GEOCHEMISTRY AND PETROLOGY OF FELSIC AND MAFIC SUITES RELATED TO THE PALEOPROTEROZOIC TRANSAMAZONIAN OROGENY IN MINAS GERAIS, BRAZIL

JOEL JEAN GABRIEL QUÉMÉNEUR AND CARLOS MAURICIO NOCE

ABSTRACT  Paleoproterozoic (ca. 2.0-2.1 Ga) intrusive rocks exposed along the southern border of the São Francisco Craton have been divided into three suites: granite suite, TTG (tonalite-trondhjemite-granodiorite) suite, and gabro-diorite suite. The granite suite comprises two distinct groups of plutons, one composed of highly differentiated peraluminous granites, and the other including less evolved metaluminous to peraluminous high-K granites. It is suggested that granitic plutons are not derived from a single magma source, probably due to their association to more than one stage of the orogen evolution. TTG and gabro-diorite suites follow a calc-alkaline trend, and may constitute a single large suite originated from mantle-derived magmas at a plate margin setting. However, chemical data of some granodioritic plutons of the TTG suite indicates contribution of crust-derived material.

Keywords: geochemistry, petrology, felsic suites, mafic suites, Paleoproterozoic

GEOLOGICAL SETTING  Several granitoid and mafic intrusions exposed along the southern border of the São Francisco Craton in Minas Gerais have been dated at ca. 2.0-2.1 Ga (Teixeira 1985, Quéméneur and Vidal 1989, Heilbron et al. 1989, Choudhuri et al. 1992, Teixeira et al. 1998, Avila et al. 1998, Noce et al. 1998). These intrusions are part of a magmatic arc related to the Transamazonian Orogeny, and are intrusive into an Archean crust composed of TTG gneiss, granite-gneiss, migmatite, granulite, and greenstone belt remnants (Fig. 1).

Metamorphic grade of Archean rocks increases westward, from amphibolite facies in the São João del Rei-Lavras area to granulite facies in the Lavras-Carmópolis area. Granulitic rocks comprise charnockite, enderbite, charnockite gneiss, mafic granulite, and spinel-bearing ultramafic rock. Charnockites are probably of magmatic origin and yielded a Rb-Sr whole-rock isochron of 2660±30 Ma (Quéméneur 1995). Migmatites of granitic composition predominate to the north of the granulitic rocks, and are included in the Campo Belo Complex. The migmatization event was dated at 2839±17 Ma (U-Pb age, Teixeira et al. 1998).

Greenstone successions mainly composed of mafic- to ultramafic rocks of tholeiitic to komatitic composition make up a disrupted belt that extends south of the Quadrilátero Ferrífero to the west of Lavras (Barbacena Greenstone Belt, Pires et al. 1990).

THE TRANSAMAZONIAN MAGMATIC ARC  The magmatic arc was first defined by Quéméneur et al. (1994). It extends from more than 250 Km from east to west comprising roughly aligned granitoid and mafic bodies. This paper will focus on the central part of the belt, where the intrusive rocks have been divided into three suites: granite suite, TTG (tonalite-trondhjemite-granodiorite) suite, and gabro-diorite suite.

Chemical analysis presented hereafter were carried out at the École de Mines de Saint Etienne (France) by using a X-ray fluorescence and ICP-MS.

Figure 1 - Geologic map of southern border of the São Francisco craton displaying Transamazonian intrusive bodies and the Archean basement
Granite suite

It comprises two distinct groups of plutons. Ritápolis, Itutinga and Perdões intrusions are highly differentiated peraluminous granites, while the Porto Mendes massif is a less evolved metaluminous to peraluminous high-K granite (Table 1).

RITÁPOLIS MASSIF

Granitic rocks of Ritápolis have been studied by many authors, including Guimarães and Guedes (1944), Ebert (1956), Quéméneur and Baraud (1983), Porto Jr. (1988), among others. The Ritápolis massif is a large (25×13.5 km, 250 km²) ovoid-shaped body intrusive into Archean greenstone belt rocks, and associated to a surrounding pegmatite field that includes lithium-tin-tantalum-bearing pegmatites. Its southern contact with the Pilões granodiorite is rather irregular and many enclaves of this rock are found within the Ritápolis massif, even in its central portion.

