GEOLOGY, PETROGRAPHY AND EMPLACEMENT MODE OF THE MORRO DOS GATOS ALKALINE INTRUSIVE COMPLEX, STATE OF RIO DE JANEIRO, BRAZIL

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(3) Departamento de Geologia, Universidade Federal Fluminense (LAGEMAR/UFF). Avenida Milton Cardoso sem número 4º Andar, Niterói, RJ. Endereço eletrônico: kenji_dl@hotmail.com.

RESUMO - *Geraldes, M.C., Motoki, A., Vargas, T., Iwanuch, W., Balmant, A., Motoki, K.F. Geologia, petrografia e modo de posicionamento do complexo intrusivo de rochas alcalinas do Morro dos Gatos, RJ.* Este artigo apresenta características geológicas, litológicas e petrográficas do complexo intrusivo de rochas alcalinas do Morro dos Gatos, que é situado na região central do Estado do Rio de Janeiro. As rochas alcalinas ocorrem na parte oeste do Morro dos Gatos e tem 1,2 x 1,2 km de extensão sendo distribuídas em uma área de 0,5 km^2. A parte leste do corpo intrusivo é constituída por rochas alcalinas félsicas, constituídas por feldspato alcalino, plagioclásio, clinopiroxênio, biotita e muito pequena quantidade de quartzo, variando de sienito a monzonito. Observam-se os cristais relativamente grandes de feldspato, de 2 x 5 mm, cujo centro é constituído por plagioclásio e a borda por feldspato alcalino de crescimento epitaxial. Plagioclásio ocorre também como arcabouço de textura intersticial. Os espaços triangulares são preenchidos por feldspato alcalino. A biotita é idiomórfica, de 2 a 3 mm de tamanho e tem cor marrom. O clinopiroxênio, identificado opticamente como augita, tem forma semi-arredondada e cor verde claro, apresentando notável textura poikilítica com abundantes inclusões minerais de apatita e magnetita. Observa-se uma notável heterogeneidade litológica tanto na composição mineralógica quanto na granulometria. O traquito ocorre tanto como intrusão precursora constituindo a borda do corpo intrusivo principal de sienito e monzonito, denominado traquito da primeira geração, quanto como diques que cortam o corpo principal, a segunda geração. O traquito da primeira geração ocorre na parte noroeste da área de distribuição das rochas alcalinas formando um corpo de 700 m x 400 m e na borda sul, como diques e *sills* de 0,5 a 3,0 m de largura. Não se observa a passagem gradativa entre o traquito e monzonito. O traquito é porfirítico e contém fenocristais de feldspato alcalino de 4 a 6 mm de tamanho. A massa fundamental é holocristalina e relativamente grossa, sendo composto de micrólitos de feldspato alcalino de 0,1 x 0,4 mm. Ocorrem pequenos cristais de biotita, hornblenda e magnetita. A granulometria da massa fundamental sugere que este traquito não seja formador de derrame ou domo de lava mas um corpo intrusivo pequeno. Encontram-se, localmente, o tufo soldado com abundância de cristais e dique composto de rocha piroclástica. Os corpos piroclásticos constituem fissuras subvulcânicas e acompanham o traquito da segunda geração ao longo do contato dos diques. A exposição atual do corpo intrusivo do Morro dos Gatos corresponde à parte inferior de um plutão. O complexo intrusivo foi formado por: 1) intrusão precursora do traquito da primeira geração; 2) intrusão principal do monzonito; 3) intrusão dos diques piroclásticos junto com o traquito da segunda geração.
Palavras-chave: Morro dos Gatos, sienito, monzonito, traquito, dique piroclástico.

ABSTRACT - This article presents geologic, lithologic, and petrographic characteristics of the Morro dos Gatos alkaline intrusive complex, which is situated in the central region of the State of Rio de Janeiro, Brazil. The alkaline rocks are exposed at the western part of the Morro dos Gatos massif and have 1.2 x 1.2 km of extension, distributed in an area of about 0.5 km^2. The eastern part of the intrusive body is constituted by felsic alkaline rocks ranging from syenite to monzonite, constituted by alkali feldspar, plagioclase, clinopyroxene, biotite, and very small amount of quartz. There are relatively large feldspar crystals, 2 x 5 mm, whose core is constituted by plagioclase and the border by alkali feldspar of epitaxial growth. Plagioclase occurs also as framework of the interstitial texture. The triangular spaces of the framework are filled by alkali feldspar. The biotite is idiomorphic, of 2 to 3 mm, and brown in colour. The clinopyroxene, identified optically as augite to aegirine-augite, has semi-rounded form, light green colour, and notable poikilitic texture with abundant mineral inclusions of apatite and magnetite. There is a notable lithologic heterogeneity either in the mineralogical composition or in the grain size. The trachyte occurs either as the precursor intrusion constituting border of the main intrusive body, namely the first generation trachyte, either as dykes cutting the main body, the second generation. The first generation trachyte occurs at the northwest part of the alkaline complex forming a body of 700 m x 400 m and at the south border as dykes and sills of 0.5 to 3.0 m in width. A transitional relation between the trachyte and the monzonite is not observed. This trachyte is porphyritic and contains alkali feldspar phenocrysts of 4 to 6 mm. The groundmass is holocrystalline and relatively coarse-grained, being constituted by alkali feldspar of 0.1 x 0.4 mm. Small crystals of biotite, hornblende, and magnetite also are observed. The groundmass grain size suggests that this trachyte is not constituent of lava flow or lava dome but small intrusive body. There are eventual occurrences of the composite dykes whose centre is constituted by crystal welded tuff and the border by the second generation trachyte, forming subvolcanic fissures. The present exposure of the Morro dos Gatos intrusive complex corresponds to the

lower part of a pluton. The intrusive complex was formed by: 1) precursor intrusion of the first generation trachyte; 2) main intrusion of the monzonite; 3) intrusion of the pyroclastic dyke and coeval second generation trachyte.
Keywords: Morro dos Gatos, monzonite, syenite, trachyte, pyroclastic dyke.

INTRODUCTION

Felsic alkaline plutonic rocks, such as nepheline syenite and alkali syenite are rare in field occurrence. Syenite and monzonite are also scarce. These rocks occur generally in extensional tectonic setting, such as continental break-up regions and back-arc areas of continental collision zones (Motoki et al., 2010; 2013).

In the State of Rio de Janeiro, Brazil, there is a dozen of late Cretaceous to early Cenozoic felsic alkaline intrusive bodies (Figure 1), such as: Itatiaia (Brotzu et al., 1997), Morro Redondo (Brotzu et al., 1989), Tinguá (Derby, 1897), Mendanha (Motoki et al., 2007a; Petrakis et al., 2010), Itaúna (Motoki et al., 2008a), Tanguá, Rio Bonito, Soarinho (Motoki et al., 2010), Morro de São João (Brotzu et al., 2007; Mota et al., 2009), and Cabo Frio Island (Motoki & Sichel, 2008; Motoki et al., 2008b). The Morro dos Gatos intrusive complex belongs to this magmatic suite (Motoki et al., 2012a). It is emplaced at a depth of 3 km and now are exposed on the present surface due to regional uplift and consequent denudation in the early Cenozoic (Hackspacher et al., 2004; Riccomini et al., 2004). These bodies constitute eastern part of the Poços de Caldas - Cabo Frio magmatic alignment (Thomáz Filho & Rodrigues, 1999).

