THE PROTEROZOIC GRANITE MASSIFS OF CAMPO FORMOSO AND CARNAIBA (BAHIA, BRAZIL) AND THEIR Be, Mo, W MINERALIZATIONS

[1] Luc Rudowski, [2] Gaston Giuliani, [2] Pierre Sabaté

[1] *Université Pierre et Marie Curie Laboratoire de Géologie Appliquée, Tour 26, 5ème étage 4, Place Jussieu 75230 Paris Cedex 05 (France)*
[2] *ORSTOM – C.P. 4021 Alameda da Barra 40.000 – Salvador (Bahia) Brazil*

I. INTRODUCTION

The granite massifs of Campo Formoso and Carnaíba are located in the northern part of São Francisco Craton (Fig. 1a) and belong to a family of small to medium sized granitoids that include Miguel Calmon, Saúde, Jaguarari, Flamengo and Juazeiro plutons. Rb-Sr radiometric data indicate an age of 1.9 Ga, suggesting that the emplacement of these granitoids occurred during the Early Proterozoic, thus characterizing the Transamazonian phase (Torquato *et al.,* 1978). New field data are presented concerning the generation, emplacement and geological features of these two granites together with the associated Be, Mo, W mineralizations.

II. GEOLOGICAL FRAMEWORK OF THE GRANITES

The Campo Formoso and Carnaíba massifs intrude the volcano-sedimentary terranes of the Serra da Jacobina, apparently related to the Early Proterozoic (Couto *et al.,* 1978). This series is composed mainly by fuchsitic quartzites, pelitic schists, graywackes, amphibolites and chromitiferous ultrabasic bodies. The terranes exhibit a monoclinal structure dipping to the East and show successive imbrications with a western vergence. The imbricated structure is related to the thrusting of the series over a migmatic Archean basement along a "décollement" surface localized in the ultrabasic horizon.

Similar petrographic and structural features from the Campo Formoso and Carnaíba granite massifs provide evidence in favor of a common source and similar thermodynamic genesis conditions for the respective magmas.

III. CAMPO FORMOSO PLUTON

1. Geological and petrographic data

The pluton exhibits a concentric structure characterized by an outer muscovite-biotite leucocratic granite unit (γ_1) and a central biotite-muscovite mesocratic granite unit (γ_2) (Fig. 1a). Radar and field observations show a sharp contact between the two granitic units: in the northern part of the pluton, enclaves of γ_1 are encountered in γ_2 and along the contact, a γ_2 fine grained granite intrudes γ_1. A two-step intrusive mechanism is suggested for the emplacement of the two units.

The outer unit is composed of a light, coarse grained granite characterized by the abundance of muscovite crystals (1-3cm), and contain an assemblage of quartz, oligoclase, albite, microcline (I, II), biotite, allanite, zircon, apatite and opaques. The central unit presents the same mineralogical association but biotite predominates on muscovite. Structural relations permit the separation of two facies in γ_2:

– γ_{2_a}, a medium to fine grained two-mica granite, observed in dykes or veins.

– γ_{2_b}, an equigranular to porphyritic two-mica granite that forms the main facies of the central unit.

Furthermore, relatively small outcrops of muscovite granite appear within the two units as granitic intrusive dykes.

2. Aplopegmatites and deuteric-hydrothermal evolution

Aplopegmatites are well developed and sometimes form important dyke swarms in γ_2; they are characterized by an assemblage of K-feldspar, quartz, muscovite and garnet, sometimes with tourmaline and plagioclase. Locally, beryl, molybdenite and sulphides mineralizations are observed.

The deuteric-hydrothermal evolution of Campo Formoso pluton is characterized mainly by muscovitisation, greisenisation, episyenitisation and tourmalinisation phenomena.

Muscovitisation: Muscovite appears either in straight relationship with biotite or in isolated flakes. The problem of muscovitisation is very complex and field observation on γ_1 shows the presence of muscovite veinlet swarms inducing a huge muscovitisation in the granite.

These veinlets present a longitudinal extension varying from several centimeters to 3 or 4 meters; no significant distinction can be made between muscovite in the granite and in the veinlets. At the contact zone of the veinlets, the granite does not show any bleaching or alteration: this muscovitisation appears very different from greisenisation.

