Koci drill for drilling in ice, sand and rock: drill requirements, design, performance, difficulties

J. GREEN, B. KOCI,[†] J. KYNE

Ice Coring and Drilling Services, Space Science and Engineering Center, University of Wisconsin–Madison, 1225 West Dayton Street, Madison, WI 53706-1612, USA
E-mail: jimg@ssec.wisc.edu

ABSTRACT. A new man-portable drill designed to perform in ice with entrained sand and rock has been built. Designated the 'Koci drill', it was first used on rock-covered glaciers in the McMurdo Dry Valleys, Antarctica, during the 2006/07 field season. This drill is designed to be disassembled into component parts no heavier than 30 kg (not including the generator). For stability, the drill platform weight can be augmented with available rock. The field performance of the drill was generally good and both ice and rock were successfully penetrated and acceptable-quality ice cores up to 1 m long were collected during the 2007/08 season. The maximum depth achieved was 10.25 m. Given a concentrated effort at one or two sites per season, a depth of 40 m is achievable. Problems encountered in the field will be addressed in the next-generation design.

INTRODUCTION

In the 2003/04 austral summer season a standard PICO (Polar Ice Coring Office) hand auger (Koci, 1984), a Kovacs Mark II drill (Kovacs Enterprises, Inc.) and a drill modified by one of us (J.K.) were used by the first author and others to drill in rock-covered glaciers in the McMurdo Dry Valleys, Antarctica. These drills proved unable to take acceptable-quality core samples to the required depths in these glaciers. However, we were able to test many different cutter geometries by drilling with re-sharpened, damaged cutters. This evolutionary process provided insight for the best cutter geometry. A new drilling system, now called the 'Koci drill', was designed using the knowledge gained from the 2003/04 drilling season. The Koci drill was used for the first time on rock-covered glaciers in Mullins and Beacon Valleys in the austral summer of 2006/07. It performed successfully in ice with entrained rock and sand as well as solid rock. The drill's characteristics, limitations and problems are described in this paper.

ENVIRONMENTAL AND LOGISTICAL CONSTRAINTS

To be used in the Dry Valleys, an Antarctic Specially Managed Area (ASMA) under the Antarctic Treaty, the drilling operation was required to meet very stringent environmental requirements**:**

The drill had to be set up on a small footprint to minimize the environmental impact of its use.

No drilling fluids could be used in the drilling operation.

The drill could not leak lubricants or fuel, or leave significant consumable debris in or around the borehole.

Generators could be used, but sound environmental practice had to be followed. Fuel and oil spills had to be minimized; if any did occur they had to be cleaned up and reported to the logistical support contractor's environmental services department.

The glaciers in Mullins and parts of Beacon Valley and sub-valleys are rock sublimation glaciers that range in altitude from 300 to 500 m. The ambient temperature during the drilling season ranged from –25 to –10°C. Most of the time the sky was clear, but there was occasional snowfall and frequent katabatic winds.

The debris covering is made up of a base of mixed sand and larger rocks. The surface is mostly covered by larger, 0.03–0.5 m^3, rocks and occasional boulders up to 25 m^3. Seasonal snowmelt causes up to 6 cm of ice cement to form on the surface of the glacier at the base of the till. The total thickness of rock-surface covering observed ranged from 10 cm to 1.5 m. The top 5 m of glacial ice has sand and rock in it. The rock and sand are mostly dolerite with an occasional sedimentary rock. Ages of undisturbed surface ash-fall deposits suggest the valleys may contain buried ice ranging in age from modern in the accumulation zone to as old as 8×10^6 years in central Beacon Valley (Sugden and others, 1995; Marchant and others, 2002; Kowalewski and others, 2006).

The rocky till surface prevents the use of sleds to transport the drilling equipment. The use of wheeled and tracked vehicles in Mullins and Beacon Valleys is prohibited by the Management Plan of the ASMA, so the drill equipment had to be transported by helicopter (maximum load 700 kg) or man-packed (maximum load 45 kg) between drill locations.

DRILL DESCRIPTION

The basic design requirements of the drill were that it should produce 80 mm diameter cores of good quality in lengths no less than 0.2 m and that it should be able to reach a minimum depth of 10 m. Based on those requirements and past experience, the new drill (Fig. 1) was built, with the following characteristics (Table 1).

