Preliminary SCEC Community Rheology Model

SCEC — AN NSF+USGS CENTER

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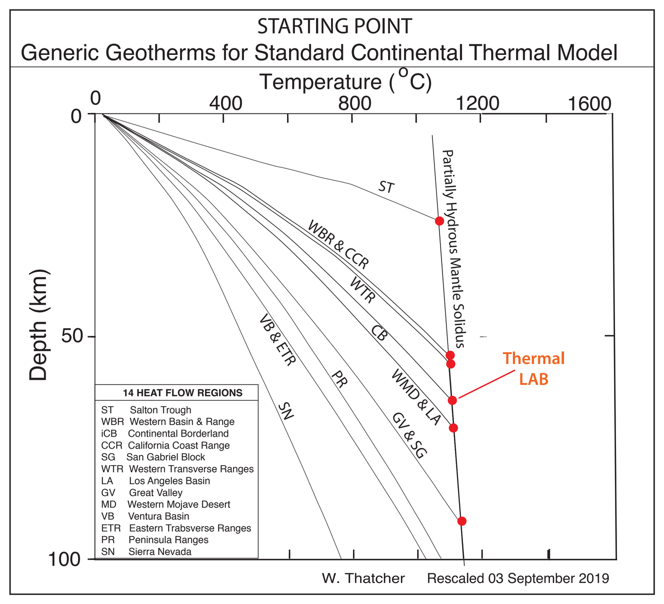
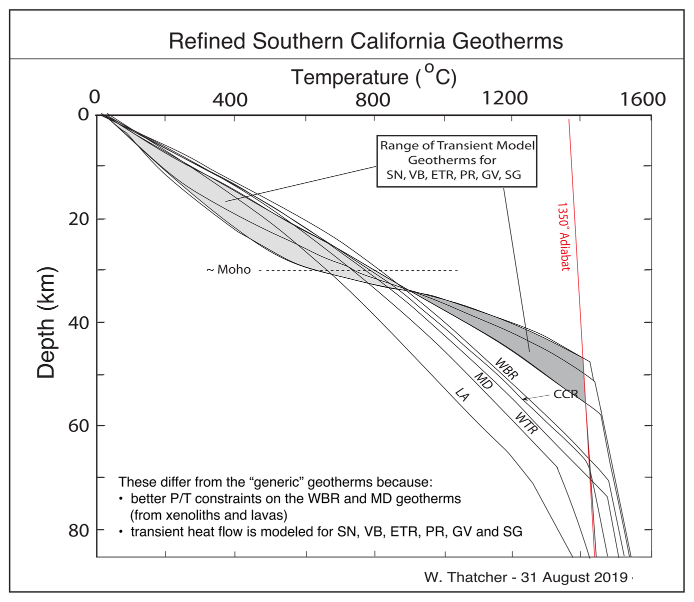
The SCEC Community Rheology Model (CRM) is a three-dimensional description of the rheology of southern California's lithosphere, based on an ongoing synthesis of data from a wide range of sources. These sources include but are not limited to seismic imaging studies, rock deformation experiments and theory, regional-scale geological mapping, detailed descriptions of rocks (petrology and fabric), and thermal modeling constrained by surface heat flow data and depth to the seismic LAB. During the SCEC5 period we have been assembling a preliminary version of the CRM that makes use of a simplified representation of the regional geologic and thermal structure. This *preliminary* CRM comprises a thermal model (CTM), a geologic framework model (GFM), and viscous rheologies for each of the GFM rock types. The preliminary CTM and GFM are depth profiles of temperature and lithology, respectively, assigned to geographic subregions. Viscous flow laws for each GFM rock type have been developed, based on mixing relationships and rheological information for the component minerals. We are in the process of integrating these components for distribution via the SCEC UVCM framework and other formats.

