Journal of Glaciology, Vol. 40, No. 135, 1994

Instruments and Methods

Diamond wire-saw cutting technique for investigating textures and fabrics of debris-laden ice and brittle ice

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ABSTRACT. This paper presents an original method for sampling special ice types like debris-rich ice or brittle ice that cannot be prepared using the standard band-saw/microtome procedure. The general working principles of the diamond wire-sawing technique are explained, and special adaptations for ice-cutting, thick-sectioning and thin-sectioning are discussed.

INTRODUCTION

Debris-laden ice is formed in the basal parts of most of the ice bodies flowing at the Earth's surface, and is a major component of rock glaciers and soils in permafrost areas. As pointed out by Chamberlain and Gow (1979), cutting samples in this type of composite material is difficult to achieve with the standard band-sawing and microtoming techniques (Langway, 1958), and this partly explains the relative paucity of information on the properties of this particular ice type.

Recent developments in ice-sheet modelling, within the framework of the "global-change" perspective, point out the need for an accurate evaluation of boundary conditions at the ice–bedrock interface where debris-laden ice is present. Therefore there is a growing need for alternative sampling techniques allowing sample-cutting and thin-sectioning that do not damage either the sample or the sampling equipment. This paper shows how diamond wire-sawing procedures can achieve such results.

Chamberlain and Gow (1979) used a "shaving" technique on frozen silts and clays. Samples are first fixed to a glass plate, then reduced to the thickness of a few millimetres with a band-saw and finally scraped down to a thickness of 0.2–0.1 mm by using a microtome knife and/or the edge of a glass plate. For obvious reasons, this technique is, however, difficult to apply to ice samples with sand or gravel inclusions. Osterkamp (1977) briefly described a method entailing the use of a diamond wire-saw (Laser Technology®) in preparing small-sized thin sections of frozen soil. We extend this application to making thin sections of debris-rich and brittle ice, and develop a general procedure, from field sample to 600–700 μm thin sections on glass-plate supports, emphasising the critical steps of this technique.

GENERAL WORKING PRINCIPLES OF THE WELL® DIAMOND WIRE-SAW

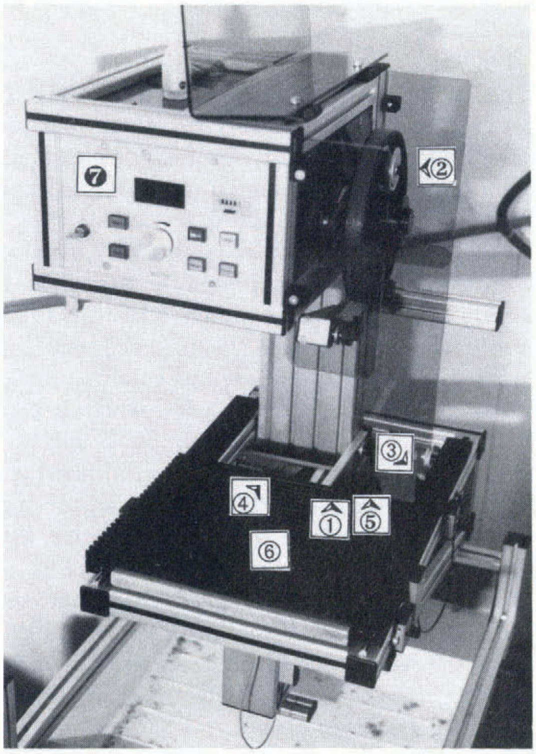
The Well® diamond wire-saw (WDWS) exists in different sizes and models depending on the application. The one used in the Brussels laboratory is Model 6234 illustrated in Figure 1a. The 20 m diamond-encrusted wire (Fig. 1b) is wound and rewound on a drum which is driven by a d.c. motor via a timing belt. Wire tensioning is obtained by weights and is effected by a reversal reel at the bottom. An electromagnetic brake prevents the drum from rotating more than the wire length permits and an end switch stops the motor drive when wire tension can no longer be maintained.

