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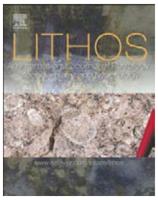

Tracking S-type granite from source to emplacement: Clues from garnet in the Cape Granite Suite

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ABSTRACT

This study investigates, via a pseudosection approach, the conditions of formation of garnet in the leucogranitic to granodioritic S-type Cape Granite Suite (CGS), South Africa. Previous work has stressed the importance of peritectic garnet entrained from the anatectic source in the petrogenesis of these granites. In this study, garnet from S-type granites of the CGS, showing as little evidence for replacement as possible, was studied for major and trace element geochemistry. Surprisingly, the compositions of all the crystals investigated are essentially identical, despite significant differences in the composition of the host granite. The garnet major element compositions are characterised by homogeneous, unzoned core domains with a relatively Mg-rich composition ($Alm_{69-71}Py_{14-21}Gro_3Sps_{3-5}$) surrounded by a more Mn-rich rim, some 200 µm wide ($Alm_{70-76}Py_{5-12}Gro_3Sps_{6-12}$). Trace element compositions are similarly characterised by unzoned cores surrounded by thin rims of relative REE enrichment. Pseudosections calculated for compositions ranging from granite to granodiorite illustrate that garnet is a stable phase in all compositions at high temperatures. Garnet core compositions equilibrated under *P*–*T* conditions of 4 to 6.2 kbars and 740 to 760 °C, whilst the rims record conditions of 2.5 to 5 kbars and 690 to 730 °C. Rare granulite-facies metamafic xenoliths also may record the conditions in the source of the granite magma and provide estimated *P*–*T* condition above 10 ± 2 kbars and 810 ± 54 °C. This estimate overlaps with the *P*–*T* conditions required for fluid-absent biotite melting, the process believed to have produced the CGS magmas within the lower crust. The pseudosections show that garnet was present in the CGS magmas from the source down to near-solidus conditions, but that the composition of peritectic garnet entrained within the source is not preserved in the magma. Calculation of the time required to homogenise garnet compositions within the magma indicates that this cannot occur by diffusion within the garnet crystals, as this would require several orders of magnitude longer than the typical duration of felsic magmatic events. Thus, the findings of this study argue for 1) entrainment of peritectic garnet into melt at the source, 2) the subsequent re-equilibration of this garnet to lower pressure and temperature conditions within the magmatic environment through a dissolution precipitation mechanism, and 3) a near-solidus complete replacement of garnet in some compositions. Collectively, these three processes explain the chemical connectedness between granites and their sources, as well as why the details of the connection have remained so elusive.

1. Introduction

S-type granites result from the melting of aluminous metasediments (metapelites–metapsammites) and are typically strongly peraluminous (Chappell, 1984; Chappell and White, 1992; Chappell, 1999; Collins and Hobbs, 2001; Foden et al., 2002; Clemens, 2003). Some studies (e.g. Chappell et al., 1987; Barbero and Villaseca, 1992), see these granites as the source-contaminated consequence of relatively low temperature anatexis. However, such magmas would be close to water saturated and would remain in the neighbourhood of their source environments because of the shape of the water-saturated granite solidus (Cann, 1970). In addition, as discussed by Clemens and Droop (1998), the negative change in volume associated with melting of this type makes it unlikely that such melts would escape their source. Consequently, granite magmas that intrude at a high level in the crust, or that erupt, are believed to be the products of incongruent fluid-absent melting of biotite in aluminous sources (Le Breton and Thompson, 1988; Clemens, 1992; Vielzeuf and Montel, 1994; Patino-Douce and Beard, 1995; Montel and Vielzeuf, 1997). These reactions always produce garnet and/or cordierite as a peritectic phase, depending principally on pressure and bulk-rock Mg# (e.g. Hensen, 1977). Higher pressures and lower Mg#s favour garnet. Thus most deep crustal melting in typical metapelitic compositions (relatively low Mg#s) produces melt in equilibrium with peritectic garnet. This is reflected in some S-type granites where magma formation appears to involve the selective entrainment of peritectic garnet in the source (Stevens et al., 2007). Melts formed from such sources are thus saturated with garnet in the source and even if they segregate efficiently are likely to be garnet-bearing just below the liquidus. Consequently, the garnet that is