Community Thermal Model (CTM)

Refined Community Thermal Model (CTM) geotherms are very different and much improved from generic starting model



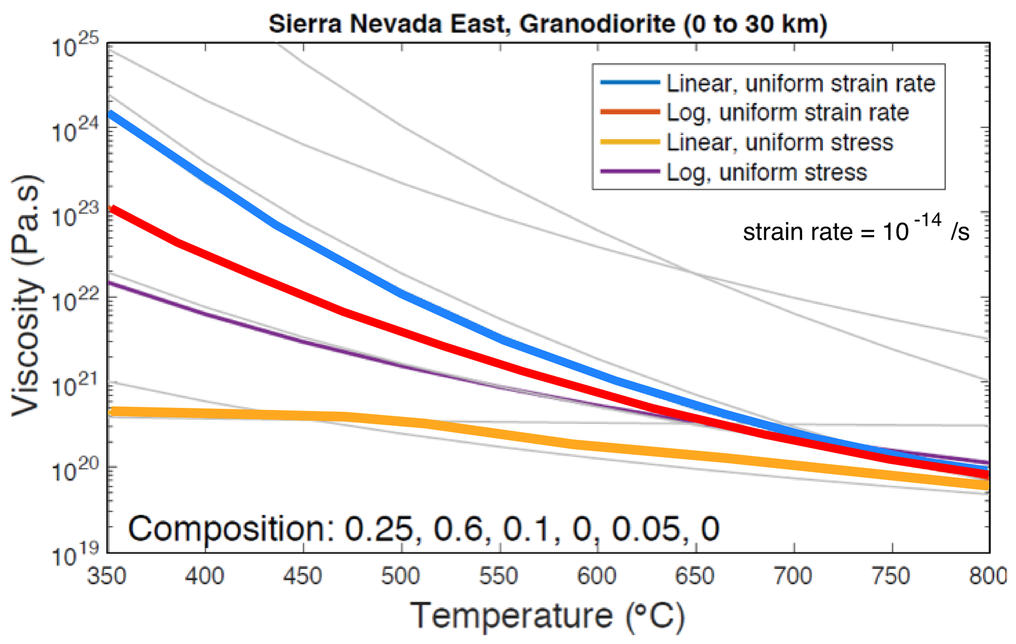


- Narrower temperature range than generic geotherms
- Almost all SoCal has warm crust and upper mantle lid
- LAB temperature is warmer too: 1200˚ - 1400˚ C

Important implications for CRM: Less lateral rheological variation

Rock Rheologies

- Mineral flow laws are specified for feldspar, quartz, pyroxene, olivine, biotite and amphibole (table below)
- GF "rocks" are defined by % of these minerals, per GFM lithology descriptions
- Aggregate viscous rheology is calculated from mixing relations, assuming dislocation creep (box below)
- Viscosity and rock type estimates based on the SCEC CVM and thermal models are also being incorporated into the gridded GFM (Shinevar et al., 2018)



Viscosity for granodiorite/ quartz diorite, calculated with four different mixing assumptions

- Quartz 25%
- Feldspar 60%
- Amphibole 5%
- Mica 10%

Effective viscosity for granodiorite exceeds 10^20 Pa s at temperatures typical for the lower crust (450-780°C at 25-30 km depth, per CTM). Mixing law choice matters, though less at high temperatures.

For non-shear zone rocks, we recommend the Huet et al. (2014) mixing law and assume uniform strain rate (result is similar to average of red and blue lines on figure above). For shear zone rocks, the linear, uniform stress relationship (orange line on figure above) is recommended. Note that shear zone strain rate will be about 100 times higher than assumed above, resulting in much lower effective viscosities than indicated by the orange line.

