From GMF to CRM

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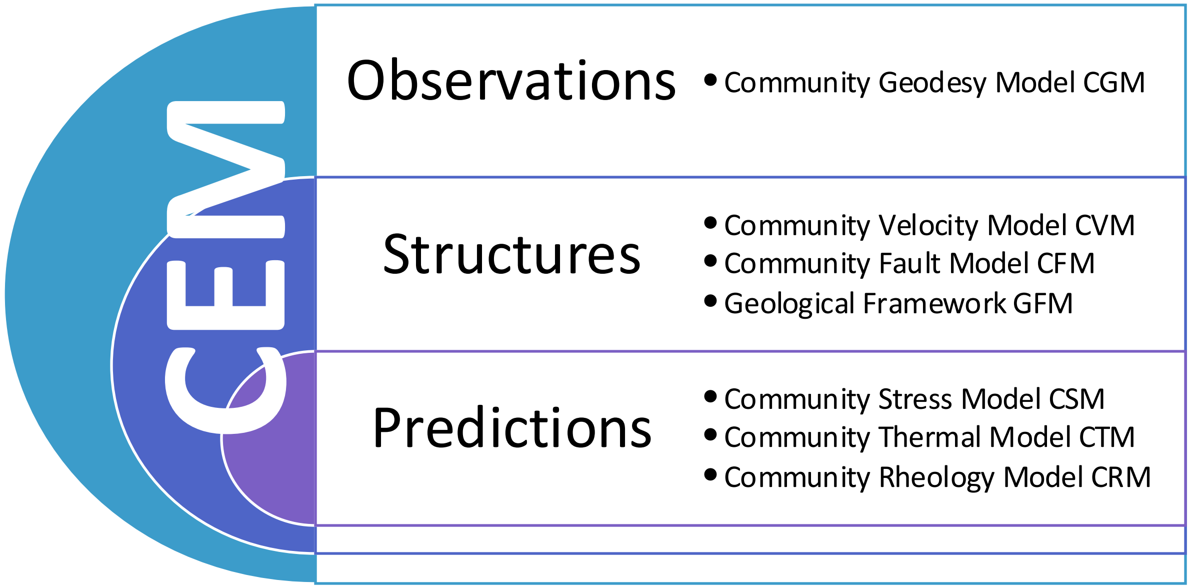
with material stolen from
Wayne Thatcher & Liz Hearn

SCEC's Community model ecosystem

Community models are built by working groups assembled within the agile and open organization of SCEC

Each model is a living product made publicly available for the benefit of the general public and the scientific community

https://www.scec.org/science/community-earth-models/



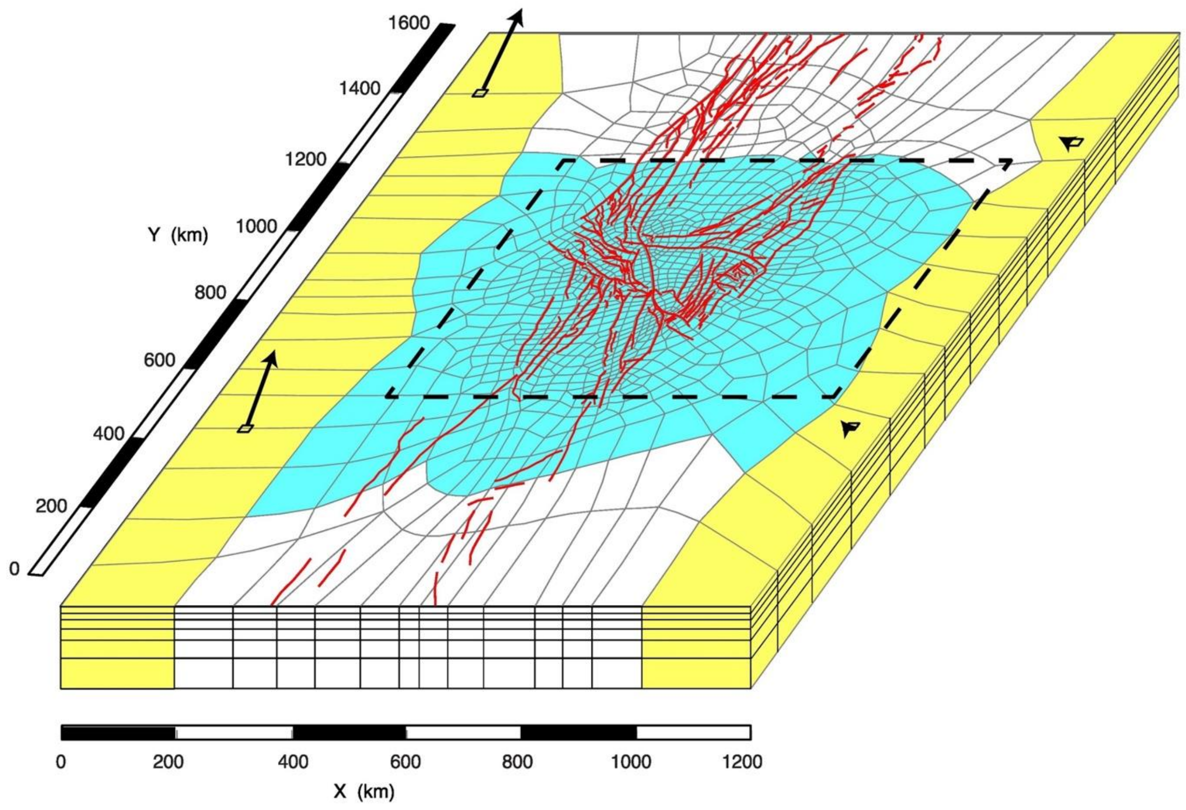
Why a rheology model?

Testing geodynamics concepts at all scale

- Stress transfer from one fault to another
- Origin of the state-wide stress field

Community Rheology Model (CRM) initiated in SCEC5

- q1. How are faults loaded across temporal and spatial scales?
- q2. What is the role of off-fault inelastic deformation on strain accumulation, dynamic rupture, and radiated seismic energy?



Hearn (2019) tectonophysics
DOI 10.1016/j.tecto.2019.02.016

Cover of 2019 workshop

History of the CRM

SCEC Workshop on Ductile Rheology of the Southern California Lithosphere

- May 1-2, 2013, Menlo Park, CA
- Conveners: Wayne Thatcher, Yuri Fialko, Liz Hearn, and Greg Hirth
- EOS Report: Thatcher et al. (2013) DOI 10.1002/2013eo320006

SCEC5 – 1 May 2017 to 30 Apr 2022.

- *Community Models.* We will enhance the accessibility of the SCEC Community Models, including the model uncertainties. Community thermal and rheological models will be developed.
- Working group: Hearn (lead), Thatcher, Oskin, Hirth, Behr, Legg, Montesi

Additional workshops and meetings (last: February 2023)

August 2020: First release Hearn et al. https://doi.org/10.5281/zenodo.4579627

What is a “rheology”?

