depths of 110 to 90 m during the Little Ice Age. They have deduced the warm climate from the concentration and thickness of infiltration ice layers. As they have proposed two time-scales for the ice core, the warm period can be interpreted approximately from c. 400 to c. 300 years BP, after the colder period began 1200–1300 years BP.

According to the oxygen-isotope profile obtained for an ice core from Vestfonna, Nordaustlandet (Vaykmae and others, 1985), the warm period continued from c. AD 1200 to c. AD 1600 prior to the cold period from c. AD 1600 to c. AD 1900.

Prior to AD 1700, there may have been a negative mass balance during these and earlier warm periods.

In conclusion, we suppose the following glaciological history at Høghetta in northern Spitsbergen: that the formation of glacier ice re-commenced at around AD 1700 during the Little Ice Age on stagnant ice after an hiatus of about 4000 years and the annual mass balance has been reduced since the middle 1960s.

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Subglacial water and sediment samplers

The current focus of glaciological research on basal processes and hydrology makes the acquisition of samples from the subglacial environment a vital enterprise. In this letter, we describe two devices for obtaining samples of basal water and sediment within the confines of a narrow borehole. The samplers have been operated at depths ranging from 70 to 300 m. They are lightweight and require only a single operator.

Niskin sampler

Collecting water at depth has been a concern of oceanographers for centuries (see McConnell, 1982); designs for sampling bottles abound and are slowly modified by generations of researchers. The modern Niskin sample bottle consists of an open-ended tube which can be closed on command by a pair of stoppers. A Niskin bottle, attached to a wire rope, is lowered into the water and when the bottle reaches the desired depth, a messenger block is dropped along the rope. The block strikes the Niskin bottle and trips the sampling mechanism.

We have designed a modified Niskin sampler having a trigger mechanism that operates axially. This action allows the device to operate in a narrow borehole. Figure 1 shows the sampler in its open, cocked position. The sampler consists of four major units that move relative to one another: (1) The lower stopper is fixed to a hollow central rod. The central wire rope upon which the sampler is suspended passes through the rod and is held by a crimp at the bottom. (2) Two perforated brass disks are fixed within a Plexiglas sampling tube. The disks slide on the central rod and the perforations allow water to move through the tube when the stoppers are open. (3) The head block, with the upper stopper attached, is free to slide on the central rod, but two spring-loaded catches hold the block in a cocked position at the top of the rod. Two lengths of fine wire rope suspend the Plexiglas tube below the head block. The wire ropes are attached to small eye-hooks on the block and upper disk (for clarity, these fixtures are not shown in Figure 1). (4) A brass messenger block slides along the central wire rope.

The sampler, in a cocked position, is lowered into position at the borehole bottom and the messenger block is dropped along the wire rope. When the messenger strikes the catches, they spread apart and release their grip on the central rod; the head block falls against the sampling tube, the tube falls against the lower stopper, and a 220 ml water sample is trapped inside the device. The weight of the upper block ensures a watertight seal between the two stoppers and the tube. The sampler is opened, and the