Consensus major mineral flow laws for the preliminary CRM

Mineral	Quartz	Feldspar	Biotite	Pyroxene	Amphibole	Olivine
RHEOL code	HTD01	RD06wd	Kr90	DD05Dd	HC90amp	HK03dw
Reference	Hirth, Teyssier and Dunlap, 2001, quartzite	Rybacki and Dresen 2006, wet An100 in dislocation creep	Kronenberg et al., 1990, biotite dislocation creep	Dimanov and Dresen 2005, wet diopside, dislocation creep	Hacker and Christie, 1990, Amphibole	Hirth and Kohlstedt, 2003, wet olivine, dislocation creep
Category	2 (function of T and fw)	6 (function of T, P and fw)	1 (function of T)	1 (function of T)	1 (function of T)	6 (function of T, P and fw)
Strain rate	R=@(s,T,fw)(s/B).^n.*exp(-Q./(RG*T)).*fw.^p	@(s,T,P,fw)(s/B).^n.*exp(-(Q+P*V)./(RG*T)).*fw.^p	R=@(s,T)(s/B).^n.*exp(-Q./(RG*T))	R=@(s,T)(s/B).^n.*exp(-Q./(RG*T))	R=@(s,T)(s/B).^n.*exp(-Q./(RG*T))	@(s,T,P,fw)(s/B).^n.*exp(-(Q+P*V)./(RG*T)).*fw.^p
Stress	@(r,T,fw)B.*exp(Q./(n*RG*T)).*r.^(1/n).*fw.^(-p/n)	B.*exp((Q+P*V)./(n*RG*T)).*r.^(1/n).*fw.^(-p/n)	@(r,T)B.*exp(Q./(n*RG*T)).*r.^(1/n)	@(r,T)B.*exp(Q./(n*RG*T)).*r.^(1/n)	@(r,T)B.*exp(Q./(n*RG*T)).*r.^(1/n)	B.*exp((Q+P*V)./(n*RG*T)).*r.^(1/n).*fw.^(-p/n)
n	4	3	18	5.5	3.7	3.5
Q	135000	345000	51000	534000	244000	520000
V	0	38e-6	0	0	0	22e-6
B]	1.1941e+10	5.1951e+07	2.7013e+07	4.2398e+05	7.0505e+06	8.3362e+06
A	6.3096e-42	1.5849e-24	1.0000e-138	6.3096e-33	6.9405e-27	1.0095e-25
m	0	0	0	0	0	0
p	1	1	0	0	0	1.2

Example: flow law for non-shear zone granodiorite. Use Huet et al. (2014) equation for aggregate viscosity of rock with i mineral phases in proportions ϕ_i:

$$\eta_{aggregate} = \sum_i \frac{\phi_i n_i}{n_i + 1} \prod_i \left(\eta_i \frac{n_i + 1}{n_i} \right)^{\frac{\phi_i \alpha_i n_i}{\sum_i \phi_j \alpha_j n_j}}$$

$$a_i = \prod_{j \neq i} n_j + 1 = \frac{\prod n_i + 1}{n_i + 1}$$

After much math, this simplifies to a power law:

$$\eta_{huet} = 1.3934 \times 10^8 \exp\left(\frac{9376.1}{T}\right) \dot{\varepsilon}^{-0.7246} * f_w^{0.2551}$$

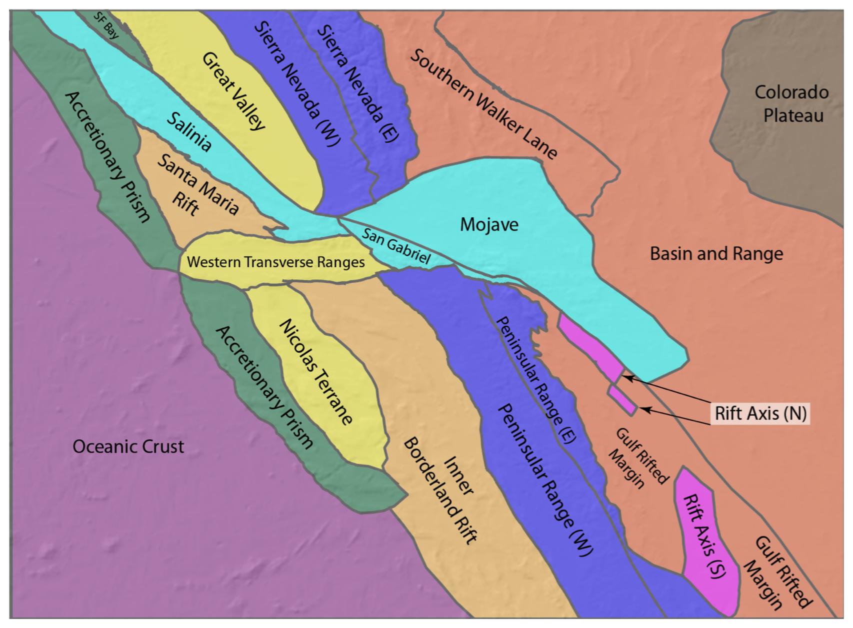
The CRM will include aggregate flow laws and guidance for each GF rock type, for low- and high-strain rocks. Some may require numerical solutions. Equations and parameter guidance for water fugacity (fw) will also be provided.