Elasticity

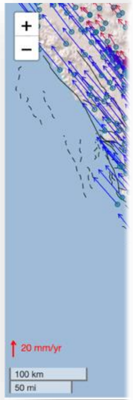
- Link to seismic velocity, stress transfer

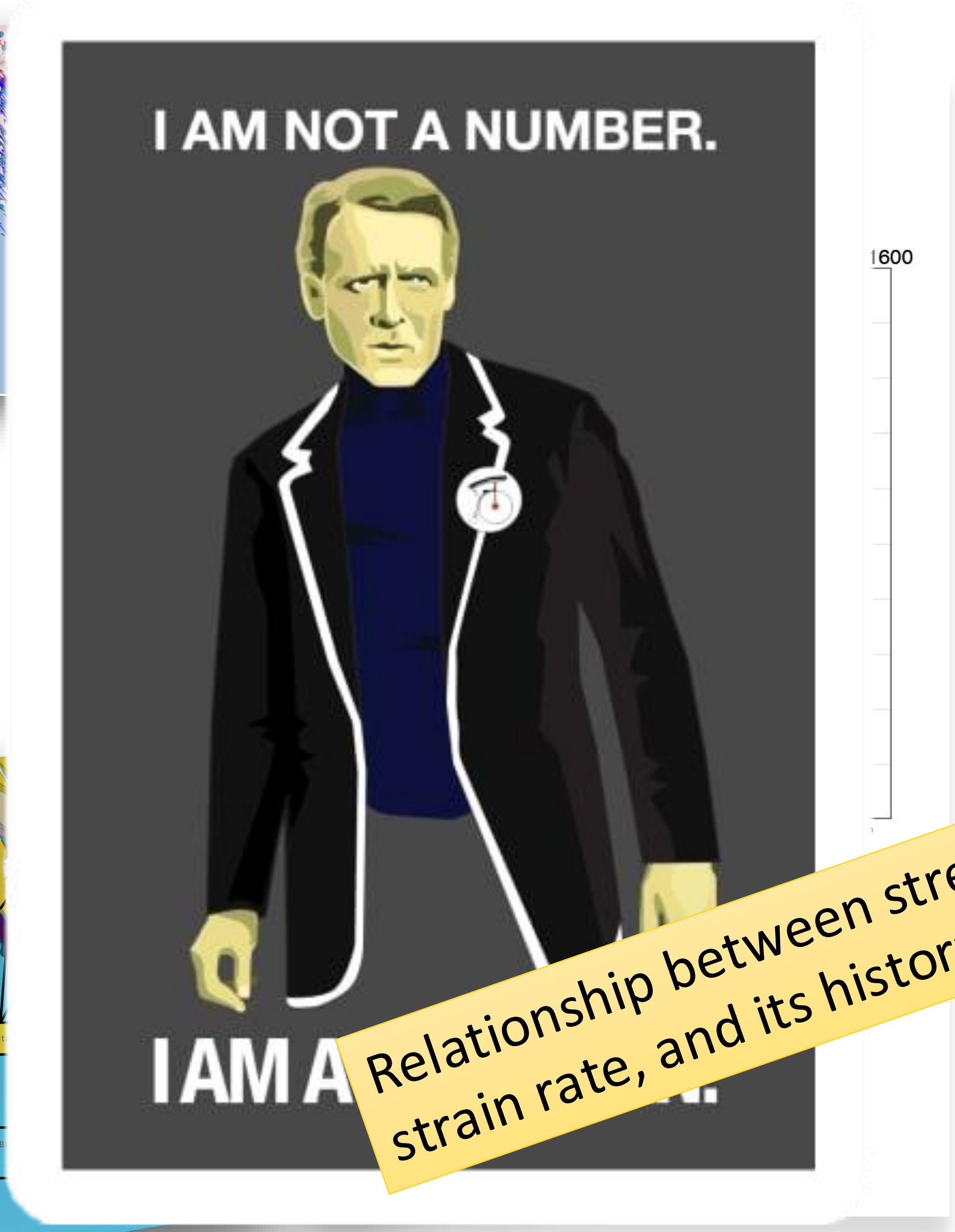
Frictional sliding

- Link earthquake cycle

Ductile flow law

- Link to long-term stresses
- $\sigma = f(\boldsymbol{\varepsilon}, \dot{\boldsymbol{\varepsilon}}, \boldsymbol{T}, \boldsymbol{P}, \boldsymbol{C}, F, g, C\_OH, \Xi \ldots)$





Relationship between stress, strain rate, and its history

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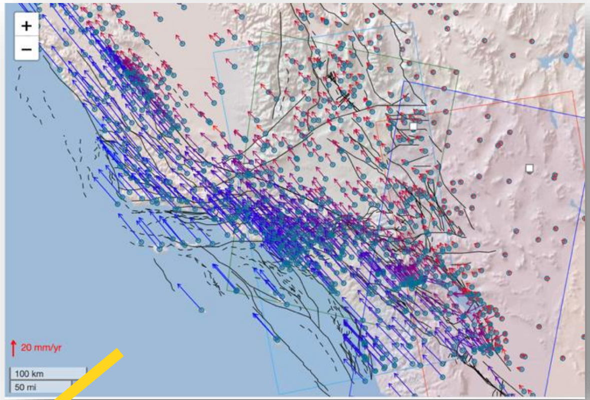
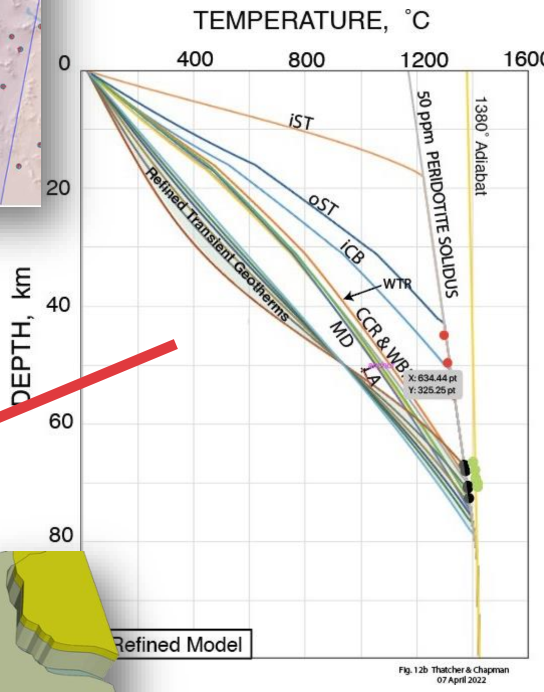
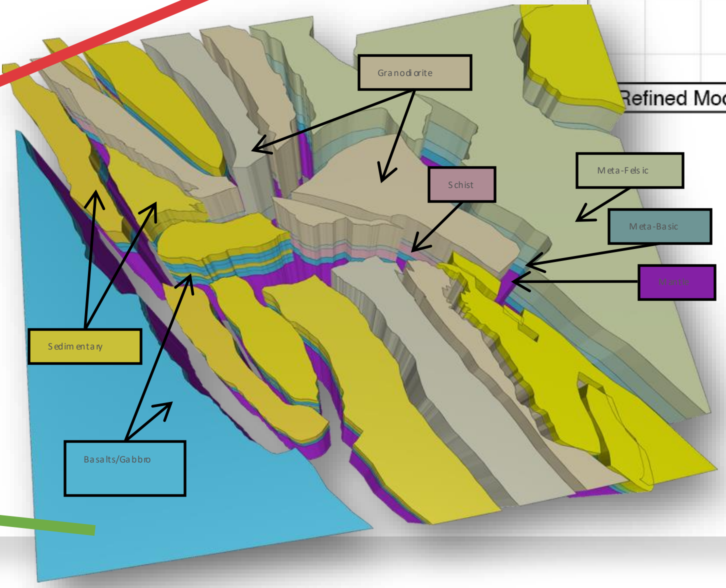




