Community Rheology Model Workshop: Establishing a Geologic Framework

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ABSTRACT

Because stress is difficult to directly measure, a testable modeling scheme is needed to infer stress by linking observables, such as strain rate, stress directions, topography, and seismic velocity, to far-field plate motion and mantle dynamics. To accomplish this, SCEC5 will feature a community rheology model (CRM) that formally links strain rate to stressing rate, and, ultimately, absolute stress state in southern California. A geologic framework, containing lithology and thermal properties, is a necessary constituent of such a model. The CRM-Geologic Framework workshop, held June 8th and 9th, 2016, brought together geologists, geophysicists, and geodynamicists to define how a geologic framework for southern California should be constructed during SCEC5.

TECHNICAL REPORT:

The Community Rheology Model - Geologic Framework (CRM-GF) workshop was held June 8-9, 2016 at the Kellogg West Conference Center in Pomona, California. A diverse group of 45 geologists and geophysicists, ranging from graduate students to retired faculty, met from 9am to 5pm on the 8th to discuss the model and the major geologic and geophysically imaged features that it should reflect. A smaller group of 10 persons met on the 9th for a half-day discussion of the geologic framework model to outline project milestones and research tasks.

From 9am to about 2pm on the 8th the workshop featured a series of short talks followed by questions and discussion. The workshop began with one hour of introductory material, consisting of four 15-minute talks: welcome, agenda review, and introductions (Behr); goals of the CRM (Hearn); requirements of the geologic framework (Oskin), and a review of the Unified Structural Representation (Plesch). This was followed by 90 minutes of presentations on the geology of southern California at scales relevant to the CRM-GF, including its major lithotectonic provinces onshore (Matti) and offshore (Legg), implications from palinspastic reconstructions (Powell) and large-magnitude rotation (Nicholson), and the structure of the Salton Trough and Gulf of California (Stock). A sixth speaker (Brownlee) was unable to make the meeting. Her talk would have addressed the extent and emplacement of the Pelona Schist beneath southern California. After lunch, a set of two talks addressed geophysical constraints from active-source seismic imaging (Fuis) and potential fields (Langenheim), followed by a trio of talks on tomography and shear-wave splitting results and implications (Hauksson, Klemperer, and Ford). Presentations were concluded by two talks on fault zones as rheological features in the brittle crust (Fletcher) and the mid- to lower-crust to upper mantle (Behr).

Following the presentations, the meeting attendees were split into four breakout groups. Each was given the same set of four questions and sub-questions to be addressed. The attendees recombined for the last hour of the workshop. Group leaders synthesized the responses from each group and presented these to the workshop. The workshop concluded with an overall discussion of the geologic framework model and how it should be accomplished.

The second half-day of the workshop featured ten participants: The four conveners (Behr, Hearn, Oskin, and Thatcher) and six others (Allam, Brown, Hauksson, Plesch, Powell, and Tullis). This smaller group focused on defining research tasks and milestones for the CRM-GF and CRM overall, based largely upon the outcomes of the breakout groups from the previous day. Their recommendations, along with those consistent with the breakout groups, are summarized below beneath the breakout-group questions and sub-questions. Major lithotectonic provinces of southern California and a list of proposed milestones are summarized at the end of this report.

Breakout-Group Questions with an overview of answers

How do you envision the CRM-GF being used?

- *What should be the outputs of a CRM-GF: lithology, rock properties, flow laws, etc?* The CRM-GF should provide lithologic information sufficient to assign constitutive relationships at every resolved element of the lithosphere of southern California. Meeting attendees emphasized that the model should contain sufficient referencing and metadata so that it could be reconstructed from this metadata.
- *What should be the logical boundaries and effective resolution of the CRM?* There was general consensus that the model should extend from the southern creeping section of the San Andreas fault to just south of the Agua Blanca fault in Baja California, west past the Patton Escarpment into the oceanic lithosphere, and east to the Nevada border. The model should continue into southwestern Arizona in order to extend beyond the easternmost major outcrops of Pelona-Orocopia schist (Cemetery Ridge). Oceanic crust will form a uniform boundary to the southwest, and the Basin and Range province will form a uniform boundary to the northeast. The depth should extend past the lithosphere-asthenosphere boundary, perhaps as deep as 200 km.

What are the essential details of lithology and structure for the CRM-GF?