References:
Huet, B., P. Yamato, and B. Grasemann (2014), The Minimized Power Geometric model: An analytical mixing model for calculating polyphase rock viscosities consistent with experimental data, J. Geophys. Res. Solid Earth, 119, 3897–3924, doi:10.1002/2013JB010453.
Shinevar, W. J., Behn, M. D., Hirth, G. and Jagoutz, O. (2018), Inferring crustal viscosity from seismic velocity: Application to the lower crust of Southern California, EPSL, 494, 83-91.

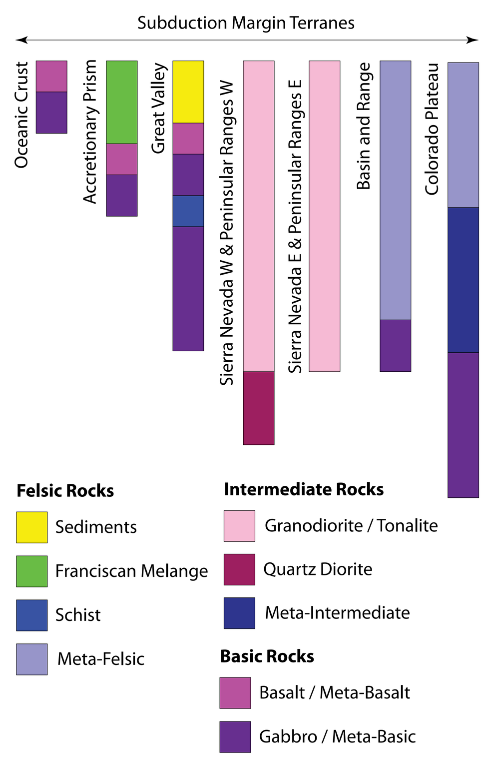
Geologic Framework Model (GFM) and query tool

Preliminary Geologic Framework Model (2018)