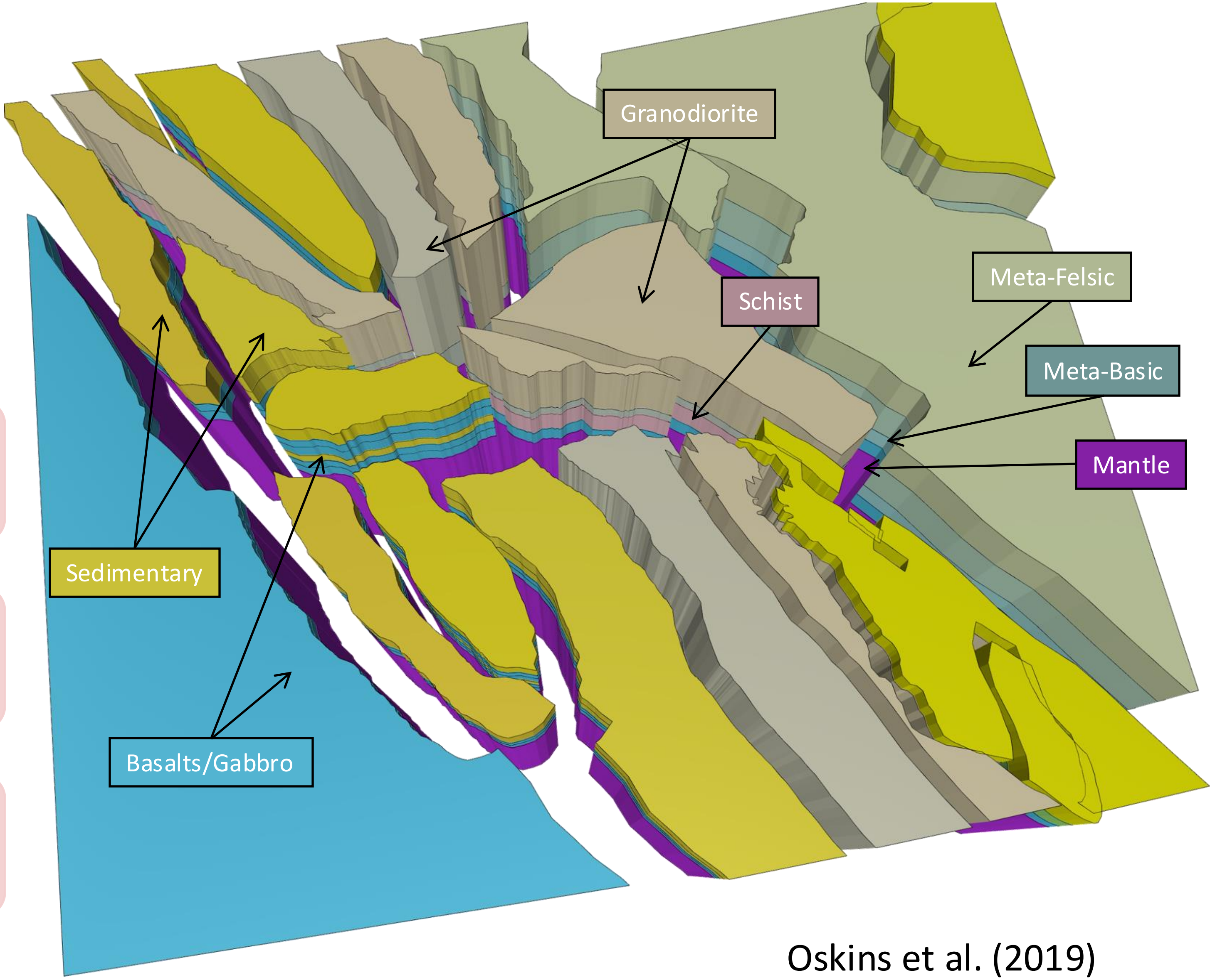


Building the Community Rheology Model

GFM: Geological Framework
- Lithotectonic blocks with stratigraphy
- Define flow laws for each rock type

CTM: Temperature Model
- Constrained by heat flow regions
- Includes transient effects

CFM: Fault Model
- Define the surfaces of the framework
- Associate friction laws



Oskins et al. (2019)

GFM: included in Hearn et al. 2020, https://doi.org/10.5281/zenodo.4579626
CTM: Thatcher et al., 2020, https://doi.org/10.5281/zenodo.4010834

How does lithology influence rheology?

Schist ©Richard Harwood
Gabbro ©Learning Geology
Granodiorite and peridotite ©James St. John

- Most lab work focused on fundamental physical mechanisms and “cleaner” mono-mineral samples
- Need rheological model
- Mixing relation
  - Logarithmic mixing (Ji et al., 2001) with Uniform strain rate
  - Minimize power (Huet et al., 2014)

Estimating rheologies

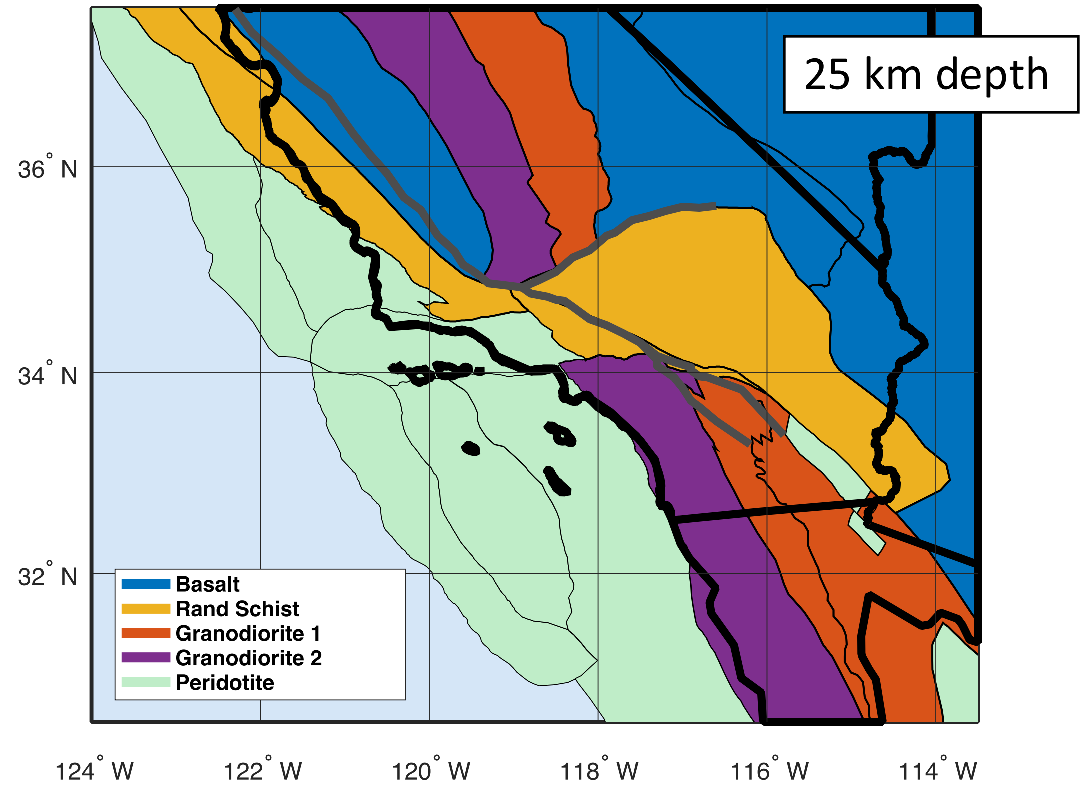
	n	p	Q [J/mol]	V [m]	B [Pa.s$^{1/n}$]	Reference
Quartz	4	1	13500		$1.1941 \times$ [illegible]	[illegible])
Feldspar	3	1	34500[illegible]	[illegible]	[illegible]	[illegible]06)
Biotit[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Kronenberg et al. (1990)
Pyroxe[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.2398×10^5	Dimanov and Dresen (2005)
Amphibo[illegible]	[illegible].7		244000		7.0505×10^6	Hacker and Christie (1990)
Olivine	3.5	1	520000	22×10^{-6}	8.3362×10^6	Hirth and Kohlstedt (2003)

