Geology and Lithogeochemistry of the Supracrustal Sequence and Interlayered Metabasites of NE Santos Dumont Region (MG)

Geologia e Litogeoquímica da Sequência Supracrustal e Metabasitos Intercalados da Região NE de Santos Dumont (MG)

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Recebido em: 24/10/2017       Aprovado em: 22/11/2017
DOI: http://dx.doi.org/10.11137/2017_3_359_376

Abstract

The region near Santos Dumont town consists of a sequence of interlayered metabasic rocks and supracrustal gneisses. Two lithological units were individualized based on geological-structural mapping (1:50,000), petrography and lithogeochemistry: a metasedimentary sequence interlayered with metavolcanic rocks (Conceição do Formoso Group), and a group of metabasic rocks (Oliveira Fortes Unit). The metavolcanic sequence is represented by gneisses of dacitic and riolitic compositions, with calc-alkaline affinity and weak peraluminous character, suggesting that the original magma was contaminated by crustal component. These gneisses have a geochemical signature of a destructive margin environment and their origin can be related to volcanic arc magmatism. The metabasic rocks present geochemical signature of intraplate tholeiitic basalts and are interpreted as sills interlayered within the metavolcanosedimentary sequence.

Keywords: lithogeochemistry; geology; metabasites; supracrustal sequence

Resumo

A região próxima à cidade de Santos Dumont é constituída por uma sequência gnáissica supracrustal intercalada com rochas metabásicas. Duas unidades litológicas puderam ser individualizadas baseando-se no mapeamento geológico estrutural (1:50.000), petrografia e litogeocquímica: uma sequência metassedimentar intercalada com rochas metavulcânicas (Grupo Conceição do Formoso), e um grupo de rochas metabásicas (unidade Oliveira Fortes). A sequência metavulcânica é representada por gnaisses de composição dacítica a riolítica, com filiação cálcio alcalina e caráter levemente peraluminoso, sugerindo que o magma original foi contaminado por um componente crustal. Esses gnaisses têm uma assinatura geoquímica de margem destrutiva e sua origem pode ser relacionada a ambientes de arcos vulcânicos. As rochas metabásicas apresentam assinatura geoquímica de basaltos intraplaque toleíticos intraplaque, interpretados como sills alojados na sequência metavulcanosedimentar.

Palavras-chave: litogeocquímica; geologia; metabasitos; sequência supracrustal
1 Introduction

Santos Dumont region, situated in the southeastern portion of Minas Gerais State, can be considered as a key area to unravel the tectonic evolution of Araçuaí and Ribeira belts. The area can be located within the Mantiqueira Province (Almeida et al., 1977, 1981), near the SSE boundary of the São Francisco Craton and raises different interpretations of its tectonic position. The tectonic and temporal relations, the boundary position and the interference zones between the Ribeira and Araçuaí belts, as well as the relation to the São Francisco Craton, are not well established and is still an open subject of discussion. The study area is considered part of the Autochthonous Tectonic Domain (ATD) of the Ribeira Belt (Heilbron et al., 2004) and also can be included in the External Domain of the Araçuaí Belt (Pedrosa-Soares & Wiedemann-Leonardos, 2000). In a different interpretation, Trouw et al. (2013) insert the region in the southernmost portion of the Araçuaí Belt limited to the south by the Brasilia belt.

The existence of open to tight folding, associated with NE-SW low angle ductile shear zones characterize its position on the external portion of the Ribeira Belt. These shear zones show a near down-dip stretching lineation coeval to the Ribeira belt deformation and deflect a NNW-SSE low angle foliation, with open folds and NE-SW gently limbs, related to the Araçuaí Belt structures.

To the south of the thrust boundary (Figure 1, geological map of the area), granitic to tonalitic orthogneisses, which can be correlated to the Mantiqueira Complex (Brandalise et al., 1991b), occur as basement rocks to supracrustal sequences interlayered with metabasites of unknown age. To the north of this thrust boundary, no basement associations were found and rocks consists of thick sequences of gneisses of different origins (Conceição do Formoso Group) interlayered with metabasites of unknown age. To the north of this thrust boundary, no basement associations were found and rocks consists of thick sequences of gneisses of different origins (Conceição do Formoso Group) interlayered with metabasites of unknown age. To the north of this thrust boundary, no basement associations were found and rocks consists of thick sequences of gneisses of different origins (Conceição do Formoso Group) interlayered with metabasites of unknown age.

