

COMMENT

THE CENTER POND PLUTON: THE RESTITE OF THE STORY (PHASE SEPARATION AND MELT EVOLUTION IN GRANITOID GENESIS)

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Scambos, Loiselle, and Wones (1986), in a study of the Center Pond pluton (Maine), concluded that its petrogenesis and zoning is principally due to variations in the segregation of melt from restite, with a subordinate contribution by crystal fractionation. They showed that the whole-rock geochemistry and mineral chemistry together are not compatible with a single process of petrogenesis. This led me to examine two aspects of their model: the evidences for the two contributing petrogenetic processes and the far more interesting consideration of the implications in their preferred model.

Firstly, I wish to argue that the evidence for fractionation is unambiguous, while that for the other process is inconclusive, even though it is apparently the dominant factor. The evidence for the role of fractionation includes

1. the parallel compositional variations in plagioclase and whole rock;
2. zoning in plagioclase and zircon crystals;
3. change in biotite-hornblende modal ratio with rock type;
4. changes in Fe:Mg ratios in biotite and hornblende.

Points (3) and (4) may be compatible with restite unmixing if the diorite represents a higher degree of partial melting, although Scambos, Loiselle, and Wones (1986) considered that temperature did not vary greatly across the pluton.

The interpretation of the following geochemical features is more ambiguous:

1. the set of linear trends in the major elements is strong evidence that fractionation is not the dominant process and may indicate either restite-melt unmixing or magma mixing;
2. the uniformity of Sr isotope, and hence source rock, composition may be explicable in terms of magma mixing, if the two magmas were derived from the same source rock, diverged in composition by fractionation in a deep magma chamber, or by a range in degrees of partial melting, and backmixed during ascent and final emplacement. Andrew, Loiselle, and Wones (1986) originally interpreted a moderate range in $\delta^{18}\text{O}$ from the Center Pond pluton as a result of fractionation or magma mixing;
3. in addition to the zoned parts of the larger plagioclase crystals, there is a distinct set of plagioclase analyses (An50–55) that occur as crystal cores in the diorite, granodiorite, and granite (fig. 7 of Scambos, Loiselle, and Wones, 1986). If these are also zoned (not clear in their

paper), these cannot be regarded as restite (Clemens, Wall, and Clarke, 1983; Vernon, 1983). The data of Johannes (1984) indicate that restite plagioclase of An55 would be in equilibrium with a Qz-Or-An-Ab-H₂O melt that would crystallize plagioclase of An5-10. The average plagioclase composition at Center Pond is An20-30 (excluding the An55 cores), and these would grow from a melt in equilibrium with restite plagioclase of An80. These relationships appear to be largely independent of P_{H_2O} where it equals P_{total} . These calcic cores may be better viewed as early phenocrysts or as xenocrysts incorporated by mixing with another magma:

4. Scambos, Loiselle, and Wones (1986) gave no details of the "partially disaggregated mafic xenoliths" and "partially disaggregated mafic clots." Are these one and the same thing? They could indicate a mingling of magmas (Vernon, 1983):

5. Scambos, Loiselle, and Wones (1986) suggest that the biotite and hornblende are restite, and that the variation in their mineral chemistries is due to subsolidus alteration. However, plagioclase has preserved a zonation while other feldspars, microperthitic orthoclase, have been altered.

In summary, then, the major petrogenetic process producing geochemical variation in the Center Pond pluton is very likely to be magma mixing and/or restite unmixing, but the evidence is ambiguous. While there is no sound petrographic evidence for any restite in any of the rock types, the uniformity in Sr isotope composition can be reconciled with magma mixing in only a contrived manner. The evidence is more reliable in showing that fractionation was a factor, albeit minor.

The most interesting aspect of their paper is the implication of their preferred model of restite unmixing. Originally, the degree of restite unmixing was used to explain geochemical variations *between* plutons *within* suites (White and Chappell, 1977), for example in the Moruya Batholith (Griffin, White, and Chappell, 1976). Vernon, Etheridge, and Wall (1983) concluded that magma mixing was an important process in the Tuross Head tonalite, a pluton in the Moruya Batholith. The new idea of Scambos, Loiselle, and Wones (1986) is that the geochemical variation *within a pluton* is due to variations in the degree of unmixing (few of the plutons of the Lachlan Fold Belt are zoned: White and Chappell, 1983), and this is important for consideration of the processes whereby melt and restite segregate. Their model implies that, through time, a more and more completely segregated melt begins ascent and is emplaced. This suggests that the magmas segregated at different stages and maintained their geochemical identities during ascent without remixing. This, in turn, may imply that a magma batch segregates and commences ascent immediately after generation. This is, in fact, the conclusion at which Walker, Stolper, and Hays (1978), Ahern and Turcotte (1979), and McKenzie (1985) arrived with regard to basalt-residual mantle systems. McKenzie (1985), however, found that segregation of a granitic melt by percolation between residual crystals

would be exceedingly slow, due to the melt's high viscosity. Somehow, granitic melts must be able to segregate, ascend, and avoid mixing with geochemically different batches of magma generated at approximately the same place and time. Perhaps fracture systems in the melting terrain are necessary to expedite segregation and to isolate magma batches.

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REPLY:

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We appreciate the review by Dr. Bateman, and, indeed, it outlines similar comments made informally by other readers of Scambos, Loiselle, and Wones (1986). Thus we welcome this opportunity to clarify points the study attempted to make.

Several of the comments may be resolved by a review of the (qualitative) model proposed for the formation of Center Pond. In it, a mass of basic lower crust (dioritic to aluminous gabbroic) partially melts under $P_{H_2O} < P_{tot}$ conditions. At some percentage of melting, the mass becomes gravitationally unstable and begins to rise through the crust. The restite-melt phase separation model we propose would suggest that the melt fraction in the initial migmatitic mass is large enough (perhaps 20–30 percent) to cause loss of grain support, and, because of the high viscosity of the melt, discrete grains (and occasional partially disaggre-

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