The Ritápolis granite displays an isotropic texture except for its southern portion where it is affected by the north-verging São João do Rei-Nazareno shear zone, developing an E-W foliation. With its size, the massif is quite homogeneous and composed of a leuocratic medium-grained granite, porphyritic at some places. The rock-forming minerals are K-feldspar (30-40%), comprising large (4-8 mm) subidiomorphic mesoperthite crystals and small microcline crystals, quartz (30-40%), plagioclase (15-25%), An₆₋₅-An₃₋₂ 2-6 mm in size, and garnet, represented by the Itutinga granite and Archean gneiss. The minerals are apatite, epidote, allanite, sphene, ilmenite and zircon. The Ritápolis granite plots on the monzogranite field of the Streckeisen's diagram.

The chemical analysis plot on the granite and adamellite fields of the Debon and Lefort’s (1983) diagram, and on the peraluminous field of the Maniar and Piccoli’s (1989) diagram based on Shand’s index. The Ritápolis granite is a highly fractionated S-type granite, with high contents of Si, Rb and U, and low contents of Fe, Ti, Mg, Ca, Ba, Li (24 ppm) and V (3 ppm). Rocks from the western portion of the massif are enriched in Ti, Zr, Ba, U, Th and REE, compared to the ones from the eastern portion, what may imply in the presence of two distinct intrusions.

RESTINGA GRANITE (Y-RICH GRANITE)

It is a small body (6.5×1.2 km) located at the northeastern border of the Ritápolis Massif. It is a homogeneous fine-grained (1-2 mm) mesocratic granite, composed by K-feldspar (40-45%), quartz (30-35%), oligoclase (20%), and minor secondary albite, and biotite (6-7%).REE-, Y- and Zr-rich accessory minerals like allanite, monazite, xenotime, and zircon are always present.

The Restinga granite chemical composition is in marked contrast to the Ritápolis granite composition. The Restinga granite is less fractionated and displays an alkaline trend. It contains high values of boron and rare earth elements like Rb, U and Th, and compatible elements like Ba, Zr, V (average 16 ppm) and Li (average 65 ppm). High Y content (average 357 ppm) is the most characteristic feature of this granite. The alkaline trend is indicated by the Y and also by the high RHEE contents. No radiometric ages are available for the Restinga granite, and its field relations with the Ritápolis granite are not observed. Thus, its inclusion into the Transamazonian arc is still uncertain.

ITUTINGA GRANITE

This pluton was deformed during the Neoproterozoic Brasiliano Orogeny. An oblique NE verging thrusting system, associated to the São João do Rei-Nazareno shear zone, affected both the metasediments of the Andrêlandia Group and its breccia assemblages like Rb, U and Th, and compatible elements like Ba, Zr, V (average 16 ppm) and Li (average 65 ppm). High Y content (average 357 ppm) is the most characteristic feature of this granite. The alkaline trend is indicated by the Y and also by the high RHEE contents. No radiometric ages are available for the Restinga granite, and its field relations with the Ritápolis granite are not observed. Thus, its inclusion into the Transamazonian arc is still uncertain.

ITUTINGA GRANITE

This pluton was deformed during the Neoproterozoic Brasiliano Orogeny. An oblique NE verging thrusting system, associated to the São João do Rei-Nazareno shear zone, affected both the metasediments of the Andrêlandia Group and its breccia assemblages like Rb, U and Th, and compatible elements like Ba, Zr, V (average 16 ppm) and Li (average 65 ppm). High Y content (average 357 ppm) is the most characteristic feature of this granite. The alkaline trend is indicated by the Y and also by the high RHEE contents. No radiometric ages are available for the Restinga granite, and its field relations with the Ritápolis granite are not observed. Thus, its inclusion into the Transamazonian arc is still uncertain.