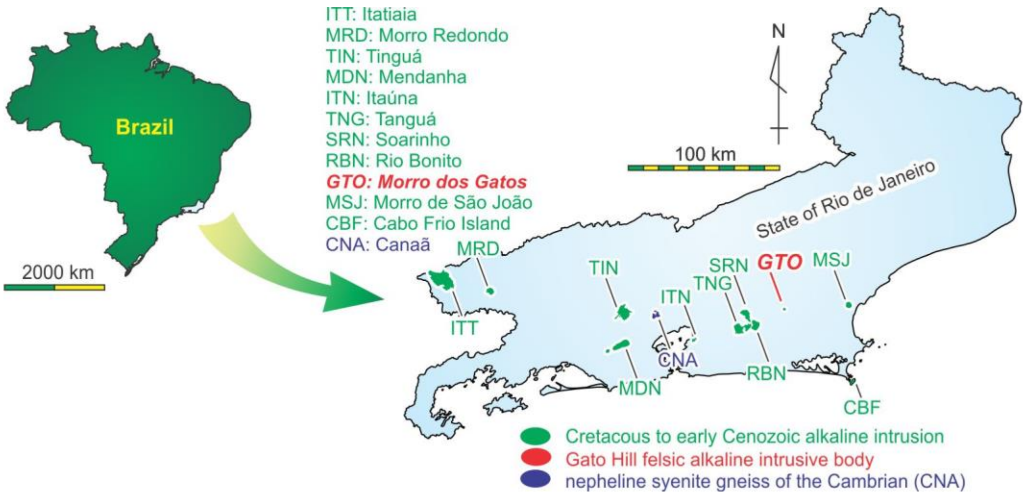

Figure 1. Location map for the Morro dos Gatos alkaline intrusive body and the other alkaline complexes of the Poços de Caldas - Cabo Frio magmatic alignment in the State of Rio de Janeiro.

The Morro dos Gatos complex is located at 22º37.7'S, 42º29.0'W, in the central region of the State of Rio de Janeiro, about 83 km to the east-northeast of the Rio de Janeiro City, 10 km to the west-northwest of Silva Jardim, 1.5 km to the north of Cesário Alvim, and 1.0 km to the south of Imbaú (Figure 2).

The Morro dos Gatos massif is 3 km long (ENE-SWS), 1 km wide (NWN-SES), and 400 m high. According to the topographic map based on the ASTER GDEM processed by the BAZ system (Motoki et al., 2012b; Aires et al., 2012), the maximum altitude is 420 m.

The geologic maps of Mineral Resource Department of the State of Rio de Janeiro (DRM-RJ, Reis & Mansur, 1995) and Brazilian Geological Survey (CPRM, Silva, L.C. et al., 2000) show that the alkaline rocks are distributed in an area of about 5 km^2. That is, the Morro dos Gatos massif should be constituted entirely by alkaline rocks. However, recent fieldworks have revealed that only the western part of the hill exposes the alkaline rocks in an area of 0.5 km^2 (Motoki et al., 2012a). The other parts of the massif are composed of the country porphyritic granite.

Martins & Borghi (1982) presented the first report of Morro dos Gatos alkaline complex with preliminary descriptions. Chaves et al. (1993) referred this intrusive complex as a similar intrusion of Guanabara Bay, State of Rio de Janeiro. Moraes (2009) show petrographic and geochronological studies of the porphyritic granite of Silva Jardim. Motoki et al. (2012a) exhibited descriptions and discussions of the pyroclastic rocks of Morro dos Gatos complex, identifying them as vent-filling welded tuff breccia. Aires et al (2012) characterized geomorphologic features of the felsic alkaline bodies of this region, including this alkaline complex. Sichel et al. (2012) discussed geochemical evolution of these felsic alkaline magmas, indicating the monzonite of this complex as a rare occurrence.

From 2009 to 2011, the authors have performed a series of fieldworks and petrographic studies. The present article reports the field description, lithologic annotation, and petrographic observation of the Morro dos Gatos alkaline intrusive complex and considers its emplacement mode.

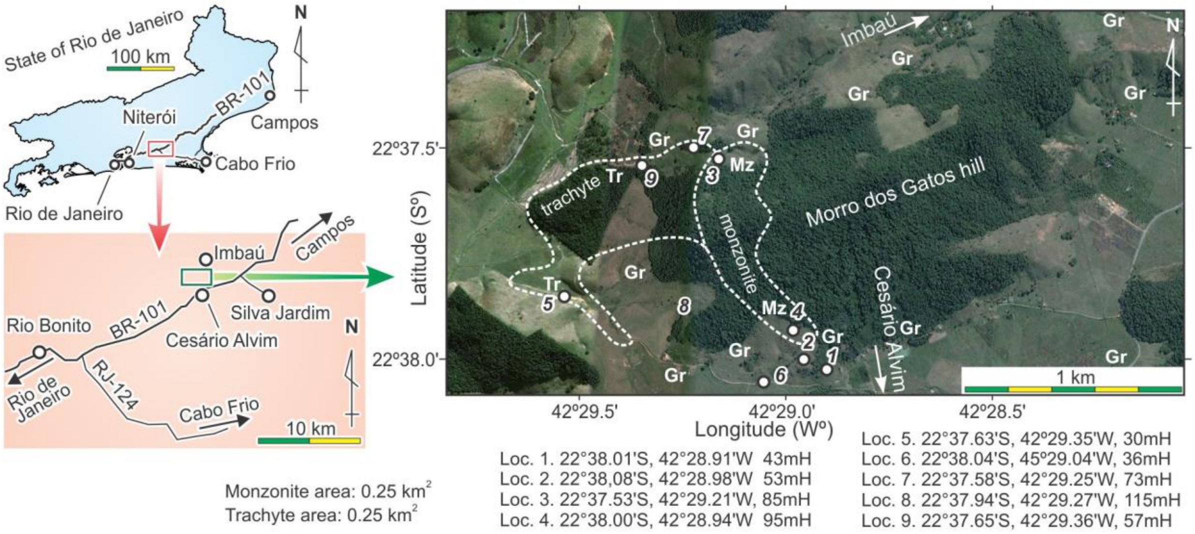

Figure 2. Access map to the Morro dos Gatos alkaline intrusive rock body, modified from Motoki et al. (2012a). The satellite image is originated from Google Earth™. The distribution areas are calculated Wilbur ver, 1.0 (Motoki et al., 2005; 2006) according to the method of Motoki et al. (2009b). Gr - host porphyritic granite; Tr - first generation trachyte; Mz - monzonite, syenite.

REGIONAL GEOLOGY

The basement of this region is constituted by paragneiss of the Costeiro Unit, orthogneiss of the Oriental Terrane, and post-tectonic granite of the Pan-African orogeny (Heilbron et al., 2000; Heilbron & Machado, 2003). They were cut by silicified tectonic breccia of the last phase of the orogeny (Motoki et al., 2011; 2012c). All of them were intruded by early Cretaceous mafic dykes related to the flood basalt magmatism of the Paraná Province (Guedes et al., 2005; Motoki et al., 2009b).

The Morro dos Gatos body intruded into the Silva Jardim porphyritic granite (Figure 3). It is characterised by abundant large alkali feldspar phenocrysts of 4 x 3 x 1 cm in size with mineral orientation and network-like aplite veins. The phenocrysts are in contact with one-another showing cumulative texture. The modal amount of the phenocrysts ranges from 40 to 60%. The aplite veins are generally 3 to 8 cm wide, up to 30 cm. The intrusive age by the U-Pb is 505±2 Ma (Moraes, 2009).