3 Geological Units

Santos Dumont area is characterized by a supracrustal sequence interlayered with metabasic rocks in several scales (Figure 1). The supracrustal sequence, here named as Conceição do Formoso Group, could be subdivided into two main lithological units, which cannot be individualized in map scale (<1:50,000); one with homogeneous gneisses (biotite leucogneiss and hornblende-biotite gneiss) of possible igneous protolith and the other represented by heterogeneous paragneisses. The intrusive metabasic rocks of Oliveira Fortes Unit occur as lenses interlayered with the whole sequence (Figure 2) and exhibit preserved subophitic textures in garnet metagabbros and,
subordinately, in metagabbros. In high deformed areas, petrographic compositions vary from garnet amphibolites and amphibolites to biotite amphibolites within the thrust zone.

The homogeneous biotite leucogneiss is fine-grained and characterized by equigranular texture and schistosity followed by the orientation of millimetric to submillimetric biotite-muscovite crystals. Its mineralogical composition is given by variables quantities of quartz (16-42%), microcline (13-52%), plagioclase (8-30%), biotite (14-22%) and muscovite (0-3%), with zircon and opaque minerals (~2) as accessories. Locally, exhibits relict euhedral to subhedral phenocrysts of microcline (Figure 3), with a degree of alteration characteristically superior as compared to the granoblastic matrix. These textural features together with its granitic composition, the abundance in microcline, the usual homogenous aspect, the fine grained texture with individual crystals of biotite and its form of occurrence in outcrops, sometimes representing thick homogeneous sequences over large areas, suggest the hypothesis that it might represent a sequence of rhyolitic volcanism, possibly associated to pyroclastic flow deposits and acid tuffs.

Also are present interdigitations of homoge-
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Figure 2 Biotite leucogneiss (Bt-Ign) from Conceição do Formoso group; note the interlayered metabasic (Mb) rock in a homogeneous gneiss sequence.

Figure 3 Aspects of the biotite leucogneiss. A. close outcrop view; B. hand sample with leucocratic and homogeneous aspect; C-F Granoblastic textured of homogeneous biotite leucogneiss showing euhedric to subhedral microcline (K-fdsp) phenocrysts. Figures C and E under parallel nicols. d and f under crossed polars. Legend: Qtz – quartz.
eneous mesocratic (hornblende)-biotite gneiss that differs from the leucogneiss mainly for higher biotite and lower microcline contents. This mesocratic gneiss presents granonematoblastic texture and is fine-grained. It is composed of quartz (13-20%), plagioclase (33-39%), biotite (20-27%), microcline (2-7%), titanite (5-10%), hornblende (1-10%) and, as accessories, may contain metamorphic clinopyroxene, zircon, apatite and opaque minerals (Figure 4). Modal analyses (Figure 5) allowed attributing to this lithotype a tonalitic composition.

These gneisses are frequently interlayered or associated to a metasedimentary sequence, characterized by heterogeneous paragneisses (Figure 6) that can be described as a succession, in varied scales, of different types of biotite-muscovite-garnet-sillimanite gneiss, locally with centimetric to metric bands or lenses of quartzites, gondites and cherts. Within the NE-SW shear zones, these rocks display overall migmatitic textures (Figure 7) and muscovite is not present.

The metabasites of the Oliveira Fortes Unit show composition ranging from quartz dioritic/gabbroic to dioritic/gabbroic, and occur as centimetric to hectometric tabular bodies, invariably parallel to the structures of the country supracrustal sequence rocks described above (Figure 2). Based on detailed petrographic analyses, and following an order from the least the most deformed rocks, it is possible to individualize four main lithotypes for the metabasic rocks unit: metagabbro, garnet metagabbro, (garnet) amphibolite and biotite amphibolite.

The two types of metagabbro (metagabbro and garnet metagabbro) are fine to medium and locally coarse-grained with subophitic and granular texture...
Figure 5 Compositional QAP (Q- quartz, A- alkali feldspar, P- plagioclase) diagram (Streickeisen, 1976) for metabasic rocks (green plots), homogeneous biotite leucogneiss and (hornblende)-titanite-biotite gneiss.

