Deformation mechanisms in naturally-deformed blueschist facies metabasalts: Constraints from exhumed subduction complexes in Greece and California

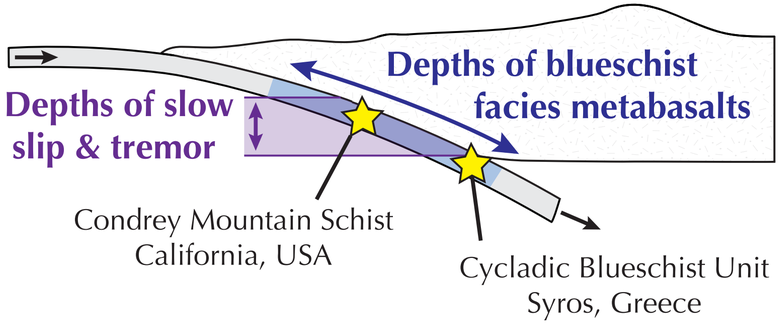
Carolyn Tewksbury-Christle[1]
Alissa Kotowski[2]
Whitney Behr[1]

Motivation

⇦ all buttons like this will take you to more information

Subduction interface viscosity plays a key role in large-scale subduction processes. Blueschist facies metabasalts can be present along much of the subduction interface and coincide with depths at which slow slip & tremor events are observed in modern subduction zones, but their rheology is poorly constrained. We used samples from northern California, USA (CMS) & Syros, Greece (CBU) to characterize:

- ***Viscosity contrasts to other lithologies***
- ***Microscale mechanisms for creep***
- ***Variation with pressure-temperature conditions***



For more information on the rocks, check out the: **Geologic Settings**

Field Observations

Blueschist facies metabasalts and metasedimentary rocks have a low viscosity contrast (right).

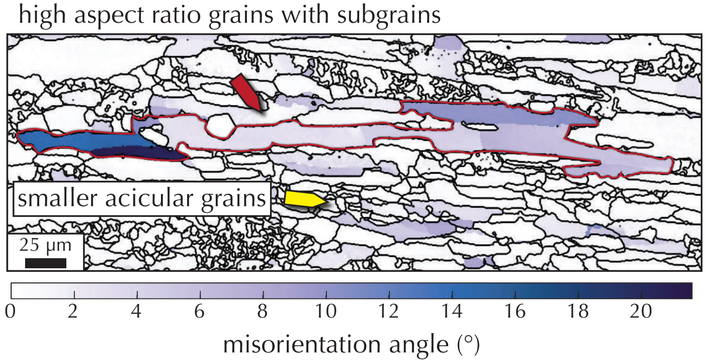


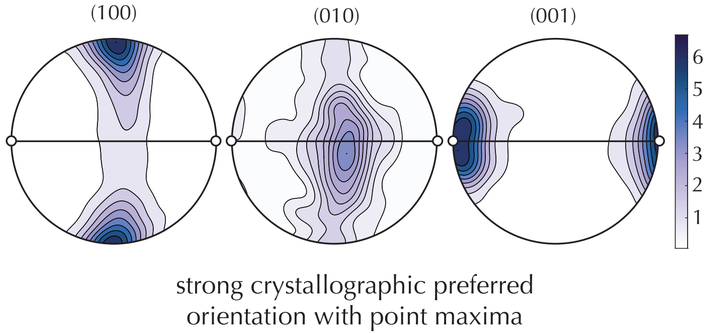
Microstructures

EBSD

Strain was primarily accommodated via dislocation activity in Na-amphiboles.

Na-amphiboles from both locations have high aspect ratios, shape & crystallographic preferred orientations, & bimodal grain size distributions. Subgrain analysis suggests activation of 2+ slip systems.





Implications

Blueschist facies metabasalt deformation was governed by low-viscosity power law creep in Na-amphiboles at both pressure-temperature conditions.

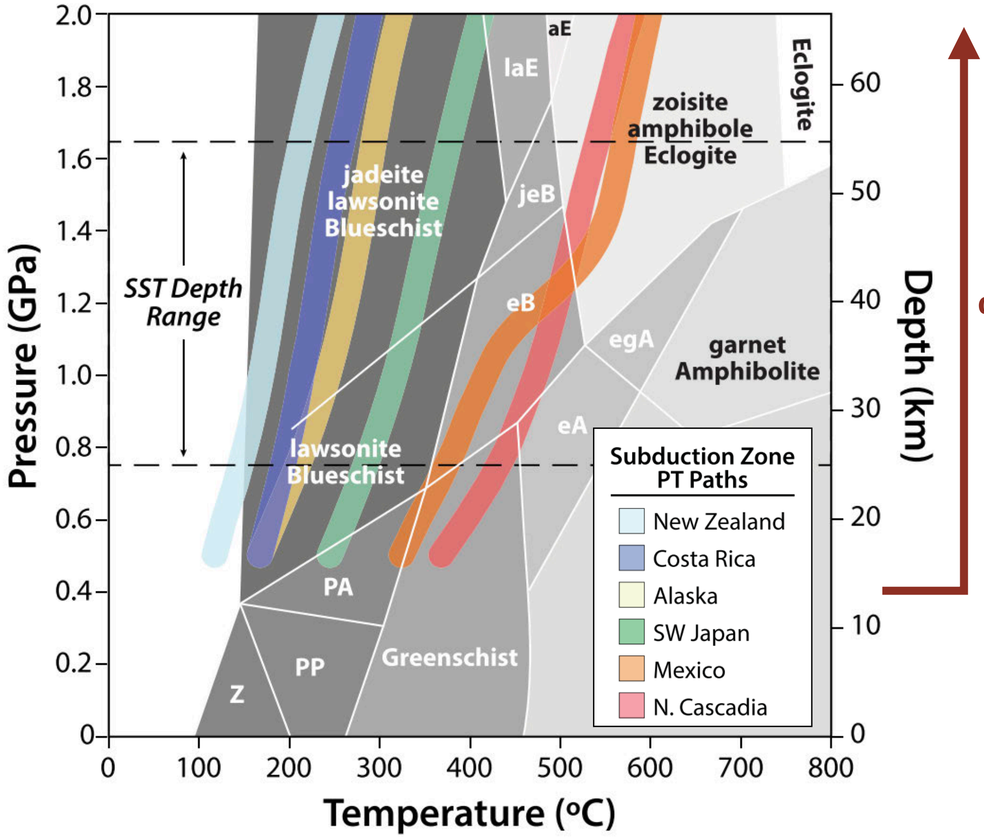
The subduction interface from ~15-60+ km depth can be occupied by low viscosity metamafic & metasedimentary rocks, facilitating motion between the plates.

Power law rheology may have implications for transient slip events, where the rheology allows for stress communication within the interface shear zone & results in large-scale slow slip.

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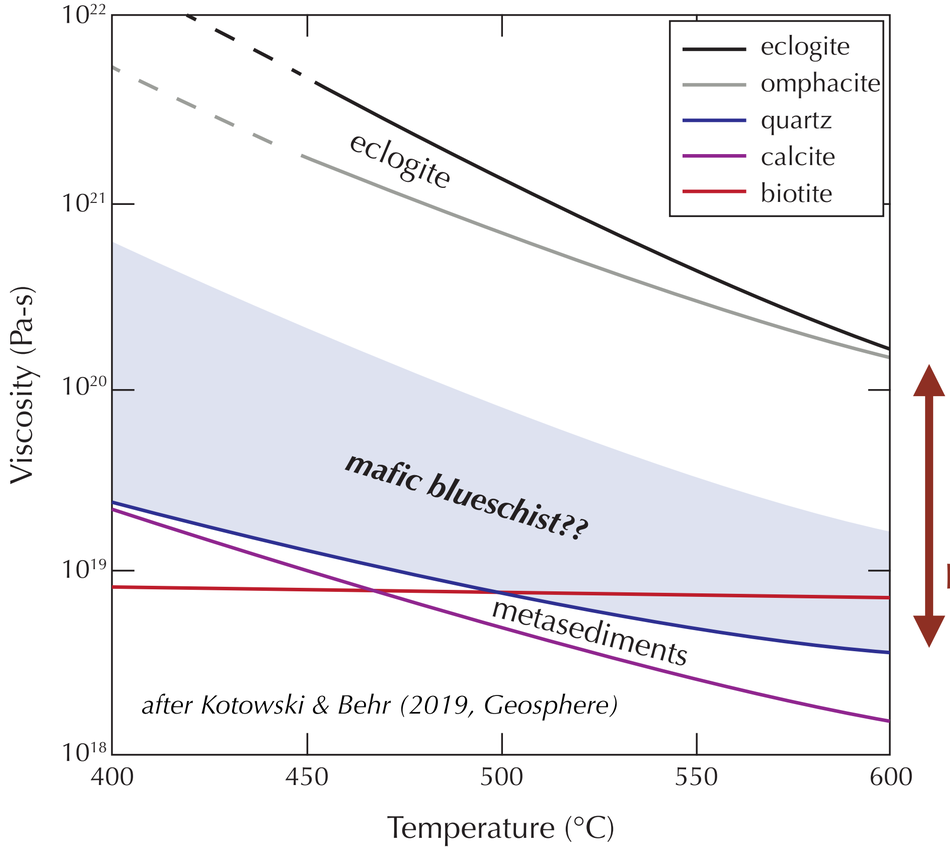
SGT ETHZ · ETH zürich · McGill University · TEXAS Geosciences The University of Texas at Austin Jackson School of Geosciences Department of Geological Sciences · erc · Sediments & Subduction Interface Mechanics S-SIM · NSF

Why does blueschist facies metabasalt rheology matter?



