Predicted Ductile Rheology of Textured and Non-Textured Rocks in Southern California

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Rheology from endmembers

Each mineral is associated with a flow law: $\sigma = B\dot{\varepsilon}^{\frac{1}{n}}\exp\left(\frac{Q+PV}{nRT}\right) f_w^{-\frac{p}{n}}$

- Assumes dislocation creep: no grain size dependence (yet)
- Assumes water saturation: $f_w = 5.521\times10^9 \exp\left(\frac{-31{,}800+10.09\times10^{-6}P}{RT}\right)$
- Because there is no analytical solution for $\sigma(\dot{\varepsilon})$ (but there is one for $\dot{\varepsilon}(\sigma)$ in the case of a sheared rock, we impose stress, not strain rate.
- Present results in term of effective viscosity: $\eta = \sigma/2\dot{\varepsilon}$

For non textured rocks (including the initial CRM release)
Follow MPGe mixing relation of Huet et al., (2014):

$$\eta_b = \frac{1}{2}\bar{B}^{\bar{n}}\sigma^{1-\bar{n}} \exp\left(\frac{\bar{Q}+P\bar{V}}{RT}\right) f_w^{\overline{-p}}$$

- $\bar{n} = \frac{\sum_i \phi_i a_i n_i}{\sum_i \phi_i a_i}$
- $\bar{Q} = \frac{\sum_i \phi_i a_i Q_i}{\sum_i \phi_i a_i}$
- $\bar{V} = \frac{\sum_i \phi_i a_i V_i}{\sum_i \phi_i a_i}$
- $\bar{p} = \frac{\sum_i \phi_i a_i p_i}{\sum_i \phi_i a_i}$
- $\bar{B} = \sum_i \frac{\phi_i n_i}{n_i+1} \times \prod_i \left(B_i \frac{n_i+1}{n_i}\right)^{\frac{\phi_i a_i n_i}{\sum_i \phi_i a_i}}$
- $a_i = \frac{\prod_i (n_i+1)}{n_i+1}$

For shear zone rocks (fabric-parallel strain)
Linear mixing assuming uniform stress

- $\eta_s = \frac{\sigma}{2\sum\left(\phi_i\left(\frac{\sigma}{B_i}\right)^{n_i} \exp\left(-\frac{Q_i+PV_i}{RT}\right) f_w^{p_i}\right)}$

Proposed simplifying assumption based on the weakest mineral:

- Follow the viscosity of the weakest mineral

$$\eta_m = \min_i \frac{1}{2} B_i^{n_i} \sigma^{1-n_i} \exp\left(\frac{Q_i+PV_i}{RT}\right) f_w^{p_i}$$

- All minerals rigid except for the weakest

$$\eta_r = \frac{1}{\phi_i} \min_i \frac{1}{2} B_i^{n_i} \sigma^{1-n_i} \exp\left(\frac{Q_i+PV_i}{RT}\right) f_w^{p_i}$$

- The limits to the conditions where one mineral or another dominate can be determined analytically by solving for $\eta_{i_1} = \eta_{i_2}$

Here: Evaluate for which rocks types the strength of the weakest mineral is an acceptable approximate.

