**Workshop Project Report**
**SCEC Award 19195**

# 2019 Community Rheology Model Workshop: Testing and Refining the Preliminary CRM

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The 2019 SCEC Community Rheology Model (CRM) workshop was held May 5, 2019 in Palm Springs, immediately before the annual leadership retreat. This focused, invitation-only workshop brought together deformation modelers who are likely to be users of the preliminary CRM; as well as representatives from the CXM and CRM focus groups,and SCEC IT. Approximately 20 attendees were present at any given time (we had some late arrivals and other attendees were in and out of the meeting due to other commitments). Prior to the workshop, the conveners conducted a phone poll of modelers (some of whom also attended the workshop) to seek feedback on design and implementation of the preliminary CRM. Results of that poll are attached to this report.

During the morning, the workshop conveners gave presentations of the current status of the CRM, and Tom Jordan (USC) gave a guest presentation on applying machine learning to the SCEC CVM to constrain geologic framework lithologies and regional structure (see Agenda below). The afternoon began with two motivating science talks. Sylvain Barbot (USC) and Eric Dunham (Stanford) described their research on postseismic deformation and fault zone seismic cycles, how they would make use of the CRM in their research, and suggestions for the CRM.

Three afternoon discussion sessions followed the science talks. Each was devoted to a question from a phone survey of deformation modelers conducted by the CRM PI's in February and March (see questions and responses below). Roland Burgmann (Berkeley) led the first discussion on rheologies the CRM should include, after briefly summarizing the plastic and ductile continuum rheologies most commonly used by modelers. John Shaw (Harvard) gave a short presentation on the CRM Geological Framework (GF) to lead into discussion of the second question, how the CRM should be stored and queried. He showed a gridded ("Lego") version of the GF, which is to be incorporated into the UCVM pending discussion and approval of the community. Scott Marshall (Appalachian State) led the discussion of CRM format, storage and access, as well as delivery of a "minimum viable product" in time for the Annual Meeting. The

third question, on SCEC community models modelers do and don't use (and why) was addressed more briefly in a discussion led by Liz Hearn.

Throughout the meeting there was much discussion, and a summary of some of the main suggestions, concerns and questions is given below. (Two files with Liz Hearn's notes from the discussions are archived at the Google Drive: https://drive.google.com/drive/folders/1agd-o8x_2GbrO-tpQZdf2y6DeWuI9KI8.)

Main points raised by the workshop attendees are listed below. An asterisk means this task/topic may be appropriate for SCEC research via the annual proposal process, rather than the responsibility of those of us who are putting together the CRM.

- The CRM needs a continuum plastic rheology and fault friction (mu and (a-b)). Pore pressures will be important where these rheologies are applied but the CRM should not specifically supply them. (*note - this would be after the ductile CRM is developed*)

- Format should be simple, e.g. ASCII tables, because modelers will be using a variety of codes and generating CRM inputs in correct format for each is beyond our scope. Lookup tables for GF lithologies, and tables of CTM temperatures and high- and low-strain flow law coefficients were suggested.

- Modelers prefer tools to a gridded effective viscosity product. Tools could interpolate a gridded (UCVM) product to generate effective viscosities (for example) at user-specified locations, and to explore the effects of parameter uncertainties.

- After discussing what the CRM product is, there was agreement that constitutive relationships and a 3D representation of lithologies together form a set of "rules" for generating rheologies. These "rules" represent a synthesis of current knowledge of southern California lithosphere materials, state, and likely constitutive relationships. Hence, they are a stand-alone product.

- The CRM needs to incorporate transient (e.g. Burgers) rheology.*

- CRM and CTM are coupled products so we must make sure that they are consistent with each other.*

- Shear zones should be optional components of the CRM. For the initial CRM, shear zone specifications could be made solely for major shear zones (e.g. the SAF). A "strong shear zone" end-member model would just leave CRM shear zones out.

- Modelers expressed concern about abrupt temperature transitions between CTM regions, and schemes for diffusing the temperatures laterally or smoothing the T field were discussed.

- Modelers also were concerned about uncertainties in flow law parameters and temperatures, and propagating these uncertainties. However, using different mixing laws to assemble whole-rock flow laws can affect resulting effective viscosities even more than uncertainties in individual mineral flow law parameters, or temperature. This means being too concerned about uncertainties in these flow law parameters is like rearranging deck chairs on the Titanic. One possibility: allowing ranges in parameters, but requiring triads of stress, strain rate and temperature triads to fall within a specified range at select locations.

