19 Evidence of Fluid Phase Behaviour and Controls in the Intrusive Complex and Its Aureole

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19.1 Introduction

This chapter brings together evidence pertaining to the presence, composition, influence and mobility of fluids rich in volatile species (principally H_2O and CO_2) in the development of the Ballachulish intrusive complex and its aureole. We examine fluid-mineral-rock interactions over the complete range of scales from that of the small-scale systems represented by individual rocks, to that of the large-scale system represented by the combined intrusive complex and its aureole. This will allow comparison with models of fluid behaviour identified in other low- to high-grade metamorphic situations (see reviews in Walther and Wood 1986; and Valley 1986), such as the hydrothermal circulation system of the Hebridean intrusive complexes (Taylor and Forester 1971; Forester and Taylor 1977), and the high fluid-pressure model of regional metamorphism in orogenic belts (Etheridge et al. 1983, 1984).

We shall begin by considering data concerning fluid presence and behaviour on the small scale within individual rocks and lithologies, thereby gathering information for the subsequent consideration of the overall pattern of fluid behaviour in the Ballachulish igneous-metamorphic Complex as a whole. The data we shall summarize is given in detail and illustrated in other chapters in this volume, to which we shall make frequent reference.

For simplicity in this chapter the use of the word fluid will be restricted to volatile-rich (H-C-O) fluids, and will not include melts (very silica-rich fluids) which will be designated separately. The pressure of the fluid phase will be symbolized by P_F, and the pressure on the solid phases, which is expected to be essentially a function of depth of burial or load pressure, will be symbolized by P_L.

Pattison (Chap. 16, this Vol.) shows that the best estimates from the fluid-absent equilibrium garnet + plagioclase + orthopyroxene + quartz are 0.30 to 0.32 GPa, and these estimates are supported by other data from the high-grade pelitic assemblages. A solid pressure (P_L) of 0.3 GPa indicates that at the time of contact metamorphism, the rocks had a depth of burial of approximately 10 km, and we shall use these pressure/depth estimates in the following discussion of fluid behaviour.

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19.5 Conclusions

Considering the evolution of the Ballachulish complex and aureole, we may note the following features with respect to volatile-rich fluids:

1. Fluid developed during late-stages of magmatic crystallization of the quartz diorites and granites with P_F approximately equal to P_L (0.3 GPa).
2. Fluid was generated in the pelites, semi-pelites and calcareous rocks as a consequence of metamorphism leading to devolatilization. Independent evidence from both pelitic and calcareous rocks suggests that P_F was approximately equal to P_L (0.3 GPa).
3. Some parts of the intrusive complex and aureole probably did not contain a fluid phase during their crystallization and metamorphism.
4. The extent of fluid mobility in the calcareous rocks was limited, and internal rock buffering of fluid to high X_{CO_2} values is indicated locally.
5. Partial melting of pelites and semi-pelites in the innermost aureole probably absorbed any locally available H_2O during prograde metamorphism and acted as a barrier to fluid transport between the intrusive complex and the aureole rocks.
6. Retrogressive development of hydrous minerals suggests that the fluid for its occurrence was internally derived (i.e., from within the retrograde rocks themselves), because it is most extensive in igneous rocks and country rocks where melts are expected to have released H_2O on crystallization.
7. Stable isotope data show no evidence of widespread fluid flow between the major lithologies of either the intrusive complex or the aureole or both. No system of hydrothermal fluid circulation was established.
8. There is no evidence of heat transport by fluid flow. Thermal modelling adequately accounts for the T distribution in the aureole by conduction.

The distinctive features of the Ballachulish situation, by comparison with very high-level intrusions showing hydrothermal circulation, and many models of regional metamorphism showing extensive fluid transport, may be accounted for by:

1. A depth of burial of 10 km, which is greater than that possible for maintenance of a system of cracks open to the surface. Thus, $P_F = P_L$, and the circulation of meteoric water was impossible.
2. The intrusive magmas released little volatile-rich fluid during crystallization. Furthermore, some diorites did not develop fully hydrated assemblages in the subsolidus and could act as consumers of available volatiles.

3. The aureole rocks had been metamorphosed and significantly dehydrated during previous regional metamorphism. Thus these rocks had both limited fluid production and restricted permeabilities. Partial melts formed at the peak of metamorphism in the inner aureole would have consumed any available H_2O.
4. The lack of deformation during contact metamorphism led to diminished transient microcracking and therefore permeability.