Geochemistry of the ore fluids in the Bonfim and Itajubatiba gold skarn deposits, Northeastern Brazil: a PIXE method study

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Skarn deposits are characterised by their high variety of metals and contents. The variety of metals become an interesting economic characteristic of these deposits, that could be an important source of many metals. In this scenario, each particular skarn can show different geochemical associations. Different ore types and their complex geochemical association reflect the parental fluid, the composition of the host rocks and the temperature and pressure of ore formation (Meinert, 1992). The characterisation of the ore fluids can give fundamental information to elaborate a metallogenic model and to provide important criteria for ore exploitation, in each particular deposit.

Detailed characterisation of the ore fluids composition can be obtained by mineral chemistry and fluid inclusions studies of the ore paragenesis. The advance of new techniques allows, for example, to measure traces elements in minerals, in a non destructive way. That is the case of the PIXE Method (Particle Induced X-Ray Emission), where the highly intense *photon* beam from the *synchrotron* allows deep atoms to be excited by the *photons* remaining after the attenuation by the matrix (Volfinger *et al.*, 1997).

This contribution reports PIXE analyses carried out on the samples from the ore paragenesis of two gold skarn deposits, in Northeastern Brazil: Itajubatiba (Au) and Bonfim (W-Au). The principal objective is to determine the composition of the ore fluids and their geochemical association. Its purpose is to estab-lish a geochemical and metallogenic model for these deposits and elaborate some be used in a more rational exploitation of them.

Geological setting of the deposits

The Itajubatiba gold deposit is situated 35 km southwest of the town of Patos in the state of Paraíba. It was discovered in the 1940's and has been mined during about thirty years with a cumulated production of approximately 5 tons of gold. The ore grade ranges from 0.5 to 2.0 ppm and the highest grade reached 6.3 ppm (Lins and Scheid, 1981). The geological setting consists of marble, mica schist (Mesoproterozoic and Neoproterozoic ages, respectively - Van Schmus *et al.*, 1995), migmatite and alkaline rocks (Neoprotero-zoic). The region is located in the Patos lineament zone which has been affected by a transpressional tectonic with dextral shear in the E-W direction, during the Brazilian/Pan-African orogeny (*c.* 600 Ma). During the last tectono-metamorphic episodes (ductile to brittle behaviour and amphibolite to green-schist facies transitions), a metasomatic event trans-formed the marble and alkaline rocks into calc-silicate rocks in several places. The calc-silicate rocks occur in the form of lenses (0.1 to 10 m thick) in the marble and along the margins of the alkaline rocks that are controlled by shear. The calc-silicate parageneses are constituted by:

(1) Garnet ($Gross_{25-80}$), pyroxene ($Diop_{25-75}$), plagio-clase (An_{26-97}) and titanite; (2) Amphibole (Act_{12-70}) and epidote; (3) Magnetite, pyrrhotite and chalcopyrite; (4) Quartz, calcite, pyrite, arsenopyrite, hematite and gold.

Gold occurs either disseminated or in shear fractures and is associated with quartz, calcite, pyrrhotite, chalcopyrite, pyrite and arsenopyrite within the calc-silicate rocks.

The Bonfim W-Au deposit is situated 27 km southeast of the town of Lajes in the state of Rio Grande do Norte. The deposit has a proven total reserve of 70 tons of scheelite. In the early 1990's gold was discovered into the dumps of the abandoned mine, and about 100 kilos of gold has been extracted from this material. The geological setting comprises ortho-gneiss (Palaeoproterozoic), marble, quartzite, mica schist (Mesoproterozoic to Neoproterozoic) and granitoid rocks (Neoproterozoic). The region is located in the Seridó fold belt that was affected by a transpressional tectonic (Brazilian/Pan-African orogeny) with dextral shear in the NE-SW direction. Late in this tectonic history a metasomatic episode occurred, which transformed the marble and the mica schist into calc-silicate rocks.

The calc-silicate rocks show interdigitated contact with their country rocks. Calc-silicate rocks were formed into the marble and mica schist, or in the contact between both. Their parageneses are composed by: (1) Garnet ($Gross_{30-40}$), pyroxene ($Diop_{40-80}$), plagioclase (An_{88-97}), titanite, allanite, scheelite and molybdenite; (2) Amphibole (Act_{4-74}), zoisite-clinozoisite and sericite; (3) Magnetite, pyrrhotite and chalcopyrite; (4) A black fine grained material (carbonaceous matter?), pyrite, bismuthinite, bismuth and gold; (5) Calcite and quartz.

