SCEC Report

Construction of the Geologic Framework for the Community Rheology Model

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Summary
This past year, we developed a first iteration Geologic Framework (GF) within the SCEC Unified Structural Representation (USR) (Hearn et al., 2018) that is intended to support SCEC's efforts to create a Community Rheologic Model (CRM). The Geologic Framework consists of eleven lithotectonic provinces that share similar rock types and attributes, and that cover significant parts of the model domain. These provinces reflect the inherent geologic history of southern California, including Mesozoic to Early Cenozoic subduction tectonics, and Late Cenozoic rifting and translation along the San Andreas system.

The initial GF has been incorporated into the Unified Structural Representation (USR) framework. The SCEC USR is a self-consistent set of community models that describe fault and wavespeed structure in the southern California crust and upper mantle (Shaw et al., 2015). The lithologic blocks were defined based on maps of surface geology and subsurface geophysical constraints. Many of the boundaries between these blocks correspond to faults within the SCEC Community Fault Model (CFM) (Plesch et al., 2007). These fault representations, along with additional block boundaries projected from surface rock exposures to depth, were used to define a set of closed, interconnected volumes. These volumes are bounded by topography/bathymetry, the sediment-basement interface, and the Moho. This block model was then use to develop a gridded volume, where each point is associated with associated with a specific region (sediment, crust, mantle) and lithologic type. The GFM will be made accessible through the SCEC UCVM modeling framework, and ultimately populated with other properties to help support the development of the Community Rheologic Model (CRM).

Geological Framework Model
The objectives of the Community Rheologic Model (CRM), as outlined in the SCEC5 proposal, are to understand bulk-rock and fault constitutive laws and their implications for strain localization, fault-zone evolution, the brittle-ductile transition, and coupling of crustal deformation to mantle convection. Ultimately, the CRM will support the mechanical modeling of a viscoelasto-plastic plate-boundary deformation zone that is permeated by faults, edge-loaded by rigid plate interiors, and basal-loaded by mantle convection. The goal of Geologic Framework Model (GFM) is to provide lithologic information sufficient to assign constitutive relationships at every resolved element of the lithosphere of southern California. This project has developed an initial GF in the context of the SCEC Unified Structural Representation (USR) (Figure 1). This ensures the faults which represent boundaries between lithologic units are consistent between the GF and CFM in the region where the two representations overlap.

Defining Lithologic Boundaries
The GF is based on major lithotectonic provinces, or blocks, that make up southern California and neighboring areas (Figure 1). Province boundaries correspond to faults or suture zones, defined on the basis of the tectonic history of southern California. The lithology of each province is presently 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 second year of the project, we focused on coregistering block

boundaries to CFM faults, refining other boundaries from geophysical constraints, and developing 1-D lithologic columns for all GF blocks.

Based on a map of CFM faults at the top of basement, we refined positions for all block boundaries inferred to correspond to active faults. For those defined by inactive faults and other mapped contacts, we delineated lines on a digital version of the statewide geologic map. Finally, for those boundaries buried by water or younger sediments, we used potential field data (gravity, magnetic) to define transitions between blocks. The latter define compositional contacts, especially where more iron and magnesium-rich (mafic) middle crust of oceanic affinity is juxtaposed against continental basement at suture zones.

Defining Composition

Composition of the GF blocks is derived from a synthesis of literature sources and geologic maps. Areas where lower crustal rocks are exhumed provide key compositional information for the southern Sierra Nevada (Saleeby, 2003; Chapman et al., 2012), Death Valley (Mattinson et al., 2007), Peninsular Ranges (Axen and Fletcher, 1998), Mojave Desert (Fletcher et al., 2002), and continental borderland (Platt, 1975). The broadest compositional pattern follows the west-facing subduction complex (Crouch and Suppe, 1993), augmented by Jurassic-Early Cretaceous accretion of an island arc terraine constructed on mafic crust. Three major events have modified this pattern: (1) Late Cretaceous-Early Cenozoic subduction of an aseismic ridge, resulting in underplating of the Pelona-Orocopia-Rand (POR) schist underneath southern California (Saleeby, 2003); (2) Rifting of the continental borderland and rotation of the western Transverse Ranges; (3) Translation along the San Andreas fault and opening of the Gulf of California. POR schist outcrops along the San Andreas fault and Garlock fault, and continue into southern Arizona (Jacobsen et al., 1983). Correlative schist outcrops occur in the Sierra de Salinas (Salinian Block), translated northward along San Andreas fault (Ducea et al., 2003). It remains unclear how continuous the schist may be beneath the Mojave Province (Allison et al., 2013). Because of the preponderance of weak mica phases and fluids, the extent of schist is important for understanding the rheology of southern California. Subduction-related accreted schist is also an important constituent of the rifted continental borderland area (e.g. Platt, 1975). In the Salton Trough and northern Gulf of California, active rifting has proceeded to continental rupture (Martin-Barajas et al., 2013). Underplated basalt and basalt intrusions into thick, quartz-rich deltaic sediments likely characterize this region (Han et al., 2016).

