Effect of olivine anisotropic viscosity in advancing and retreating subduction settings

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Introduction

Lattice preferred orientation (LPO) of olivine crystals occurs due to deformation in the mantle and laboratory experiments have shown that such textures induce anisotropic viscosity in olivine aggregates. It is thus important to study the formation of LPO and AV and their relationship to better interpret seismic anisotropy and understand mantle dynamics. For example in an upper mantle setting that can undergo a large variety of deformation paths, AV could modify the mantle flow and in turn affect the LPO. Here we compare the LPO evolution in two subduction settings with a slowly advancing trench and a retreating trench, with and without AV, to study the significance of AV in different regions of a subduction system and under different subduction settings .

Method

Subduction models are ran with ASPECT and particle texture is computed using **D-REX [1,2]**. We obtain the initial orientation, stress and strain rate from the ASPECT model and recalculate the texture evolution using the **Modified Director Method (MDM) [3] and MDM+AV[4]**. To calculate texture under the effect of AV, we first compute the fluidity tensor in the LPO reference frame using Hills' parameters and then rotate it back to model reference frame. The texture and strain rate for the next time step is predicted using the fluidity tensor as a representation of anisotropic viscosity.

Model evolution

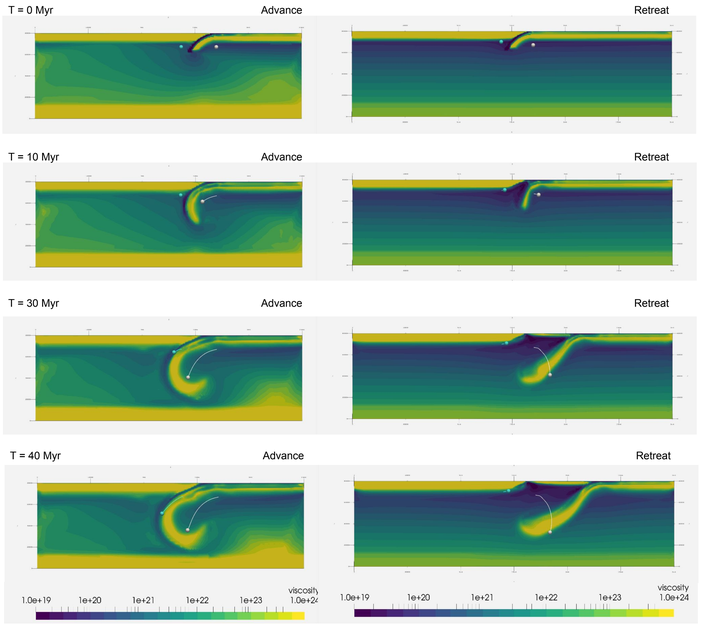

Figure 4. Cross sections taken from the middle of the subduction models showing the viscosity (Pa s))in log scale. Two particles that are analysed are represented by the spheres and their displacement is tracked by the path line. The sub-slab particle (particle 0 from both models) is white and the mantle wedge particle (particle 48 and particle 29 from the subduction with advancing and retreating trench respectively) is cyan.

Discussion

- The effect of anisotropic viscosity on texture prediction is reflected in the texture orientation, strength, and the alignment of olivine a-axis versus the principal stress direction.
- In the subduction model with a retreating trench, texture predicted by MDM+AV is stronger than from the subduction model with an advancing trench.
- In all these models, one particle is not representative enough and analysis will benefit from having more particles scattered in the domain of interest.

References

[1] Kaminski, É., & Ribe, N. M. (2002). Timescales for the evolution of seismic anisotropy in mantle flow. Geochemistry, Geophysics, Geosystems, 3(8). https://doi.org/10.1029/2001GC000222
[2] Fraters, M. R., & Billen, M. I. (2021). On the implementation and usability of Crystal Preferred Orientation Evolution in geodynamic modeling. Geochemistry, Geophysics, Geosystems, 22(10). https://doi.org/10.1029/2021gc009848
[3] Hansen, L., Conrad, C., Boneh, Y., Skemer, P., Warren, J., & Kohlstedt, D. (2016a). Viscous anisotropy of textured olivine aggregates: 2. Micromechanical model. Journal of Geophysical Research-Solid Earth, 121(10), 7137-7160. doi:10.1002/2016JB013240Kaminski, E., Ribe, N., & Browaeys, J. (2004).
[4] Hill, R. (1948). A theory of the yielding and plastic flow of anisotropic metals. Proceedings of the Royal Society of London. Series A. Mathematical and Physical Sciences 193(1033):281-297.

