SCEC PROJECT REPORT

Construction of the Geologic Framework for the Community Rheology Model

Abstract: We commenced construction of a geologic framework (GF) model for southern California, based on major lithotectonic blocks. Block boundaries are defined by faults or tectonic suture zones contained within the SCEC Unified Structural Representation (USR). For this first stage of the GF, rock compositions of each block are defined as 1-D columns averaged over the block extent. A fully 3-D framework is the subject of future work. Block boundaries are drawn from faults within the SCEC USR, where intersecting the top of basement surface. For this first year, we focused on gathering lithologic information relevant to understanding the rheology of the Mojave province. This included digitizing over 1000 rock compositions from the deeply exhumed southern Sierra Nevada batholith, and compiling mineralogy and expected metamorphic transformations of underplated schist. These results were presented at the 2017 SCEC annual meeting, and form the basis for ongoing development of the GF.

Intellectual Merit: Lithology is one of the primary controls on rheology. The Geologic Framework describes the profound lithologic variation across southern California at a scale appropriate for physics-based simulation of the fault system. This will better inform the physical conditions for earthquake rupture, increase understanding of the depth extent of shear zones, and constrain post-seismic deformation and stress transfer.

Broader Impacts: This is an open community model that contributes to key SCEC initiatives. A U.C. Davis graduate student, Alex Morelan, was supported by this project to digitized mineralogy data. Alex will be a co-author of a short publication describing this dataset and its implications for faulting in southern California.

Technical Report: Understanding stress conditions and strain distributions within the crust is a key component of physics-based earthquake rupture forecasting. Because stress is difficult to directly measure, a testable modeling scheme is needed to infer stress by linking observables, such as lithospheric structure, strain rate, stress directions, topography, heat flow, and seismic velocity, to far-field plate motion and mantle dynamics. To accomplish this, SCEC5 features a community rheology model (CRM) that formally links strain rate to stressing rate, and, ultimately, absolute stress state in southern California. The GF comprises one of the essential components of the CRM, providing rock-type and mineralogy information essential to predicting rheology.

The GF is based on major lithotectonic provinces, or blocks, that make up southern California and neighboring areas (see Figure 1 for current version province map). Province boundaries correspond to faults or suture zones, defined on the basis of the tectonic history of southern California (e.g. Crouch and Suppe, 1993). Most of these boundaries currently exist within the SCEC USR (Unified Structural Representation), and a handful will be added. The lithology of each province is defined by a 1-D lithologic column inferred from surface outcrops, subsurface imaging, and inference based on the tectonic history of southern California. In this first year of the project, we focused on refining the block boundaries, and on developing 1-D lithologic columns for the batholith belts (Sierra Nevada, Peninsular range) and the Mojave Desert.

The USR (Shaw et al., 2015) is comprised of two main components - the Community Fault Model (CFM) and Community Velocity Model (CVM) - that both contribute to the Geologic Framework. The CFM includes 3D representations of more than 300 active faults in California (Plesch et al., 2007), many of which naturally define

boundaries between crustal blocks with distinct lithologies. The CVM (Süss et al., 2003; Shaw et al., 2015) incorporates these fault representations to define geologic surfaces – including the contact between sedimentary and basement (crystalline or meta-sedimentary) rocks. The CVM also includes topography and a Moho surface that is based on receiver functions, and seismic refraction and reflection studies (Tape et al., 2012). Regions, bounded by these faults and horizons, are then parameterized with Vp, Vs, and density using rule-based or geostatistical methods and tomographic models. The USR model is gridded, and metadata associated with each grid cell defines the region (e.g., sedimentary basin, crust, mantle) where it is located. As part of this project, this system is being adapted to define more detailed model regions based on lithology for the GF and to provide additional metadata that describe lithologic and/or rheologic properties.

