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Small-scale convection at the interface between stratified layers of mafic and silicic magma, Campbell Ridges, NW Palmer Land, Antarctic Peninsula: syn-magmatic way-up criteria

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Abstract—Experimental data suggest that some igneous mafic inclusions are formed at the interface between underlying mafic magma and more silicic magma in a reservoir by a process of gas exsolution and vesiculation. We report cm-scale plume-like structures exposed over several m^2 at a candidate interface in a large composite pluton from NW Palmer Land, Antarctic Peninsula and suggest that, as well as representing 'frozen' mafic inclusion formation, plume-like structures of this type can be used as way-up criteria and may be of particular value in the interpretation of palaeomagnetic data.

INTRODUCTION

The experimental results of Thomas *et al.* (1993) demonstrated that convective overturn and mixing of dense-underlying-lighter stratified liquids can be driven by the accumulation of a foam-layer at the interface between the two liquids. Thomas *et al.* (1993) argued, after Eichelberger (1980), that a similar situation can exist where hot, volatile-rich mafic magma ponds beneath silicic magma within a reservoir and cools, crystallizing, and exsolving volatiles which accumulate at the interface between the two magmas forming a foam-layer. The rate of accumulation of the foam layer and hence its thickness and behaviour is controlled by the relative viscosities of the two liquids. For viscosity differences which approximate to those which exist in real magmatic systems, Thomas *et al.* (1993) demonstrated that the foam layer becomes gravitationally unstable forming two-phase plumes with cm- to m-scale diameters. In this paper we report cm-scale plume-like structures with a two-phase structure at the interface between subhorizontal basaltic and granitic layers from Campbell Ridges in NW Palmer Land, Antarctic Peninsula (Fig. 1).

REGIONAL SETTING

Campbell Ridges (Fig. 1) comprise Mesozoic igneous and metamorphic rocks of the Antarctic Peninsula magmatic arc (Harrison 1989). A detailed geochronological study of these rocks is in progress, and will be reported elsewhere. The basement of Campbell Ridges is composed of stromatic and strongly migmatised granitic gneiss which has yielded a Triassic U–Pb zircon age (Ian Miller unpublished data). The gneisses were partially melted during a Late Jurassic magmatic event (Harrison & Piercy 1990). The gneiss is cut by Early Jurassic foliated granite, and a weakly deformed, bimodal gabbro–granodiorite suite. Aplite dykes, which cut the gabbro, gave early Cretaceous ages (Ian Millar unpublished data). The granodiorite component of the suite has not been dated, but granodiorite from a similar suite of rocks to the west at Creswick Peaks (Fig. 1) has given a U–Pb zircon age of 141 ± 3 Ma (Vaughan & Millar in press). The intrusives which exhibit synmagmatic structures (below) form part of a large, composite intrusion exposed over several 100 m^2. They have not been dated. Their low degree of deformation suggests that they form part of the Late Jurassic–Early Cretaceous gabbro–granodiorite suite (Vaughan & Millar in press) which shows abundant evidence of mingling between mafic and felsic liquids in NW Palmer Land.

MAGMATIC STRUCTURES

At NE Campbell Ridges (Fig. 1) a weakly foliated, microdiorite body is in contact on its upper surface with a shallowly N-dipping to subhorizontal, 30 cm thick layer of porphyritic microgranodiorite. Within 10 cm of the contact the overlying light grey microgranodiorite exhibits cm-scale, medium to dark grey, plume-like structures composed of fine-grained microdiorite (Fig. 2). In plan these are exposed over several m^2 and form