Figure 6 Aspects of the heterogeneous biotite gneiss; A. gneiss banding with leucocratic and mesocratic bands; B. sillimanite-garnet-muscovite-biotite gneiss with garnet porphyroblasts; C-D. garnet-muscovite-biotite gneiss exhibiting well developed crystals of sillimanite under parallel nicols and cross nicols.
(Figure 8A, C-D), mainly composed of metamorphic clinopyroxene (probably augite), and plagioclase (labradorite), and varied contents of orthopyroxene (hypersthenes), also metamorphic hornblende, garnet, magnetite and ilmenite. Based on petrographic analysis and their disequilibrium textures, it is assumed that the two types of metagabbros, have a metamorphic clinopyroxene and hornblende grains, on the other hand the orthopyroxene grains probably are relics of the previous igneous phase, since no reaction to generate this last mineral could be observed in thin section. The first litohype is medium to coarse grained and its mineralogy is formed by orthopyroxene, clinopyroxene, plagioclase and magnetite, hornblende occurring as a subordinate phase. Despite being texturally very similar to the metagabbro, the garnet metagabbro contains coronas of garnet and magnetite around plagioclase, hornblende, and clinopyroxene (Figure 8E-F). The (garnet) amphibolite is a medium to fine-grained rock and displays granonematoblastic to mylonitic texture (Figure 8G-H). The mineralogical assembly is composed essentially of hornblende, plagioclase, titanite and garnet. Igneous orthopyroxene is absent and metamorphic clinopyroxene may appear also as relict minerals.

The biotite amphibolite is fine-to medium-grained, displaying inequigranular granoblastic to nematoblastic array (Figure 8I-J), with protomylonitic texture and local mineral stretching (Figure 8B). The paragenesis is composed essentially of hornblende, plagioclase and biotite with titanite, apatite, clinopyroxene, quartz and opaque minerals as accessories. This unit is observed in the higher deformation areas, therefore the constituent minerals are constantly deformed and recrystallized. Moreover, in these areas, the hornblende crystals are altering to biotite, and titanite reaches to compose 4% of rock.

The metabasic rocks display a highly varied structures pattern, since magmatic preserved subophitic textures, with massive aspect, to mylonitic structures, with stretched minerals, closely associated with NE-SW shear zones, where the biotite amphibolite predominate.

Near the thrust boundary (Figure 1), NE-SW low angle ductile shear zones are associated to open to isoclinal folding, and a mylonitic foliation is frequent, and can be characterized in outcrops by a constant compositional banding, giving a strong intercalation between mesocratic and leucocratic layers. Locally, there are rotated feldspar porphyroclasts, L-tectonites and quartz ribbons. In thin section, this pattern is characterized by the presence of quartz ribbons in a fine-grained recrystallized matrix, which displays a protomylonitic texture. At less deformed areas structures as irregular compositional banding and/or penetrative schistosity occur, showing, in thin section, a granoblastic texture and few or almost no evidence of dynamic recrystallization.

In the areas where deformation is less intense, pelitic rocks bear primary muscovite and show no longer evidences of partial melting. These indicate a medium-grade metamorphism under...
Figure 8 Aspects of the metabasic rock of Oliveira Fortes unit;
A. metagabbro hand sample;
B. Strongly deformed amphibolite showing penetrative foliation;
C-D. Metagabbro showing preserved subophitic texture under parallel nicols and crossed pollars;
E. Garnet metagabbro showing coronas of garnet around grains of plagioclase slightly recrystallized;
F. same as “E” under crossed pollars (x 2.5);
G-H. Amphibolite with nematoblastic texture under parallel nicols and crossed pollars;
I and J. Biotite amphibolite exhibiting biotite in the borders of hornblende grains under parallel nicols and crossed pollars.
lower amphibolite facies conditions. On the other hand, in the most deformed areas, evidences of medium to high-grade metamorphism are revealed by the presence of schlieren and stromatic migmatitic textures, well developed within pelitic rocks, indicating that conditions of partial melting were overcome. The presence of sillimanite and anatectic leucosome with granitic composition, added to the absence of primary muscovite, point to metamorphism under upper amphibolite facies condition.