Behr & Bürgmann (2021, Phil. Trans. R. Soc. A)

Blueschist facies rocks can be present across a wide range of depths, including depths associated with slow slip and tremor (SST), but…



…strength & associated deformation mechanisms are poorly constrained

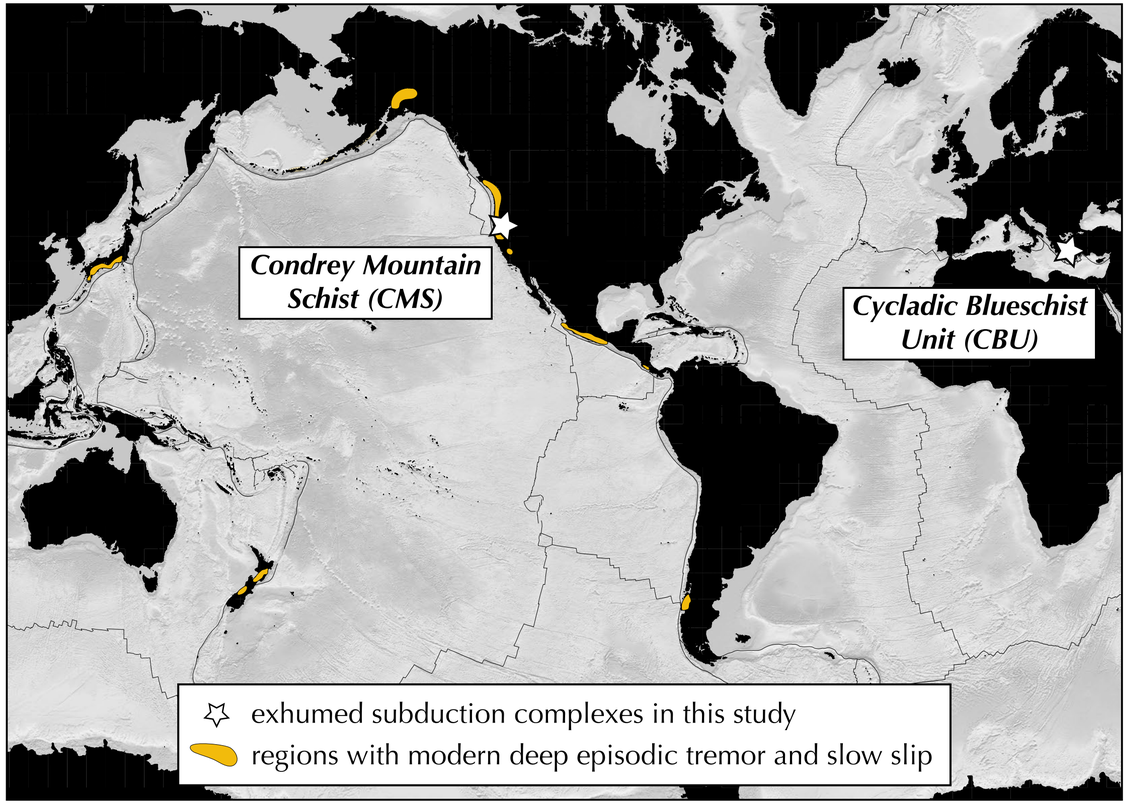
Previously inferred viscous deformation mechanisms include: dislocation glide and climb, dissolution-precipitation creep, rigid body rotation, & oriented growth. We use natural blueschist facies metamafic samples to answer the following questions:

1. What are the viscosity contrasts with other lithologies?
2. What are the microscale mechanisms for creep?
3. How do they vary with pressure and temperature?

Use the arrow keys or tabs at the bottom of the slide to go through a summary version or click on the 'more information' buttons for further details on each section.

Click here for more information

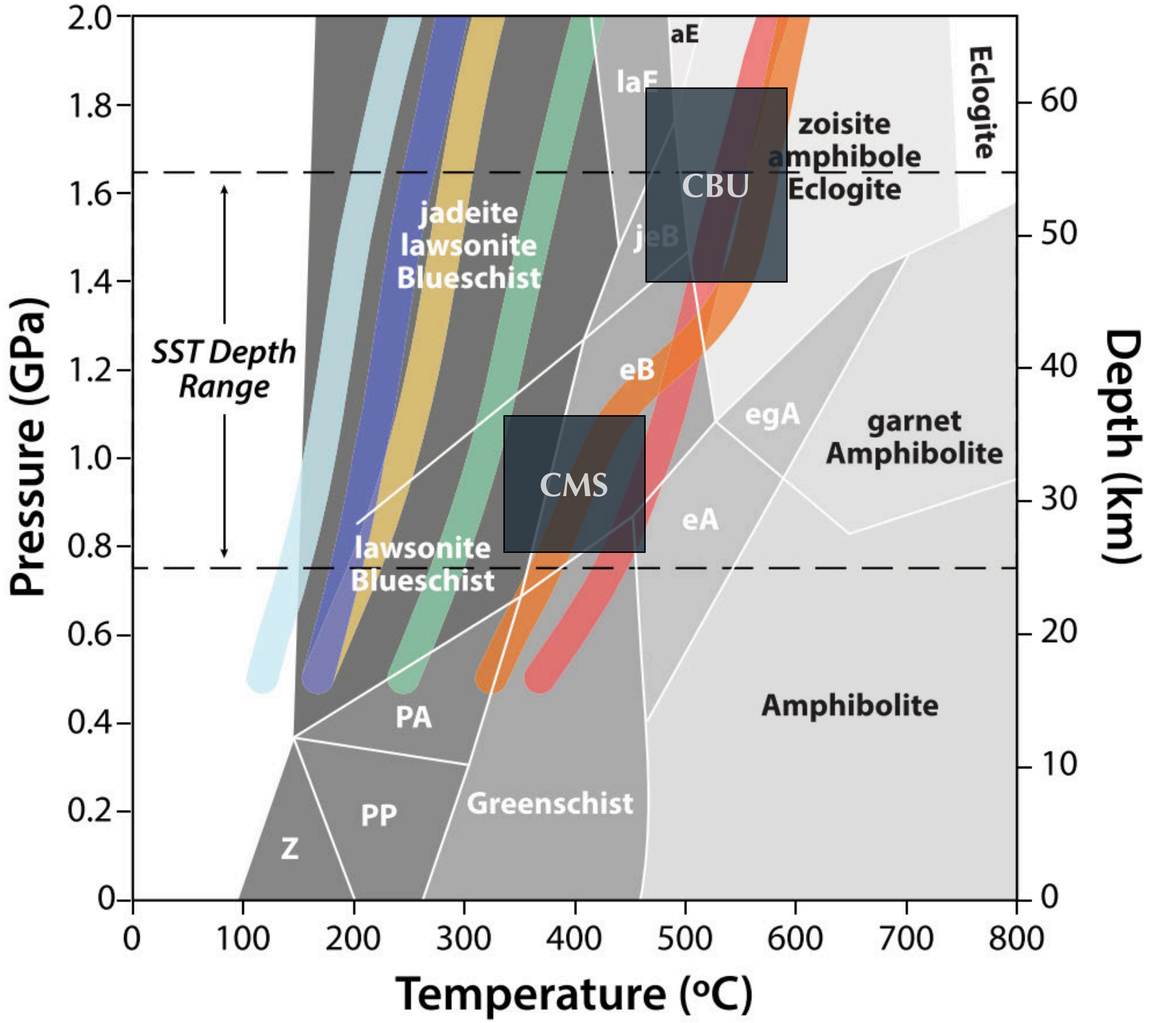
Geologic Settings



Behr & Bürgmann (2021, Phil. Trans. R. Soc. A)

