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PETROGENESIS OF THE CAMPO ALEGRE BASIN MAGMATISM, BASED ON GEOCHEMICAL AND ISOTOPIC DATA

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STRATIGRAPHY

The Campo Alegre Basin is located in the northeastern portion of the Santa Catarina State, between São Bento do Sul city and the Serra do Mar in Santa Catarina, being the Campo Alegre city situated in its center-northern portion. The various authors who studied the Campo Alegre Basin divide its volcanic and sedimentary filling in three major units: 1) Bateias Formation, with epiclastic sedimentation dominated by polymictic conglomerates with subordinated sandstones and pelites. To the south, in the Corupá Subbasin, at the same basal position, fine sedimentary rocks, interpreted as being turbidites, predominate and were grouped under the name Corupá Formation by Citroni (1998); 2) at an intermediate position there is the Campo Alegre Group (named Campo Alegre Formation by Ebert, 1971), which is the main group of volcanic and volcaniclastic rocks of the Basin. Citroni (1999) proposed its ranking to the Group category, dividing it in four formations: *Rio Negrinho Formation* – made of basaltic and andesitic lavas intercalated with fine silty-argillaceous sediments; *Avenca Grande Formation* - composed of crystalloclast-rich acid ignimbrites; *Serra de São Miguel Formation* – consisting of trachyte and quartz-trachyte flows, and *Fazenda Uirapuru Formation* – constituted by an oligomictic, volcanic breccia with glassy matrix, vitrophyric and criptocrystalline rhyolite pebbles and angular blocks, representing a proximal explosive deposit related to caldera collapse and 3) *Rio Turvo Formation* (Ebert, 1971) – occupying a top position, constituted by silty and argillaceous sedimentary rocks, with variable contributions of volcanic ashes, and also with rdinated intercalations of acid lavas and ignimbrites, corresponding to lake deposits inside the caldera.

PETROGRAPHY AND GEOCHEMICAL CHARACTERIZATION

Lava samples of three of these units were analyzed regarding their mineralogy and chemical composition. Rio Negrinho Formation: The basic and acid lavas plot respectively in the basalt and andesitic basalt, and trachyte fields of the TAS diagram. In the AFM diagram the Rio Negrinho Formation lavas plot in the calc-alkaline field. The basic rocks are phaneritic, fine to very fine-grained, present intersertal to subophitic textures, and are formed by plagioclase (andesine, labradorite) and pyroxene (pigeonite, augite and diopside), and subordinately opaque minerals, olivine, altered to antigorite, and glass, altered to chlorite, sericite, carbonate and epidote; quartz and potassic feldspar can also occur. The phenocrysts are of plagioclase (predominantly) and pyroxene. The acid lavas have trachytic, microlitic and spherulitic textures, are made of potassic feldspar (sanidine), the modal quartz varies from rare to common; subordinately, plagioclase occurs and zircon is an accessory mineral. The phenocrysts are of potassic feldspar and quartz. Serra de São Miguel Formation: the rocks plot in two clusters in the TAS diagram: trachytes and alkaline to subalkaline rhyolites. Strongly recrystallized microcrystalline and criptocrystalline textures predominate. The minerals present are potassic feldspar (sanidine), quartz, opaque minerals (magnetite); subordinately biotite, tourmaline and microcline occur. Zircon is an accessory mineral; sporadically olivine and plagioclase are found, besides sericite and epidote as alteration minerals. Rio Turvo Formation: The ignimbrites of this unit are of trachytic and rhyolitic composition. Potassic feldspar (sanidine), quartz, opaque minerals (magnetite) are common, together with biotite, tourmaline, plagioclase, muscovite and zircon. The presence of fiamme is a marked characteristic of these ignimbrites.

