2020 SCEC Report

Enhancements to the Velocity (CVM) and Geological Framework (GFM) Models to support the next generation community modeling efforts

SCEC Award 20071

Principal Investigators:

John H. Shaw
Professor of Structural & Economic Geology
Andreas Plesch (Co-Investigator)
Senior Research Scientist
Harvard University
Dept. of Earth and Planetary Sciences
20 Oxford St., Cambridge, MA 02138
shaw@eps.harvard.edu // (617) 495-8008

Thomas Jordan
University Professor and W. M. Keck Professor of Earth Sciences
Southern California Earthquake Center
University of Southern California
Los Angeles, CA 90089-0740
Phone: 213-821-1237; Fax: 213-740-0011

Philip Maechling
Associate Director for Information Technology
Southern California Earthquake Center, University of Southern California
3651 Trousdale Parkway, Suite 169
Los Angeles, California, 90089-0742

Proposal Categories:

Data Gathering and Products; Collaborative Proposals

SCEC Science Priorities:

P3b, P4a, P4c

Duration: 1 February 2020 to 31 January 2021

1. Summary

This past year, we developed a series of new resources to support the next generation Community Velocity Modeling (CVM) effort, and to complete development of the first Geological Framework Model (GFM) to support the Community Rheology Modeling (CRM) project. For the CVM's, we:

- Developed basin velocity representations as standalone CVM components that can be incorporated into current and future velocity models. These models describe Vp, Vs, density, and other properties for the major sedimentary basins in southern California. This framework will support alternative basin models, enabling comparison and evaluation of sedimentary basin structure and sediment velocity characteristics. These models will be accessible through the UCVM framework, thus facilitating their use in next generation CVM's. These efforts were proposed and supported at the CVM TAG Workshop in Palm Springs (9/2019), and presented at the Dynamic Rupture TAG Workshop on 10/27/21.

For the GFM, we:

- Developed topologically well-defined boundary representations of all blocks, enabling robust queries near fault boundaries. This ensures that model queries retrieve correct region descriptions and properties, which is of critical importance in using the GFM to define contrasts in rock and associated rheologic properties across major faults and other boundaries that are represented in the model.

- Parameterized the first generation GFM with lithologic and thermal properties as defined by the Community Rheological Model (CRM) working group.

- Coordinated with SCEC IT group to support their development of UCVM-based tool (UCVM-GF) for accessing the GFM. This included provisioning of gridded model versions suitable for use in UCVM-GF, benchmarking UCVM-GF output, and supporting the development of enhancements to the software platform.

These efforts have led to the completion of the first generation GFM and its provision through the UCVM framework. Our proposed efforts involving the CVM and GFM were combined in this proposal as they represent elements of the SCEC Unified Structural Representation (USR).

This project represents a collaboration between the Associate Director for IT (Maechling), CXM software developer (Mei-Hui Su), Community Velocity Model (CVM) planners and developers (Plesch, Shaw, and Jordan), and GFM/CTM researchers and developers (Hearn, Oskin).

2. CVM Basin Models

SCEC currently supports three regional velocity models (CVM-H, CVM-S4, CVM-S4.26). CVM-S4 includes rule-based parameterization of sediment velocities with crust and upper mantle velocity descriptions (Magistrale et al., 2000). This model was used as starting point for full 3D waveform tomography with scattering-integral and the adjoint-wavefield methods to develop CVMS 4.26 (Lee et al., 2014). CVM-H includes geostatistical parameterizations of sediment velocities based on tens of thousands of direct velocity measurements with crust and upper mantle velocity descriptions defined by full 3D waveform tomography with spectral element and adjoint-wavefield methods (Tape et al., 2010). The CVM-H basin descriptions also include major faults represented in the Community Fault Model (CFM) (Plesch et al., 2007), and together comprise a Unified Structural Representation (USR) (Shaw et al., 2015). Thus, the SCEC models have different velocity descriptions, and several studies have highlighted their impact of on wave propagation simulations and other seismologic applications (e.g., Olsen, 2000; Taborda et al., 2014).

