Field Observations, Petrography, and Microstructures of Granite from Abeokuta Southwestern Nigeria

Terenska opažanja, petrografija in mikrostrukture granita iz Abeokuta v jugozahodni Nigeriji

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Abstract in English

The granite of Abeokuta is part of the Older Granite suite of the basement complex of southwestern Nigeria. Field observation has identified the granite as porphyritic in texture, with a preferred alignment of megacrysts of K-feldspar >5 cm that are mostly euhedral to subhedral in shape. K-feldspar megacrysts are predominantly yellowish, but whitish and pinkish colouration has also been observed. The dark grey porphyritic, mafic rock composition occurs as enclaves within the granite, with phenocrysts having a preferred alignment as the enclosing granite. Also, K-feldspar megacrysts show zoning defined by concentric arrangement of inclusions of biotite relative to the crystal faces. Petrographic study shows the following minerals in order of abundance: K-feldspar, biotite, quartz, and plagioclase, with K-feldspar having a microperthitic intergrowth and biotite crystals aligned in a preferred direction. Evidence such as the crystal shape of K-feldspars, preferred alignment of K-feldspar phenocrysts, and concentric crystallographic arrangements of inclusions of biotite in K-feldspar support a magmatic/phenocrystic origin of K-feldspar megacrysts of Abeokuta granite rather than originating by growing in a solid state as porphyroblasts.

Keywords: megacrysts, microperthitic, K-feldspar, zoning, porphyroblasts

Abstract in Povzetek

Abeokutski granit pripada Starejšemu granitu Bazalnega kompleksa v jugozahodni Nigeriji. Glede na terenska opažanja ima granit porfirsko strukturo. Več kot 5 cm veliki evhedralni do subhedralni vtrošniki kalijevih glinencev kažejo usmerjenost. Vtrošniki kalijevih glinencev so večinoma rumenkasto obarvani, čeprav so prisotni tudi beli do rožnati kristali. V granitu se pojavljajo vključki temno sive porfirске mafične kamnine, ki vsebuje fenokristale z enako orientacijo kot jo imajo kristali kalijevih glinencev v okolnem granitu. Vtrošniki kalijevih glinencev nadalje kažejo conarno zgradbo, ki jo določa koncentrična razporeditev vključkov biotita. S petrografsko preiskavo so bili določeni naslednji minerali, naštetih od najpogostejših do najbolj redkih: kalijevi glinenci, biotit, kremen in plagioklazi. Kalijevi glinenci imajo mikropertitsko preraščanje. Kristali biotita so med seboj enako usmerjeni. Oblika kristalov kalijevih glinencev, preferenčna orientacija fenokristalov kalijevih glinencev in koncentrična razporeditev vključkov biotita v kalijevih glinencih so nekatere lastnosti, ki podpirajo magmatski/porfirski izvor vtrošnikov kalijevega glinenca v Abeokutskem granitu in ne porfiroblastično rast iz trdnih raztopin.

Ključnebesede: vtrošniki, mikropertit, kalijev glinenec, conarna rast, porfiroblasti

Introduction

Granite is the most abundant rock in the continental crust. A-type granite is proposed to originate from the fractional crystallization of the upper mantle [1–6]. Abeokuta, the study area, shares a boundary with the sedimentary rocks of the Dahomey Basin. Large crystals of K-feldspar with the preferred alignment typifies the granite of Abeokuta (Figure 1). Arguments have been put forward to suggest the origination of these megacrysts in granite. In some of the literature, it is agreed that phenocrysts are formed through early growth by crystallization from the molten portion of magma [7–11], while the later developing porphyroblasts arise from a water-rich fluid phase usually in the subsolidus environment [12–16]. The current study uses field observations and petrographic

features to determine the origin of K-feldspar megacrysts in the granite of Abeokuta.

Geological Setting

Nigeria is located within the section of Pan-African reactivation 600 + 150 Ma [17, 18] to the east of the West African craton. The older granite suite of Nigeria comprises for the most part tonalitic to granitic calc-alkaline intrusions which were emplaced at a period of about 800–500 Ma ago [19–22]. The Older Granite suite of Nigeria has been described as a high-level, I-type intrusion [23–25]. The phrase ‘Older Granite’ was coined by Falconer [26] to separate the deep-seated, often concordant granites of the Precambrian basement complex of Nigeria from the highly discordant tin-bearing granite which is found in Northern Nigeria. Older Granite is one of the substantial rock units identified in the Precambrian basement complex of Nigeria [27]. Older Granite suites have a wide range of composition that varies

Figure 1: a) Field photograph showing dispersed K-feldspar megacrysts with the preferred alignment from Abeokuta. Megacrysts are subhedral to euhedral b) Hand specimen sample of porphyritic granite from Abeokuta showing a large phenocryst of K-feldspar in a matrix of biotite.

