Research Networking Programmes

Short Visit Grant ☐ or Exchange Visit Grant ☒

(please tick the relevant box)

Scientific Report

The scientific report (WORD or PDF file – maximum of eight A4 pages) should be submitted online within one month of the event. It will be published on the ESF website.

Proposal Title: Development of Anisotropic Fabrics in Uni-axially Deformed Polycrystalline Ice; Cryo-EBSD Data and Time-lapse Ultrasonic Measurements

Application Reference N°: 4912

1) Purpose of the visit

Plastic deformation in the interior of ice sheets, and in laboratory experiments under imposed stress, is dominated by internal deformation, during which crystal-plastic mechanisms give rise to dynamic recrystallization (Duval et al. 1983) in order to reduce mechanical strain. Which mechanisms dominate this re-crystallization process are dependent on the instantaneous stress, strain and strain-rate conditions and have a relationship to the development of crystalline fabrics (Castelnau et al. 2008). Direct, detailed observation and quantitative characterization of these fabrics are important for understanding how each of the various mechanisms is expressed micro-structurally.

C-axis orientation fabrics are of particular interest for quantifying the development of acoustically anisotropic ice as observed in large grounded ice sheets, on seismic lines and in ice core studies (Horgan et al. 2011). Deformation via dislocation-glide parallel to the basal plane in ice is at least an order of magnitude easier to achieve than perpendicular to it. This orientation dependence on deformation confers a strong visco-plastic anisotropy to the individual crystals (Donges et al. 2013) and leads to the evolution of strong crystallographic preferred orientation (CPO). These fabrics give rise to elastic-wave velocity anisotropies (p-wave and shear wave splitting) and consequently, englacial reflections. Real-time monitoring of the development elastic-wave velocity anisotropy may provide significant insight into the timing and development of CPO in ice undergoing various mechanisms of creep.

The primary objectives of this visit were:

- To use laboratory experiments in a time-lapse configuration to test the hypothesis that compression wave velocities are sensitive to the anisotropic micro-structures that develop in ice undergoing strain.

-To transfer knowledge and expertise on ice sample manufacturing, time-lapse ultrasonic velocity measurements, uniaxial compression experiments and environmental control between investigators at UCL and Otago

-To outline how relationships established in laboratory experiments establish a parameterization by which deformation microstructures and CPO can be identified and interpreted from active source seismic data containing englacial reflections

2) Description of the work carried out during the visit

Sample Manufacturing:

A methodology for manufacturing cylindrical samples of "standard ice" was developed with the aim of producing a bubble-free, crack-free, grain-size controlled polycrystalline material with uniform (random) grain orientations. It is essential to maintain uniform grain orientations in order to deconvolve the textural evolution of the samples during deformation from any previously existing textural elements. Bubbles have been shown to significantly impact grain boundary migration rates (Azuma et al 2012).

First, large ice blocks were frozen from distilled water, crushed and sieved to a desired grain size (200-250 Microns). The grains were then packed into a sample mould such that the porosity is 40%. The mould was then connected to the vacuum manifold. Following 2 hours of equilibration in an ice water bath to 0 deg C., the vacuum was used to evacuate atmosphere from the sample mould and hosing. A flask containing degassed, milli-Q (triple distilled) water was then inverted above the sample mould and water is bled into the evacuated mould gravitationally. The mould is placed on a copper plate in a deep freeze and uni-axially frozen to avoid any fracture formation due to expansion.

Environmental Control:

A new approach to environmental control for ice deformation experiments, developed and tested at the University of Otago Ice Laboratory, involves the use of peltiers to create a thermo-electric heat exchanger. For these experiments, a peltier element and a liquid-cooled CPU heat exchanger were mounted on a large, silicon oil filled aluminium cylinder with a base plate. A PID controller equipped with a K-type thermocouple was used to provide power to both the peltier and the CPU fan, and to maintain a target set-point by measuring the oil temperature. This peltier-cooled flask serves as a compact and mobile cold environment, enabling the investigator to conduct unconfined deformation experiments on ice in an ambient temperature laboratory.

Ultra-sonic velocity measurements:

In order to measure the evolution of anisotropy in real-time, it was necessary to develop a method for coupling piezoelectric transducers to a cylinder of ice that was undergoing uni-axial shortening. Transducer mounting rings developed at the University of Otago, were designed with the objective of holding transducers in place around a cylinder of ice with geometric precision, but without imparting excessive confining pressure.

Side-mounted springs allowed for built-in elasticity, providing enough sprung load to keep the transducers in position, while accommodating the changing shape of the sample. Vertical co-location rods were used for controlling the relative position of each mounting ring. Counter-sunk ports controlled the orientation of each transducer and allowed for coaxial cables to pass horizontally through the rings.

Additional sensors were placed at the top and bottom of the ice sample. These sensors are embedded is stainless steel platens behind alumina disks and are held onto the sample by the force of uni-axial compression during shortening.

A custom built UCL pulser/recorder was used for controlled pulsing and receiving of elastic waves through the sample on 10 transducers. Surveys were conducted at 5 minute intervals for the duration of the tests, sampling waveforms at 50 Mhz and pulsing at 250V. A 64 pulse stack was used on each survey to improve signal to noise ratios.

Uniaxial Compression:

An Instron hydraulic uni-axial press was used to conduct pure shear experiments in the Rock Physics lab at UCL. The peltier-cooled chamber was positioned on the base plate of the press and used to control sample temperature. The ambient temperature of the laboratory and the silicon oil bath was monitored and recorded using LabView at 1 Hz on a National Instruments cDAQ 4-channel USB 9011 thermocouple module. These elements were combined with the ultrasonic pulsing equipment to conduct the time-lapse ultrasonic velocity measurements during uniaxial shortening.

Cryo-EBSD:

This section of the work will be completed at Otago in March, 2015 to examine the crystalline fabrics that have developed during the compression experiments and to relate full orientation data to time-lapse measurements of anisotropy.

3) Description of the main results obtained

Several data-sets have been produced during these experiments are currently undergoing analysis and interpretation. Mechanical data for over 15 constant strain rate experiments and time-lapse ultrasonic velocity data from 5 experiments are currently being interpreted. Preliminary processing suggest that there is a detectable and quantifiable relationship between magnitudes of anisotropy as measured by ultrasonic velocities and magnitudes of uniaxial strain. Early processing suggests a non-linear evolution of anisotropy through time. However, these data are still in the early stages of analysis and EBSD data is still required to generate a more complete dataset and continue with interpretation.

4) Future collaboration with host institution (if applicable)

Future collaborations involve: The completion of Masters Thesis based on a portion of this work by a student at UCL and the design and construction of a pulser/recorder for future use in ice experiments at Otago University and Auckland University. The peltier cooler will remain at UCL for several months beyond the completion of this work for further experiments looking in greater detail at the mechanical properties of standard ice at the brittle-ductile transition. Sample moulds manufactured at UCL will be sent to Otago for on-going work.

5) **Projected publications / articles resulting or to result from the grant** ***(ESF must be acknowledged in publications resulting from the grantee's work in relation with the grant)***

Projected publications on this work include a paper on the mechanical properties of the standard ice used in these experiments (based on work of Masters Student), an article on some new environmental control methods for ice experiments, and a paper relating time-lapse velocity measurements to crystal fabric evolution as determined from Cryo-EBSD.

6) Other comments (if any)

ESF has been a valuable partner in the completion of these experiments. This collaboration has helped to establish new connections in the Cryo-science community and will continue to be a useful avenue for scientific investigation in the future.