

9-28-2012

Collaborative Research: Dynamics at the Base of a Pseudotachylyte-bearing Fault System

Scott E. Johnson

Principal Investigator; University of Maine, Orono

Peter O. Koons

Co-Principal Investigator; University of Maine, Orono, peter.koons@maine.edu

Follow this and additional works at: https://digitalcommons.library.umaine.edu/orsp_reports



Part of the [Geophysics and Seismology Commons](#)

Recommended Citation

Johnson, Scott E. and Koons, Peter O., "Collaborative Research: Dynamics at the Base of a Pseudotachylyte-bearing Fault System" (2012). *University of Maine Office of Research and Sponsored Programs: Grant Reports*. 406.
https://digitalcommons.library.umaine.edu/orsp_reports/406

This Open-Access Report is brought to you for free and open access by DigitalCommons@UMaine. It has been accepted for inclusion in University of Maine Office of Research and Sponsored Programs: Grant Reports by an authorized administrator of DigitalCommons@UMaine. For more information, please contact um.library.technical.services@maine.edu.

Final Report for Period: 07/2011 - 06/2012**Submitted on:** 09/28/2012**Principal Investigator:** Johnson, Scott E.**Award ID:** 0810039**Organization:** University of Maine**Submitted By:**

Johnson, Scott - Principal Investigator

Title:

Collaborative Research: Dynamics at the Base of a Pseudotachylyte-bearing Fault System

Project Participants**Senior Personnel****Name:** Johnson, Scott**Worked for more than 160 Hours:** Yes**Contribution to Project:****Name:** Koons, Peter**Worked for more than 160 Hours:** Yes**Contribution to Project:****Name:** West Jr., David**Worked for more than 160 Hours:** Yes**Contribution to Project:**

David West is our primary collaborator on this proposal, having submitted a collaborative proposal (0810033) through Middlebury College.

Post-doc**Graduate Student****Name:** Price, Nancy**Worked for more than 160 Hours:** Yes**Contribution to Project:**

Nancy is a PhD student conducting her dissertation work in the Norumbega Fault System on topics defined in this proposal.

Name: Marsh, Jeffrey**Worked for more than 160 Hours:** No**Contribution to Project:**

Jeff is one of Johnson's PhD students, and he has participated in this project by conducting some preliminary numerical analyses of how the kinematic vorticity number determined from mylonites is affected by strain localization at porphyroclast boundaries.

Name: Roy, Samuel**Worked for more than 160 Hours:** Yes**Contribution to Project:**

Sam is one of Johnson's MS students, and he has participated in this project by conducting some preliminary numerical analyses of the thermal field around faults is affected by transient fluid flow.

Name: Song, Won Joon**Worked for more than 160 Hours:** Yes**Contribution to Project:**

Won Joon is a PhD student working with the PI on EBSD and computational aspects of the project, with special emphasis on the seismic anisotropy of major faults and shear zones.

Name: Frieman, Benjamin

Worked for more than 160 Hours: No

Contribution to Project:

Ben is a graduate student helping with the field and EBSD components of the project.

Undergraduate Student

Name: Lenferink, Hendrik

Worked for more than 160 Hours: Yes

Contribution to Project:

Hendrik completed his Senior Thesis on the topic of kinematic vorticity in these rocks. His work was partly supported by this grant.

Name: Ryan, Patrick

Worked for more than 160 Hours: Yes

Contribution to Project:

Patrick is an undergraduate student helping with sample preparation and EBSD analyses of quartz microstructures

Technician, Programmer

Other Participant

Name: Beane, Rachel

Worked for more than 160 Hours: No

Contribution to Project:

Rachel maintains the SEM-EBSD system at Bowdoin College, which we are making some use of in the early stages of this project. We are installing our own SEM-EBSD system here at UMaine in April of 2009. Rachel is the external member on the PhD student's (Nancy Price) dissertation committee.

Name: Seaman, Sheila

Worked for more than 160 Hours: No

Contribution to Project:

Sheila runs the FTIR lab at the University of Massachusetts, Amherst. The PhD student (Nancy Price) working under this award has developed a collaboration with Sheila in order to characterize the H₂O in the rocks.