Figure 2: Field photograph showing a xenolith of porphyritic mafic rock within a felsic, porphyritic granite.

from granite through granodiorite, adamellite/quartz monzonite to syenite [27]. The granitic rock of Abeokuta is porphyritic in texture, with phenocrysts of K-feldspar aligned in the preferred direction and thus defining foliation (Figure 1a). Where aligned, the phenocrysts trend in a NW-SE direction on the field. There are quartz-feldspathic veins and pegmatitic veins of different dimensions running through the granite. Xenoliths of porphyritic mafic rock composition exist within the main porphyritic granite (Figure 2). The sizes of phenocrysts observed on the field vary from a few millimeters to about 10.5 cm in length (Figure 3a).

Granite has a greater amount of K-feldspar megacrysts (Figure 3a and 3b) as compared to matrix and can be described as megacryst-dominated. Some K-feldspar megacrysts are zoned (Figures 3c–3h), with inclusions of biotite-defining zonation. The inclusions of biotite are arranged in a concentric pattern along the crystal faces of the zoned megacrysts (Figures 3c, 3e, and 3f). K-feldspar megacrysts vary in colour from yellowish, whitish, and in some cases pinkish colouration. The associated mafic porphyritic rock component also shows zoned crystals of K-feldspars (Figures 3g and 3h). The mafic rock components, which occur as enclaves within the porphyritic granite, have micro-phenocrysts aligned in the same direction as the megacrysts in the porphyritic granite (Figure 4).

Materials and methods

Thin sections of porphyritic granite were prepared at the Department of Geology, Obafemi Awolowo University in Ife, Nigeria. The petrographic study was carried out at the Department of Geosciences, University of Lagos using a polarizing microscope, and optical properties of the minerals were studied under both plane-polarized light (PPL) and cross-polarized light (XPL).

Results

Petrography

The granite comprises the following minerals in order of abundance: K-feldspar, biotite, quartz,

and plagioclase with apatite occurring as an accessory mineral. The crystals of K-feldspar are subhedral to anhedral in shape and occur as phenocrysts in a matrix of quartz and biotite (Figure 5). K-feldspar is poikilitic, having inclusions of biotite (Figure 5a). A cross-hatched twinning is an indication of the presence of microcline, a type of K-feldspar (Figure 5b). The plagioclase feldspar has polysynthetic twinning, also referred to as albite twinning (Figure 5c). Plagioclase shows a high level of albitization (Figure 5c). K-feldspar exhibits perthitic texture (Figures 5d and 5e). Quartz crystals occur as inclusions in phenocrysts of K-feldspar (Figure 5e), and exhibit a symplectic texture between K-feldspar and plagioclase (Figure 5f). Biotite has crystals with a preferred alignment (Figures 5g and 5h).

Discussion

Megacryst K-feldspars are prominent features in Abeokuta granite. For growth of crystals, essential components in the magma must diffuse through the melt to the crystal-melt interface, and also excess or excluded components need to diffuse away from the interface. It has been shown that diffusivities in silicate melts usually reduce in the sequence $\text{Na} \geq \text{K} > \text{Ca} > \text{Al} \gg \text{Si}$ [28, 29]. Therefore, the rate-limiting event necessary for the crystallization of feldspars and quartz is the attainment of the correct percentages of Si:Al available at the crystal-melt margins. To this end, the megacrystic nature of K-feldspars means that the composition of K-feldspar is highly similar to that of the granitic liquid in terms of the major components that diffuse slowly in silicate melts. Other granite-forming minerals do not share this compositional similarity with the granitic liquid. The time at which K-feldspar starts to crystallize also depends on the bulk chemical composition of the magma. More alkalic magmas will naturally precipitate K-feldspar earlier than those of less-K-rich compositions [30]. Difficulty in the nucleation of K-feldspar has been given as the reason why K-feldspar forms megacrysts; once nucleation commences, it grows rapidly, thus a small number of very large crystals is formed [31]. The phenocrysts of the K-feldspars can be termed megacrysts

Figure 3: Field photographs showing: a) megacrysts of K-feldspar, b) subhedral-euhedral megacrysts of K-feldspar, c) zoned crystals with concentric inclusions of biotite, d) zoned crystals of K-feldspar with a core rich in biotite inclusion, e) K-feldspar megacrysts with inclusions of biotite-defining zonation, f) Zoned K-feldspar crystal with inclusions of biotite, g) zoned crystal of K-feldspar in porphyritic mafic rock, h) matrix-dominated porphyritic mafic rock with zoned megacrysts of K-feldspar.

Figure 4: Field photograph showing enclaves of a porphyritic mafic rock component within porphyritic granite. The micro-phenocrysts, megaphenocrysts, and biotite crystals are all aligned in the same direction.