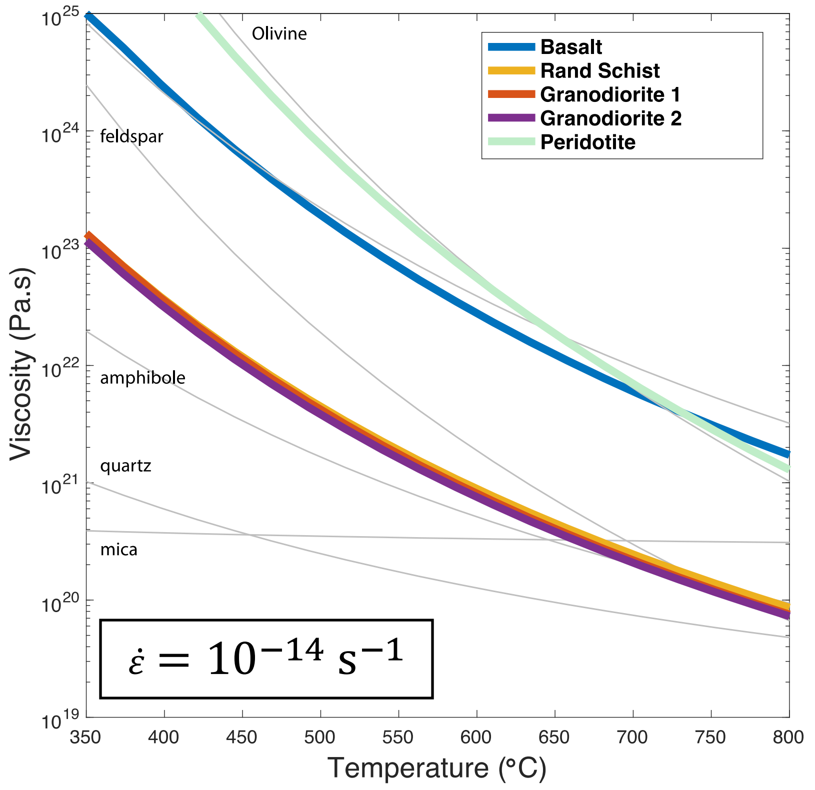
Do we need additional minerals for a statewide CRM?

- Each mineral is associated with a flow law:
  - Assumes dislocation creep: no grain size dependence (yet)
  - $\sigma = B\dot{\varepsilon}^{\frac{1}{n}} \exp\left(\frac{Q+PV}{nRT}\right) f_w^{-\frac{p}{n}}$
  - Assumes water saturation (Shinevar et al., 2018): $f_w = 5.521 \times 10^9 \exp\left(\frac{-31{,}800+10.09\times10^{-6}P}{RT}\right)$
- For non textured rocks (included in the initial CRM release)
  - Follow MPGe mixing relation of Huet et al., (2014):
  - $\dot{\varepsilon} = \left(\frac{\sigma}{\bar{B}}\right)^{\bar{n}} \exp\left(-\frac{\bar{Q}+P\bar{V}}{RT}\right) f_w^{-\bar{p}}$
- For textured rocks
  - Linear mixing assuming uniform stress
  - $\eta_s = \frac{\sigma}{2\sum\left(\phi_i\left(\frac{\sigma}{B_i}\right)^{n_i} \exp\left(-\frac{Q_i+PV_i}{RT}\right) f_w^{p_i}\right)}$

Example results (non-textured)

- Calculate effective viscosity for lower crustal materials
- Main difference is between mafic and felsic rocks





Two Alternative CTMs

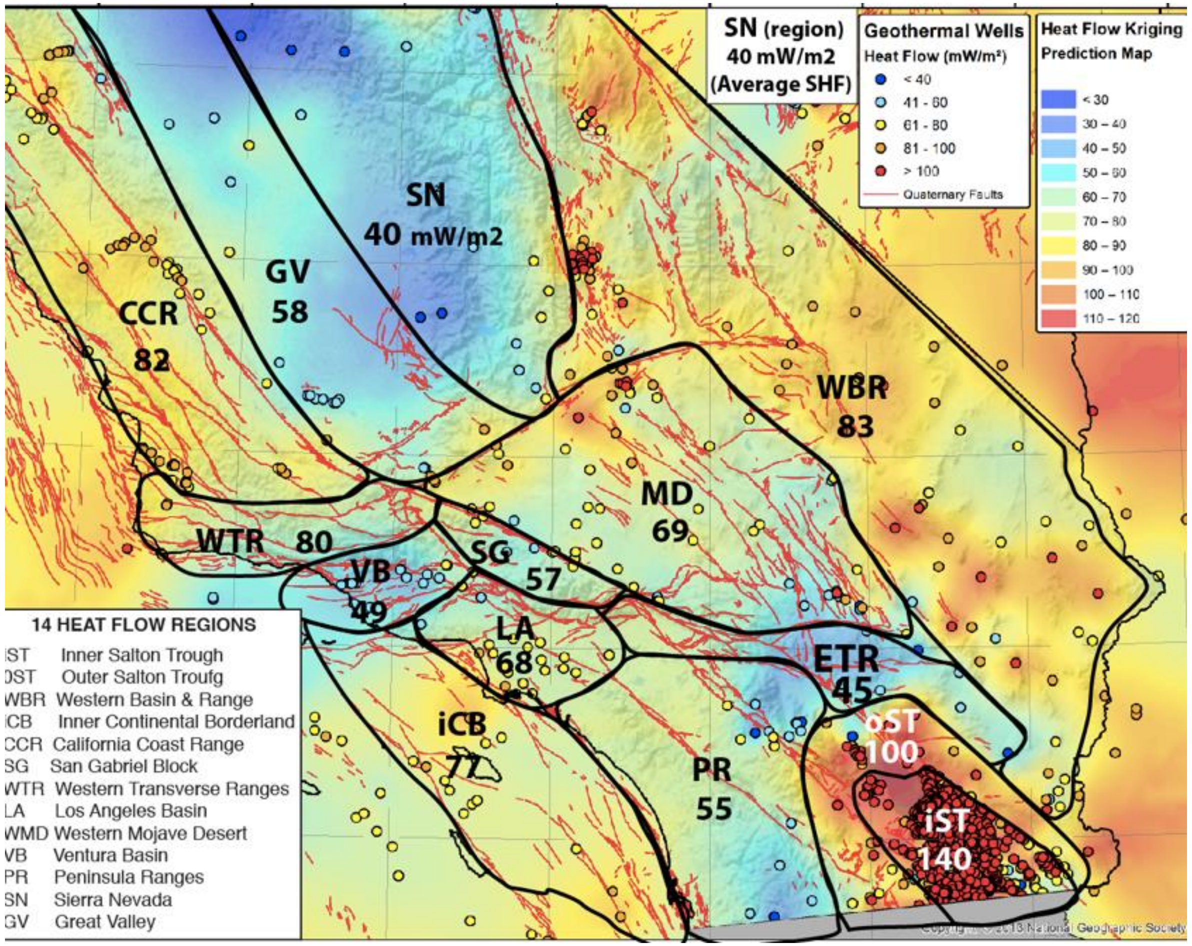
CTM v.20.8 (Thatcher & Chapman, 2019)

