MINERALOGICAL MAGAZINE, DECEMBER 1971, VOL. 38, PP. 446–50.

The origin of the granitic sheets and veins in the Loch Coire migmatites, Scotland

P. E. BROWN
Department of Geology, The University, Sheffield 1

SUMMARY. Most of the granitic sheets and veins in the Loch Coire migmatite complex do not have chemical compositions in accordance with a formation by local anatexis. Regional metasomatism by fluids from outside the exposed confines of the complex was an important factor in the development of the sheets and veins, although there was probably some overlap with magmatic conditions.

IN a previous account (Brown, 1967) of the granitic sheets and veins in the Loch Coire migmatite complex, a metasomatic origin was postulated. This has now been confirmed by new analyses.

Read (1931) described the Loch Coire complex as made of three zones; one of unmigmatized meta-sediments, one of granitic veins and one of 'injection' or migmatite. The sheets and veins of granite (*sensu lato*), pegmatite, and aplite, which occur in the zone of veins and in profusion in the zone of migmatite, are a distinctive feature of the complex. They are clearly defined rock bodies distinct from the more intimate admixture of granitic and host-rock material that characterizes the migmatites themselves (the injection and permeation gneisses of Read). Read (1931) described the variety and distribution of the sheets (broadly concordant) and veins (discordant) in detail.

It has been argued (Soper and Brown, 1971) that the migmatite complex was the heat source responsible for the regional metamorphic pattern in Sutherland.

The granitic sheets have considerable variety but a common type is medium-grained, leucocratic, foliated, and between tens of centimetres and several metres thick, being more or less concordant. The internal structure of these sheets, and probably of the majority of foliated sheets, is of regional tectonic origin, as the internal foliation is sometimes parallel to the regional (axial plane) schistosity rather than parallel to the walls of the sheet itself and may contain a weak ESE lineation. The foliation is not of magmatic origin. The mineral assemblage is quartz–oligoclase–potassium-feldspar–biotite–late-muscovite with accessory garnet and more abundant oligoclase than potassium feldspar.

Discordant veins of pegmatite are common in the peripheral parts of the complex and concordant sheets in the interior. These pegmatites have similar dimensions to the granite sheets and are distinct from the diffuse pegmatitic material common in the migmatites. Tightening of the regional ESE folds affected some pegmatites, which are ptygmatically folded or have undergone boudinage. Oligoclase–quartz–biotite pegmatites are dominant but there is wide range in mineralogy and texture, and in some pegmatites potassium feldspar and muscovite are dominant. Garnet is a common accessory.

Aplites, which are not as abundant as the granites and pegmatites, are planar, unfoliated, discordant veins, 10 to 20 cm wide with sharp contacts and have sometimes been definitely emplaced by dilation. The aplites are composed of variable proportions of potassium feldspar, quartz, oligoclase, biotite, and late muscovite, with common accessory garnet.

Quartz veins are particularly conspicuous in the outer part of the zone of veins where, as Read (1931) noted, they succeed and partly overlap a belt of pegmatite veining. Confirmation is also made of Read's (1931, p. 145) broad generalizations that the oligoclase-rich bodies are usually concordant and earlier than the orthoclase-rich ones, which are usually cross-cutting and later and are commoner in the outer part of the complex.

The origin of the sheets and veins. In the forty analysed granitic rocks salic components make between 92 and 99 % of the C.I.P.W. norm and so the omission of micas from the C.I.P.W. norm does not significantly affect any deductions based on the system Or–Ab–An–Qtz.

Kleeman's (1965) provisional phase diagrams for this system at P_{H_2O} up to 10 Kb plus the experimental results of von Platen (1965) and James and Hamilton (1969) have defined the position of the low-temperature trough along which liquids coexist with two feldspars and silica. In the melting of rocks containing two feldspars and quartz the first liquids fall in the trough while the plotting of granites in this low temperature trough is well known and indicates control by liquid–crystal equilibria in their solidification.

If the Loch Coire sheets and veins were magmatic, either as injections or as the products of local anatexis, then the low-temperature trough should have exercised a dominant control over their compositions. Figs. 1 and 2 show that, in general, this is not so, nor do their compositions follow any recognized trend of magmatic differentiation. Temperatures rise steeply away from the low-temperature trough, even assuming $P_{H_2O} = P_{total}$; thus a temperature–pressure regime compatible with the anatectic development and independent injection of such very varied liquids would not exist in the vicinity of the migmatites, which are normal amphibolite-facies rocks. The occurrence of veins and sheets in unmigmatized as well as migmatitic host rocks does, however, show that they were introduced and not developed *in situ* and so if they were not magmatic they must have been metasomatic.

