Rutford Ice Stream Drilling and Instrumentation Project (RABID)

Physical Characterization of the Ice Core at UCL

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January 2009

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Introduction

**Fabric** refers to the c-axis orientations of the ice crystals. Ice fabric records the history of crystal deformation in a polycrystalline ice (e.g., Azuma and Higashi, 1985). **Texture** refers to the grain size and shape of crystals. Texture records both flow dynamics and climate history.

Langway (1958) described how the c-axes of ice crystals in thin section could be determined, taking advantage of the 'birefringence' of ice, using cross-polars and a universal stage. This process has been automated through computer-controlled fabric analyzers (e.g., Wang and Azuma, 1999). After the crystals in thin section have had their c-axes determined then the data are be plotted on a Schmidt net. Using manual measurement, 200 crystals are needed: but with an automated analyzer this requirement can be relaxed. The longitudinal strain of a single ice crystal, with the c-axis at $\phi$ to the axis of uniaxial compression or tension is proportional to the geometric factor, the Schmid factor, such that (Alley, 1988):

$$s = \cos \phi \sin \phi$$  \hspace{1cm} (Eqn. 1)

The mean of this ($\bar{s}$) for a polycrystalline ice is the geometric softness of ice under uniaxial compression, varying with total strain. When the c-axes are randomly oriented ($\bar{s}$) = 1/3.

In the upper regions of an ice sheet normal grain growth occurs (e.g., for the Greenland GRIP ice core):

$$D^2 = D_0^2 + k t$$  \hspace{1cm} (Eqn. 2)

where $D$ is the grain diameter, $D_0$ is the initial grain diameter, $t$ is the time and $k$ is the growth rate. $k$ is dependant on temperature according to the Arrhenius relation. (See Thorsteinsson et al., 1997.)

Methodology

**Visual Stratigraphy**

3 cores from the Rutford Ice Stream were analyzed at UCL: Cores 1, 2, 3. These had been cut into approximately 0.5m lengths. From each length thick sections were cut. 48 thick vertical sections were prepared (see Appendix 2). These were photographed through a binocular microscope on a light box under diffuse light. The images (see Table 1) are labeled according to the thin section ID (e.g. I05-01AL 1 for the first section from core 01AL), with a letter indicating the sequence of photos taken from the same thick section (e.g. I05-02E 2c.JPG is the third photo of the second thick section from core 02E). Three photographs with different polarization states were taken of the edge of thick section I05-01B 3 (which corresponds to the edge of core section) because it revealed a transparent refrozen boundary of ~3 mm.

Thin sections were prepared from the thick sections (see Appendix 2). 48 were prepared. Only thin sections from Core 2A to 2D were photographed under cross-polars with the microscope. Fabric and texture analysis in the thin sections from Cores 1, 2 and 3 has been performed at the Alfred Wegner Institute. 20 were used for fabric analysis (see Table 1).
Physical characterization

One core section, Core 3-G, was scanned using the Geotek Multi-Sensor Core Logger. This was a trial to see its suitability for use with ice core. The scan took about 45 mins. This was the first time the instrument had been used for ice. Gamma rays to measure density, electrical conductivity, magnetic susceptibility, temperature and sample thickness were measured. The P-wave velocity sensor was not used. The data are shown below but need calibrating against manual measurements. Measurements need to be corrected for core thickness.
Results and Analysis

The results from the visual stratigraphy, fabric and texture analyses are given in Table 1. The measured fabrics are all random. Ice crystals are fine grained with an increase from 1.3mm in Core 1, to 1.4mm in Core 2 and 2.8mm in Core 3. All air bubbles are sub-grain sized, both inter- and intra-granular.

The ice fabrics and textures are typical of shallow ice core just below the firn close-off depth. The increase in grain size with depth is consistent with normal grain growth. Detailed analysis of grain growth with depth would constrain estimates of warming rate of the Rutford Ice Stream.

We found no fabric or textural anomalies that would give rise to distinctive radar reflectors and speculate that these are therefore due to impurities in the ice.

