

Formation of the Sierra Nevada Batholith: Magmatic and Tectonic Processes and Their Tempos

CONVENERS

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OVERVIEW

Fifty-seven geologists from all over the world came together for this week-long GSA Penrose Field Forum in the superbly exposed Sierra Nevada of sunny California to think about magmatic and tectonic processes and their tempos in arcs. These participants have expertise in diverse fields, including field geology, petrology, geochemistry, geo- and thermochronology, structural geology, tectonics and geodynamics. Twenty-one of the attendees were students or post-docs. Several geologists actively working in different parts of the central Sierra Nevada combined efforts to present data from individual intrusions and their host rocks to arc-scale data syntheses collected over the past decade. The goal was to foster cross-disciplinary discussions with the multidisciplinary group of participants so as to provide a better understanding of batholith formation, as well as the significance of important new field, structural, geochronologic, and geochemical databases, and the tectonic controls on the tempo of arc development implied by such.

The field forum started in Oakhurst, in the western foothills of the Sierra Nevada, and worked its way across the arc to Mammoth Lakes, on the east side of the Sierra Nevada, examining different intrusive complexes and/or host rocks each day. On the last day, the arc was traversed again on the return trip from Mammoth Lakes to Oakhurst, where we dedicated our discussions to the synthesis of arc-scale datasets and of observations from prior days.

Each evening participants of the field forum led follow-up group discussions. These discussions were enriched by a number of posters presented by the participants. Two students, Laura Waters at the University of Michigan, and Jesse Hahm from the University of Wyoming, received Best Student Poster awards, which earned them each a trip to the GSA Annual Meeting in Charlotte, North Carolina, USA. Plans are underway to publish the field guide as a GSA Special Paper following this field forum.

DAILY ACTIVITIES

Day 1 was organized by Keith Putirka and Scott Paterson, who kicked off the field forum by presenting outcrops of the Jurassic, 28° tilted, upper crustal Guadalupe Igneous Complex and nearby Hornitos pluton intruding oceanic host rocks of the western foothills of the Sierra Nevada. The Hornitos consists of vertical mafic and felsic dikes, which appear to feed compositionally equivalent magmas into the overlying Guadalupe Igneous Complex (GIC). The GIC is in turn composed of moderately dipping sheets of gabbro and meladorite at its base, which are overlain by a mingled granite and gabbro zone. These lower sheets are capped by layers of granite, granophyre, and rhyolite at the top of the section. Discussions revolved around the geochemical imprint indicating whether a simple fractionation model could explain overall compositional variations, the significance of mingling, lack of true mixing in this bimodal system, and finally, to what extent the GIC is representative of other intrusions in the Sierra Nevada arc. The group also debated whether the temporally related rhyolite was genetically connected to the rest of the intrusive complex.

Day 2 was led by Jade Star Lackey, who introduced various units of the >3300 km² Fine Gold Intrusive Suite (FGIS)—the Bass Lake tonalite being its largest—and some outcrops of the host rock into which the suite intruded. The host rock is only preserved in highly deformed and metamorphosed interplutonic screens, a picture that is commonly seen in the Sierra Nevada arc, which is composed of 80%–90% plutonic material. A prevalent theme on this day was to think about the derivation of the magmas that created this huge composite intrusion and what the plutonic geochemistry implies about the location of “terrane” boundaries (Foothills suture) and the variable recycling of accreted arc terranes versus continental crust in the production of the melts. Also discussed was the issue of how to “map a pluton” using geochronologic data and how to decide what belongs to the same magmatic system given the heterogeneous nature and the more than 19-m.y. magmatic history of the Fine Gold Intrusive Suite.

Day 3 was organized by Jonathan Miller, Bob Miller, and Greg Stock, and was spent examining outcrops of the Yosemite Valley Intrusive Suite, Sentinel granodiorite, and Yosemite Creek granodiorite, which form the western plutonic host rock units of the Tuolumne Intrusive Complex. We started the day with Yosemite National Park geologist Greg Stock, who presented results of detailed mapping on the North American wall of El Capitan in Yosemite Valley in collaboration with Roger Putnam at the University of North Carolina. Their work shows complex mingling between different composition rocks in the El Capitan

granite as well as numerous dikes; Greg also showed results obtained from rockfall studies in Yosemite Valley and the implications these have for safety and park planning operations. The rest of the day was spent looking at different degrees of compositional heterogeneity, particularly in the Sentinel and Yosemite Creek granodiorites. In addition, Jonathan and Bob presented structural, geochemical, and geochronologic results that suggest that these plutons were assembled by multiple increments, which recycled earlier intrusive increments. Production of the high-SiO₂ rocks in the plutons is consistent with late stage fractionation in the presence of titanite. But the question of the time scale of these processes and length scales of heterogeneity were a topic of extensive discussion.

Day 4 was dedicated entirely to the growth and evolution of the Tuolumne Intrusive Complex (TIC). Vali Memeti, Scott Paterson, and Roland Mundil presented data and interpretations on the tectonic context of the complex at the time of intrusion, geochronologic and geochemical patterns from whole rocks and single minerals from the different units, and the magmatic structures observed and their implications for magma chamber processes. The presenters stressed the importance of recycling and mixing of older pulses into younger in the TIC that requires extended areas of magma mush, and the necessity of downward flow of the host rocks (including older intrusive units) during the rise of magmas (vertical material transfer) to “make space” for

subsequent pulses. Other discussions focused on the structural and petrologic importance of local magmatic structures and magmatic fabrics and how these can be used as tools to evaluate the growth and evolution of these magmatic systems.