SCEC is currently engaged in planning for the next generation of CVM's through a Technical Activity Group (TAG). Following the recommendation of the TAG, we developed a set of velocity models for the major basins in Southern California that are independent of the current regional models (Figure 1). This helps address a significant limitation in that to access current basin models that are consistent with CFM faults, one must use the CVM-H model. However, a user can now combine these basin descriptions with CVM-S velocity descriptions, or to parameterize new models. In addition, this structure will promote the development and provisioning of alternative basin velocity descriptions (e.g., for the Salton Trough, LA basin) that could be implemented in new regional models and tomographic studies. This would help in evaluating and refining basin velocity descriptions, and enable model applications (e.g., CyberShake; Graves et al., 2011; Jordan et al., 2018) to employ the most accurate basin representations that are available rather than being tied to a given set of basin structures based on the regional models (e.g., CVM-S, CVM-H, or others).

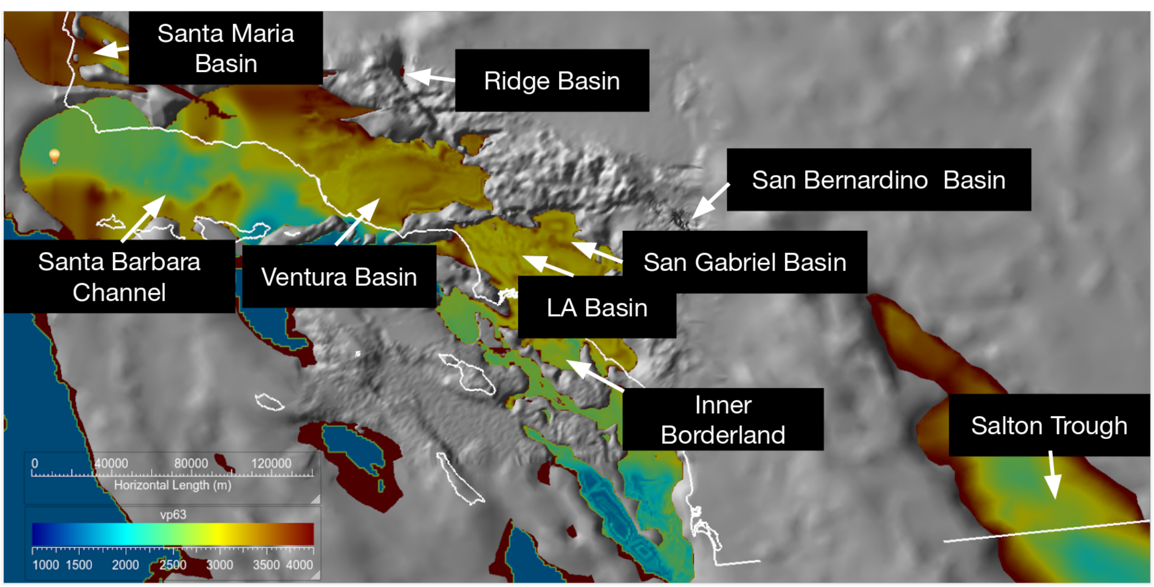

Figure 1: Horizontal section at -1700m elevation of CVM-H showing basin sediment Vp parametrizations (color scale) above the top of the basement surface (shaded grey). These and other basin representations will be refined and provided as stand-alone elements through UCVM as part of this proposal.

The basin models were carefully extracted from the existing regional CVM's using grid cell identifiers that denoted sediment velocity descriptions. These were then evaluated relative to bounding surfaces, including the top basement (i.e., sediment to basement transition). Finally, lateral basin boundaries were defined based on geologic structure. While some of the basins have distinct, natural boundaries (e.g., Salton Trough), others are more complex. For example, the boundary of the Inner Borderlands basin is transitional, both to the onshore Los Angeles and offshore Outer Borderlands. Thus, we used the locations of major faults in the SCEC Community Fault Model (CFM 5.3) and the geometry of basin structures to define natural limits (Figure 2).

