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Geochemical variability within "closed system" granites – a consequence of incremental assembly of granite plutons and batholiths

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Documentation of geochemical variation in "closed system" granite plutons and suites

The extent of compositional variation of major, trace and REEs within individual granite plutons or a granite suite as determined from the analysis of whole rock samples is portrayed and evaluated using graphical methods (e.g., variation diagrams, chondrite normalized REEs diagrams). Algebraic methods (e.g., least squares regression, Rayleigh fractionation) are also used to model sample to sample differences in the abundance of any element and evaluate different processes thought to produce geochemical variation during crystallization. This is commonly accomplished by choosing one sample from the suite to represent the original bulk composition of the magma and then incrementally subtracting or adding to this whole rock composition the bulk composition of a set of minerals. The variation trends defined by modeled compositions are compared to the variation trends in the actual data set. The goodness of fit is used to accept or reject the likelihood of the modeled process being significant in producing the actual geochemical variation observed in the data set. For granitic plutons interpreted to have crystallized as "*closed systems*" the geochemical variation present in the data set is commonly attributed to modification of the original bulk composition of the melt/magma by fractional crystallization or restite unmixing, or some combination of these processes. Textures and rock fabrics such as schlieren, accumulations of crystals, aplites etc. can be locally abundant and are used to support an origin for pluton wide geochemical variation being the result of processes such as fractional crystallization.

Fractional crystallization is an engineered outcome

The way in which samples are collected and the popular "mental image" of the physical characteristics of the magma chamber greatly influences the likelihood that fractional crystallization will be considered as the dominant process that produces geochemical variation in closed system granitic intrusions. Major element, trace element, and REEs abundances are determined from "whole rock" samples collected from individual outcrops or quarries that are *widely distributed* throughout the granite pluton. Inherent in modeling the geochemical variation among widely dispersed samples as the result of fractional crystallization (as previously discussed) are two tacit assumptions: 1) all the samples are consanguineous and crystallized from a single initially homogeneous batch of magma and 2) rock compositions record the composition of the melt at some point in the crystallization sequence. This approach, that all rocks within "closed system" granite plutons crystallized from a single batch of magma is a direct outcome of the paradigm of visualizing magma chambers as large subterranean storage facilities, instantaneously filled with melt, and slowly solidifying - thus allowing magmatic processes such as gravitational settling, sidewall accumulation, and filter pressing to produce *pluton wide* geochemical variation as a result of fractional crystallization. Large volume high silica rhyolites require the presence of large volume chambers to host or store felsic magma within the crust prior to eruption. However, the preservation of significant heterogeneity in the initial isotopic composition of granite plutons that crystallized as "closed systems" allow for the possibility of an alternative style of granitic magma chambers in the crust – one in which granitic plutons and batholiths are constructed incrementally over time from emplacement and crystallization of many small discrete batches of magma (Deniel et al., 1987, Hogan and Sinha, 1991). Careful field investigations and the capability for high precision geochronologic studies are documenting the presence of granitic plutons and batholiths constructed incrementally from localized intrusion of multiple batches of granitic magma (Wiebe and Collins 1998, Glazner et al., 2004)

Implications of incremental assembly of granitic plutons and batholiths

The preservation of isotopic heterogeneity in granitic plutons that crystallized as "closed systems" is consistent with their construction from intrusion of discrete batches of melt/magma that coalesce but do not undergo extensive homogenization by vigorous convective mixing during emplacement. For incrementally constructed granite plutons, processes such as fractional crystallization will be physically constrained to operate within the boundaries of individual batches of melt and can produce localized geochemical variations as observed by the presence of schlieren, accumulations of feldspars, and formation of aplite dikes. Consequently, these physical spatial limitations would seem to eliminate fractional crystallization as a viable model to account for mineralogical and compositional variability among samples widely dispersed throughout the pluton. The subtle mineralogical, compositional, and isotopic distinctions that exist between different rock samples more likely reflect geochemical variability that is intrinsic to the broadly similar but unique batch of magma that each rock crystallized from. A more viable explanation of the geochemical and isotopic heterogeneity in "closed system" granitic plutons is that these variations *are inherited from the source region during anatexis* due to variations in P, T, aH_2O, source material mineralogy, composition, and age. Fractional crystallization can produce compositional variation, superimposed upon these intrinsic differences (e.g., initial isotopic heterogeneity) but its effects may be confined to individual batches of magma.

Heterogeneity in the initial isotopic composition of many granites that crystallized as closed systems is inherited from the source region and preserved as a result of the incremental construction of the batholith from the assembly of small batches of magma. In this sense, the isotopic variability commonly present in whole-rock Sr isochrons and "errorchrons" may reflect an intrinsic variability of the source region rather than incomplete resetting due to post-crystallization disturbance. In particular, the initial Pb isotopic composition of individual batches of melt is sensitive to the age(s) and abundance of zircon in the source and the amount of radiogenic Pb that can be incorporated into the melt through dissolution of the zircon (Hogan and Sinha, 1991). Monazite contain in the source region may have a similar effect on producing heterogeneity in the initial Nd isotopic composition of these granites. This isotopic variability has important implications for how the isotopic composition of granite plutons can be applied to define unique source regions and map out the presence of terrane boundaries in the lower crust. The challenge to understanding the true origin of pluton-wide geochemical variation in closed-system granite plutons requires defining the existence, nature, and extent of these discrete batches of magma, the fundamental building units of granite batholiths. Thus the template for geochemical investigations of granite plutons, batholiths, and suites must change.

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