Day 5 was organized by Scott Paterson, who led the group on a hike along Sawmill Canyon near and into the eastern edge of the TIC. We started at the Triassic base of the arc, which unconformably overlays Paleozoic strata, and hiked up the steeply tilted section of Triassic, Jurassic, and Cretaceous volcanic and sedimentary strata to where the eastern margin of the TIC intrudes and cuts out parts of the Cretaceous and Jurassic sections. The large Steelhead Lake shear zone cuts across this volcanic arc section, exhibiting a more distributed, ductile expression and a younger, narrower, brittle expression, with a number of discrete brittle fault splays with impressive quartz vein breccias and pseudotachylite localities. Participants spent the afternoon looking at an amazing collection of magmatic structures (layering, tubes, troughs, pipes, diapirs, magmatic folds, and faults) in the Sawmill Canyon sheeted complex, a spot where the older Kuna Crest and Half Dome units are abruptly truncated by porphyritic Half Dome and Cathedral Peak magmas.

Day 6 ended the field forum with the conveners presenting large, synthesized datasets collected at the arc scale (e.g., geochronology, geochemistry, structures, strain, emplacement, numerical modeling), plus comparisons of the different intrusive



Participants: From left to right, upper row: John Bartley, Norbert Gajos, Philip Ruprecht, Barry Walker, Chip Leshner, Gareth Davies, Roland Mundil, Ryan Ickert, Ryan Taylor, Jesse Hahm, Calvin Barnes, Adam Kent, Rose Turnbull, Michelle Gevedon, Scott Paterson. Middle row: John Williams, Keith Putirka, Sergio Rocchi, George Bergantz, Bill Leeman, Greg Dunning, David Greene, Moritz Kirsch, Bill Hirt, Mark Brandriss, Monte Marshall, Ian Hagmann, Graham Andrews, Harold Stowell, Karen Parker, Oliver Jagoutz, Jill vanTongeren, John Neil, Bob Hildebrand, Bob Wiebe, David Mustart, Craig Lundstrom, Bob Miller, Ben Clausen, Sam Coleman. Lower row: Giorgio Pennacchioni, Erik Klemetti, Dave Westerman, Chunzeng Wang, Stacy Phillips, Jonathan Miller, Peter Lipman, Laura Waters, Laura Bilenker, Callie Sendek, Claire McLeod, Crystal Hout, Wenrong Cao, Xiaofei Pu, Rebecca Lange. *Not pictured:* Greg Stock, Jade Star Lackey, and Vali Memeti.

suites seen during Days 1–5, in order to discuss arc-scale magmatism and tectonic processes and their tempos in the Sierra Nevada arc. Discussions were carried out at scenic stops at June Lake, Lee Vining Canyon, Olmsted Point, Tenaya Lake, and Yosemite Valley.

In summary, much of what was discussed during the field forum concerned the building and evolution through time of the Sierran arc at scales ranging from parts of individual intrusive suites to a large section of the arc. Also discussed were the connections of these magmatic systems to different melt sources, to the intruded crustal columns, and to the once overlying volcanic section. Comparisons with other ancient and modern arcs were drawn and differences and similarities established. The incremental growth of the Sierra Nevada arc and enclosed magmatic systems emphasized the importance of temporally constrained datasets, and discussions focused on the shape and frequency of the intruding magma pulses, the resulting size and duration of magmatic activity of an individual magma body, and its interconnectedness with the greater magmatic system in both horizontal and vertical dimensions through time.

Participants recognized the variations in the degree of magmatic interaction at the emplacement level in different intrusive suites (e.g., significance of mixing, mingling, magmatic

recycling, and crustal assimilation in the upper crustal GIC versus mid-crustal FGIS or TIC). Episodes of rotations of host rock units to steep dips, regional faulting, and host rock strain during contraction (Triassic) to dextral transpression (Cretaceous) and downward displacement of host rock and magmatic material during the rise of magmas were stressed as an important mechanism of material transfer in the Sierra Nevada. When viewed in 4-D at arc scales, it becomes apparent that these processes in the magmatic bodies and the host rocks are interconnected and undergo temporal patterns or “arc tempos,” creating mutual feedbacks and resulting in a waxing and waning of magmatism and tectonism in the arc. The discussion of the underlying causes of arc tempos had just begun during the latter stages of this field forum, and much remains to be studied. We hope to see you in the field to continue the discussions!

ACKNOWLEDGMENTS

The forum conveners gratefully acknowledge financial support for students and early postdocs from GSA, NSF EAR 1247432, REU funding from the Petrology and Geochemistry panel, and TecTask. Thanks also to the Mineralogy, Geochemistry, Petrology, and Volcanology (MGPV) Division of GSA for providing the two best student poster presentations awards. This report was written by Vali Memeti.

Read more about this trip at <http://geosociety.wordpress.com/2012/10/03/gsa-sierra-nevada-field-forum/>.



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Field Forums are designed to capture the essence of exciting discoveries or controversial topics via forays into the field for *on the spot* discussions of a particular geologic feature or area. This is both an opportunity to get out into the field and to bring together experts on the topic at hand to exchange current knowledge, ideas, and theories. Recent Field Forum locations include Samos, Greece; Northern Owens Valley and the Volcanic Tableland, California, USA; and the Canadian Shield.

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March 2012 Penrose Conference location: Castelvechio Pascoli, Lucca, Italy.