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# Plagioclase crystal size distribution in some tholeiitic mafic dykes in Cabo Frio–Buzios, Rio de Janeiro, Brazil

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A B S T R A C T

Crystal size distribution (CSD) has been constrained in plagioclase in two mafic dykes of the Conchas Beach and one at the Lagoinha Beach in the Cabo Frio–Buzios NE-trending dyke swarm. At contact with the metamorphic basement the texture is fine-grained and microporphyritic and intergranular at the center of the larger dykes. Samples were collected at the margins and at the center of the dykes. The plagioclase average characteristic size ($C$) varies from 0.07 to 0.13 mm at the margins of the narrow dykes and from 0.09 to 0.20 mm at the margins of the larger dyke. At the center of the Lagoinha and Conchas dykes $C$ varies from $0.19 \pm 0.02$ mm and $0.60 \pm 0.07$ mm respectively. The CSDs at the dyke margins are concave-up. At the center of the larger Conchas dyke (8.2 m), the CSD is log-linear, consistent with simple steady-state crystallization pattern. From the mineralogy the plagioclase phenocrysts have a high An content (bytownite–labradorite) than the groundmass grains (labradorite–andesine). At the margins olivine is richer in Fo than at the center, and respectively, pyroxene is richer in Ca. These results indicate that the chilled margin is more mafic than the center suggesting a normal chemical evolution in a cooling magma that ascended upward from depths by Newtonian to pseudoplastic flow. The concave-up CSDs probably depict heterogeneous crystallization rates possibly induced by depressurization during the magma ascent followed by rapid cooling. The log-linear CSD pattern at the center of the Conchas dyke (8.2 m width) is attributed to a higher residence time of the magma which favors the processes of chemical diffusion and textural re-equilibration. From the calculated cooling rates the larger Conchas dyke (8.2 m in width) would be completely crystallized (at ~900 °C) in about 2 years.



## 1. Introduction

Crystal size and its distribution, habit, orientation and how crystals interrelate always characterize igneous rocks. Igneous rock textures depend on magma cooling, crystal nucleation and growth rates and growth (residence) time. Besides Randolph and Larson (1971) who pioneered the development of crystallization models and characteristic crystal size in chemical engineering, Marsh (1988) employed the model of CSD in volcanic systems, and others, for example, Cashman and Marsh (1988), Higgins (1996, 2000, 2006a, 2006b); Marsh (1998); Brugger and Hammer (2010) have applied it in volcanic and metamorphic systems. The CSDs of minerals during the crystallization history in a magma plumbing system could be inferred if the nucleation rate, which defines the number of crystals, and the growth rate, which determines crystal size, and the cooling rates are known. Other important factors include where the crystallization of a mineral begins in the plumbing system involved, the nature of magma flow or rheology in the conduit and the depth of emplacement of the igneous body.

We present in this paper, an investigation of crystal size distributions of plagioclase in three representative dykes in the dyke swarm of Cabo Frio–Buzios (CFB) in Rio de Janeiro, Brazil and to use them to infer the crystallization kinetics (nucleation, growth and cooling rates) in the associated subvolcanic magmatic system. These data from our study of some dykes of CFB are compatible to those of other dykes in literature.

## 2. Geological context

### 2.1. General geology

Intense tholeiitic magmatism accompanied the reactivation of the southeastern part of the Brazilian Platform during the separation of South America from Africa. This magmatism, which attained its peak at 137–127 Ma in the formation of the Parana Flood Basalts (Renne et al., 1996), was accompanied by the emplacement of mafic feeder dykes in the littoral and interior of the Rio de Janeiro state. These dykes trend NE–SW and are 148 to 127 Ma (Deckart et al., 1998; Guedes, 2001) of age.

In Rio de Janeiro, the mafic dykes are concentrated mostly at the southern margin of the coastline (Fig. 1). The NE-trending dykes are

