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Magmatic processes during the interaction between alkaline mafic-ultramafic rocks and intruding syenites near the Jabaquara Beach, north of the São Sebastião Island, São Paulo, Brazil

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"Da varanda suspensa

De São Sebastião

Entocada por ipomeas

Pés de manga, costela-de-adão

Eu me sentava para ver

Aquele quadro vivo mudar

Vista para a Ilhabela

Éramos a tela impressionista"

Varanda Suspensa - Céu

RESUMO

A mistura de magmas é um processo comum que varia desde a mistura puramente física até a hibridização completa de magmas quimicamente distintos. Algumas das provas típicas de misturas são a presença de enclaves magmáticos e cristais em desequilíbrio, porém a assimilação da rocha encaixante também é um evento relevante com relação à contaminação dentro de uma câmara magmática. Um afloramento costeiro no lado norte da Ilha de São Sebastião (SE Brasil) exibe uma série de blocos e enxames de enclaves de rochas alcalinas máficas-ultramáficas e melasienitos brechados por rochas sieníticas e venulações. O melasienito também contém pequenos enclaves máficos que apresentam contatos corroídos e desintegração. Normalmente, os enclaves máficos estão associados à injeção de um magma básico mais quente em um magma silicático, mas os enclaves aqui descritos são os fragmentos dispersos de uma rocha máfica cumulática mais antiga. Esta característica é incomum nas rochas alcalinas da Plataforma Sul-Americana e seus efeitos sobre a diversidade magmática são mal compreendidos. Esta dissertação mostra que as rochas encaixantes máficas que caíram na câmara reagiram com o magma sienítico saturado em água e suas reações servem como *proxy* para compreender a formação do melasienito. Duas zonas principais de reação foram identificadas com o auxílio da petrografia, da química mineral e dos mapas de composição de raios X: uma borda carregada de clinopiroxênio ao redor do enclave e uma faixa interna rica em biotita. Geotermômetros baseados apenas em minerais sugerem que o magma sienítico quente fundiu parcialmente a borda do enclave e assimilou seus cristais. Conforme o magma esfriava e cristalizava, a fração fluida aumentava. Este fluido potássico mais frio, percolou os enclaves substituindo o anfibólio por biotita. Os resultados sugerem que estes processos também ocorreram quando um pulso de magma sienítico anterior intrudiu e fragmentou o *mush* em cristalização do corpo máfico-ultramáfico, assimilando seus cristais. O clinopiroxênio derivado das rochas máficas reequilibrou com o líquido sienítico, com posterior cristalização de hidratação formando o anfibólio a ~900° C e a biotita a ~700 °C. As reações de assimilação geralmente mascaram e eliminam os processos formadores e a composição original de um material, mas o melasienito estudado ainda preserva evidências de sua formação. Isto pode representar uma janela para a contaminação pela assimilação de rochas encaixantes e a diversificação dos magmas alcalinos.

Palavras-chaves: Brecha magmática, reações de assimilação, contaminação magmática

ABSTRACT

Magma mixing is a common process that ranges from purely physical mingling to complete hybridization of chemically distinct magmas. Some of the typical pieces of evidence for mixing are magmatic enclaves and crystal disequilibria, however, assimilation of wall-rock is also a candidate for contamination of a magma chamber. A coastal outcrop on the northside of the São Sebastião Island (SE Brazil) displays an array of blocks and enclave swarms of alkaline mafic-ultramafic rocks and melasyenite brecciated by syenitic rocks and veinlets. Melasyenite also hosts mafic enclaves that exhibit corroded contact and disintegration. Mafic enclaves are commonly associated with the injection of hot basic magma into silicic magma, but the described enclaves are the dispersed fragments of an older mafic cumulate rock. This feature is unusual in the alkaline rocks of the South American Platform and its effects on magmatic diversity are poorly understood. This dissertation shows that the fallen mafic wall-rock reacted with the water-saturated syenite magma and its reactions serve as proxy to comprehend the formation of the melasyenite. Two main reaction zones were identified with the aid of petrography, mineral chemistry, and X-ray compositional maps, a clinopyroxene-laden seam around the enclave, and its rinds rich with biotite. Mineral-only geothermometers suggest that the hot syenite magma partially melted the border of the enclave and assimilated its crystals. As the magma cooled and crystallized, the fluid fraction increased. This colder, K-rich fluid percolated the enclaves and replaced amphibole with biotite. The results suggest that these processes also occurred when an earlier pulse of syenitic magm intruded and fragmented the crystallizing mush of the mafic-ultramafic body, assimilating its crystals. The mafic-derived clinopyroxene reequilibrated with the syenitic melt, with later hydration crystallization forming amphibole at ~900° C and biotite at ~700 °C. Assimilation reactions commonly mask and eliminate the resulting processes and original composition of a material, but the studied melasyenite still preserve clues of its formation. This may represent a window into contamination by assimilation of country rock and the diversification of alkaline magmas.
Keywords: Magmatic breccia, assimilation reaction, magma contamination