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relatively common in the more mafic varieties of S-type granite may be either magmatic or peritectic in origin. Another possibility is that the garnet is metamorphic and occurs as a restitic remnant from digested source material (Chappell et al., 1987) or from higher level xenoliths (Clarke, 2007; Erdmann et al., 2007). This potential uncertainty around the origin of garnet in S-type granites hampers its use as a tool for unravelling granite petrogenesis. This contrasts strongly with the enormous contribution that studies involving garnet have made toward understanding the petrogenesis of metamorphic rocks.

In metamorphic rocks, garnet has proven very useful in tracking pressure–temperature change in a number of different ways. Garnet is central to partitioning-based geothermometry and geobarometry (e.g. Ferry and Spear, 1978; Newton and Haselton, 1981; Hoisch, 1991). Patterns of garnet zonation are often interpreted to have metamorphic grade and *PT* path trajectory significance (e.g. Ferry and Spear, 1978; Lanzirotti, 1995; Escuder Viruete et al., 2000; Hwang et al., 2003). Assemblages containing garnet commonly have limited ranges of pressure–temperature stability when expressed on pseudosections (Hensen, 1977; Carrington and Harley, 1995; White and Powell, 2002). Such techniques have not commonly been applied to S-type magmatic rocks, possibly because the relatively short time scales of igneous events are considered insufficient to allow for appropriate degrees of equilibration, and possibly because of the difficulties in distinguishing between the different generations of garnet that may occur. The distinction between magmatic and xenocrystic crystals may be based on mineral shape and compositional zoning (Munksgaard, 1985; Dahlquist et al., 2007), or on the presence and the nature of inclusions (e.g. Roycroft, 1991). Thus, the fact that garnet in S-type granites is commonly characterised by flat or inverse bell-shaped Mn zonation patterns (e.g. Dahlquist et al., 2007); that metamorphic mineral inclusions are extremely rare (Clemens and Wall, 1984); and, that inclusions of magmatic crystals occur (Roedder, 1979), would appear to rule out a xenocrystic origin for most examples of garnet in such granites. However, the distinction between garnet of peritectic and magmatic origin is more difficult, as both varieties form in the presence of melt and will present similar characteristics, such as melt inclusions (Cesare et al., 1997). The main difference between peritectic and magmatic crystals lies in the *P*–*T* conditions of formation and the composition of the magmatic system from which the garnet grows. The peritectic generation forms at the discrete *P*–*T* conditions of the granite's source and within the source composition. In contrast, the magmatic generation forms at typically lower *P*–*T* conditions, although, as S-type melts formed by biotite breakdown are almost certainly garnet-saturated in the source (as discussed above), magmatic garnet could potentially form very early in the history of such magmas, and crystallise from the magma composition (e.g. McLaren et al., 2006). Recently, Dahlquist et al. (2007) used garnet zonation patterns to distinguish magmatic from xenocrystic metamorphic garnet in the S-type Peñon Rosado Granite in Argentina. This study successfully applied partitioning-based thermobarometry to determine the *P*–*T* conditions that applied during early stages of crystallization of the granite. Using such an approach, it may be possible to discriminate peritectic garnet from magmatic garnet if the *P*–*T* conditions within the source region are known and if the magmatic garnet crystallization occurred at a pressure sufficiently lower than that of the source to be resolvable.