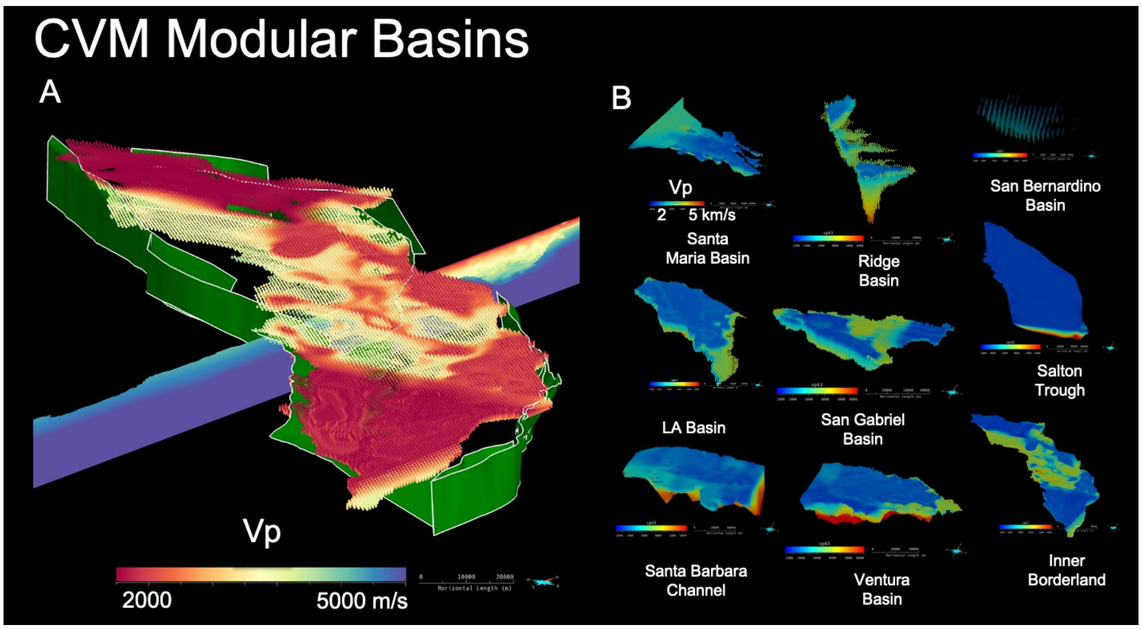

Figure 2: Perspective views of CVM basin models. A: The Inner California Borderlands model, showing Vp for basin sediments and regional faults from the SCEC CFM used to define the basin extent. B: Views of individual sediment basin models.

These models have been generated as a series of gridded voxets that will be made accessible through the UCVM framework. Associated surfaces (topography, sediment basement interface, bounding fault surfaces) will be made available through the SCEC CVM website.

3. GFM Framework

Developing appropriate descriptions of the rheologic behavior of the southern California crust and upper mantle is critical for wide range of SCEC modeling effort that span geologic to earthquake cycle time scales. Thus, SCEC has invested in the development of a Community Rheologic Model (CRM) that will provide suites of constitutive relations and thermal properties that are deemed viable for such efforts (Hearn et al., 2018). A central part of this process is the development of a Geologic Framework Model (GFM) that describes lithology in the crust and upper mantle of California that can be used to guide rheologic descriptions. In prior efforts, we worked collaboratively with Mike Oskin (UCR) and others to develop a first generation GFM that includes 23 lithologic regions and 41 tectonic domains. We also worked with PI Jordan to evaluate the relationship of the GFM regions to velocity characterizations in the SCEC CVM's using kmeans approaches (Eymold and Jordan, 2019).

In 2020, we prepared the first iteration GFM for use in the model querying and provisioning tool developed by SCEC IT (P. Maechling et al., 2020 - SCEC Poster 10315). A key element of this work was developing topologically precise, water-tight definitions of each model region. Such definitions help ensure that queries of the model in the neighborhood of faults or other regional boundaries return the correct lithologic definition and associated rheological properties. This is of critical importance in defining contrasts in rock and rheologic properties across faults, which is an important goal for the CRM and required to achieve reliable model output through the UCVM-GR framework (Fig. 3).

