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Growth of complex sheeted zones during recycling of older magmatic units into younger: Sawmill Canyon area, Tuolumne batholith, Sierra Nevada, California

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ABSTRACT

In Sawmill Canyon, located near the eastern margin of the Tuolumne batholith, central Sierra Nevada, California, a series of petrologically and structurally complex, magmatic sheeted zones intrude older granodioritic units (Kuna Crest and equigranular Half Dome) and in one case truncate these units along a sharp contact. These sheeted zones (a) consist of numerous batches of (now frozen) magma, (b) display clear outward growth directions, (c) were actively deforming during and after emplacement resulting in magmatic folds, faults and multiple magmatic mineral fabrics, and (d) are the location of numerous, but localized magma flow structures (schlieren-bounded tubes, troughs, megacryst-rich pipes) and instabilities (load casts, flame structures, slumps, diapirs, ridge and pillar structures). Geochemical data indicate that the sheeted zones largely consist of magmas derived from the Half Dome granodiorite with some late Cathedral Peak granodiorite pulses, and with fractionation and flow sorting forming widespread layering in the above structures.

We interpret these sheeted zones to record the pulsing of magma during propagation and expansion of opening-mode (Mode I), submagmatic fractures at the margins of large blocks of older, fairly solidified magmatic pulses that were subsequently removed from the present crustal level. Elsewhere in the Tuolumne batholith we see similar features suggesting that a "recycling" process, i.e., the breaking off of older parts of the magma chamber and incorporation into younger intrusive units, occurred in this batholith. This recycling removed a significant portion of older units and resulted in the formation of sheeted zones and local instabilities in this batholith. Finally this recycling is one process responsible for transfer of zircon crystals between units and for obscuring whole-rock geochemical signatures.

1. Introduction

There is a large literature debating which physical and chemical processes are important in forming the compositional and structural diversity preserved in granitic plutons (e.g., Hildreth, 1981; McBirney, 1993; Sisson et al., 1996; Bergantz, 2000; Bachl et al., 2001; Jellinek and DePaolo, 2003; Coleman et al., 2004; Barbarin, 2005) and the related volcanic eruptions (Nakada et al., 1994; Bachmann et al., 2002; Bachmann and Bergantz, 2004; Bacon and Lowenstern, 2005; Charlier et al., 2005). Addressing these issues is challenging given that it has been known for many decades that magma chambers may grow incrementally by the addition of a few to numerous pulses of magma and that this growth may be fairly complex (e.g., Pitcher and Berger, 1972; Hardee, 1982; Hutton, 1982; Lagarde et al., 1990; Hutton, 1992; Paterson and Vernon, 1995; McNulty et al., 1996; Vigneresse and Bouchez, 1997; Paterson and Miller, 1998; Wiebe and Collins, 1998; Johnson et al., 1999; Miller and Paterson, 2001; Coleman et al., 2004; Matzel et al., 2005, 2006a; Lipman, 2007; Walker et al., 2007).

Questions raised by the incremental growth of magma chambers include: (1) What is the relative proportion and spatial distribution of melt in the magma chamber through time? (2) What is the role of individual physico-chemical processes in smaller juxtaposed pulses as opposed to in larger magma chambers? (3) To what degree do the above processes lead to early-formed parts of growing plutonic bodies being recycled into younger portions of the active magma chamber? Specifically, (4) over what time and length-scales can such recycling/mixing take place? And (5) how is space made for younger pulses of magma coming into older pulses? The answers to these questions not only affect our understanding of the evolution of magma chambers, but also our understanding of links to the processes driving volcanic eruptions and forming the diversity of volcanic materials resulting from these eruptions (e.g., Hildreth, 2004; Bachmann et al., 2007a; de Silva and Gosnold, 2007; Lipman, 2007).

