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Relationships between fluid composition and rheology in ecologites from the eastern Alps

Jane Selverstone

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Jane Selverstone, University of New Mexico, selver@unm.edu

ABSTRACT

Finely banded, dolomite-rich mafic eclogites from the Tauern Window equilibrated at >2 GPa and 600-650°C. Previous work (*Selverstone et al. 1992; Getty & Selverstone, 1994*) showed that:

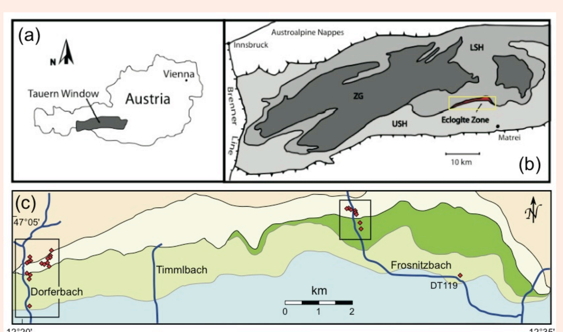
- ***a*(H_2O)** varied from **~0.2 to 0.9** across layers at peak pressure
- **$\delta^{18}O$** of dolomite varied by up to **1.0 ‰** between layers
- there is little to no variation in *a*(H_2O) or $\delta^{18}O$ **within** layers
- *a*(H_2O) and $\delta^{18}O$ values co-vary with dolomite modal abundance

These data indicate that **the rocks acted as a closed system during high-P metamorphism, with little to no fluid communication across layers only mm to cm in thickness.** This study evaluates the mechanical behavior of the eclogites as a function of fluid composition within individual layers.

All layers show a single, well-developed foliation defined by elongate omp ± czo ± zoi ± dol. Average matrix grain size varies from 40 to >200 microns, but shows no correlation with fluid composition. Garnet is abundant throughout and typically displays rounded, inclusion-rich cores with sub- to euhedral inclusion-free overgrowths. **Garnets are subequant in layers with low *a*(H_2O) and elongate (aspect ratios up to 2.5) in layers with high *a*(H_2O).**

Fractures oriented at ~70° to the foliation are abundant in layers with *a*(H_2O) ≥ 0.6 but are absent in layers with lower *a*(H_2O). Complex gar and czo zoning in these layers is consistent with strain accommodation via dissolution/reprecipitation creep prior to cracking. High *a*(H_2O) likely facilitated solution creep and growth of grains with high aspect ratio. These elongate inclusions were subsequently favored for brittle failure during ongoing ductile deformation of surrounding layers (*Mandal et al., 2001; Ji & Zhao, 1993*). **The mode of ductile strain accommodation thus preconditioned certain layers to localize later brittle deformation.** This study highlights the role that fluid composition plays in controlling rheology during high-P metamorphism.