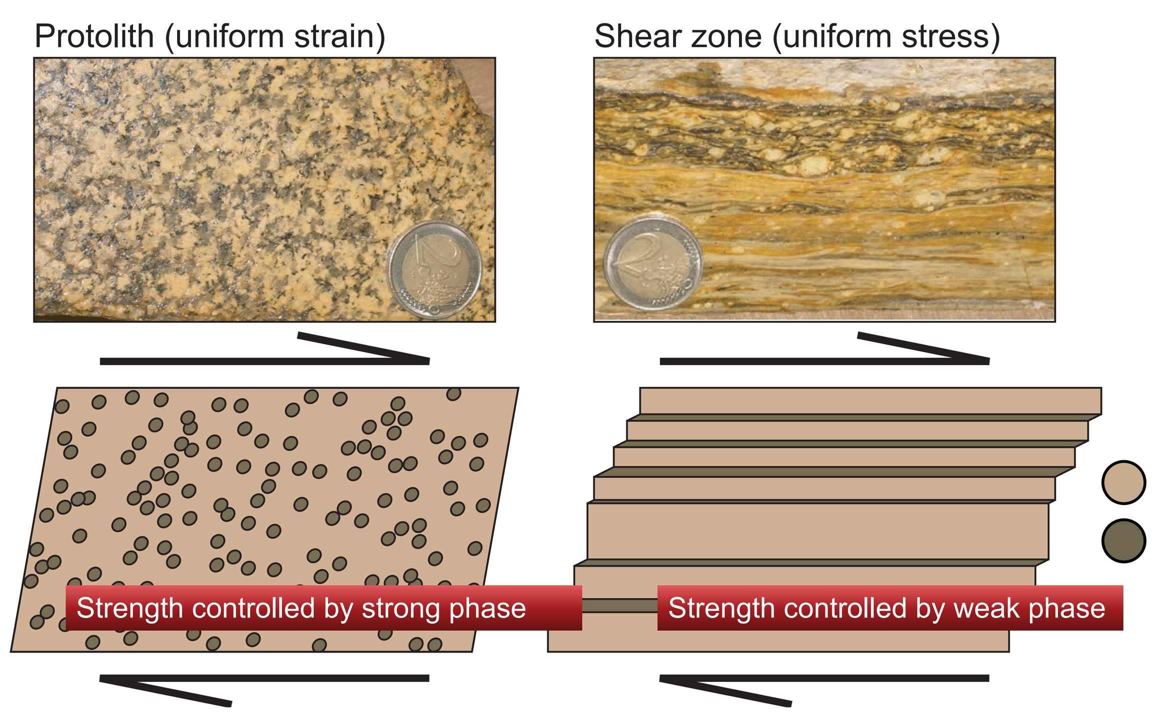


Table 1: flow law parameters for each constituent mineral

	n	p	Q [J/mol]	V [m]	B [Pa.s$^{1/n}$]	Reference
Quartz	4	1	13500		1.1941×10^{10}	Hirth et al., (2001)
Feldspar	3	1	345000	38×10^{-6}	5.1951×10^{7}	Rybacki and Dresen (2006)
Biotite	18		51000		2.7013×10^{7}	Kronenberg et al. (1990)
Pyroxene	5.5		534000		4.2398×10^{5}	Dimanov and Dresen (2005)
Amphibole	3.7		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)

Shear zone strength and weakening

Take ratio of viscosity between shear zones mixing rheology and the viscosity of the weakest mineral

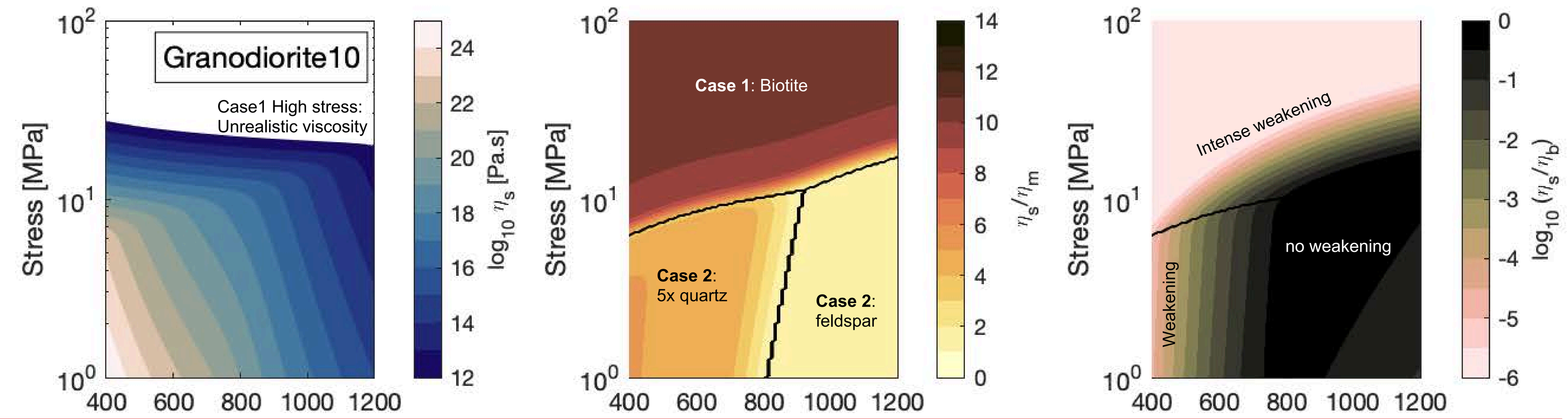
- Present systematic error associated with the weakest mineral approximation
- Compared to viscosity contrast between non-textured and shear zone rock
- Shear stress should be identical inside and outside the shear zone

Case #1: Biotite is present and stress is high (>~10 MPa)