Research Experience for Undergraduates

Organizational Partners

Middlebury College

This is a collaborative proposal with Dave West at Middlebury College.

Other Collaborators or Contacts

Activities and Findings

Research and Education Activities:

The PIs and other faculty/technical participants were actively involved in helping the students formulate their thesis/project goals. They spent a lot of time in the field with the students and worked with them in the microstructural, SEM and microprobe analyses among other

activities.

PhD student Nancy Price completed her degree in May, 2012 (Price, 2012). She collected >200 samples over three field seasons and investigated microstructural relationships within these samples. Among other things, she has spent a considerable amount of time completing SEM-EBSD, electron microprobe, CL, XRD, and FTIR work during these investigations. Nancy also co-organized and co-executed a field trip for a New England Intercollegiate Geological field conference and led a collaborative effort to create the field trip guide chapter based in part on her research (Price et al., 2010).

Graduate student Sam Roy conducted some preliminary numerical analyses of how the thermal field around faults is affected by transient fluid flow. He completed his Masters thesis and graduated in May of 2011.

PhD student Won Joon Song is working with the PI on the seismic anisotropy of faults and shear zones. Won Joon is using SEM-EBSD mineral orientation maps of these rocks as input files for some of his numerical models.

Masters student Benjamin Frieman studied kinematic vorticity in the rocks hosting the shear zone using the SEM-EBSD and numerical modeling. He completed his degree in August 2012 (Frieman, 2012) and is now a Ph.D. student at the Colorado School of Mines.

Undergraduate student Hendrik Lenferink completed his undergraduate honors thesis on the topic of kinematic vorticity in these rocks under Johnson's guidance (Lenferink, 2008), and is now pursuing a PhD at MIT.

Findings:

PhD student Nancy Price's work on the Sand Hill Corner shear zone focused on characterizing both the transient, coseismic and long-term, interseismic deformation and the relationships between the two, specifically (1) the transformation of pseudotachylyte into ultramylonite through recrystallization and deformation, and (2) the deformation of mono-mineralic quartz ribbons and interpretation of their complex crystallographic preferred orientation (CPO) patterns.

1. Through her work on pseudotachylyte-derived ultramylonites in the Sandhill Corner shear zone, Nancy (a) documented the mineralogical and microstructural changes associated with recrystallization and deformation of pseudotachylyte and from these observations, compiled a list of criteria for identifying deformed pseudotachylyte. Using her criteria, she proposed that a significant majority (>30%) of the ultramylonite layers within the Sandhill Corner shear zone represent deformed pseudotachylyte. This research is globally significant because it suggests that deformed pseudotachylyte may be more prevalent than previously thought in faults exhumed from the base of the seismogenic zone. This research resulted a peer-reviewed paper (Price et al., 2012).

2. Using c-axis CPO patterns derived from mineral orientation maps of mono-mineralic quartz ribbons collected from within the Sandhill Corner shear zone, Nancy (a) identified and isolated the inherited host rock CPO pattern from the shear zone pole figures, (b) proposed how the pole figures evolved with dextral shearing to transform the host fabric into the complex shear fabrics found (including the role of the host rock fabric in facilitating dynamic recrystallization in quartz), and (c) identified microstructural patterns little-documented in the literature that may have been the result of elevated stresses/strain rates during the transient portion of the seismic cycle. This research is of significance to the microstructure research community because it proposes how transient deformation might affect interseismic quartz fabric development in fault zones, an effect that has until recently been unaddressed. A manuscript based on this research will be submitted for publication within

the next 6 months. Nancy is continuing this work (in collaboration with the PI) beyond her dissertation by correlating transient quartz-filled fractures as imaged with cathodoluminescence with the SEM-EBSD derived mineral orientation maps.