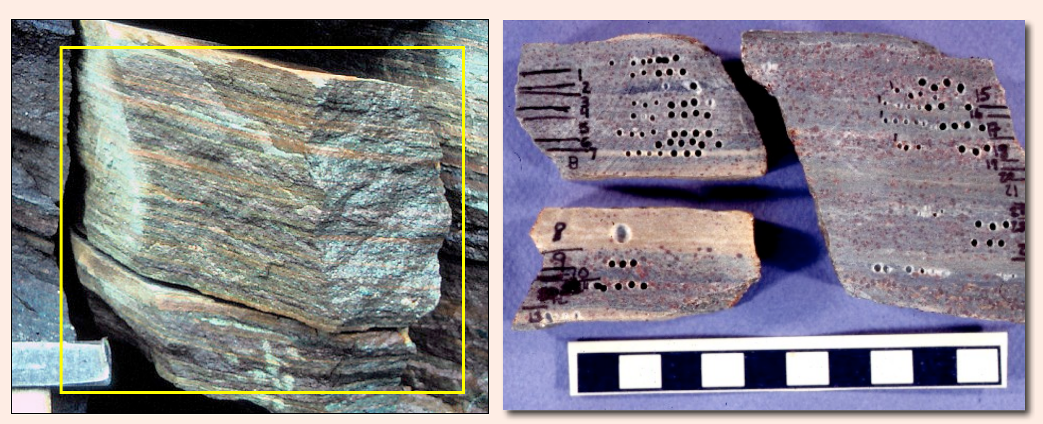
GEOLOGIC SETTING



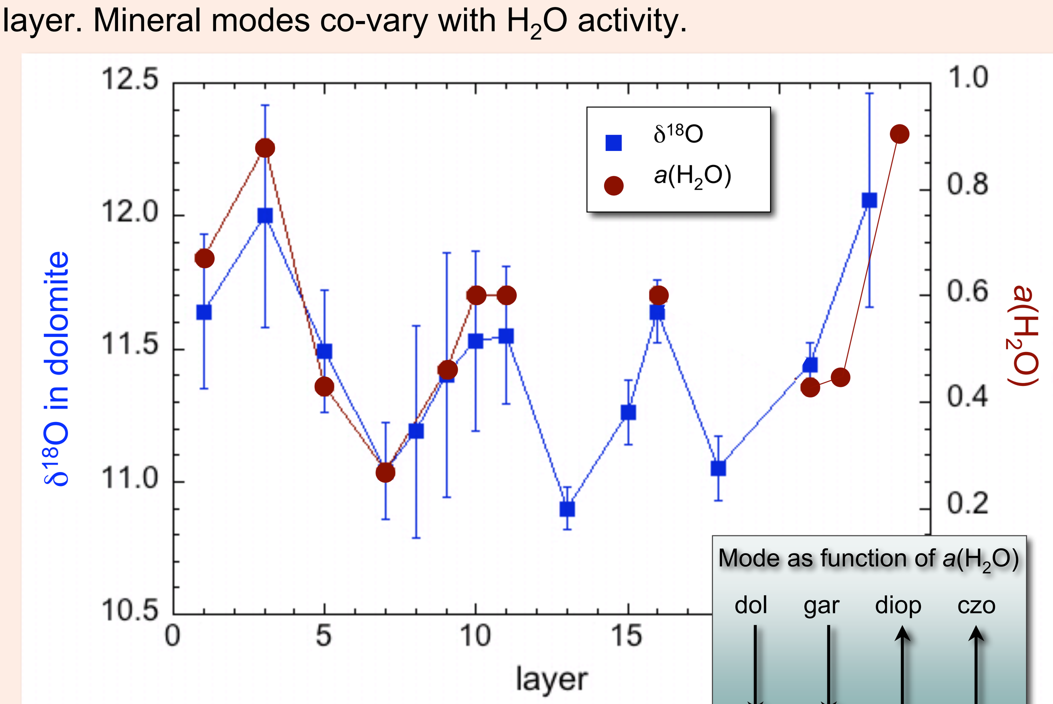
- Peak eclogite conditions: ~625°C & 2 GPa
- Maximum pressure attained ca. 32 Ma
- Unroofing to ~1 GPa by ca. 31 Ma
- Assemblage = Omp + Gar + Czo/Zoi + Dol

Samples are from Eclogite Zone in the central Tauern Window, Austria.

NO FLUID COMMUNICATION ACROSS LAYERS



Previous work (Selverstone et al. CMP 1992; Getty & Selverstone JMG 1993) showed that H_2O activity, CO_2 activity, and the oxygen isotope composition of dolomite varied across layers on a mm scale. This implies that the rocks acted as a **closed system** during eclogite metamorphism. Oxygen isotope composition of dolomite varies as a function of dolomite modal abundance and is consistent with internal equilibrium within each layer. Mineral modes co-vary with H_2O activity.



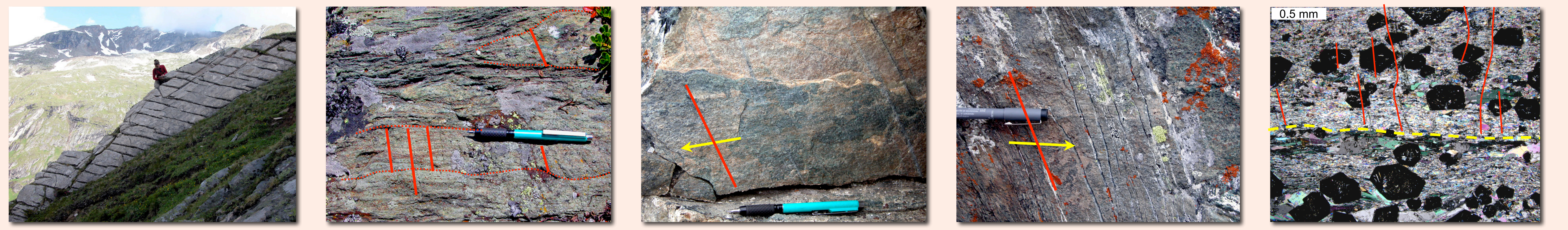
Increasing a(H_2O)*:*

Dolomite + Qtz → **Diopside** + CO_2

Ca-Mg Garnet + Qtz + H_2O → **Clinozoisite** + **Diopside**

EXTENSION FRACTURES ARE UBIQUITOUS, BUT ARE CONFINED TO SPECIFIC LAYERS

Fracturing began prior to "peak" eclogite equilibration at 2 GPa, and continued with same orientation throughout exhumation