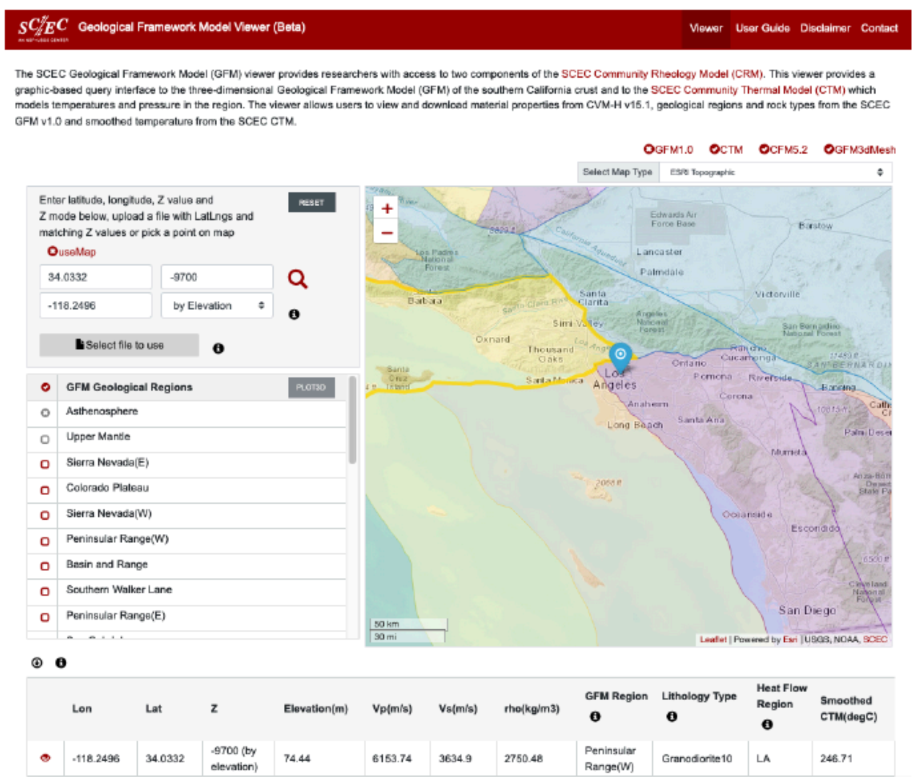

Figure 3: View of the Geological Framework Model Viewer developed by M.H. Su and P. Maechling. The left panel shows lithologic regions queried at an arbitrary x,y,z location, which is shown in the map viewer to the right. (from Maechling et al., 2020 - SCEC Poster 10315).

The next step was to develop and parameterize a series of regular grids within this framework that could store and deliver GFM properties. These grids were parameterized with Block ID, which are linked to data tables generated by the CRM working group that define associated lithologic and rheologic properties for those units. In this way, the GRM model parameterization can remain stable while additions and updates are made to the rheologic descriptions (we envision the latter to be an ongoing process). In addition, we parameterized the GFM grids with temperature from the Community Thermal Model (CTM) (Thatcher et al., 2019).

4. Application to SCEC5 Goals

Through its development of the Geological Framework Model that supports Community Rheologic Modeling efforts, the proposed work helps to address the following SCEC priorities, (among others):

P1.b: Determine the spatial scales at which tectonic block models provide descriptions of fault-system deformation that are useful for earthquake forecasting.

P3.b: Constrain the active geometry and rheology of the ductile roots of fault zones.
Moreover, through improvements to 3D velocity models, the proposed work helps to:

P4.a: Determine the relative roles of fault geometry, heterogeneous frictional resistance, crustal material heterogeneities, intrinsic attenuation, shallow crust nonlinearities and ground surface topography in controlling and bounding ground motions.

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