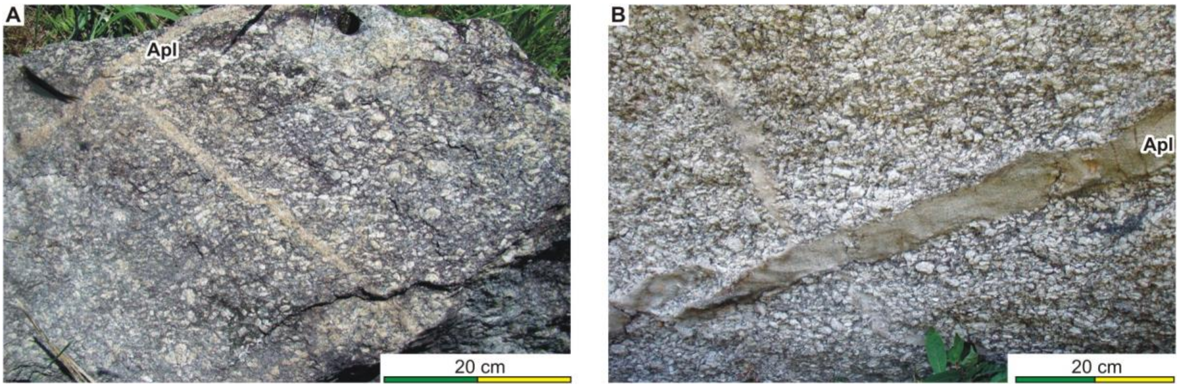

Figure 3. The Silva Jardim granite, which is the country rock of the Morro dos Gatos alkaline intrusive body: A) at a ceased block extraction quarry near Silva Jardim; B) at the southern slope of the Morro dos Gatos hill, Loc. 1 (Figure 2). Apl - aplite vein.

GEOLOGY OF THE MORRO DOS GATOS HILL

Recent fieldwork revealed that the most parts of the hill are made up of Silva Jardim porphyritic granite (Figure 4A; Motoki et al., 2012a). Only the western border is composed of alkaline rocks, with total distribution area of 0.5 km^2 (Figure 2).

Because of the erosive resistance of nepheline syenite and alkaline syenite with the help of weathering passivity effects (Motoki et al., 2008c; Silva, S., 2010), the alkaline bodies of this region form morphologic elevations with relative height of 300 to 900 m. However this effect is not relevant for the Morro dos Gatos because of the limited distribution area of their alkaline rocks. The outcrops are scarce and the rocks appear only as boulders of the size varying from 50 cm to 10 m (Figure 4).

Figure 4. Field photos for the constituent rocks of Morro dos Gatos hill: A) Silva Jardim porphyritic granite boulder with aplite vain at Loc. 2 (Figure 2); B) monzonite boulder showing fluting at Loc. 3; C) close-up view of the monzonite at Loc.4; D) porphyritic trachyte with relatively gross groundmass at Loc. 5. Gr - porphyritic granite; Apl - granitic aplite vein; Sap - fine vein of syenitic aplite.

The eastern part of Morro dos Gatos complex is constituted by coarse-grained rocks, varying from syenite to monzonite. They are distributed in an area of about 0.25 km^2 and show heterogeneous lithologic aspects. Some of their boulders show fluting on the surface with the interval of 30 cm to 80 cm (Figure 4B). Even in the same outcrops, the mineral composition is variable, ranging from syenite to monzonite (Figure 4C). Syenitic aplite veins are commonly found.

Some granite boulders at Loc. 2 (Figure 2), situated close to the contact with the area of syenite and monzonite, show veins of 2 to 10 cm in width forming a network with interval of 30 cm a 60 cm (Figure 5A) composed of syenite and monzonite. They are not straight but complexly curved. In the initial phase of the syenitic intrusion the magma should intrude into cold and brittle country rock forming straight veins (Figure 5B). In the advance intrusive phase, the country rock was heated by the voluminous magma of the main intrusive body, resulting plastic deformation (Figure 5C). The above-mentioned phases occurred one-another in a short period. Because of the strong thermal effect, this phenomenon is found more probably in pluton bottom than pluton top. In fact, similar fabric is known at the intrusive contact of the Pedra Branca granite at the Bangu Quarry, Rio de Janeiro.

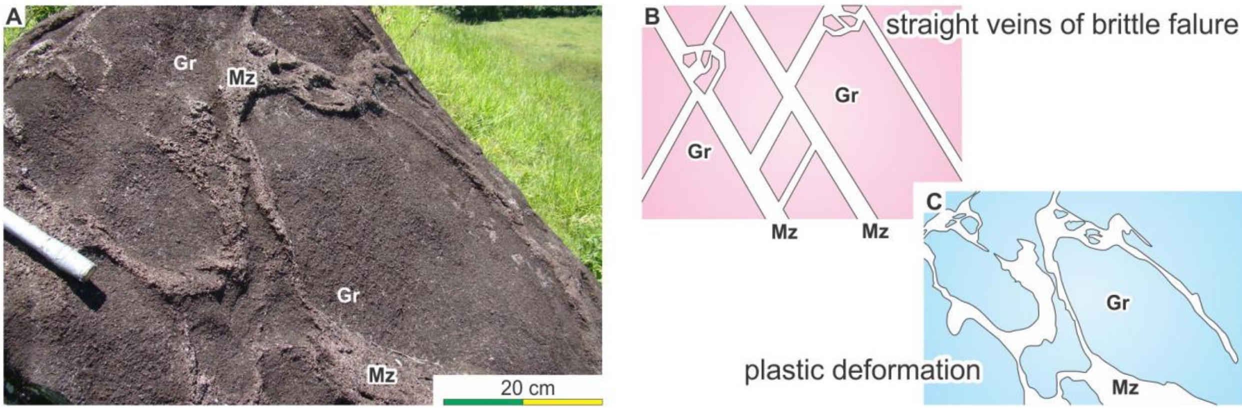

Figure 5. Plastically deformed monzonite veins at Loc. 2 (Figure 2) and its interpretation: A) field photo; B) straight monzonite vein formation at an initial intrusive phase by the magma intrusion into cold and brittle country granite; C) plastic deformation of the veins at an advanced intrusive phase due to country rock heating by voluminous magma of the main intrusive body. Gr - host granite; Mz - monzonite vein.

The trachyte with a relatively coarse-grained holocrystalline groundmass occurs at the western part of the alkaline body between the monzonite and the granite in a continuous area of hundreds meters in size, with total distribution area of about 0.25 km^2. The contact between the syenitic to monzonitic main intrusive body and the trachyte is sharp. These observations indicate that this trachyte is not constituent of lava flows or dykes, but of a small massive intrusive body. The main plutonic body intruded after the cooling and consolidation of the trachyte, and therefore, this precursor intrusion is called “first generation trachyte”.

On the other hand, the holocrystalline trachyte occurs also as dykes and sills. They are 50 cm to 5 m wide and sometimes include xenoliths of 1 m (Figure 6). Many dykes are composed of white colour trachyte because of partial transformation of alkali feldspar into kaolin due to deuteric alteration. The similar phenomenon is known in the dykes and sills of the intrusive complex of Mendanha, Cabo Frio Island, and Tanguá (Motoki et al., 2007b; 2008b; 2010). These dykes are coeval or later than the main intrusion, and therefore, they are called “second generation trachyte”.