- Biotite is the weakest mineral. Its essentially plastic behavior controls stress
- The sheared rock much weaker than the non-textured rock
- Viscosity is unrealistic for stress higher than ~40 MPa

Case #2: Felsic rock with biotite, low stress (<~10 MPa)

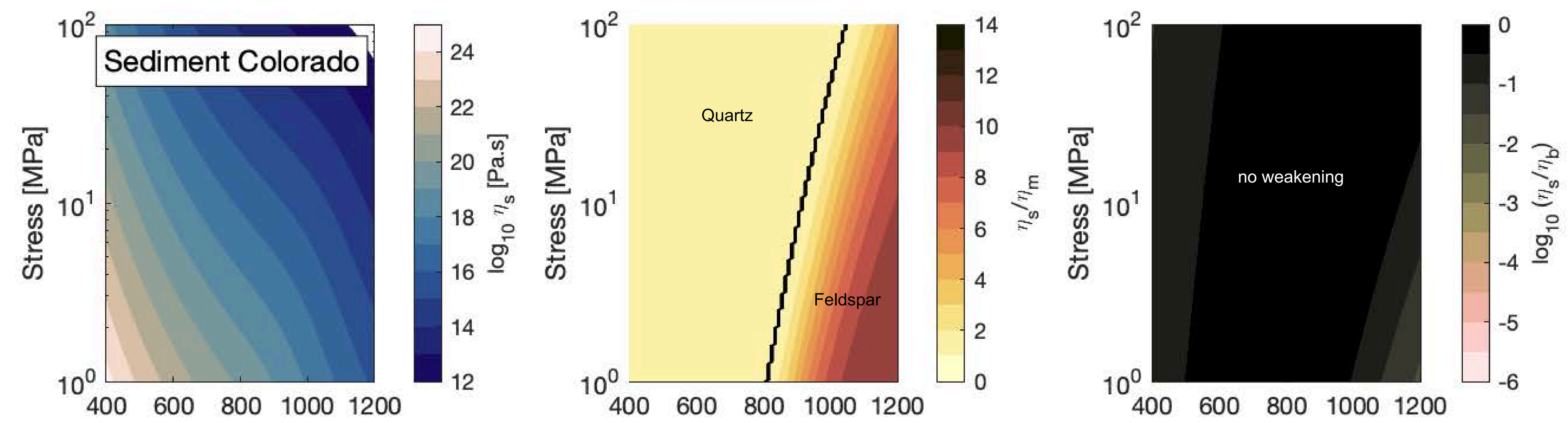
- Quartz is the weakest mineral if T<~800°C (otherwise it's feldspar)
- The sheared rock is significantly weaker than the bulk rock only at the lowest temperature; its viscosity is ~ 6 times that of pure quartz



Cases 1 and 2 illustrated with the strength of a granodiorite composition (left), the ratio of shear viscosity ot that of the weakest mineral (center) and the ratio of shear zone to bulk rock viscosity (right)

Case #3: Felsic rock without biotite

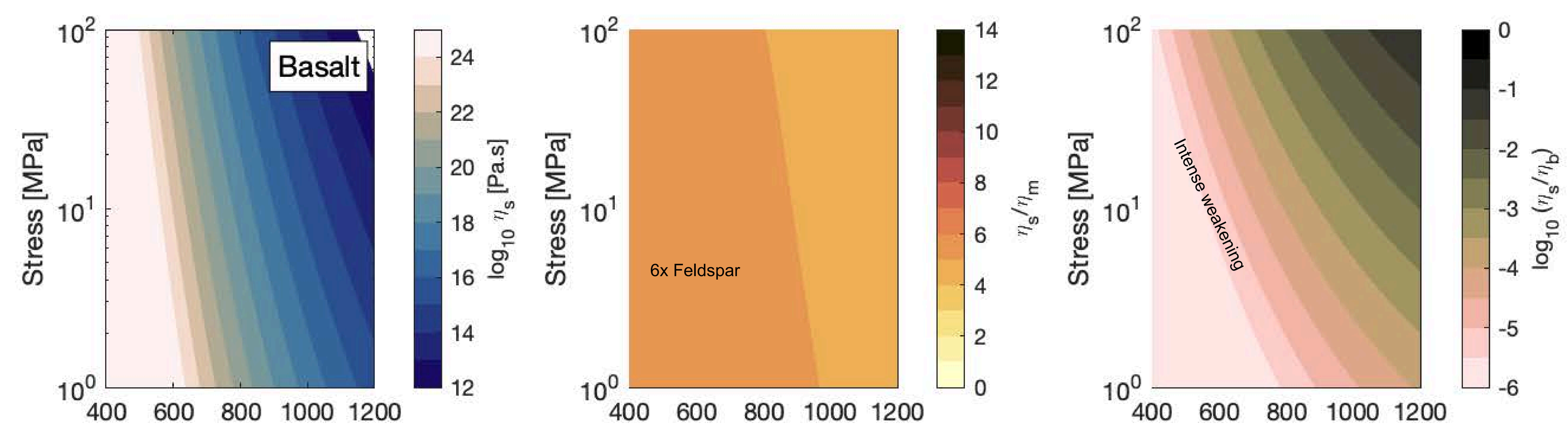
- Quartz is the weakest mineral if T<~800°C (otherwise it's feldspar)
- The sheared rock is not significant weaker than the bulk rock