The samples are fixed on a horizontal work table (400 mm × 290 mm) which allows sample-cutting by travelling back and forth under a variable tension generated by interchangeable counterweights. The motor, equipped with a harmonised control system, enables the wire speed to be varied continuously, between 0 and 2 m s^{-1} (linear speed). Built-in micro-switches control the wire's back and forth threading-like movement on the wire-drum. In the standard version, a liquid container and a moistening roller are supplied to clean the wire. However, the use of a fluid to assist in cutting debris-rich ice samples was unnecessary, and this precluded possible contamination of ice samples to be used for other purposes.

USING THE WDWS FOR ICE-CUTTING AND THIN-SECTIONING

a. Adaptability to a cold environment

A prototype of the WDWS 6234, lubricated with special low-temperature grease, was installed for testing in our cold-room laboratory in Brussels. Especially at temperatures below −20°C, there were frequent problems which were linked with the individual microswitches controlling the drum-rotation speed and rotation reversal. A new model with an "all-in-one" built-in microswitch was designed by the company; this works well over the whole temperature range down to −25°C.



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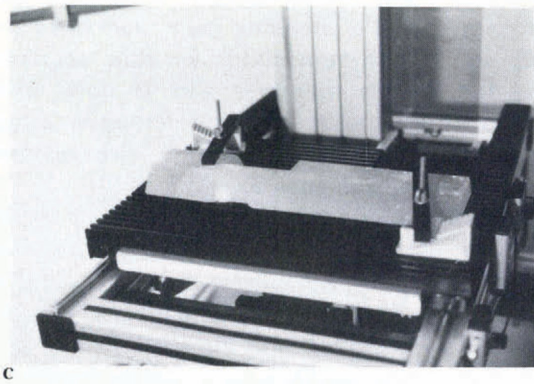

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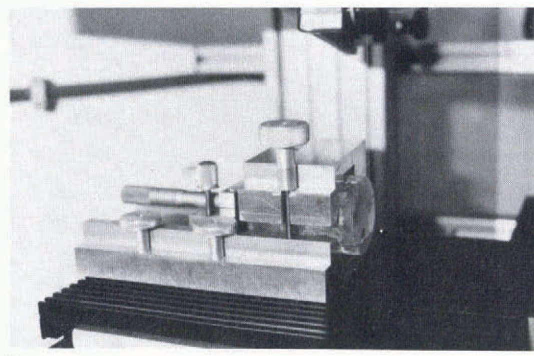

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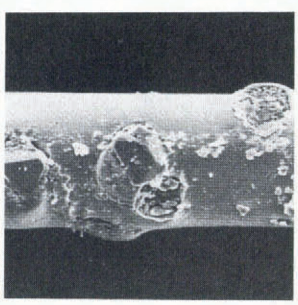

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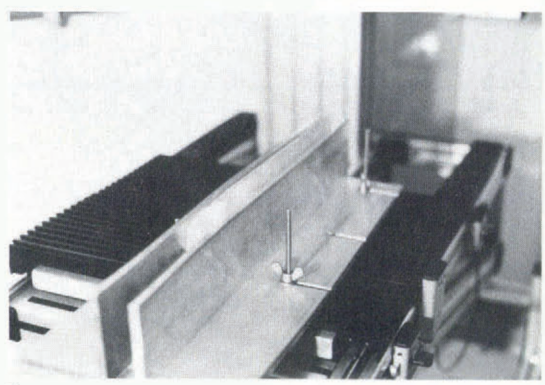

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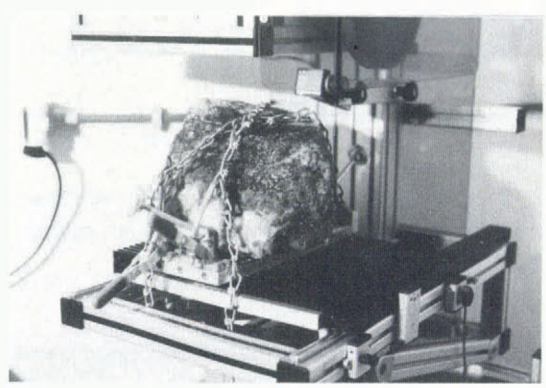

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Fig. 1. The Well® Diamond Wire-Saw, Model 6234, for ice sampling: (a) General view of the wire-saw with wire (1), wire-drum (2), work-table traction counter-weights (3), tension weights (4), reversal reel (5), work table (6) and control panel (7); (b) Wire with diamond-clast encrustations (wire diameter: 0.3 mm); (c)–(f) Various special mountings for ice-cutting and thick-sectioning.

b. Fixing and cutting ice samples

The machine is delivered with a simple specimen-mounting system that can satisfactorily be used for cutting ice specimens with existing flat surfaces (Fig. 1c). However, the work table is designed in such a way that it allows easy interchangeability of different sample holders adapted for cutting ice cores transversely (Fig. 1d) and longitudinally (Fig. 1e), as well as ice blocks (Fig. 1f). Maximum sample dimensions are 40 cm × 29 cm × 25 cm, and the maximum cutting length is 23 cm.

