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Coupled Deformation and Metamorphism, Fabric Development, Rheological Evolution and Strain Localization

Scott E. Johnson

Principal Investigator; University of Maine, Orono

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Final Report for Period: 01/2009 - 12/2009

Submitted on: 02/07/2010

Principal Investigator: Johnson, Scott E.

Award ID: 0440063

Organization: University of Maine

Submitted By:

Johnson, Scott - Principal Investigator

Title:

Coupled Deformation and Metamorphism, Fabric Development, Rheological Evolution and Strain Localization

Project Participants

Senior Personnel

Name: Johnson, Scott

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Guidotti, Charles

Worked for more than 160 Hours: No

Contribution to Project:

Dr. Charles V. Guidotti passed away during the term of this award.

Post-doc

Graduate Student

Name: Marsh, Jeff

Worked for more than 160 Hours: Yes

Contribution to Project:

Jeff Marsh is a PhD student working with Johnson. Jeff is working on the coupling of chemical and mechanical processes in foliation development, specifically in shear zones. Jeff is supported partly by this grant, and partly by other funding sources.

Name: Thijssen, Felice

Worked for more than 160 Hours: Yes

Contribution to Project:

Felice Thijssen is a PhD student working with Johnson. Felice is working on the coupling of chemical and mechanical processes in foliation development, specifically in pluton aureoles. Felice is supported partly by this grant, and partly by other funding sources.

Undergraduate Student

Name: Lenferink, Hendrik

Worked for more than 160 Hours: Yes

Contribution to Project:

Hendrik is doing an Honors Thesis, through the University of Maine Honors College, and vorticity partitioning in shear zones. His project is partially supported by this award.

Technician, Programmer

Name: Yates, Martin

Worked for more than 160 Hours: Yes

Contribution to Project:

Marty Yates manages the University of Maine electron microprobe laboratory, housed in the Department of Earth Sciences. Marty has been guiding the probe work of Jeff Marsh and Felice Thijssen. Marty has 2 weeks of summer salary from this grant.

Other Participant**Research Experience for Undergraduates****Organizational Partners****Other Collaborators or Contacts**

Senthil Vel is Professor of Mechanical Engineering at the University of Maine. Senthil's expertise is in theoretical continuum mechanics and microstructural modeling of functionally engineered materials. Senthil worked closely with us to develop a modeling methodology for assessing the effects of progressive rock fabric development on evolving crustal seismic anisotropy.

Mark Jessell is a Professor in France and a lead developer of the ELLE microstructural modeling platform. He worked closely with Johnson and students early in the project to develop numerical subroutines to investigate the coupling of chemical and mechanical processes in foliation development.

Mike Williams is a Professor at the University of Massachusetts in Amherst. Mike is the external PhD thesis committee member for student Felice Thijssen and is therefore collaborating on her project.

Donna Whitney is a Professor at the University of Minnesota. Donna is the external PhD thesis committee member for student Jeff Marsh and is therefore collaborating on his project.

Rachel Beane is a Professor at Bowdoin College. Rachel runs an SEM with electron backscatter diffraction, and collaborated early in the project with Felice Thijssen in the analysis of her rocks. We have since acquired our own SEM with EDS/EBSD capabilities so we do our work in house now.

Peter Koons is a Professor at the University of Maine and has expertise in numerical exploration of coupled processes. He is a member of both PhD thesis committees (for Thijssen and Marsh), and is collaborating on their projects.

Dave West is a Professor at Middlebury College. He is the regional expert with respect to shear rocks that PhD student Jeff Marsh is working on in Maine, and has collaborated closely with Jeff on that portion of his dissertation work.

Activities and Findings**Research and Education Activities:**

The PI and other faculty/technical participants have been actively involved in helping the students formulate their thesis/project goals. He has spent a lot of time in the field with the students and worked with them in the microstructural and microprobe analyses among other activities.