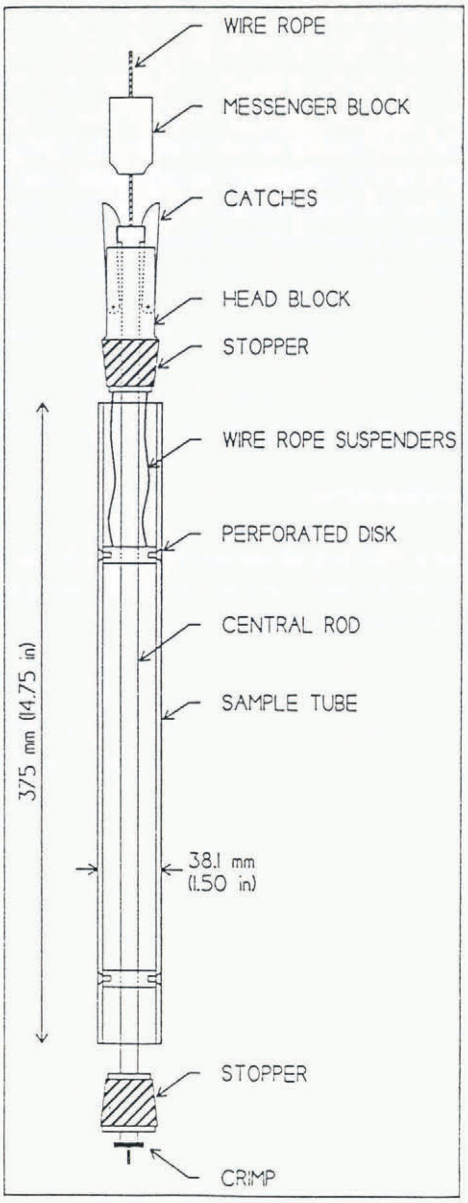

Fig. 1. The modified Niskin sampler in a cocked position. As the messenger block strikes the catches, the head block is released from the top of the central rod and slides down to seal the top of the sample tube. The sample tube falls against the lower stopper; this seals the bottom of the sample tube and traps a water sample inside the device.

sample collected, by pushing on the top of the rod. Experience has demonstrated that wire rope (~0.5 mm diameter) must be used to connect the block and disk because weaker materials (such as fine chain or string) will break.

The modified Niskin sampler is simple to operate and performs reliably; accidental triggering of the mechanism is unusual. Since the introduction of the Niskin sampler to our field program in 1986, we have obtained basal water samples from more than 300 boreholes of 70 m depth and one sample from a 300 m borehole. Samples from the glacier bed often contain significant quantitites of fine particulate matter, and sometimes subglacial material is found adhering to the lower stopper. The axial design allows the device to take samples in a borehole as narrow as 31.8 mm [1.25 in] in diameter.

Subglacial vacuum sampler

The modified Niskin sampler excludes the sand, pebble and gravel fractions of the bed. In order to collect these larger-sized particles, we built an active vacuum sampler that is powered by the high-pressure pump on our hot-water drill. Because it works like a vacuum cleaner, we dubbed this device the "Hoover".

The Hoover design was inspired by the airlifts used to clear sediment from shallow submarine archaeological sites. According to Throckmorton (1969, p. 175), airlifts were invented at the turn of the century for clearing mine sumps and for mud-pumping in harbours. The first archaeological application was by Jacques Cousteau in the early 1950s at the Mediterranean site of Grand Congloué near Marseilles, France. An airlift consists of a large-diameter flexible pipe (perhaps 15–20 cm in diameter) leading from the archaeological site at the sea floor to the deck of a support vessel. Injection nozzles mounted inside the pipe force air into the pipe. The presence of air in the pipe has two consequences of interest: (1) Viscous drag between the rising air bubbles and the water in the pipe causes upward flow. (2) The bulk density of the mixture in the pipe is lowered to such a degree that buoyancy forces lift the mixture up the pipe. Buoyancy forcing is the stronger of the two effects. Given sufficient air content, water in the pipe can be lifted well above the free water surface and on to the deck of the vessel. Artifacts small enough to be entrained by the water flow can then be collected in a sieve. An advantage of this system is that no impellers are required to drive water through the pipe; artifacts are not damaged and the pipe is unlikely to clog.

The subglacial Hoover uses viscous drag from water jets (rather than air bubbles) to move water up through a Plexiglas tube that has a one-way valve at the bottom. Figure 2 shows the design of the Hoover with an exploded view of the valve assembly. Cold water from our hot-water drilling system is fed into the 37° JIC swivel hose fitting. The water travels down the central feed pipe to the nozzle assembly where the direction of flow is reversed as the water emerges through two 1.59 mm [0.0625 in] nozzles. Vibration of the nozzle assembly is prevented by three pins that reach out to meet the inner walls of the sample tube. The pressure drop across the nozzles is about 2 MPa at a flow rate of 18 $\mathrm{l\,min^{-1}}$. The valve consists of a cylindrical rip-stop nylon fabric sock. The lower edge of the sock is sewn to a sock cage; the cage consists of a brass ring that is brazed to a tetrahedral wire frame. The three wires in the cage prevent eversion of the sock, but also reduce the maximum particle size that can be admitted by the valve. A threaded retainer ring holds the valve assembly on to the valve seat. The bulkhead at the top of the Hoover has eight 11.1 mm [0.4375 in] holes drilled around its periphery; these holes provide an outlet for the injected and entrained water.