Nancy also built maps showing the spatial distribution of rock type, amount of pseudotachylyte and deformed pseudotachylyte, quartz microstructure, and quartz grain sizes within the Sandhill Corner shear zone. From these maps, Nancy proposed an across-strike architecture of a shear zone core rich in deformed pseudotachylyte, an inner shear zone characterized by the finest quartz new grain sizes, and an outer shear zone, which are comparable to the width to the upper crustal principal slip zone, fault core, and damage zone, respectively. This is one of the few studies where such a detailed view of a shear zone from frictional-to-viscous transition depths has been presented. Nancy will continue to work with the PI to build this work into a manuscript for publication.

In addition to Nancy's dissertation research, undergraduate Hendrik Lenferink and graduate student Ben Frieman have addressed questions of vorticity from rocks collected in and near the Sandhill Corner shear zone. For his undergraduate thesis, Hendrick conducted numerical modeling of lubricated clast rotation across the full range of kinematic vorticity numbers. The implications of this work turned out to be rather large; he showed that the rigid clast rotation method of determining kinematic vorticity is strongly compromised by clast lubrication. Two papers were published from this work (Johnson et al, 2009 a,b).

For his Masters thesis, Ben investigated the rotational component of strain in the shear boundinage of staurolite porphyroblasts in the host rocks of the shear zone using mineral orientation maps and numerical modeling. He found that the mode and distribution of mica minerals affects the rotational behavior of the porphyroblast fragments during shearing. A paper based on this research is in review (Frieman et al., in review).

Training and Development:

The students are gaining research experience by interacting with the PIs and collaborators, and gaining skills on a range of analytical equipment including electron microprobe, SEM-EBSD, XRF, XRD and FTIR. They are also incorporating numerical modeling into their dissertation/thesis work. The undergraduate student received the same opportunities and training.

Outreach Activities:

Journal Publications

Johnson, S.E., "Rotation of porphyroblasts and strain localization: Debate settled!", *Geology*, p. 663, vol. 37, (2009). Published, 10.1130/G25729A.1

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. 132, 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.", *Journal of the Virtual Explorer*, p. , vol. 30, (2008). Published, 10.3809/jvirtex.2009.00208

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. , vol. 37, (2009). Published, 10.1130/G30227A.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

Johnson, S.E., "Reply to Comment: Rotation of porphyroblasts and strain localization: Debate settled!", *Geology*, p. , vol. 38, (2010).
Published, 10.1130/G30835Y.1

Price, N.A., Johnson, S.E., Gerbi, C.C., & D.P. West Jr., "Identifying deformed pseudotachylyte and its influence on the strength and evolution of a crustal shear zone at the base of the seismogenic zone", *Tectonophysics*, p. , vol. , (2012). Published, 10.1016/j.tecto.2011.11.011

Frieman, Ben M.; Gerbi, Christopher C.; Johnson, Scott E., "The effect of microstructural and rheological heterogeneity on porphyroblast kinematics and bulk strength in porphyroblastic schists", *Tectonophysics*, p. , vol. , (2012). Submitted,

Books or Other One-time Publications

Price, N.A., "Structure and rheology of the Sandhill Corner shear zone, Norumbega fault system, Maine: A study of a fault from the base of the seismogenic zone", (2012). Thesis, Unpublished
Bibliography: University of Maine

Frieman, B., "The Effect of Microstructural and Rheological Heterogeneity on Porphyroblast Kinematics and Bulk Strength in Porphyroblastic Schists", (2012). Thesis, Unpublished
Bibliography: University of Maine

Lenferink, H.J., "Kinematic vorticity and porphyroblast rotation in mylonites of the Norumbega Fault System: Implications for paleoviscometry", (2008). Undergraduate Honors Thesis, Unpublished
Bibliography: University of Maine

Price, N.A.; West, D.P., Jr.; Johnson, S.E.; & Marsh, J.H., "Coupled deformation and metamorphism, ultramylonite development, and evidence for paleoseismicity during protracted dextral shearing in south-central Maine", (2010). Field Guide Chapter, Published
Editor(s): Gerbi, C.C.; Yates, M.

