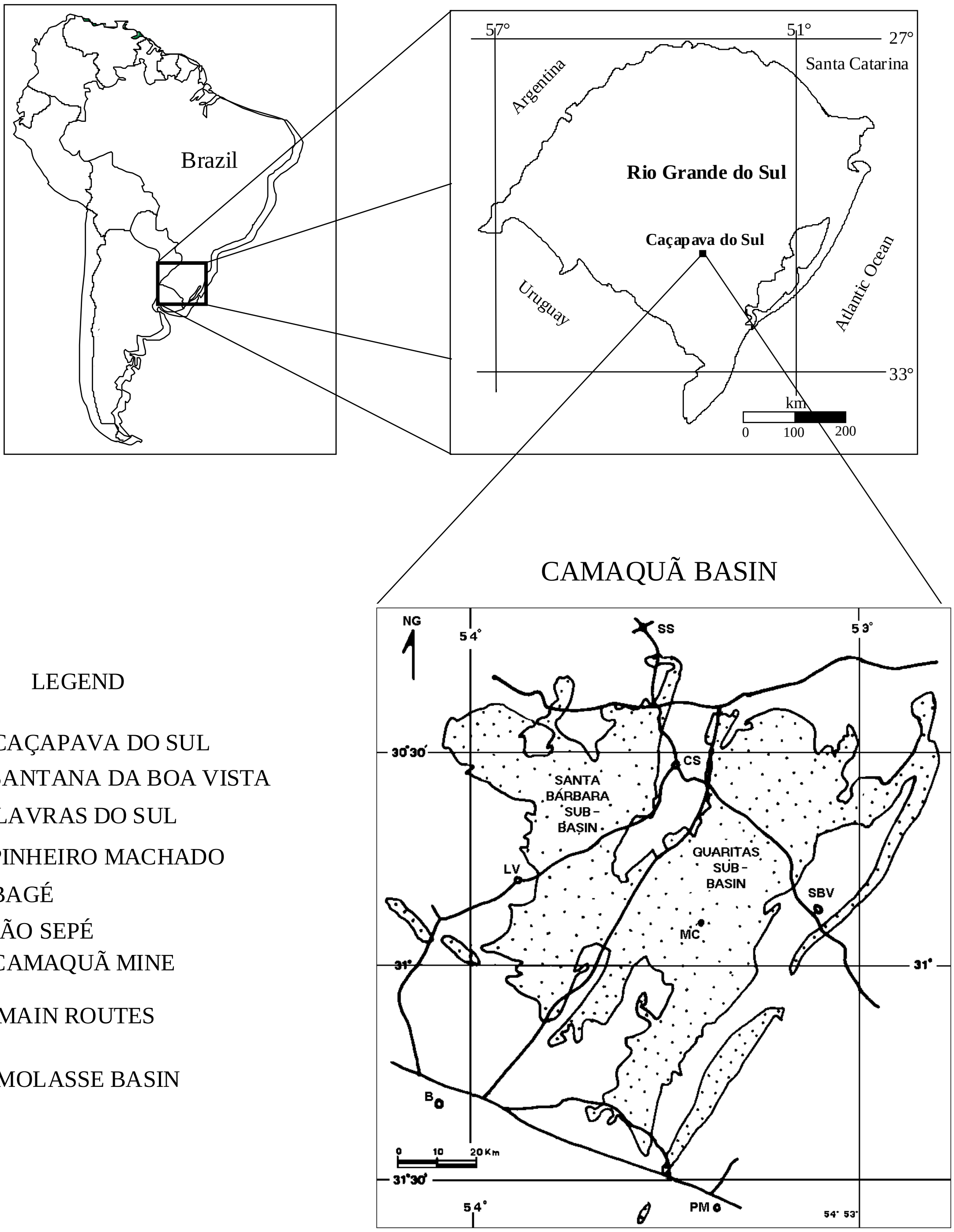

Figure 1. Locality map of the Camaquã Basin

Higher association (rhyolitic) *FACIES 3 – LAPILLITES* Red strata with variable thickness (up to 40 m), without lateral continuity throughout the area studied (Fig. 2). They have an abrupt lower contact with the andesitic basalt facies 1 (Fig. 2). They are interbedded with the tuffs and welded tuffs of Facies 4 and 5, respectively (Fig. 2). It has an originally horizontal stratification (tilted beds). The clasts are poorly selected (3 mm-20 mm in diameter), consisting of lithoclasts (microcrystalline acid volcanic), vitroclasts (*fiammes*) and crystalloclasts (quartz, sanidine, plagioclase). According to the classification by Schmid (1981), the lapillites of this facies are lithic to crystalline (Fig. 3). The matrix is tuffaceous, composed by ash.