Barrel and drill head

The core barrel stock is 6061-T6 aluminum. The flighting is milled out of the core-barrel tube stock. The drill head is made of 304 stainless steel and is connected to the core barrel using flat-head stainless-steel rivets. The drill head has

[†]Deceased.

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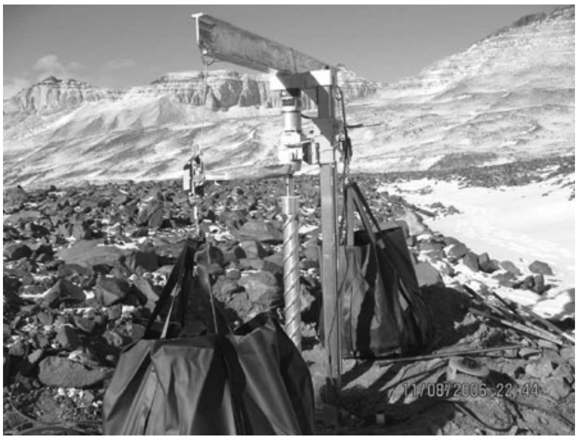

Fig. 1. Koci drill rig in Beacon Valley.

three cutters (Fig. 2) because we believe a three-cutter drill runs more smoothly and is more stable in the hole than a two-cutter drill. We have also found it easier to start a new hole with a three-cutter drill. The drill cuts a thin kerf in order to minimize the force required to penetrate rock when using the rock-coring bits.

Cutters with inserts

When drilling in ice with sand and rock, cutters wear out rapidly and they are expensive to replace. For this reason, the cutters in the Koci drill have inserted cutting edges. Inserts can be made in large quantities for much less cost than the entire cutters. Also, we could then use two different types of inserts:

Type 1: 10 V tool steel, made by Crucible Materials Corporation. The rake angle is 45°, and the relief angle is 15° (see Fig. 3 for definition of angles). The 10 V tool steel cutters were hardened to Rockwell 60 hardness scale C.

Type 2: VM-15m+ tungsten carbide, made by Vista Metals. The rake angle is 30° and the relief angle is 10°. These angles were reduced from those for 10 V tool steel because tungsten carbide is more brittle and less impact-resistant.

Both types of inserts have rounded corners, a relief angle of 15° on the core side of the cutter and no relief on the bore wall side. They are held in place by a countersunk socket-head Torx™ drive set screw. The cutting pitch is controlled

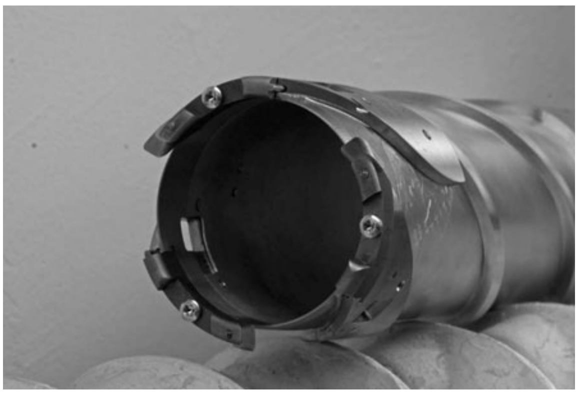

Fig. 2. Koci drill 3 cutter core head.

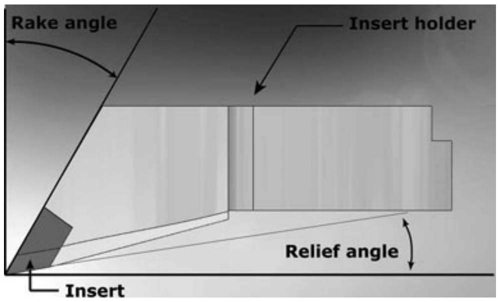

Fig. 3. Koci drill cutter assembly showing rake and relief angles.

using penetration shoes. These penetration shoes were pre-machined for a 0.8° pitch.

Core dogs

Three PICO-style straight-edge core dogs were used to catch ice core. The core dogs were electrical-discharge machined from 440C stainless steel and hardened to Rockwell 60 hardness scale C. The core dogs pivot on a dowel pin. A torsion spring is used to assist engagement.