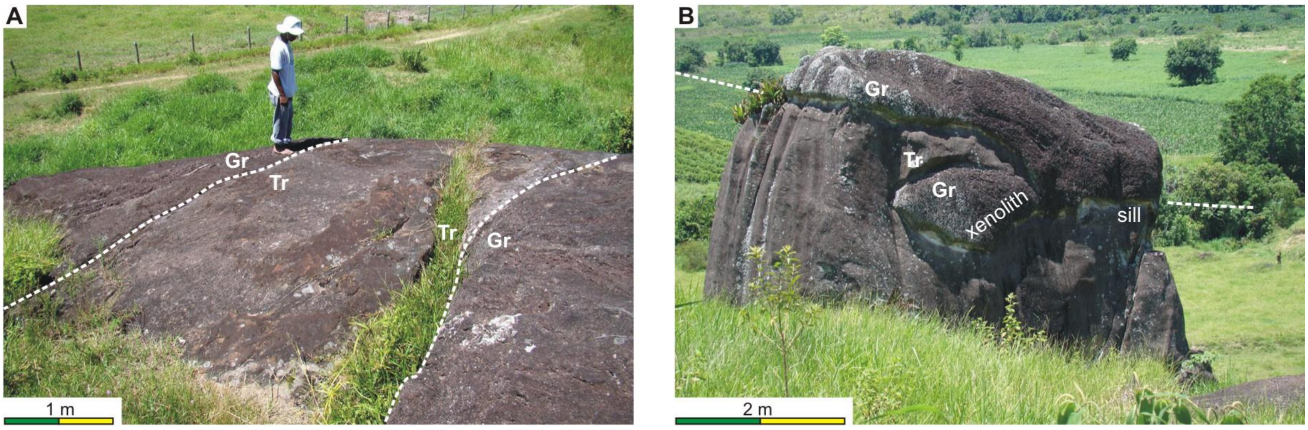

Figure 6. Tabular intrusive rock body of the holocrystalline trachyte into the host granite at Loc. 2 (Figure 2): A) dyke of 2.5 m in width; B) sill of 4 m of thickness.

There is a pyroclastic dyke intruding into the porphyritic granite and trachyte of this rock body. The outcrop at the southern foot of the hill shows that the dyke is 0.4 to 0.8 m wide with the intercalation of the second generation trachyte along the contact zone (Figure 7A, Tr). This rock is classified as a lithic tuff breccia with the angular trachyte clasts and the strongly welded matrix. At another site, there is welded crystal tuff (Figure 7B).

The Figure 8 shows the intrusive relation between these bodies. The geologic mode of occurrence of the Morro dos Gatos is very similar to that of the Mendanha, Itaúna, Tanguá, and Cabo Frio Island intrusive complexes (Motoki & Sichel, 2006; Mota & Geraldes, 2006; Motoki et al., 2007c; d; 2013).

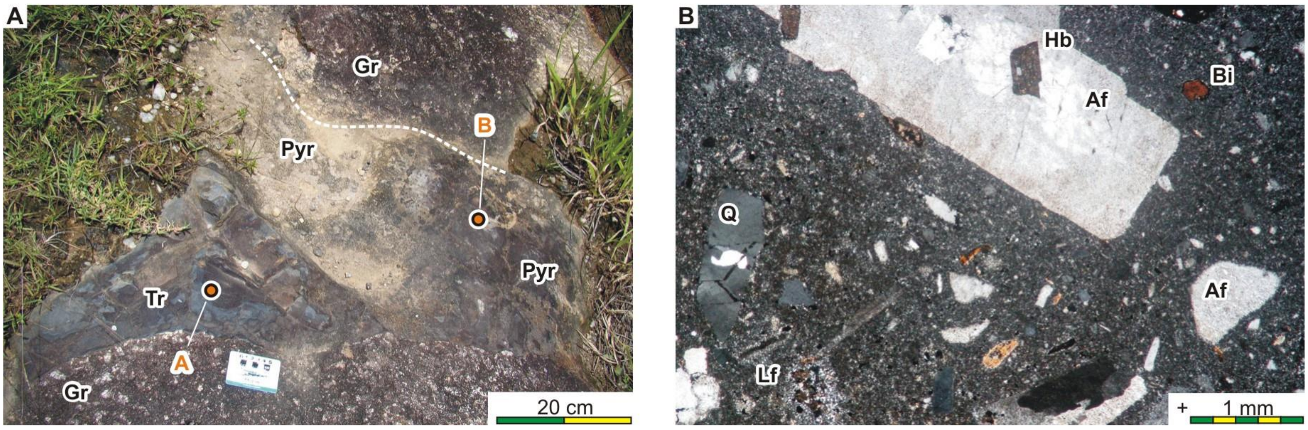

Figure 7. Pyroclastic rocks of the Morro dos Gatos, State of Rio de Janeiro, Brazil: 1) outcrop of the composite pyroclastic dyke intruding into the porphyritic granite with the marginal intercalation of fine-grained trachyte at the outcrop at Loc. 6 (Figure 2); B) photomicrography of crystal welded tuff under the crossed polarizer of the sample collected from Loc. 7. The position A and B are exact sampling point of the photomicrography shown on the Figure 12. Gr - porphyritic granite; Tr - second generation trachyte; Pyr - pyroclastic dyke; Af - alkali feldspar; Bi - biotite; Hb - hornblende; Q - quartz; Lf - lithic fragment.

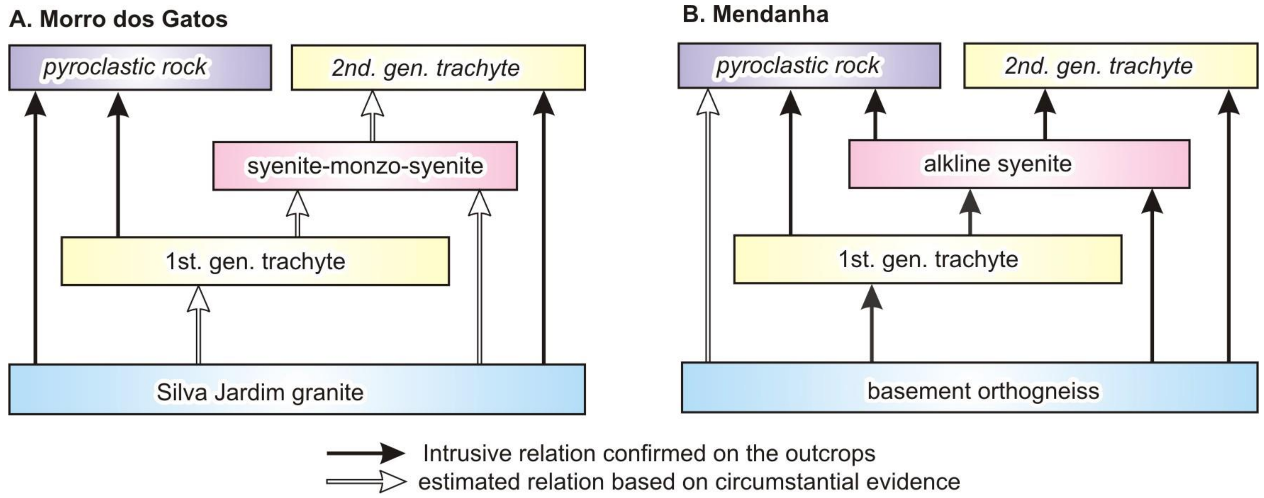

Figure 8. Intrusive relation between the basement and the felsic alkaline rock bodies, according to the expression method of Motoki (1979) Motoki et al. (2007a), and Sichel et al. (2008): A) Morro dos Gatos complex; B) Mendanha complex.