Figure 5: Photomicrographs of porphyritic granite showing a) inclusions of biotite in K-feldspar (Kfs), XPL b) tartan twinning in K-feldspar (Kfs), XPL c) albitization of plagioclase feldspar (Kfs), XPL d) perthitic texture in K-feldspar (Kfs), XPL e) K-feldspar with perthitic intergrowth and inclusions of quartz (Qtz), XPL f) symplectic texture between K-feldspar and plagioclase (Pl), XPL g) biotite (Bt) crystals with a preferred alignment, PPL h) biotite (Bt) and K-feldspar (Kfs) in close association, XPL.

on the basis of their size, which is several times larger than the plagioclase. This might be due to the low rate of nucleation and the rapid growth rate [9, 32]. However, Moore and Sisson [33] have proposed that K-feldspar grows into larger megacrysts than other minerals in granite because of the similarities in the composition of K-feldspar and the granitic components that diffuse slowly in silicate melts. In most zones, a preferred alignment of the K-feldspar megacrysts forms (Figure 1a), defining foliation. Foliated granite has been reported in the members of the Older Granite suite in other parts of the Basement Complex of Nigeria [34, 35, 19, 36]. These foliations in granitoids can form through magmatic flow [37, 38]. The preferred alignment of crystals suggests that the magma attained a high viscosity and could have occurred in the later stage of crystallization for the preferred orientation to be preserved [39]. Zoning is a common feature in the K-feldspar megacrysts (Figures 3c–3h). Dark inclusions of biotite are displayed in internal zones aligned to the outer margins of megacrysts (Figures 3c and 3e). A number of igneous microtextural features, such as simple twinning and concentric arrangements of inclusions, are typical of K-feldspar megacryst of magmatic origin [8, 40, 41]. Microgranite enclaves have also been (Figure 4) derived, which implies that the megacrysts moved as independent crystals suspended in liquid, and therefore did not develop in situ [42]. The elongation of such microgranitoid enclaves (Figure 4), without the presence of plastic contortion of the minerals provides evidence of magmatic flow [38, 43]. The inclusions within the megacrysts are far smaller than their matrix equivalents, and thus show characteristics specific to magmatic growth, which includes zonal alignment (Figures 3c and 3f) and euhedral shape [8]. K-feldspar megacrysts have been interpreted to be early crystallizing phases [16]. Symplectic intergrowth between K-feldspar and plagioclase can be observed in thin section (Figure 5f), which provides us with a clue about the final crystallization process in the granite under study. Symplectic texture has been reported in granitoids from southwestern Nigeria [44]. Symplectic texture in petrology is characterized by the intergrowth of two minerals that crystallized simultaneously [45].

Symplectic intergrowth in granite has been described by different authors across continents [46, 47]. Replacement of plagioclase by K-feldspar (Figure 5c), as described by Collins [48], appears to be a very common phenomenon. Replacement of plagioclase by K-feldspar at low temperatures has been reported [49], but a high temperature alteration of plagioclase to K-feldspar is also possible [49, 50]. For instance, at a temperature of about 25–350°C, plagioclase feldspars are altered to sericite through weathering [51]. Some of the quartz crystals exhibit a wavy form of extinction. There are minor fractures on some K-feldspar megacrysts (Figure 3c) and micro-fractures on K-feldspar crystals (Figure 5b), which are evidences of deformation. The fact that biotite occurs as inclusions in the K-feldspar follows the Bowen reaction series in which the biotite crystallizes first at a higher temperature before the K-feldspar crystallizes at a much lower temperature (Figure 5a). The K-feldspar has many of the other minerals in the rock present as inclusions, which is an indication of the late-stage crystallization of K-feldspar [8]. The alkali feldspar shows flame perthitic to mesoperthitic structure (Figures 5d and 5e). The formation of perthite has been explained to be a replacement-type reaction (Na-K exchange) that takes place between K-feldspar and plagioclase in an environment of low-moderate differential stress usually accompanying rapid cooling [52–56]. The presence of exsolution lamellae (Figures 5d and 5e) could be found in recrystallized K-feldspar formed at hypersolvus temperatures [37, 57]. Several researchers have used microtextures, such as perthite and myrmekite, as tools to investigate the cooling mechanism of rocks [58–61], which can also be linked to exsolution and hydrothermal subsolidus activity.

Conclusion

Observations such as the crystal shape of K-feldspars and concentric crystallographic arrangements of inclusions of biotite in K-feldspar have provided evidence supporting a magmatic/phenocrystic origin for K-feldspar megacrysts in Abeokuta granite rather than

originating while growing in a solid state as in the formation of porphyroblasts. K-feldspar's inclusion of other minerals and the preferred alignment of K-feldspar megacrysts attributed to magmatic flow suggest late crystallization of K-feldspar.

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