ITUTINGA GRANITE

This pluton was deformed during the Neoproterozoic Brasiliano Orogeny. An oblique NE verging thrusting system, associated to the São João do Rei-Nazareno shear zone, affected both the metasediments of the Andrêlandia Group and its breccia assemblages like Rb, U and Th, and compatible elements like Ba, Zr, V (average 16 ppm) and Li (average 65 ppm). High Y content (average 357 ppm) is the most characteristic feature of this granite. The alkaline trend is indicated by the Y and also by the high RHEE contents. No radiometric ages are available for the Restinga granite, and its field relations with the Ritápolis granite are not observed. Thus, its inclusion into the Transamazonian arc is still uncertain.
diorite intrusion covering the São Sebastião da Vitória Massif and Baragar's (1971) AFM diagram, and may constitute a single large content. However, both suites follow a calc-alkaline trend in the Irvine that are distinguished from the TTG suite by their high amphibole content. The Cassiterita pluton is limited by the Caburu shear zone to the north, and the São João do Rei-Nazareno shear zone to the south. Where deformation is more intense, like the central portion of the pluton, the rock is medium-grained biotite gneiss. However, it differs from the adjacent Archean TTG gneiss because the latter always displays a characteristic banded texture. A fine-grained (1-3 mm) granodiorite predominates in less-deformed zones like the northeastern margin. The intrusion is predominantly composed of granodiorite and tonalite, cut by several trondhjemitic veins. Its easternmost portion displays a trondhjemitic- to tonalitic composition (Avila 1992). Rock-forming minerals are plagioclase (40-50%), quartz (30-35%), microcline (8-15%), and biotite (6-10%). The most common accessory minerals are sphene, ilmenite, apatite, secondary epidote, allanite and zircon. Granodioritic rocks are rich in Ti, Ba, Zr and REE. Their mantelic character is indicated by high Zn/Pb values (average 3.49). Trondhjemitic rocks are more leucocratic and poorer in K, Ti, Ba, Zr and REE. Zn/Pb values are also slightly lower (3.06) when compared to granodiorites. Chemical compositions of Cassiterita and Pilões intrusions are very similar, suggesting that they are co-genetic (see table 2).

**Gabbro-diorite suite** It includes four gabbro- to diorite intrusions that are distinguished from the TTG suite by their high amphibole content. However, both suites follow a calc-alkaline trend in the Irvine and Baragar’s (1971) AFM diagram, and may constitute a single large suite.

**SÃO SEBASTIÃO DA VITÓRIA MASSIF** This is the largest gabbro-diorite intrusion covering ca. 60 km². Deformation along the São João del Rei-Nazareno shear zone resulted in numerous zones of schist cutting the massif. The same event was probably responsible for widespread chlorite and epidote alteration of gabbros and diorites. Aplite veins of trondhjemitic composition that may be related to the Cassiterita pluton also cut the massif.

**IBITUTINGA DIORITE** This intrusion was named as Ibitutinga diorite by Ávila (1992), who lately proposed its subdivision into two bodies, Brumado and Gloria diorites (Avila et al. 1998). In fact, outcrops of the Ibituruna granite and the Pilões granodiorite separate the two sides of the massif, but they could represent a single body affected by younger granitic intrusions. Alternatively, dioritic rocks may represent more mafic facies of the Pilões granodiorite.

**IBITURUNA MARTINS AND ROSÁRIO MASSIFS** The Ibituruna massif is made of a greenish-gray rock, medium-grained (3-6 mm) and amphibole-rich. Its composition varies from diorite to tonalite, and it may represent an extension of the Taboão tonalite. Dioritic rocks are composed of plagioclase (44-55%) intensively altered to epidote, hornblende (10-20%), quartz (5-15%), microcline (5-10%), and biotite (2-4%). Accessory minerals are sphene, ilmenite, epidote, apatite, allanite, and pyrrhotite. Southern of the Ibituruna massif lies a small body of gabbro (Martins gabbro) that may be part of the same intrusion.

The Rosário diorite is highly deformed and mylonitic at its southern half, due to its location within the Serra do Bonsucesso shear zone. It contains significant amounts of sulfide minerals like pyrrhotite and chalcopyrite.