- Modelers suggested we not release preliminary CRM that is not consistent with Mojave earthquake postseismic deformation.*

- Modelers requested a paper to cite for the CRM and new DOI's with major updates.

- Modelers support incorporating a gridded Geological Framework into the SCEC UCVM.

Many other comments on science being presented and other topics are not relayed here but are noted in the summaries at the Google Drive mentioned above.

Following the workshop, the CRM PI's held our fourth conference call of 2019 and outlined our summer activities, as informed by our previous planning and modelers' suggestions from the phone poll and the workshop. Mike Oskin will work with John Shaw and Andreas Plesch to build a first-cut gridded representation of the Geological Framework for inclusion in the UCVM. Greg Hirth and Laurent Montesi will deliver a pre-packaged mixing model and mineral flow laws, from which whole-rock flow laws for GF lithologies may be constructed. Wayne Thatcher will complete a draft CTM taking into account non-steady heat flow. Liz Hearn will assemble ASCII tables of CTM and CRM parameters, and develop simple lookup tools linking user-supplied coordinates to CTM heat flow region and temperature, and GF province and lithology (to be superseded by UCVM tools). Together, these components will form (1) a set of "rules" synthesizing our community's understanding of southern California lithosphere rheology, based on its materials, state, and structure, and (2) tools to help modelers query this information and represent it in deformation models. Once this preliminary model is in place, we will begin work on suggested refinements and additions (e.g., adding plastic rheology, incorporating uncertainties, diffusing CTM temperatures, working with SCEC IT on UCVM query tools, and preparing a manuscript).

**Agenda**

**2019 SCEC Community Rheology Model Workshop: Testing and Refining the Preliminary CRM**
**5 May 2019 - Palm Springs Hilton**

8:30-9:00 Workshop Check In

Session 1: Introduction and the preliminary CRM

9:00 - 9:30 Introduction and overview *Elizabeth Hearn, Capstone*

9:30 - 10:00 CTM: Summary and pre-SCEC Deliverables *Wayne Thatcher, USGS*

10:00-10:15 Break

10:15 - 10:45 Geological Framework: Summary and pre-SCEC Deliverables *Michael Oskin, UC Davis*

10:45 -11:15 Presentation on tectonic regionalization of southern CA using the SCEC CVM and cluster analysis *Tom Jordan, USC*

11:15 - 12:00 Provisional Rheologies: Summary and pre-SCEC deliverables *Greg Hirth, Brown*

12:00 - 1:00 Lunch

Session 2: Using, Testing, and Improving the CRM

1:00 - 1:45 "Constitutive law and parameters for lower-crustal flow in the Salton Trough, Southern California" *Sylvain Barbot, USC*

1:45 - 2:30 "A vision for utilizing CRM products in earthquake sequence simulations" *Eric Dunham, Stanford*

2:30 - 3:00 Break

3:00 - 5:00 Focused Discussions (ALL)

- Which rheologies do we use and which do we want for the CRM?
  *Roland Burgmann, Berkeley*: facilitator; *Liz Hearn*, recorder
- CRM nuts and bolts: tools, format, versions and access
  *Scott Marshall, Appalachian State*: facilitator; *Liz Hearn*, recorder
- Other SCEC community models we do and don't use: What can we learn?
  *Liz Hearn*, facilitator; *Wayne Thatcher*, recorder

**Attendees (* indicates remote)**

Kali Allison (Maryland), Sylvain Barbot (USC), Yehuda Ben-Zion (USC), Peter Bird (UCLA), Roland Bürgmann (UC Berkeley), Judi Chester (TAMU), Eric Dunham (Stanford), Yuri Fialko (Scripps), Elizabeth Hearn (Capstone Geophysics), *Greg Hirth (Brown University), Kristel Izquierdo (Maryland), Tom Jordan (USC), Mark Legg (Legg Geophysical), Phil Maechling (USC), Scott Marshall (Appalachian State), *Laurent Montesi (Maryland), Michael Oskin (UC Davis), Fred Pollitz (USGS), Wayne Thatcher (USGS), Max Werner (drop-in; Bristol)

**Deformation Modeler March-April 2019 phone poll results with names redacted from individual responses. Responses are paraphrased from notes.**

**We obtained responses to at least one question from Sylvain Barbot, Eric Dunham, Thorsten Becker (one question), Kali Allison, Yuri Fialko, Roland Bürgmann, Kaj Johnson, Peter Bird, and Charles Williams. We tried but failed to reach Gene Humphreys and Bridget Smith-Konter.**