4 Lithogeochemistry

The analysed rocks (Table 1) correspond to eight samples of metabasic rocks of Oliveira Fortes (metagabbros and garnet amphibolites), four samples of homogeneous biotite leucogneiss and one sample of hornblende-biotite gneiss. As the area is affected by tectonism that developed several shear zones, which are often related to metassomatic processes, care was taken to avoid sampling within these zones. Thus, with the exception of sample EF-24, which was sampled near to, but not within, the thrust zone, sampling was carried out far away from this and all other minor shear zone areas. Moreover, sample selection was performed on the basis of petrographic analyses in order to preclude post-magmatic chemical modification processes. Thus, all selected metabasic rocks bear no biotite, no quartz and show subophitic or granoblastic texture; none of them presents mylonitic texture (Table 2).

4.1 Metabasites

The metabasites of Oliveira Fortes unit plot in the field of gabbro, show a subalkaline nature (Figure 9A), with tholeiitic affinity (Figure 9B).

From the binary diagrams, it can be observed that the majority of the oxides display a negative correlation with MgO, except CaO and Al₂O₃ (Figure 10).

Continuing the analysis of binary diagrams, were chosen for composition projections, trace elements with the following characteristics: two compatible elements (V and Co); one immobile incompatible element (Zr); and one mobile incompatible element (Ba). With the exception of Co and Ba the other trace elements display a clear negative correlation with MgO (Figure 10).

With regard to the method of minimal squares, it is known that to be considered a meaningful correlation result, the values of the squares of the Pearson’s correlation coefficients must be within the 95 - 99% interval. For the majority of the oxides/elements of the studied metabasites yield poor results (Table 3): values are below 80% for Al₂O₃, CaO, Fe₂O₃, MnO and all the trace elements with the exception of V which yields good values within the 95-99% interval.

This suggests that the set of basic samples cannot be related by a process of fractional crystallization and, therefore, it is most probable that all the samples do not belong to the same suite. A hypothesis that can be brought up is that the samples could be correlated by processes of partial melting, and may be associated to different quantities of partial melting from a same source, or been generated by partial melting of different sources. To test these hypothesis rare earth elements geochemical modeling will be discussed in a following section.

Incompatible elements ratios do not vary substantially during fractional crystallization processes and thus it is expected a maximum variation of 1.5 times among cogenetic rocks (Cox et al. 1979). Some authors such as Cullers et al. (1974) and Muecke et al. (1979) indicate that there is usually little modification of the rare earth elements during the metamorphic events and, therefore, we can use them for the geochemical analysis of the protolith. For this reason, [La/Yb]₉ ratios were applied in order to verify any relation between samples (Table 1).

In an attempt to relate values of MgO with [La/Yb]₉ ratios, it was verified that the increase of MgO do not correspond to the increase or decrease of [La/Yb]₉. This fact corroborates with the fact that the analyzed samples cannot be part of only one suite, meaning that they are not all cogenetic.

4.1.1 Geochemistry of the Rare Earth Elements and Multi-Element Diagrams

On the basis of [La/Yb]₉ ratio values (Table 1), samples were subdivided into three groups. In the first group, metabasites display lower values
### Table 1: Whole-rock, major and trace element geochemistry for metabasic rocks (met), biotite leucogneiss (bt-leu) and (hornblende)-biotite gneiss (hb-bt-gn).

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Table 1: Whole-rock, major and trace element geochemistry for metabasic rocks (met), biotite leucogneiss (bt-leu) and (hornblende)-biotite gneiss (hb-bt-gn).
of $[\text{La}/\text{Yb}]_N$ (3.19 and 4.25) and, therefore, lower fractionation of the elements is observed. The second group, that yields $[\text{La}/\text{Yb}]_N$ values between 5.00 and 7.40, displays a higher fractionation of the light rare earth elements. The last group consists only of one sample (EF-92) and shows light rare earth elements enrichment, displaying, consequently, a highly fractionated pattern ($[\text{La}/\text{Yb}]_N$ - 13.74).

A small positive anomaly of Eu (Table 1) is observed in all samples and could be attributed to accumulation of plagioclase during differentiation of mafic, underplated magmas (Rudnick et al., 1986; Kempton et al., 1990) (Figure 11).