- 14 “constant heat flow regions”
  - Additional constraints for LAB depth or xenoliths
- 1D temperature profiles
  - Most at steady-state
  - Some include transient thermal processes

Alternative CTM: Shinevar et al. (2018)

- Interpolated heat flow data
- Steady-state temperature profile

Thatcher et al. (2020)



https://southern.scec.org/research/ctm
https://doi.org/10.5281/zenodo.4010834

Basic steady-state geotherm

Crustal Geotherm

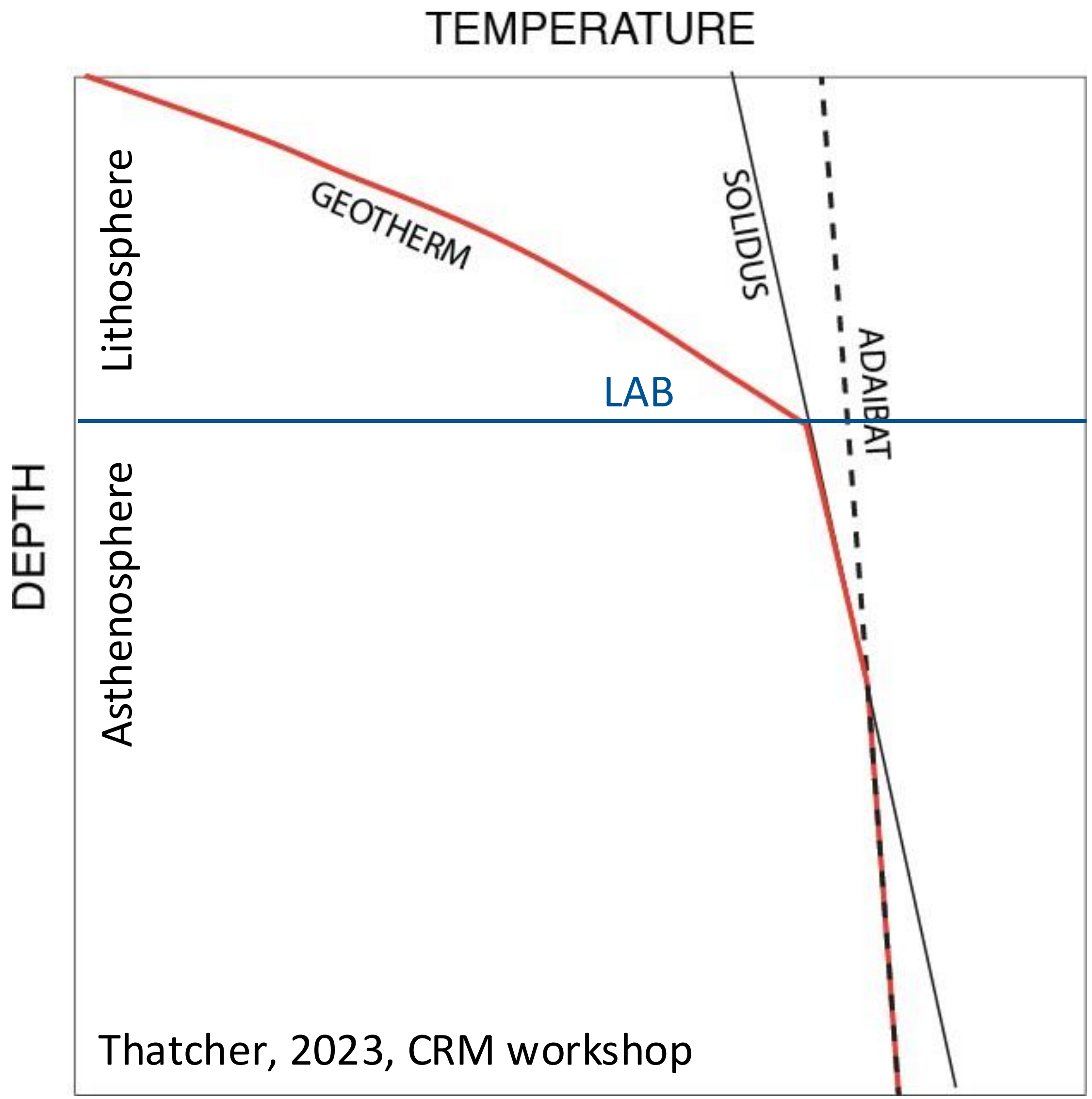
- T_o ~ 20 °C at surface
- Surface heat flow => gradient ~10-30 °C/km
- Include radiogenic heating (40% of heat flow)

Mantle adiabat

- T_o 1200 to 1400°C, gradient 0.4 °C/km

Mantle melting curve (solidus)