Both PhD students (Marsh and Thijssen) have written and defended thesis proposals, have passed their comprehensive examinations, and have advanced to candidacy. Both have spent considerable time reviewing the nature of self organized, complex systems in order to define a framework for examining the coupling of chemical and mechanical processes in foliation development. Both have also spent considerable time on the electron microprobe collecting mineral chemical data, the SEM collecting electron backscatter diffraction data, and on our various workstations developing methodologies for numerical exploration of the coupling.

Both Marsh and Thijssen are expected to graduate in August of 2010. Undergraduate student Lenferink is now pursuing his PhD at MIT.

Findings:

PhD student Marsh is working on two related projects. First, he is working on a deformation gradient from undeformed to mylonitic granitoid that preserves subtle microstructural evidence for how deformation, fluids, and reactions facilitated the fabric transition. The paper was published in 2009 in the Journal of Metamorphic Geology, and is one of only a few papers to carefully address the topic. Marsh's second project is in the Parry Sound shear zone in Ontario, Canada. This work is collaborative with Drs Chris Gerbi (UM) and Nick Culshaw

(Dalhousie). Jeff's focus is on the role of fluids in strain localization, and several papers are either in review or being prepared for submission. PhD student Thijssen is examining evidence for diffusional anisotropy as a function of crystallographic orientation during dissolution-precipitation creep. Thijssen has also made strong progress in the numerical modeling of elastic energy associated with crystallographic preferred orientation of quartz and mica in foliated rocks, with a paper currently in press in the *Journal of Structural Geology*. Thijssen is also involved in a collaboration with Johnson and Senthil Vel in Mechanical Engineering on the effects of fabric development on crustal seismic anisotropy. Several papers that contain important numerical sensitivity analyses are nearly ready for submission for publication.

Training and Development:

The two PhD students are gaining research experience by interacting with the PI and collaborators, and are gaining skills on a range of analytical equipment including our electron microprobe. Both students are incorporating analog and numerical modeling into their thesis projects. Both students have already had the opportunity to TA in our department.

The undergraduate student (Lenferink) wrote a wonderful thesis, is second author on two important publications, and is now doing a PhD at MIT.

Outreach Activities:

In order to provide a sustainable flow of quality outreach material, members of the Geodynamics and Crustal Studies Group at UM have implemented web-based publication of student projects that explore or review fundamental information, concepts and processes in the Earth Sciences. Student response has been very positive, and we are delighted by the process and its positive effect on learning. The following URL shows some of the results to date.

<http://www.geology.um.maine.edu/geodynamics/analogwebsite/>

Our aim with these web-based projects is to develop an education/outreach archive of 'modules'. We know of examples in which our modules have served as a useful resource for earth-science teachers and students at all levels. Our department hosts a yearly workshop for ~50 Maine State teachers, and they have enjoyed exploring Earth processes through our modules, and through hands-on experience in our facilities. We have also received emails from students and teachers at other institutions in the USA and abroad complimenting us on our efforts.

The two PhD students and one undergraduate student associated with this grant have all contributed projects to the analog site above.

Journal Publications

Johnson, S.E., Jin, Z.-H., Naus-Thijssen, F.M.J., Koons, P.O., "Coupled deformation and metamorphism in the roof of a tabular mid-crustal igneous complex", *Bulletin of the Geological Society of America*, p. , vol. , (2010). Submitted,

Johnson, S.E., Dupee, M.E., Guidotti, C.V., "Porphyroblast rotation during crenulation cleavage development: an unequivocal example from the aureole of the Mooselookmeguntic pluton, Maine, USA.", *Journal of Metamorphic Geology*, p. 55, vol. 24, (2006). Published,

Groome, W.G., Koons, P.O., and Johnson, S.E., "Metamorphism, transient mid-crustal rheology, strain localization and the exhumation of high-grade metamorphic rocks.", *Tectonics*, p. , vol. 27, (2008). Published, 10.1029/2006TC001992

Johnson, S.E., Lenferink, H.J., Marsh, J.H., Koons, P.O. and West, D.P., Jr., "Kinematic vorticity analysis and evolving strength of mylonitic shear zones: new data and numerical results.", *Geology*, p. 107, vol. 37, (2009). Published, 10.1130/G30227A.1

