Friction of megathrust gouges at in-situ subduction zone conditions

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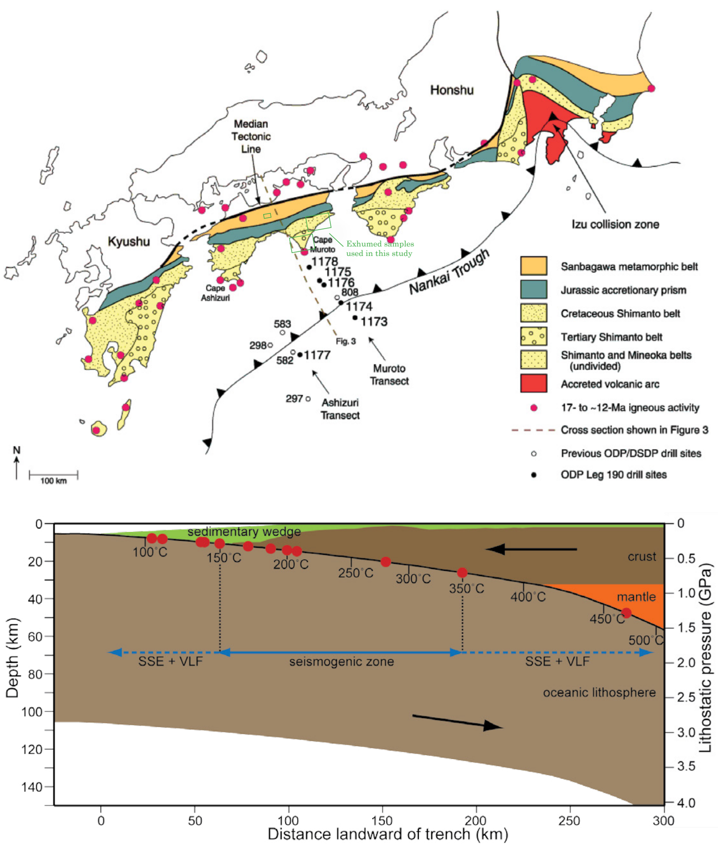
The objective of this project is to investigate the frictional behavior of natural subduction megathrust fault rocks representative of a range of in situ conditions from the trench to the downdip reaches of the seismigenic zone (T>350-400 °C). One important and novel aspect of this ongoing effort is the incorporation of a unique suite of natural megathrust fault zone samples obtained by drilling and from extraordinarily well-characterized exhumed subduction paleo-décollements (Fig. 1), thus allowing friction experiments on relevant, natural megathrust materials at their in-situ pressures and temperatures (i.e. in their natural "habitat"). Specifically, the work focuses on:



1. Using samples from (1) the Shimanto & Sanbagawa Belts: exhumed subduction fault rocks as analogs for the in situ megathrust at depth; and (2) drillcore from IODP/ODP expeditions in which the shallow plate boundary initiates. <u>These collectively sample conditions along the megathrust from ~50- 450°C</u>;

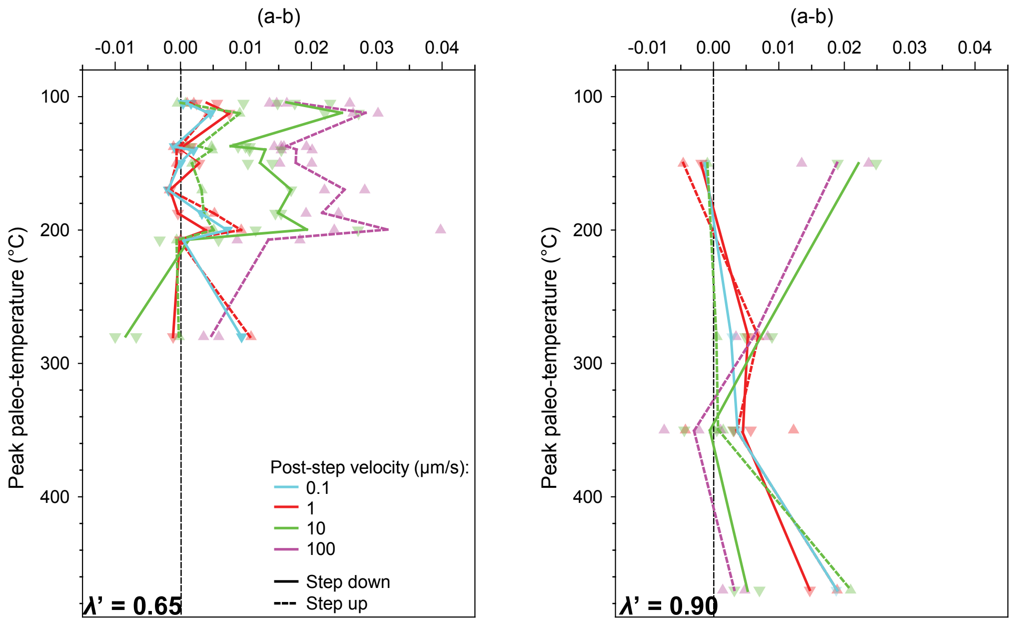
2. Conducting direct and rotary shearing experiments under hydrothermal conditions to reproduce the in situ P-T conditions for each sample;

3. Evaluating the frictional stability of these megathrust materials in their natural "habitat" in order to better understand the processes and compositional factors controlling the limits of the seismogenic zone; and

4. Linking frictional behavior to micromechanical models in order to extrapolate to other compositions and conditions, and to generalize our results.

