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Earth & Environmental Science

Rock and Mineral Physics

Backstresses in polycrystalline olivine and implications for transient deformation of the mantle

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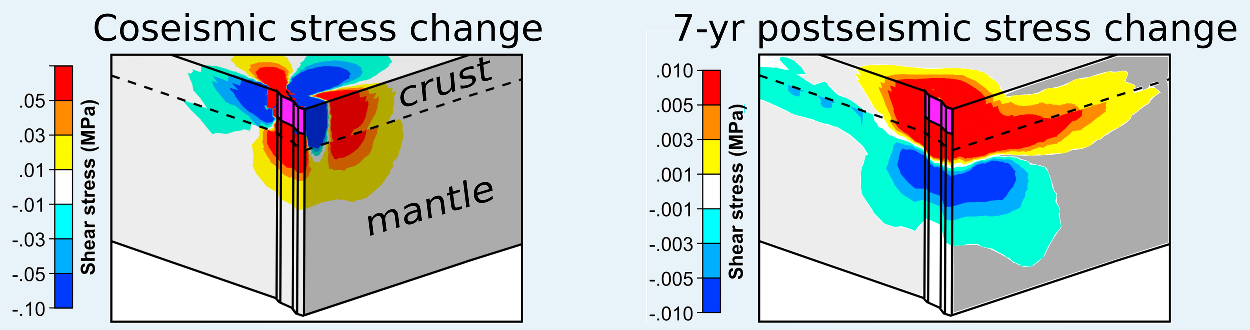
TAKEAWAY: Stress-relaxation experiments on polycrystalline San Carlos olivine demonstrate that relaxation exhibits steady-state creep behavior, suggesting that the backstress in deforming olivine is approximately equal to the applied stress. Therefore, we expect that dislocation recovery on (010)[001] dictates the relaxation behavior of the upper mantle.

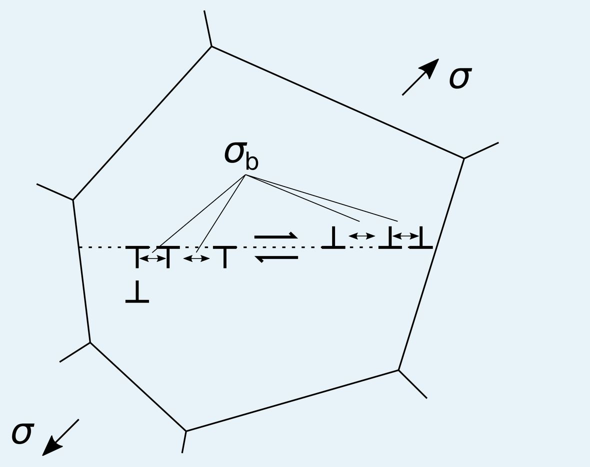
INTRODUCTION

- Transient creep of polycrystalline olivine controls the behavior of the upper mantle at human timescales (hr to kyr).
- Relevant processes include post-seismic creep, glacial isostatic adjustment, and tidal deformation of tidally-locked planetary bodies.



Finite element model of postseismic relaxation in the upper mantle after the 1999 Hector mine earthquake, California (Freed et al. 2012)

- The relaxation of backstresses (σ_b) in olivine has been observed to control transient behavior in single crystals.



$$\dot{\varepsilon}_p = A_1 \exp\left(\frac{-\Delta F}{RT}\right)\sinh\left(\frac{\Delta F}{RT}\frac{\sigma - \sigma_b}{\Sigma}\right)$$

Plastic strain rate ($\dot{\varepsilon}_p$) is proportional to sinh of applied stress (σ) minus the backstress (σ_b).