PETROLOGY OF THE CAMPO ALEGRE BASIN LAVAS

18 samples of lavas and ignimbrites of the Campo Alegre Basin were analyzed. The geochemical data suggest that the basic and acid lavas of the basin are cogenetic. The alignments obtained in several major- and minor-element variation diagrams are compatible with a fractional crystallization process. In this process, plagioclase removal would mainly occur, followed by olivine and clinopyroxene. For the acid lavas potassic feldspar removal is more important.

According to Wilson (1989), fractional crystallization is the only differentiation process able to preserve unaltered the ratios between the contents of two incompatible elements, whereas any other process, such as crustal contamination, tends to modify them. A first group of diagrams involving La/Ce, Zr/Hf and Hf/Sm ratios resulted in consistent alignments for all the plotted samples. The Hf *vs.* TiO_2 diagram presents a non-linear negative relation, such that Ti contents decrease with Hf increase. The HREE diagrams show stronger alignments for incompatible elements (Dy/Ho, Y/Yb, Yb/Lu and Tm/Lu). The ratios obtained by means of these alignments were not able to define a specific source for the rocks in question, being coincident or closer to oceanic island basalt (OIB) and upper or lower crust values, depending on the pair of elements involved (see Table 1).

	La/Ce	Zr/Hf	Hf/Sm	Dy/Ho	Y/Yb	Yb/Lu	Tm/Hf
Samples	0.5	42	0.95	5.2	9.33	7.250	0.06
Chondrite	0.3873	36.304	0.697	4.488	9.235	6.693	0.17
Primitive Mantle	0.3870	36.246	0.696	4.494	9.229	6.662	0.24
MORB-N	0.3333	36.089	0.779	4.505	9.180	6.703	0.24
MORB-E	0.4200	35.961	0.781	4.494	9.283	6.695	0.18
OIB	0.4625	35.897	0.780	5.283	13.43	7.200	0.04
Upper Crust	0.4688	41.379	1.289	4.375	10.00	6.850	0.06
Lower Crust	0.5	56.11	1.091	4.675	5.83	7.586	0.15

Table 1: Comparison between the incompatible element ratios for the analyzed samples and the possible sources for these magmas (the ratios closer to the obtained for the samples analyzed are highlighted). The order of compatibility proposed by Sun & McDonough (1989) is utilized.

GEOCHRONOLOGICAL DATA

Isotopic analyses were carried out for a series of lava samples of the Serra de São Miguel and Rio Negrinho formations, and a sediment sample from the Rio Turvo Formation. The determinations were made by means of the Rb-Sr, Sm-Nd and U-Pb methods. The Rb-Sr analyses yielded an isochron that indicates an age of 570 ± 39 Ma for the acid lavas of the Rio Negrinho Formation. The lava samples of the Serra de São Miguel Formation present greater dispersion of values, making the isochron acquisition difficult.

U-Pb data, analyzed in the concordia diagram yielded an age of 598 ± 29 Ma for the upper intercept (Basei et al., in the press), interpreted as representative of the time of crystallization of the analyzed zircons and, consequently, of the volcanism. More precise determinations were obtained from SHRIMP analyses in zircons separated from the same volcanic rock, which yielded a crystallization age of 595 ± 5 Ma (U.G. Cordani, oral comm.).

The whole rock Sm-Nd analyses allowed the determination of high model ages, always with strongly negative ε_{Nd} values. The Rio Negrinho Formation lavas presented the most negative values, between -22.10 and -22.49, with model ages (T_{DM}) within the 2,2-2,3 Ga range. The Serra de São Miguel Formation lavas yielded slightly lower model ages (1,923 ± 47 and 1,971 ± 62 Ma), and ε_{Nd} values within –16.42 and –20.77. The sample from the tuffaceous sediment of the Rio Turvo Formation yielded an age of 2,355 ± 35 Ma and ε_{Nd} of –10.2. These results show that the crystallization of the protolith of these lavas must have occurred between 1,900 and 2,300 Ma, with younger values for the acid lavas of the Serra de São Miguel Formation.