Two wire diameters are available for the WDWS: 0.3 and 0.5 mm. The 0.3 mm diameter wire was used initially, because it obviously allows more precise cutting and less material loss. However, although no trace of melting was detectable during the cutting procedure, especially at the very low wire speed available, the fine, dry powder produced remained in the cut space between the two subsamples and stuck them firmly together. Because of this, there is a great chance of breaking the section when the pieces are split apart, especially for thin sections. Therefore, the 0.5 mm diameter wire is now used, although the cutting surface it provides often shows slight undulations connected with the wire reversal movement, especially with an older wire.

Inserting a fine metallic plate into the slot cut by the wire then easily separates the cut sample from the main ice core after cutting. Typical cutting rates for basal silty ice from the GRIP (Greenland Ice Core Project) ice core (light- to medium-loaded ice with dispersed silt and clay and a few gravel-sized particles) are given in Figure 2a with a 10 kg tension on the wire and 0.4 kg of traction on the work table. Penetration rates of the wire into the ice

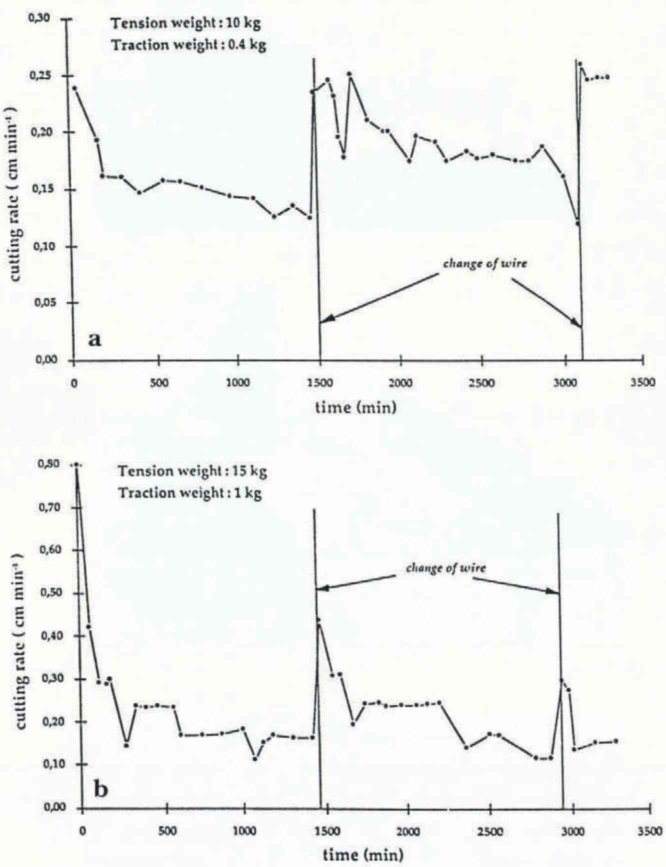


Fig. 2. Typical wire-cutting rates in light- to medium-loaded debris ice, for two different settings of cutting parameters (wire speed: 1.2 m s^{-1}).

start at values around 0.25 cm min^{-1} and decrease steadily during the first 3 h of cutting, either because of breaking away of some of the diamond clasts from the wire or, more probably, because the ice cuttings partly fill the gaps between the diamond inclusions. The penetration rates stabilise during the next 22 h at values between 0.15 and 0.18 cm min^{-1}, depending on the debris load. Increasing the tension load on the wire to 15 kg and the traction load on the work table to 1 kg considerably improves the performance, especially over the first few hours, as can be seen in Figure 2b. However, such cutting parameters are only valid for rough sample-cutting and thick-sectioning, since the high loads will cause ice slices to break at thicknesses of less than 1 or 2 mm.

c. Preparing thin sections for textural and fabric analyses

One of the main advantages of the WDWS is that it provides a means of readily reducing thick sections of a few millimetres to "ready-for-use" 0.7 mm thin sections of composite or brittle material (although thicknesses down to 0.2 mm could be obtained, if needed).