The aqueous vapour that coexists with solid granite 25 °C below the beginning of melting when calculated anhydrous is almost pure silica at low pressure, contains about 75 % silica at 5 Kb, and approaches the composition of granite at 10 Kb (Luth and Tuttle, 1969). The vapour in equilibrium with granite magma 25 °C above the beginning of melting is, at all pressures, not far removed from the composition of the magma but somewhat more sodic. The hydrous vapour carries about 8 % solids at 10 Kb and 6 % at 5 Kb pressure. Movement of these fluids along a pressure gradient would cause metasomatic granitization.

Luth and Tuttle (1969) also demonstrated that with alkali-over-saturated magmas there is a continuum between hydrous magma and hydrothermal fluid, but analyses of the granitic rocks in the migmatite complex, including the large Loch Coire granite itself, contain normative corundum, not excess alkali.

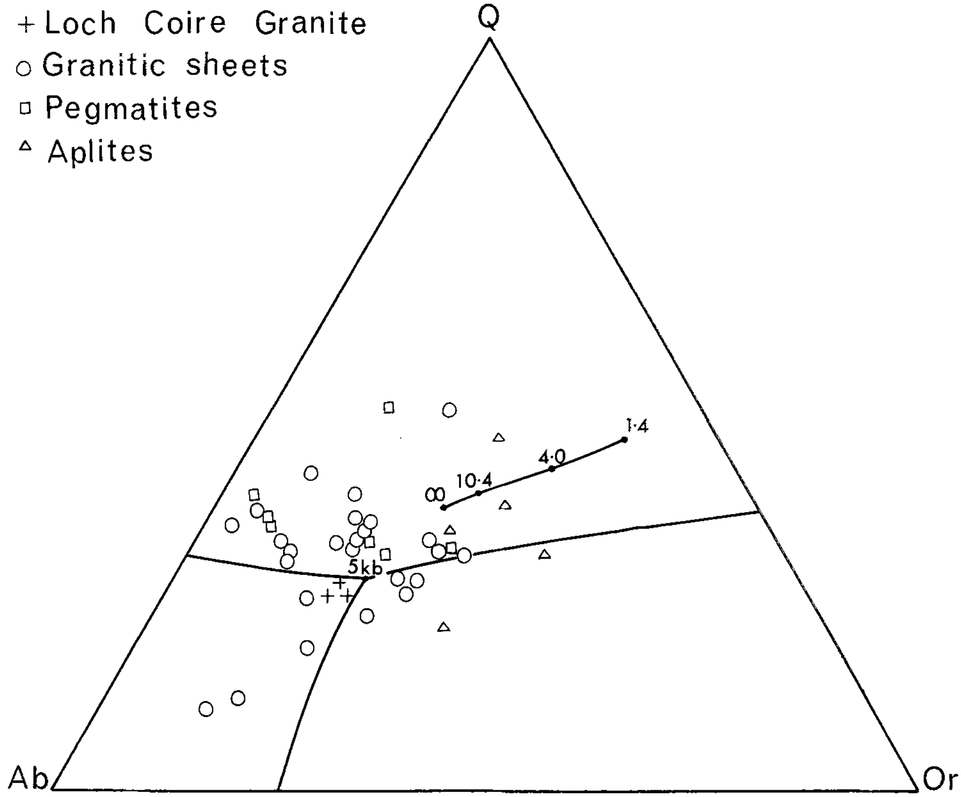

FIG. 1. Normative compositions of 25 granitic sheets, 7 pegmatites, 5 aplites, and the Loch Coire granite, plotted on the Q–Ab–Or face of the tetrahedron Q–Ab–Or–An. Field boundaries and the eutectic at 5 Kb P_{H_2O} (Luth *et al.*, 1964) are shown, also the location of piercing points for the univariant line in the tetrahedral system (at 1 Kb P_{H_2O}), on which the figures indicate Ab/An ratios (James and Hamilton, 1969). The lack of systematic correspondence of the plotted points with compositions produced by partial melting is evident.