CHAPTER I

I.1 INTRODUCTION

Large wall-rock blocks are not widely recognized in the alkaline rocks of the Serra do Mar and nearby alkaline provinces. This may be due to their generally smaller sizes compared to granitic plutons, erosion-inducing sampling bias, or different methods of wall-rock intrusion. These large blocks are commonly defined as stopped blocks, in association with magmatic stoping. Stoping is an intrusion method that fragments and incorporates wall-rock, displacing the magma upwards, however, the relevance of stoping as an ascension mechanism is still an ongoing debate (e.g. Glazner and Bartley, 2008, 2009; Paterson et al., 2012; Burchardt et al., 2016). While the importance of large xenoliths for magma movement is uncertain, they are still one of the many pieces of evidence that magmatic chambers and plumbing systems are open systems and commonly interact with the crust, proposed to also influence and contaminate the host magma (Farris and Paterson, 2007; Ferreira et al., 2015). Few notable examples are the mafic breccias at the Monte de Trigo Island (Enrich, 2000; Enrich et al., 2009) and Morro de São João (Brotzu et al., 2007) alkaline complexes and the charnockite xenoliths at the Búzios Island complex (Gomes et al., 2017). Recent studies on the northern side of the São Sebastião Island, São Paulo, Brazil, described an outcrop with large and brecciated enclaves of mafic-ultramafic rocks and a large slab of melasyenite enclave (Timich et al., 2019). More interestingly, it was found an unusual melasyenite composed of fragments of mafic rocks in a syenitic host. It was the first registered occurrence of heterogeneous mixing alkaline rock in the southeastern Brazil.

I.2 OBJECTIVES

The objective of this work is to study the interaction between large angular enclaves of alkaline gabbroic and clinopyroxenitic rocks and the alkali feldspar syenites from the Serraria stock located on the headland near the Jabaquara Beach, north of São Sebastião Island (Ilhabela), Sao Paulo State, Brazil. More specifically, this work aims to understand the assimilation processes and the textural and mineralogical changes of both the mafic-ultramafic enclaves and the syenite host, as well as the formation of the melasyenite rock found as a large enclave. The main hypothesis is that the melasyenite was formed in an earlier magmatic mixing with a crystallizing mafic-ultramafic crystal mush and that a later syenitic pulse intruded the cooled mafic-ultramafic complex and melasyenite. To test the main hypothesis it was used:

- Petrographic description of the rock types at the studied outcrop, with their mineralogical composition, texture, structures, occurrence, and position at the outcrop to better constrain what are the main interactions and their relative timings;
- Textural analysis in thin sections, to better understand the crystallization and formation of each phase and eventual reactions, especially at or nearby contact zone between different rock types;
- Detailed textural investigation using a scanning electron microscope to visualize and describe cryptic textures and chemical variations and zonations at the mineral phases;
- Mineral chemical analysis with an electron microprobe analyzer detailed the composition of major minerals in relation to each rock type and texture to grasp possible evolutionary trends and the effects of mineral reactions;
- X-ray compositional mapping of contact zones between rock types helped to decipher medium-scale chemical variation trends in the thin sections, as well as combine texture and mineral compositions to understand the formation and extent of reactions.

I.3 STRUCTURE OF THE DISSERTATION

This dissertation presents a systematic approach to investigating an uncommon magmatic breccia within felsic alkaline rocks at the Serra do Mar Alkaline Province, Brazil, and it comprises four chapters. Chapter I, this current chapter, introduces the location and general problem tackled by the research, its objectives, and how they were planned to solve each question to test the main proposed hypothesis. Chapter II reviews the literature on the large magmatism at the South American Platform during and after the breakup of the Western Gondwana, with the main events of the tholeiitic magmatism of the Paraná-Etendeka Igneous Province and the alkaline-carbonatite magmatism. In this section, the Serra do Mar Alkaline Province is detailed, as the province in which the studied rocks are located, with a special notion of the different magmatic events and their timings. A synthesis of the description of the São Sebastião Island is also present. In concluding the chapter, a description of the methods and software used to analyze the rocks and minerals. Chapter III is presented as the main body of a scientific manuscript to be published in an international journal, with results of petrography, mineral compositions, X-ray compositional mapping, thermometry, and mixing models and tests, that are later discussed to comprehend the formation of the enclaves, their reactions with the host magma, and what are the main processes that formed the melasyenite. The final Chapter IV is the conclusion of the research, synthesizing the results, findings, general remarks and implications, and eventual guides to future research at the studied location or nearby areas.

CHAPTER IV

IV.1 CONCLUSION

The integration of petrographic description and chemical analysis via the electron microprobe allowed the identification and characterization of reaction zones at enclaves of mafic-ultramafic wall-rock by the host syenite. The comparison of mineral texture and composition between the reaction zones and the amphibole-biotite and plagioclase clots at the melasyenite suggested that its formation evolved in a similar manner to the assimilation of the mafic enclaves. The main conclusions of the dissertation can be summarized as follows:

- The Serraria Stock was formed by multiple pulses, with at least two identified at the studied area: the first pulse that intruded the mafic-ultramafic complex and disintegrated, dispersed and assimilated the late-stage formation of its crystal mush as crystal clots; and the second pulse that originated the large blocks and slabs culminating in the brecciation of the enclaves into mosaic breccias;
- Elemental compositional maps are indispensable to analyze and comprehend the magmatic interactions, specially reactions with physically assimilated material;
- Water-saturation in syenitic magma lowered the enclave *solidus* temperature enough to be partially melted. Clinopyroxene crystals at the outer edge were chemically equilibrated and assimilated by the host magma. The same processes occurred with feldspar by transforming the enclave plagioclase into an albite-rich alkali feldspar;
- Cooling and crystallization of the syenitic magma increases fluid fraction. This fluid is enriched with K_2O and its percolation at the enclave replaces the amphibole to biotite, concentrates Fe–Ti oxide minerals, titanite and apatite;
- Melasyenite is composed of crystal clots that are dispersed mafic-ultramafic fragments. Textural and chemical evidence indicate that the assimilated crystals went through similar reactions to that of the mafic enclave;
- Alkaline intermediate rocks at the Serra do Mar Province are commonly considered to be the result of fractional crystallization, but origin or contribution wall-rock assimilation must be assessed.

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