Implementing the GF

Identifying coincident CFM fault representations

As a first step towards implementing a volumetric (3D) realization of a GF throughout the crust into the upper mantle, we identified CFM fault representations which coincide with the lithologic unit boundaries described above (Fig. 1). Other lithologic boundaries are either outside the CFM 5.2 model domain, or are defined by juxtaposition of important geologic bodies and not active faults included in the model. To the north of the CFM 5.2 model domain, we use the latest version of the statewide CFM to identify further GF unit bounding faults. For other lithologic boundaries, we gathered published data, for example in the form of large scale cross-section and conceptual tectonic models informed by seismological observations, to allow us to better characterize these boundaries and make decisions on how to implement them at depth.

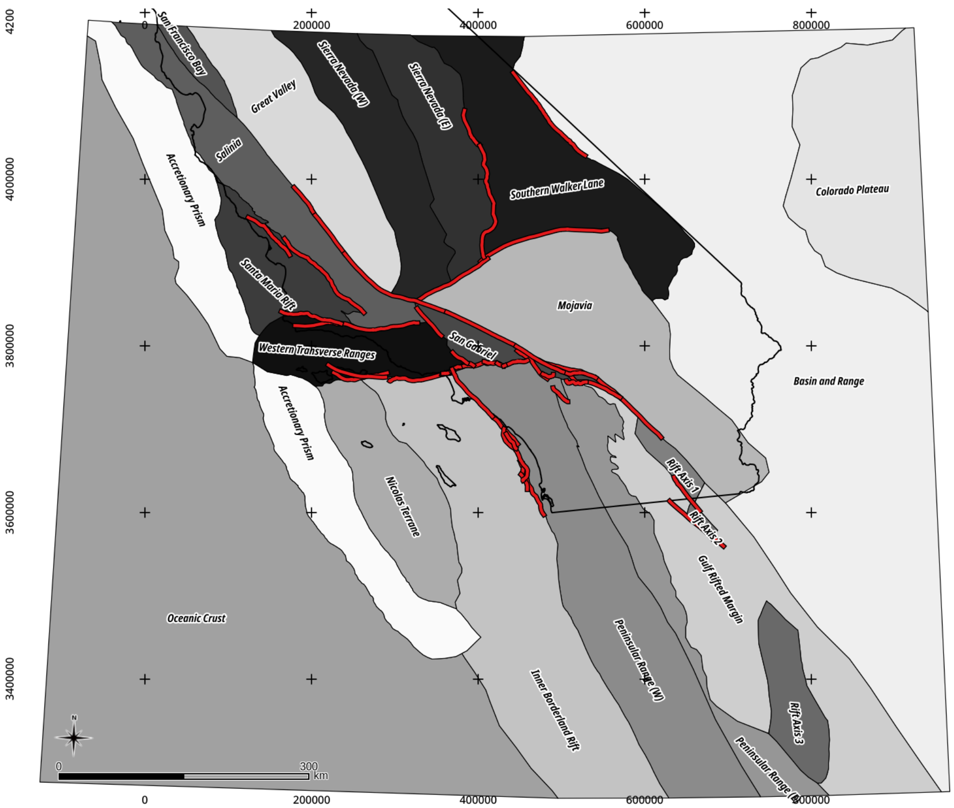

Fig.1: labeled lithologic units (grey tones) in relation to CFM v.5.2 fault representation (red traces).

Integrating the polygonal model into the 3d fault model

Having identified the CFM 5.2 representations which coincide with lithologic boundaries, we proceeded to integrate the polygonal lithology map with the 3D fault representations (Fig. 2). This integration required cartographic projection and revealed a good fit between lithologic boundaries and faults representations. Most faults associated with lithologic boundaries are not vertical in the upper crust. Indeed, some have rather gentle, albeit variable dips, such as the southern boundary of the Western Transverse Ranges unit. For other boundaries that are not associated with CFM faults, we used a vertical orientation to project them to depth in the initial GF model. We anticipate that for many linear boundaries, such as between the Eastern and Western Peninsular Ranges units, this is a reasonable approximation. However, we anticipate that for other complex boundaries boundaries, such as that between the Eastern Peninsular Ranges and the Gulf Rifted Margin units, future model versions may need to refine these boundary representations at depth. For all boundaries, we generated contiguous surfaces by joining neighboring elements, filling in gaps where necessary and by extending surfaces laterally to form watertight volumes.