- T_o ~ 1100 °C, gradient ~ 3 °C/km
- Intersection becomes the LAB



Thatcher, 2023, CRM workshop

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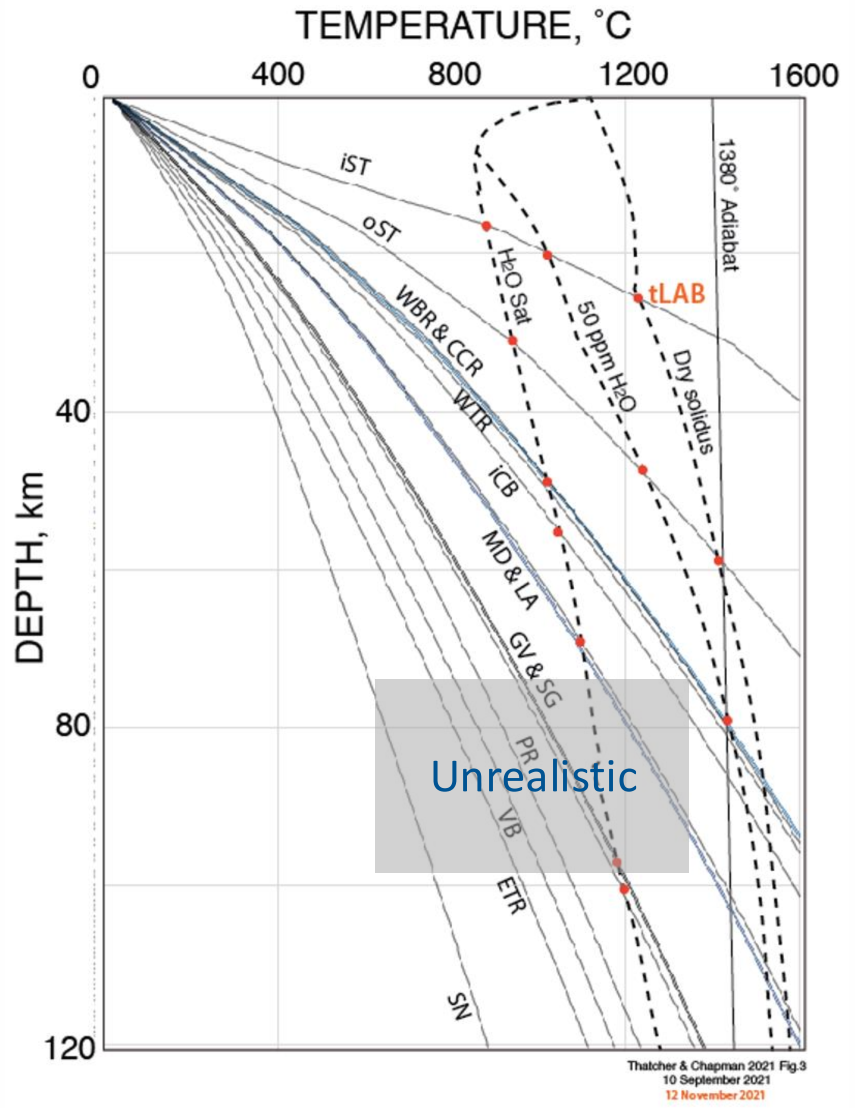
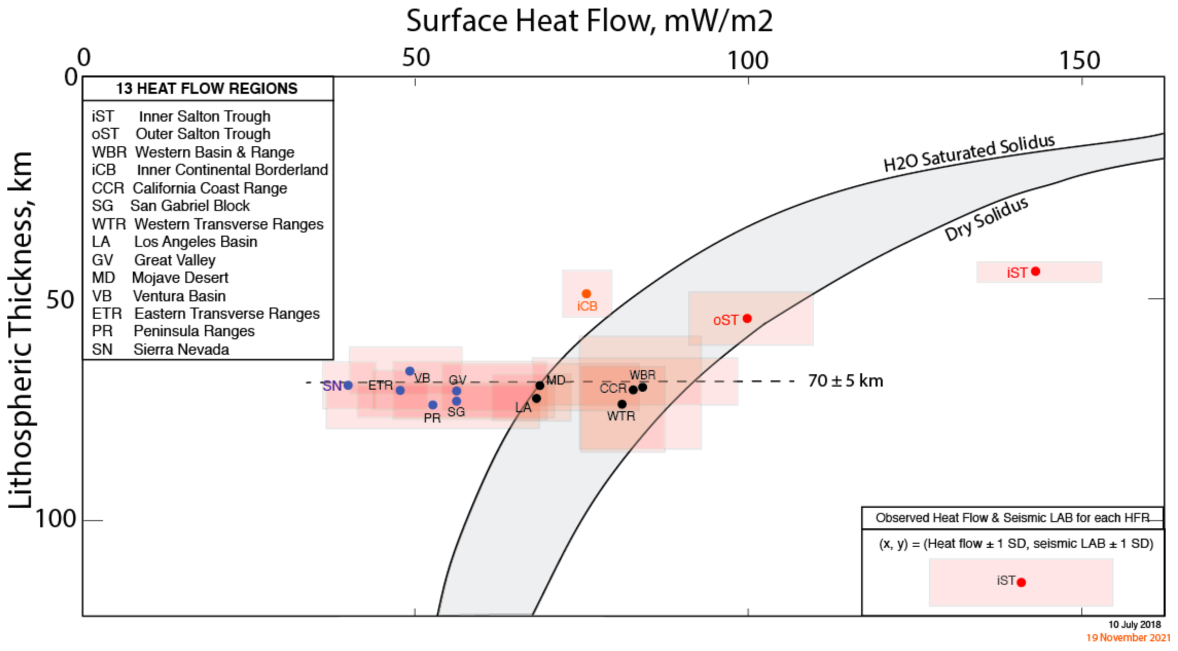




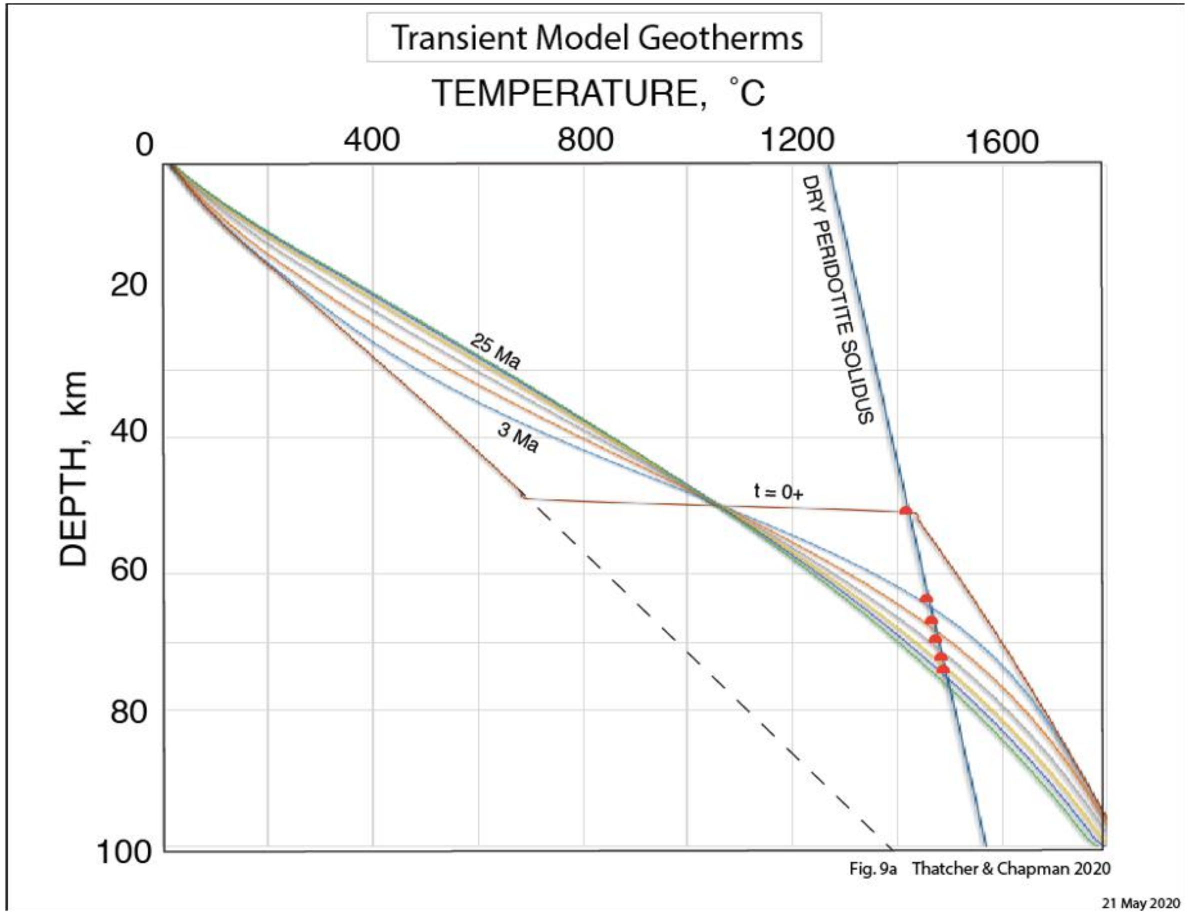
Additional constraints

Xenolith

- Well-constrained WBR geotherm

Seismic LAB

- Surprisingly little variation despite range of surface heat flow
- Model Transient effects