Locally, the muscovitisation is developed following magmatic planar structures, marked by the joining of muscovite crystals and feldspars phenocrysts, and formed during a plastic granitic deformation stage. This development seems to result from an early concentration of fluids closely associated with magma during the first stage of crystallisation. However, the muscovite veinlets can cross aplopegmatitic joins or sometimes dykes of γ_{2_a}. These different chronologic relations appear to show a con-

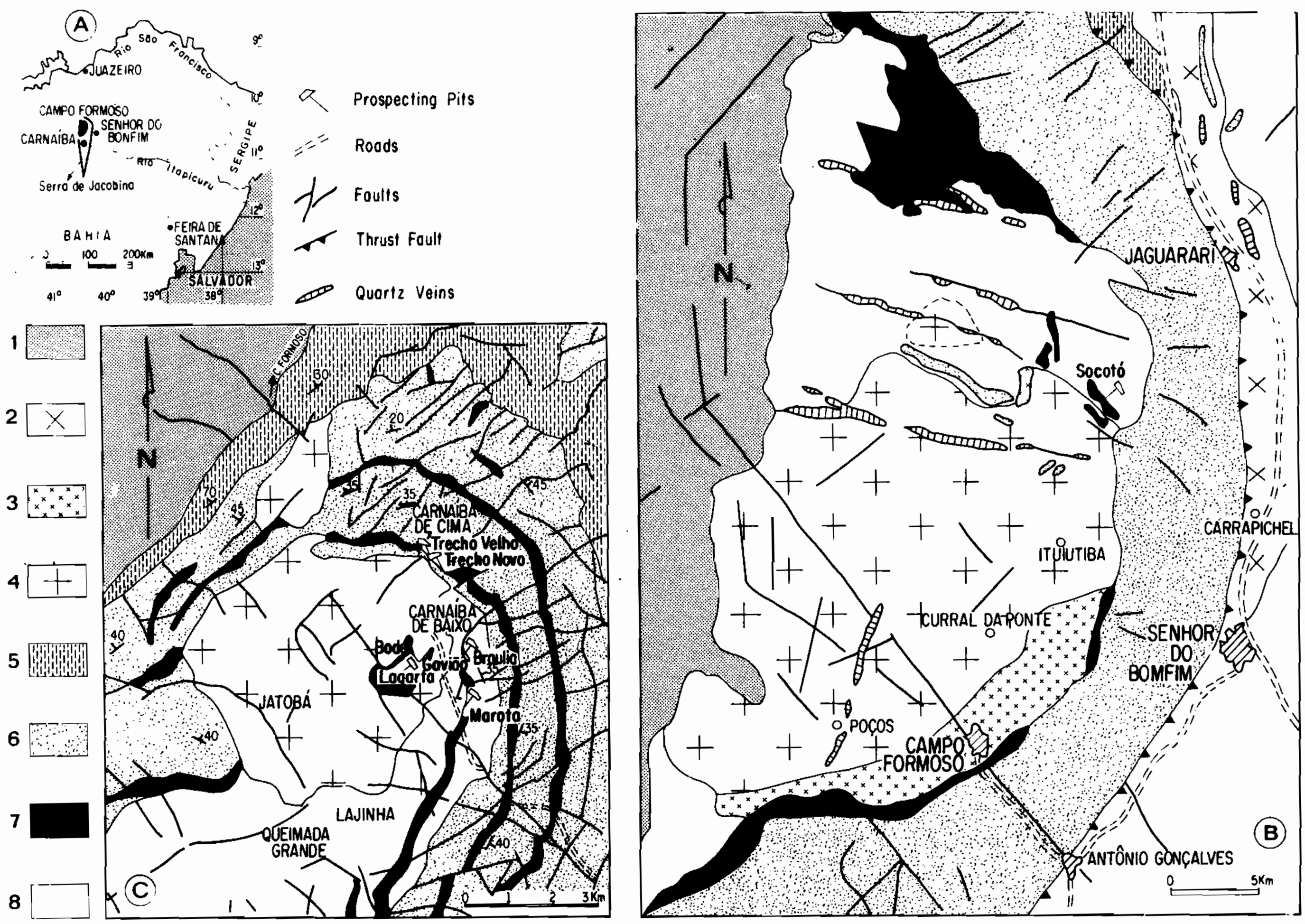

Figure 1.

Scheme of localisation of the granitic massifs; B and C Geologic skech maps of the Campo Formoso and Carnaíba granites. 1: Proterozoic superior cover; 2: Jaguarari granite; 3: Two-mica granite; 4: Porphyroid two-mica granite; 5: Chloritoschist phyllites; 6: Quartzites and volcano-sedimentary formations; 7: serpentinites; 8: Archean gneisses, metatexites and diatexites.

tinuity with time of this muscovitisation process during a magmatic, tardimagmatic and hydrothermal stage.