**DISCUSSION AND CONCLUSION** The three suites plot separately on a SiO₂/Al₂O₃ versus Log Zn/Pb diagram (Fig. 2), and also on a Ba versus Zr diagram. In the latter the granodioritic rocks plot apart from other rocks of the TTG suite because of their high Ba and Zr contents. In Ti versus Mg and TiO₂ versus Zr diagrams (Fig. 3) all rocks of the TTG suite plot together. In MgO versus TiO₂ and TiO₂ versus Zr diagrams chemical data of the granite suite display a linear trend, suggesting a differentiation process of a magma with a composition similar to the Porto Mendes granite. However, based on other diagrams its is more likely that the linear array reflects the degree of fractionation of distinct magmas. In Ce versus Zr, Log (Rb/Sr) versus Ba (Fig. 4), and Zr versus (La+Ce) it can be distinguished two separate fields, one of Porto Mendes and Perdões granites, and the other of Rítopolis, Ibitinga and Restinga granites. Isotopic data (Noce et al. 2000) had already indicated the presence of distinct magma sources of rocks of the granite suite.

Intrusion ages of the TTG suite are around 2.12-2.16 Ga (Noce et al. 1998, Ávila et al. 1998), while Sm-Nd TDM ages range from 2.27 to 2.43 Ma (Noce et al. 2000). It is proposed that this suite is derived from mixing of varied proportions of Paleoproterozoic mantelic material and Archean crust material (Noce et al. 2000). The granite suite displays older Sm-Nd TDM ages: 2.66-2.77 Ma for Rítopolis and Ibitinga granites, and ca. 3.0 Ga for Porto Mendes and Perdões granites.

![Figure 2: SiO₂/Al₂O₃ versus Log Zn/Pb diagram. Granite suite: Ibitinga (open circle). Rítopolis (filled circle), Restinga (filled diamond), Porto Mendes (filled square), Perdões (half-filled square). TTG and gabbro-diorite suites: Taboão tonalite (X), Cassiterita and Pilões granodiorites (+), Ibituruna diorite (filled triangle), Martins gabbro (updown filled triangle).](image1)

![Figure 3 - TiO₂ versus Zr diagram (symbols as in Fig. 2).](image2)

<table>
<thead>
<tr>
<th>Table 2: Selected chemical data of the TTG and gabbro-diorite suites. Major elements expressed as wt%, trace elements expressed as ppm.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Element</td>
</tr>
<tr>
<td>Fe₂O₃</td>
</tr>
<tr>
<td>TiO₂</td>
</tr>
<tr>
<td>MgO</td>
</tr>
<tr>
<td>Rb</td>
</tr>
<tr>
<td>Ba</td>
</tr>
<tr>
<td>Zr</td>
</tr>
<tr>
<td>Ce</td>
</tr>
<tr>
<td>Na/Ca</td>
</tr>
<tr>
<td>Sr/Rb</td>
</tr>
<tr>
<td>Zn/Pb</td>
</tr>
</tbody>
</table>


Guimarães D. and Guedes S.W. 1944. Nota preliminar sobre a região estanferia de São João del Rei, Minas Gerais, DNPM-CPRM, Avulso 58, p. 13-26


Figure 4 - Log (Rb/Sr) versus Ba diagram (symbols as in Fig. 2).

granites. These values reflect the age of the Archean crust surrounding the granitic intrusions, as demonstrated by the Mesoarchean ages of the Campo Belo Complex adjacent to the Porto Mendes massif (Teixeira et al. 1998).

The three suites are probably associated to distinct evolutionary stages of the Transamazonian Orogeny. TTG and Gabro-Diorite suites may have originated from mantle-derived magmas at a plate margin setting. Some intrusions like the Cassiterita and Piôes massifs are relatively rich in K, Ba and Zr, suggesting contribution of crust-derived material. The granite suite comprises less-fractionated rocks like the Porto Mendes granite, and highly fractionated S-type granites like the Rítópolis massif. It is not clear if they were originated at the same tectonic stage, as precise magmatic ages are not available. In the tectonic discrimination diagrams of Pearce et al. (1984), Porto Mendes granite plots on the volcanic-arc field, while the majority of data of Rítópolis, Itutinga and Perdões granites plot on the within-plate field.

Acknowledgements

To FAPEMIG (Project CEX-2157/96) for financial support and two anonymous referees of RBG for their suggestions to the original.

References


Quéméneur, J.J.G. 1995. Os magmatismos de idade Arqueana e Transamazonica na região Campos das Vertentes, sul do Craton do São Francisco, com base em geoquímica e geocronologia. Instituto de Geociências, Universidade Federal de Minas Gerais, Belo Horizonte, Tese de Professor Titular, 79p


