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Thermal Ice Drilling Technology

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Any sufficiently advanced technology is indistinguishable from magic.
Arthur C. Clarke

Preface

This book is a continuation of the review of ice drilling technology published in 2016, where, in the beginning, a general introduction to ice drilling technology was given (Talalay 2016). The present book includes the design, parameters, and performance of various tools and drills for making holes in snow, firn, and ice via thermal methods. The melting point of ice at normal atmospheric pressure is quite low compared with that of common rocks and is close to 0 °C (Feistel and Wagner (2006) found that the melting point of purified ice is 0.002519 ± 0.000002 °C), and thus melting looks like the obvious solution for making boreholes in ice.

At first glance, thermal drills are simpler and more attractive than mechanical drills because they do not rotate and, for that reason, do not need driving downhole or surface units, anti-torque systems, slip rings, etc. On the other hand, the specific energy required for melting ice (590–680 MJ/m^3) is much higher than the energy required by mechanical systems (1.9–4.8 MJ/m^3) (Koci and Sonderup 1990). Thermal drills also need reliable heating elements that can work for long periods of time at high pressures and a wide temperature range. These drills are difficult to use for penetrating debris-rich ice and recovering subglacial bedrock samples because even though rock melting is possible, it is extremely power-consuming (Armstrong et al. 1962).

On April 1995, T. Folger published a remarkable paper in "Discover" about strange mole-like animals that melt ice holes in the Antarctic ice. Individuals of this newly discovered species were approximately 15 cm long and had a very high metabolic rate—their body temperature was 43 °C. Perhaps their most fascinating feature was a bony plate on their forehead. These animals radiated tremendous amounts of body heat through their "hot plates", which they use to melt holes in ice. That is why they were named as *hotheaded naked ice borers*. News of the ice borers drew more letters from "Discover" readers than any other piece in the magazine's previous 15-year history. Most readers were amused and elaborated on an April's fools hoax.

Joking aside, several years later, hybrid drilling–melting drill heads were designed in Hong Kong Polytechnic University to penetrate through debris-laden ice based on the assumption that the particles would be pushed backward by the hot rotating blades in combination with a solid heating tip. Another "bionic" thermal probe IceMole, was developed in FH Aachen University of Applied Sciences, Germany. Like a mole, the probe is able to "dig" holes in ice horizontally and even vertically upwards (see Sects. 1.4.5 and 1.4.6).

A critical issue in thermal drilling technology is water refreezing in the open hole. The freezing of meltwater in boreholes drilled in temperate glaciers that are at their melting point throughout the year from their surface to their base is relatively slow. However, in polar glaciers, refreezing is very rapid (according to Humphrey and Echelmeyer 1990, 4–23 h with an ice temperature of −25 °C and an initial diameter of 100–240 mm). Thus, refreezing or the removal of meltwater is challenge No. 1.

The diameter of the borehole just above the melting tip is larger than the diameter of the melting tip. Therefore, knowing the refreezing and penetration rates allow for estimating the time for the safe removal of the thermal drill before the hole becomes smaller than the probe. When drilling deep holes in polar ice, the time for the safe removal of thermal drills (except for hot-water drilling systems) is not enough, and the hole needs to be filled with antifreeze drilling fluid. In addition, the melted hole walls tend to be irregular, which could be a problem for some types of logging.

Depending on drilling ability and performance, thermal drilling tools can be divided into the following groups: (1) hot-point drills; (2) electric thermal coring drills; (3) hot-water drilling systems; (4) steam drills; and (5) unconventional thermal drilling systems. Hereinafter, the different drills and tools available for thermal drilling in ice are reviewed and discussed, focusing on particular aspects of drilling operations, drilling problems, and possible solutions. In each section, a description of each type of drill is given in chronological order. Although this review could be useful for learning about ice drilling technology, the experience will ultimately become the best guide, as happens with most equipment.

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Drilling in ice is often a nontypical and challenging process. The deepest hole drilled in ice via thermal methods was bored at Vostok station, East Antarctica, to a depth of 2755.3 m (Vasiliev et al. 2007). The deepest hole drilled in ice via mechanical methods was bored to a depth of 3769.3 m also at Vostok station (Lukin and Vasiliev 2014). However, the thickest Antarctic ice, which is at Terre Adélie (69° 54’ S, 135° 12’ E), is 4776-m deep (Riffenburgh 2007). Therefore, the deepest polar ice has not been drilled yet. Ice drills that worked perfectly in some ice intervals or sites failed under different conditions. Whenever this occurred, designers and engineers would have more questions than answers. I selected Clarke’s third law from his book “Profiles of the Future”, 1961, as an epigraph to this book because the separating line between state-of-the-art engineering and magic can frequently be blurred.

Changchun, China Pavel G. Talalay
December 2018

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