Geologic Framework Province Boundaries and Names



Lithology versus Depth: Preliminary GFM

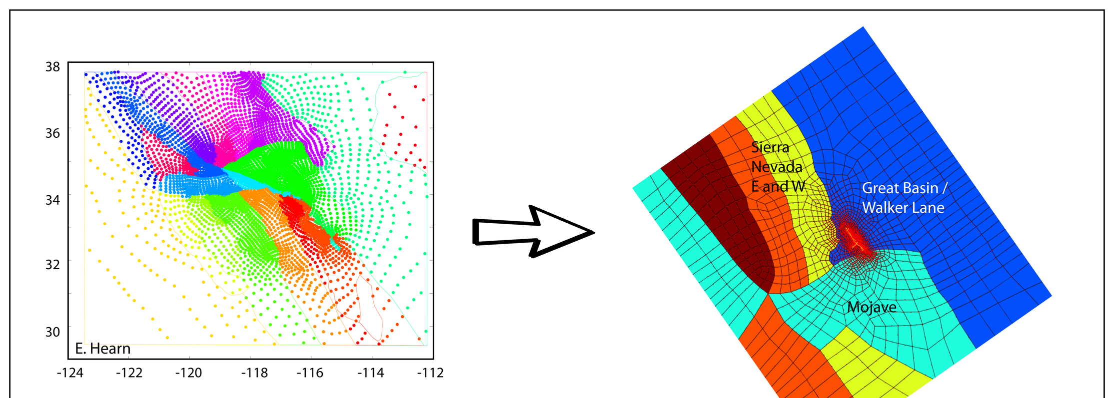


Note that some of these are the same for multiple (related) GF provinces

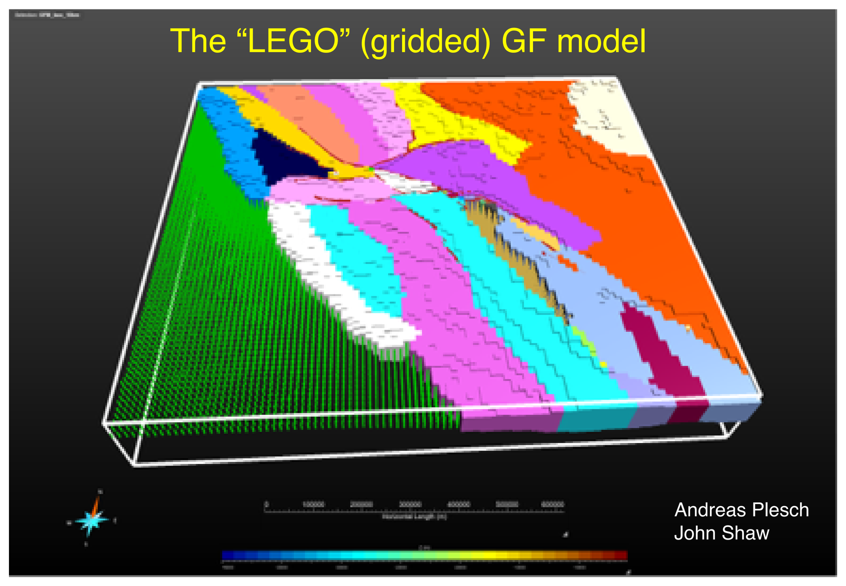
Examples of GF lithology descriptions for rocks in each province
Proportions of minerals are required to calculate whole-rock flow laws

CRM Crustal Columns										
Slab Format										
	DEPTH			Mineral %						
Domain	Start	End	Rock Type	Quartz	Feldspar	Mica	Pyroxene	Amphibole	Olivine	TOTAL
Sierra Nevada East	0	30	Granodiorite	25	60	10	0	5	0	100
Sierra Nevada East	30	35	Quartz Diorite	15	60	10	0	15	0	100
Sierra Nevada West	0	30	Granodiorite	20	60	10	0	10	0	100
Sierra Nevada West	30	40	Quartz Diorite	15	60	10	0	15	0	100

Gridded version of the GFM compatible with the SCEC UCVM



Each dot is an element center. A point-in-polygon test is used to assign a GF province to each element. Once the province is identified, a1D lithology profile can be assigned to model elements based on depths to their centers.

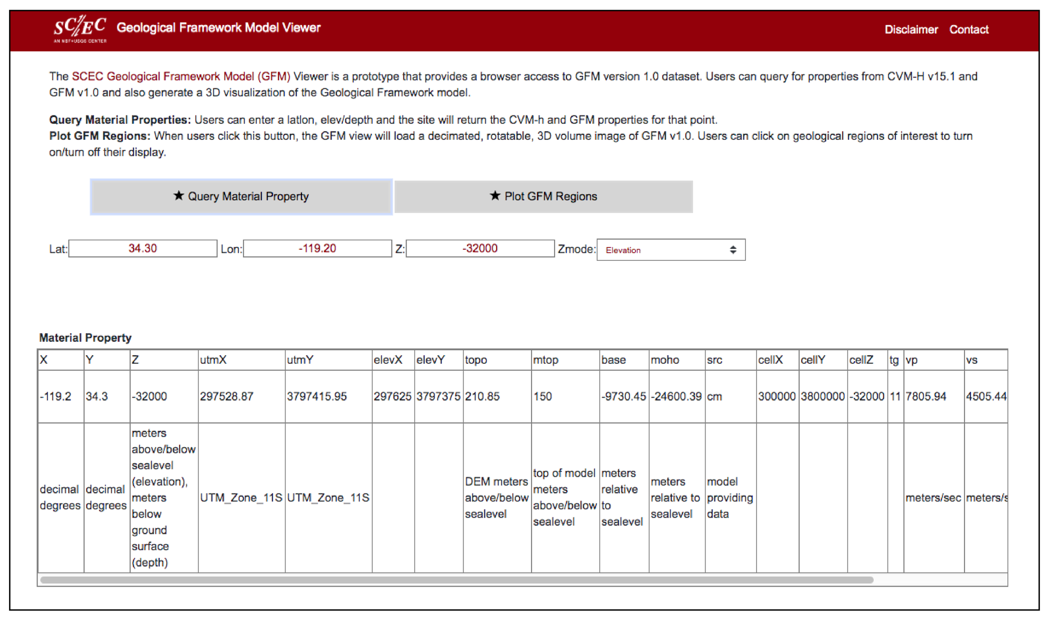


It is possible to use the GF model as is to populate a finite element model (for example) but the UCVM or similar will be needed as the GF moves beyond 1D lithology profiles within terranes with vertical boundaries). Hence, the gridded "LEGO" version (right) and the query tool (below).

