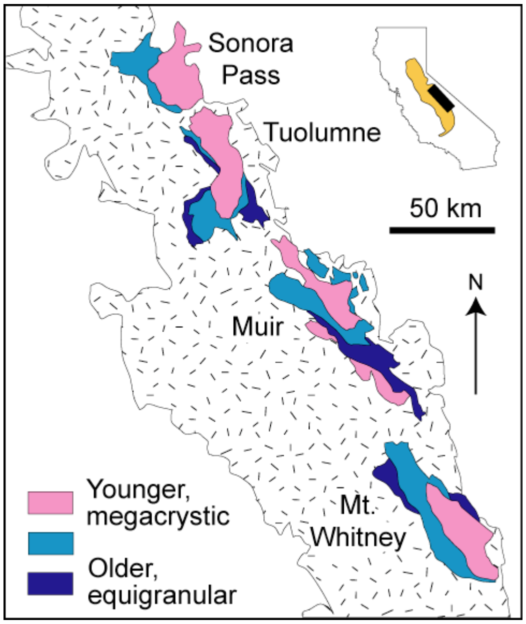
Chemical and Textural Variations in Sierra Nevada Plutonic Suites: Many Kitchens, Same Recipe

Allen F. Glazner[1], Drew S. Coleman[1], John M. Bartley[2], Breck R. Johnson[1]
[1]Dept. of Geological Sciences, University of North Carolina, Chapel Hill, NC USA
[2]Dept. of Geology and Geophysics, Univ. of Utah, Salt Lake City, UT USA

Eroded plutonic terranes provide a view into ancient continental-margin arcs and thus into the processes that link volcanic rocks to melting and fractionation deeper in the lithosphere. Of critical interest to understanding arcs are the processes that produce the observed variety of plutonic rocks. Are plutons largely the solid residues of crystal fractionation and thus complementary to erupted rocks, or are they instead frozen magmas that failed to erupt? In either case, to what degree are plutons modified by late-stage processes? Although zoned intrusive complexes are often interpreted as first-order evidence for the occurrence and preservation of large, fractionating magma chambers, we propose that many owe their geochemical variations to processes operating at the magma source, and their textural variations to processes operating at the level of emplacement. Textural evidence for crystal-liquid separation processes can be misleading because plutonic textures may be strongly modified by late-stage processes.

Five or more zoned intrusive suites comprise the majority of Late Cretaceous plutonism along the crest of the Sierra Nevada batholith in California (Figure). These suites, which are spaced 50-100 km apart and may be the midcrustal roots of major volcanic centers, share remarkable similarities in the timing and sequence of assembly. Similarities include: (1) Each suite is characterized by an early outer intrusion of mafic granodiorite and tonalite, a younger ring of hornblende porphyritic granodiorite, and an inner core of K-feldspar megacrystic granodiorite and granite. (2) Contacts between rock types are typically gradational over tens or hundreds of meters. (3) There is significant overlap in whole-rock composition between texturally distinct units. (4) A growing geochronologic data set demonstrates that the timing of assembly of the suites was remarkably prolonged and consistent; both the Tuolumne and Muir suites were emplaced over ~8 Ma, with the oldest tonalites intruding at 95-93 Ma and the youngest megacrystic granites intruding at 86 Ma. The Whitney suite (work in progress) may follow this pattern as well.



The transition from more mafic, older, outer units to more felsic, younger, inner units led Bateman and Chappell (1979) to propose that rock diversity in the Tuolumne Intrusive Suite (TIS) arose via crystal fractionation, a concept that persists to this day. However, several lines of evidence indicate that crystal fractionation was a minor process in the overall chemical evolution of this suite. First, the ranges of crystallization ages and of isotopic compositions across individual suites eliminate the possibility that the evolved liquids from which the inner plutons grew were derived from early intruded tonalites, and the age range precludes mixing between tonalitic and granitic magmas to generate the variation. Second, Gray (2003) showed that whole-rock chemical variations in the TIS cannot be explained by fractionation of observed mineral phases. Third, the rocks lack geochemical evidence (e.g., Eu anomalies) for significant liquid extraction. We conclude that although some local variability resulted from crystal fractionation, overall chemical variation in the TIS arose below the level of emplacement.

Although pluton textures (such as a feldspar framework suggesting removal of silicic liquid) are commonly used to interpret processes in magma chambers, textures in the TIS have clearly been modified by prolonged late-stage processes. Evidence includes: (1) K-feldspar in all units of the TIS is reset to ~Or_{90} from magmatic compositions closer to Or_{65} (Gray, 2003); (2) the gradational transition from equigranular to K-feldspar megacrystic granodiorite proceeds at constant K-feldspar modal % by concentration of K-feldspar from small crystals into megacrysts; and (3) many rocks contain 3-feldspar assemblages of K-feldspar (Or_{90-99}), albite (An_{1-3}), and oligoclase. Highly potassic K-feldspar compositions and 3-feldspar assemblages that straddle the peristerite solvus suggest equilibration down to temperatures on the order of 400°C.

This evidence for significant re-equilibration of feldspar composition and texture indicates that at least some textural features commonly ascribed to magmatic or structural processes may instead reflect post-magmatic textural maturation. For example, flow imbrication and concentration of megacrysts are unlikely if the megacrysts grew to their present sizes after the magma was largely crystallized, and foliations ascribed to cumulus processes may instead reflect late-stage recrystallization and reorganization. Such processes are increasingly recognized in layered mafic intrusions (e.g., McBirney and Hunter, 1995; Boudreau and McBirney, 1997), and we propose that they may be common in granodiorites.

Textural variation in plutonic rocks thus may prove to be a red herring in understanding their geochemical evolution. Rather than imaging distinct batches of magma, textural variations may instead reflect thermal maturation of the system at the level of emplacement. Early intrusions cool below the solidus relatively quickly and preserve medium-grained, equant textures. As the system evolves thermally, later additions of magma stay above the solidus for longer periods and textures ripen into progressively more porphyritic varieties as crystals evolve to lower-energy shapes. Thus, mapped textural contacts may reflect the complicated interplay between temperature and time rather than boundaries between magma batches.

The presence of several zoned intrusive suites of nearly identical petrography, chemistry, sequence, and age of emplacement demonstrates that the various kitchens for the Sierran arc used remarkably similar recipes and materials. This uniformity appears to include processes both at the magma source, where large-scale compositional zonation arose, and at the emplacement level, where significant textural variation developed.

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Boudreau, A. E., and McBirney, A. R., 1997, The Skaergaard layered series; Part III, Non-dynamic layering: Journal of Petrology, v. 38, p. 1003-1020.

Gray, W. M., 2003, Chemical and thermal evolution of the Late Cretaceous Tuolumne Intrusive Suite, Yosemite National Park, California [Ph.D. thesis]: University of North Carolina, 202 p.

McBirney, A. R., and Hunter, R. H., 1995, The cumulate paradigm reconsidered: Journal of Geology, v. 103, p. 114-122.