To implement the Geologic Framework, the Harvard team developed a GIS map coverage that registers fault traces on the sediment-basement interface in the USR. This map was provided to the UC-Davis team to assist in their development of a geologic map of basement rock type (Figure 1). Notably, this mapping effort has identified additional, major faults that are inactive (and therefore not in the CFM), yet represent major lithologic boundaries that are important to represent in the Geologic Framework Model.

The UC Davis team focused on developing a mineralogic depth profile for the Sierra Nevada batholith and Peninsular Ranges batholith, using the deeply exhumed crustal section of the southern Sierra and Tehachapi region (Saleeby, 2003; Chapman et al., 2012). Over 1,300 thin-section point counts were culled from a series of USGS open-file reports from Dr. Doug Ross at the U.S. Geological Survey (e.g. Ross, 1987). Dozens of hand-drawn map figures were georeferenced to locate samples into a GIS database. Using hornblende paleobarometry compiled in Chapman et al., (2012), we obtained a paleo-depth estimate for each rock mineralogy measurement. The results of this effort, shown in Figure 2, are that the batholiths are remarkably homogeneous in composition from the surface to 25 km depth. The deepest parts of the western batholith are more mafic in composition, though plagioclase feldspar is the dominant strong mineral phase throughout, with quartz as the most abundant weaker phase.

The Mojave Block is tectonically stratified. Different crustal levels of the batholith are juxtaposed along low-angle fault interfaces. Both shallow volcanic and hypabyssal intrusions (Dibblee, 1964) and deeply exhumed high-pressure rocks similar to the southern Sierra Nevada (Fletcher et al., 2002) are exposed in different parts of the Mojave Block. Probably the most important components of the Mojave Block are underplated units not visible over most of its surface. These units are the Pelona-Orocopia-Rand schist emplaced by shallow subduction in the Late Cretaceous (Jacobsen, 1983) and mafic underplating, evident from mantle zenoliths (Wilshire, 1990) that could correspond to a remnant of subducted oceanic crust or younger magmatism associated with Basin and Range extension.

Eventually, the completed GF will be incorporated in the USR framework and used to develop crustal blocks that represent distinct lithologic units. These blocks will extend from the base of sediments to the Moho surface within the USR. We anticipate close coordination between the UC-Davis and Harvard groups, as well as other SCEC researchers, to assess how best to extrapolate these lithologic boundaries to depth. The initial model has simple vertical boundaries derived from a generalized version of the first iteration of the geologic map. Generalization was performed by applying a 1km buffer around all included fault traces some of which include detail and branches, merging the buffered area in order to make faults more continuous, and then filtering the

results by a 1km spatial smoothing. The result defines a number of crustal basement blocks on top of which sedimentary basin structure can be imposed (Fig. 3).

