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Magmatic to Solid-State Fabric Transition in a Post-Tectonic Tonalite Pluton

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Principal Investigator: Johnson, Scott E. **Award ID:** 0087661

Organization: University of Maine

Title:

Magmatic to Solid-State Fabric Transition in a Post-Tectonic Tonalite Pluton

Project Participants

Senior Personnel

Name: Johnson, Scott

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Vernon, Ronald

Worked for more than 160 Hours: Yes

Contribution to Project:

Participant under subcontract to the University of Southern California.

Name: Fanning, Mark

Worked for more than 160 Hours: No

Contribution to Project:

Performed SHRIMP U-Pb geochronology at the Australian National University.

Name: Fletcher, John

Worked for more than 160 Hours: No

Contribution to Project:

Collaborator at University in Baja California, Mexico.

Name: Paterson, Scott

Worked for more than 160 Hours: No

Contribution to Project:

Long-term collaborator in Baja studies.

Post-doc

Name: Upton, Phaedra

Worked for more than 160 Hours: No

Contribution to Project:

Phaedra is a postdoctoral fellow at UMaine working with Peter Koons. She became involved owing to her expertise in numerical modeling.

Graduate Student

Name: Melis, Erwin

Worked for more than 160 Hours: Yes

Contribution to Project:

Erwin is one of my PhD students. His thesis project was largely funded by this grant. He intends to finish in 2004.

Name: Gerbi, Christopher

Worked for more than 160 Hours: Yes

Contribution to Project:

Chris is one of my PhD students. Although he is working on a different project for his PhD, with different NSF funding, he became interested in numerical modeling of magma chanber growth - an important topic for the current proposal.

Undergraduate Student

Name: Perry, Ethan

Worked for more than 160 Hours: No

Contribution to Project:

Ethan conducted an undergraduate research project on rocks collected in this project.

Technician, Programmer

Other Participant

Research Experience for Undergraduates

Organizational Partners

University of Southern California

R.H. Vernon at USC was subcontracted under this award.

Other Collaborators or Contacts

Activities and Findings

Research and Education Activities:

The mechanical properties of a magma chamber change during cooling and crystallization, as accommodation of deformation changes from magmatic flow to solid-state processes. To understand the thermo-mechanical evolution of magma chambers, it is crucial to understand the relative importance of magmatic and solid-state flow, and the nature of the transition between them. This project investigated such a transition preserved in the San JosÚ pluton, Baja California, MÚxico. The pluton postdates the regional deformation, and so the transition from magmatic to solid-state flow reflects internal magma-chamber dynamics. Such transitions are rarely observed in post-tectonic plutons. Some specific topics that have been evaluated include: (1) microstructural evidence for fast strain rates during pluton growth; (2) evidence for contact melting and whether it plays a progressively more or less
important role as the volume percent of melt decreases; (3) how rapidly the microstructural transition from melt-dominated to solid-state deformation occurs from the interior of the pluton to its margins; (4) whether solid-state deformation in the pluton margins continued after complete crystallization; (5) changes in deformation mechanisms and fabric-forming processes through time during crystallization; and (6) whether we can track deformation histories
in rocks that have experienced the magmatic to solid-state flow transition.

We have mapped several hundred square kilometers in and around the San Jose pluton, collected hundreds of samples for microstructural and chronological analysis, conducted numerical experiments designed to
explore rates of pluton growth and foliation development during pluton emplacement, conducted electron microprobe analyses of relevant igneous and metamorphic rocks, presented 11 talks/posters at national meetings and published 5 papers in leading journals. We will present additional abstracts at the spring 2004 AGU, and PhD student Erwin Melis will have three chapters of his thesis submitted for publication by the end of 2004.

Findings:

We have made several findings that we believe represent advances in the science. These are listed below in no particular order of importance.

1) We evaluated the emplacement history of the San Jose pluton using what is probably the most detailed data sets of any pluton-emplacement publication (Johnson et al., 2003). We have some of the best evidence ever published that the pluton expanded laterally during emplacement. This opens the question of whether a magma chamber can generate sufficient stress to cause ductile deformation of wall rocks during emplacement - we are currently addressing this problem with 3D thermo/mechanical modeling.