- *What are the major lithotectonic units to be included in the CRM-GF?* Two sets of answers emerged from the breakout groups. On one hand, it is important to identify blocks in southern California by their lithotectonic assemblage of rocks. That is, by their similar tectonic history. Even if provinces are similar felsic compositions in the upper crust, their tectonic history implies differences in lower crust and upper mantle characteristics. Once these provinces are defined, it is then crucial to translate these lithotectonic assemblages into a more general set of lithologies, such as general chemical composition (e.g., felsic or mafic, of igneous, sedimentary, or metasedimentary origin), and whether there is a pre-existing fabric in the rocks.
- *How should basins be represented?* As a start, the present representation of basins in the USR should be sufficient. A point to be followed up on is whether this definition includes older forearc basin rocks, and whether the nature of various basin fill units should eventually be included within the CRM-GF due to their impact on shallow faulting processes.
- *How should the CRM-GF represent the middle and lower crust?* The middle to lower crust is the least known part of the lithospheric structure of southern California. There are several important exposures exhumed by low-angle normal faulting that should be exploited. In many tectonic provinces, major decollement horizons are inferred to separate supracrustal felsic rocks from foliated, accreted metasedimentary materials at depth. Potential fields may be used to help delineate the extent of these units. Alternative

representations of the mid- to lower-crust will be important to express epistemic uncertainty.

- *What should the CRM-GF incorporate in the mantle?* Though compositionally more uniform than the lower crust, the provenance of the upper mantle and its composition and water content require careful consideration in constructing the CRM-GF. Research is needed to synthesize geochemical, geophysical, and xenolith information for the upper mantle.
- *How should faults be represented within the CRM-GF?* There was general agreement that faults and their surrounding rock volume should be parameterized and overlain upon the geologic framework model based on the fault geometries available within the USR. The parameterization should depend on fault maturity (total slip), and should include geologic information relevant to both long-term steady-state and dynamic slip (e.g. minerals controlling fault friction, orientations relative to the surrounding stress field). Major CFM faults will need to be extended below the seismogenic zone and possibly to the lithosphere-asthenosphere boundary, but they should include alternative models representing the deep roots of faults as either discrete ductile shear zones or more continuous zones of distributed shear. The development of these parameterizations and fault extensions is an important research task.

What sorts of activities should SCEC support to construct the geologic framework model?

- Develop the USR into the geologic framework for the CRM.
- Develop 1-D lithologic models for major lithotectonic blocks of southern California, and integrate these with the community thermal model.
- Define constitutive relationships applicable to faults, including below the seismogenic zone, and block interior regions of southern California, and the upper mantle composition and water content.
- Reconcile disparate velocity models and their implication for lithology, including using independent data such as geologic map relationships, tectonic history, MT, gravity, and magnetics.
- Refine and test lithospheric architecture of blocks and the rheology of their constituent fault zones, using geology, potential fields, velocity structure, post-seismic transients, etc.
- Support for expert review, revision, and validation of the CRM geologic framework.

How should the CRM (and GF) be validated?

- Major lithotectonic provinces should be at isostatic equilibrium
- Compatibility of model predictions with observed post-seismic deformation.
- Waveform modeling through major structural features of the geologic framework.
- Modeling replicates essential pattern of fault loading, areas of uplift and subsidence, etc.

Lithotectonic Provinces For a Preliminary CRM-GF:

- Basin and Range
- Mojave-Salinia
- Sierra Nevada
- Great Valley
- Peninsular Ranges
- Inner Borderland
- Forearc
- Accretionary Prism
- Oceanic Crust
- Salton Trough

Proposed Milestones for the CRM and Geologic Framework

- Year 1: Provisional lithologic block model, documented with metadata, based on 1-D lithologic functions for each block.
- Year 1: Select initial areas or blocks to focus on developing full CRM capability, with long wavelength 3-D geology, constitutive relationships, and thermal model.
- Year 1: Provisional CTM, incorporating 1-D lithologic functions from the GF.
- Year 2: Provisional fault rheology model, perhaps as a function of displacement, integrated with the geologic framework.
- Year 3: Extend CFM major faults to the base of the crust or lithosphere-asthenosphere boundary, as appropriate.
- Year 3: CRM version 1.0 released (geologic framework + fault zone model + constitutive relationships + thermal model)
- Year 4: Geologic framework with long-wavelength 3-D architecture
- Year 5: Deliver a CRM with constitutive relationships based on lithology of southern California for both blocks and faults.