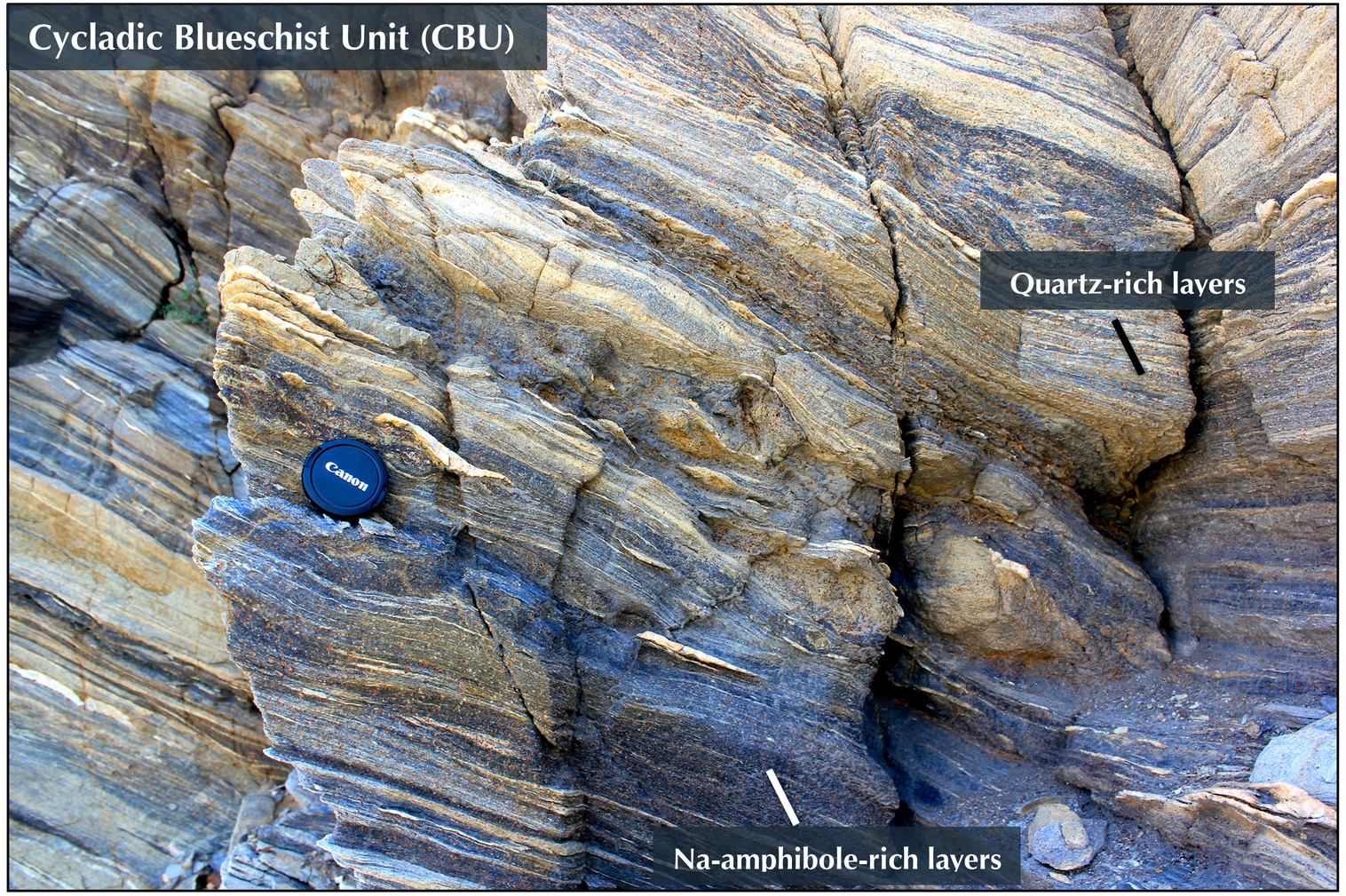
Both complexes were exhumed from the depths of slow slip & tremor, a common enigmatic phenomena in modern subduction zones, & record viscous deformation in blueschist facies metabasaltic & metasedimentary rocks. The CBU subducted to higher peak P-T conditions along a comparable geotherm.

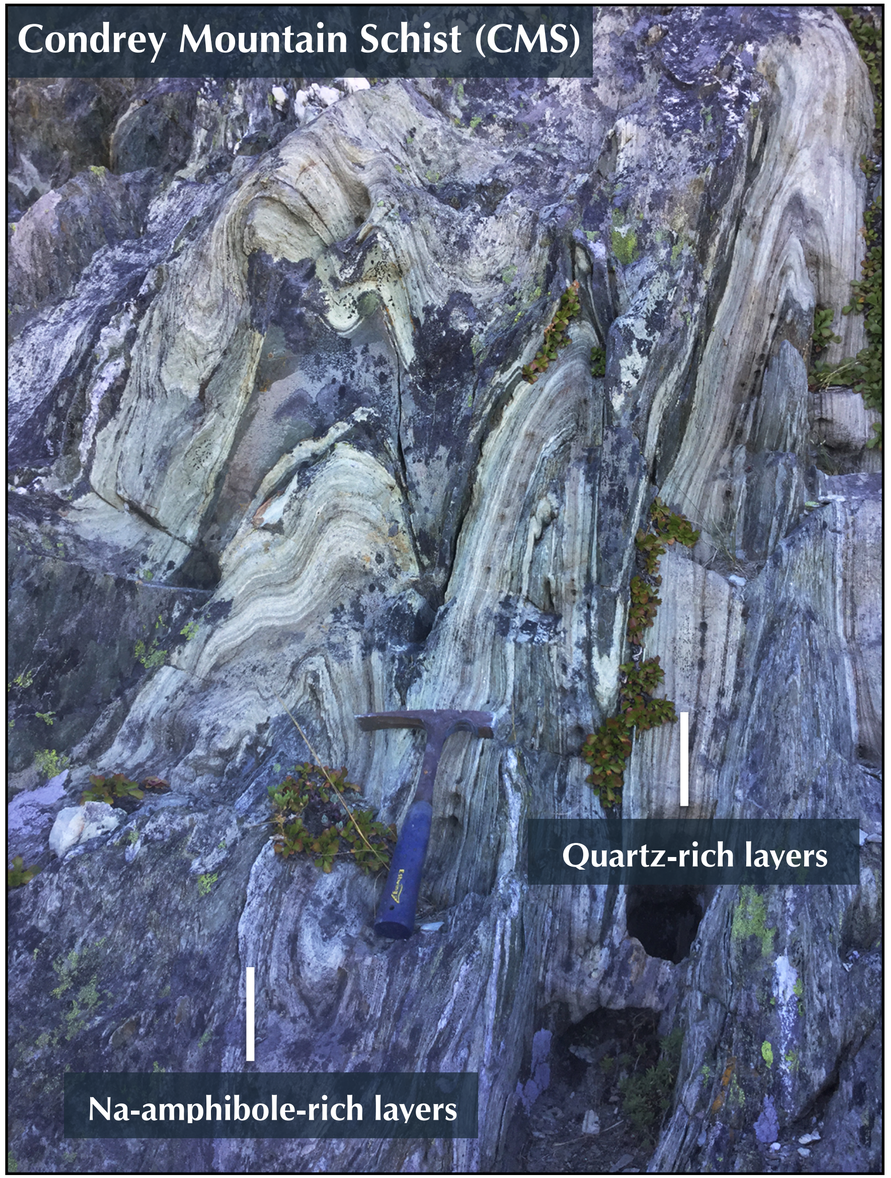
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Behr & Bürgmann (2021, Phil. Trans. R. Soc. A)

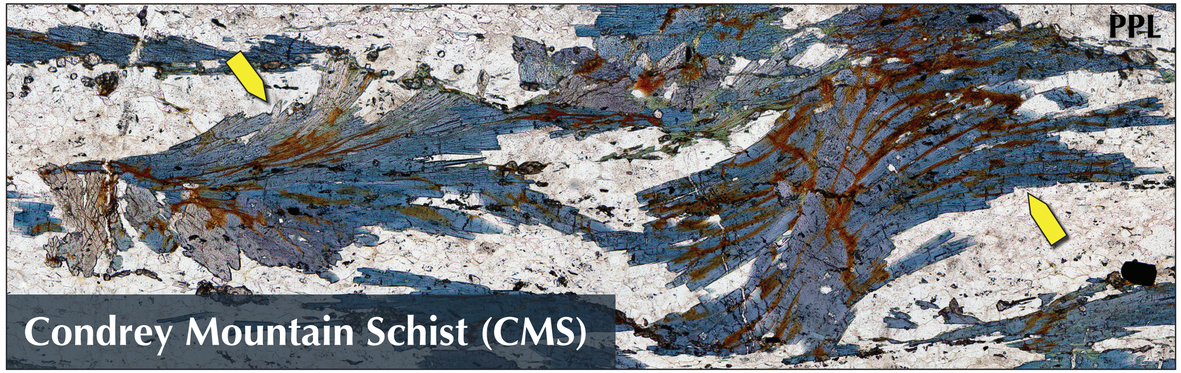
Field Observations

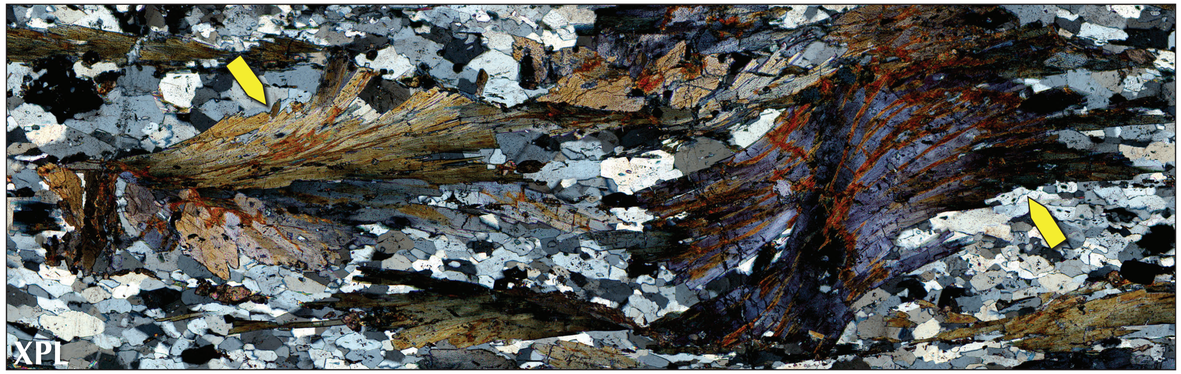


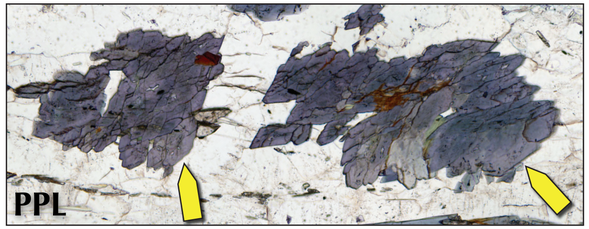


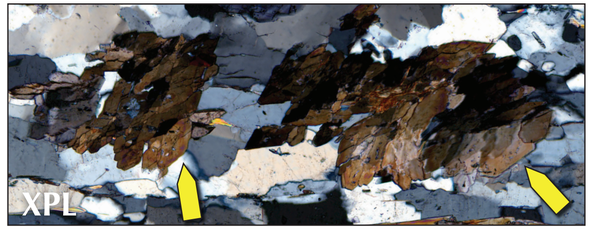
Fold wavelengths of quartz-rich & Na-amphibole-rich layers are comparable. Strain was distributed and not localized to one lithology or the margins of the lithologies. Both suggest similar strengths & viscosities.

