Size and Longevity of Magma Chambers in the Tuolumne Batholith: A Comparison of Thermal Modeling and Cooling Thermochronology

Our field studies on the 1200 km² Tuolumne batholith and the controversy about how this 95–85 Ma composite batholith was constructed, motivated us to evaluate the thermal evolution of volumetrically large magma bodies formed by an amalgamation of a few to many pulses. We use finite difference 1D and 2D models with full spatial heterogeneity of rock properties, fine-scale internal grid spacing that allows for the definition of intricate rock geometries, and small internal time steps for calculations over any time duration. Careful code construction for numerical stability, computational efficiency, and resource management (dynamic memory allocations and CPU parallelization) allows us to model at scales between sub-m to km's for time durations of days to many millions of years. Several types of initial and boundary conditions including thermal gradients and heat flux and the effects of latent heat of fusion are installed. We have modeled a number of chamber construction scenarios. (1) single intrusions of rectangular or elliptical geometry (i.e., sills, dikes, or blobs) emplaced at variable time; (2) A sequence of intrusions emplaced at specified but
arbitrary times or according to a time rate. Shapes in the sequence are fixed or set to randomly vary within a range of dimensions and aspect ratios. (3) A sheeted dike complex can be created wherein the thermal model actually expands according to a growth (extension) rate to accommodate the emplacement of new but thin dikes. Dike width and the time between dikes are coupled based on growth rate; (4) Finally, irregularly shaped bodies from a series of maps or cross-sections can be emplaced into our thermal model and digitally rendered into rock types, which are assigned thermal properties. These mapped shapes are emplaced into the thermal model at specified times so that they represent new thermal pulses. The use of maps or cross-sections allows us to examine the thermal behavior of observed field geometries. This wide range of chamber construction scenarios naturally result in a wide range of length and timescales of magma chambers. But many likely scenarios indicate that the lobes of the Tuolumne batholith will crystallize in less than 500,000 years, whereas large parts of the main chamber stayed above the solidus for 1–3 million years. Both our field studies throughout this batholith and thermochronology (U/Pb zircon, Ar40/Ar39 of hornblende and large and small biotite populations) along three transects support this conclusion.

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