Johnson, S.E., "Rotation of porphyroblasts and strain localization: Debate settled!", *Geology*, p. 66, vol. 37, (2009). Published, 10.1130/G25729A.1

Johnson, S.E. and Jin, Z.-H., "Magma extraction from the mantle wedge at convergent margins through single and multiple dikes: A parametric sensitivity analysis.", *Geochemistry, Geophysics, Geosystems*, p. , vol. 10, (2009). Published, 10.1029/2009GC002419

Marsh, J.H., Johnson, S.E. and Yates, M.G., "Coupling of deformation and reactions during mid-crustal shear zone development: an in situ frictional-viscous transition", *Journal of Metamorphic Geology*, p. , vol. 27, (2009). Published, 10.1111/j.1525-1314.2009.00841.x

Johnson, S.E., Lenferink, H.J., Price, N.A., Marsh, J.H., Koons, P.O. West, D.P., Jr., and Beane, R., "Clast-based kinematic vorticity gauges: the effects of slip at matrix/clast interfaces", *Journal of Structural Geology*, p. 1322, vol. 31, (2009). Published, 10.1016/j.jsg.2009.07.008

Johnson, S.E., Marsh, J.H. and Vernon, R.H., "From tonalite to mylonite: coupled mechanical and chemical processes in foliation development and strain localization. In: (Ed.) Declan De Paor, Making Sense of Shear (In honour of Carol Simpson)", Journal of the Virtual Explorer, p. , vol. 30, (2008). Published, 10.3809/jvirtex.2009.00208

Johnson, S.E., "Reply to Comment: Rotation of porphyroblasts and strain localization: Debate settled!", Geology, p. , vol. 38, (2010). Accepted,

Naus-Thijssen, F.M.J., Johnson, S.E. and Koons, P.O., "Modeling crenulation cleavage: a polymineralic approach", Journal of Structural Geology, p. , vol. , (2010). Accepted,

Books or Other One-time Publications

Johnson, S.E., "Numerical investigation of the effects of strain localization on rigid object kinematics.", (2008). Book, Published
Collection: Microdynamics Simulation, Lecture notes in Earth Sciences, Volume 106
Bibliography: Springer

Groome, W.G., Johnson, S.E., "Modeling changes of effective viscosity ratios in metaturbidites during porphyroblast growth.", (2008). Book, Published
Editor(s): Bons, P.D.D., Koehn, D., Jessell, M.W.
Collection: Microdynamics
Simulation, Lecture Notes in Earth Science v. 106
Bibliography: Springer

Web/Internet Site

URL(s):

<http://www.geology.um.maine.edu/geodynamics/analogwebsite/>

Description:

We have implemented web-based publication of student projects that explore or review fundamental information, concepts and processes in the Earth Sciences. The listed URL shows some of the results to date.

Our aim with these web-based projects is to develop an education/outreach archive of learning modules that will serve as a useful resource for earth-science teachers and students at all levels. The students involved in this grant have contributed several projects during the course of their residence.

Other Specific Products

Contributions

Contributions within Discipline:

We are developed new numerical techniques for evaluating coupled strain, diffusion and advection during deformation and metamorphism.

We are developed new techniques for quantifying the rheological effects of metamorphic mineral growth and fabric development in regions of strain localization.

We are developing new techniques for assessing the effects of fabric development on crustal seismic anisotropy.

Contributions to Other Disciplines:

Contributions to Human Resource Development:

This project partly supported the thesis work of 2 PhD students and one undergraduate student.

Contributions to Resources for Research and Education:

In order to contribute to national and international educational and research resources, we have implemented web-based publication of student projects that explore or review fundamental information, concepts and processes in the Earth Sciences. The following URL shows some of the results to date.

<http://www.geology.um.maine.edu/geodynamics/analogwebsite/>

Contributions Beyond Science and Engineering:

Conference Proceedings

Categories for which nothing is reported:

Organizational Partners

Any Product

Contributions: To Any Other Disciplines

Contributions: To Any Beyond Science and Engineering

Any Conference