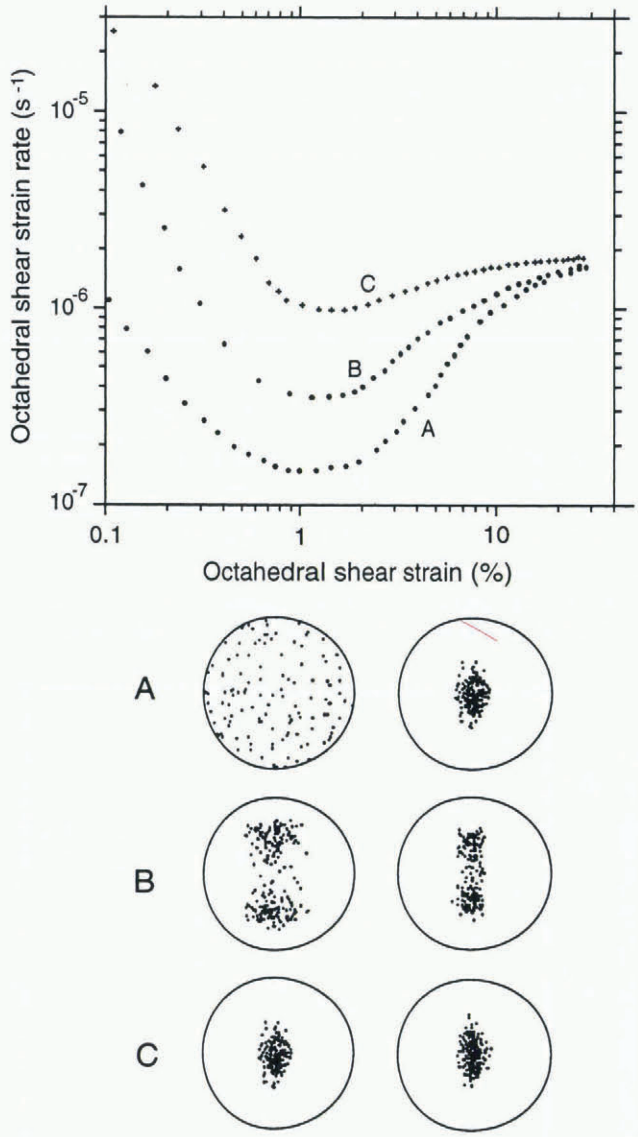

Fig. 2. Creep curves for deformation tests on rectangular oblong samples in simple shear at −2°C and 0.3 MPa. Samples were initially isotropic (test A), exhibiting a two-maxima crystal-fabric pattern (test B), and exhibiting a single-pole crystal-fabric pattern (test C). Also shown are the Schmidt equal-area c-axis fabric diagrams at the start (left) and conclusion (right) of the tests. For the fabric diagrams, the shear direction is to the right, and for the initial sample of test B, the sample length was aligned left to right during the compression test.

would have been no minimum strain rate: the creep curve would have approached directly to the steady-state strain-rate value. The crystal-fabric pattern at the conclusion of this test was similar to but slightly stronger (the median *c*-axis angle to the vertical changes from 20° to 17°) than the initial pattern.

Tests B (horizontal shear on the ice with vertical compression fabrics) show strain rates decreasing to a minimum value, then increasing with strain, again to a steady-state value similar to that in the other tests. The minimum strain rate is (for both cases) a factor of ~2.5 greater than the isotropic minimum strain rate; i.e shear of ice exhibiting a small-circle girdle or a two-maxima fabric pattern, in the direction perpendicular to the symmetry axis of the fabric, generates easy glide with a strain rate a factor of ~2.5 greater than the minimum isotropic strain rate. With increasing strain, the strain rate increases to a tertiary rate similar to those for the other shear tests. The crystal fabric at the conclusion of this test, again, is similar to the fabric at the conclusion of the other two tests.

CONCLUSION

Vertical compression fabrics after large strain tend to have a degree of concentration of *c* axes towards the vertical characterized by (1) in unconfined compression, at higher stresses and temperatures leading to recrystallization, a small-circle girdle pattern with median angle to the vertical of ~25° to 40°; (2) in compression confined in the line of flow, again at higher temperatures and stresses leading to recrystallization, a two-maxima pattern with similar median angle; or (3) a girdle-like rotation fabric generated at lower stresses and temperatures than required for formation of a true girdle.

The horizontal shear rates of samples with vertical compression fabrics exhibit flow enhancements of ~2.5 relative to the minimum strain rates for isotropic ice. With increasing shear strain the enhancement increases to ~10 with the development of a strong single maximum fabric. These fabric and strain-rate developments are similar to those occurring in ice sheets from vertical compression near the surface to high shear with increasing depth

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Technique for improving core quality in intermediate-depth ice drilling

One of the factors that determine the quality of palaeoenvironmental records obtained by the analysis of ice cores is the quality of the ice core itself. Broken or cracked cores are difficult to sample even for simple measurements and can be unusable for contamination-sensitive studies such as trapped-air and trace metals. Core quality in intermediate-depth dry-hole drilling is discussed by Gillet and others (1984), Schwander and Rufli (1994) and Shoji (1994).