To illustrate the geotectonic environment in the formation of the metabasic rocks, were used binary or ternary diagrams of Pearce & Norry (1979)
(Figure 12A), Pearce & Cann (1973) (Figure 12B) and Meschede (1986) (Figure 12C) that indicate a predominantly intraplate environment.

In order to identify the genesis and the geotectonic environment in which these rocks were generated, it was made the chondrite-normalized $[\text{La/Yb}]_N$ and $[\text{La/Nb}]_N$ ratios (Thompson, 1982). Based on the obtained values it can be observed that the rocks of Oliveira Fortes unit were generated from a process of melting of the enriched mantle, suggesting the subcontinental lithospheric mantle as source material and pointing to a geotectonic environment like that of the intraplate flood basalt provinces. In addition, chondrite-normalized multi-element diagrams (Thompson, 1982) were generated in order to establish a comparison with chondrite normalized diagrams for basic rocks and
suites of modern environments. The result (Figure 13) indicates a great resemblance to the intraplate basalts of Decan and Paraná, pointing again to the hypothesis that the protoliths of these rocks were originated from continental basaltic floods.

Lastly, considering that these metabasites are not correlated by a process like fractional crystallization, it was carried out a partial melting geochemical modeling as proposed by Pearce (1968). Partial melting geochemical modeling was performed on the basis of the obtained [La/Yb]N ratio values (Table 1). Results of geochemical modelling indicate that different rock generating magmas could not have been generated from the same source. Having as base the partial melting experiments of Mysen and Kushiro (1977), performed in peridotite nodules, and the experiments of Walter and Presnall (1994), carried out in hetherolite of simple composition, Ne-free melts form by a minimum of 25% partial melting. Furthermore, 45% would be the expected maxima limit of degree of partial melting; above this value, melts generated would be komatitic. However, the performed geochemical modelling yields some unexpected results: it would be necessarily a higher than 45% degree of melting to generate the 3.20 [La/Yb]N ratio value of one of the metabasic samples; and it would be necessarily degrees lower than 25% of partial melting to generate [La/Yb]N ratio of 13.7. Thus, different amounts of partial melting from the same source could be discarded. In this way, the more plausible scenario is that the protholiths of the study metabasic rocks were generated by partial melting of different mantle sources. A very heterogeneous sub-continental lithospheric mantle should be considered as the local source.

4.2 Gneisses of Conceição do Formoso Group

Four samples of homogeneous biotite leucogneisses and one sample of (hornblende)-biotite gneiss were analyzed (Table 1). The geochemical data show SiO₂ contents between 70.60 and 75.35, for the biotite leucogneisses, indicating a rhyolitic composition, and between 63.9 and 67.37, for the hornblende-biotite gneiss, pointing to a dacitic composition (Figure 14 A). All five samples belong to the calc-alkaline series (Figure 14 B) and display weak peraluminous character (A/CNK > 1) (Figure 14 C).


4.2.1 Geochemistry of the Rare Earth Elements and Spidergrams

Gneisses of Conceição do Formoso Group show rare earth elements patterns of light REE enrichment (Figure 15A) and, at least, two groups can be separated, based on Eu anomalies; the first group presents a positive anomaly (Eu/Eu* ~ 1.4); the other group composed of two samples shows a negative anomaly (Eu/Eu* ~ 0.8).

4.2.2 Geotectonic Environment

Gneisses of Conceição do Formoso Group (Figure 15B) display enrichment in mobile elements (Ba, Rb, Th, K) and negative anomalies of Nb, Sr and P, which are typical signatures of destructive margin environments (volcanic arcs).

Negative anomalies were observed for P and Sr which can be controlled by apatite and plagioclase...
fractionation. Nb is controlled by ilmenite, rutile and titanite fractionation. The metavolcanic rocks were probably generated in a subduction environment (volcanic arc) as can be observed in the Rb/Y+Nb \( x \) Nb/Y diagram (Pearce et al., 1984) (Figure 16).

5 Geological and Lithogeochemical Conclusions

The NE-SW shear zones are characterized by SE low angle stretching lineation, near down-dip and are associated to tight to isoclinals folds. These structures points to a strong correlation with deformation phases attributed to the structural evolution of the Ribeira belt (Nogueira 1999; Nogueira et al. 2003). The low angle shear zones affected the rocks that had already been through a previous history of deformation, causing migmatization and formation of protomylonitic textures. Within the less deformed areas, structures associated with the older deformation are preserved.
and display open folds with low angle NE and SW limbs, related to the Araçuaí belt structures. The metamorphic minerals content indicates that in this region the rocks were metamorphosed under lower to upper amphibolite facies conditions.

