



Sodalite Cancrinite Nepheline Syenite of Mendanha Massif, State of Rio de Janeiro, Brazil, Called Commercially Blue Guanabara Granite, and its Origin from Deuteric Metasomatism
Sodalita Cancrinita Nefelina Sienito do Maciço Mendanha, RJ, Chamado Comercialmente de Granito Cinza Azul Guanabara, e sua Origem de Metassomatismo Deutérico

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Resumo

Este artigo apresenta observações de campo, descrições petrográficas e considerações genéticas do sodalita cancrinita nefelina sienito, chamado comercialmente de *Granito Cinza Azul Guanabara*, que se encontra na zona de contato sudoeste da intrusão alcalina félsica de Mendanha, RJ. Esta rocha ornamental ocorre ao longo do eixo central de um dique sienítico com 15 m de largura. A cor macroscópica em rocha total é caracterizada por saturação baixa (S=5~7) e clareza média (B~62). A cor de minerais opacos tem clareza relativamente alta (B~28). O feldspato alcalino é comumente alterado em muscovita. Os feldspatóides são presentes nos espaços intersticiais do arcabouço de feldspato alcalino. O anfíbólio e biotita são alterados em minerais opacos e vermiculita, apresentando pseudomorfo. Os minerais acessórios são magnetita primária e titanita. Existe uma significativa quantidade de carbonatos com quantidade modal de 6,8%, constituindo agregados de forma irregular ou preenchendo espaços. A cor macroscópica dos agregados de feldspatóides varia de azul profundo para azul claro de acordo com o teor relativo de sodalita. A sodalita e cancrinita são originadas de nefelina e foram formadas através de metassomatismo deutérico do fluido rico em Cl.

Palavras-chave: Granito Cinza Azul Guanabara; sodalita sienito; metassomatismo deutérico

Abstract

This article reports field observations, petrographic descriptions, and genetic consideration on the sodalite cancrinite nepheline syenite, called commercially *Blue Guanabara Granite*, which is found in southwest contact of Mendanha felsic alkaline intrusion, State of Rio de Janeiro, Brazil. This natural stone occurs along the central axis of a syenitic dyke of 15 m in width. The whole-rock macroscopic colour is characterised by low saturation (S=5~7) and medium brightness (B~62). The opaque minerals colour has relatively high brightness (B~28). The alkaline feldspar is often altered into muscovite. The feldspathoids occur in the interstitial frameworks of alkaline feldspar. The amphibole and biotite are altered into opaque minerals and vermiculite, showing pseudomorph. The accessory minerals are primary magnetite and titanite. There is a significant amount of modal carbonates of 6.8%. The macroscopic colour of the feldspathoid aggregates ranges from deep blue to light blue according to the relative contents of sodalite. The sodalite and cancrinite are originated from nepheline and formed through Cl-rich fluid deuteric metasomatism.

Keywords: Blue Guanabara Granite; sodalite syenite; natural stone; deuteric metasomatism

1 Introduction

The *Blue Guanabara Granite* (*Granito Cinza Azul Guanabara*; Azambuja & Silva, 1977; Teixeira *et al.*, 1991; *Granito Azul Guanabara*; Erthal *et al.*, 2003) is a commercial name of the coarse-grained natural stone with light blue grey colour (Figure 1) which was extracted from southern part of Marapicu Peak, southwestern Mendanha Massif, State of Rio de Janeiro, Brazil. This rock is widely known in the Brazilian dimension stone market because of the exotic colour, and the slab samples are widely distributed to the stonework factories. However, in fact only few commercial products were shipped because of the limited amount of exploitation. The rock is classified as sodalite cancrinite nepheline syenite (Vargas *et al.*, 2001). According the quantitative colour specification (Motoki *et al.*, 2005; 2006), the whole-rock colour of this rock is 195.15°, 5.82%, and 53.22% in HSB parameters (Figure 1).

