Contrasting geochemistry of granulite-facies leucosomes and S-type granites: K-feldspar as culprit

D.P. Carrington   *Department of Geology and Geophysics, University of Edinburgh, West Mains Road, Edinburgh EH9 3JW, UK.*

G.R. Watt   *Division of Geology and Cartography, Oxford Brookes University, Gipsy Lane Campus, Headington, Oxford OX3 0BP, UK.*

Introduction. Experimental studies show that vapour-absent melting of fertile pelitic lithologies can generate substantial quantities of water-under-saturated melt (Vielzeuf and Holloway, 1988; Patiño Douce and Johnston, 1991). These findings have led to a model for crustal differentiation that links granulite formation to the generation and extraction of water-undersaturated peraluminous magmas (Stevens and Clemens, 1993; Clemens, 1990; Vielzeuf et al., 1990; Wall et al., 1987). The extraction of an S-type granite melt should give rise to granulites with positive Eu anomalies and depleted incompatible element concentrations (Taylor and McClellan, 1985; Rudnick and Presper, 1990). However, geochemical evidence in support of this is scarce and many metapelitic granulite terranes show non-restitic geochemistry. The geochemical data presented here show that analysed granulite-facies leucosomes have positive Eu anomalies in contrast to the negative Eu anomalies of S-type granites. The experimental data show that K-feldspar can be a reactant during vapour-absent melting under water-poor conditions. Disequilibrium melting of K-feldspar provides a mechanism by which the measured granulite-facies leucosome geochemistries can be explained.

Controls on the behaviour of K-feldspar. K-rich feldspar is enriched in Eu but its role during vapour-absent biotite melting has been unclear. Whilst some experimental studies have shown the K-feldspar to be a product (Bohlen et al., 1983; Le Breton and Thompson, 1988; Vielzeuf and Clemens, 1992), in many others it is a reactant or is not formed (Vielzeuf and Holloway, 1988; Peterson and Newton, 1989; Montana and Brearley, 1989; Patiño Douce and Johnston, 1991; Carrington and Harley, in rev.).

The role of K-feldspar is strongly controlled by the H_2O/K_2O of the melt, which will vary with pressure and temperature. If the melt has a higher H_2O/K_2O than the biotite, then K-feldspar will be produced, but melts with low H_2O/K_2O values will consume K-feldspar (or will not produce K-feldspar, if none is present). New data from a set of experiments on KFMASH-system metapelitic granulites (Carrington and Harley, in rev.) allows conclusions to be drawn about the relative H_2O/K_2O values of the melt and biotite. The melt values are estimated using a mass-balance/point-counting technique cross-referenced against an independent model (Holtz and Johannes, 1994). In the P-T range investigated (850–1000°C, 5.0–12.5 kbar) the maximum molar H_2O/K_2O ratio for the melt, 1.97 ± 0.2, is found on the solidus (900°C) at the highest pressures (see Carrington and Watt, in rev.). This is within uncertainty of the ideal biotite value of 2.0 (indicating near degeneracy), but all lower pressure estimates fall below that for biotite, showing that K-feldspar is a reactant.

The melt phase in the natural system will contain sodium which may reduce the potassium content of the melt. With increasing temperature, the water in biotite is frequently substituted by fluorine. These factors increase the H_2O/K_2O of the melt and, therefore, the likelihood of K-feldspar being a product in a biotite melting reaction in a natural rock. However, the closeness of the synthetic system experiments to degeneracy and the variable character of the natural system means that the role of K-feldspar may well vary from one rock to the next, depending on the bulk composition: of the three published experimental studies using natural rock samples, one produced K-feldspar and two did not.

REE geochemistry of granulite-facies leucosomes. Water-undersaturated partial melting during high-temperature, moderate pressure (6kb, 860°C) granulite-facies metamorphism has produced a suite of migmatitic pelitic gneisses at the Brattsrand Bluffs, eastern Antarctica. Leucosome proportions reach a maximum of 40% in some areas but evidence of melt-producing reactions involving the breakdown of biotite, sillimanite and quartz has been preserved in some metapelitic layers where melting has been less extreme.

The Brattstrand Bluffs leucosomes (BBL) are close to original melt compositions (Watt & Harley, 1993). *REE* patterns in the BBL are characterised by low *LREE* and *HREE* abundances, moderately

fractionated patterns and large positive Eu anomalies. The depletion of *LREE*, Th and Zr was ascribed by Watt & Harley (1993) to melt segregation before equilibration due to restricted dissolution of monazite and zircon in water-undersaturated melts. The high Eu concentrations of monazite (Ward *et al.*, 1992), however, would lead to a depletion of Eu in the melt, even if monazite was retained in the residue. An alternative mechanism, therefore, must control the BBL *REE* patterns: the melting of K-feldspar is proposed.