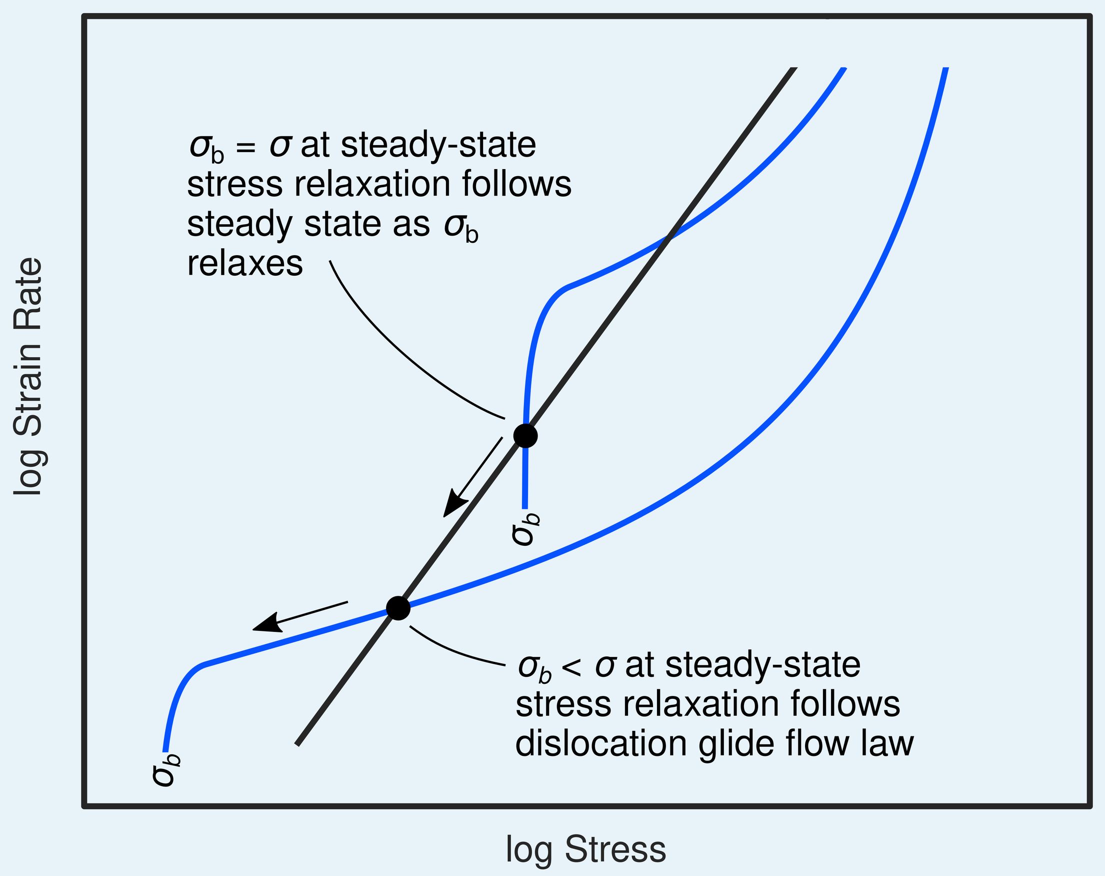
$$\sigma_b = \alpha\mu b\sqrt{\rho}$$

Long-range elastic interactions between dislocations produce backstresses.