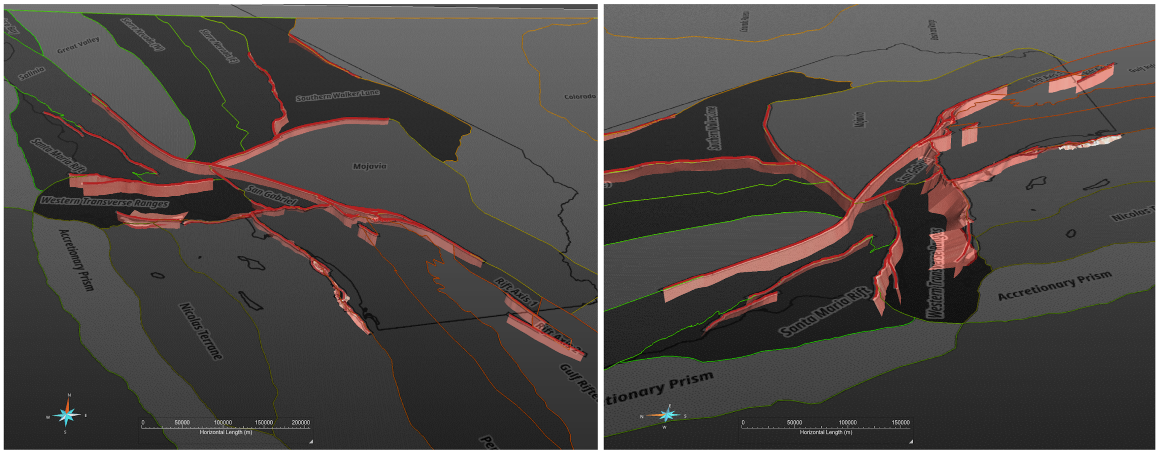

Fig.2: perspective views (S to N on left, W to E on right) of the polygonal GFM (grey map) embedded into a subset of the CFM-v.5.2 (red fault representations). Missing polygon boundary surfaces will be characterized and implementations then added.

Extending GF boundaries through the crust to the mantle

The GF is envisioned as a crustal, perhaps ultimately lithospheric scale model. While CFM representations provide a measure of fault geometry to mid-crustal levels, eg. to the base of the seismogenic crust, defining unit boundaries below that level requires additional constraints or assumptions. For the current GF, we extended lithologic bounadries to the Moho surface (Fig. 3) as defined by Tape et al. (2012). Where there was consistent evidence for dipping boundary attitudes in the mid-and upper, we used this information to extend boundaries to the Moho. For all other boundaries, these projection are vertical.

Distribution of the GF

The GF consists of about three dozen closed blocks corresponding to lithologic regions above and below the base of seismicity surface. Given that we directly incorporated faults, where appropriate, to define these lithologic boundaries, the GTL is geometrically consistent with both the CFM and the associated SCEC Community Velocity Model (CVM-H). This will help to facilitate future analysis of the GF using seismic properties to refine lithologic divisions and boundaries, as well as inform choices about appropriate rheologic properties to assign for these regions in the Community Rheologic Model (CRM). To distribute the GF, we will provide surfaces that define lithological regions in simple ascii-based formats, as well as develop a grid representation of the model that can be incorporated into the SCEC UCVM framework. The UCVM will allow users to access the complete model, or extract lithologic properties for arbitrary x,y,z coordinates to facilitate their evaluation and use of the GFM

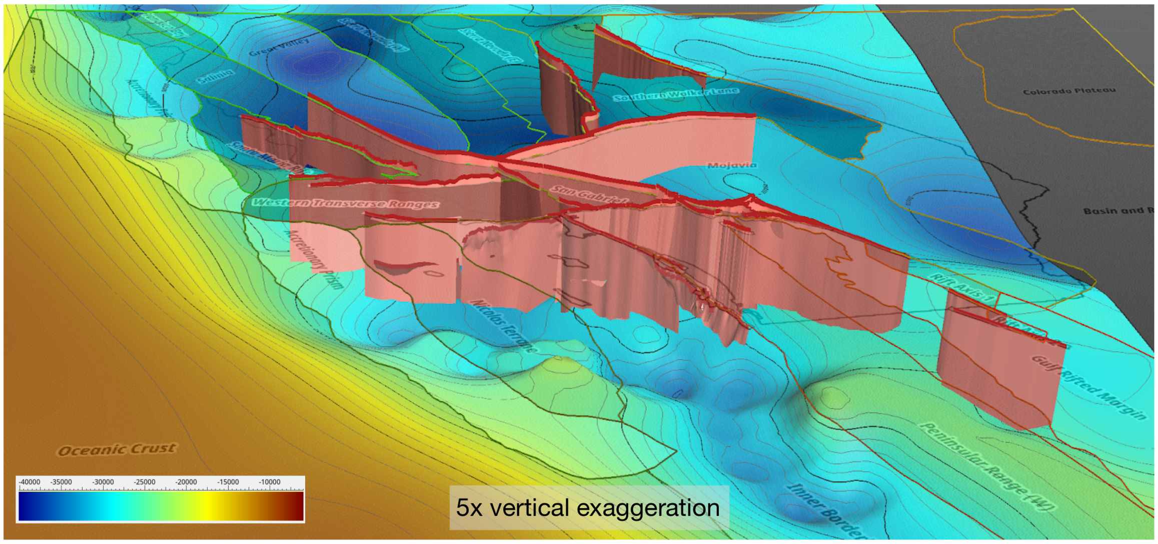

Fig. 3: vertically exaggerated, perspective view of GFM fault boundaries and the Moho, reaching depths of 40 km. The gap between the base of the fault representations and the Moho surface is closed by extending the boundaries.

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