SOURCE OF THE BACIA DE CAMPO ALEGRE VOLCANISM

The initial ratio R_0 obtained for the 570 ± 39Ma Rb-Sr isochron was 0.70690, suggesting a mantle or lower crust source. The negative ε_{Nd} values and the Sm-Nd model ages exclude the possibility of an exclusively mantle source for these magmas. Two main possibilities remain to explain the isotopic composition of these lavas: origin from the lithospheric mantle or by mixing of juvenile mantle material with crustal rocks. $^{87}Sr/^{86}Sr$ *vs.* 1/Sr and $^{87}Sr/^{86}Sr$ *vs.* Sr diagrams indicate contamination of the Campo Alegre Basin acid lavas in relation to the element Sr, which agrees with what is suggested by the geochemical analyses. $^{87}Sr/^{86}Sr$ *vs.* $^{143}Nd/^{144}Nd$ diagrams place the samples in field IV (magmas of mantle origin contaminated by crustal rocks); however, this is also the field in which the majority of the xenoliths coming from the subcontinental lithosphere plot, this being the source from where these magmas differentiate (Wilson, 1989).

Model ages for the basement rocks vary between 2,275 and 2,822 Ma for the Curitiba Domain gneisses (ε_{Nd} between −14.3 and −31.4); for the Luís Alves Domain granulitic gneisses, the model ages fall in the 2,270- 3,086 Ma range (ε_{Nd} between −29.4 and −33.5). The basic/ultrabasic rocks of this terrain yield much higher ages (2,500 to 3,653 Ma) with ample variation of ε_{Nd} values (-2.4 to −32.2). The Rio Turvo Formation tuffites are examples of mixing of materials from different sources, including rock fragments from the basement of the Campo Alegre Basin and pyroclastic material formed just before deposition. Model age and ε_{Nd} obtained were 2,354.8 ± 34.7 Ma and −10.2, respectively.

The model ages for the Campo Alegre Basin lavas, when compared to those for the Rio Piên anorogenic granitoids and the deformed granitoids, point at similar sources. One of the possibilities was to consider the model ages obtained as resultant from mixing between material of juvenile mantle origin at 600 Ma (model ages close to the crystallization ages of the magmas) and basement rocks (model ages between 2,275 and 3,600 Ma). This possibility is not easily accepted because all lavas (which vary from rhyolites to basalts) and granitoids should have resulted from mixing of more or less equal parts of both materials.

ε_{Nd} *vs.* model age diagrams (Figure 1), with ε values calculated for the present and the model age times, show lines that define two groups: one for the Campo Alegre Basin lavas and the other for the tuffaceous sediments of the Rio Turvo Formation and the basic dikes of the Serra Geral Formation. For the latter, model age values are higher and ε_{Nd} values are less negative. Contamination by basement material is evident or at least expected, intervening in the formation processes of these rocks. If the distinct slope for the tuffite and diabase samples is due to crustal contamination, then we must admit that this contamination was much less for the Campo Alegre Basin lavas.

CONCLUDING REMARKS

The interpretation of the chemical data and mineralogy of the Campo Alegre Basin lavas, as well as field relations, suggest that basic and acid lavas are cogenetic, evolving from basic to more acid terms. The process involved in the differentiation seem to have been mainly fractional crystallization of a basic magma. The observed trends indicate that olivine, clinopyroxene (augite and pigeonite) and mainly plagioclase fractionation was responsible for the generation of more acid magmas from magmas of transitional basaltic to alkaline compositions. For the trachytic and rhyolitic lavas, the process of mineral segregation would essentially involve potassic feldspar, especially when silica contents exceed 70%.