Low water contents in the BBL are indicated by the restricted dissolution of monazite and zircon, the low water contents of cordierite and comparison with the water-content model of Holtz and Johannes (1994) and potassium contents are high (Watt and Harley, 1993). The experimental data presented above show that low H_2O/K_2O of the melt favours the consumption of K-feldspar during melting and this, therefore, is likely to have occurred in the Brattstrand Bluffs. Furthermore, the undersaturation of Zr and *LREE* in the BBL shows that disequilibrium melting occurred. We suggest, therefore, that the positive Eu anomalies of the BBL arise from disequilibrium melting of an assemblage containing K-feldspar.

Geochemical studies of leucosomes produced by vapour-absent melting are scarce in the literature, but it is interesting to note that, in those found (Barbey *et al.*, 1990; Barbero and Villaseca, 1992), the leucosomes also have positive Eu anomalies. Positive Eu anomalies have also been noted in leucosomes from the Ivrea Zone, although Schnetger (1994) suggests that, because of this aspect of their chemistry, they do not represent true melt compositions.

Leucosomes from amphibolite facies migmatites (e.g. Sevigny *et al.*, 1989; Bea, 1991) show moderately fractionated *REE* patterns with small to large negative Eu anomalies. Negative Eu anomalies in amphibolite facies leucosomes are consistent with water-rich melting of pelitic lithologies (i.e. the *production* of K-feldspar in the restite), where accessory phase dissolution is rapid and equilibration more likely. Batholith-scale S-type granites described in the literature exhibit *REE* patterns with negative Eu anomalies, almost identical to those of amphibolite facies leucosomes. This geochemical affinity between peraluminous granite bodies emplaced in orogenic belts and water-rich leucosomes (amphibolite facies), rather than melts produced under water-poor conditions (granulite facies), implies that granulites may not represent a depleted residue left in the lower crust after extraction of large volumes of peraluminous granitic melt, and that S-type granites may be more readily produced by water-

rich melting under amphibolite facies conditions.

Conclusions. We have presented experimental and geochemical data in an attempt to demonstrate contradictions in current models which link the production of granulite facies metapelites and granitic magmas. The experimental data shows that K-feldspar has alternative roles during the vapour-absent melting of biotite, depending fundamentally on the H_2O/K_2O of the melt relative to biotite: in water-poor environments K-feldspar, if present, will be consumed. Disequilibrium melting of K-feldspar provides a plausible mechanism for the positive Eu anomalies reported from the all the granulite facies leucosomes analysed thus far. This disequilibrium is also manifested by trace-element undersaturation which is ascribed to slow dissolution rates of accessory phases in water-poor melts. In contrast, S-type granites show negative Eu anomalies and trace-element saturation, consistent with K-feldspar being produced during melting in a more water-rich environment. Thus, melts formed during the production of metapelitic granulites are distinctly different from S-type granites and no genetic link should be inferred.

References.

Barbero, L. and Villaseca, C. 1992. *Trans. Roy. Soc. Edin. Earth Sci.*, **83**, 127–38.

Barbey, P., Macaudiere, J. and Nzenti, J. P. 1990. *J. Pet.* 31, 401–27.

Bea, F. 1991. *Geochem. Cosmochim. Acta*, **55**, 1859–74.

Bohlen, S. R., Boettcher, A. L., Wall, V. J. and Clemens, J. D. 1983. *Contrib. Mineral. Petrol.* **83**, 270–77.

Carrington, D.P. and Harley, S.L. 1994. Submitted to *Contrib. Mineral. Petrol.*

Carrington, D.P. and Watt, G.R. 1994. Submitted to *Chem. Geol.*

Clemens, J. D. 1990. In: Vielzeuf, D. & Vidal, Ph. (eds), *Granulites and Crustal Evolution.* Dordrecht: Kluwer Academic Publishers, pp 25–36.

Holtz, F. and Johannes, W. 1994. *Lithos*, **32**, 149–59.

Le Breton, N. and Thompson, A. B. 1988. *Contrib. Mineral. Petrol.*, **99**, 226–37.

Montana, A. and Brearley, M. 1989. *Amer. Mineral.*, **74**, 1–4.

Patiño-Douce A. E. and Johnston A. D. 1991. *Contrib. Mineral. Petrol.*, **107**, 202–18.

Peterson, J. W. and Newton, R. C. 1989. *J. Geol.* **97**, 465–86.

Rudnick, R. L and Presper, T. 1990. In: Vielzeuf, D. & Vidal, Ph. (eds), *Granulites and Crustal evolution.* Dordrecht: Kluwer Academic Publishers, pp 523–50.