INTRODUCTION

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1) Calcite as a secondary mineral from alteration of ferromagnesian minerals by hydrothermal alteration, a common process affecting host rocks.
2) Calcite in the chlorite zone (ZC1), iii) quartz-carbonate veins, and iv) carbonate veins.

Carbon and oxygen isotope data and $^{87}Sr/^{86}Sr$ ratios were obtained for calcite from carbonate veins and from quartz-carbonate vein samples. These data will be interpreted in the following sections and resulting implications, with respect to the possible source of the fluids will be discussed.

Calcite samples were hand crushed and reacted with 100% phosphoric acid (H3PO4) for 1 hr at 25°C (modified method of McCrea 1950). An OPTIMA mass spectrometer was used to perform the isotopic analyses. Results were calculated using the phosphoric acid-CO2 fractionation factor (1.01025 , modified after Sharma and Clayton 1965).

GEOLOGICAL SETTING AND MINERALIZATION

The Cabaçal mineralizations are enclosed within a sequence of tuffs and Volcaniclastic rocks of the Alto Jauru Greenstone Belt. Carbonate and quartz-carbonate veins are common associated with the mineralized zone. Calcite is the only carbonate mineral in these veins that are divided in two groups: lenticular or slightly sigmoidal veins that cross cut the main schistosity in a low angle, and fine veins that occur in swarms, cross cut the main rock schistosity, but in a high angle. Carbon and oxygen isotope data, as well as $^{87}Sr/^{86}Sr$ ratios of the Cabaçal carbonate veins indicate that the first group of veins, and the quartz-carbonate veins are related to igneous processes. The second group is believed to have been formed by metamorphic or meteoric fluids, which percolate through extension fractures and interacted with the country rocks after the cessation of the tectonic processes.

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Petrographic and microprobe studies have detected the presence of fluorite and pyrite in the carbonate veins. Fluorite occurs as later fractures fill, or is present as small triangular crystals. It is a major component in sample SN110.

0.92% and MgO from zero to 0.92%. Sample SN1401 is the richest in these two oxides. CaO varies from 51.17 to 56.07%. Low values in CaO correlate with high values of FeO, MnO, and MgO. SrO is present in the sample SP70-34.20 with values that range from 0.1 to 0.7%.

Stereographic projection showing the average orientation of the main schistosity and carbonate vein systems in Cabaçal mine, plotted in Wulf stereonet. Main schistosity pole in circle, carbonate vein poles in stars, plan represents main schistosity.


Figure 2 - Stereographic projection showing the average orientation of the main schistosity and carbonate vein systems in Cabaçal mine, plotted in Wulf stereonet. Main schistosity pole in circle, carbonate vein poles in stars, plan represents main schistosity.

The veins of the second generation show a wide variation and an increase in δ¹⁸O values. Value range from 8.20 to 18.03‰, but only one value is below 10.4 and only one is above 15.99‰. The δ¹⁸O values are variable too, ranging from -10.78 to -3.02‰ relative to SMOW.

Results plotted in the diagram δ¹³C versus δ¹⁸O (Fig. 4), show that samples from the first group and from the quartz-carbonate veins have similar δ¹³C and δ¹⁸O ratios. These samples plot in the magmatic CO₂ field but the sample SP76-101.10 that shows a higher δ¹⁸O value.

Histograms of the δ¹³C and δ¹⁸O data of the Cabaçal samples show the isotopic ratios to vary between -7 and -3‰ relative to PDB and 7 to 9‰ relative to SMOW, respectively (Fig. 5). On a δ¹³C versus δ¹⁸O diagram, most of the samples lie in general within or close to the CO₂ field, and to the gold occurrence field (Fig. 4).

Ohmoto and Rye (1979) stated that the range of δ¹³C of most of the carbonate veins (-8 to -4‰) is consistent with deep-seated carbon as compared to analyses from igneous rocks. In contrast, Bethke and Rye (1979) argued that values of -8 to -5‰ have been observed in hydrothermal and carbonate minerals from ore deposits in all types of rocks, irrespective of whether or not carbonate rocks are present.

Burrows et al. (1986), interpreting δ¹³C histograms from 14 Au-mineralized locations in the Timmins area, found a concentration of values ranging from -5 to -3‰, and concluded that the Archaean gold-vein mineralization is of a magmatic origin. This evidence also agrees with Wood (1980) who stated that granodiorite gneiss-granodiorite-quartz monzonite-type material which intruded the lower parts of Archaean greenstone belts, could constitute an indirect, or direct fluid source to generate mineralizations in that region.

Carbon and oxygen isotopic data from the first group of veins and from the quartz-carbonate veins from the Cabaçal deposit suggest that deep-seated, probably magmatically derived fluids may have created these veins. Problems related to quartz-carbonate vein analyses must be considered. Due to the low percentage of calcite in the quartz-carbonate veins (less than 2%), the quantity of produced CO₂ was very small, causing problems during sample preparation on the vacuum line. However, samples were analyzed in duplicates and show consistent results.