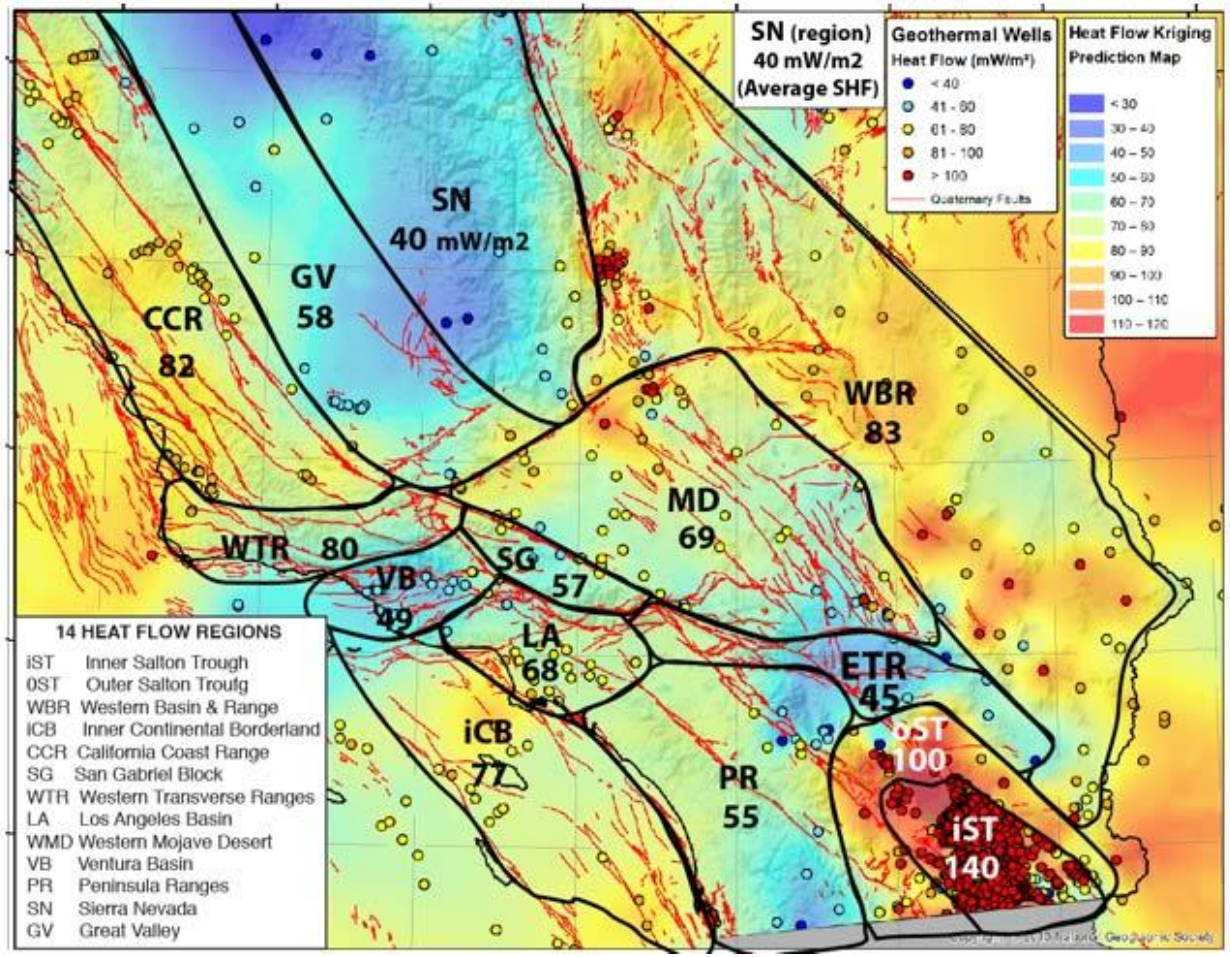


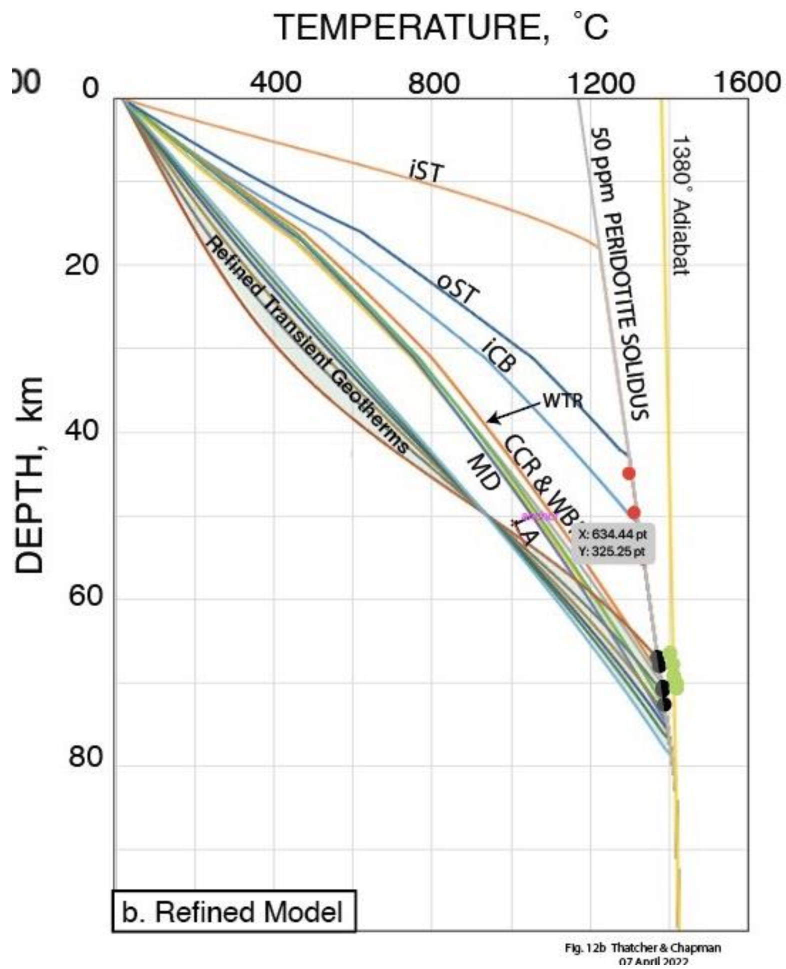
Transient models

Start with a cold subduction-like geotherm

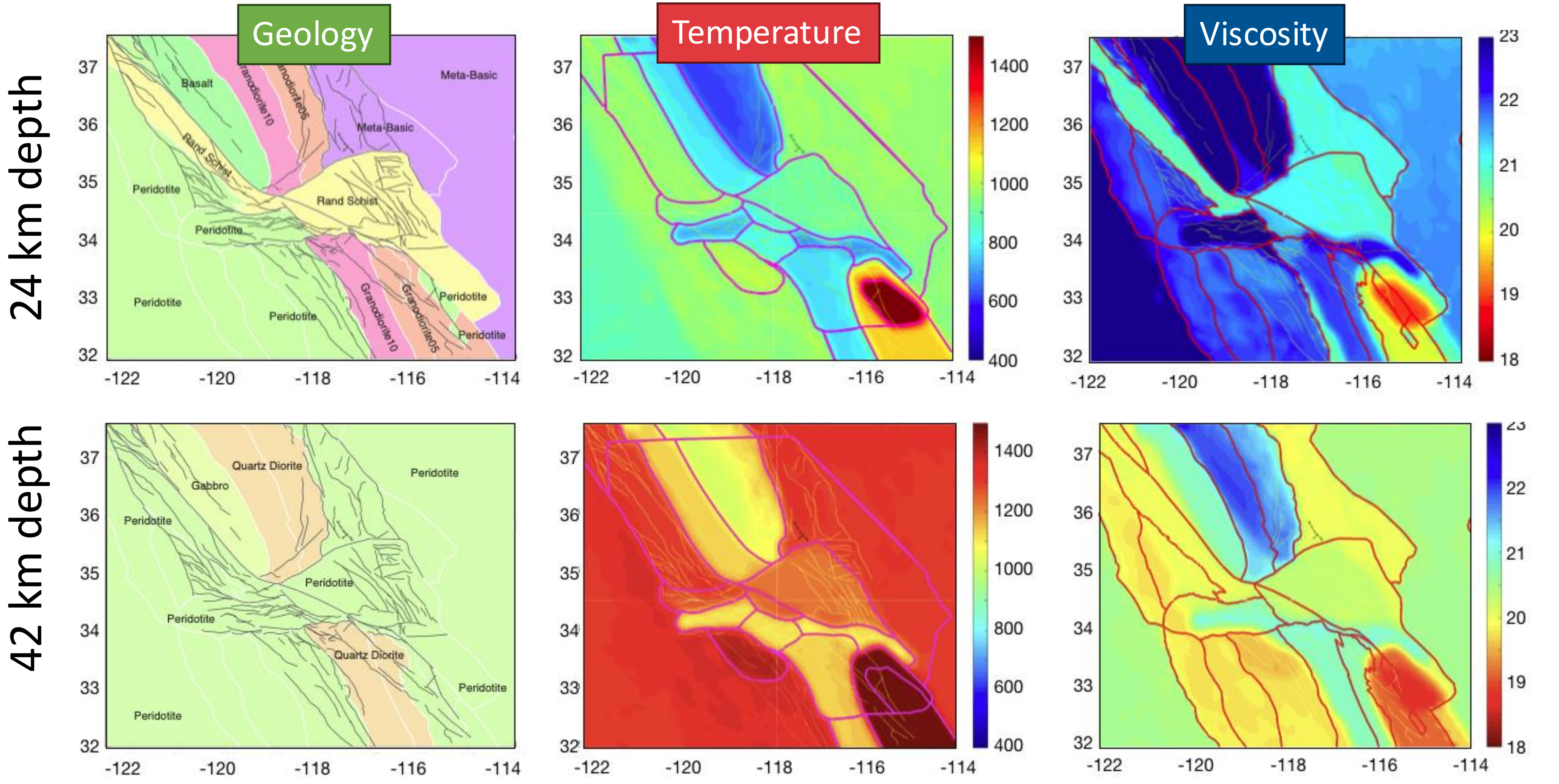
Relict Farallon fragments detach corresponding to a sudden asthenosphere exposure at the base of a 50 km thick lithosphere

Evolve for 28 Myr



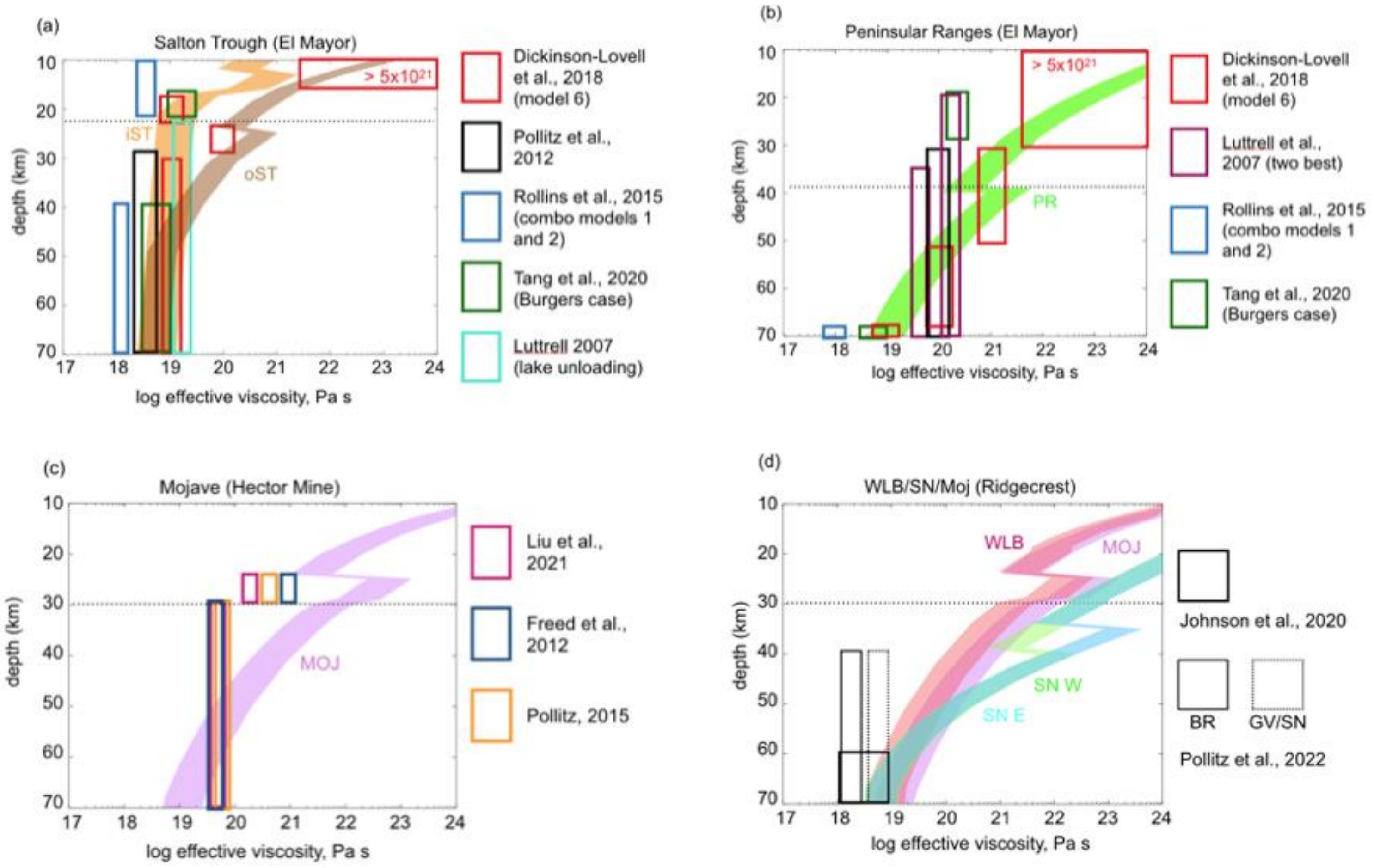


Final CTM geotherms



Hearn et al. (in revision)

All together now: the CRM!



Hearn et al. (in revision)

Are CRM realistic?

Envisioning a future CRM

Wider range of bulk rheologies

- Elasticity!

Friction on faults

- 2025 CRM workshop!
- Link GFM boundaries to CFM
- Also helpful for shear zones

Better explorer

California-wide focus

- Need CA-wide GFM, CTM
- 2025 GFM/CTM workshop!