Figure 1. A) Map of south-central Alaska showing proposed study region on the Alaska Peninsula between Cold Bay and Iliamna volcano, Quaternary volcanoes of the Aleutian and Wrangell arcs (yellow triangles), and selected Eocene igneous rocks (green triangles). FP = Foraker pluton; AR-TM = Alaska Range-northern Talkeetna Mt.ains; FB/HB = Finger Bay and Hidden Bay plutons on Adak Island. Thick gray dashed line shows boundary between oceanic (O) and continental (C) crust. B) Simplified geologic map showing Late Cretaceous through Quaternary igneous rocks in the proposed study region. Blue dashed outlines show the targeted sample areas. The table shows the targeted number of samples in each area for major and trace element analyses.

Figure 2. Results of friction experiments, showing frictional rate-dependence (a-b) determined from velocity-stepping tests, as a function of peak burial/past temperature for each sample, for a scenario in which effective stress in the experiments corresponds to a modestly overpressured megathrust (λ = 0.65; panel A), and a highly overpressured megathrust (λ = 0.90; panel B). Colors indicate stepping tests conducted at different sliding velocities (as noted).



The project is thematic in scope, but closely linked to the GeoPRISMS SCD primary site at Alaska, and to the former MARGINS focus Site in SW Japan, through the use of natural subduction zone material collected from the exhumed subduction zone sediments and faults found on Kodiak Island, Alaska, from Shikoku Island, SW Japan, and recovered from the modern Nankai megathrust during ODP Leg 190.

Our results to date are in general agreement with previous studies of synthetic phyllosilicate-quartz mixtures under hydrothermal conditions, in which gouges show stable, velocity-strengthening (or near-neutral) behavior at low temperatures (Regime 1), potentially unstable, velocity-weakening at intermediate temperatures (Regime 2) and velocity-strengthening at the highest temperatures (Regime 3) [den Hartog et al., 2012, 2013]. For our samples, rate-weakening (Regime 2) occurs between ~300-400 ˚C is experiments that simulate low effective stress conditions (λ = 0.90); this behavior is shifted to lower temperatures under higher effective stress conditions (λ = 0.65), consistent with previous work on synthetic mixtures (Fig. 2). The three-regime behavior is well-explained by a microphysical model in which frictional behavior is governed by a competition between rate-independent frictional slip on aligned phyllosilicates and thermally activated deformation of intervening quartz clasts by pressure solution [den Hartog et al., 2012, 2013].

Our initial data also show that at their in situ conditions, the fault rocks are, overall, nearly rate-neutral (a-b =~0), and exhibit a decrease to rate-weakening behavior (negative (a-b)) for lower slip velocities, and for T between ~250-350°C. The rate weakening of friction is greater at slower slip velocities. This behavior also raises the interesting possibility that these rocks could host slow slip, wherein unstable slip may nucleate at low velocity (where we observe rate weakening), but is damped by rate-strengthening at higher slip velocities [e.g., Rubin, 2011].

This project has also provided extensive mentoring experience for post-doctoral researcher Sabine den Hartog. She has supervised the work of a PhD student on high-temperature friction tests, and has gained broad experience in the lab working with a new direct shear system and supervising a second graduate student in our engineering program.

Publications to date from this project

den Hartog, S.A., Saffer, D.M., Spiers, C.J., The roles of quartz and water in controlling unstable slip in phyllosilicate-rich megathrust fault gouges, Earth, Planets and Space, Frontier Letter, 66:78, doi:10.1186/1880-5981-66-78 (2014).

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Fisher, D.M., and den Hartog, S. Role of Silica Redistribution in the Rate-State Behavior of Megathrusts: Field Observations and Experimental Results. AGU Fall Meeting. San Francisco, CA (2014).

den Hartog, S.A., A. Niemeijer, D.M. Saffer, C. Marone. Frictional behavior of exhumed subduction zone sediments from the Shimanto Belt, Japan, at in-situ P-T conditions and implications for megathrust seismogenesis. EGU Annual Meeting. Vienna (2014).

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Den Hartog S.A.M., et al.. New constraints on megathrust slip stability under subduction zone P-T conditions. Earth and Planetary Science Letters 353-354, 240-252 (2012).

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Rubin, A. M. Designer friction laws for bimodal slow slip propagation speeds. Geochem. Geophys. Geosyst. 12, Q04007 (2011).