δ⁸⁷Sr/δ⁶⁶Sr ratios from calcite veins in the Cabaçal mine vary between 0.7029 and 0.7144 (Table 1). These range points to a contribution from mantle like to continent-derived sediments, or reworked crustal materials. Notwithstanding, only two samples from the first group were analyzed for δ⁸⁷Sr/δ⁶⁶Sr ratios, and these show a consistently low value of 0.7029. These data clearly confirm the above idea, concluded from δ¹³C and δ¹⁸O data, in which magmatic fluids could be the source for the generation of the carbonate veins from the first group.

Faure and Hurley (1963) observed that the enrichment in radiogenic δ⁸⁷Sr in the continental crust contrasts sharply with the much lesser increase of the δ⁸⁷Sr/δ⁶⁶Sr ratio in the upper mantle. The identification of this difference was helpful in permitting the identification of crustal-derived strontium (elevated Sr/⁶⁶Sr ratio), and to distinguish it from mantle-derived strontium. δ⁸⁷Sr/δ⁶⁶Sr ratios from calcite veins in the Cabaçal mine vary between 0.7029 and 0.7144 (Table 1). These range points to a contribution from mantle like to continent-derived sediments, or reworked crustal materials. Notwithstanding, only two samples from the first group were analyzed for δ⁸⁷Sr/δ⁶⁶Sr ratios, and these show a consistently low value of 0.7029. These data clearly confirm the above idea, concluded from δ¹³C and δ¹⁸O data, in which magmatic fluids could be the source for the generation of the carbonate veins from the first group.

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the lack of data from sedimentary country rocks must be considered. However, values of 0.7075, others have values of above 0.7119. There is a wide range of values (0.7075 to 0.7144). Only one sample shows a value of 0.7075, others have values of above 0.7119. Fluid inclusion analyses would be useful to confirm this theory. Extensional fractures have been recognized as an important process during the exhumation of metamorphic terranes. Veins generated by downward fluid movement along high or low angle faults and fractures with organic carbon oxidation may therefore be a characteristic feature of such exhumation processes (Ganor et al. 1994).

Craig (1963) reported that meteoric waters could have very positive δ¹⁸O values, even as high as those typical of magmatic fluids as a result of exchange with high-temperature country rock. Waters could obtain δ¹⁸O values of the magmatic range, simply by coming in contact with igneous rocks at their crystallization temperatures, and by oxygen isotopic exchange (Taylor 1967). Similarly, metamorphic waters can also exchange oxygen with sedimentary rocks, hence increasing the δ¹⁸O values (Taylor and Epstein 1962). Carbon with δ¹³C values of -8 to -0.5‰ could be derived from various reservoirs, given that the average δ¹³C values in igneous, sedimentary and metamorphic rocks is -5. and that of juvenile carbon is -5 ±2‰ (Ohmoto and Rye 1979).

Ganor et al. (1994) interpreted the generation of low δ¹³C calcite veins in the Cycladic Complex (Greece) have been generated by oxidation of organic carbon. These veins have δ¹⁸O values of -12 to -8‰, and high values of δ¹³C. They suggested an origin of meteoric or seawater or solution of soil-CO₂ in downward percolating rain waters. Extensional brittle tectonic fractures provided a flow path for the fluid during the late stages of exhumation of the Cycladic Complex.

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Source for the second group of carbonate veins still remains unanswered. However, δ¹³C and ⁸⁷Sr/⁸⁶Sr ratios suggest that fluids from crustal sources formed them. A metamorphic and/or meteoric fluid that percolated and interacted with the country rocks before calcite precipitated in the extensional fractures could be suggested.

Fluid inclusion analyses would be useful to confirm this theory. Fluid inclusions in calcite from veins were analyzed at the University of Windsor during the development of the present work. However, problems related to constant linking caused by the opening of cleavage planes, make the obtained data not trustful.

In contrast to the samples from the first vein group, the seven samples from the second group analyzed for ⁸⁷Sr/⁸⁶Sr ratios display a wide range of values (0.7075 to 0.7144). Only one sample shows a value of 0.7075, others have values of above 0.7119.

The second group of carbonates exhibits a range of ⁸⁷Sr/⁸⁶Sr values greater than that of the wall rocks in Cabaçal region (Fig. 6). However, the lack of data from sedimentary country rocks must be considered.