PETROGRAPHIC CHARACTERISTICS

The coarse-grained rocks have equigranular texture without notable mineral orientation. The main constituent minerals are alkali feldspar, plagioclase, clinopyroxene, and biotite. Quartz is scarce and no nepheline or amphibole is present. Apatite and magnetite are relevant as accessory minerals. Some parts of monazite body are pegmatitic.

The alkali feldspar is in general 1 x 3 mm and shows Carlsbad twin (Figure 9A). Flame type and string type perthite textures, which are common in highly potassic feldspar, are not observed. Antiperthite texture is sometimes observed. These observations suggest that the alkali feldspar is not as potassic as expected in granitic rocks. It is intermediate alkali feldspar which is common in syenitic rocks. The spaces of the interstitial texture are filled generally by alkali feldspar.

Different from the other alkaline intrusions of this region, the syenite and monzonite of Morro dos Gatos contain plagioclase, varying from andesine to oligoclase in composition. This mineral shows relevant albite twins and takes place in two different forms: 1) at the core of large feldspar crystals; 2) framework of interstitial texture (Figure 9B). This monzonite contains phenocryst-like large feldspar crystals, of 2 x 5 mm, whose core is constituted by plagioclase and the border by alkali feldspar of epitaxial growth (Figure 9C). The core made up of plagioclase shows antiperhite texture. According to the whole thin-section digital image analyses by the pixel counting method of Motoki et al. (2007d; Figure 10), the large feldspar crystals are of high modal abundance, from 20 to 30%. The plagioclase of the interstitial framework is 0.5 x 3 mm. The P/(A+P) ratio is 0.3 to 0.4, and therefore, the rock is classified to be syenite of the field 7 passing to monzonite of the field 8, according to the classification nomenclature of the IUGS (Streckeisen, 1973). Quartz is scarce and occurs in the small spaces between alkali feldspar and plagioclase.

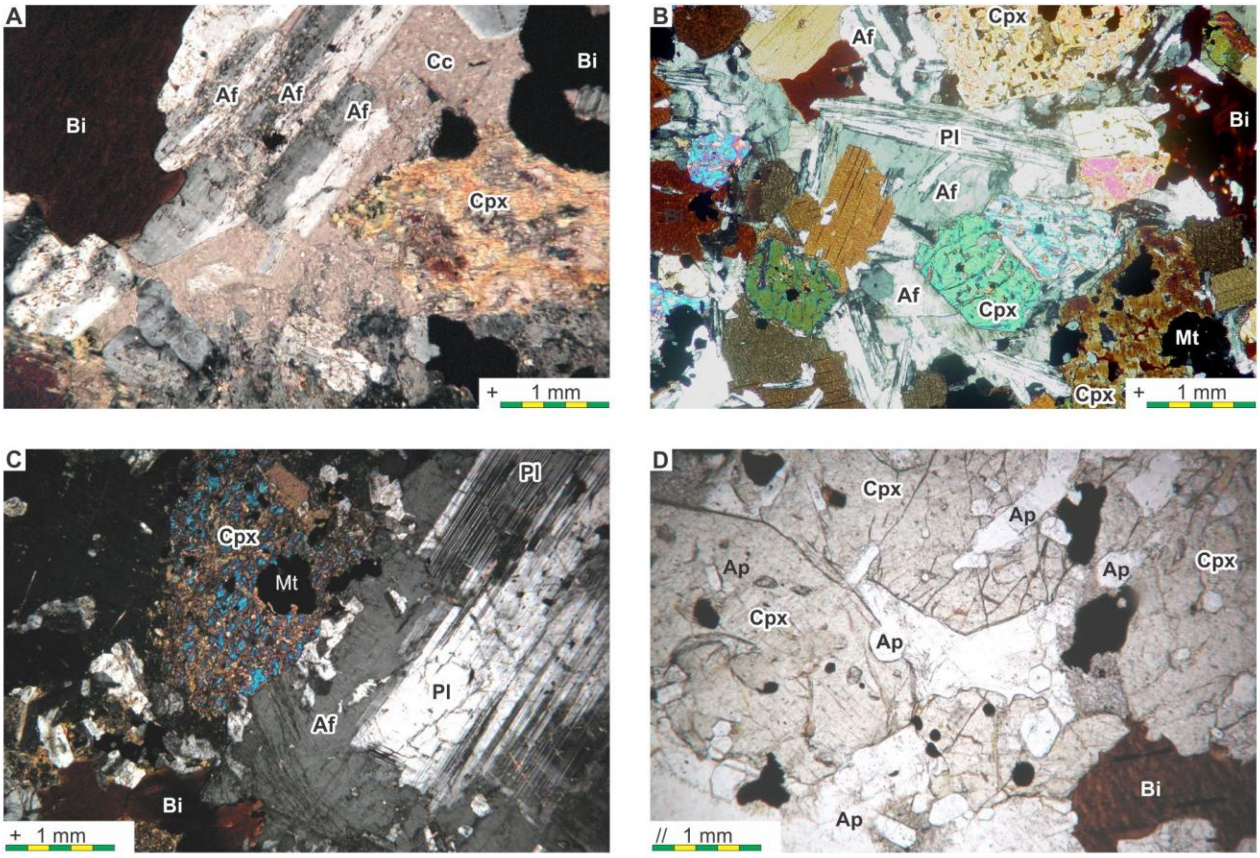

Figure 9. Photomicrography for the monzonite and syenite of the Morro dos Gatos alkaline intrusive rock body, State of Rio de Janeiro, Brazil: A) Carlsbad twin of alkali feldspar crystals: B) Tabular plagioclase and semi-rounded shaped of clinopyroxene; C) Large feldspar crystal with plagioclase core and alkali feldspar border; D) Abundant occurrence of apatite. Af - alkali feldspar; Pl - plagioclase; Cpx - clinopyroxene; Bi - biotite; Mt - magnetite; Ap - apatite; Cc - calcite.

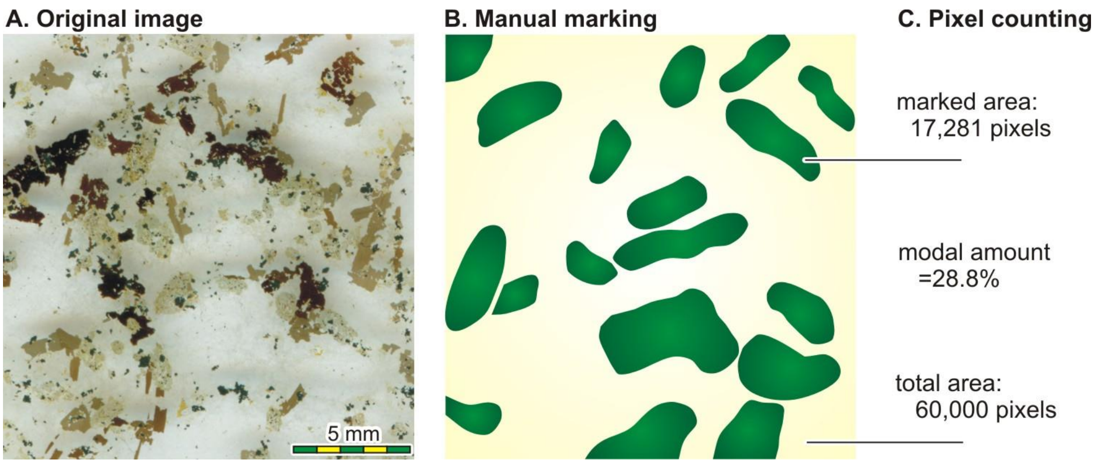

Figure 10. Modal analyses method for phenocryst present in a large area based on the digital image pixel counting after Motoki et al. (2007b): A) original entire thin section image of the Morro dos Gatos monzonite; B) manual marking of large feldspar crystal areas; C) pixel counting using the software Wilbur (Motoki et al., 2006).