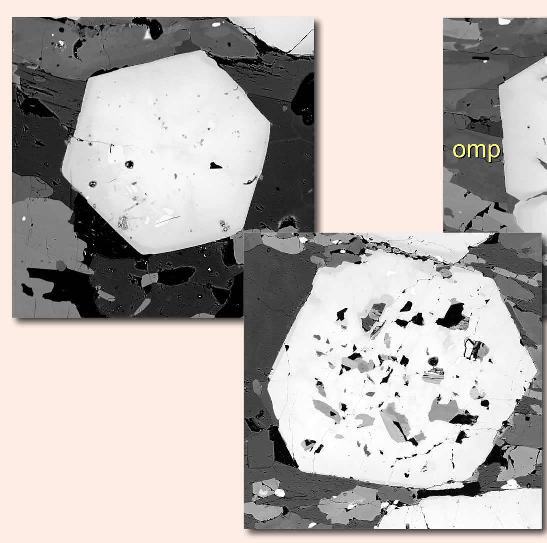


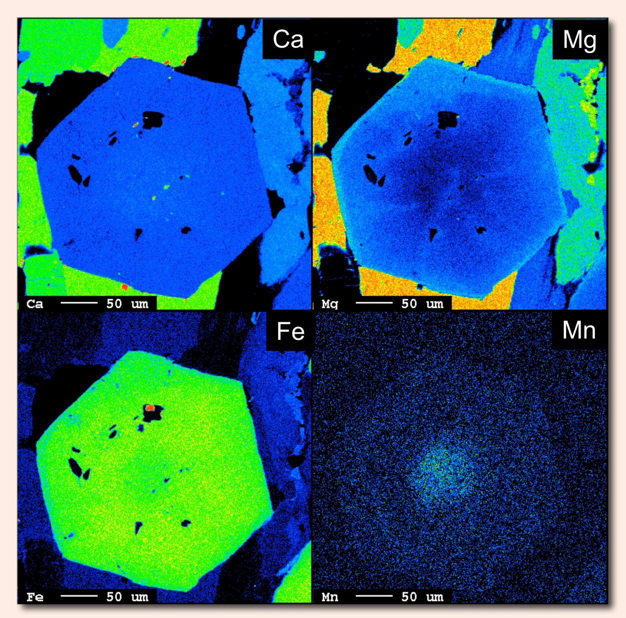
WHY DO FRACTURES OCCUR IN SOME LAYERS BUT NOT OTHERS? EVIDENCE FROM MICROSCOPIC SCALE

SUMMARY OF KEY OBSERVATIONS

- Outcrop-scale evidence for **plastic flow** and for **boudinage/fracturing** at eclogite conditions
- **Mineral assemblage is ~constant**, but modal abundance varies between layers
- Filled and unfilled fractures occur on **all scales** and have **similar orientation** with respect to foliation
- There is **no** systematic relationship between grain size and degree of fracturing
- Fractures are best developed in layers with **high aspect ratio** mineral grains
- Layers **without** fractures have stronger matrix CPO than layers with fractures
- Fractures are best developed in layers with **high concentrations of omphacite and clinozoisite**
- Fractures are least abundant in layers with high concentrations of dolomite
- Healed cracks in garnet cores indicate **earliest fractures formed prior to eclogite pressure peak**