Microstructural evidence for deformation mechanisms



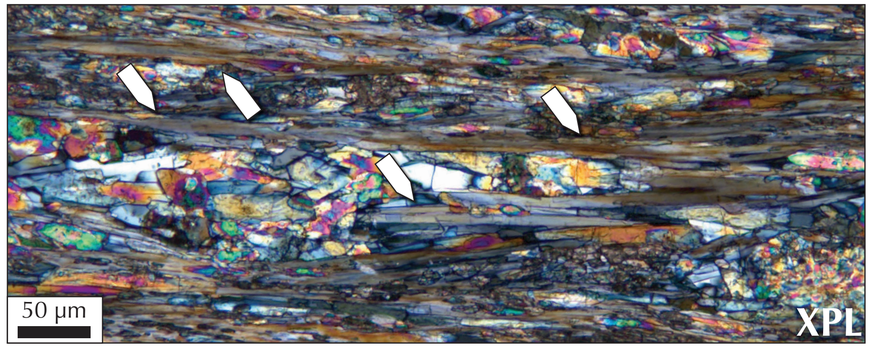






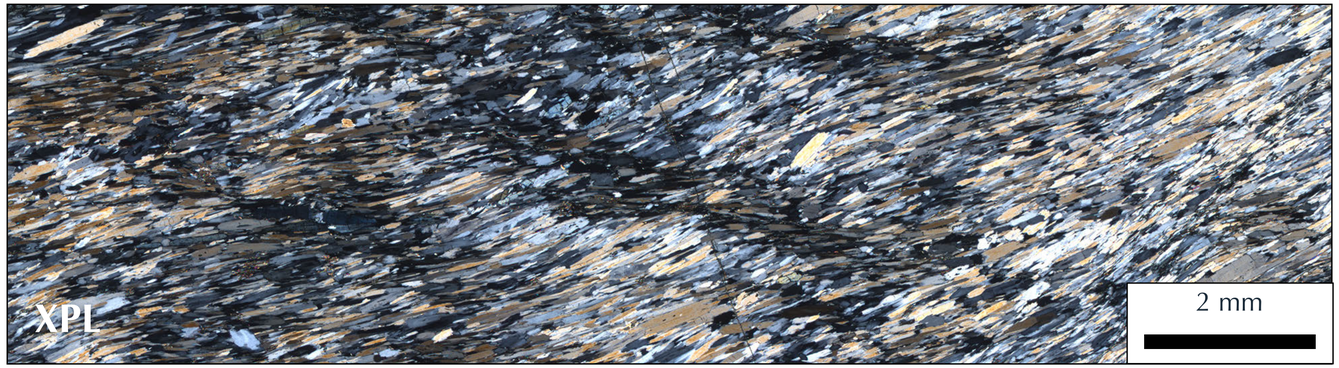
Dislocation creep textures with sweeping undulose extinction (top) & subgrains (bottom) observed in preserved Na-amphibole porphyroblasts are a possible precursor to both elongated & recrystallized grains in other samples.

Condrey Mountain Schist (CMS)



Na-amphibole rich samples have elongated grains with sweeping undulose extinction that wrap epidote. Na-amphiboles rarely have zonation (see more information for examples).

Cycladic Blueschist Unit (CBU)

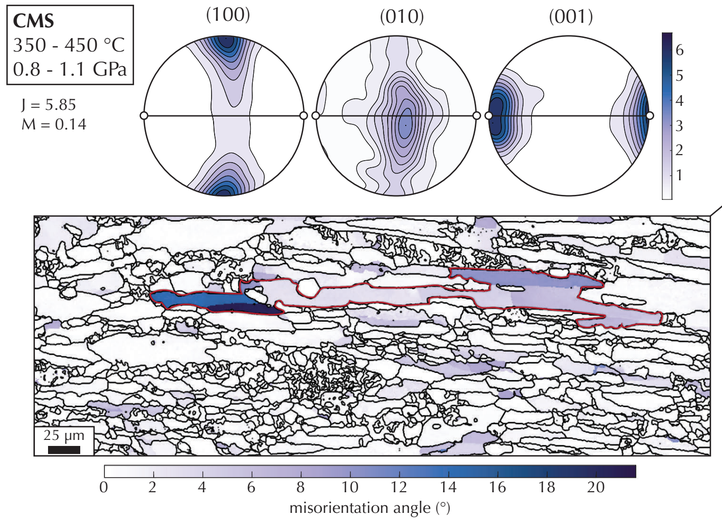


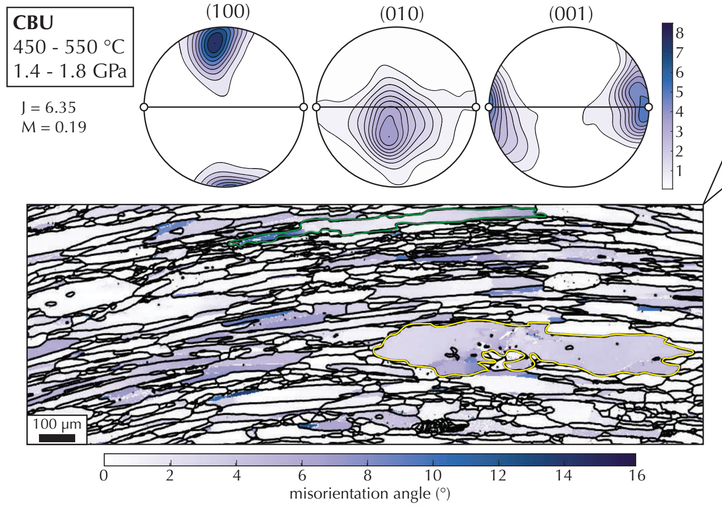
Small, needle-like acicular grains common in Na-amphibole-rich samples are consistent with either recrystallization via dislocation creep or oriented growth, or a combination.

Click here for more information

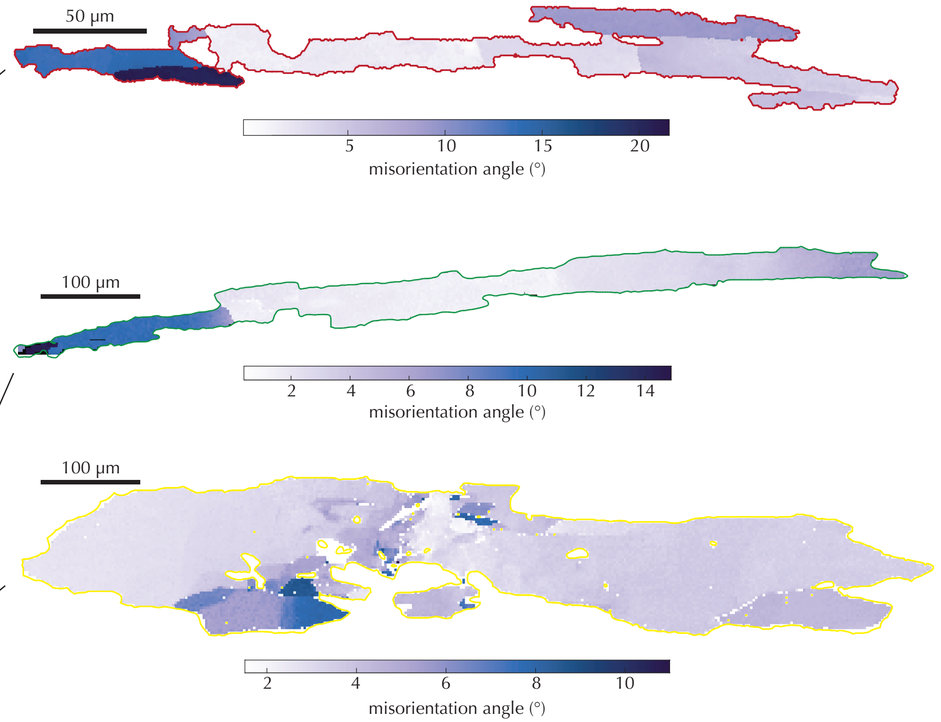
Electron Backscatter Diffraction (EBSD) characterization of fabrics

Strong CPO with (001) parallel to lineation & (100) perpendicular to foliation.