2) We developed a three-dimensional geometric model to quantify host-rock strain rates during dike-fed pluton expansion. Because dikes must maintain a critical width and velocity in order to propagate from source to sink without freezing, they must support a high volumetric magma flow rate. We calculate, for example, that strain rates in a mechanically homogeneous aureole approach 10-7.5 s-1 around 1 km radius spherical plutons filling at 179 m3 s-1 (Gerbi et al., in press).

3) We have 2 papers in press discussing structural evidence for such high strain rates in pluton aureoles (Johnson et al., in press; Vernon et al., in press). These two papers are the first that we are aware of in which natural microstructural observations are used to document brittle deformation at high temperature, melt-enhanced cataclasis, and very fast strain rates during pluton emplacement.

Training and Development:

The project has supported the PhD thesis research of Erwin Melis. Erwin has learned about advanced field mapping techniques, analytical techniques for geochronology and electron microprobe analysis, techniques for microstructural analysis of deformed rocks, and techniques for 2D and 3D thermal modeling. Erwin has also had the opportunity to be a teaching assistant in our department, and has also presented talks and posters at national meetings, and in our department.

Chris Gerbi is another PhD student affected by this project. Chris was responsible for developing numerical models for dike-fed pluton growth, which also introduced him to thermal modeling. Although this is a small part of Chris's thesis work, he has had the opportunity to present a talk on his numerical modeling at a national meeting and in our department, has also had the opportunity to be a TA in our department, and has even taught his own section of introductory geology in our department as a Continuing Education offering.

Ethan Perry is an undergraduate student who learned skills of microstructural analysis and electron microprobe analysis as part of an undergraduate research project that he conducted on rocks collected for this project.

Outreach Activities:

Journal Publications

Johnson, S.E., Fletcher, J.M., Fanning, C.M., Vernon, R.H., Paterson, S.R. and Tate, M.C., "Structure, emplacement and lateral expansion of the San Jose tonalite pluton, Peninsular Ranges batholith, Baja California, Mexico.", Journal of Structural Geology, p. 1933, vol. 25, (2003). Published

Gerbi, C.C., Johnson, S.E. and Paterson, S.R., "Implications of rapid, dike-fed pluton growth for host-rock strain rates and emplacement mechanisms.", Journal of Structural Geology, p. , vol. 26, (2004). Accepted

Johnson, S.E., Vernon, R.H. and Upton, P., "Initiation of microshear zones and progressive strain-rate partitioning in the crystallizing carapace of a tonalite pluton: microstructural evidence and numerical modeling.", Journal of Structural Geology, p. , vol. 26, (2004). Accepted

Vernon, R.H., Johnson, S.E. and Melis, E.A., "Transition from magmatic to solid-state flow in the marginal deformation of an intruding pluton: the San Jose tonalite, Baja California, Mexico.", Journal of Structural Geology, p. , vol. 26, (2004). Accepted

Johnson, S E., Koons, P.O., Upton, P.,, "Transient Dilatancy in the Transport of Magma and Flareup Magmatic Events.", Eos Trans. AGU, p. V41A-08, vol. 86, (2003). Published

Johnson, S.E., Vernon, R.H., Upton, P., Melis, E.A., "Evidence for fast magma chamber construction: the deformed carapace of the San Jose tonalite pluton, Mexico.", Geological Society of America Abstracts, p. 93, vol. 34, (2003). Published

Johnson, S.E., Vernon, R.H., and Upton, P., "Emplacement-related microstructures in the deformed carapace of a tonalite pluton: evidence for fast chamber construction.", Geological Society of America Abstracts, p. 23-8, vol. 35, (2003). Published

Schmidt, K.L., Paterson, S.R. and Johnson, S.E., "The Jurassic eastern Peninsular Ranges batholith in Baja California, Mexico: new ages from an ancient continental arc.", Geological Society of America Abstracts, p. A-97, vol. 34, (2002). Published

Johnson, S.E., Gerbi, C.C. and Paterson, S.R., 2001, "Modeling strain rates around rapidly growing plutons.", Geological Society of America Abstracts, p. A-212, vol. 33, (2001). Published

Melis, E.A. and Johnson, S.E., "Syndeformational melting in Mesozoic tonalites and metapelites from the Sierra San Pedro Martir area, Baja California, Mexico.", Geological Society of America Abstracts, p. A-83, vol. 33, (2001). Published