FACIES 4 - TUFFS Strata with variable thickness (up to 30 m), in the form of lenses without lateral continuity throughout the area studied (Fig. 2). They occur in abrupt lower contact with the andesitic basalts of Facies 1 (Fig 2), and also in abrupt upper contact with the rhyolitic flows of Facies 6 (Fig. 2). This facies is interfingered with Facies 3 and 5 (Fig. 2). It should be mentioned that intermediate transition terms are found between this Facies and Facies 3 (lapillites). Internally, it presents originally horizontal strata (tilted layers). The color is green or gray, generally with a poor selection, with predominance of dust over ash. Vitroclasts (*shards*) and albitized quartz and plagioclase occur in the ash fraction (Ab_{100}) (Fig. 4). According to the classification of Schmid (1981), these rocks have a crystalline composition (Fig. 3).

FACIES 5 - WELDED TUFFS With metric thickness of up to approximately 350 m, this facies does not present lateral continuity throughout the studied area, consisting of lens-shaped layers (Fig. 2). This facies is in abrupt lower contact with the lower facies association

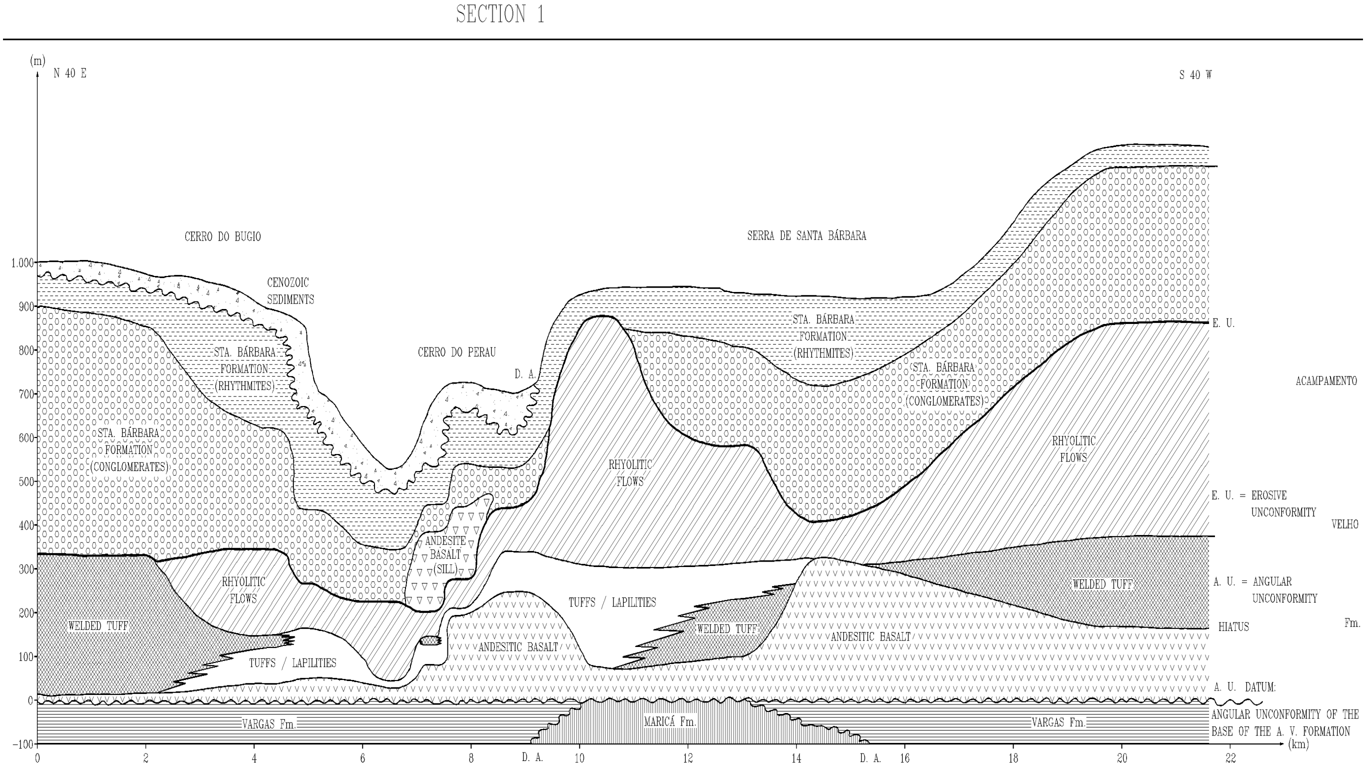

Figure 2 – Strike section (NE-SW) in the Cerro do Bugio, Cerro do Perau and Serra de Santa Bárbara region.