In the course of dry-hole mechanical drilling a 270 m deep core on Law Dome, East Antarctica, over the 1997–98 season, it was found that a weight of ~4 kg resting on the core during cutting greatly reduced core breakage. An Eclipse II drill (Blake and others, 1998) was being used to drill in the high-accumulation (0.7 m a^{-1} ice-equivalent) area near the summit of Law Dome. This drill, which takes 1 m long, 80 mm diameter cores, is designed to be used in a dry hole, but the Law Dome drill had a sealed motor and gearbox assembly which allowed drilling in a small depth of fluid. Immersing the head and part of the core barrel in fluid has been suggested as a method of reducing core breakage (Narita, 1994).

Drilling down to 90 m proceeded smoothly, with the retrieved core being of very good quality. Below 90 m, core quality started to deteriorate, and by 102 m most of the recovered core was in the form of flat discs, a few cm thick, with multiple internal fracture lines. Efforts to improve core quality included drilling at different speeds (40–75 rpm), varying the depth of cut (5 to < 2 mm/rev.), varying cable tension and drilling shorter cores (650 mm as opposed to 1 m). Other tests involved eliminating the load of chips on the core by suspending the chip-separator plug (which normally rides on top of the core) by a string from the top of the core barrel and drilling with the core dogs retracted. It was known that cutters with rounded faces had been suggested as reducing core breakage (Gillet and others, 1984), so one set of cutters had their inner edges reshaped with a radius of about 1 mm. It was also thought that friction between the core and the core barrel (and in particular any protruding screws) might tend to twist the core, so the barrel was honed to give a highly polished surface. None of these techniques or modifications had any effect on the core quality.

It was finally decided that, despite the risk of contamination for trace-chemical measurements, fluid would be used to lubricate the drilling process. Twenty litres of kerosene was lowered down the hole in a bladder and released at the bottom. The first drill run in fluid produced no noticeable difference in the top section of the core, but the bottom section showed some improvement. A second core showed marked improvement, with only one break, but subsequent cores were not as good, and four cores after the fluid was placed in the hole, core quality was again unacceptable. At this stage, most of the fluid had been brought back up from the hole with the cuttings, and the chips were almost dry again. Adding another 15 L of kerosene produced only a slight improvement for two cores, and three cores later quality was again unacceptable.

It was noticed that while the top third of most cores was rubble or very thin "pucks", the bottom two-thirds was considerably less broken. It was therefore decided that instead of trying to keep the weight of chips off the core, a weight, which simulated the top section of a core, would be placed in the core barrel above the chip-separator plug. The first test, using a 1.8 kg weight, resulted in a core with just two breaks. As a check, the following core was drilled without the weight; its top third was again badly broken. From then on, all cores were drilled with a weight in the core barrel (except for another check at 146 m where the top third was again badly broken). Adding a further 1.7 kg did not appear to result in any further improvement, but to make a more convenient system for the remainder of the drilling down to 270 m, a 3.5 kg weight which took the place of the chip-separator plug was made. Ice cores still appeared to be very brittle, often breaking into several pieces after removal from the drill barrel, but the complete disintegration of core sections that was experienced without the weight no longer occurred. Later examination showed that cores drilled with the weight, although unbroken, still had extensive internal fracturing. This does not affect isotope-ratio and peroxide-concentration measurements, but makes the cores unsuitable for trace-chemical analysis and probably not usable for trapped-air studies.

In 1998, a weighted separator plug was tested during drilling on Devon Island, Canadian Arctic Archipelago (personal communication from M. D. Gerasimoff, 1998). It was observed that although the weight did improve core quality, drilling in fluid was even more effective. The drill used on Devon Island incorporated a booster pump to assist raising the fluid and chips up the spiral flights between the inner and outer tubes.

Ice cores from just below close-off, especially from high-accumulation sites, are very fragile. Crystal bonding is not yet well developed, and forces due to air pressure in the relatively large bubbles are high. A possible explanation for the apparently greater fragility of cores from high-accumulation cores is that there has been less time for consolidation and crystal bonding compared with low-accumulation sites where the ice at depth is much older. Drilling results in the abrupt removal of the overburden pressure right at the point where the cutters are making fine horizontal grooves in the core. Our experiments show that applying a load of only 4 kg (on an 80 mm diameter core) by a free weight in the drill-core barrel significantly improves core quality without the use of drilling fluid. The improvement is surprising since this load is considerably less than the overburden pressure which, for comparison at a depth of 100 m, is equivalent to a load of 350 kg on the core cross-section.

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