The total modal amount of mafic and opaque minerals is about 20 wt%, being higher than in other plutonic rocks of the main intrusion of the others alkaline rock bodies of the Poços de Caldas - Cabo Frio alignment. Some samples have more than modal 30 wt% of mafic minerals. Martins & Borghi (1982) reported the existence of malignite, that is, a nepheline-rich alkaline gabbro. However, the authors do not find a rock with nepheline in the Morro dos Gatos intrusive complex. There is notable local variation of mafic mineral contents.

The clinopyroxene is of general size of about 2 mm and has light green colour, which suggests aegirine-augite composition. The shape is semi-rounded with the embayment originated form resorption (Figure 9C). Most of the grains show Schiller texture (Figure 9A, C) and relevant poikilitic texture with inclusion of apatite and magnetite. The apatite crystals are relatively large, about 0.4 x 1.5 mm, and its content is remarkably high, up to 5% in volume (Figure 9D). The biotite is idiomorphic of 2 to 3 mm in size and brown in colour, but locally, large biotite crystals, up to 2 cm, are present.

The first generation trachyte is characterized by porphyritic texture and holocrystalline ground mass. The phenocrysts are composed of alkali feldspar of 4 to 6 mm in size. Many samples contain phenocrysts of low aspect ration, around 1,5 (Figure 4D; 11A), that is, rather cubic than tabular. On the other hand, some of them have highly tabular phenocrysts. According to the digital image analyses, the modal amount of alkali feldspar phenocrysts is 5 to 10% in volume. Biotite, hornblende, and magnetite are of little amount. Being different from the trachyte that constitutes lava flows and dykes, the groundmass of this trachyte is relatively coarse, being constituted by alkali feldspar microliths of 0,1 x 0,4 mm. The mineral preferential orientation is not notable. The above-mentioned textural characteristics indicate that this trachyte constitutes an intrusive body of relatively large size.

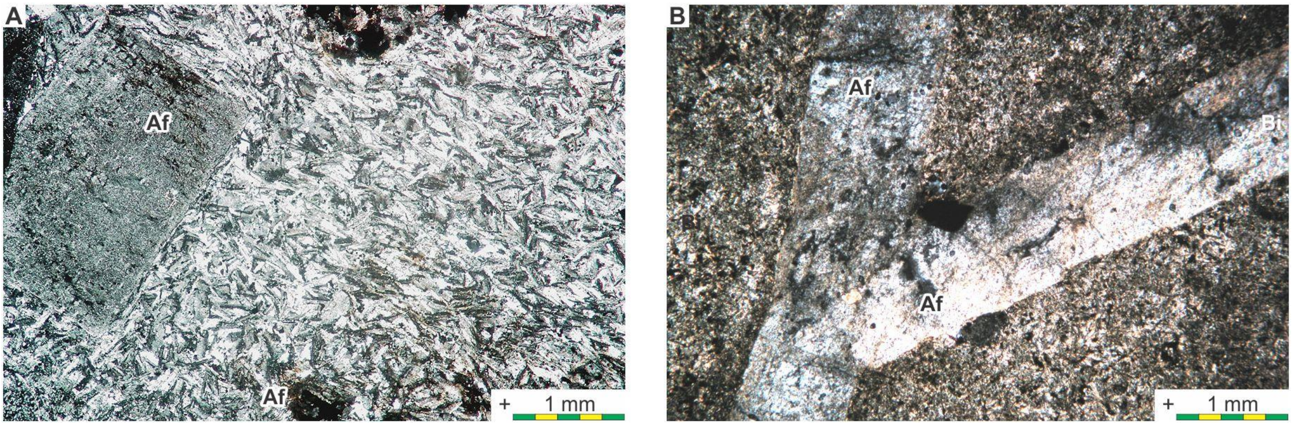

Figure 11. Photomicrography of the first generation trachyte of the Morro dos Gatos intrusive body: A) first generation trachyte with low aspect ratio alkali feldspar phenocryst (Af); B) that has high aspect ratio alkali feldspar phenocrysts (Af).

The second generation trachyte occurs along the contact plane of the pyroclastic dyke (Figure 7A). This rock is characterised by the presence of small alkali feldspar microlith, in average 0.2 mm x 0.05 mm in size, almost without preferential orientation. There are little amount of phenocrysts of alkali feldspar, 0.8 mm x 0.6 mm, amphibole, 0.5 mm x 0.2 mm, and biotite 0.8 mm x 0.2 mm. The trachyte of dyke margin has very similar petrographic aspects with the trachyte that forms clast in the pyroclastic rock (Figure 12). The groundmass shows devitrified texture. Different from the first generation trachyte, this trachyte indicates rapid magma cooling. Therefore, the trachyte magma intruded into the cold host rock forming a small dyke the following explosive eruption generated the clasts of second generation trachyte. The trachyte along the contact is remnant one. These observations fit well the model of conduit implosion proposed by Motoki et al. (2007b; 2008d).

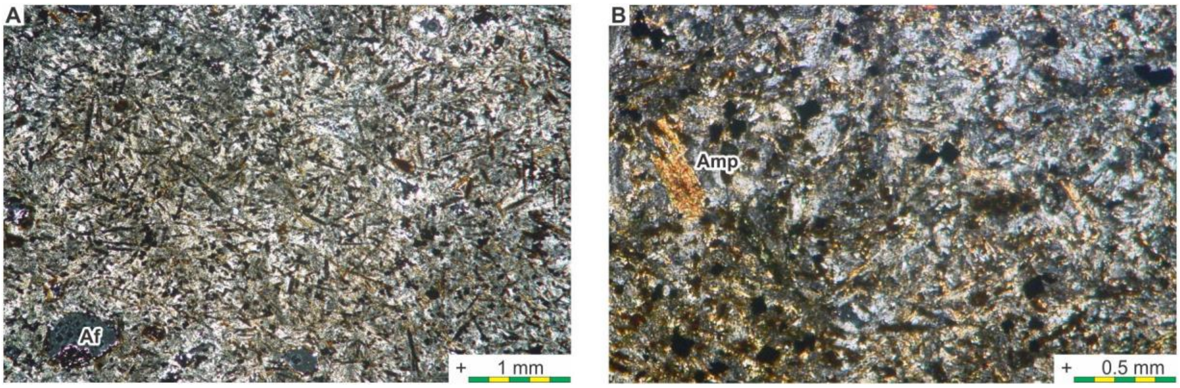

Figure 12. Photomicrography of the second generation trachyte of the Morro dos Gatos of the outcrop of Loc. 6 (Figure 2, 7) showing devitrified matrix: A) contact zone of the pyroclastic dyke; B) clast of the pyroclastic dyke. The sampling positions are shown on the Figure 7. Af - alkali feldspar; Amp - amphibole.