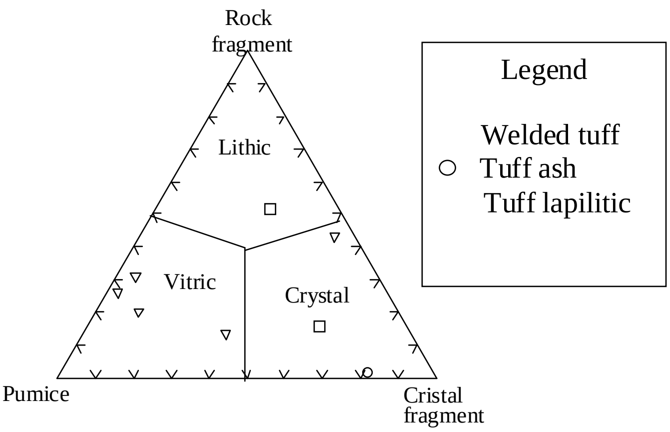

Figure 3 – Standard classification of pyroclastic rocks (after Schmid 1981)

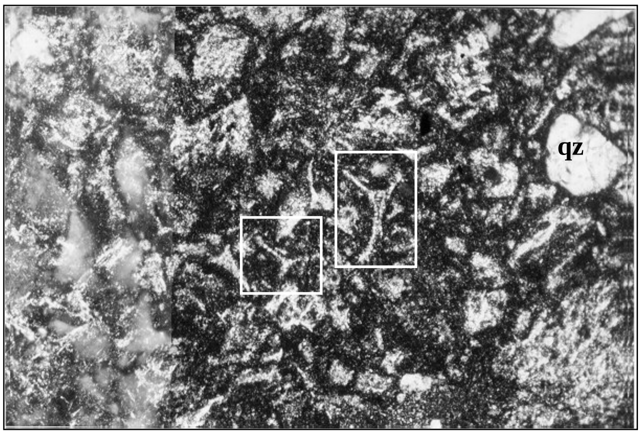

Figure 4 - Photomicrograph of a tuff; qz= quartz crystaloclasts. White boxes contain vitroclasts (shards). With crossed nicol; 40x.

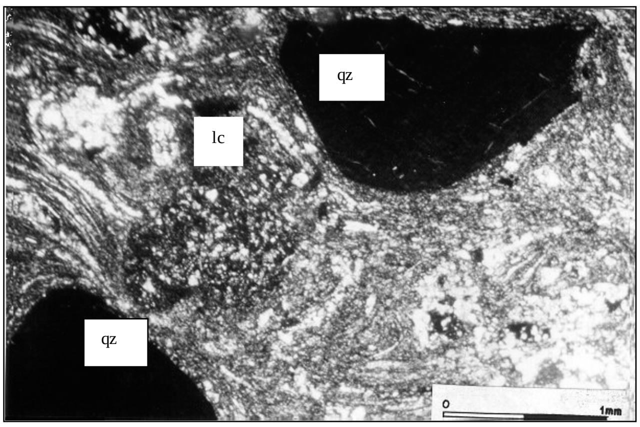

Figure 5 – Photomicrograph of a welded tuff; lc = basalt/andesite lithoclast, qz = quartz crystaloclast. White boxes contain elongated vitroclasts (fiammes).With crossed nicols

(Fig. 2) and in also abrupt upper contact with the rhyolitic flows of Facies 6 (Fig. 2). Internally, an originally horizontal stratification is tilted. The rocks are lilac-colored, and poorly selected, with predominance of the ash fraction. Quartz and cryptoperthitic sanidine crystalloclasts, vitroclasts (*fiammes*) and rare basalt/andesite lithoclasts occur (Fig. 5). Using the Schmid´s (1981) classification, the rocks of this facies are glassy or pumiceous (Fig. 3).

FACIES 6 - RHYOLITIC FLOWS There is a continuous layer, with variable thickness (ranging from 20 m to 600 m, Fig. 2), in abrupt lower contact with the pyroclastic rocks of Facies 3, 4 and 5 (Fig. 2). Internally they present flow foliation, frequently folded (Fig. 6). Pink-colored, the rhyolites of this facies are homogeneous or banded. When banded they show an intercalation of thick spherulitic bands and microcrystals, and when massive they have a microfelsitic matrix. Quartz, perthitic sanidine and more rarely biotite occur as phenocrystals. Perlitic fractures are common, indicating devitrification. The presence of large spherulites together with microcrystalline bands

Figure 6 - Rhyolitic flow with folded flow foliation. Arroio Pessegueiro region, Cerro do Perau.

indicate devitrification at temperatures of 300°C to 400°C, close to the *liquidus* (Allen 1986).

Facies 3, 4 and 5 are associated with pyroclastic flows during the rhyolitic manifestation, a product of collapse of the eruptive column, and lateral variation occurs as a function of grain-size (distance to the volcanic center) and degree of welding. The degree of welding in turn depends on temperature. Experimental studies indicate that the welding begins between 600°C and 750°C (Cas & Wright 1988) and could follow up to 950°C (Mazzoni 1986).

