SCEC has developed six community models. The Community Rheology Model (CRM) is the latest.

The CRM is a three-dimensional representation of the rheology of southern California’s lithosphere, informed by available geophysical and geological data.
Non-unique estimates of southern CA viscosity from models

<table>
<thead>
<tr>
<th>POSTSEISMIC</th>
<th>lower lithosphere effective viscosity Pa s, Maxwell if not otherwise indicated</th>
<th>references</th>
</tr>
</thead>
<tbody>
<tr>
<td>El Mayor-Cucapah M 7.2</td>
<td>heterogeneous, Maxwell or power-law. 1-3 e18 Pa s mantle and (local) lower crust</td>
<td>Rollins et al, 2015; Gonzalez-Ortega et al., 2014; Pollitz et al., 2012</td>
</tr>
<tr>
<td>Central Nevada Quakes M 6.9 - 7.4</td>
<td>1e18 to 1e19 Pa s</td>
<td>Hammond et al., 2009</td>
</tr>
<tr>
<td>Landers and Hector Mine M 7.4 and 7.2</td>
<td>1e18 to 1e20 Pa s; Maxwell, power-law and/or transient flow laws with assumed T; heterogeneous</td>
<td>Pollitz (2015 and earlier refs), Fialko, Freed…</td>
</tr>
</tbody>
</table>

| “LONG-TERM” DEFORMATION                         |                                                                                  |                                                      |
| So Cal                                           | From Kirby (1983) and computed T field, then perturbed to fit data              | Bird and Kong, 1994                                 |
| So Cal                                           | 4e19 to 1e21                                                                    | Li et al., 2009                                     |
| San Andreas                                      | 2e18 to 5e19 (below 70 km plate)                                                | Smith and Sandwell, 2004                           |

| EARTHQUAKE CYCLES                                |                                                                                  |                                                      |
| SSAF                                             | 2e19 - 1e21 layered and transient rheol. or 5e20 uniform Maxwell               | Hearn et al. 2013                                   |
| SoCal-wide                                       | 6e18 mantle, 2e20 lower crust                                                  | Chuang and Johnson, 2011                            |
| SSAF                                             | 0.1 - 3e20 mantle asthenosphere                                                 | Johnson and Segall, 2004                            |
| Carrizo SAF                                      | 2 - 5 e19 lower crust/upper mantle                                             | Schmalzle et al., 2006                              |

see also upcoming summary by Fred Pollitz (viscosity estimates, worldwide)
Preliminary CRM: *first step* beyond uniform or layered material properties and oversimplified rheologies in deformation models

- **temperatures:** community thermal model (CTM)
  - Wayne Thatcher
  - David Chapman

- **distribution of rock types:** 3D geologic framework (GF)
  - Mike Oskin
  - Mark Legg

- from laboratory experiments (etc.): rock and shear zone rheologies
  - Greg Hirth
  - Laurent Montesi
  - William Shinevar

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**Diagram:**

- Draft CTM
- Draft GF
- GF virtual workshop
- Draft Mojave CRM
- Sept 2017 CRM Workshop
- Revised CTM and GF
- 2018 Mojave CRM Workshop
- 2019 SoCAL CRM 1.0
- 2019 CRM Workshop
- 2021 CRM Science Workshop
- 2022 SCEC5 SoCAL CRM

**Timeline:**

- 2017
- 2018
- 2019
- 2020
- 2021
- 2022

**Events:**

- Teleconferences Coordination (PI’s)
- TAG research
- Coordination with SCEC CS
- Coordination with SCEC CXMs
- Revised CTM and GF
- 2018 Mojave CRM Workshop
- 2019 SoCAL CRM 1.0
- 2019 CRM Workshop
- 2021 CRM Science Workshop
- 2022 SCEC5 SoCAL CRM

**Notes:**

- (CXM unification guidelines?)
- TAG research
  Coordinate with SCEC IT and web
  Coordinate with other SCEC CXMs
  Teleconferences
  Virtual workshops
  Tutorials

- Final SCEC5 CTM and GF

**Timeline Notes:**

- on track for Sept 2019.
- today.
- (2018 CXM-CS Workshop)
  focused, one-hour meeting at 2018 SCEC Annual Meeting

**Move to 2020?:**

- move to 2020?