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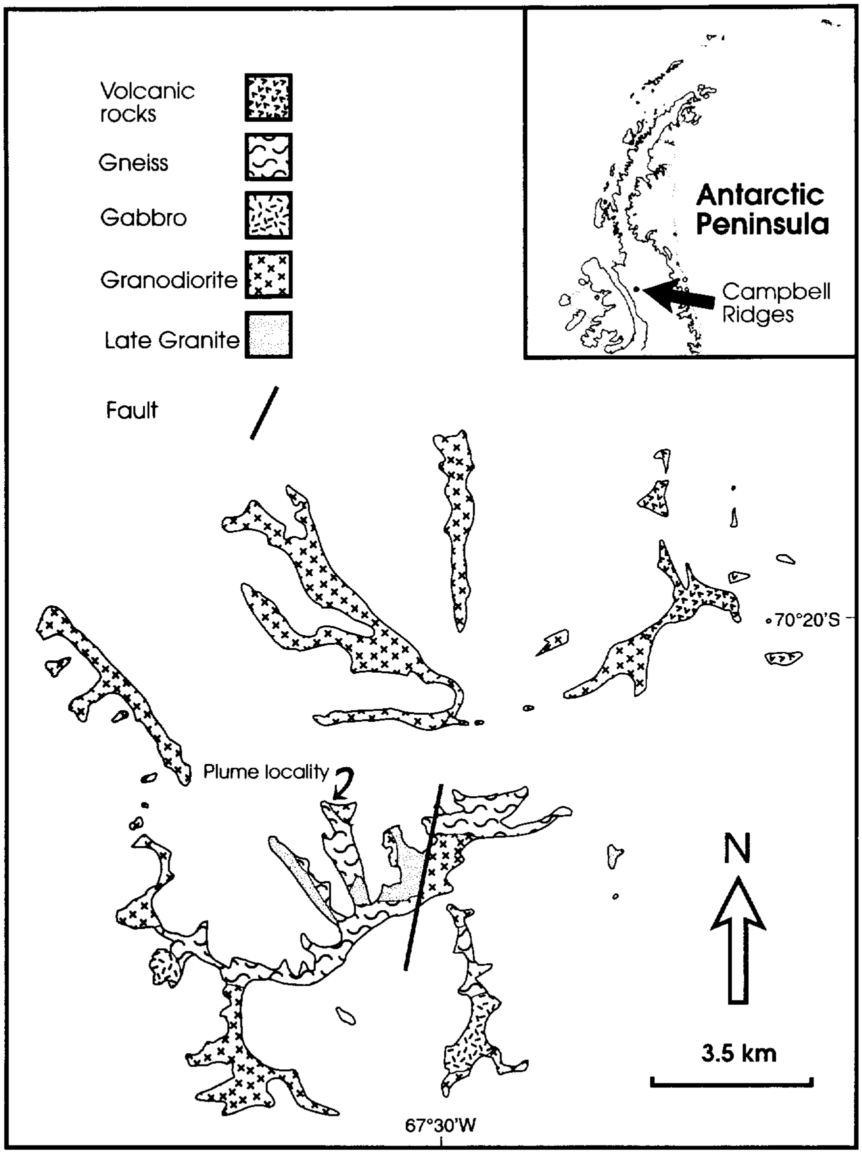

Fig. 1. Location and simplified geology map of Campbell Ridges (modified after Harrison 1989).

medium to dark grey microdiorite patches, with diameters on the cm- to dm-scale, in a net of light grey microgranodiorite (Fig. 3). In section they exhibit long-axes perpendicular to the trend of the microdiorite-microgranodiorite contact (Fig. 4). Although K-feldspar phenocrysts, up to 1 cm maximum dimension, are abundant in the main microgranodiorite, they are sparse or absent in the 10 cm basal zone containing the microdiorite 'plumes'. The contacts between microdiorite 'plumes' and the surrounding microgranodiorite are 'ragged' on a mm-scale, consistent with vesiculation of the magma, although vesicles are not evident. The upper surface of the microgranodiorite sheet, which is also in contact with diorite, exhibits cm-scale, pillow-like structures. The 'pillows' appear to have formed as small-scale diapirs driven by melt buoyancy (Philpotts 1972) rather than gas vesiculation, and are examples of more widely-known gravity instability structures in magma chambers where felsic, and presumably lighter, magma underlies, presumably denser, mafic magma (e.g. de Bremond d'Ars & Davy 1991).

DISCUSSION

The textures outlined above, exhibited by the diorite and granodiorite, suggest that, although microgranodiorite was emplaced slightly earlier than microdiorite, both were liquid simultaneously. The 'plumes' of microdiorite within the microgranodiorite and the paucity of K-feldspar phenocrysts in the lower section of the microgranodiorite sill are consistent with the convectively admixing foam layer model of Thomas *et al.* (1993). The stratiform nature of the intrusions and the 'plume' geometries favour 'plume' emplacement by buoyancy rather than forceful injection. The scale of convection and plume radius is similar to that predicted by Thomas *et al.* (1993) for mixing between fluids with a viscosity ratio of the order of 100. The lack of significant penetration by microdiorite plumes into the assumedly overlying microgranodiorite sheet, and the absence of detached microdiorite enclaves, suggests that the microgranodiorite sheet was behaving semi-plastically and may have partially cooled prior to microdiorite