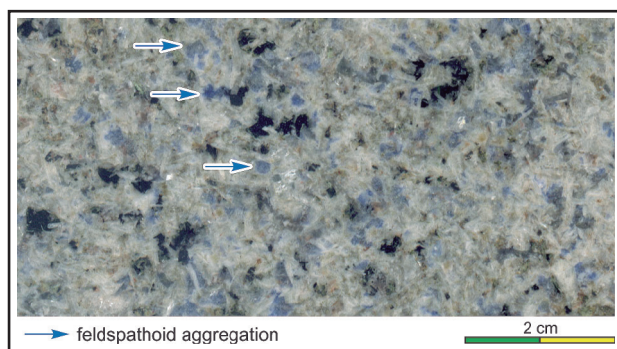


Figure 1 Polished surface of the *Blue Guanabara Granite*, State of Rio de Janeiro, Brazil. The light blue spots (arrows) are sodalite-bearing feldspathoids aggregates.

The global occurrence of blue natural stone for ornamental use is rare. The *Blue Bahia Granite* (*Granito Azul Bahia*), which is sodalite syenite produced in the southeastern region of State of Bahia, Brazil, is a representative product. Similar rocks are shipped from Namibia, Zimbabwe, Malawi, and Mozambique. In the central-western region of State of Bahia, there is another blue ornamental rock, called commercially *Blue Macaúbas* (*Granito Azul Macaúbas*, Visser *et al.*, 1997; Borghi *et al.*, 2004), which is a dumortierite quartzite.

Different from *Blue Bahia Granite*, the *Blue Guanabara Granite* is scientifically little studied. This article presents geologic, lithologic, and

petrographic characteristics of this sodalite cancrinite nepheline syenite, with quantitative colour compared to *Blue Bahia Granite*, and discusses its genesis with special attention in the deuteric metasomatism.

2 Felsic Alkaline Intrusive Rocks of Rio de Janeiro

In the State of Rio de Janeiro, there are more 10 than intrusions of felsic alkaline rocks (Figure 2) of the Cretaceous to the Early Cenozoic. The basement is constituted by metamorphic rocks of Oriental Terrane of Pan-African continental collision event (Heilbron & Machado, 2003). The gneiss is intruded by dyke-like post-tectonic granitic bodies, called Andorinha Granite (Valeriano *et al.*, 2011). They are cut by silicified tectonic breccia (Motoki *et al.*, 2011; 2012a). All of them are intruded by Early Cretaceous mafic dykes of Paraná Province (e.g. Bennio *et al.*, 2003; Motoki *et al.*, 2009).

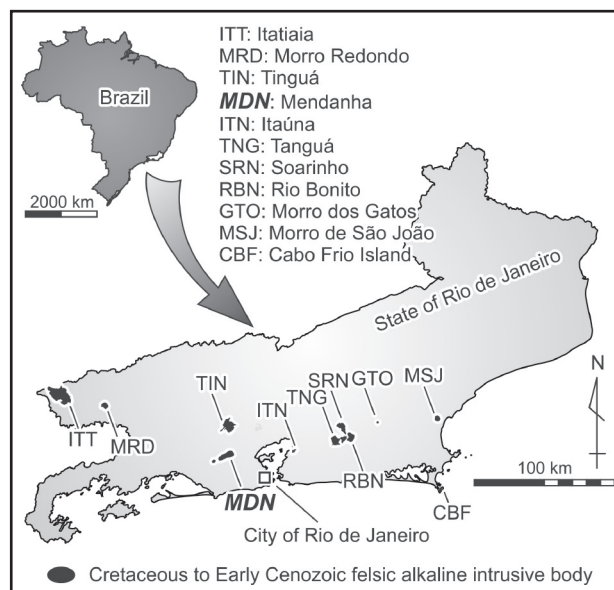


Figure 2 Felsic alkaline intrusive rock bodies of the Cretaceous to Early Cenozoic of the State of Rio de Janeiro, modified from Sichel *et al.* (2012). The *Blue Guanabara Granite* is present at the southwestern limit of the Mendanha (**MDN**) intrusive body.

The alkaline bodies are constituted mainly by nepheline syenite and partially by syenite, phonolite, and trachyte, such as: Itatiaia (Brotzu *et al.*, 1997); Morro Redondo (Brotzu *et al.*, 1989); Serra dos Tomazes (Ferrari *et al.*, 1977); Tinguá (Derby, 1897); Mendanha (Motoki *et al.*, 2007a); Itaúna (Motoki *et al.*, 2008a); Tanguá; Rio Bonito; (Valença, 2008; Motoki *et al.*, 2010; 2013); Morro

dos Gatos (Geraldes et al., 2013); Morro de São João (Brotzu et al., 2007; Motoki et al., 2014a; b); Cabo Frio Island (Motoki & Sichel, 2008; Motoki et al., 2008b; 2013). Due to the high resistance to erosion (Petrakis et al., 2010; Aires et al., 2012), the intrusive bodies form morphologic elevation with relative height of 300 m to 900 m (Motoki et al., 2008c; Aires et al., 2012), called alkaline massifs.