**Conference Calls:**

- monthly conference calls 2018-2019

**Additional Information:**

- Revised CTM and GF
- Final SCEC5 CTM and GF

**Additional Events:**

- 2018 Brittle Rheology Workshop
- 2022 SCEC5 SoCAL CRM

**Other Events:**

- 2018 Brittle Rheology Workshop
- 2017 Brittle Rheology Workshop

**Quoted from:**

- modified from our 2017 proposal
Southern California May Be Divided into 14 Distinct Heat Flow Regions

- geotherm for each heat flow region (HFR): 1 km intervals
- heat flow, thermal properties, LAB depth and other model data, avg values for each HFR
- documentation of steady and non-steady heat flow calculations and assumptions

Wayne Thatcher
David Chapman
Geologic Framework

GF province boundaries

lithologic columns and descriptions for each GF province

Felsic Rocks
- Sediments
- Franciscan Melange
- Schist
- Meta-Felsic

Intermediate Rocks
- Granodiorite / Tonalite
- Quartz Diorite
- Meta-Intermediate

Basic Rocks
- Basalt / Meta-Basalt
- Gabbro / Meta-Basic

Miocene to Pliocene
GF province boundaries

- Mike Oskin
- Mark Legg
Preliminary CRM Rheologies

Whole-rock rheology for rocks from modal mineralogy and mixing laws

OR expert consensus on suitable monominerallic flow laws (plural) to represent lithologies. A, n, Q* and V* for each rock type.

Shear zone rheology: dislocation creep of the weakest phase, guidance on shear zone effective width and other parameters

\[ \dot{\epsilon} = A \sigma^n e^{\frac{P V - Q}{R T}} f_{H_2O} \eta \]

- T from Community Thermal Model
- P from density\( \times g \times \)depth
- assume stress or strain rate
- CRM includes guidance on volatile content

Shear zone rheology: dislocation creep of the weakest phase, guidance on shear zone effective width and other parameters

- Greg Hirth
- Laurent Montesi
- William Shinevar
A tool for using the CRM to generate effective viscosities: REOL_GUI

\[ \dot{\varepsilon} = A \sigma^n e^{\frac{PV - Q}{RT}} f_{H_2O}^r \]

CTM (or other) temperatures

“granodiorite/tonalite”

- Laurent Montesi

RHEOL-GUI (Montesi) is available via GitHub
Or just take the components and add them to your FEM. For example:

\[ \dot{\epsilon} = A\sigma^n e^{\frac{PV - Q}{RT}} f_{H_2O}^r \]

“granodiorite/tonalite”

- PyLith
- GAEA
Matlab routine to locate element center coordinate in a GF province or CTM HFR polygon
Matlab routine to locate element center coordinate in a GF lithology polyhedron

Use my CTM HFR and my GF province at each model element center, plus depth, to calculate effective viscosity for reference differential stress and CTM temp

For power-law flow, use reference stress, effective viscosity and stress exponent n with modeled stress to recalculate off viscosity for each time step

Not rocket science but maybe we could automate some of this
FE mesh with CRM domains. Extending the boundaries is an issue. Prescribe a way or not?

Flow Law + CTM temperatures

\[ \dot{\varepsilon} = A \sigma^n e^{\frac{PV - Q}{RT}} f_{H_2O}^r \]

“granodiorite/tonalite”

- PyLith
- GAEA
Matlab routine to locate element center coordinate in a GF lithology or CTM HFR polygon
What do modelers want from the CRM - for example, prix fixe or a la carte?

- a grid of effective viscosities calculated from rock rheologies and CTM temperatures at reference strain rates?

- tools for using all or some CRM components in your own models?

- both? (we have limited resources)

We will discuss these and related questions during the afternoon discussions.
Deformation modeling can inform the CRM, so let’s think of some project ideas for the RFP

How sensitive is surface deformation to ductile and brittle rheology variations? Do such variations affect model-inferred slip rates or crustal stresses?

Do sharp contrasts, small-scale heterogeneities or material anisotropy observably influence crustal deformation? What level of detail or precision is needed for the GF?

How can we prioritize future additions to the CRM based on modeling?

Are community models consistent with each other, e.g. the CGM, CSM and CRM? Do GF rock types make sense w/r/t the latest CVMs?
Agenda

Session 1: Introduction and the preliminary CRM
9:00 - 9:30   Introduction and overview  Elizabeth Hearn
9:30 - 10:00  CTM: Summary and pre-SCEC Deliverables  Wayne Thatcher
10:00-10:15   Break
10:15 - 10:45 Geological Framework: Summary and pre-SCEC Deliverables  Michael Oskin
10:45 -11:15  Presentation on tectonic regionalization of southern CA using the SCEC CVM and cluster analysis  Tom Jordan
11:15 - 11:45 Provisional Rheologies: Summary and pre-SCEC deliverables  Greg Hirth (remote)
11:45 - 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”
              Invited Talk and discussion (Sylvain Barbot, USC)
1:45 - 2:30   “A vision for utilizing CRM products in earthquake sequence simulations”
              Invited Talk and discussion (Eric Dunham)
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, facilitator; Liz Hearn recorder)
              - CRM nuts and bolts: tools, format, versions and access  
                (Scott Marshall, facilitator; Liz Hearn, recorder)
              - Other SCEC community models we do and don’t use: What can we learn?  
                (Liz Hearn, facilitator; Wayne Thatcher, recorder)
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.