Greisenisation: greisen veins exist in association with γ_{2b} granite in the northern part of the pluton. In all the area, the greisen veins are barren or contain only a few sulphides.

Episyenitisation: episyenitic feldspathic veins and episyenitised granites occur in γ_1 and γ_2 as late hydrothermal granite alteration. This is characterized either by the presence of an episyenitised granite (chloritisation of the biotite, feldspathisation) or/and by the development of red monomineral feldspathic zones. This alteration results from the circulation of hydrothermal fluids along shear zones.

Tourmalinisation: This is characterized by the development of tourmaline and quartz lode or veinlets. Two types are considered:

– veinlets developed mainly in γ_1 along the contact γ_2 – γ_1; locally, the intense development of microcracks causes a diffuse granite tourmalinisation.

– huge regional fracturing, affecting Campo Formoso granite and the surrounding rocks (Fig. 1b). These structures, oriented NS or E-W, are probably associated to extension fractures in shear zones.

IV. CARNAÍBA PLUTON

The Carnaíba intrusive massif forms a small and circular pluton, occurring in an antiform structure within the Serra de Jacobina (Fig. 1c). The presence of quartzite enclaves and roof-pendants of serpentinites confirms the intrusive character of the granite. The main granitic facies is a mesocratic prophyritic two-mica granite, similar to the γ_{2b} facies from Campo Formoso. Aplopegmatitic joins are well expressed and exhibit the same mineralogical composition of those from Campo Formoso with beryl and sulphides mineralization.

V. Be-Mo-W MINERALIZATIONS FROM CARNAÍBA AND SOCOTÓ PROSPECTING PITS

The total production of emerald in Brazil was, until 1980, related to the Carnaíba prospecting pits. The mineralisation was discovered in 1964-1965 (Cassedanne, 1985) and the production between 1970 and 1980, was 204 tons of negociated emerald with a productivity factor of 2.17kg/m^3 (Moreira and Santana, 1982).

In 1983, the occurrence of Socotó was discovered in the region of Campo Formoso.

In spite of field mapping (Couto and Almeida, 1982) and structural study (Griffon *et al.*, 1967) devoted to the Carnaíba prospecting pits, little work has been done concerning their genesis. Schwartz (1984) studied the solid inclusions associated to emerald from Socotó and Carnaíba, and classified these occurrences in the Ural Mountains type (Schwartz, 1986).

• Structural and geometrical features.

The emerald (emerald and green beryl) and molybdenite mineralization is contained in phlogopitites resulting from the metasomatic transformation developed in ultrabasic rocks from aplopegmatitic or/and plagioclasic veins with locally intercalated tremolitic or talc formations.

These serpentinites present several types of occurrences:

– as imbricated structures on the Archean gneissic basement from Socotó. In this case, the deformation of the phlogopitites and veins is important and materialized by boudinage, shearing, zig-zag folds, etc...

– as roof-pendants in the Carnaíba granite forming the prospecting pits fields of Bode, Lagarta and Gavião (Fig. 1c). The phlogopitites present in this case well developed metasomatic zonations without important deformation.

– as country rock terranes in Carnaíba granite field with the development of the prospecting pits of Trecho Novo, Trecho Velho, Braúlia, Formiga and Morota (Fig. 1c).

1. Aplopegmatitic and plagioclase veins

These veins present a variable thickness (cm to several cm) and are composed either of an aplopegmatite (similar to those observed in Campo Formoso and Carnaíba massifs) with K-feldspar, quartz, muscovite, garnet, or of a plagioclase (albite, oligoclase with sometimes tourmaline). For instance, no aplopegmatite veins were encountered in Socotó field.

2. Metasomatic zoning and mineralizations

A metasomatic zoning is developed at the contact of aplopegmatite and/or plagioclasic veins with serpentinites. It presents imbricated zones with clear rectilinear limits and different mineralogy (Fig. 2).

In the case of a plagioclase central zone, from internal to external zones, the following mineralogical successive zones are encountered:

– a brown phlogopitic zone presenting huge crystals of biotite (0.2 to 3cm) with local apatite concentration. Chromite is present in the outer part of this zone and remains constant in all the other following external zones.

– a light brown fine grained phlogopite zone associated with chromite.