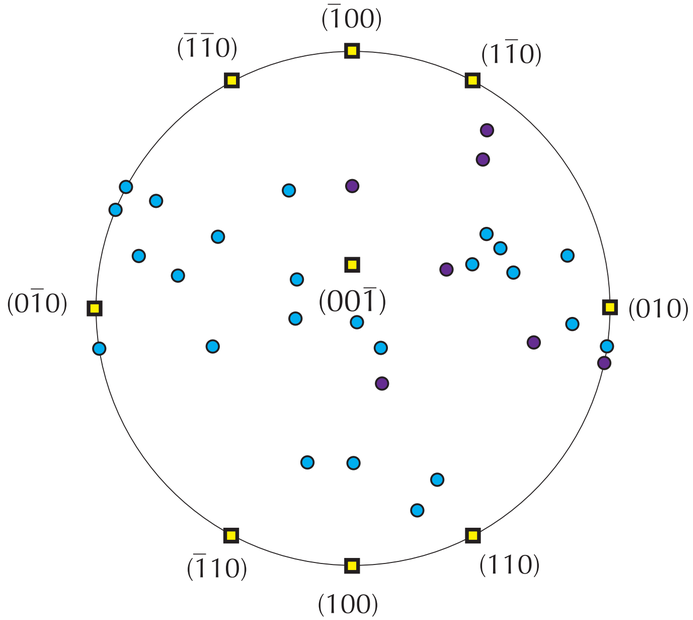


Subgrain development with subgrain walls forming two primary sets: parallel and perpendicular to Na-amphibole long-axes.



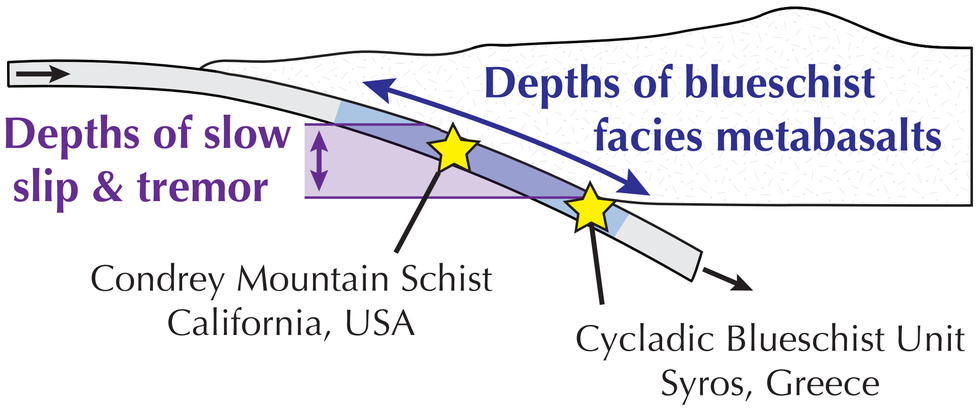
Grain size distribution (left & above left) characterized by high aspect ratio grains with subgrains & smaller, acicular grains that are approximately the same size as the subgrains.

Best fit rotation axes suggest 2+ slip systems activated to form subgrain walls.



Click here for more information

Implications for subduction interface rheology



Relative viscosities?

Blueschist facies metabasalts and metasedimentary rocks have a low viscosity contrast, making mafic blueschists a potentially major strain accommodating lithology from ~15-60+ km depth.

Microscale creep mechanisms?

Strain was primarily accommodated via dislocation activity in Na-amphiboles with slip on 2+ slip systems despite relatively simple CPOs. Other mechanisms, such as oriented growth or dissolution-precipitation creep, may have also contributed.

Pressure-Temperature control?

Microstructures, interpreted deformation mechanisms, & slip systems are similar at both pressure-temperature conditions.

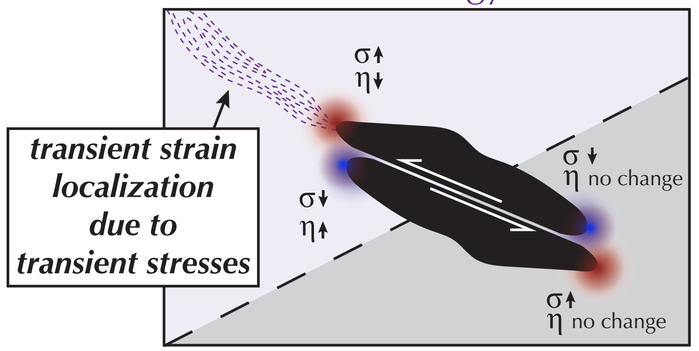
With *power law rheology*, increasing the stress greatly increases the strain rate & decreases the overall viscosity.

$$\uparrow \dot{\epsilon} \propto \uparrow \sigma^{n} \qquad \downarrow \eta \propto \frac{\sigma \uparrow}{\dot{\epsilon} \uparrow}$$

With *Newtonian rheology*, increasing the stress linearly increases the strain rate & does not affect the overall viscosity.

$$\uparrow \dot{\epsilon} \propto \uparrow \sigma \qquad \eta \propto \frac{\sigma \uparrow}{\dot{\epsilon} \uparrow}$$

Power law rheology matrix



Newtonian rheology matrix

Slow slip & tremor is associated with frictional failure of rigid blocks within a ductile matrix. Transient strain localization in a power law rheology matrix could communicate with other rigid blocks, triggering failure of multiple blocks & migration of slow slip within the interface.

Blueschist facies metabasalts are a potentially major strain accommodating rock type in the subduction interface, comparable to weak metasediments, but have power law rheology that could affect transient deformation behavior & shear zone evolution through time.

Thank you for visiting this presentation! If you have any questions, please feel free to post a comment to the EGU system, join the chat from 14:15-15:00 and from 16:00-17:00 on Monday, 26 April, or to contact the corresponding author directly at: carolyn.tewksbury-christle@erdw.ethz.ch

We are immensely grateful to Luiz Morales & James Maner for help in collecting the EBSD data, to Mark Helper, Kostis Soukis, and Miguel Cisneros for outstanding field discussions, and to the rest of our colleagues at the Structural Geology & Tectonics Group at ETH Zürich for feedback on this research.

To see further information, click on the tabs below to return to the summary slide of each section and then click the "more information" button.

Summary | Motivation | Geologic Settings | Field Observations | Microstructures | EBSD | Implications

Further slides for Motivation

Observations of Na-amphibole deformation mechanisms

	Shape Preferred Orientation (SPO)	Zonation	Crystallographic Preferred Orientation (CPO)	Subgrains	Recrystallized grains
Rigid Body Rotation	✓	✗	✓ c-axis aligned, girdle in b-axis	✗	✗
Oriented Growth	✓	✓	? If grown from crystals with existing CPO	✗	✗
Dissolution-precipitation	✓	✓	? If grown from crystals with existing CPO	✗	✗
Dislocation creep	✓	✗	✓ SL-type CPO with point maxima in all axes	✓	✓

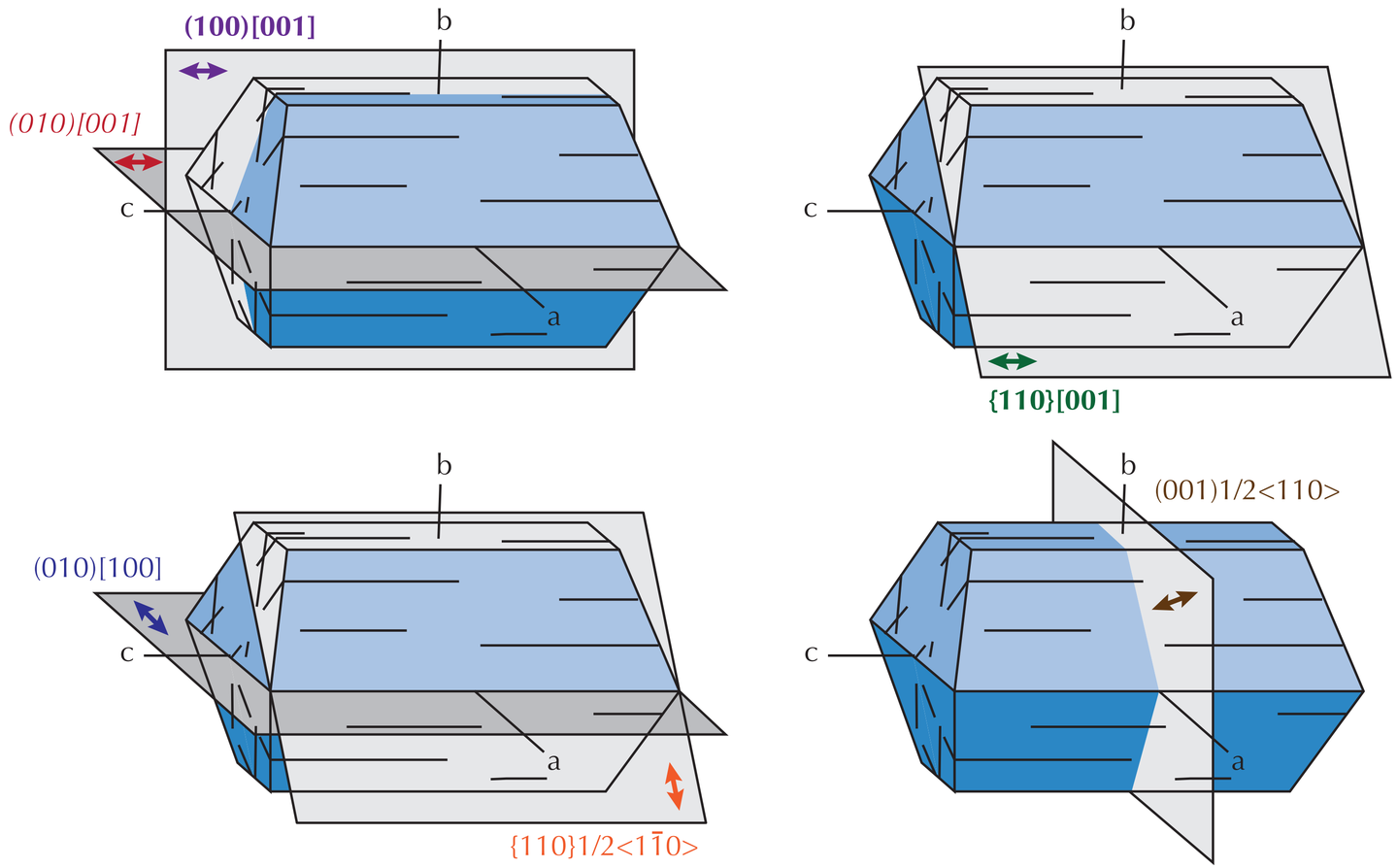
Evidence for dislocation creep is commonly a strong CPO, evidence of intracrystalline plasticity (e.g., subgrains, undulose extinction), lack of zonation, & a bimodal grain size distribution indicative of recrystallization.