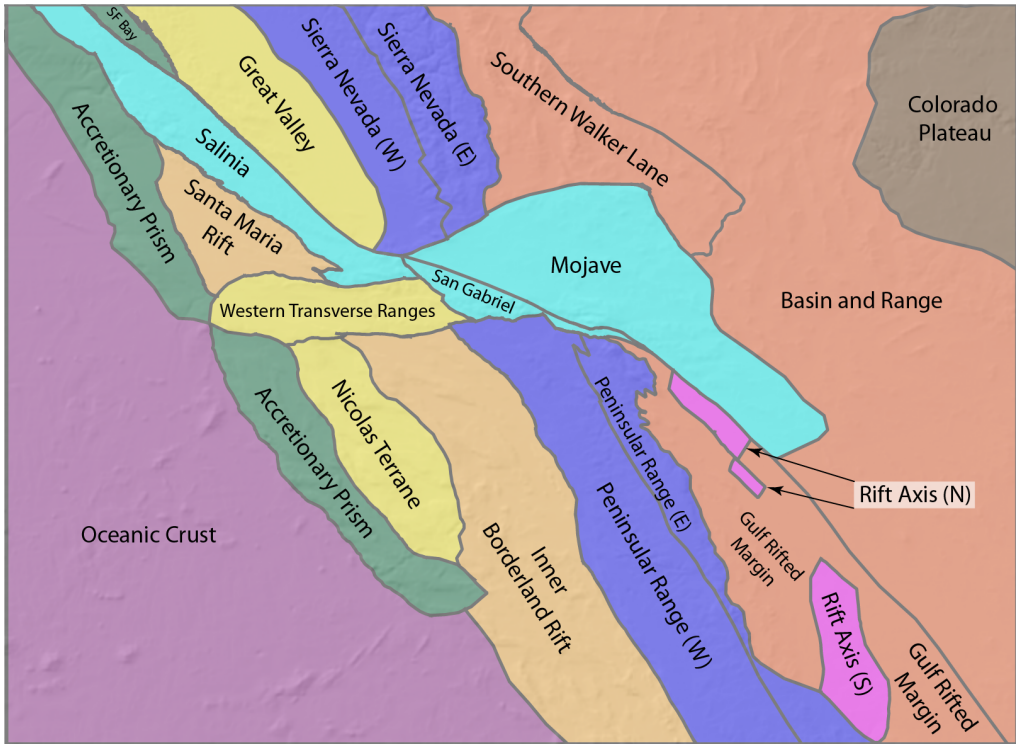

Figure 1. Lithotectonic blocks comprising version 1.0 of the Geologic Framework (GF).

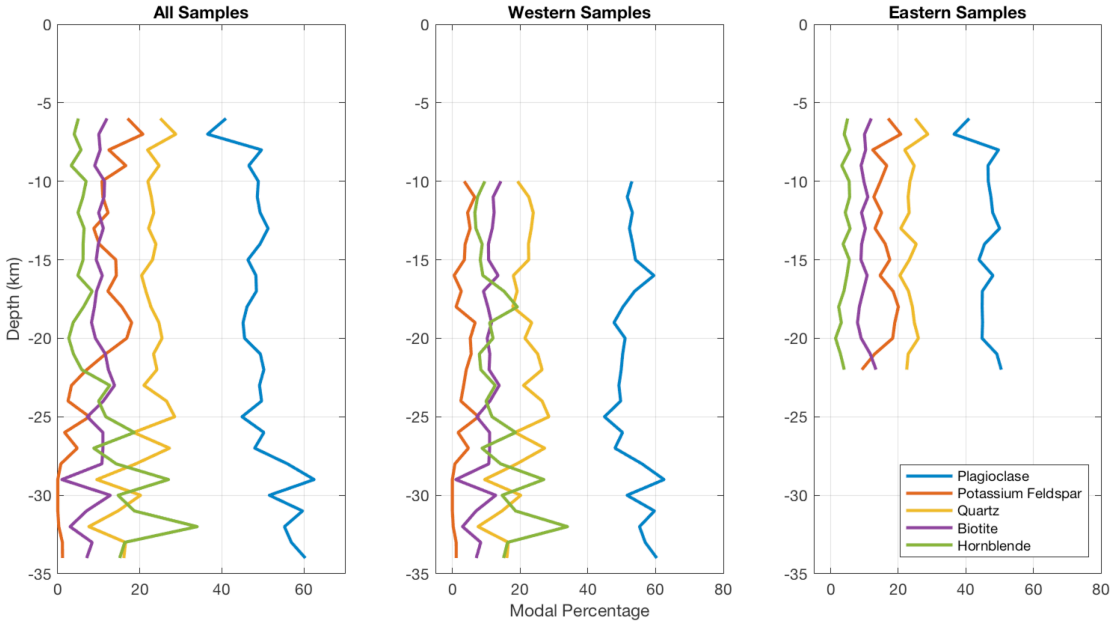

Figure 2. Average modal mineralogy over 5 km depth window for the Sierra Nevada batholith from point-counting of mineral phases. The composition of the batholith is remarkably uniform from 5 to 25 km depth, becoming enriched in feldspar and hornblende below 25 km. Quartz is preset as an abundant weak phase throughout.