EMPLACEMENT MODEL

The studied area is poor in outcrops and the field information is not enough to propose a definitive geologic emplacement model for the Morro dos Gatos alkaline intrusive complex. Therefore, the geologic emplacement of trachyte is difficult to grasp. At least, part of the trachyte forms dykes and sills which intruded into the porphyritic granite (Figure 6) and it could be either of precursor intrusive body or of a dyke swarm.

The precursor intrusion model is based on the distribution of this rock in a continuous area of hundreds of meters. The trachyte and phonolite of such geological setting (Figure 8) are known in the Mendanha complex (Figure 13; Motoki et al., 2008d) and the Tanguá body (Motoki et al., 2010), and called respectively first generation trachyte and first generation phonolite.

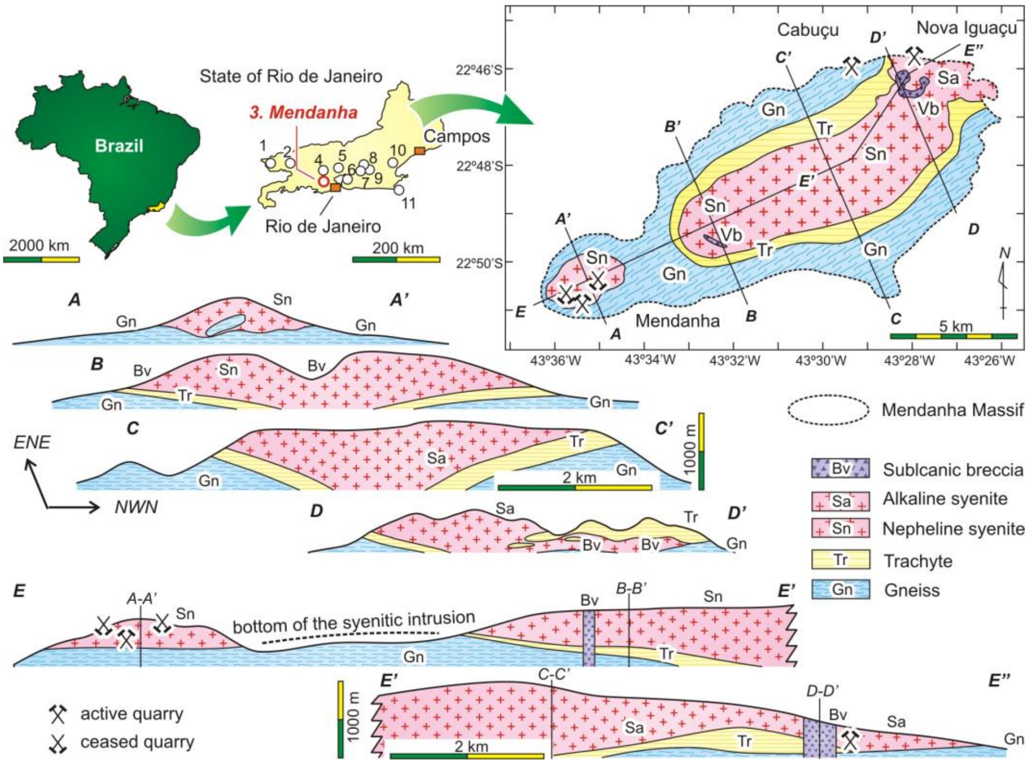

Figure 13. Schematic geologic cross section of the Mendanha felsic alkaline intrusive rock body, State of Rio de Janeiro, Brazil, showing the relation between the precursor intrusion of the first generation trachyte (Tr) and the main intrusion of nepheline syenite (Sn) and alkaline syenite (Sa), after Motoki et al. (2008d).

The outcrop observations of the Mendanha complex present the following intrusive history: 1) trachyte magma with relatively low volatile content intruded, constituting the precursor intrusive body and the magma started to consolidate from the contact zone forming the first generation trachyte; 2) when the central part of the precursor intrusion was still not consolidated, a relatively volatile rich magma intruded, forming the alkaline syenite main intrusion; 3) after the cooling of the above-mentioned bodies, the intrusion of the second generation trachyte dykes, subvolcanic conduits, and pyroclastic fissures dykes took place. In case of the Morro dos Gatos complex, the intrusive relation is not so exactly observed but is considered to be similar: 1) precursor intrusion of the first generation trachyte (Figure 14A); 2) main intrusion of the monzonite (Figure 14B); 3) explosive eruption through the subvolcanic pyroclastic fissure that is represented by the pyroclastic dyke (Figure 14C). The present exposure corresponds to the subvolcanic magma chamber (Figure 14D).

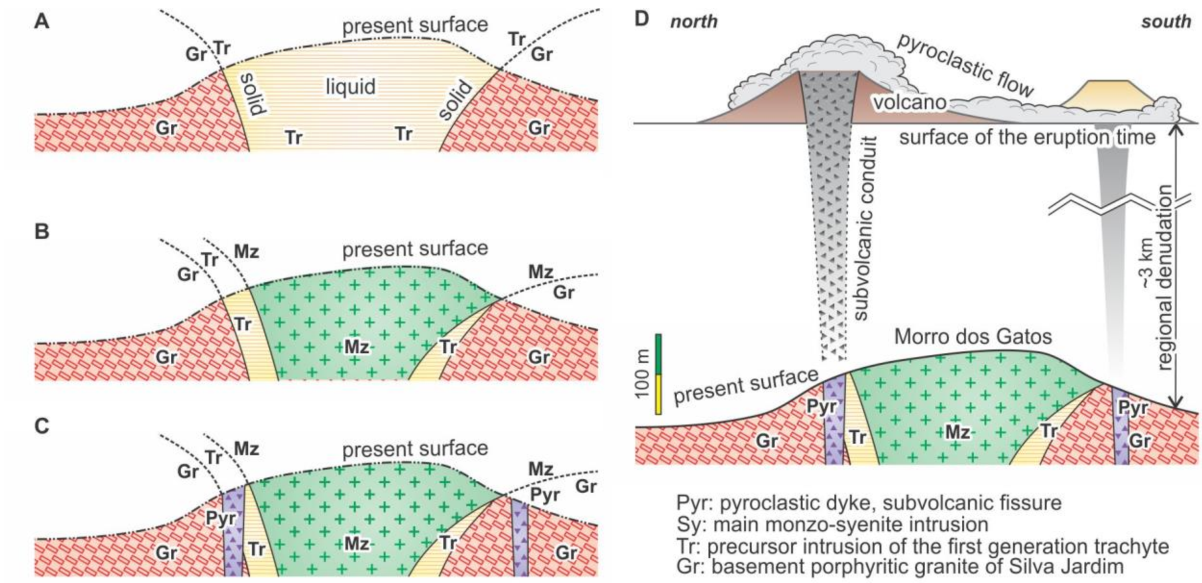

Figure 14. Schematic cross-sections explaining the formation process and geologic evolution of the Morro dos Gatos intrusive complex: A) precursor intrusion of the first generation trachyte; B) main monzonite intrusion; 3) explosive eruption though the fissure vent; D) present geologic cross-section and its relation with the volcanic eruption of the Cretaceous to early Cenozoic and the later regional denudation. The cross section D is based on Motoki et al. (2012a).