Some of the intrusive complexes are associated with strongly welded pyroclastic lapilli and breccia. Among them, those of Mendanha and Itaúna were considered as constituents of volcanic edifice with well preserved volcanic cone and crater (e.g. Klein & Vieira, 1980; Klein & Valença 1984; Klein, 1993; 1999; Klein et al., 2001).

However, recent studies have revealed that the supposed volcanic bombs are not vesicular but massive. Detailed field observations and petrographic descriptions revealed that they are attributed to the weathering fabrics of case-hardening and pseudovesicular structure of large rounded boulders of second generation trachyte (Motoki et al., 2007a; b). The contact plane between the pyroclastic body and the country rock is vertical and of intrusive mode (Motoki et al., 2007c). The pyroclastic rocks occur only on the hill, and not, on the urban lowland of this region (Motoki et al., 2008d). Therefore, they are not constituents of volcanic edifice or surface eruptive deposit, but of subvolcanic conduits and pyroclastic dykes (Motoki et al., 2007a; c). The geomorphologic studies with the help of summit level technique demonstrate the inexistence of volcanic cone and crater (Motoki et al., 2008d).

The pyroclastic rocks of Mendanha alkaline massif are not constituents of volcanic edifice or surface eruptive deposits, but vent-filling materials composing subvolcanic conduits and pyroclastic dykes. According to fission-track datings for apatite, the emplacement depth is estimated to be about 3 km from the surface of the eruptive time (Motoki et al., 2007a). The welded pyroclastic rocks of Itaúna, Morro dos Gatos, and Cabo Frio Island felsic alkaline intrusive complexes show the same geologic emplacement mode (Motoki et al., 2008a; 2012b; Sichel et al., 2008). A shallow intrusive body composed of eruptive deposit-like fine-grained rock is known also at the subvolcanic conduit of Cabugi Peak, State of Rio Grande do Norte. The supposed

bread crust bombs of ultrabasic composition were identified as the massive blocks of disintegrated columnar joints with surface cracks originated from rapid cooling (Motoki et al., 2012c).

The felsic alkaline intrusions form an east-west trend, called Poços de Caldas-Cabo Frio Alignment (Riccomini & Assumpção, 1999). Thomáz Filho et al. (2005) interpreted that this trend continues to Vitória-Trindade Chain, forming single hot-spot track. This idea is widely known in Brazil. However, the alkaline magmatic alignment is of E-W trend and the absolute motion vector of South America Plate is of NE-SW direction (O'Connor & Roex, 1992; Steinberger, 2000). In addition, Vitória-Trindade Chain is 380 km from Poços de Caldas-Cabo Frio Alignment. These findings disagree to the single hot-spot track model (Skolotnev et al., 2010; Motoki et al., 2012d).

3 Field Occurrence and Lithologic Aspects

The Mendanha felsic alkaline intrusive body is situated at about 40 km to the WNW of the city of Rio de Janeiro (Figure 2). The body is ENE-WSW elongated with dimension of 18 x 3 km. It is constituted mainly by nepheline syenite, syenite, and trachyte. The nepheline syenite at the western end of the intrusive complex is extracted in blocks for ornamental uses with commercial name of *As de Paus Grey Granite* (*Granito Cinza As de Paus*). The laser-spot Ar-Ar ages range from 58 Ma to 67 Ma (Motoki et al., 2007a). New laser-spot Ar-Ar datings show more accurate ages: 80.40 ± 0.58 Ma for the nepheline syenite of Marapicu, 64.12 ± 0.40 Ma for the syenite of Nova Iguaçu, and 58.55 ± 0.45 Ma for the lamprophyre dyke of Nova Iguaçu (unpublished data of Rio de Janeiro State University).

The light blue rock occurs along the central axis of a syenitic dyke of 15 m in width. It was extracted either from boulders or outcrops. Certain boulders show linear surface depressions, called fluting, called regionally *canelura*. The mineral composition is leucocratic and the texture is equigranular and homogeneous without mineral orientation. The grain size is 2 to 3 mm (Figure 1), being a little finer than nepheline syenite of the main intrusion, which also is extracted with commercial name of *As de Paus Grey Granite*.