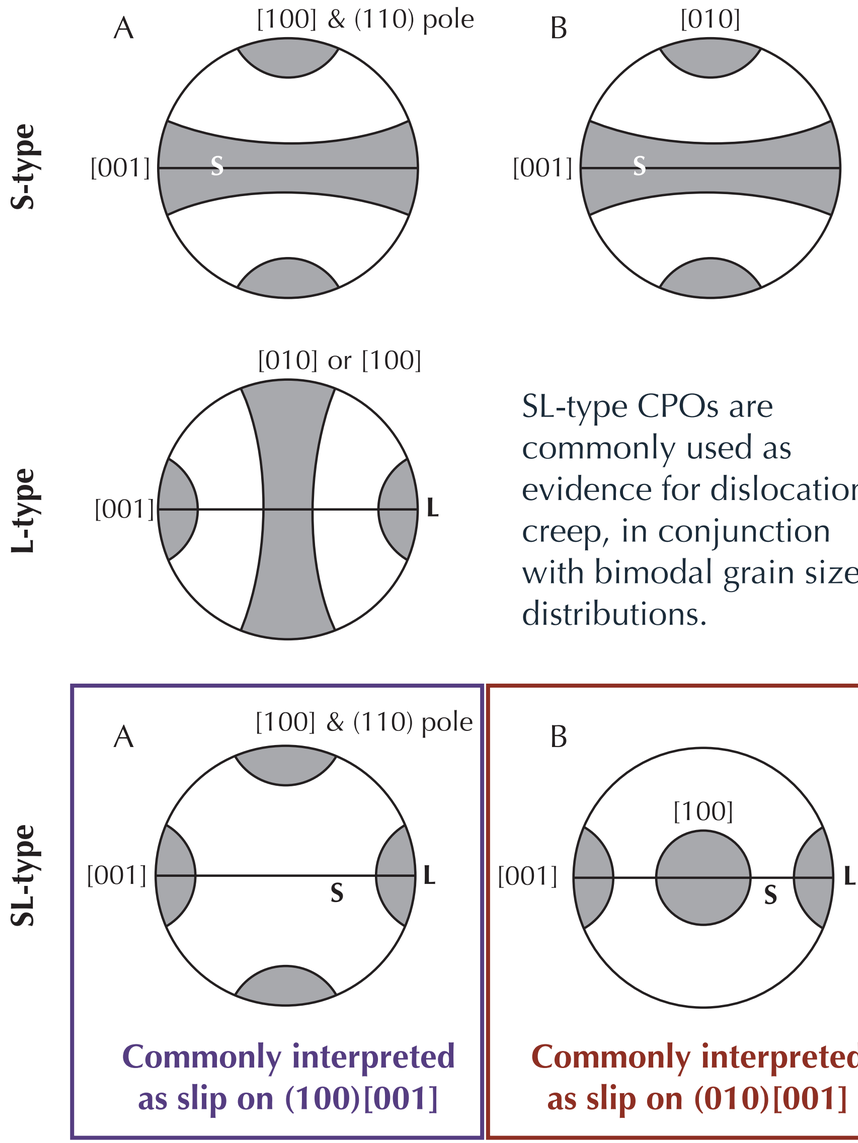
Next

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Return to Motivation

Published Na-amphibole slip systems & CPOs





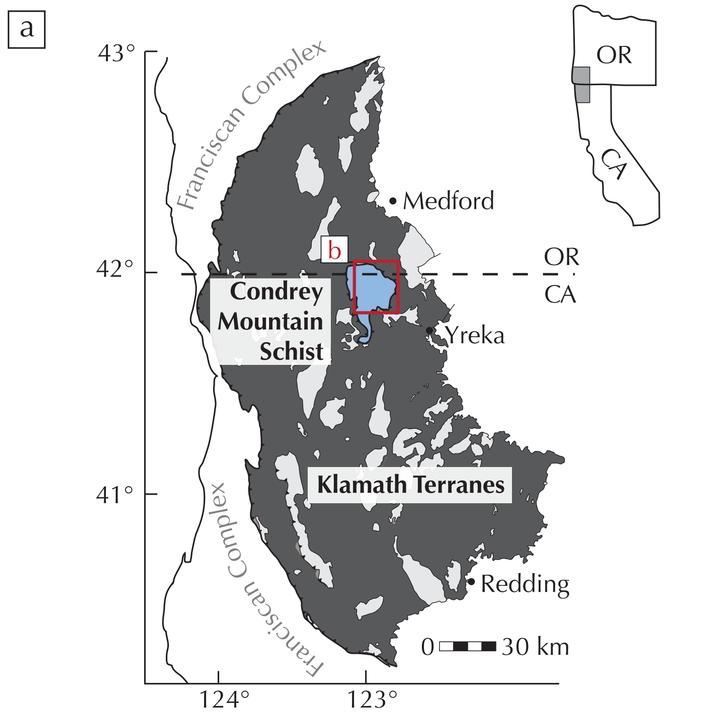
SL-type CPOs are commonly used as evidence for dislocation creep, in conjunction with bimodal grain size distributions.

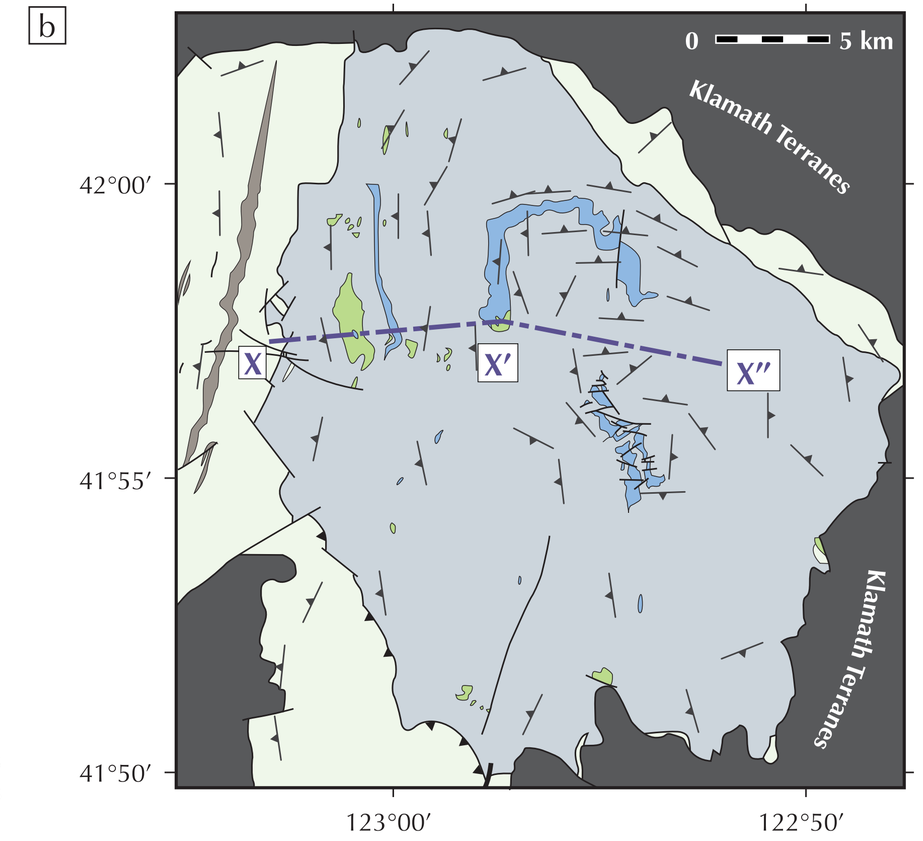
Documented slip systems (see Reynard et al., 1989) meet von Mises criterion. The (010)[001] slip system (italicized) is primary for T = 350-450°C and (100)[001] and {110}[001] slip systems (bolded) for T = 550-650°C. If this holds true, different slip systems should be active in the CMS versus the CBU.