Collection: Guidebook for fieldtrips in coastal and interior Maine, 102nd New England Intercollegiate Geological Conference

Bibliography: p. 109-131
Price, N.A.; Johnson, S.E.; Gerbi, C.C.; Koons, P.O., "The structure of a shear zone at the base of the seismogenic zone, Norumbega fault system, Maine", (2012). Conference Abstract, Published
Bibliography: Structural Geology and Tectonic Forum, Williamstown, Massachusetts

Price, N.A.; Johnson, S.E.; & Gerbi, C.C.; Koons, P.O., "Structure of a shear zone at the base of the seismogenic zone, Norumbega fault system, Maine; Potential for comparison with upper-crustal fault structure", (2011). Conference Abstract, Published

Bibliography: American Geophysical Union, Fall Meeting 2011, T33E-2463.

Price, N.A.; Johnson, S.E.; Gerbi, C.C., "Using heterogeneous quartz CPO data to interpret the deformation history of a shear zone at the base of the seismogenic zone", (2011). Conference Abstract, Published
Bibliography: Geological Society of America Abstracts with Programs, 43(5), 648

Price, N.A.; Johnson, S.E.; Gerbi, C.C., "The influence of pseudotachylyte on the strength and evolution of a crustal shear zone at the base of the seismogenic zone", (2011). Conference Abstract, Published
Bibliography: Penrose Conference on Deformation Localization in Rocks: New Advances, Cadaques & Cap de Creus Peninsula, Catalonia, Spain.

Price, N.A.; Johnson, S.E.; Gerbi, C.; Koons, P.O., "The influence of pseudotachylyte formation and deformation on bulk rock strength within a shear zone from the base of the seismogenic zone", (2010). Conference Abstract, Published
Collection: Geological Society of America Abstracts with Programs
Bibliography: Vol. 42, No. 5, p. 423.

Price, N.A.; Johnson, S.E.; Koons, P.O., "The Influence of Transient Structures on the Rheology and Stability of a Shear Zone from the Base of the Seismogenic Zone, Norumbega Fault System, Maine", (2010). Conference Abstract, Published
Bibliography: Gordon Research Conference on Rock Deformation, Tilton, N.H.

Price, N.; Johnson, S.E.; Gerbi, C.C., "Microstructural Evidence for Strain Localization at the Frictional-to-Viscous Transition, Norumbega Fault System, Maine", (2009). Conference Abstract, Published
Bibliography: American Geophysical Union, Fall Meeting 2009, T53B-1575

Price, N.A.; Johnson, S.E.; Koons, P.; Yates, M., "Microstructural record of coseismic/postseismic cycles near the base of the seismogenic zone, Sand Hill Corner Mylonite Zone, Norumbega Fault System, Maine", (2009). Conference Abstract, Published
Collection: Geological Society of America Abstracts with Programs
Bibliography: 41(3), 87

Price, N.A.; Johnson, S.E.; Koons, P.;

Seaman, S., "Microstructural Evidence for Seismic Rupture, Post-seismic Creep, and Fluid Transport in the Frictional-to-Viscous Transition, Norumbega Fault System, Maine, USA", (2008). Conference Abstract, Published Bibliography: American Geophysical Union, Fall Meeting 2008, T53C-1963

Web/Internet Site

Other Specific Products

Contributions

Contributions within Discipline:

We developed new numerical techniques for evaluating the coupling of viscous flow in shear zones to the frictional flow on an overlying fault.

We developed new criteria for identifying deformed pseudotachylyte in seismogenic fault zones.

We developed new techniques for evaluating complex and ambiguous quartz LPO data.

We are developed new techniques for evaluating the kinematic vorticity number in clast-bearing mylonite zones.

We are developing new techniques for evaluating the strength of clast-bearing mylonite zones.

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 is partly supporting the thesis work of 3 PhD students, 2 MS student and 2 undergraduate students.

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:

Activities and Findings: Any Outreach Activities

Any Web/Internet Site

Any Product

Contributions: To Any Other Disciplines

Contributions: To Any Beyond Science and Engineering

Any Conference