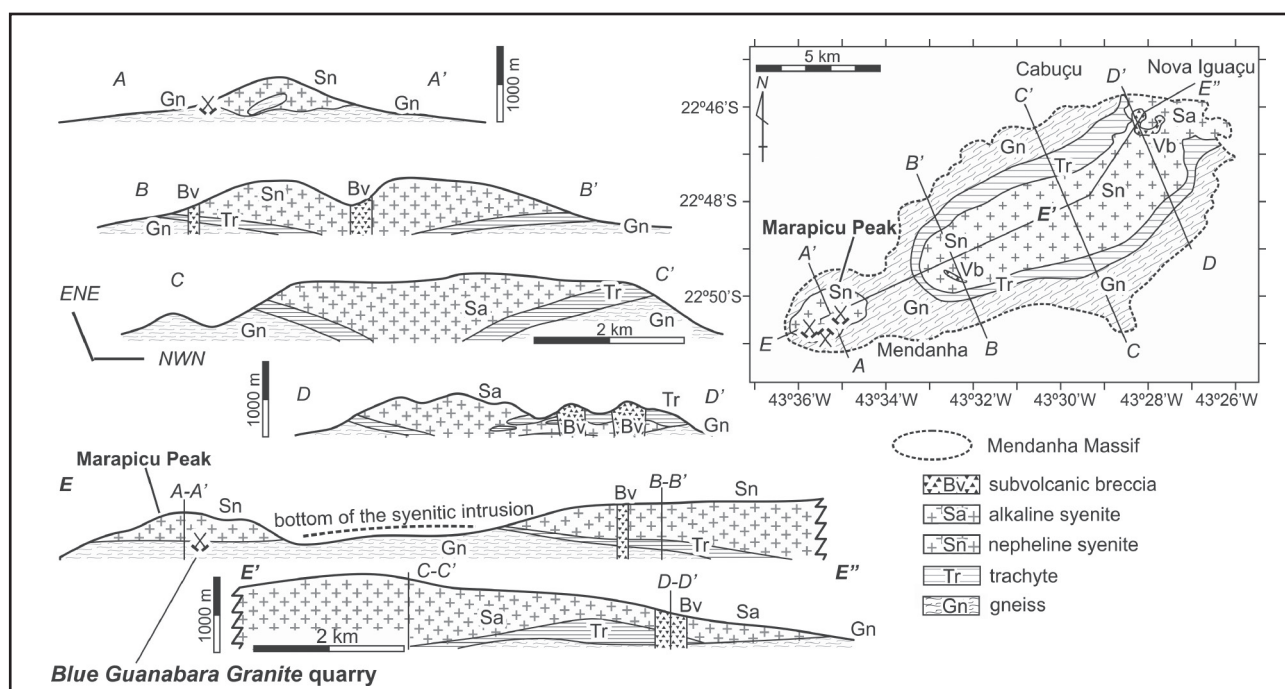


Figure 3 Schematic cross sections of the Mendanha alkaline intrusion, Municipal District of Nova Iguaçu and Rio de Janeiro, State of Rio de Janeiro, Brazil. Blue Guanabara Granite quarry is situated at the south-western corner of this alkaline massif.

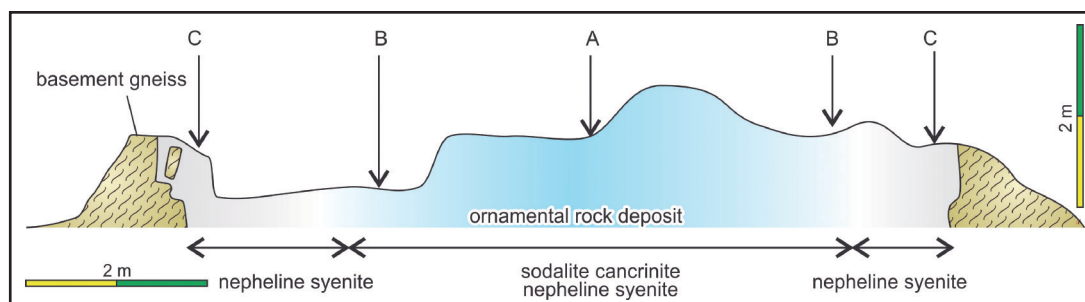


Figure 4 Schematic cross section of Blue Guanabara Granite quarry at the south-western corner of Mendanha alkaline intrusive body, State of Rio de Janeiro.