As above but for the "sediment Colorado" lithology illustrating Case #3. Note that phase stability is not considered

Case #3: Mafic rock

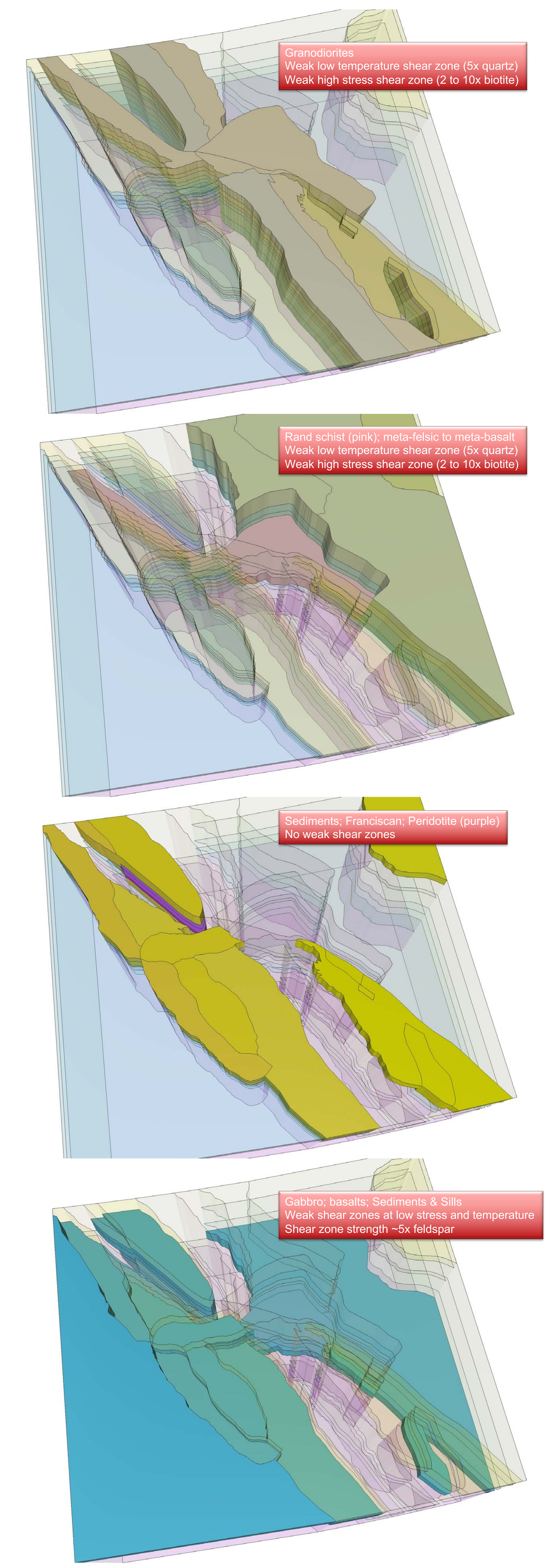
- Feldspar is the weakest mineral.
- The viscosity of the sheared rocks is ~5 times that of pure feldspar
- The sheared rock is weaker than the non-textured rock at low stress and/or low temperature



As above but for the "Basalt" lithology illustrating Case #4.

Importance for the CRM

Each block of the Geological Framework is associated with a sequence of rock types for which we calculate a flow with and without fabric.



Resources

The initial release of the GFM and CRM is available at https://www.scec.org/research/crm and http://www.doi.org/10.5281/zenodo.4579626
This release contains a complete description of the calculation of bulk rheology from end–member mineral flow laws as well as a complete reference list.

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