– a phlogopite zone (often composite) with talc, chromite and magnetite.

– a talc chromite, magnetite, serpentinite zone with some phlogopite crystals which disappear in the external part of this zone.

The mineralization is composed of beryl (emerald), molybdenite with sometimes scheelite, alexandrite, phenacite, tourmaline, chalcopyrite, pyrrotite, pyrite and fluorite.

The green beryl is observed from the center zone associated with the aplopegmatites and/or plagioclasites, to the phlogopite zones where its colour is more intense. It is in the first internal chromite-free zone where emerald presents gem quality. Molybdenite appears in all the metasomatic section. Scheelite is not abundant and is found either associated to phlogopitite zones, or in metasomatic zones which possess more calcic composition i. e. with the appearance of tremolite, resulting probably from the metamorphic transformation of basic intercalations in the serpentinites (cases of Braúlia and Marota prospecting pits).

• Other mineralized structures

The phlogopitite zones are sometimes crossed by other aplopegmatite veins mineralized in molybdenite and beryl. At Socotó and Carnaíba, an important swarm of quartz veins (up to 80 cm in thickness), mineralized in molybdenite and pale green beryl cut all the metasomatic system inducing a muscovitisation.

Sometimes, massive molybdenite veinlets occurs as cross-cutting structures in the plagioclase veins.

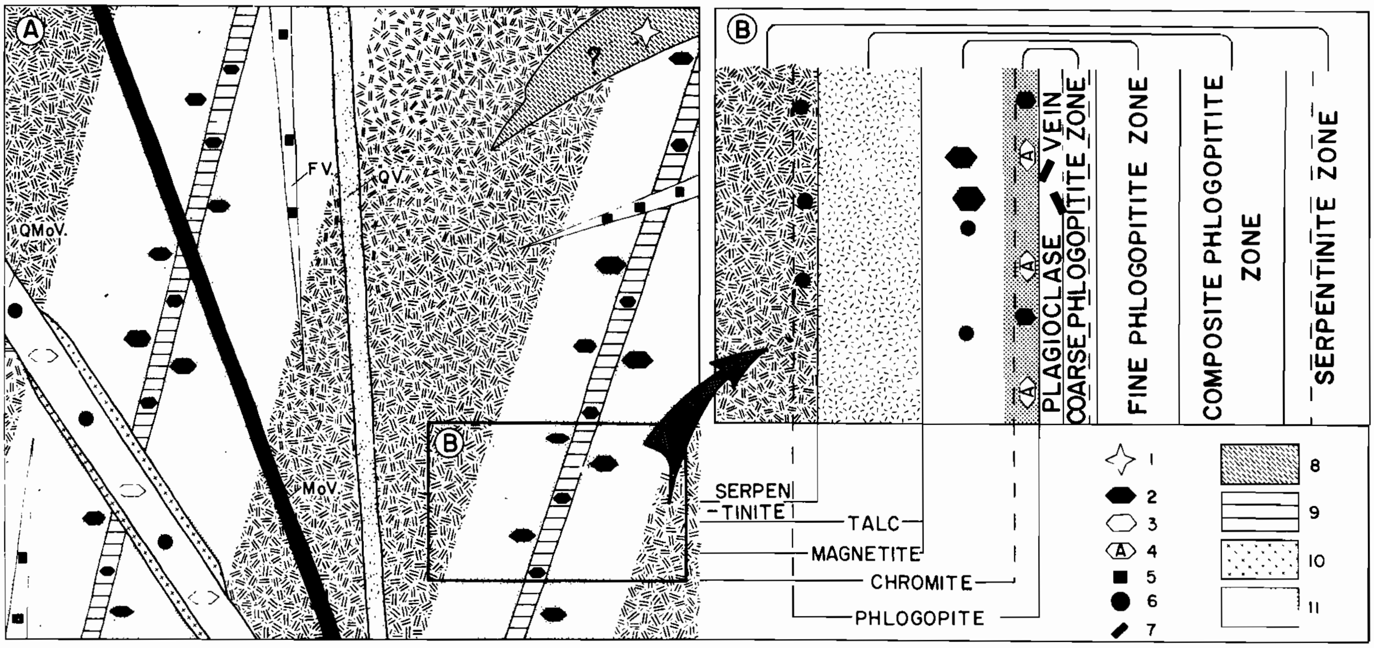

Figure 2.
Schematic diagram showing the evolution of the Carnaíba and Socotó hydrothermal system. Aplopegmatitic and/or plagioclasic veins inducing the development of metasomatic phlogopite zones in the serpentinite formations. Development of an important swarm of veins: – barren (QV.) or molybdenite bearing quartz veins (QMoV.) producing generally a muscovite salband alteration; – fluorite veins (FV.); – massive molybdenite veins (MoV.). (Fig. 2A)

