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Polar Science 2 (2008) 15–26
http://ees.elsevier.com/polar/

Laboratory experiments and thermal calculations for the development of a next-generation glacier-ice exploration system: Development of an electro-thermal drilling device

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Received 22 June 2007; revised 4 February 2008; accepted 28 February 2008
Available online 16 March 2008

Abstract

A next-generation drilling system, equipped with a thermal drilling device, is proposed for glacier ice. The system is designed to penetrate glacier ice via melting of the ice and continuously analyze melt-water in a contamination-free sonde. This new type of drilling system is expected to provide analysis data in less time and at less cost than existing systems. Because of the limited number of parameters that can be measured, the proposed system will not take the place of conventional drilling systems that are used to obtain ice cores; however, it will provide a useful method for quickly and simply investigating glacier ice.

An electro-thermal drilling device is one of the most important elements needed to develop the proposed system. To estimate the thermal supply required to reach a target depth in a reasonable time, laboratory experiments were conducted using ice blocks and a small sonde equipped solely with heaters. Thermal calculations were then performed under a limited range of conditions. The experiments were undertaken to investigate the effects of the shape and material of the drill head and heater temperature on the rate of penetration into the ice. Additional thermal calculations were then performed based on the experimental results.

According to the simple thermal calculations, if the thermal loss that occurs while heat is transferred from the heater to ice (in melting the ice) is assumed to be 50%, the total thermal supply required for heaters in the sonde and cable is as follows: (i) 4.8 kW (sonde) plus 0 W (cable) to penetrate to 300 m depth over 10 days into temperate glacier ice for which the temperature is 0 °C at all depths and to maintain a water layer along 300 m of cable; (ii) 10 kW (sonde) plus 19–32 kW (cable) to penetrate to 1000 m depth over 1 month into cold glacier ice for which the temperature is −25 °C at the surface and 0 °C at 1000 m depth and to maintain a water layer along 1000 m of cable; and (iii) 19 kW (sonde) plus 140–235 kW (cable) to penetrate to 3000 m depth over 2 months into an ice sheet for which the temperature is −55 °C at the surface and 0 °C at 3000 m depth and to maintain a water layer along 3000 m of cable. The thermal supply required for the cable is strongly affected by the thickness

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doi:10.1016/j.polar.2008.02.002

of the water layer, cable diameter, and the horizontal distance from the ice wall at which the ice temperature was maintained at its initial temperature. A large thermal supply is required to heat 3000 m of cable in an ice sheet (scenario (iii) above), but penetration into glacier ice (scenarios (i) and (ii) above) could be realistic with the use of a currently employed generator.

Keywords: Glacier ice exploration; Ice drilling; Melt-drilling; Thermal transfer

1. Introduction

Existing methods for the direct exploration of glacier ice involve drilling into the ice, continuous coring, and subsequent analysis of the ice cores. There are two current methods of core drilling: electro-mechanical and electro-thermal. New electro-mechanical drilling technologies have recently been developed to enable the deep coring of glacier ice, and research groups in many countries have developed drilling tools (e.g., Fujii et al., 2002; Kudryashov et al., 2002; Takeuchi et al., 2004). The electro-mechanical drill developed in Japan (Fujii et al., 1990; Narita et al., 1995; Takahashi et al., 1996, 2002; Tanaka et al., 1994) has already provided good performance: the 48th Japanese Antarctic Research Expedition (JARE-48) succeeded in reaching a depth of 3,035 m in 2007 using such drill technology (Motoyama, 2007).

The glacier ice-core sampling method is an important approach in investigating glacier ice, and is likely to retain its role in the future because it enables the direct observation of glacier ice; however, the method is time- and capital-intensive because it requires a massive drilling device, an expensive drilling cost, and long drilling and analysis times. To address these limitations, we propose a next-generation drilling exploration system for glacier ice (Fig. 1). In this system, a sonde penetrates the glacier by melting the ice. The melt-water is then taken into the sonde and analyzed immediately. A contamination-free melt-water sample is obtained because antifreeze liquid is not employed in the process. Although a limited number of parameters can be measured, the system enables a simple and rapid analysis. This is useful in those cases when, for example, drilling and analysis must be completed in a short time upon warm glacier ice, or when a rough investigation is needed during horizontal drilling from a vertical hole after coring. Candidate parameters for analysis using such a system might be electrical conductivity, pH, dust concentration, and the concentrations of selected ions.

In the proposed system, an electro-thermal drill is employed to penetrate the glacier by melting the ice. In previous studies of electro-thermal drilling, a cartridge heater was set in the central axis of the head for non-coring electro-thermal drilling (Korotkevich and Kudryashov, 1976; Philberth, 1976; Taylor, 1976), whereas for electro-thermal coring, ring- or spiral-shaped heater elements have been employed as electric heaters fitted to the end of a core barrel (Bird, 1976; Narita et al., 1994; Paterson, 1976; Suzuki, 1976; Suzuki and Takizawa, 1978). Because the aim of the proposed system is to analyze the melt-water sucked into the drill during the drilling operation, it is not possible to fit a cartridge heater to the central axis of the drill head, as in conventional non-coring thermal drilling. Moreover, much more heat energy is needed for our proposed method than for conventional thermal coring because circular cross-section melting is required, whereas only annular melting is required for coring.

Other studies have developed fluid-filled thermal coring technology, in which the hole is filled with an antifreeze fluid during drilling (e.g., an ethanol–water solution) to prevent the hole from shrinking (Augustin

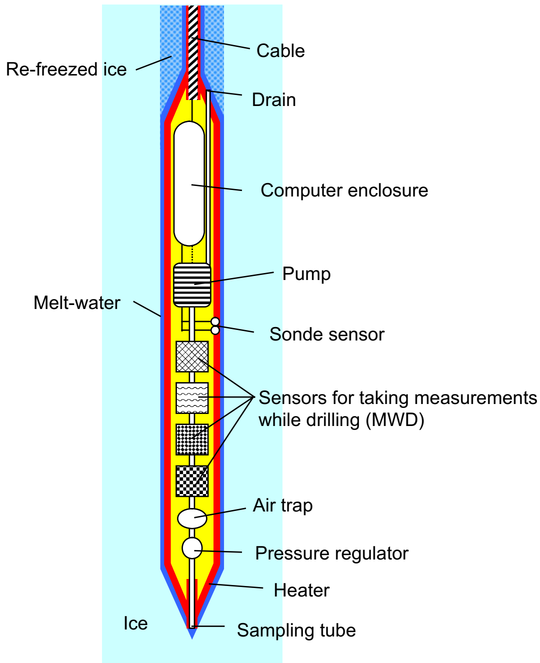

Fig. 1. Conceptual model of a next-generation exploratory drilling system for glacier ice.