Hydraulic and thermal characterisation of the central Alpine Fault

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Overview

This work was one component of the much-larger second phase of the Deep Fault Drilling Project (DFDP-2) and specifically addressed the thermal and hydraulic states of the Alpine Fault based on field and laboratory measurements undertaken in the course of Lucie Janku-Capova's PhD research. Understanding the thermal and hydraulic properties of the fault is crucial because temperature and fluid pressure are known to be two primary factors that control earthquake behaviour. Lucie participated in the drilling phase of the DFDP-2 drilling project, and then led post-drill monitoring of temperature using a novel new technology — distributed temperature sensing (DTS) using fibre optic cable cemented into the borehole. That portion of Lucie's PhD research project was conducted in collaboration with Schlumberger and was, as far as we know, the first time that such technology has been applied to an Earth science research question in New Zealand. Lucie made many measurements of temperature and fluid pressure during the course of her thesis. The DTS analysis has led to a collaborative project led by the University of Auckland and funded by the Marsden Fund of the Royal Society Te Apārangi to develop a new generation of more suitable field sensors for temperature and seismic sensing in remote regions.

As of November 2018, Lucie has published one journal article as senior author ("Fluid flux in fractured rock of the Alpine Fault hanging-wall determined from temperature logs in the DFDP-2B borehole, New Zealand"; *Geochemistry, Geophysics, Geosystems*, 2018 — see link below). In addition, she has made a significant contribution DFDP-2 overall and is a co-author on six other journal articles. She is first author on another two manuscripts that are in an advanced state and nearly ready for submission. The first of these two manuscripts in preparation addresses the thermal properties of rocks close to the Alpine Fault. The second is a detailed description of the DTS temperature measurements, which show many small-scale variations that may be related to individual fluid pathways; and we see a tantalising signal that the temperature at 800 m depth, close to the Alpine Fault, may have changed by about 0.5°C after the 2015 Wanaka earthquake.

Lucie presented her work at the 2015 American Geophysical Union Fall Meeting and the 2017 European Geophysical Union Meeting, as well as at several New Zealand Geoscience Society meetings. Her contribution has also been presented in many other places at many other times by other members of the large DFDP team. For example, Sutherland presented some of Lucie's findings as a the opening keynote address at the geothermal industry association conference in Rotorua in 2017.

Lucie made a substantial contribution to outreach during the DFDP-2 experiment. She helped inform the local community with guided tours of the drill site and by visiting the local primary school to explain earthquakes and the scientific research to the pupils. She co-authored a paper on Alpine Fault earthquakes that was written solely by postdocs and graduate students (Boulton et al., 2017).

The DFDP-2 project attracted considerable media interest. Our first publication in the journal Nature focussed on the extreme hydrothermal conditions that discovered (Nature 546:137-140; Altmetric score 277). There is ongoing interest due to the fact that a research project about understanding earthquakes may have discovered a commercially-significant geothermal energy resource. Lucie's work was central to the highest-profile media interest in our project, and continues to be relevant to understanding geothermal fluids in the fault zone.

Objectives

This project constituted the PhD research of Lucie Janku-Capova and had three objectives:

1. Develop and implement improved methods of calculating thermal parameters using cores, cuttings and wireline logging data acquired from DFDP-1 and planned for collection in DFDP-2;
2. Integrate wireline logging data from DFDP-1 and DFDP-2 with core scanning data, geochemical measurements, and other data sets in order to determine how the presence of phyllosicilicates, carbonates, and other minerals affect petrophysical and hydraulic parameters;
3. Develop hydrogeological models of the Whataroa River valley that incorporate observations made in DFDP-2 and enable temperature and fluid pressure conditions at greater depth to be estimated.

These objectives were closely aligned with the broader objectives of the second phase of the Deep Fault Drilling Project and contributed to six publications to date with a further two publications in advanced states of preparation.

Conclusions and key findings

Objectives 1–3 were each addressed in the course of Lucie Janku-Capova's PhD research. Key findings were as follows:

1. Using repeated wireline temperature logs collected during drilling of the DFDP-2B borehole, Lucie interpreted temperature anomalies and found that fracture zones intersecting the borehole have a hydraulic conductivity of 10^{-7} to 10^{-6} m/s. This conductivity is 100–1000× larger than the regional fluid flux. Lucie and her co-authors also developed a new method of analysis the evolution of temperature anomalies which can be applied elsewhere.
2. Temperature measurements made with the optical fibre installed in the DFDP-2B borehole were used to measure conductive heat flux and constrain the relative proportions of conductive and advective heat transport in the shallow Alpine Fault damage zone.
3. Using conventional and newly developed methods of measuring thermal properties, Lucie determined the bulk thermal conductivity (2.8±0.6 W/m/K) and thermal diffusivity ($1.8\pm0.2\times10^{-6}$ m^2/s) of the rocks forming the Alpine Fault's hanging-wall. She also measured the radiogenic heat productivity of these rocks, obtaining values of $1.8\pm0.4\times10^{-6}$ W/m^3 on cuttings and $2.1\pm0.1\times10^{-6}$ W/m^3 from wireline total gamma logs.

Together, these in situ and laboratory measurements provide the first comprehensive suite of thermal properties for the central Alpine Fault and impose important constraints on heat flow and thermal structure models developed by Lucie and her co-workers.

Impact

Temperature exerts a first-order control on rock rheology and on the distribution of slip during large earthquakes. The central Alpine Fault is known to produce large earthquakes very regularly, but what controls the down-dip (vertical) extent of Alpine Fault rupture — and thus each earthquake's overall size — has been poorly understood. The thermal models developed in Lucie's PhD research and the broader Deep

Fault Drilling Project provide rare insight into the thermal processes and are already forming the basis for interpreting the distribution of present-day microseismicity.

A second ramification of Lucie's work is that long-term, continuous temperature measurements may provide a means of studying the Alpine Fault's (and other faults') state and evolution at different points in the earthquake cycle. This may ultimately contribute to time-dependent hazard models of large earthquakes.

Future work

Applications for funding in support of further scientific drilling in order to fully characterize the geothermal potential of the central Alpine Fault and further understand the fault's earthquake-generating processes have been made to the Ministry of Business, Innovation and Employment. To date, those applications have been unsuccessful. Separate work funded by the Marsden Fund of the Royal Society of New Zealand (to Townend in 2013, to Calum Chamberlain in 2017 and to Emily Warren-Smith in 2018) is ongoing.

Links to publications/theses

Janku-Capova, L. (2018). Thermal and hydraulic characterization of the hanging-wall of the central Alpine Fault. Unpublished PhD thesis, Victoria University of Wellington, 220 p. http://researcharchive.vuw.ac.nz/handle/10063/7648.

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