Melis, E.A. and Johnson, S.E., "Microstructures in the post-tectonic San Jose pluton, baja California, Mexico: Evidence for both magmatic and solid-state deformation and their bearing on pluton emplacement.", Geological Society of America Abstracts, p. A-19, vol. 33, (2001). Published

Albertz, M., Paterson, S.R., Okaya, D. and Johnson, S. E., "Constraints on geological strain rates in contact aureoles during pluton emplacement: insights from thermo-mechanical modeling.", Geological Society of America Abstracts, p. A-172, vol. 32, (2000). Published

Johnson, S. E., Fanning, C.M., Albertz, M. and Paterson, S.R., "Testing pluton growth models: approaches and examples.", Geological Society of America Abstracts, p. A-172, vol. 32, (2000). Published

Johnson, S.E., Schmidt, K.L. and Tate, M.C., "Ring complexes in the Peninsular Ranges Batholith, Baja California, Mexico and southern California, USA: middle- to upper-crustal magma plumbing systems.", Lithos, p. 187, vol. 61, (2002). Published

Books or Other One-time Publications

Web/Internet Site

Other Specific Products

Product Type:

Data or databases

Product Description:

All of the geological field data collected in this project is included in an ongoing GIS-based database for our Baja research.

Sharing Information:

If other researchers wish to have access to this data they are welcome.

Product Type:

Physical collection (samples, etc.)

Product Description:

All samples and thin sections accumulated as part of this project are retained at the University of Maine.

Sharing Information:

Scientists wishing access to these collections are welcome.

Contributions

Contributions within Discipline:

1) The debate continues in the granite/structure communities about whether or not plutons can expand laterally during emplacement. We have published what is probably the most compelling evidence for lateral expansion during the emplacement of a mid-crustal tonalite pluton in Baja California. This raises the interesting question of stresses that can develop within magma chambers in instances where devolatization may not be a viable mechanism.

2) Debate continues regarding the primary mechanism for magma ascent and emplacement in Earth's crust, the two leading hypotheses being diapirism and dike-fed pluton growth. These two models apparently cannot be uniquely tested solely on the basis of structural geometry. In a

publication that led to this proposal (Johnson et al., 2001, Geology, 29, 727-730) I discussed the fact that the rates of these two processes would be markedly different, and quantified the rates at which wall rocks would need to deform during dike-fed pluton growth. This has led to a new geometrical/numerical model for calculating strain rates during the growth of spheroids (Gerbi et al., in press).

3) The marginal rocks of the San Jose pluton have been used to test whether or not microstructures could preserve evidence for very fast strain rates in an instance where lateral pluton expansion was know to occur. Our two papers on this subject (Johnson et al. and Vernon et al., in press) represent landmark studies in the use of microstructures to infer strain rates. They also provide the first real evidence for contact melting and melt-enhanced embrittlement in naturally deformed, melt-bearing rocks.

4) Johnson et al. (in press), mentioned above, makes the case that strain-rate and stress incompatibilities across the interfaces of different minerals can drive brittle deformation leading to ductile foliation development. To explore the physics of this process, I used 3-D mechanical modeling. The model results indicate that strain-rate and stress incompatibilities across biotite-plagioclase interfaces, given reasonable velocity boundary conditions, can be high enough to fracture a plagioclase stress-supporting framework. The finer-grained plagioclase in the fracture zones link with the adjacent biotite grains to set up a self-organizing foliation. This is the first time, to my knowledge, that this has been explored mechanically. The results are consistent with our observations in the margin of the San Jose pluton, and consistent with analog experimental work in two-phase systems.

Contributions to Other Disciplines:

Contributions to Human Resource Development:

This projects has completely supported the PhD studies of Erwin A. Melis (completing in 2004), partially supported the PhD studies of Christopher C. Gerbi (completing in 2004), and provided an undergraduate research project for Ethan Perry (graduated in 2003). In addition to these students, the project has provided research opportunities for Phaedra Upton, who is a postdoctoral researcher working with Peter Koons in our Department.

Contributions to Resources for Research and Education:

This proposal provided partial funding for a field vehicle that is used in our Baja research, and partial funding for research microscopy facilities in our Department.

Contributions Beyond Science and Engineering:

Categories for which nothing is reported:

Activities and Findings: Any Outreach Activities

Any Book

Any Web/Internet Site

Contributions: To Any Other Disciplines

Contributions: To Any Beyond Science and Engineering