The Campo Alegre Basin fits in an extensive tectonic context, with development of rifts. The magmatism in these extension basins is typically bimodal, as the observed in this case (there is an interval of silica content between 50 and 63%, for which no samples were found in the basin). As stated by Wilson (1989), continental rift lavas present characteristics that indicate two main sources: melting of the subcontinental lithosphere and mantle plumes (OIB type). Lower crust and mantle plume (OIB) should be regarded as the main candidates for magma sources of the Campo Alegre Basin, when incompatible elements are taken into account (Table 1). The hypothesis that best explains the geochemical and isotopic data points at a magma originated by lower crust melting, resultant from astenospheric mantle ascension, as an answer to the Luís Alves Microplate lithospheric extension. Some of the data also suggest initial compositions similar to those of OIB-type basalts, that is, mantle plume (Dy/Ho and Yb/Lu). Other geochemical data suggest mixing between material originated from the lower crust with

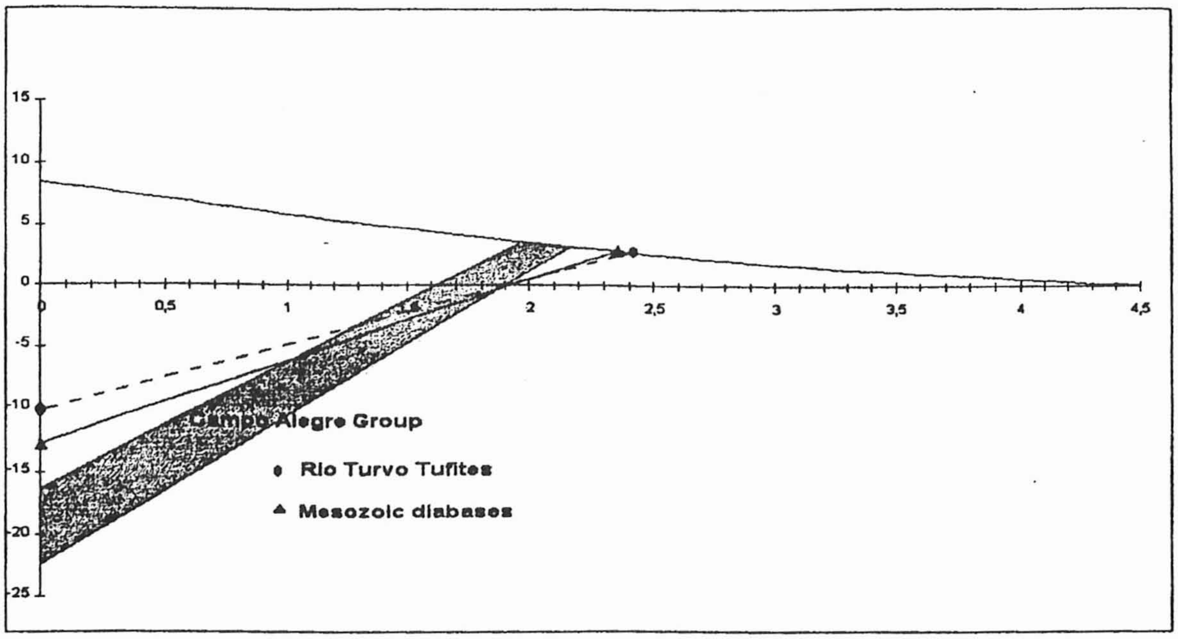

Figure 1. De Paolo's ages (Ga) *vs.* ε_{Nd} diagram for Campo Alegre Basin lavas (filled area), Serra Geral Formation Mesozoic dikes (continuous line) and Rio Turvo Formation tuffite (hatched line).

material from the upper crust (Ta/La, Nd/Zr and Th/U ratios).

Petrographic evidences of crustal contamination (xenoliths) are rare; however, the possibility of contamination of the original magma by crustal rocks cannot be ruled out. Deviations of the trend lines seen in the variation diagrams for some of the major and the more incompatible trace elements strongly suggest contamination processes.

Therefore, geochemical and isotopic evidences lead us to consider that the magmas that generated the volcanic rocks and intrusive granitoids of the Serra do Mar Suite in the Paraná and Santa Catarina states should have derived mainly from partial melting of the subcontinental lithosphere (lower crust or lithospheric mantle), being less the contribution by crustal contamination to the differentiation processes.

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