The composition and distribution of the Loch Coire sheets and veins can therefore be better accounted for if they were introduced as fluids such as those investigated by Luth and Tuttle rather than if they were magmatic. These fluids probably originated at depth but could be connected with larger granites, such as the Loch Coire granite itself, within the zone of migmatites. The fluids migrated, presumably upwards along a pressure gradient, traversing the strong pre-existing regional foliation and in particular using paths of easy access in pelites and semi-pelites, with which they reacted.

Orville (1963) showed that the alkali ratio in the vapour coexisting with two feldspars varies with temperature and so a thermal gradient will produce a compositional gradient in the alkali ratio in the vapour giving a relative enrichment of the cooler rock in potassium. This could account for the majority of the potassium-rich sheets

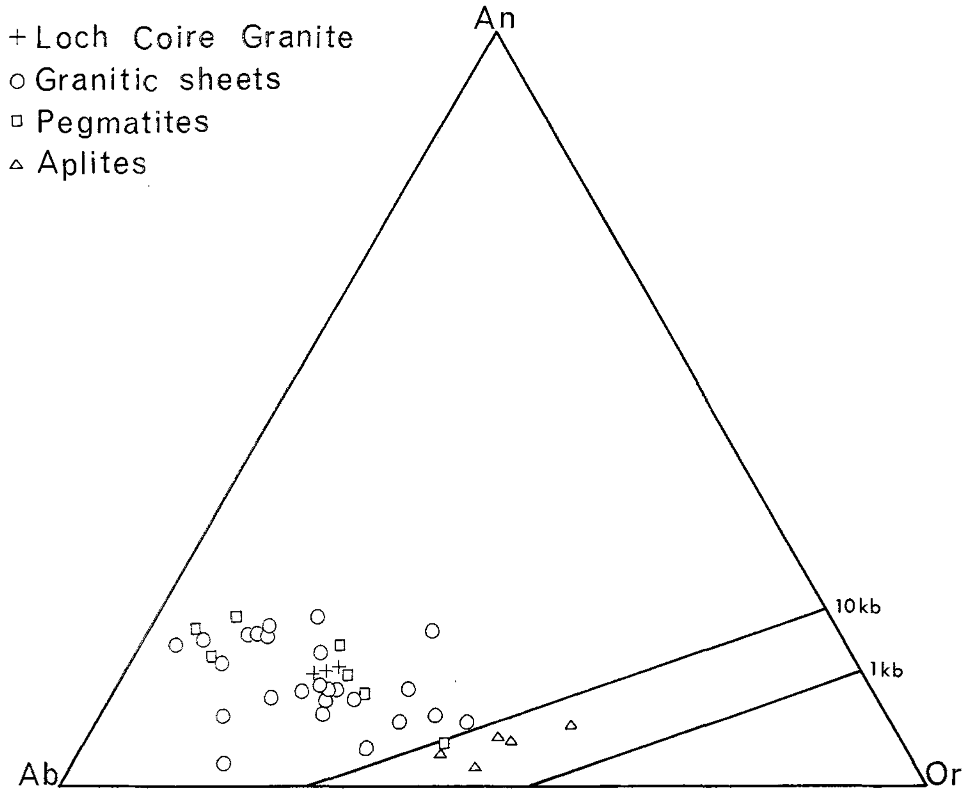

FIG. 2. The same analyses as in fig. 1 plotted on the face Or–Ab–An. The positions of the thermal trough at 10 Kb and 1 Kb (after Kleeman, 1965) are shown. As the points do not plot in a thermal trough at any pressure their compositions cannot be chiefly determined by partial melting.

and veins occurring in the outer, lower temperature, parts of the Loch Coire complex and the almost universal presence of late-stage replacive muscovite in sheets of all compositions. The outer zone of quartz veining is also explicable by a drop in temperature from near magmatic or magmatic temperatures to sub-magmatic levels, which would cause a dramatic increase in silica content of the fluids, particularly at pressures below 5 Kb (Luth and Tuttle, 1969).

Finally, if metasomatism by introduced permeating hydrous fluids was important in developing the granitic sheets and veins then it was probably also important in the genesis of the host 'injection' and 'permeation' gneisses (cf. Brown, 1967).

Acknowledgements. The author thanks Dr. N. J. Soper for discussion and Professors W. S. Pitcher and W. S. MacKenzie for commenting on the manuscript. Financial assistance from the University of Sheffield Research Fund and the skilled analytical services of Mr. V. A Somogyi are gratefully acknowledged.

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[*Manuscript received 28 December 1970.*]