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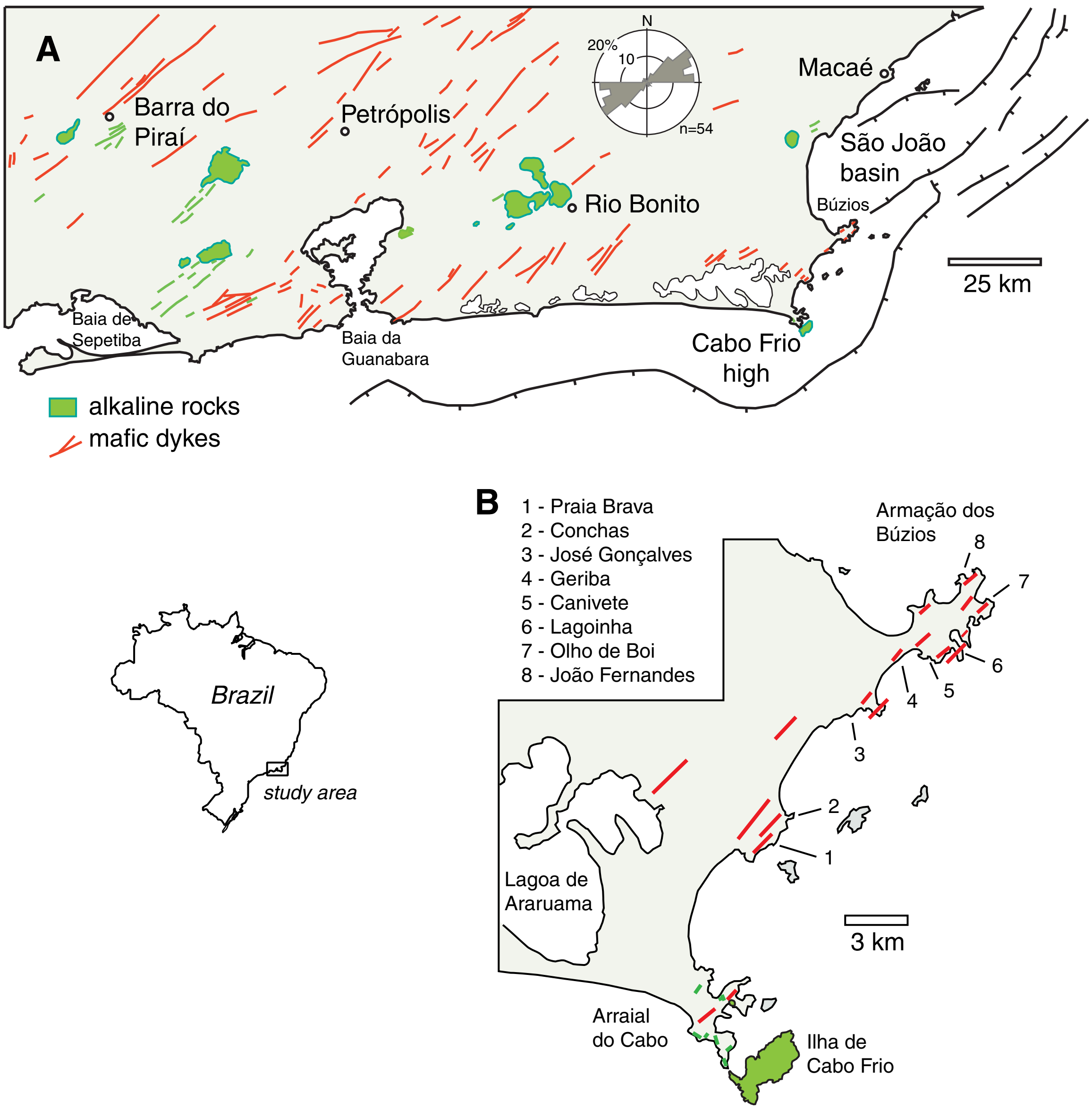


**Fig. 1.** A) Mesozoic magmatism in Rio de Janeiro state. The rose diagram represents the orientation of the dykes; B) a more detailed presentation of the studied dykes. (Map of Brazil shows the studied area)
Modified from Ferrari and Riccomini, 2001.

typically separated from one another by about 15 km. However, a few of the dykes are ENE-, NW-, EW-, or NS-trending. Dyke widths vary from a few meters to a few hundred meters with lengths from a few meters to tens of kilometers. The tholeiitic and alkaline dykes of the state of Rio de Janeiro make up the Dyke Swarm of the Serra do Mar (Valente et al, 1999; Ferrari and Riccomini, 2001; Valente, 2001). The basaltic flows at the base of the sequence are 130 to 120 Ma by K–Ar (Mizusaki and Mohriak, 1993). Age determination by the $^{39}Ar/^{40}Ar$ method by Bennio et al., (2003) show the Cabo Frio dykes to be of Early Eocene (55Ma).

### 2.2. Geology of the studied dykes of Cabo Frio and Buzios

The Cabo Frio–Buzios dyke swarm consists of about 70 igneous bodies having abrupt and defined contacts with the Precambrian gneissic basement. These subvolcanic bodies have an emplacement depth of 4–5 km (Motoki and Sichel, 2008) and are thought to be feeder dykes of Cretaceous basalt flows (Motoki, 1994). A few of the dykes were analyzed for major, trace and rare earth elements (Table 1) and this information has been used to constrain their classification on the Le Bas and Streckeisen (1991) diagram (Fig. 2) and on an AFM plot (Fig. 3). They are quartz tholeiitic basalts (Hyp and Qz normative), with E-MORB affinities (La/Yb<2; Zr/Nb<10; K/Ba<26), probably formed at shallow depth from a high degree (20–25%) of partial melting of spinel lherzolite mixed with a liquid of 10% partial melting of garnet lherzolite (Fig. 4).

## 3. Petrography and mineral chemistry

A total of 24 thin sections from the margins and centers of the three dykes were studied for petrography and mineral chemistry. Microprobe analysis were performed on a JEOL JXA 8600 Superprobe while oxides were analyzed by Scanning Electronic Microscope coupled with an Energy Dispersive Spectroscope (SEM-EDS), at the Institute of Geosciences, University of São Paulo. In the JEOL JXA 8600 apparatus, the accelerating voltage was 15 keV and a beam current of 10 nA and corrections and calibrations were done according to the PROZA programme. The modal compositions of the common minerals in these dykes are given in Table 2 and the representative