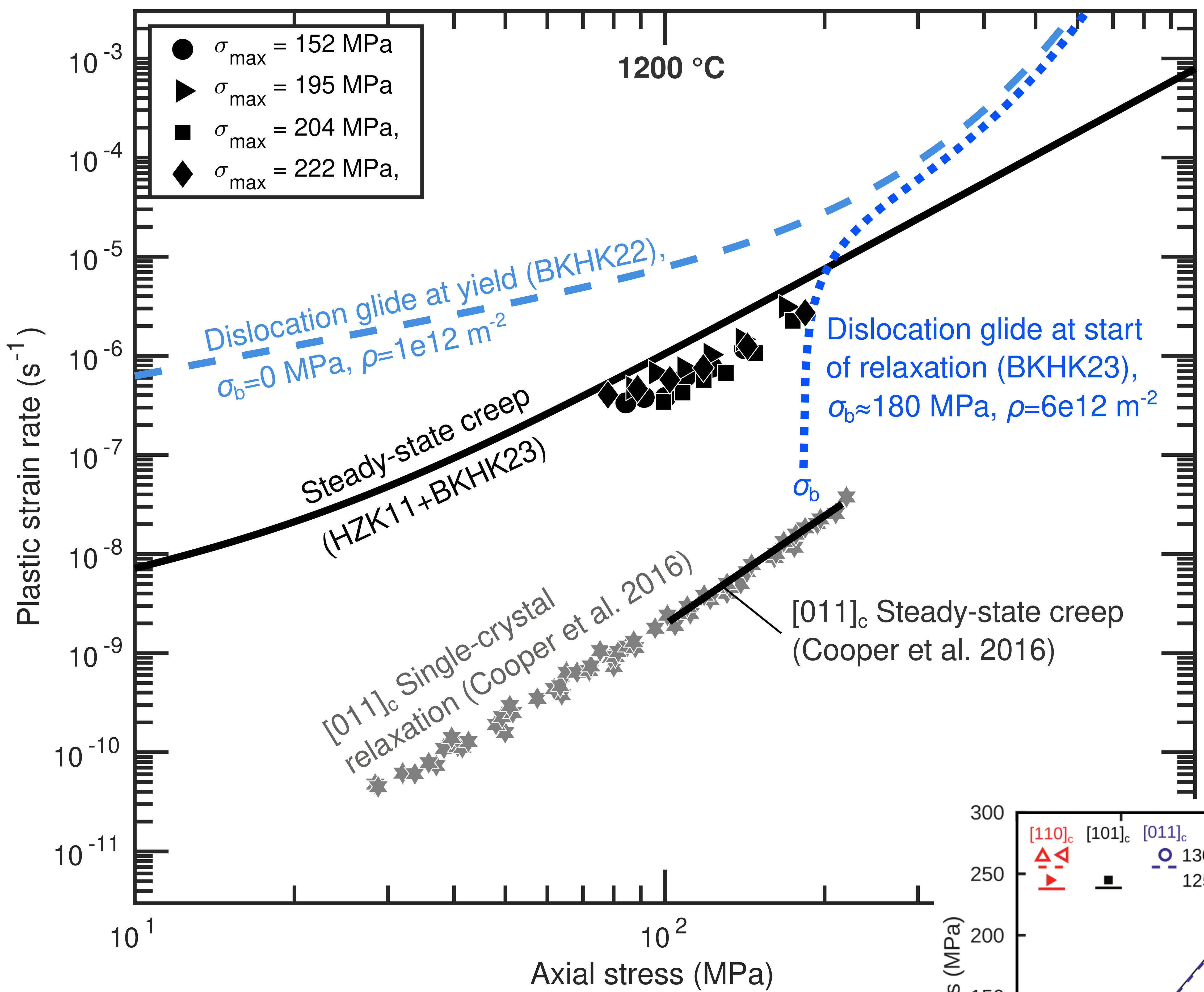
Backstresses are proportional to dislocation density (ρ) through the Taylor equation.

- Backstress magnitude controls the path of relaxation, but backstresses in polycrystalline olivine remain unconstrained.

What is the magnitude of backstresses in *polycrystalline* olivine?