The dyke borders are constituted by grey nepheline syenite (Figure 4, Position C), which is a little finer than the sodalite syenite, showing grain size from 1 to 2 mm. Slight mineral orientation in parallel to the contact planes is observed. Along the dyke contact gneissic xenolithic enclaves are found. No vitric chilled margin is found. The grey nepheline syenite grades into the light blue sodalite syenite.

4 Petrographic Observations

Under the microscope, the rock is characterised by interstitial framework made up of tabular crystals of alkaline feldspar. The modal amount of this mineral is 65.4%. The crystals are typically 0.8 mm wide and 3.0 mm long. This alkaline feldspar is not potassic orthoclase or microcline, but anorthoclase

of intermediate composition between potassic and sodic. The texture of perthite patches constituted by albite is often observed. Partial alteration of alkaline feldspar into muscovite is common (Figure 5A, musc). Along the border of alkaline feldspar, small plagioclase crystals are found (Figure 6A). The modal amount of plagioclase is 0.6%.

The feldspathoids fill interstitial spaces between alkaline feldspar frameworks with modal amount of 22.6%, in which 11.7% are sodalite, 9.6% are cancrinite, and 1.3% are nepheline (Figures 5B, 6B). In addition, there are idiomorphic crystals of altered nepheline. The cancrinite has fibrous habit and the carbonates form aggregates of very small crystals. The nepheline crystals are large in comparison with cancrinite and carbonates. Several interstitial spaces are filled by alkaline feldspar with partial transformation into muscovite (Figure 5C).