The S-type granites of the Cape Granite Suite (CGS) in South Africa present an excellent opportunity to study the origin of garnet in such magmas. These granites commonly contain garnet and, in some discrete zones, are garnet-rich. Although the origin of garnet in these granites has not previously been studied, peritectic garnet has been implicated in the petrogenesis of the rocks. Stevens et al. (2007), arguing from the perspective of the major-element geochemistry of the granites compared to that of experimental melt compositions from appropriate sources, proposed that the more mafic CGS S-type granites represent mixtures of melt and up to 20% peritectic garnet (Fig. 1). As is typical for S-type granites, those of the CGS also contain a large population of xenoliths. Xenolith thermobarometry has been used to constrain the thermal structure of the crust through which granitic magmas have intruded (Hacker et al., 2000). Thus, xenoliths from the S-type CGS plutons may provide a minimum estimate of pressure conditions in the magma source area, assuming that peak metamorphic conditions recorded in the crust above the source reflects the metamorphic structure of the crust at the time of melting. The aim of this study is to investigate the origin of the garnet in the S-type granites of the CGS and to model the stability fields of the CGS garnet compositions on relevant pseudosections as a means to further developing our understanding of the petrogenesis of S-type granites. Information on the *P*–*T* conditions of equilibration of the xenoliths may form a useful backdrop to this exercise by potentially providing constraints on the conditions, particularly for pressure, in the magma source.

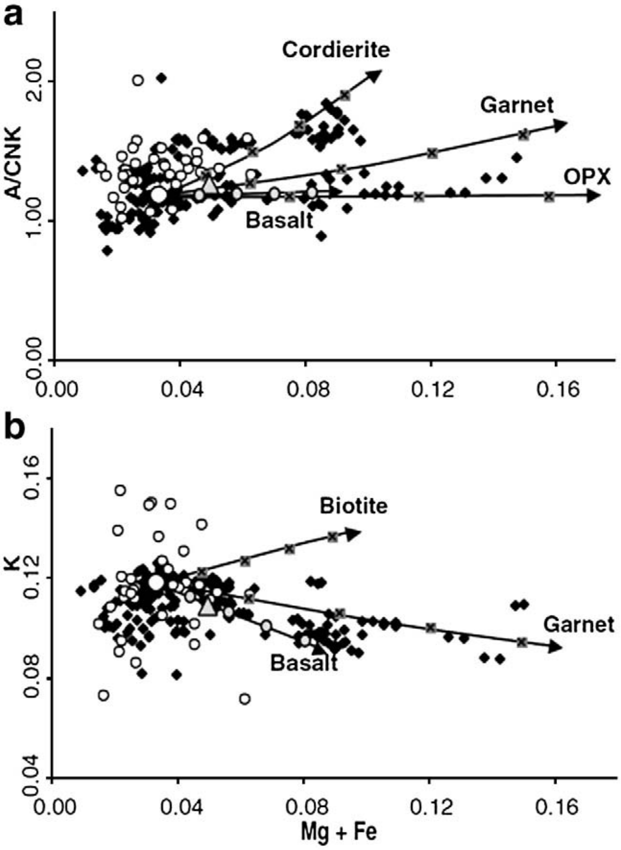

Fig. 1. A comparison of the compositions of experimental glasses (small white circles) and the compositions of Cape Granite Suite S-type rocks (black diamonds) from Scheepers (1990), Scheepers and Poujol (2002), and Scheepers and Armstrong (2002). The gray triangle represents the average of the Cape Granite Suite compositions. The evolution of this composition, as a function of the addition of the labelled mineral and basalt components in 5 wt.% increments, is shown by the evolution of the gray crossed squares away from this proposed melt composition (from Stevens et al., 2007).

2. The garnet-bearing S-type granites of the Cape Granite Suite

The Pan-African Cape Granite Suite (CGS) in the Western Cape province of South Africa comprises mainly S-type (~560 Ma to 530 Ma), and I-type (540 to 520 Ma) plutons, in association with rare A-type intrusions (~515 to 510 Ma). Rare gabbros and late ignimbrites (515 Ma) form a minor component of the suite (Joordan et al., 1995; Armstrong et al., 1998; Scheepers and Nortje, 2000; Scheepers and Armstrong, 2002; Scheepers and Poujol, 2002). The CGS formed in response to the Saldanian Orogeny (~780 to 510 Ma, Rozendaal et al., 1999) which resulted from the convergence of the Kalahari and the Rio de la Plata cratons during Gondwana assembly (Fig. 2a). At the present level of