When the Hoover is operated in air, a noticeable suction develops at the inlet. This suction is much greater when the device is operated in a water-filled borehole; we have found clasts wedged into the bulkhead outlet holes, indicating that clasts of considerable size are being driven forcibly through the sample tube. The largest clasts that we have colected have a typical grain diameter of ~20–25 mm.

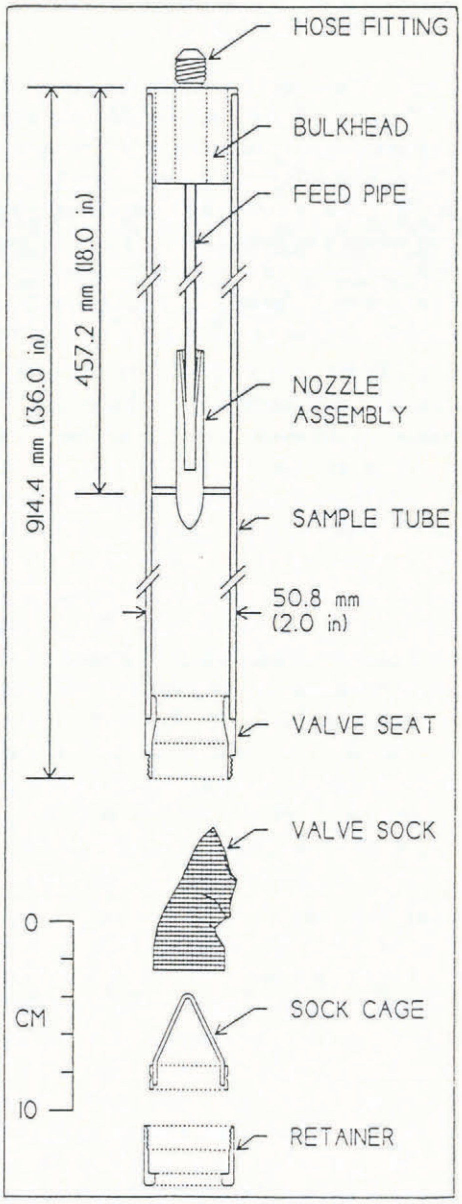

Fig. 2. An exploded view of the subglacial Hoover. Upward-directed water jets are created by forcing water through the feed pipe and nozzle assembly. Viscous drag between the jets and the water in the sample tube creates a vigorous upward flow of water through the one-way sock valve. Sediment entrained by the flow is trapped inside the tube.

Samples are taken using the following procedure. With the Hoover at the bottom of the borehole, the water supply is turned on and the pressure hose is gently moved up and down causing the Hoover to move against the glacier bed. After 20–40 s, the water supply is turned off, and the sampler is hauled to the surface. Examination of the closed valve assembly suggests that the valve does not close suddenly as the water jets stop, but rather that the valve is slowly pinched shut by the sediment falling between the valve sock and the sample tube. The sediment is released from the Hoover by removing the retaining ring and valve assembly. Samples as large as 500 g have been obtained (for a representative sample, see Clarke and Blake (1991, fig. 11)).

Considerations

The hot-water drilling system used at our field site on Trapridge Glacier, Yukon Territory, Canada, alters the glacier bed as each borehole is completed; surface water is introduced to the subglacial environment and some fine material may be flushed away. In addition, the geometry of both sampler inlets further biases the sampling of solid matter from the bed. These effects must be considered during analysis.

The Hoover tends to eject finer particles through the water outlet, although our samples do contain a significant amount of coarse and fine sand. A screen placed over the outlet might improve the retention of finer material.

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

ERRATUM

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During revision of the manuscript, the author inadvertently omitted the area of the bed, A, from Equation (2). The correct equation is:

$$\tau = \mu \mathcal{N} \Psi V_{\mathrm{N}}/A. \tag{2}$$