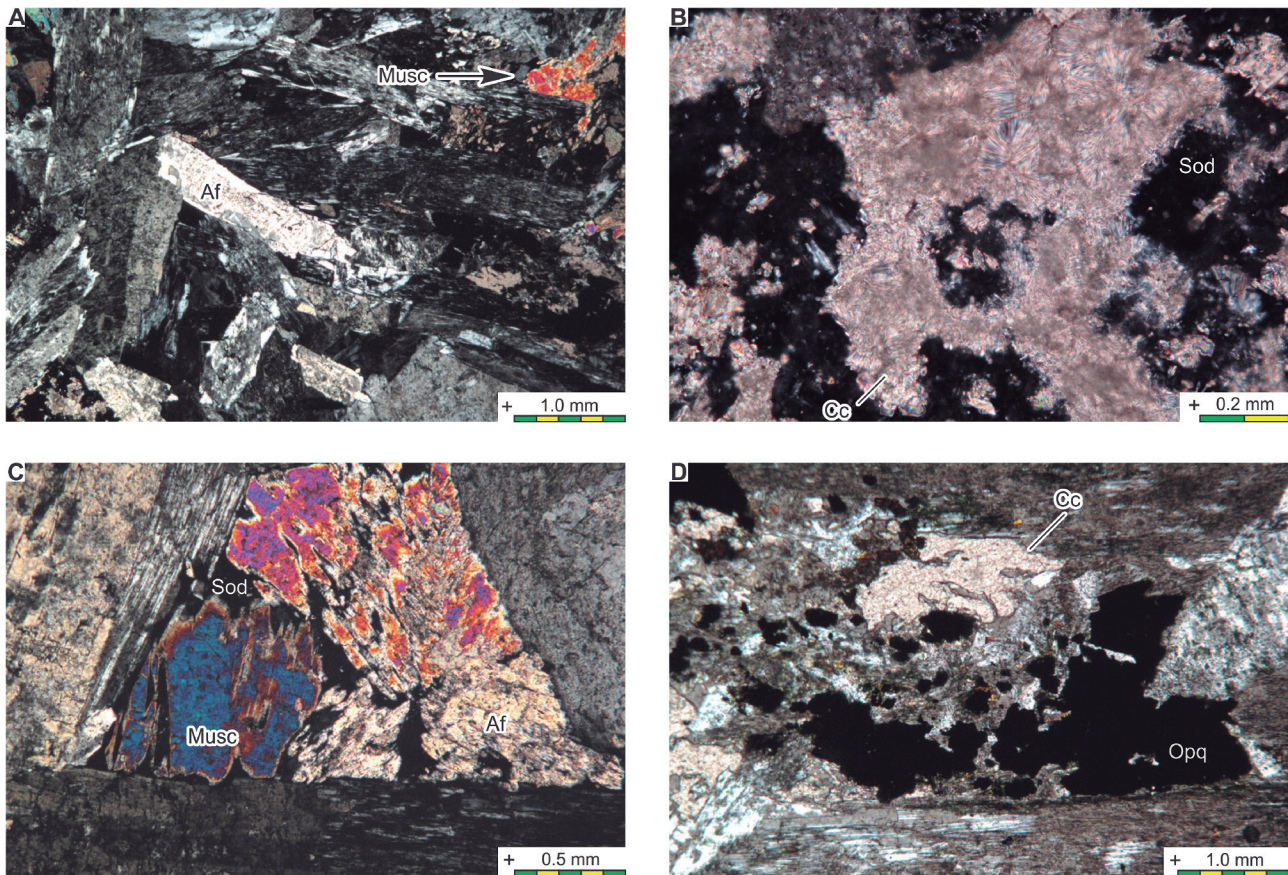


Figure 5 Photomicrographs of the *Blue Guanabara Granite*, of the south-west corner of the Mendanha body, State of Rio de Janeiro: A. Interstitial framework made up of tabular crystals of alkaline feldspar partially altered into muscovite; B. Calcite of fibrous habit and sodalite in a feldspathoid aggregate; C. Interstitial space filled by alkaline feldspar altered partially into muscovite and sodalite; D. Opaque mineral originated from amphibole. Af - alkaline feldspar; Sod - sodalite; Musc - muscovite; Cc - carbonates; Opq - opaque minerals.

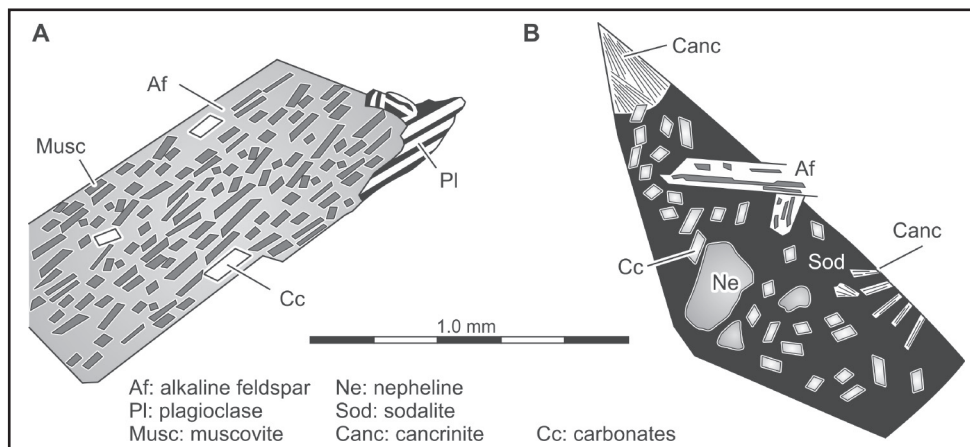


Figure 6 Microscopic sketches of the *Blue Guanabara Granite* after Vargas *et al.* (2001): A. Partial alteration of the alkaline feldspar into muscovite; B. Feldspathoids aggregates filling interstitial spaces of alkaline feldspar framework with plagioclase at the right corner. Af - alkaline feldspar; Sod - sodalite; Musc - muscovite; Canc - cancrinite; Cc - carbonates; Opq - opaque minerals.

Almost all of the mafic minerals are altered into magnetite (Figure 5D) and limonite, exhibiting pseudomorph. The modal amount of opaque minerals is about 3.0%. According to the mineral shape, it is estimated that about 2.2% is originated from amphibole and 0.8% from biotite.

The primary magnetite is 1.1%. There is a small amount of pseudomorph of chlorite after amphibole and vermiculite pseudomorph after biotite. Titanite crystals are smaller than 0.2 mm with a modal amount inferior to 0.5%. There is a notable amount of carbonates, about 6.8%, constituting the grains

smaller than 0.05 mm (Figure 5B, 6B). They compose aggregates of irregular shape, with 1 mm or larger in size (Figure 5D). Some of the carbonates fill the spaces between other minerals, suggesting carbonate dissemination by fluid activities.