LAYERS WITHOUT FRACTURES

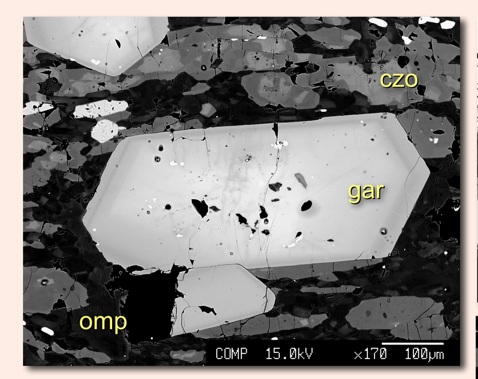




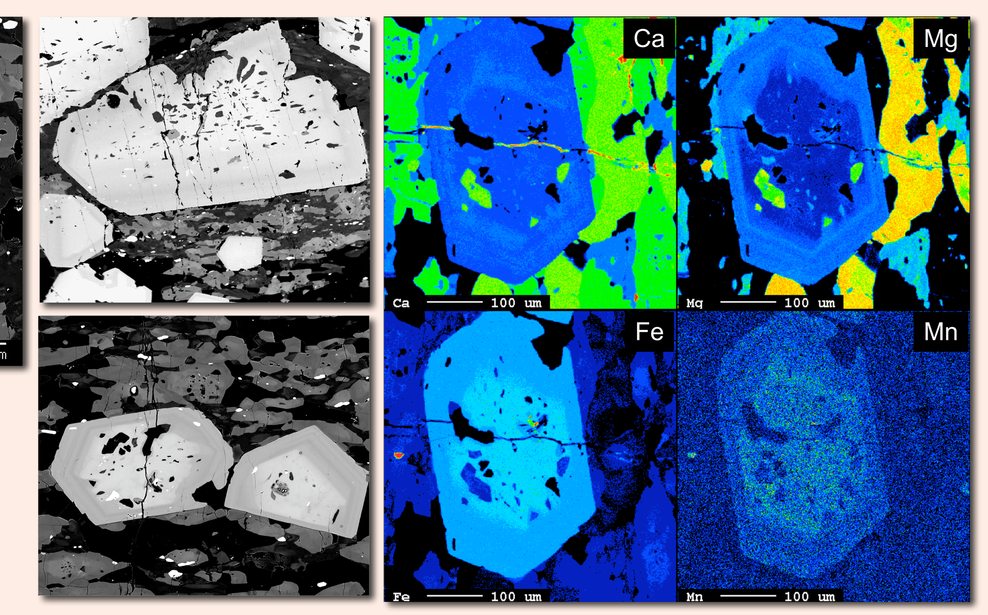
Garnets are **equant** and show limited but **concentric chemical zoning**

Omphacite and clinozoisite show limited chemical zoning, some subgrain development and undulose extinction, and moderately well-developed CPO and SPO: *strain accommodation via dislocation creep?*

LAYERS WITH FRACTURES



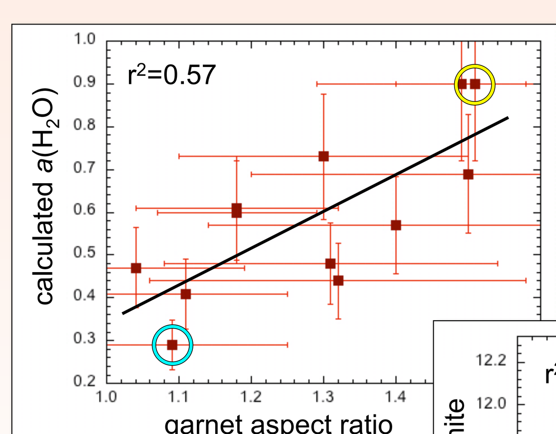
Garnets are **elongate** and show **complex chemical zoning**: oscillatory zoning, truncations, asymmetric zoning

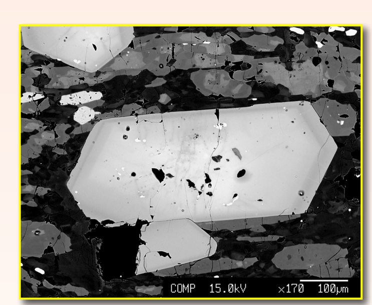


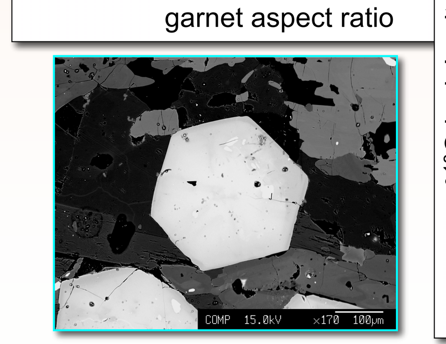
Omphacite and clinozoisite have complex chemical zoning, few obvious subgrains, and show a strong SPO but only a weak CPO: *strain accommodation via diffusion creep / dissolution-precipitation creep?*