Future work

1. No further investigation of the present ice core is proposed.

2. The Geotek scanner promises a fast, effective instrument for measuring physical properties on ice core. A multi-sensor scan takes 1 hour.
**Budget**

- Equipment development: £5,000
- Cold room costs: £1,500
- Fabric analysis: £500
- Total: £7,000

**Breakdown**
- Computer hardware: £1,540
- Computer software: £57
- Computer consumables: £52
- Refrigerants: £217
- Lab supplies: £77
- Consumables: £402
- General equipment: £4,611
- Subsistence: £43

**Human Resources**

The human resources employed the characterization of the ice core at UCL

- Benedetta Dini: Intern, 6 weeks
- Brian Barrett: Postdoc, 2 weeks
- Peter Sammonds: 1 week

In addition 2 months of technical support time was employed to develop the fabric analyze.

**Acknowledgements**

We would like to thank Richard Rabe and John Bowles for technical support at UCL and Ilka Hamann and Sepp Kipfstuhl from the Alfred Wegener Institute, Bremerhaven for their assistance and use of the AIFA.
This work was supported by the UK Natural Environment Research Council, Antarctic Funding Initiative, RABIB project (PIs: Andy Smith & Tavi Murray).

**References**


Appendix 1 – AIFA (Automatic Fabric Analyzer)
(after Eastgate, 2005)

1) The sample is placed on the sample stage of the AIFA in the cold room. Image Pro on the PC is loaded, and the AIFA “go” button is pressed, and the file name is entered. Data collection then begins.

2) The cross polars rotate at 10° 18 times to produce 19 images. The CCD camera remains at the vertical position, and sample stage remains in single position.

3) These 18 shots are saved on the PC, and then brought up on the screen of the PC. The most favourable image is selected, this being the sample with the least black crystals. Using a tagging function within Image Pro the crystals are selected. The computer saves the coordinates of these crystals as a coordinate transformation index, so that when the CCD camera or stage moves, the location of the crystals is still known.

4) Once all crystals are selected a large number of images are taken as below:

b. During this movement the grey values, that is, the brightness around the tag point of the crystal is measured and saved accordingly.

c. The CCD camera then inclines at 20°, and the slide motor places the CCD camera so that it is configured to coordinate transformation index as set earlier, so that it still has the same field of view.

d. a and b are then repeated, but with the camera now at 20° instead of 0°.

e. The stage now rotates 45° in the horizontal in respect to its starting position in a clockwise direction. The camera remains at 20°, and a and b are repeated.

f. e repeats its self 7 further times, so that the stage has now been at every 45° angle from the original location.

From the above a total of 8 extinction angles for each crystal will have been found, and the Azimuth and Zenith are determine by set parameters on the PC through Image Pro, and saved onto a WordPad file.

The data can then be plotted on a Schmid diagram using the pre designed function in Image Pro using the orientation data which has been saved on to a word pad file on the PC.
Appendix 2 – Thick and Thin Section Preparation
(after Eastgate, 2005)

Thick section preparation
First a section 5mm thick was cut from the core sample using a band saw in the -10°C to -15°C workshop cold room and then another 5 mm thick slice.

The thick section is placed onto the stage of a microtome. The section was stuck to the stage using a small amount of about 4°C de-ionised water. The sample is then lifted up on the stage until it is just about touching the microtome blade, then using the fine adjustment knob on the microtome the sample is slowly brought into contact with the sample. The slice thickness is set to 30 μm, and is sliced until the whole surface is flat and level. The slice thickness is adjusted to 10 μm and 10 slices are taken. The slice thickness is further decreased to 1 μm, and another 10 slices are taken, this ensures that the sample is perfectly flat on this side. Then using a knife the sample is gently prised of the mounting plate.

A 100 x 100 x 5 mm non- toughened glass plate (about room temperature) is brought into the workshop cold room. This is best left for no more than 15 seconds on the metal plate of the band saw to cool slightly, then with the flattened surface down, the ice sample is pressed onto the glass plate, and then put into the -25°C storage cold room to allow the sample to fully stick to the plate.

Making thin sections

Once the thick section has fully stuck, the glass plate was then mounted onto the microtome mount, and water is used to stick the glass to the stage. The sample is then slow brought up to the blade of the microtome in the same way as before. 30 μm slices are then taken from the sample until it is about 1.5mm thick. The slices are reduced to 10 μm for about 10 slices, and further reduced to 1 μm for a further 10 slices. At the end the sample should not be any thinner than 1mm at this causes the crystals birefringence to change giving wrong measurements. A check with cross polar sheets will determine if the sample is fit for analysis, if it shows birefringence then it is suitable.

The sample can now be placed in the AIFA sample stage, and the above program can run to determine the texture and fabric of the sample.

Once the sample had been measured they were placed back into a bag, with some snow to stop sublimation.