5 Macroscopic Colour

Motoki *et al.* (2006) proposed a nomenclature of colour classification for ornamental dimension stones by means of natural physical colour using the HSB system. The analysed samples of *Blue Guanabara Granite* has lower saturation ($S=5\sim7$) than the *Blue Bahia Granite* ($S=8\sim14$). The former is classified as a slight colour rock and the latter, as light colour, medium colour, and high colour rocks (Figure 7).

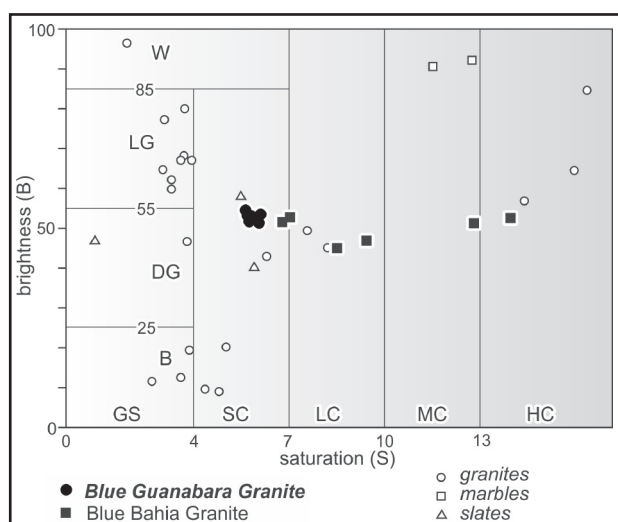


Figure 7 Classification diagram for dimensional stones of ornamental uses by macroscopic colour (Motoki *et al.*, 2006): The saturation scales are: GS - gleyscale; SC - slight colour; LC - light colour; MC - medium colour; HC - high colour. The brightness scales are: B - black; DG - dark grey; LG - light grey; W - white.

The greyscale colour analyses show that *Blue Guanabara Granite* has medium grade brightness of ca. 62 (Figure 8A). The alkaline feldspar and feldspathoids show brightness similar to *Blue Bahia Granite*. The opaque minerals exhibit relatively high brightness of ca. 28. This value is much higher than fresh biotite and hornblende, with respective average brightness of 0 and 16, because most of the opaque minerals are not primary minerals crystallised directly from the magma but originated from the alteration of mafic minerals.

6 Genesis of the Natural Stone Deposit

The contact zones of the dyke of the *Blue Guanabara Granite* are constituted by grey nepheline syenite, which maintains original composition. The sodalite cancrinite nepheline syenite along the central axis of the dyke has different mineral composition but preserves the original texture of nepheline syenite, such as alkaline feldspar frameworks and pseudomorph shape of amphibole and biotite.

On the other hand, the feldspathoids aggregates are constituted by complexly interfingered very small crystals of sodalite, cancrinite, calcite, and small amount of nepheline. The texture suggests that most of the constituent minerals of feldspathoid aggregates are secondary minerals formed by alteration of nepheline. The remnant nepheline is partially preserved.

The transformation of nepheline into sodalite needs Cl and S. They are highly mobile elements and metasomatic replacement is a probable agent. The alteration of amphibole into opaque minerals, biotite into vermiculite, alkaline feldspar into muscovite, and dissemination of secondary calcite support this