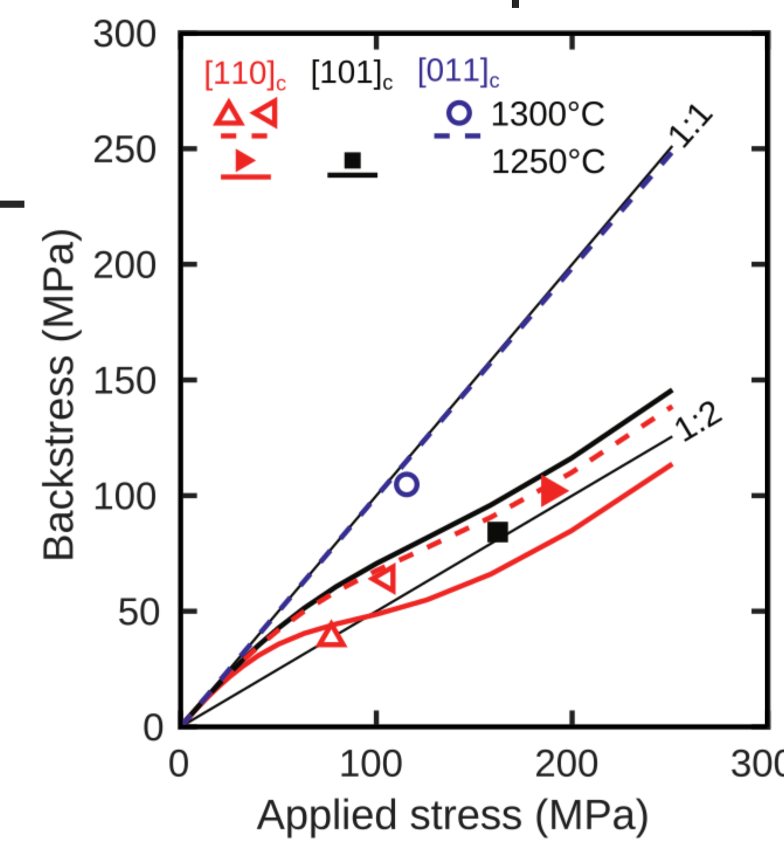


Prediction of relaxation behavior based on steady-state (straight line) and dislocation glide (curved lines) flow laws (Hansen et al. 2021)



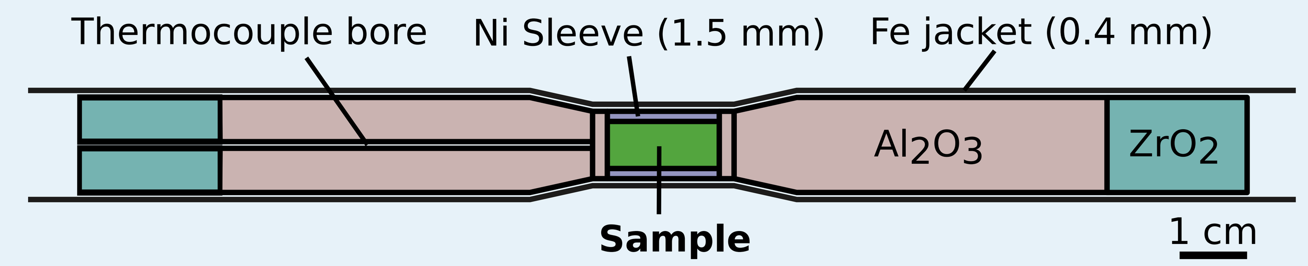
▲ *Relaxation data fall on a single hardness curve and follow steady-state creep behavior, suggesting $\sigma_b \approx \sigma$. Backstresses can only be relaxed by recovery.*

Backstresses are consistent with the hard slip system ▶ in olivine, indicating that recovery of backstress on (010)[001] slip planes controls relaxation.



Single-crystal data (Hansen et al. 2021)