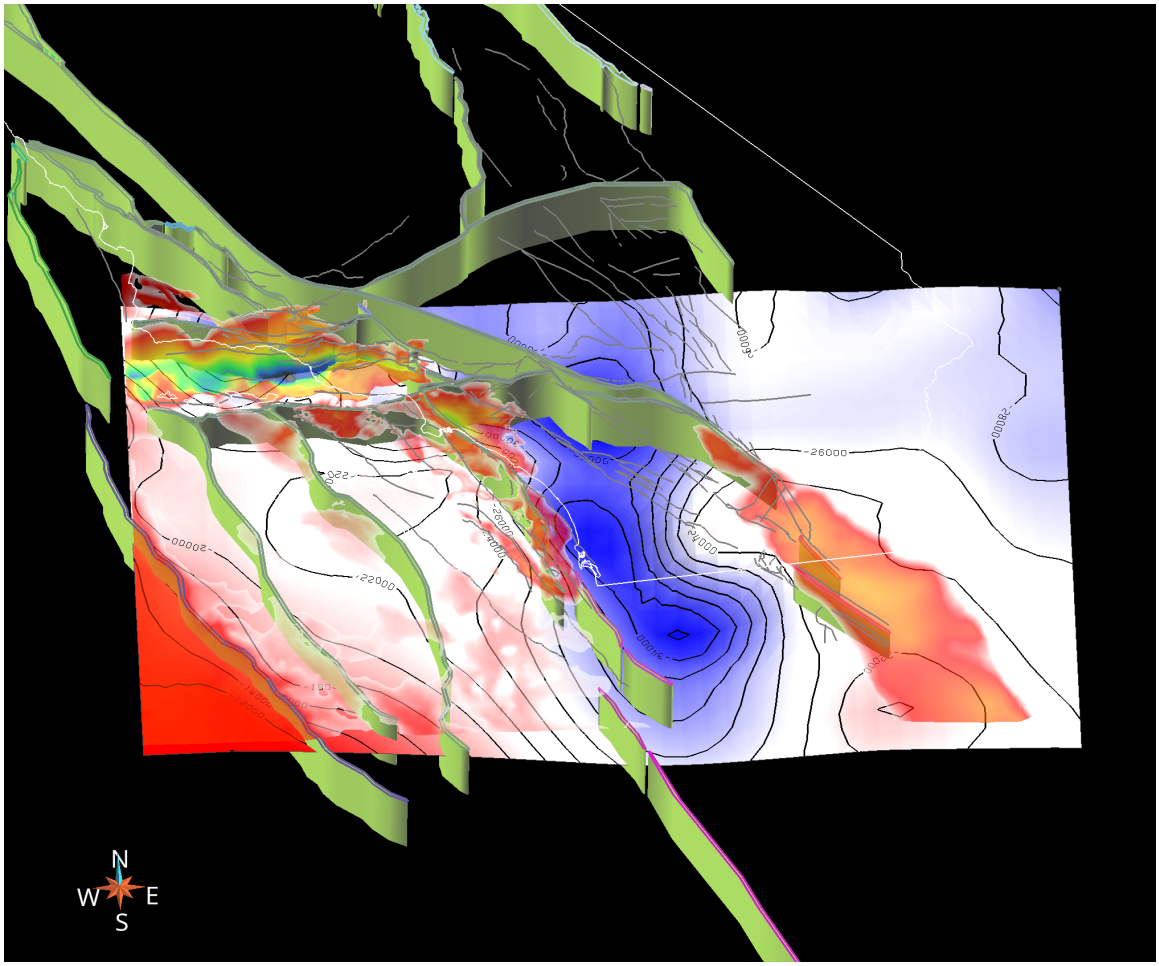

Figure 3. Perspective view of the SCEC Unified Structural Representation (USR), showing model elements (faults, topography, sediment – basement contact, Moho) that will be used to constrain the Geologic Framework. The USR grid will be populated with lithologic properties, and will be accessible through the UCVM platform provided by SCEC.

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