On the other hand, according to the dyke swarm model, all of the field occurrences of the first generation trachyte are of dykes and sills. The field data are not enough to define which model is better, small intrusive body or dyke swarm. At Loc. 8 (Figure 2), at the southwestern border of the Morro dos Gatos massif, there are boulders of granite, trachyte, and granite with trachyte dyke. However, at Loc. 9, in which the holocrystalline trachyte takes place in a continuous area, only trachyte boulders are found. The crystal welded tuff found close to Loc. 9 contains holocrystalline trachyte fragments (Photo 4B). To justify the relatively abundant trachyte lithic fragments, the trachyte body must have certain size and dykes are considered to be not large enough. For these reasons, the precursor intrusion model seems to be more consistent.

SMALL-SIZE INTRUSIVE BODY

The Morro dos Gatos alkaline intrusive complex is much smaller in distribution area than the other alkaline intrusive complexes of the Poços de Caldas - Cabo Frio magmatic alignment. This size can be due to: 1) small volume of the intrusive magma; 2) exposure of pluton top; 3) exposure of pluton bottom. If the magma volume were so small, the intrusive bodies should be constituted only by trachyte and difficult to be composed of syenite and monzonite. In case of pluton top exposure, more than one plutonic body should appear accompanied by pegmatite veins and pockets. If pluton bottom is exposed, the field and petrographic observations are well explained. There is a large modal amount of phenocryst-like feldspar crystals that shows cumulative texture. This observation supports the pluton root model. However, it is probable model and not definitive one.

The alkaline rock intrusions of the Poços de Caldas - Cabo Frio alignment present horizontal sections of different relative levels of pluton (Motoki et al., 2008d). In general, they have flattened coffee filter-like general three-dimensional form. Upper-level section is semi-circular, such as Tanguá and Morro de São João intrusive complex (Figure 15A), lower-level section is elliptic or fissure-like, as Mendanha, Rio Bonito, and Cabo Frio Island (Figure 15B), and root section is small fissure or irregular form, as Itaúna (Figure 15C). It is considered that the Morro dos Gatos complex is still deeper (Figure 15D).

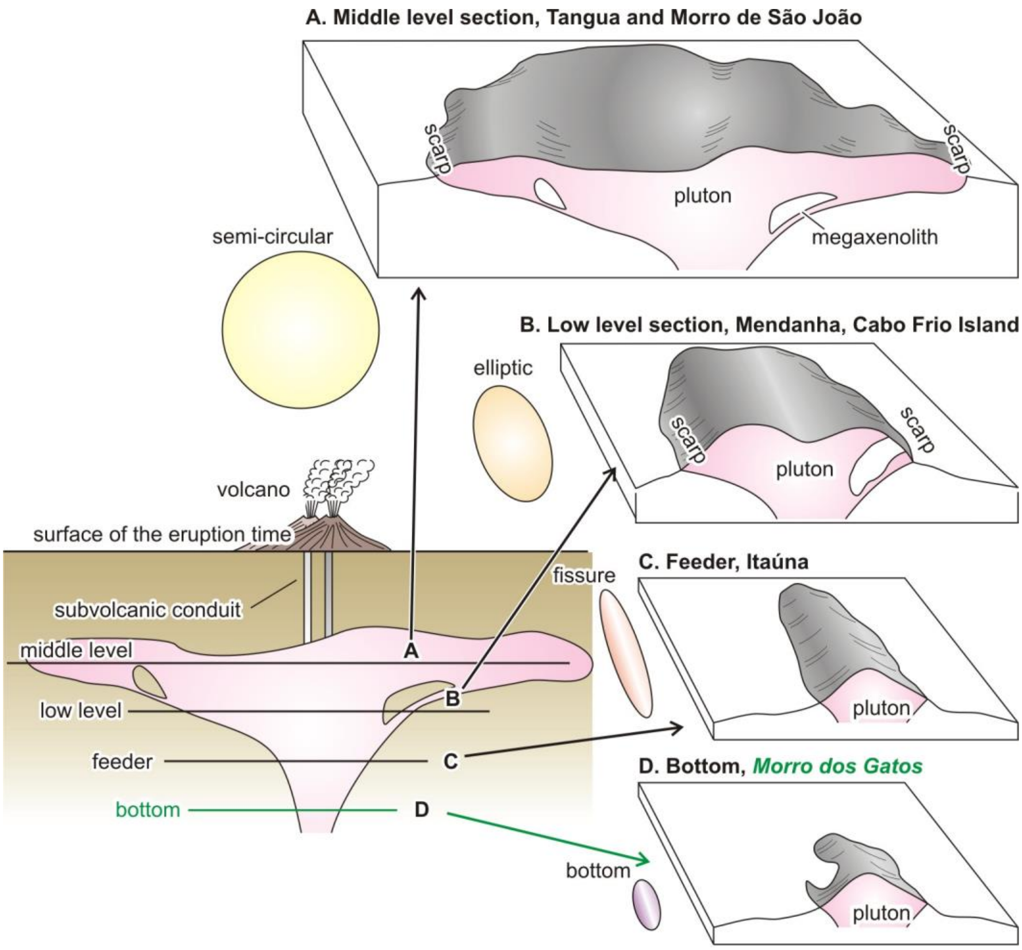

Figure 15. Schematic illustrations for the three-dimensional form of the Cretacous to early Cenozoic alkaline intrusive rock bodies of the State of Rio de Janeiro, Brazil, showing horizontal sections according to the relative level of denudation, modified from Motoki et al. (2008d): A) middle level of the intrusive body with the exposition in a semi-circular area, such as Tanguá and Morro de São João; B) low level section of the pluton cropping out an elliptic body, Mendanha and Cabo Frio Island; C) feeder fissure, Itaúna; D) pluton bottom, Morro dos Gatos.

CONCLUSION

The geologic, lithologic, and petrographic studies of the Morro dos Gatos alkaline intrusive complex, State of Rio de Janeiro, Brazil, lead the authors to the following conclusions:

1. The alkaline intrusive body is present on the western part of the Morro dos Gatos hill in an area of 0.5 km^2. It is made up of the holocrystalline first generation trachyte, plutonic rock with the composition varying from syenite to monzonite, and vent-filling pyroclastic rocks.
2. The main intrusive body is constituted by syenite and monzonite. They contain plagioclase and relatively high contents of mafic minerals. There are phenocryst-like relatively large feldspar crystals whose core is constituted by plagioclase and the border by alkali feldspar. The aegirine-augite is light green in colour, showing notable poikilitic texture with apatite. The apatite abundance is remarkable.
3. The first generation trachyte occurs at the north-western border of the intrusive body forming small intrusive body of 700 x 400 m. At the southern border, it appears as dykes and sills with 0.5 to 3.0 m of width. This rock is porphyritic with alkali feldspar phenocrysts of 4 to 6 mm. The groundmass is holocrystalline and relatively gross.
4. There are crystal welded tuff and composite pyroclastic dyke. They are accompanied by the fine-grained second generation trachyte and form subvolcanic fissures.
5. This intrusive complex was formed by: 1) precursor intrusion of the first generation trachyte; 2) main intrusion of the monzonite; 3) intrusion of the pyroclastic dyke and contemporaneous second generation trachyte. It is considered that the present exposure of the Morro dos Gatos alkaline complex corresponds to the bottom of a pluton.

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