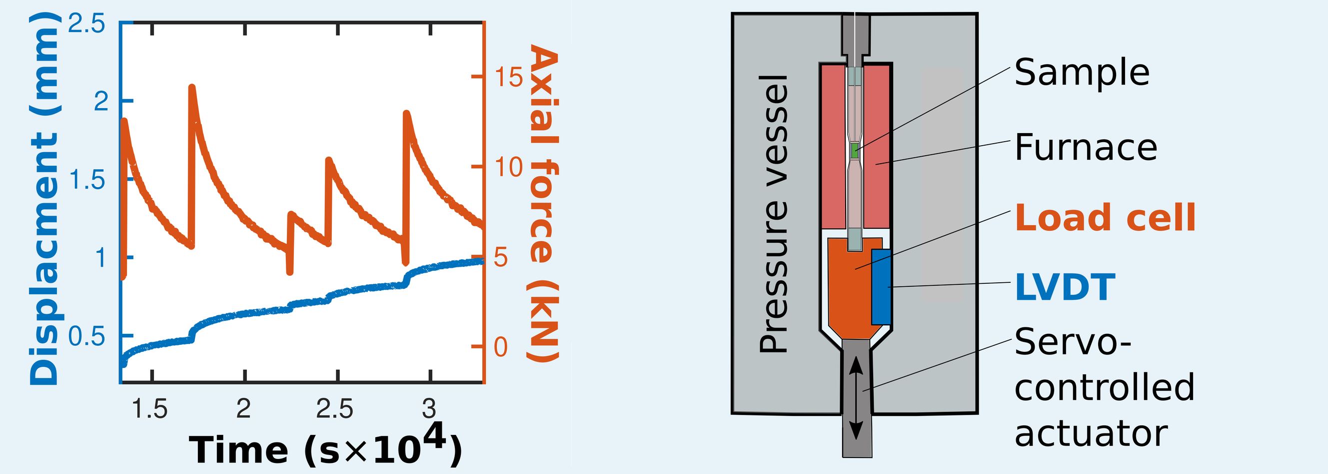
EXPERIMENTAL MATERIALS



- San Carlos olivine ($d \approx 15$ μm)
- Isostatically hot-pressed under vacuum in a gas-medium apparatus at 300 MPa and 1523 K
- Oxygen fugacity buffered at the Ni:NiO buffer

EXPERIMENTS

- Stress-relaxation experiments on polycrystalline olivine were performed in a Paterson-type gas-medium apparatus (PI10).



Mechanical data of 5 relaxation intervals, of which the largest 4 are plotted on the central panel.

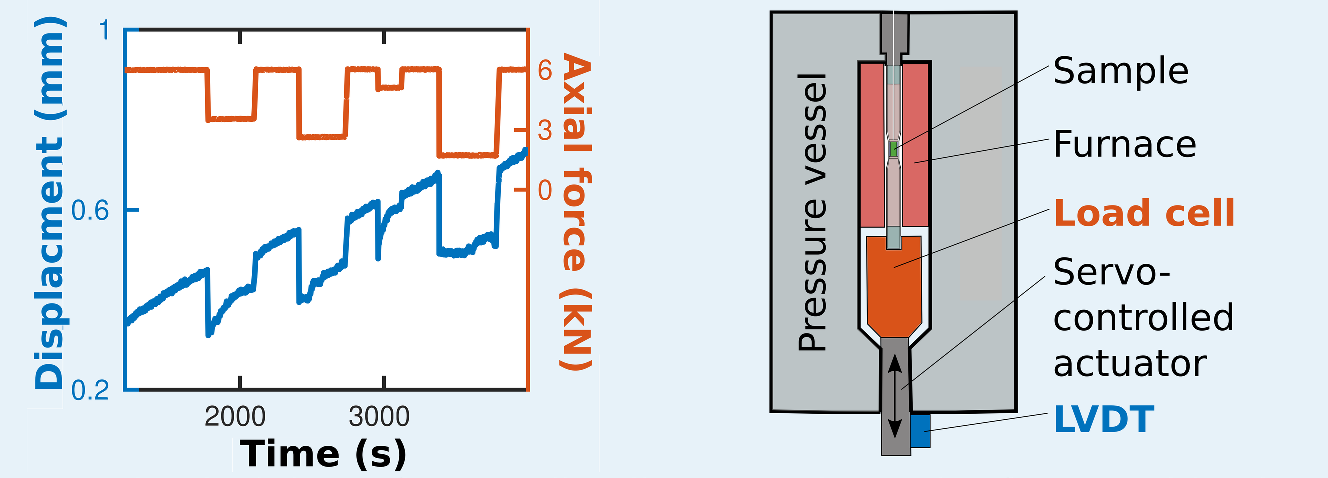
Schematic of PI10. Force and displacement are measured internally to the pressure vessel.

- After stress corrections for the Ni sleeve and Fe jacket, plastic strain rate was calculated using the stiffness of the assembly (k) and the modulus of olivine (M),

$$\dot{\varepsilon}_p = -\left(\frac{1}{k} + \frac{1}{M}\right)\dot{\sigma}.$$

WORK IN PROGRESS

- Precise quantification of backstresses in single crystals of olivine has previously been achieved through stress-dip experiments.
- Pilot stress-dip experiments on polycrystalline olivine in PI10 revealed challenges regarding precise force control. Our other apparatus, PI3, has excellent force control but poor displacement resolution:



Mechanical data of stress dip pilot experiment in PI3. Note precise load-control capability.

Schematic of PI3. Position is measured externally to the pressure vessel.

- Work in progress: Augmenting PI3 to include an internal DCDT.