In general, sedimentary rocks show elevated values of ⁸⁷Sr/⁸⁶Sr. Norman and Lands (1985) analyzed two samples of shale and quartzite from the Pasto Bueno Deposit, Peru, giving ⁸⁷Sr/⁸⁶Sr ratios of 0.7169 and 0.710, respectively. Values between 0.710 and 0.713 characterize metasedimentary rocks in the Calaveras Complex (Schweickert 1981). Furthermore, values higher than 0.714 to 0.730 have also been reported for metasedimentary rocks of the Shoo Fly Complex (Bohike and Kistler 1986).

The variation of ⁸⁷Sr/⁸⁶Sr ratio may be explained by the involvement of fluid exchange with the country rocks, including metasedimentary rocks of apparently high ⁸⁷Sr/⁸⁶Sr values. The contribution of metamorphic fluids can be excluded because the second group of veins postdates metamorphism. Therefore, meteoric water or seawater is the most probable fluid.

There are no estimated values of ⁸⁷Sr/⁸⁶Sr for meteoric waters from the Cabaçal region throughout the geologic history. However, exchange between meteoric water and country rocks is commonly described and recognized to generate a large ⁸⁷Sr/⁸⁶Sr range. Clauer (1981) carried out an experiment by leaching the soluble materials of the saprolite whole rocks from the upper and intermediate zones of the soil profile of the Chad Republic with distilled water. The ⁸⁷Sr/⁸⁶Sr
ratios of the solutions were then analyzed. They varied from 0.709 in the upper part of the profile, through to about 0.715 in the middle part, to approximately 0.765 in the lower part. This experiment shows the possibility in generating a large range of $^{87}$Sr ratios, when meteoric water percolates crustal rocks.

Fauré (1977) reviewed data from Veizer and Compston (1976), Veizer et al. (1979) and Darnaitje and Fieremans (1981), on the variations of $^{87}$Sr/$^{86}$Sr ratios of marine carbonate rocks of Precambrian age. The data suggest that the $^{87}$Sr/$^{86}$Sr ratio of the oceans in Archaean time was similar to that of the Sr in the mantle until 2.5 billion years ago. The marine Sr then increased and reached values around 0.706 in the late Proterozoic time.

The isotope data indicate that different fluids were involved in the deposition of the different generations of carbonate veins. Tentatively, the first group of veins, and the quartz-carbonate vein can be related to igneous processes. Probably, that is the igneous activity that created the first group of veins, and the quartz-carbonate vein can be related to igneous processes. However, the very positive $\delta^13$C values, remain to be explained.


References

**Table 1** - $^{14}$C, $^{81}$S and $^{87}$Sr composition of calcite veins from Cabaça Deposit.

<table>
<thead>
<tr>
<th>Sample</th>
<th>$^{14}$C</th>
<th>$^{81}$S</th>
<th>$^{87}$Sr</th>
</tr>
</thead>
<tbody>
<tr>
<td>SI-110</td>
<td>-5.91</td>
<td>0.81</td>
<td>0.709</td>
</tr>
<tr>
<td>SI-134-64</td>
<td>-5.77</td>
<td>0.68</td>
<td>0.709</td>
</tr>
<tr>
<td>FRDB-03-58-40</td>
<td>-4.38</td>
<td>0.71</td>
<td>0.709</td>
</tr>
</tbody>
</table>

**Figure 6** - Sr/Sr ratio variation for different rocks from Cabaça region; primitive mantle; seawater; sedimentary rocks from different places; and calcite veins from Cabaça. Alvorada Granite from Monteiro et al. (1986); Quatro Marcos region of lavas: granodiorite-granodioritc and tonalite from Cameiro (1985): Agra ClaraGrandodiorite, Cabaça Tonalite and Rio Vernelho Gneiss from Leite e Saes (in press); Santa Helena Gneiss from Meneses et al. (1993): Santa Cruz Gneiss from Ruiz (1992); seawater from 2.5Ga to today (Veizer and Compston 1976; Veizer et al. 1983; Darnaitje and Fieremans 1981); "primitive" mantle from various sources in Bohlke and Kistler (1986); Pasto Bueno shale and quartzitefrom Norman and Landis (1983): metasedimentary rocks from Calaveras Complex from Schweickert (1981); and metasedimentary rocks of the Show Fly Complex from Bohlke and Kistler (1989).

**Acknowledgment** To CNPq-Conselho Nacional de Desenvolvimento Científico e Tecnológico-Brasil, Professor Fred Longstaffe of the Laboratory for Isotopic Studies (University of Western Ontario), Dr. Colombo Tassinari (Universidade de Sao Paulo), and to the reviewers for their valuable comments.


Recebido em 19 de agosto de 1998

Rio Vernetto e Santa Helena Gneisses

Cabaça and Cacupuc Complexes

Agua Clara and Quatro Marcos Granodiorites

Avonhoda and Quatro Marcos Granodiorites

Regional

Cabaça Tonalite and Rio Vernelho Gneiss

Santa Cruz Gneisses

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