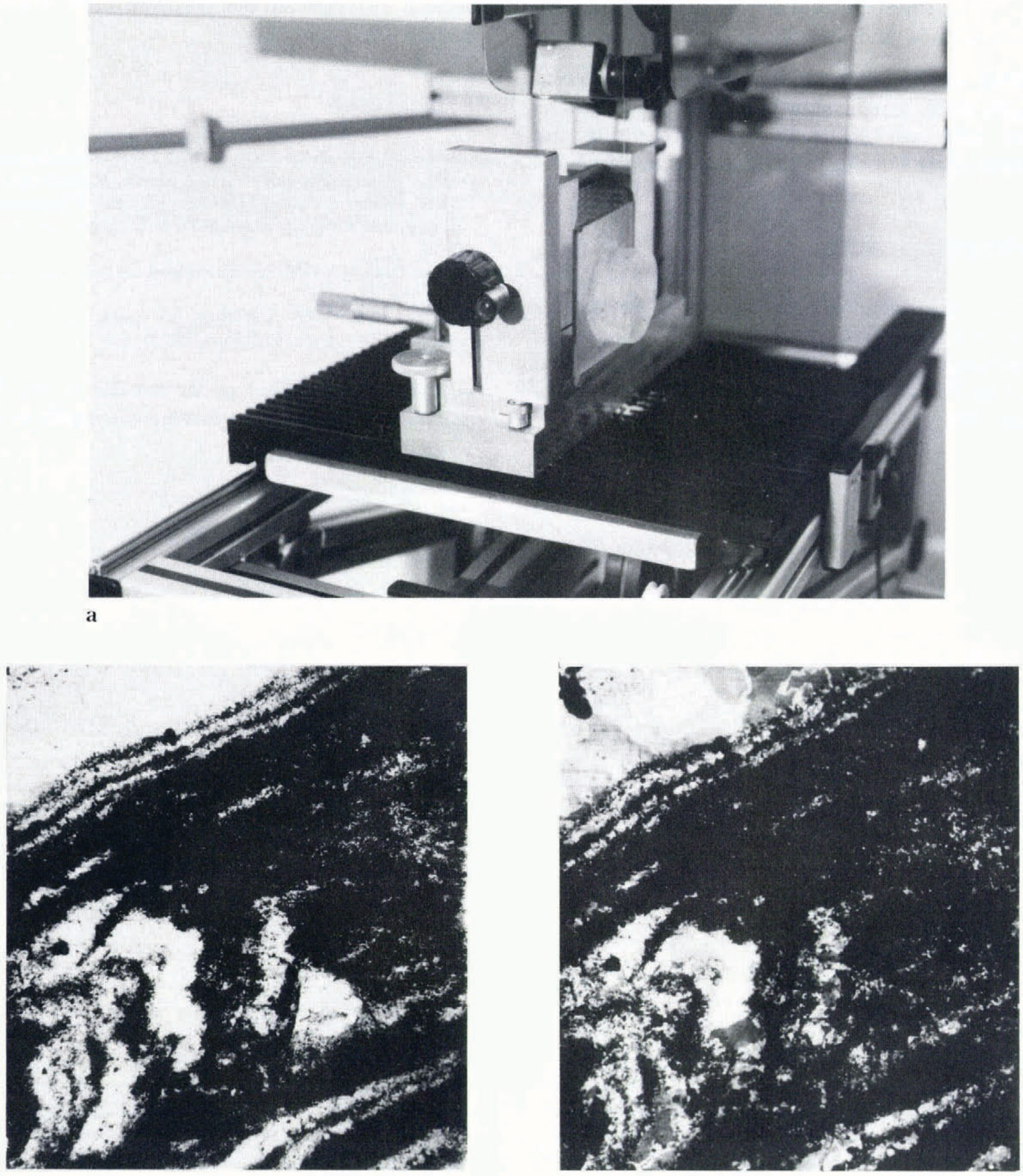
Once a thick section of minimum 2.0 mm thickness is sampled following the procedure described above, the freshly cut section of the sample is bonded to a glass plate using the conventional melting–refreezing technique. Frosted-glass plates are used to enhance surface contact between ice and glass and a low-warmth plate temperature is set up (for example, 35°C for a −15°C air temperature in the cold room) to minimise the amount of meltwater produced. The choice of a proper plate temperature is of the utmost importance, especially in this case where a composite material is used, with differences in thermal conductivities between ice and rock favouring preferential melting around the particles. Since the cooling needed to freeze the thin meltwater film should preferably occur slowly, the glass plate is placed on a thick polystyrene plate.