Metasomatic zoning developed at the contact of a plagioclase vein with serpentinites: CARNAÍBA-BRAULIA prospecting pit. 1: scheelite; 2; emerald or green beryl; 3: pale green beryl; 4: apatite; 5: fluorite; 6: molybdenite; 7: tourmaline; 8: Tremolitic zone; 9: plagioclase vein; 10: Muscovite salband alteration; 11: metasomatic phlogopite zone (Fig. 2B)

CONCLUSIONS

The Campo Formoso and Carnaíba granites present several petrographic and deuteric-hydrothermal alterations which indicate that the magma was saturated in water. Muscovitisation and chloritisation of biotite and replacement of plagioclase by K-feldspar are good examples of post-magmatic replacement and reflect with the presence of aplopegmatite joins, episyenite veins and tourmalinite veinlets, an important fluid circulation and granite transformation. The problem of muscovitisation is more complex and the muscovite appears partly as a primary constituent of the rock and another part as a clearly secondary phase.

Meanwhile, in the absence of geochemical and stable isotope studies, the origin of the fluids associated to this muscovitisation (magmatic-hydrothermal, meteoric or mixture) remains open. It is evident that these deuteric alterations can be developed during the last stage of granite emplacement, and it seems that this is related to the hydrothermal phases.

The emerald mineralization is developed in phlogopitite that results from the interaction of the fluids associated with the aplopegmatitic and/or plagioclasic veins, with serpentinite rocks. The metasomatic zoning characterized by the development of zones with variable mineralogical composition from a mono-mineralic central zone (phlogopitite) to peripheric zones (serpentinites), separated by sharp metasomatic fronts, illustrates an infiltration metasomatic process (Korzhinskii, 1970).

In another way, the presence of Be and Mo mineralizations in both metasomatic zones and granitic veins, allows the suggestion that these elements are probably carried by hydrothermal fluids related to the granitic system.

Emerald is the result of the incorporation of Cr, Fe, V (present in the chromitic serpentinites) in the lattice of beryl during the percolation of the hydrothermal fluid in the serpentinites.

REFERENCES

CASSEDANNE, J. 1985 – Au pays des Emeraudes. *Monde et Minéraux*, 66, 16-20.

COUTO, P. 1978 – Projeto Serra de Jacobina; geologia e prospecção geoquímica. Relatório final. Salvador, CPRM, 1878. 415p. Convênio DNPM/CPRM.

COUTO, P. and ALMEIDA, J.J. 1982 – Geologia e mineralização na área do garimpo de Camaíba (Bahia). Anais do XXXII Cong: Bras. Geol., Salvador, Bahia, v.3, 850-861.

GRIFFON, J.C. 1967 – Apresentação do mapa geológico (1:100.000) da parte central da Serra de Jacobina-Bahia. *In*: Congr. Bras. Geol., 2, Curitiba. Boletim Paranaense de Geociências, 26, 32-34.

KORZHINSKII, D.S. 1970 – Theory of metasomatic zoning. Clarendon press, Oxford, 162p.

MOREIRA, M.D. and SANTANA, A.J. 1982 – O garimpo de Camaíba geologia e perspectivas. Anais do XXXII Congr. Bras. Geol., Salvador, Bahia, v. 3, 862-874.

SANTANA, A.J. 1980 – Projeto Esmeralda. Relatório Final. Salvador. Companhia Baiana de Pesquisa Mineral, v.1., Convênio SME-CBPM.

SCHWARTZ, D. 1984 – Inclusões em esmeraldas. Revista Escola de Minas Ouro Preto, v. XXXVII, nº 3, 25-34.

SCHWARTZ, D. 1986 – Classificação genética das ocorrências de esmeralda. Boletim nº 1, XXXIV Congr. Bras. Geol., Resumo, p. 184.

TORQUATO, J.R.; OLIVEIRA, M.A.F.T. and BARTELS, R.L. 1978 – Idade radiométrica do granito de Campo Formoso, Bahia uma idade mínima para o grupo Jacobina. Revista Brasileira de Geociências, v. 8, 171-180.