Return to overall summary | Return to Motivation

Further slides for Geologic Settings

Condrey Mountain Schist, California, USA





Lower CMS
Epidote Blueschist Facies
- Graphitic Mica Schist
- Epidote Blueschist
- Serpentinite

Upper CMS
Greenschist to Epidote Amphibolite Facies
- Mafic Schist
- Graphite Phyllite

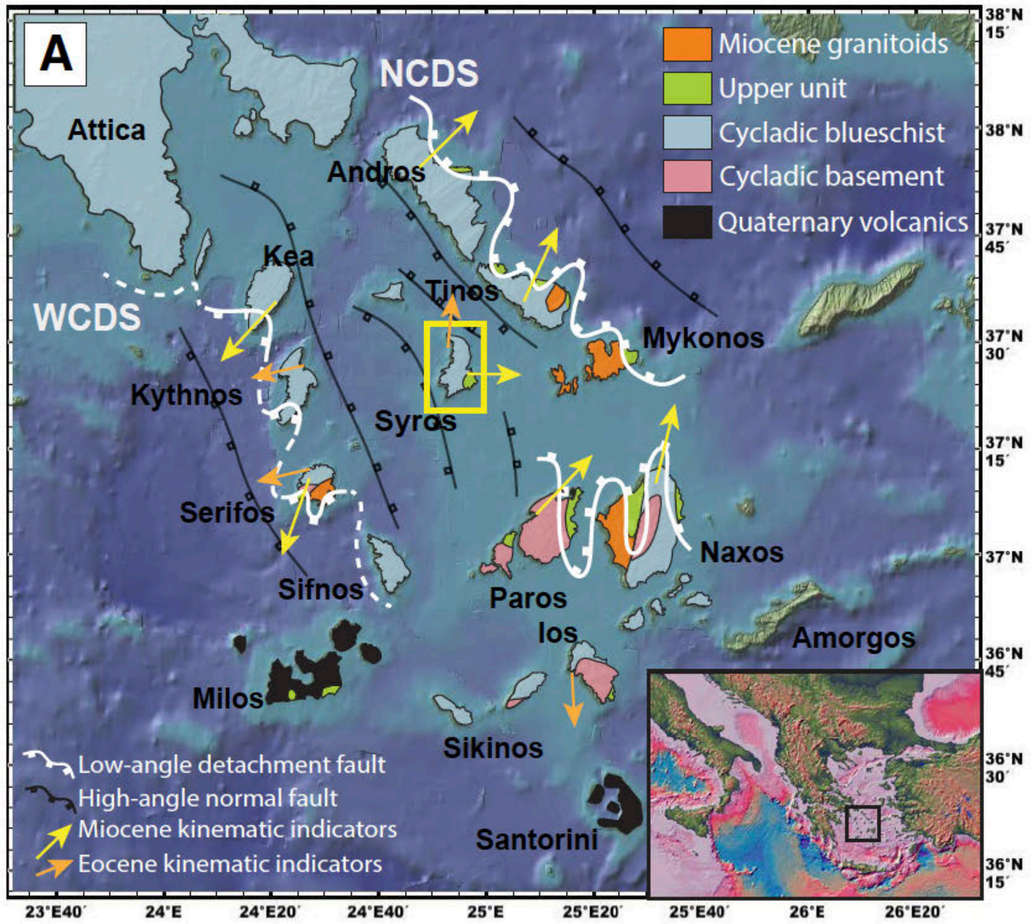
- Klamath terranes
- Pz-Mz intrusions
- thrust fault
- fault
- inferred fault
- contact
- foliation

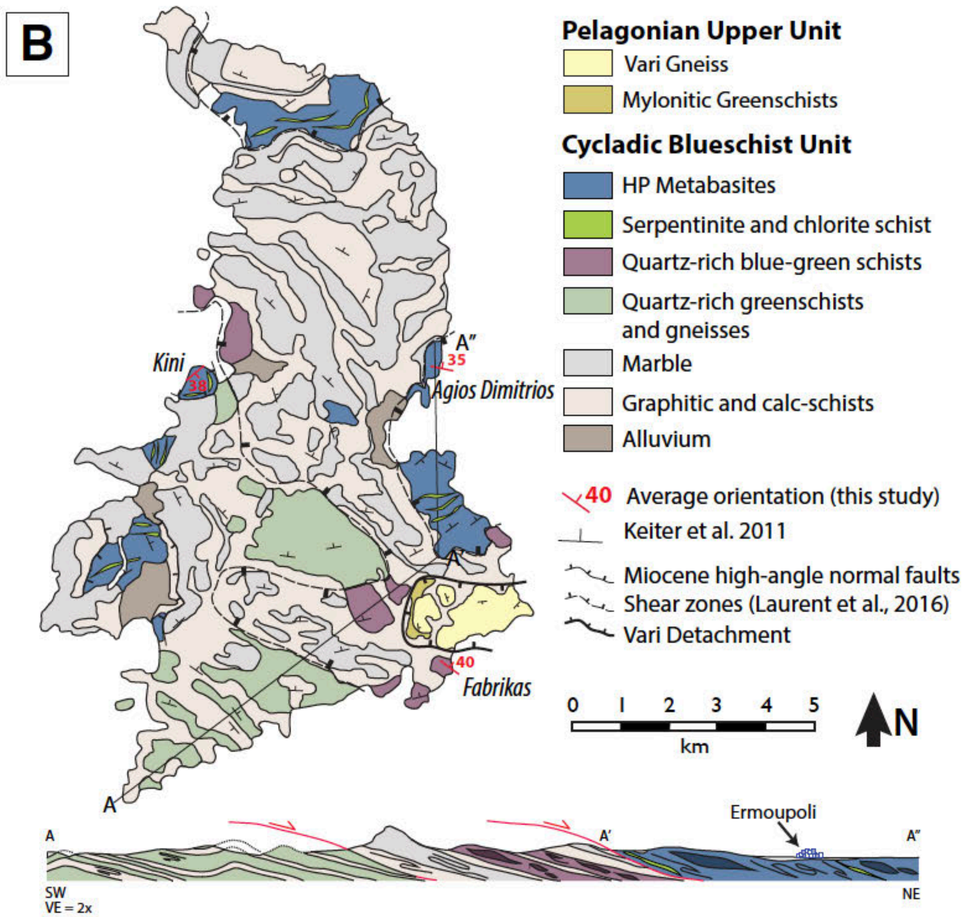
Tewksbury-Christle & Behr (submitted, GRL)

Next

Return to overall summary | Return to Geologic Settings

Cycladic Blueschist Unit, Syros, Greece



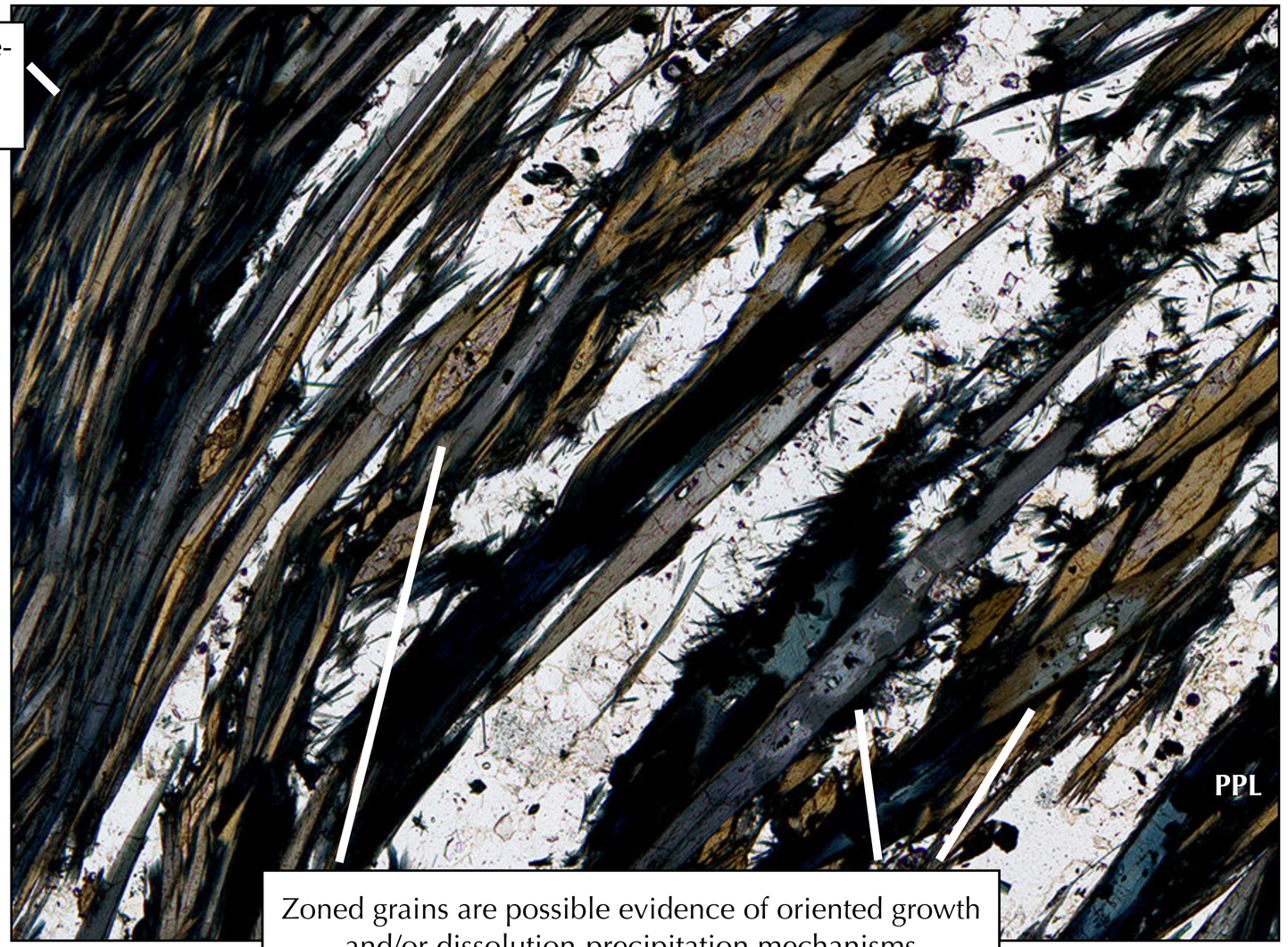


Kotowski & Behr (2019, Geosphere)