After bonding is complete (5–10 min), the glass plate is fixed to a special holder adapted to the work table of the WDWS (Fig. 3a). To provide a constant thickness for the thin section, special care must be taken in designing this adaptor, so that its vertical face is absolutely perpendicular to the work table, i.e. parallel to the cutting plane of the wire. The sample holder freely slides into the grooves of the work table so that the vertical face of the glass plate can be brought into contact with the wire. It takes a little practice and skill to find the exact position where the wire contacts the plate, with a grinding noise being created. The operation is facilitated by moving the work table back and forth slightly to bring the wire alternately "on" and "off" the glass. Once this position is found, a micrometer-advancing system is positioned at the back of the glass-plate holder and locked into contact with it. The micrometer is then backed off the required amount (600–700 μm) and the glass-plate holder is re-positioned. Cutting then begins, with traction on the work table limited to 0.4 kg. The same technique as for rough cuttings and thick sections is used to split the cutting residue off the sample bonded to the glass plate.

When the procedure described above is carefully followed, the quality of the resulting thin sections is almost equal to that obtained by using the conventional microtome technique on debris-free ice. With an older wire or when the cutting parameters are not set to their optimum, slight aberrations in polarisation colour can be seen in a single large crystal. These slight imperfections do not interfere with textural observations or with *c*-axes measurements (Fig. 3b and c).

CONCLUSION

Use of the Well® diamond wire-saw cutting technique provides a means of studying debris-laden ice and brittle ice in the same way as is done for debris-free ice. The main advantages can be summarised as follows:



a

b

c

Fig. 3. Ice thin-sectioning with the WDWS: (a) Special mounting system for glass plate supporting the ice sample, with the micrometer-advancing device in the back; (b) Thin section of basal ice, heavily loaded with debris, from Campbell Glacier (Terra Nova Bay, Antarctica) — transmitted-light photograph; (c) Thin section of basal ice, heavily loaded with debris, from Campbell Glacier (Terra Nova Bay, Antarctica) — photographed between crossed polaroids.

Ability to cut composite material (ice + rock) without damaging the sample or the equipment.

Precision cutting of section thicknesses down to 600–700 μm.

Very low loss of material.

No structural alteration as a result of melting.

Low vibration level, especially convenient for brittle ice.

A strictly mechanical and practically harmless cutting procedure.

Further work on the technique should aim to improve (either on the "engineering" side or on the "glaciological" side) the following items:

Methods to clean the wire from ice cut-offs "as it cuts", possibly by using a low-temperature liquid together with the moistening roller.

Cleaning the lower reversal wheel of ice cuttings, in order to keep a straight movement of the wire.

Increasing the lifetime and cutting rate of the wire, given its high cost.

https://doi.org/10.3189/S0022143000007498 Published online by Cambridge University Press

Avoiding the slight fluctuations of the wire position between winding and unwinding.

Designing alternative methods of fixing the sample to the glass plate, thus avoiding possible perturbations around large rock particles and preventing the formation of air bubbles at the ice–glass interface.

ACKNOWLEDGEMENTS

The author is greatly indebted to Mr W. Ebner for his enthusiasm and scientific curiosity, which contributed to the achievement of this project. The project was supported by Fonds National de la Recherche Scientifique grant No. 1.5.109.90F to the author, who is a Research Associate of the National Fund for Scientific Research (Belgium) (FNRS).

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The accuracy of references in the text and in this list is the responsibility of the author, to whom queries should be addressed.

MS received 5 May 1993 and in revised form 11 January 1994