HOW DO CATACLASITE AND MYLONITE PHYSICAL PROPERTIES DRIVE WAVE VELOCITIES AND REFLECTIVITY AT THE ALPINE FAULT, NEW ZEALAND

L. Adam[a], M. Frehner[b], K. Sauer[c], V. Toy[c], S. Guerin-Marthe[d], , D. Faulkner[e] and , S. Kanakiya[a], C. Boulton[f]

[a] *School of Environment, University of Auckland*

[b] *Geological Institute, ETH Zürich*

[c] *Department of Geology, University of Otago*

[d] *Department of Earth Sciences, Durham University*

[e] *Department of Earth, Ocean and Geological Science, University of Liverpool*

[f] *School of Geography, Environment and Earth Sciences, Victoria University*

Contact email: l.adam@auckland.ac.nz

Introduction

The Alpine Fault is of global importance for fault-zone studies because it ruptures on average every 330-years producing large magnitude earthquakes (Mw>7). The fault is thought to be late on its seismogenic cycle since its last rupture is dated to 1717 [2]. The central portion of the Alpine Fault was the focus of the Deep Fault Drilling Projects (DFDP) [3]. The DFDP are yielding direct measurements of the ambient conditions in the fault zone and novel information about the fault's long term evolution and earthquake producing characteristics. As such, the DFDP is working towards understanding how micro- and macro-scale rock properties affect large-scale rupture processes and the evolution of an earthquake cycle at upper- and mid-crustal depths.

Here we summarize some of the findings that explain the controls of physical properties on elastic wave velocities for cataclasitic rocks in the fault damaged zone and quartzo-feldspathic mylonites in the vicinity of the fault. We study the elastic wave properties on a range of cataclasites in terms of their mineralogical composition and pore shape sensitivity to effective pressures. A mylonite sample is studied in detail to understand how fractures and the spatial distribution, texture, and crystallographic preferred orientation of minerals contribute to seismic wave anisotropy. This is performed by combining laboratory experiments, numerical modelling and findings are modelled to the field to understand the high reflectivity of the Alpine Fault.

Methodology

Ultrasonic waves on cataclasite and mylonite samples are measured experimentally with transducers and laser-ultrasound under confining pressures up to 100 MPa. Analysis of elastic wave speeds in cataclasites is supported with X-ray diffraction, computerized tomography (CT) imaging and pycnometry.

Numerical modelling of elastic wave anisotropy on mylonite samples is based on scanning electron backscattered diffraction (EBSD) data. EBSD-modeled anisotropy is estimated from the (static) effective media elastic tensor following a Voigt-Reuss-Hill averaging (MTEX) [4] and with dynamic simulation of wave propagation using finite element modeling (FEM) [5]. Experimental and numerical data is used to model reflection coefficients with angle of incidence at the Alpine Fault.

Results and discussion

Sonic log P-wave velocities in the cataclasite sections in DFDP wells vary between 2000 and 6000 m/s and there is little quantitative understanding on the nature of this variability. We perform high (up to 100 MPa) and low (pressure at the core depth, 2-4 MPa) pressure P- and S-wave ultrasonic velocity measurements on the water-saturated cataclasites. Our laboratory velocities match the well data at the low pressures representative of the core depths. At pressure conditions representative of the seismogenic zone, the elastic wave speeds are significantly lower than those predicted for a non-porous cataclasite rock. By combining wave speeds and CT scan images we observed that comminuted grains impede the full closure of the rock porous space in cataclasites for depths of up to 15 km. Such observations have implications to rock strength and fluid flow at depths where porosity is commonly interpreted to be non-existent in fault zones.

Cataclasites form a narrow part of the fault core, but as we move away from the core, the fault transitions into a sequence of highly-anisotropic metamorphic lithologies such as ultramylonites, mylonites and schist. In our study we compare experimental and numerically estimated elastic wave anisotropy on mylonite samples. The numerical results show a 16-20% anisotropy based on two EBSD sections. The FEM results show a lower slow P-wave velocity compared to MTEX as the method is sensitive to both the crystal preferred orientation and the spatial distribution of minerals. Moreover, the dynamic nature of the FEM allows simulating scattered and guided waves. The laboratory measurements show much higher anisotropy (27% and 31% at pressures equivalent to 15 km and 5 km depth, respectively), as micro-cracks remain open at pressures representative of the Alpine Fault seismogenic zone. Our study provides elastic wave evidence in the context of the rock's physical properties to explain some of the identified low velocity zones and high seismic reflectivity at the Alpine Fault.

Conclusions

In this work we present how physical rock properties from the fault core (cataclasites) and fault shear (mylonite) zones control elastic wave speeds. On one hard we show evidence that porosity is still present in cataclasite samples at 10-15 km in depth. On the other hand, away from the fault core, microfractures remain open in metamorphic rocks influencing the P-wave anisotropy and fault seismic reflectivity.

Acknowledgement

This work is supported by the Royal Society of New Zealand Marsden Grant # 14-UOA-028.

References

[1] R. Sutherland, D. Eberhart-Phillips, R. Harris, T. Stern, J. Beavan, S. Ellis, S. Henrys, S. Cox, R. Norris, K. Berryman, and others. (2007) Do great earthquakes occur on the Alpine Fault in central South Island in *New Zealand? A Continental Plate Boundary: Tectonics at South Island, New Zealand*, pages 235–251.
[2] Sutherland, R., & Toy, V. (2009). Deep Fault Drilling Project–Alpine Fault, New Zealand. *Scientific Drilling*, *8*, 75-82.
[3] Mainprice, D., & Nicolas, A. (1989). Development of shape and lattice preferred orientations: application to the seismic anisotropy of the lower crust. *Journal of Structural Geology*, *11*(1-2), 175-189.
[4] Zhong, X., Frehner, M., Kunze, K., & Zappone, A. (2014). A novel EBSD-based finite-element wave propagation model for investigating seismic anisotropy: Application to Finero Peridotite, Ivrea-Verbano Zone, Northern Italy. *Geophysical Research Letters*, *41*(20), 7105-7114.