Return to overall summary | Return to Geologic Settings

Further slides for Microstructures

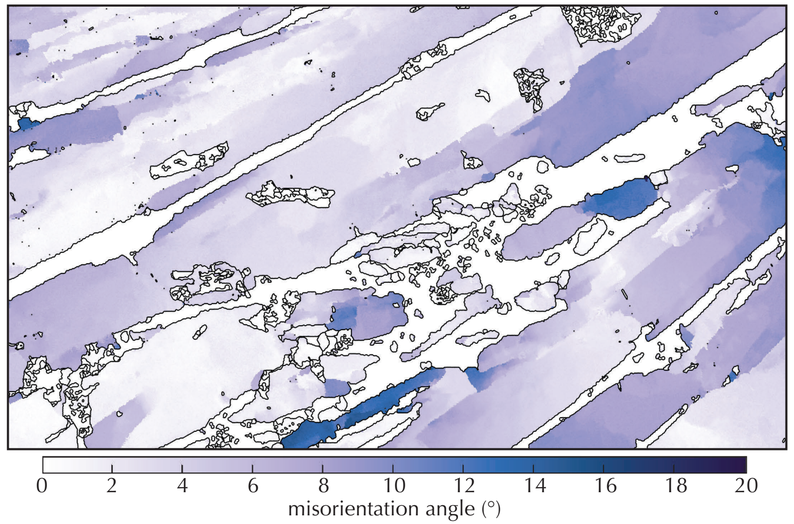
Further observations of microstructures

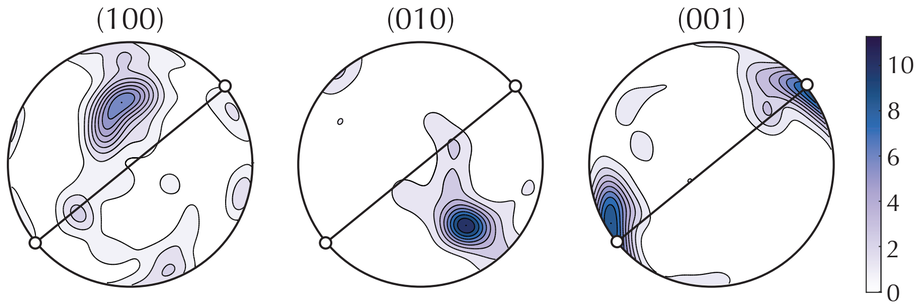


Return to overall summary
Return to Microstructures

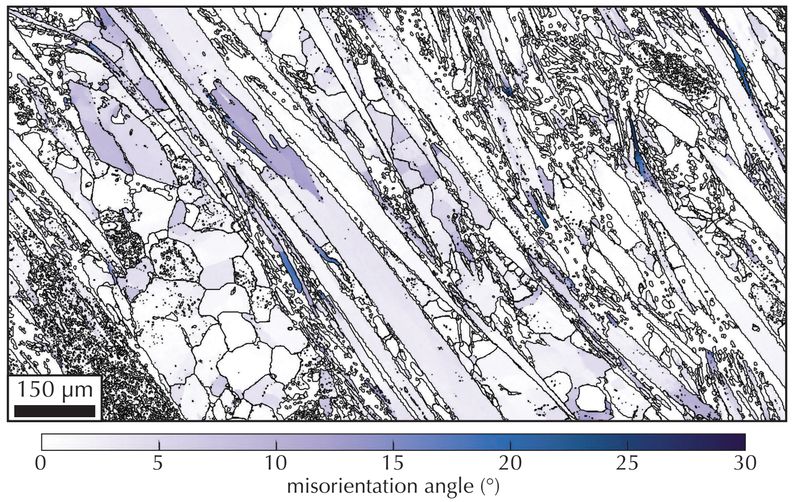
Further slides for EBSD

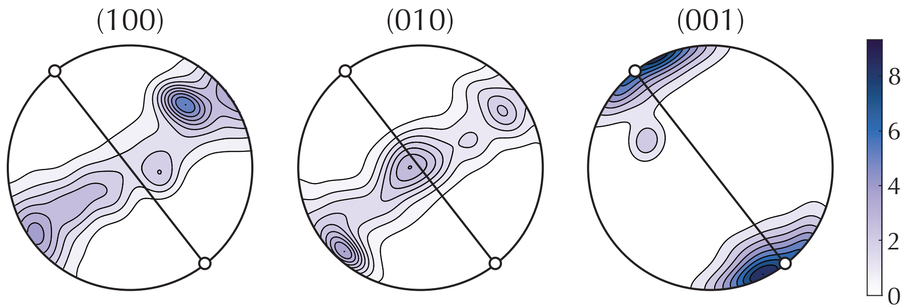
Condrey Mountain Schist EBSD Results

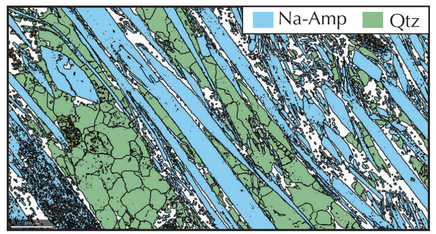




Subgrain development in Na-amphibole porphyroblasts.







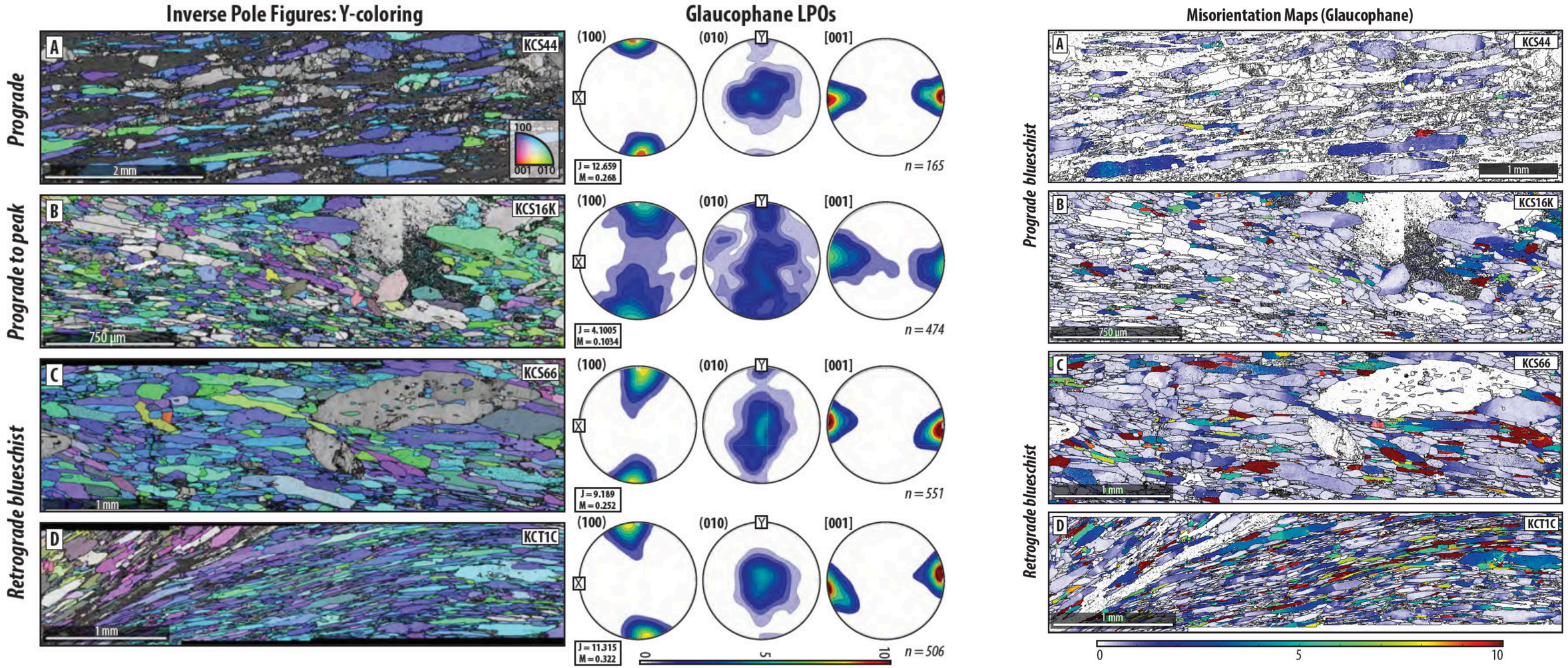
High aspect ratio grains in a Na-amphibole-rich sample. Some elongated grains have limited intracrystalline plasticity, and microstructures from this sample support some strain accommodation via oriented growth and/or dissolution-precipitation creep.

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Return to EBSD

Cycladic Blueschist Unit EBSD Results



Prograde & retrograde blueschists have strong CPOs, evidence of subgrain development in high aspect ratio grains, and smaller, needle-like acicular grains.

Return to overall summary | Return to EBSD