Gold occurs either disseminated or in shear fractures associated with the black material, bismuthinite and bismuth within the calc-silicate rocks. This paragenesis is considered relatively rare.

Results

To study the ore fluids, samples deriving from the ore parageneses of both deposits were analysed. Thus, these samples are constituted by sulphides and gold. They were analysed for major, minor and traces elements using a proton miniprobe at the CERI-CNRS laboratory, Orléans. Analytical conditions were constituted by 2.5 MeV *proton* beam, with a 1500 μm^2 spot and a current intensity of 0.7–0.8 nA. The X-ray spectrum analysis is performed quantitatively with the aid of a data base and a fitting and modelling computer program (e.g. Maxwell *et al.*, 1995).

Multi-element geochemical analysis (major and 30 minor and traces elements) in whole rock were carried out on selected samples from both deposits. Samples of calc-silicate rocks and their protoliths have been analysed.

The PIXE results obtained for the ore samples in the Bonfim deposit, are as follows:

(1) Gold: Au (76.5%) and Ag (9.4%). It was detected Fe (5.4%), Bi (8.7%) and Cu (0.12%). The analysed gold grain (40 µm diameter) is in contact with bismuthinite. As this grain is smaller than the proton beam, the portion around it could also have been excited. So, the last three elements are, probably, from the bismuthinite. These elements are present in the analysed bismuthinite (see below).

These data reveal an argentian gold, that is, an alloy of gold and silver with composition $Au_{0.89}Ag_{0.11}$.

(2) Bismuthinite: Bi (74.4%), Fe (4.2%), Au (1.5%), Ag (0.3%), Cu (0.13%) and S (19.5%, calculated by difference).

Geochemical data in whole rock to the Bonfim ore show a positive correlation between Au and Bi-Ag-As. Calc-silicate rocks present a preferential geochemical association between Te, Ni, Zn and Co. This associa-tion is defined by a relatively higher grade of these elements in the calc-silicate rocks, with regard to the country rocks.

In the Itajubatiba deposit, the analyses of the ore paragenesis reveal the following results:

(1) Pyrite: Fe (47.3%), Cu (17.3%), Mn (0.5%), Se (846 ppm), Ni (530 ppm) and S (34.8%, calculated by difference).

(2) Pyrite: Fe (41.6%), Cu (16.6%), Bi (0.5%), Se (0.13%) and S (41.2%, calculated by difference).

The pyrite is, actually, cupreous pyrite.

(3) Pyrrhotite: Fe (63.5%), Mn (0.9%), As (242 ppm), Se (96 ppm) and S (35.6%, calculated by difference).

<4) Arsenopyrite: Fe (39.4%), As (9.6%), Co (0.6%) and Ni (603 ppm). The As has been partially quantified, due to unknown analytical problems.

Geochemical data in whole rock show a positive correlation between Au and Sc-Sr-Cu-Bi-Y-Zr-Cr-Mo-As. Calc-silicate rocks show a geochemical association between As, Cu, Zn, Cr and Mo.

Discussion

The present study reveals important amounts of gold and silver in the bismuthinite, at the Bonfim deposit. It is very important for the ore exploitation. Besides the W-Mo-Au ore association already known, the new data reveal that this deposit contain enough Bi and Ag, that could be characterised as a by-product. In other words, there is a potential for these last two metals.

In the Itajubatiba deposit the results show relatively large amounts of Cu, Mn, Bi, Co and Se, which sulphides can contain.

In both studied deposits, the presence of the association Au-Ag-Bi-As-W-Mo-Ni-Co reflects the signature of the parental fluid and improve a new constraint to the genetic model. This geochemical association points to an important contribution of magmatic fluids to the ore-forming system.

Finally, PIXE analysis allows to quantify minor and traces elements in minerals, that can be an important tool to understand geochemical and metallogenic process occurring in the origin of ore deposits. PIXE data can also be used as economic indicator in the search for and exploitation of ore deposits.