Geochemical studies indicate that the metabasites characterize a subalkaline series, with tholeiitic affinity and gabbroic composition. Based on quantitative statistical analysis, made with the purpose of verifying cogeneticity among the study rocks, it was observed that the basaltic magmas were generated from melting of a mantle source with, at least, a contribution of the subcontinental lithospheric mantle. Geochemical data, which attest the absence of cogeneticity among the study metabasites, indicate that local subcontinental lithospheric mantle source was heterogeneous and, thus, capable of generate the magmas that gave origin to the study metabasites. According to the obtained results, it can be affirmed that these magmas were continental basalts, hosted in the form of dikes or sill in an intraplate environment.

For the gneisses of Conceição do Formoso Group, features such as fine homogeneous texture and the presence of preserved euhedral phenocrysts of microcline suggest a volcanic origin. In terms of its chemical composition, they constitute a calc-alkaline series with weak peraluminous character and their protoliths have rhyolitic and dacitic compositions. Negative anomalies for P, Sr, Nb e Ti suggest the participation of apatite, plagioclase, ilmenite and titanite as fractionate minerals during magmatic differentiation. These rocks have geochemical signature of arc environment, possibly involving processes of crustal contamination. Together with the paragneisses, these gneisses form a possible volcanosedimentary sequence, which are considered as country rock to the metabasic rocks.

6 Final Remarks: Regional Correlations

According to Brandalise et al. (1991b), the Mantiqueira Complex comprises tonalitic/trondhjemitic and granitic/granodioritic banded gneisses with tabular intercalations of metabasites. This unit corresponds to the arquean-paleoproterozoic basement, which crops out from the northernmost portion of the Araçuaí Belt to the southern portion, in the region of Lima Duarte to the west of Juiz de
The lithotypes of the Santos Dumont region have been interpreted as belonging to the Mantiqueira Complex (Brandalise et al., 1991a, 1991b; Silva et al., 2002; Peres et al., 2004; Alkmim et al., 2007), however, according to the data presented here, in the north of the thrust boundary of Santos Dumont region (Figure 1), these rock associations were not found.

Some authors also include these rocks within the Piedade Gneiss or Complex (Ebert, 1958; Machado Filho et al., 1983; Silva et al., 2002). However, Hasui & Oliveira (1984) also associated the Piedade Gneiss with ultrabasic, granitic to tonalitic rocks, which were not observed in the area.

For these reasons, the name Conceição do Formoso Group is proposed for the characterization of the metavolcanosedimentary sequence in order to dissociate this unit from these two regional units (Mantiqueira Complex and Piedade Gneiss or Complex).

The Conceição do Formoso Group consists of a supracrustal sequence composed of biotite leucogneiss, possibly of volcanic origin, interlayered with biotite paragneiss. This unit might be partially correlated to the Tiradentes suite, a subvolcanic–volcanic unit composed of dacites, granophyres, mafic andesites and intrusive tonalites, whose felsic rocks present some preserved igneous features such as microporphyritic and porphyritic textures with subhedral phenocrysts of plagioclase in a granophyric matrix (Ávila et al., 2014).

This sequence has also similarities with the rocks of the Dom Silvério Group, defined by Brandalise (1991a), which comprehends, in general, a metavolcanosedimentary assembly that includes pelitic schists, amphibolites, quartzites and, subordinately, gondites, metatulamafic rocks and iron formations. This correlation requires geological mapping and more detailed information about the area between these regions, in order to bring subsidies for this discussion.

7 Acknowledgements

The authors would like to thank the financial support from Brazilian funding agencies, FAPERJ (E-26/170.508/2006-APQ1; E-26/111.743/2010-APQ1) and CNPq (CT-Mineral-550291/2011-3), to fieldwork and lithogeochemical analyses. R. Hiraga received a scholarship from CNPq-Brazil during the research. We acknowledge the sustained technical support of R. Campos Coelho, M. Arcanjo and A. Fedelle for sample preparation at Universidade do Estado do Rio de Janeiro, Brazil.

8 References


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