Cold Regions Science and Technology 86 (2013) 142–166

Contents lists available at SciVerse ScienceDirect

Cold Regions Science and Technology

journal homepage: www.elsevier.com/locate/coldregions

Subglacial till and bedrock drilling

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ARTICLE INFO

Article history:
Received 19 April 2012
Accepted 23 August 2012

Keywords:
Drilling technology
Glacier bedrock sampling
Till
Subglacial environment

ABSTRACT

Drilling to till and bedrock of ice sheets and glaciers offers unique opportunities for examining processes acting at the bed. Samples of basal and subglacial material contain important paleo-climatic and paleo-environmental records and provide a unique habitat for life, give significant information on sediment deformation beneath glaciers and its coupling to the subglacial hydraulic system, subglacial geology, and tectonics. Retrieving bedrock samples under ice sheets and glaciers is a very difficult task. Drilling operations are complicated by extremely low temperature at the surface of, and within glaciers, and by glacier flow, the absence of roads and infrastructures, storms, winds, snowfalls, etc. Nevertheless, borehole drilling might be considered as the optimal method to access beds of the glaciers and to sample subglacial material. Four types of subglacial drilling technologies are considered: (1) non-rotary sampling; (2) non-core penetrating; (3) pipe-string rotary drilling; (4) electromechanical cable-suspended drilling. The most simple and effective systems for sampling in subglacial soft sediments or unfrozen till from pre-drilled access holes are non-rotary devices like gravity corer and piston corer. The maximal thickness of ice is determined by the length of wire rope attached to the corer and could possibly be more than 4000 m. Potentially, piston sampling can reach a maximal depth of 25 m in soft subglacial lake sediments. In stiffer sediments a hammer corer or vibrocorer should be used. To install different sensors and markers into the soft till beneath glaciers and to measure basal sliding, different types of sediment non-core penetrators were used. Typically the boreholes are pre-drilled by hot-water systems as well. To recover core of the true bedrock the rotary drilling systems are used. The experience of pipe-string rotary drilling in subglacial environment showed that drilling operations were very unstable, and the recovery of subglacial sediment was generally poor. Commercial drilling rigs for drilling up to the depth of 3000 m or more tend to be very heavy and require a large logistical load to move and support. They also require more equipment for the circulation system. Taking into account that they are not adapted for extremely unfavorable conditions in Polar Regions and also need high power consumption, these drill rigs were not considered for subglacial exploration. Electromechanical cable-suspended systems are widely used for core drilling in pure and debris-containing ice. The main feature of these systems is that an armored cable with a winch is used instead of a pipe-string to provide power to the down-hole motor system and to retrieve the down-hole unit. The use of armored cable allows a significant reduction in power and material consumption, a decrease in the time of round-trip operations, and a simplification in the cleaning of the hole from the cuttings. To penetrate frozen till and bedrock the electomechanical drills can be adapted for coring bedrock. This was confirmed by four successful penetrations into the bedrock carried out by U.S. and Russian specialists. The procedure of till and bedrock drilling and the geological description of retrieved debris-containing ice and bedrock cores are given.

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0165-232X/$ – see front matter
http://dx.doi.org/10.1016/j.coldregions.2012.08.009

1. Introduction

Glaciers and ice sheets cover 16.3 mn km^2 or ~11% of the entire global land area. More than 98% of Antarctica and most of Greenland are covered by ice. Beneath this ice lies a unique environment, which plays a key role in the dynamics of the overlying ice sheet: debris-containing basal ice layers usually deform more rapidly than clean ice and can contribute significantly to the flow of the ice mass (Cuffey et al., 2000; Hubbard and Sharp, 1989). Samples of basal and subglacial material contain important paleo-climatic and paleo-environmental records and provide a unique habitat for life (Christner et al., 2008; Willerslev et al., 2007). In addition, bedrock samples give significant information on sediment deformation beneath glaciers and its coupling to the subglacial hydraulic system (Boulton et al., 2001; Clarke, 2005), subglacial geology, and tectonics (Bennett and Glasser, 2009; Hansen et al., 2010).

Nowadays conditions beneath ice are known mainly due to indirect methods of geophysical remote sensing, and there is no single framework for interpreting these data. The glacier bed is very difficult to observe directly. Therefore many studies of subglacial phenomena have been based on observations of former beds exposed by ice retreating (Knight, 1999). Direct observation of contacts between ice and substrates remains understandably infrequent. In fact, glacier beds can be accessed and investigated in situ (1) through cavities at the margin; (2) via tunnels though the ice or through subglacial rocks, and (3) via boreholes.

There are a few examples of basal sliding and ice–bedrock interaction studies in natural cavities. For example, Theakstone (1967) observed the deformation and subsequent incorporation of floor ice layers on to the glacier bed in a cavity beneath Østerdalsisen, Norway. In 1976–1978, a series of caves were observed in Austre Okstindbre, the largest glacier of Okstindan, a mountain range in northern Norway (Andreasen, 1983). This type of bedrock accessing could be hazardous (access to the cave may be impeded by a waterfall), and the places for observations are random.

Tunneling technology is well known for different investigations in ice sheets and mountain glaciers. In 1957–1964, several concepts for tunneling in snow and ice were tested at Camp Century, known as the "town beneath the ice" in northwestern Greenland (Clark, 1965).[1] After several years of tunneling development work, the project was abandoned because of operational difficulties.

Kamb and LaChapelle (1964) were among the first few who made detailed observations at the glacier bed, observing glacier sliding over bedrock by means of a 50 m tunnel excavated through the Blue Glacier, a temperate glacier in the Olympic Mountains of northwestern Washington, USA. Later on, several tunnels were dug in Meserve Glacier, a cold-based alpine glacier on the south side of Wright Valley,

[1] The site was built in the frame of "Iceworm", U.S. Army project during the Cold War with the main aim to build a system of tunnels under the Greenland ice sheet (Rasmussen, 1999). The tunnel system was to connect several hundred rocket silos and about 60 bombproof firing stations which would each control half a dozen nuclear middle distance rockets — all aimed at the USSR. The idea was to move the missiles around constantly within the system of tunnels. It would then be impossible for enemy in the east to know exactly where the missiles were and make it equally impossible to attack and destroy them.