Subduction with advancing trench

Particle id 0 in the sub-slab region of subduction model with an advancing trench

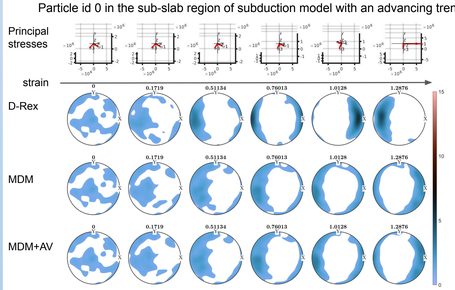

Figure 1. Texture of one olivine particle from the sub-slab area in the subduction model with an advancing trench plotted with increasing accumulated strain predicted by D-Rex, MDM and MDM+AV. The principal stresses at the selected strain is shown on top.

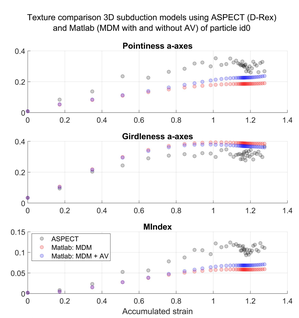

Figure 2. Texture scores (pointiness, girdleness and m-index) of this particle.

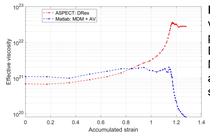

Figure 3. Effective viscosity of this particle predicted by D-Rex and MDM+AV plotted against accumulated strain.

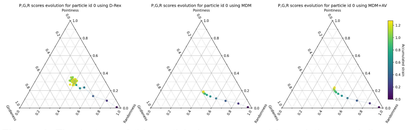

Figure 4. The texture of this particle is represented by pointiness, girdleness, randomness scores that are calculated from the eigenvalues of the orientations.

- **The effective viscosity starts to differ when the principal stresses increases and becomes more aligned with mean olivine a-axis direction。**
- **D-Rex texture is stronger compared to MDM and MDM+AV textures.**

Subduction with retreating trench

Particle id 0 in the sub-slab region of subduction model with an advancing trench

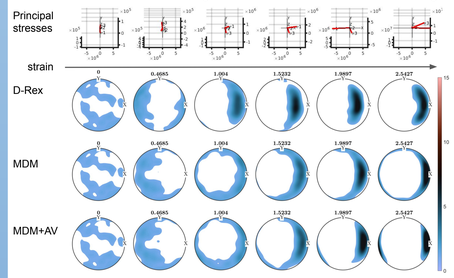

Figure 9. Texture of one olivine particle from the sub-slab area in the subduction model with a retreating trench plotted with increasing accumulated strain predicted by D-Rex, MDM and MDM+AV. The principal stresses at the selected strain is shown on top.

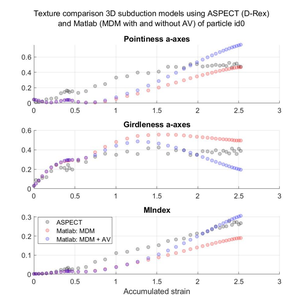

Figure 10. Texture scores (pointiness, girdleness and m-index) of this particle.

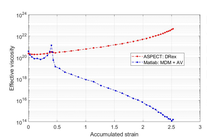

Figure 11. Effective viscosity of this particle predicted by D-Rex and MDM+AV plotted against accumulated strain.

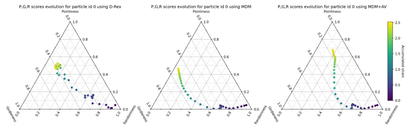

Figure 12. The texture of this particle is represented by pointiness, girdleness, randomness scores that are calculated from the eigenvalues of the orientations.