Grid cell dimensions are 10 km x 10km x 1km. Depth of volume is 60km, will extend to 80+ km. Geo-referenced surfaces will include topography/bathymetry, sediment-basement boundary, bottom of seismogenic crust, Moho, and lithosphere/asthenosphere boundary. Lithology contact surfaces are defined within provinces.

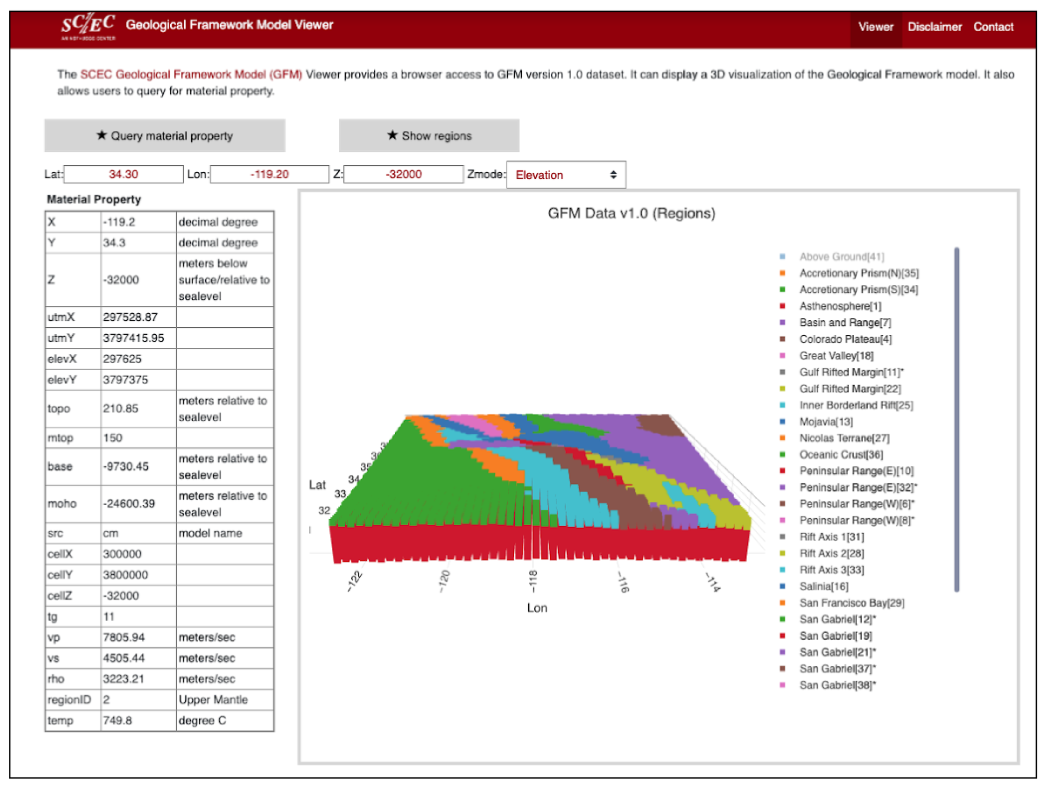
A GFM view and query tool is in development

Screen capture 1: querying the GFM



SCEC's software group expects to create a modified version of vx-lite to query the gridded GF's voxel data set. This modified vx-lite can be called by a higher-level program such as the UCVM. Retrieval of material properties for a given point will respect surface boundaries, possibly using a rule such as 'nearest neighbor' in the same lithological volume.

Screen capture 2: displaying the GFM (gridded version)



GFM view/query tool is being developed by Mei-Hui Su and Phil Maechling, with input from John Shaw, Andreas Plesch and Mike Oskin