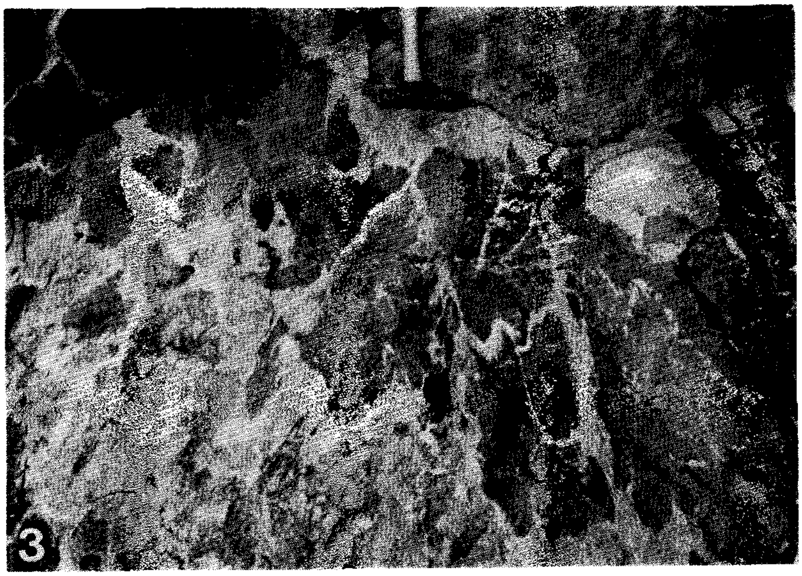

Fig. 2. Plume-like structures (dark) in microgranodiorite layer overlying microdiorite. Hammer-head is *ca*. 20 cm long.

Fig. 3. Exposed contact between microdiorite and microgranodiorite exhibiting a basal section through plume-like structures adjacent to those of Fig. 3. Hammer-head is *ca*. 20 cm long.

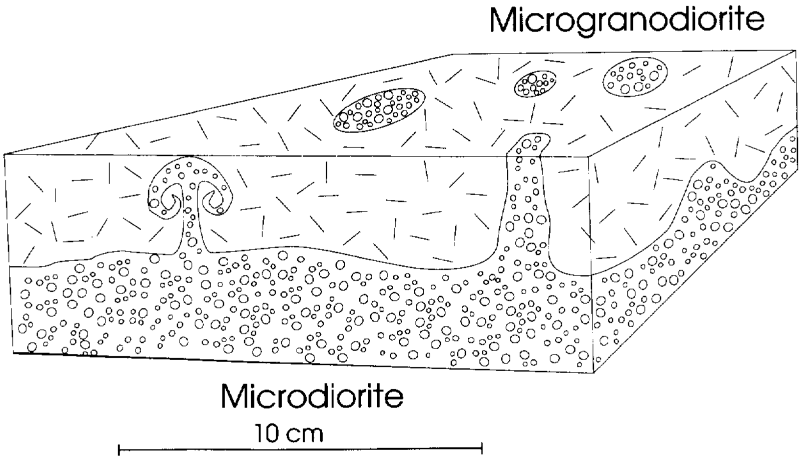

Fig. 4. Block diagram summarizing the relationship between the structures of Fig. 2 and Fig. 3.

emplacement. If, as appears to be the case, the convecting foam layer model of Thomas *et al.* (1993) provides an explanation for the magmatic textures described above, then textures of this type represent geopetal structures and can be used to provide way-up evidence. Evidence of this type is sparse in migmatitic terrains (e.g. Burg 1991) although more abundant in magmatic terrains (de Bremond d'Ars & Davy 1991). These structures also increase the possibility of collecting useful palaeomagnetic data in terrains which are normally intractable.

CONCLUSIONS

(1) Cm-scale, plume-like structures of microdiorite have been identified in microgranodiorite at the contact between microdiorite and overlying microgranodiorite at Campbell Ridges.

(2) The scale and location of these plumes supports a model of a viscosity-controlled, gravitationally-unstable foam layer for their formation.

(3) These plumes provide a means of determining way-up in some magmatic terrains and may be of value in the interpretation of palaeomagnetic data.

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