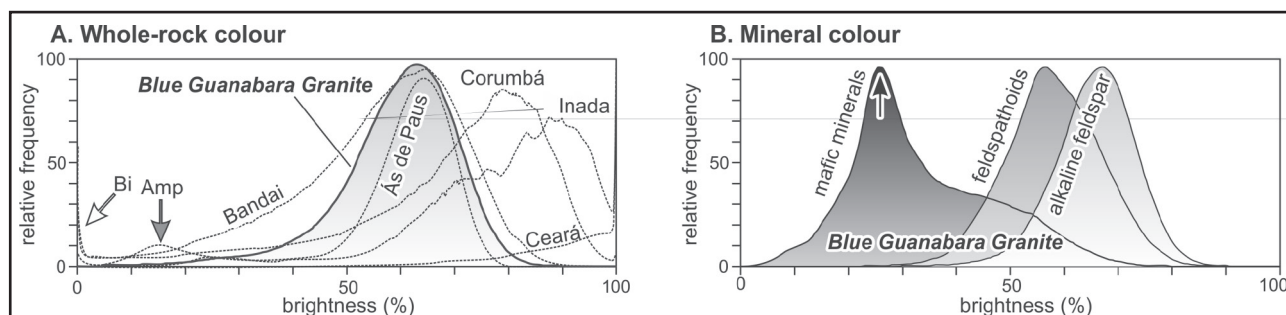


Figure 8 Greyscale colour diagrams for *Blue Guanabara Granite* in comparison with *Ás de Paus Grey Granite*, *Corumbá Grey Granite*, *Ceará White Granite*, *Inada White Granite*, and *Bandai Grey Granite*: A. Whole rock colour; B. Mineral colour of *Blue Guanabara Granite*. The former 3 rocks are Brazilian natural stones and the latter 2 are Japanese ones.

idea, especially the pseudomorphic shape of the opaque minerals and vermiculite after amphibole and biotite. The muscovite replacing the alkaline feldspar is well-crystallised, being different from the texture of hydrothermal sericite (e.g. Motoki *et al.*, 2007d; Novais *et al.*, 2007). The alteration of these minerals occurred after the establishment of the interstitial framework at late stage of the magma cooling.

In nepheline syenite, most of the Ti, Mg, and Ca constitute mafic minerals, as hornblende and clinopyroxene. The metasomatic decomposition of these minerals releases Ti, Mg, and Ca, and they recrystallise titanite and carbonates. Although these minerals are relatively abundant in this rock, but the recrystallisation process could be of secondary importance. The amount of secondary carbonates is too high and primary titanite crystals also are present.

Vargas *et al.* (2001) considered that the metasomatic alteration was caused by the fluid originated from the own magma. This field observation of dyke supports this idea. Such a metasomatism is known in some dykes, called autometasomatism or deuteric metasomatism (e.g. Elsdon, 1982; Rose & Bird, 1994; Bratzdrum *et al.*, 2009). The fluid activity related to sodalite formation is known in certain alkaline rock dykes of the world (e.g. Finch, 1991; Seckendorff *et al.*, 2000).

In the case of *Blue Bahia Granite*, that is, sodalite syenite of Itajú do Colônia, State of Bahia, almost all of the primary nepheline is transformed into sodalite. However, in the case of the *Blue Guanabara Granite*, sodalite cancrinite nepheline syenite, the relative content of sodalite is a little lower than 50%, due probably to insufficient Cl and S for total transformation of nepheline into sodalite. The grey-toned light blue colour of this rock is originated from incomplete transformation of nepheline in sodalite.

7 Conclusion

The geologic, lithologic, and petrographic observations, and surface colour specification for *Blue Guanabara Granite*, Mendanha Massif, State of Rio de Janeiro, Brazil, lead the authors to the owing conclusions.

1. The light blue natural stone occurs along the central axis of a syenitic dyke with 15 of width, 300 m of length, and E-W direction.

2. Petrographically the rock is classified as sodalite cancrinite nepheline syenite. The alkaline feldspar is often altered into muscovite. The feldspathoids are constituted by sodalite, cancrinite, and nepheline. They fill interstitial spaces between the alkaline feldspar frameworks.

3. Almost all of the mafic minerals are altered into opaque minerals. There are small amounts of pseudomorph chlorite after amphibole and pseudomorph vermiculite after biotite. There is a notable content of modal carbonates of 6.8%.

4. The colour analyses show that *Blue Guanabara Granite* has low whole-rock saturation ($S=5\sim7$), classified as a slight colour rock. The whole-rock brightness is of medium grade ($B\sim62$). The opaque minerals demonstrate relatively high brightness of ($B\sim28$), which is much higher than fresh biotite.

5. This rock presents remarkable evidences of deuteric metasomatism. The sodalite and cancrinite are originated from nepheline. The amphibole is altered into opaque minerals, biotite into vermiculite, forming pseudomorph. The alkaline feldspar is altered partially into muscovite. The greyish light blue macroscopic colour is originated from incomplete transformation of nepheline into sodalite.

6. The sodalite cancrinite nepheline syenite preserves original texture of nepheline syenite. However, the feldspathoids aggregates are constituted by very small crystals of sodalite, cancrinite, calcite, and nepheline. The alteration from nepheline into sodalite occurred after the establishment of the interstitial framework at late stage of the magma cooling.

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