- **Similarly, as a strong point-like texture develop, deformation in this direction becomes easier, as is reflected in the decrease in the effective viscosity predicted by MDM+AV.**
- **MDM+AV over-predicts the weakening effect due to anisotropic viscosity.**

Particle id 48 in the mantle wedge region of subduction model with an advancing trench

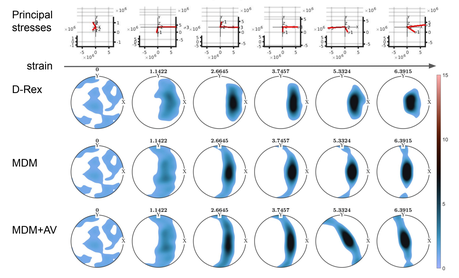

Figure 5. Texture of one olivine particle from the mantle wedge area in the subduction model with an advancing trench plotted with increasing accumulated strain predicted by D-Rex, MDM and MDM+AV. The principal stresses at the selected strain is shown on top.

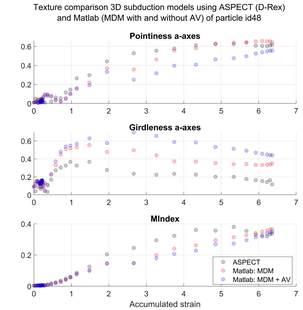

Figure 6. Texture scores (pointiness, girdleness and m-index) of this particle.

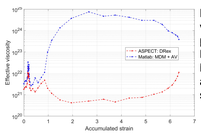

Figure 7. Effective viscosity of this particle predicted by D-Rex and MDM+AV plotted against accumulated strain.

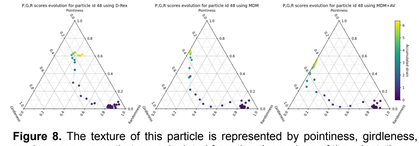

Figure 8. The texture of this particle is represented by pointiness, girdleness, randomness scores that are calculated from the eigenvalues of the orientations.

- **The largest principal stress is perpendicular to the mean a-axis orientation and the effective viscosity predicted by MDM+AV shows a hardened effect.**
- **MDM and MDM+AV predicts a more girdle-like texture while D-Rex predicts a more point-like texture.**

Particle id 29 in the mantle wedge region of subduction model with a retreating trench

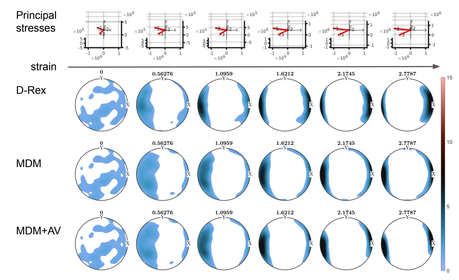

Figure 13. Texture of one olivine particle from the mantle wedge area in the subduction model with a retreating trench plotted with increasing accumulated strain predicted by D-Rex, MDM and MDM+AV. The principal stresses at the selected strain is shown on top.

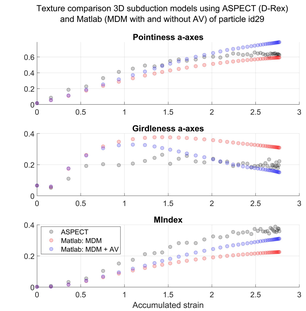

Figure 14. Texture scores (pointiness, girdleness and m-index) of this particle.

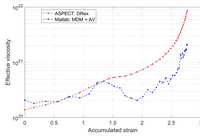

Figure 15. Effective viscosity of this particle predicted by D-Rex and MDM+AV plotted against accumulated strain.

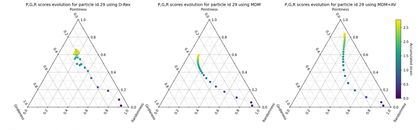

Figure 16. The texture of this particle is represented by pointiness, girdleness, randomness scores that are calculated from the eigenvalues of the orientations.

- **In this subduction model with a retreating trench, MDM+AV predicts a more point-like texture compared to using the other methods.**