There is an inverse relationship between the thickness of the facies 3, 4 and 5 and the lower association (Fig. 2), suggesting that the pyroclastic flows adjusted to relief then supported by the andesitic and basaltic-andesitic package. The pyroclastic flows could have been deposited in the depressions.

Lapillites were deposited in the more proximal portions in relation to the volcanic center. Towards the more distal areas, finer material was deposited, consisting of tuffs and welded tuffs. Although a grading is observed between the lapillites and the tuffs, suggesting a shared genesis for pyroclastic flows, the finer terms of the tuffs may occur well selected. Thus, it is accepted that in more distal regions, pyroclastic fall processes are also recorded.

Rhyolitic flows (Facies 6) cover the previously mentioned facies. This succession of pyroclastic deposits and lava extrusion is typical of plinian eruptions (Sheridan 1979).

DISCUSSION Two facies associations indicate two distinct levels within AVF. From a stratigraphic standpoint, there is therefore a discontinuity within the unit.

The chronological significance of this discontinuity is a point for discussion. The tool thus far applied to investigate this question is total rock geochemistry, especially REE and immobile trace elements. The REE pattern of the lower association is similar to that of the upper association, both for LREE and for HREE (Fig. 7), the only difference being the marked negative anomaly of Eu (strong fractionation of plagioclase) presented by the rocks of the higher association. The immobile trace elements Zr, Nb, Y used for studies of magma evolution (Pearce & Norry 1979), show two distinct evolutionary trends, beginning from the same point for both facies associations (diagrams Zr *versus* Nb and Y – Fig. 8), both associations presenting a positive correlation (less marked in the A-Abas), which may have been caused by crystallization, especially of amphibole, and on a lesser scale, clinopyroxene. In this way, the two associations would be cogenetic, but even with a common origin, the magmas would have undergone different evolutionary processes, which may imply that there is a hiatus in time.

As to the abrupt contact between pyroclastic rocks and the rhyolitic flows of the upper association, this type of contact is considered a product of the plinian-type eruption. This does not quite characterize a discontinuity in the records.

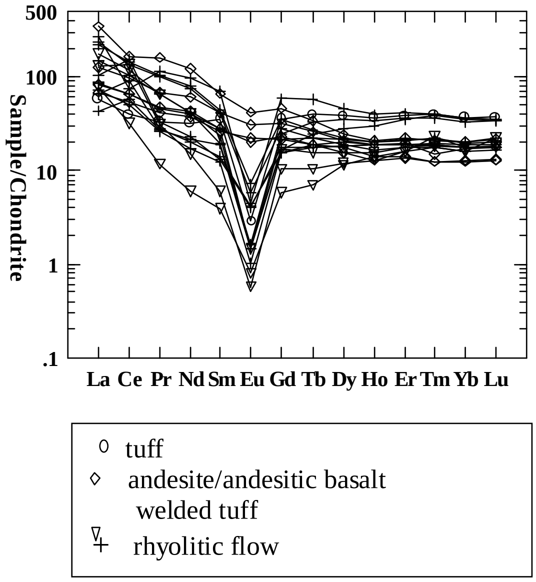

Figure 7 – REE elements diagram normalized by the chondrite.

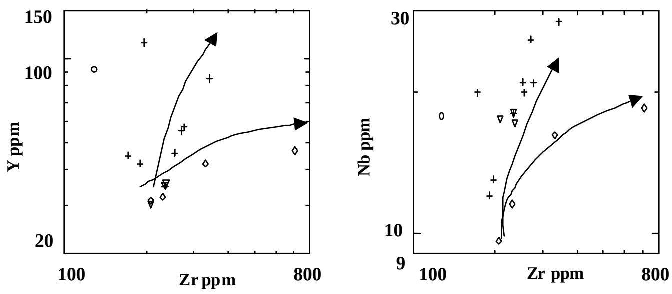

Figure 8 – Zr x Y and Zr x Nb binary diagrams (after Pearce & Vorry 1979) showing the evolutive trends for the Acampamento Velho Fm. volcanic rocks.Legend same as figure 7.

CONCLUSIONS 1 - Acampamento Velho Formation, in the area studied, represents an initially basaltic-andesitic and later rhyolitic volcanic event. The lower facies association represents the domain of basaltic-andesitic flows, with associated breccias. The upper facies association suggests that the rhyolitic volcanic manifestation began in the form of pyroclastic flows followed by rhyolitic flows in a typical plinian succession.

2- The lithologies of the two facies associations are initially cogenetic. The lower association, however, presents distinct evolutionary trend.

3- From the stratigraphic viewpoint, the discontinuity between the two associations represents a hiatus, which is corroborated by the geochemical data.

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