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The above issues are presently being debated in many magmatic/volcanic systems worldwide. These include the Tuolumne batholith (TB), a large, continental margin arc batholith in the central Sierra Nevada, California (Fig. 1; Frey et al., 1978; Bateman and Chappell, 1979; Kistler et al., 1986; Sisson et al., 1996; Gray, 2003; Coleman et al., 2004; Memeti et al., 2005a; Žák and Paterson, 2005; Burgess, 2006; Miller et al., 2007; Moore and Sisson, 2007; Paterson et al., 2007a,b; Žák et al., 2007). Below we focus on one spectacular domain (Sawmill Canyon near the eastern margin of the batholith; Figs. 2 and 3a) where the consequences of mingling/mixing, fractionation, layer formation, recycling of units, and development of local thermal–mechanical instabilities can be studied in detail. We believe that all these

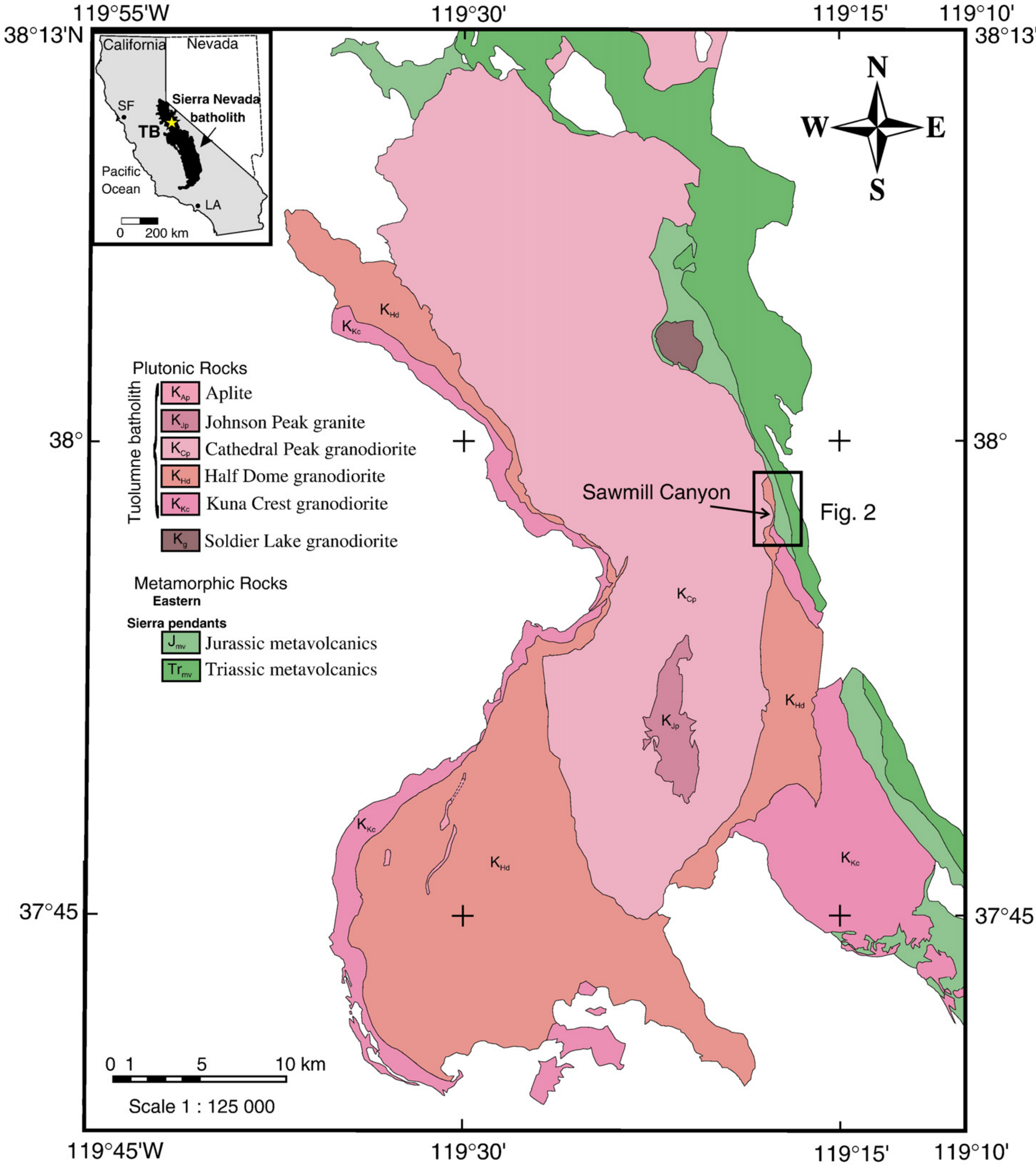

Fig. 1. Simplified geologic map of Tuolumne batholith (Huber et al., 1989). Index map shows location of the Sierra Nevada batholith in California. Box shows location of present study (see Fig. 2).