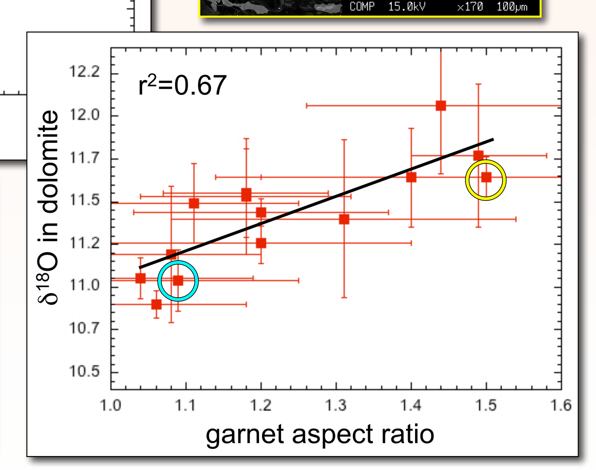
GARNET ASPECT RATIOS ARE CORRELATED WITH FLUID COMPOSITION

Because aspect ratio differs between layers with fractures and layers without, there must also be a relationship between fluid composition and strain accommodation mechanisms

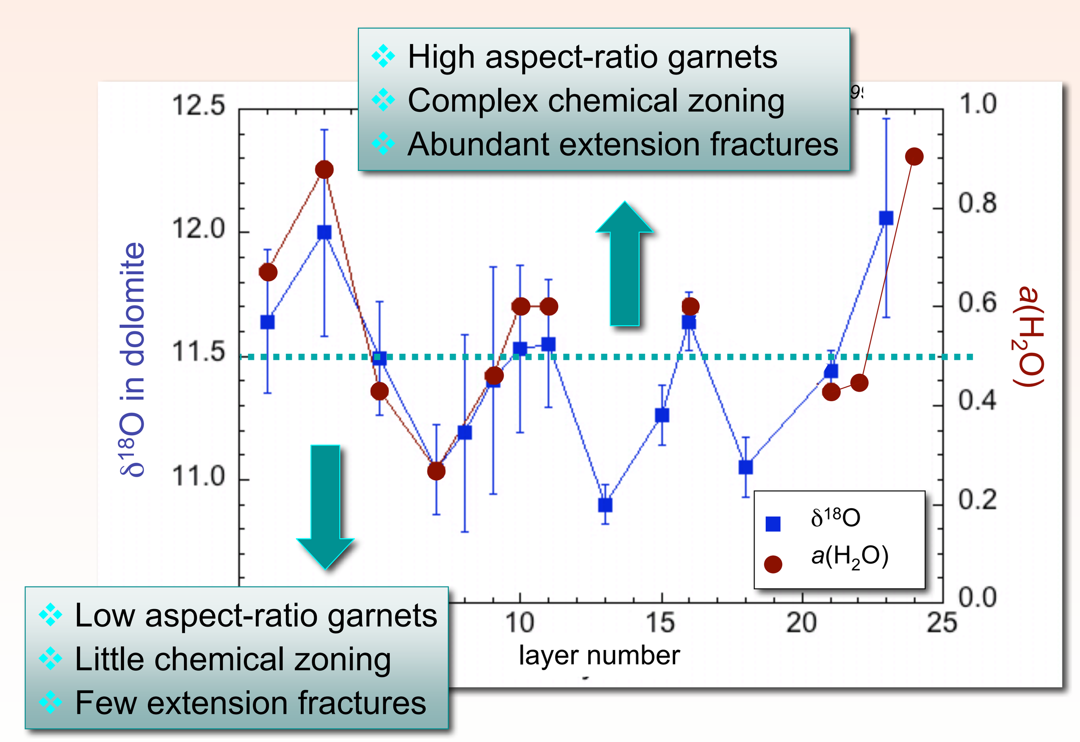








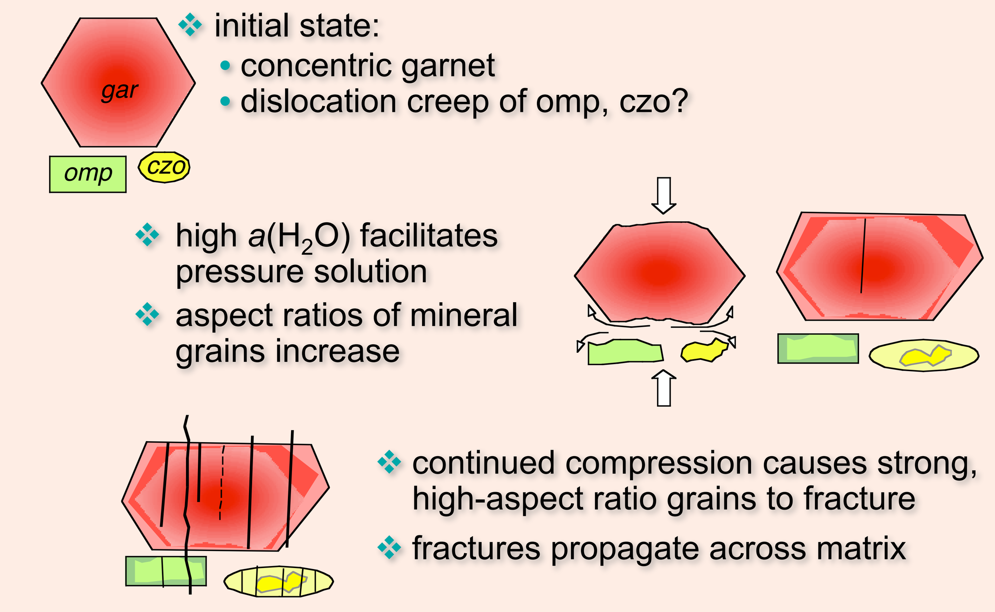
Aspect ratios measured for 10 garnets each in 15 different layers.



Fractures are confined to layers *a*(H_2O)>0.5 - why??

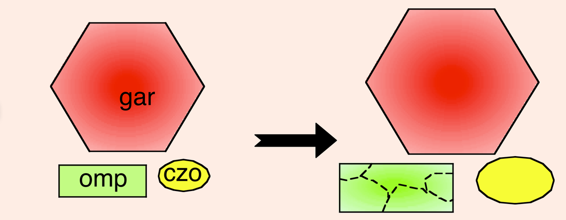
A POSSIBLE MODEL

Layers with high a(H_2O)*:*



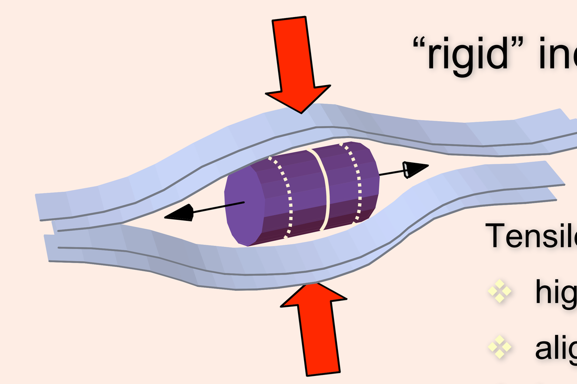
- initial state:
  - concentric garnet
  - dislocation creep of omp, czo?
- high *a*(H_2O) facilitates pressure solution
- aspect ratios of mineral grains increase
- continued compression causes strong, high-aspect ratio grains to fracture
- fractures propagate across matrix

Layers with low a(H_2O)*:*



- no dissolution/pressure solution
- concentric grain growth
- subgrain development → strain accom. via dislocation creep?
- low aspect ratios hinder intra-grain fracture development

Fracture formation -
"rigid" inclusion in ductile matrix



Tensile fracture favored by:

- high aspect ratio of inclusion
- alignment in foliation
- low ratio of inclusion tensile strength to matrix flow stress

Successive midpoint fracturing:
tensile stress is maximum at inclusion center

Some fractures propagate into matrix and/or localize subsequent brittle features

CONCLUSIONS

- Fluid composition controlled deformation mechanisms: *dissolution-precipitation creep* in layers with high water activity vs. *dislocation creep* in layers with lower water activity
- Ductile deformation mechanisms (e.g., *dissolution-precipitation creep)* preconditioned rock to localize brittle failure by affecting porphyroblast aspect ratios
- High water activities can promote brittle failure in addition to facilitating water weakening of silicate minerals
- Eclogite-stage microcracks may have localized macroscopic fractures during early stages of unroofing
- Generation and preservation of small-scale fluid heterogeneities is common in metamorphic rocks and may be very important in controlling the evolution of bulk rock rheology

ACKNOWLEDGEMENTS

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SOME RELEVANT REFERENCES

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