Anisotropic Imaging and Crystalline Fabric properties of Whillans Ice Stream (West Antarctica) obtained from multicomponent seismic data

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Abstract

The intrinsic anisotropy of polar ice likely results from crystal orientation fabric (COF) occurring within ice masses. Seismic methods can effectively be used to infer COF properties. Typically, ice dome and ice divide seismic observations show the presence of transversely isotropic ice with a vertical axis of symmetry (VTI). However, the ice structure may be different elsewhere because the balance of deviatoric stresses may play an important role in determining the axis of symmetry for fabrics. Moreover, the presence of fractures oriented along a preferential direction or finely internal layering may induce other anisotropic effects that can mask intrinsic anisotropy.

In this work (Picotti et al., 2015), surface wave dispersion analysis, ray tracing, and traveltime inversion of *P* and *S* waves are applied to the active multicomponent seismic data acquired on the Whillans Ice Stream (West Antarctica), in correspondence to the Subglacial Lake Whillans (SLW), with the purpose of characterizing the fabric and anisotropic features of the ice mass versus depth. Our methodology reveal the presence of anisotropic VTI ice beneath approximately 65 m of isotropic firn. The ice stream is characterized by weak anisotropy, involving an average ice thickness of approximately 780 m. The analysis indicates that about 95% of the ice mass is anisotropic, and the crystalline *c* axes span within an average broad cone angle of 73 ± 10° with respect to the vertical axis. Moreover, the mean temperature T (below the firn) estimated from seismic data is −15 ± 5°C, which is in agreement with the results from ice sheet modeling applied to the Siple Coast region.

Anisotropic imaging of WIS confirms the reliability of the retrieved VTI model and excludes the presence of azimuthal anisotropy due to transversely compressive flow or fractures aligned along a preferential direction. Passive multicomponent seismic data and the application of the horizontal-to-vertical component spectral ratio technique further confirm these conclusions (Picotti et al. 2017).

From a rheological perspective, the ice column at the SLW location is not as anisotropic as at ice domes and ice divides, even though it shows the same VTI structure. These findings denote that the VTI ice structure might be typical of large ice streams flowing over highly water-saturated sediments, in regions where basal shear stresses and deviatoric stresses are low, and the principal component of the ice stream motion is basal sliding or bed deformation, rather than deformation in the ice mass. In general, anisotropic analysis of ice can be important to determine whether a basal sliding regime or a glacial deformation regime dominates, providing additional insights into the interaction between ice streams and the substrate over which they flow. Knowledge of such phenomena has direct implications for the predictive modeling of polar ice sheets.

Keywords: Seismic Anisotropy, Crystalline Fabric, Ice Stream.

References

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