**(Original Google Doc link can be made public if modelers give permission.)**

**1. What are you using right now as rheologies and what would you like the CRM to provide to improve them?**

-Upper crust is elastic/plastic with Drucker-Prager yield criterion
-Ductile Lithosphere uses Hirth et al 2003 flow laws for olivine, feldspar...
-Has written a 2019 SCEC proposal to do SoCal modeling where rheology is important. -Requests that CRM rheology products be in SIMPLE formats. He has definite ideas about what'd be most useful for his research and hopes to begin his SCEC project before May workshop.
-Provided Liz with a table with plastic and ductile rheologies assumed in his past research papers. Uses a vertical avg of properties and then partitions estimates of stresses, velocities etc. with depth using 1D rheological profiles. Typical profiles are elastoplastic in upper crust and viscoelastic at depth with various feldspar and olivine rheologies. The preliminary CRM with 1D lithology and rheology profiles in different regions can be used by Shells now. By writing additional code he could handle fully 3D CRM with dipping interfaces.
-Interested in the heat flow map and lithosphere thickness estimates that are part of the CTM, but he prefers to compute his own geotherms.
-Expressed enthusiasm for the CRM, is glad we are putting it together and would likely make use of it.
-Current focus is elastic (making Greens functions). In past, linear and nonlinear viscoelastic, some elastoplastic modeling. Works mostly in NZ, not likely a heavy user of CRM except in collaboration. Suggests I contact Brad Aagaard, he might be able to write Python code to automatically link CVM and gridded version of CRM directly to PyLith.
-Has new project with US and Japanese colleagues to develop Greens functions for southern CA. 3D Maxwell VE, could also incorporate transient (e.g. Burgers) rheology. They definitely want the preliminary CRM (including the CTM) for this project, which they are working on now.
-Uses a range of viscoelastic and plastic rheologies, depending on quality of available data and target problem.
-Uses layered structure usually, transient and power-law viscoelastic materials, is interested in CRM products and wants transient rheology (Burgers parameters) to be part of the CRM

**2. Do you prefer to get the CRM on a pre-defined grid or would a query tool to extract CRM information at points of your choosing (e.g. model element centers) be better?**

-Probably wouldn't use a regular 3D grid, just CRM products to guide semi-generic 2D modeling (e. g. Mojave CRM rheology)
-Likes the idea of simple tools to access CRM databases and recommends the CRM group take advantage of existing SCEC CME and be sure our data formats are compatible with it ("Don't reinvent the wheel").
-Grids save steps for people who are using it to make maps/graphics. He could use either tools or grids.
-At first he said "grids", then he changed his mind and said either approach would work. He suggested a sensitivity study to see whether sharp rheology interfaces matter. If not then a gridded product with smooth effective viscosity transitions could work. (EHH - Maybe for ductile rheology at depth, if we are delivering eff viscosity)
-A grid of pre-computed effective viscosities would be exactly what they could use to generate Greens functions. A tool with a set of rheologies etc. would be good as well because they want to explore a range of reasonable effective viscosity structures in collaborative project.
-Prefers a query tool to a grid.
-Query tool is more flexible for studies with different levels of complexity.
-Sees no point in a gridded CRM. Tool should be compatible with SCEC CME.
-Interested in CRM flow laws, served in a consistent manner (so presumably a tool rather than a grid of effective viscosities - EHH)

**3. Do you already use the CVM, CFM, or other SCEC community models in your research? If so, which ones and how?**

-No, doesn't use any SCEC Community Models Has used CVM and some aspects of CME.
-No. In the past he used a simplified version of an old SCEC CFM (rectangular patches) that was adopted for the UCERF3 study.
-Used very old gridded CVM on a past project, predates the variable grid density CVMs and the UCVM. Was in collaboration with Carl Gable at LLNL and Brad Hager at MIT, also used now-defunct Community Block Model (unsuccessfully? I was there and I don't think anyone ever made it work -EHH). Currently all research is in NZ. He generates his own geometry (for sub zone), and downward extrudes mapped traces of crustal faults (less info available than for CA)
-Paper in review on Ventura region makes use of the latest CFM (regularized fault surfaces from Scott Marshall). Collab. project will make use of the CVM to assign 3D elastic structure to southern CA and the CFM as earthquake sources for so Cal Greens functions.
-Uses CVM to assign elastic parameters, uses CFM (how?). Is especially looking forward to using the CTM. Uses UCERF3 fault geometries, no other CXM's.