Rock-coring bits

For drilling rocks, the drill employs a second core barrel that accepts rock-coring bits. No core catchers are used with the rock-coring bits. Once a rock is penetrated the ice-core barrel is used to catch the core. Three different rock-coring bits were used:

Crushed carbide (Fig. 4)

Temperature-stabilized diamond (Fig. 5)

Medium-grained surface-bonded diamond abrasive

Table 2 shows the ice conditions under which the different cutters and rock-coring bits were used.

Drilling rig

The rock-coring bits require a substantial force to cut through a hard rock like dolerite. To provide the necessary force, a Husqvarna DS 800 drill stand with a 2 m column and a Husqvarna Cardi D3-250S drill motor are used as the main platform. The speed of the motor is controlled by a 30 A variable transformer. Power for the drill motor was supplied by a 5 kW generator. An I-beam support system is mounted to the top of the post of the drill press and centers the reaction force over the drill spindle. Hand-operated cable winches are attached to the ends of the I-beam and fastened either to ice screws or to rock bags. Each rock bag is designed to hold 450 kg. As the drill itself weighs about 90 kg, a total force of nearly 1 t can be applied to the rock drill bit. The drill rig can drill ice from the surface to 40 m

Table 1. Koci drill characteristics and specifications

Core diameter	80 mm
Maximum core length	1.07 m
Borehole diameter	102 mm
Drill speed	0–600 rpm
Power requirements	25 A, 120 V a.c. 60 Hz
Weight	550 kg (includes packaging, tools, accessories and spare parts)

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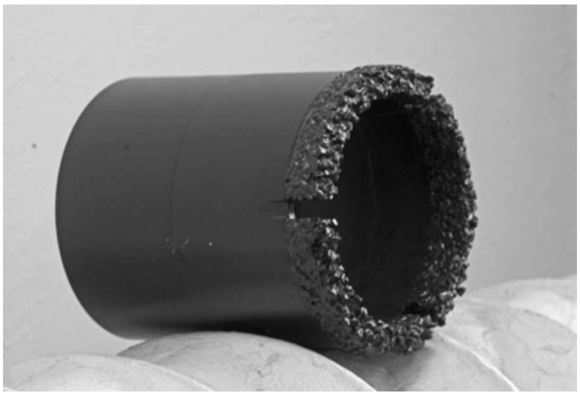

Fig. 4. Crushed carbide rock-coring bit.

Fig. 5. Temperature-stabilized diamond rock-coring bit.

depth. The first meter of ice core is drilled by attaching the core barrel directly to the drill motor. Deeper drilling is accomplished by using PICO drill rods made of fiberglass-reinforced epoxy tubing in 1.2 and 2.2 m lengths.

DRILL PERFORMANCE

The drill produced acceptable-quality ice cores in unbroken lengths up to 1 m long. The surface of a core typically had a slightly rough texture. The surface texture did not have features that would initiate cracks; 'poker chips' did not form.

The drill equipped with tungsten carbide inserts (even chipped and dull) was able to drill through small (<10 mm) to medium-sized (<50 mm) rocks and continue producing good-quality core. When ice-drilling through larger rocks (>100 mm), some water from melted ice would collect in the bottom of the hole. This water acted like a cutting fluid. The friction from rock drilling produced enough heat to prevent the water from freezing as long as drilling continued.

PROBLEMS ENCOUNTERED

Vibration

The vibration of rock drilling caused everything to loosen up. It was necessary to bring the drill up every 5 min to tighten the cutter and insert screws.

Chip transport

Chip transport was not a problem as long as the core barrel was shiny and new. After a few holes were drilled, the flights on the core barrel were no longer smooth enough for efficient chip transportation.

Diameter

We chose to make the rock-drilling bits a little larger than the ice-coring head with inserts, assuming the rock-coring bits would be able to ream out the hole left by the ice-core drill. This assumption turned out to be incorrect. The rock-coring bits heated up and started to freeze into the hole.

Inserts

The 10 V tool steel inserts did not perform as well as expected. They were easily damaged and wore out quickly. As previously noted, they were hardened to Rockwell 60 hardness scale C. They could have been hardened to Rockwell 64 hardness scale C, but this probably would have made little difference.

Core dogs

Drilling in dirty ice quickly wears the edge off the core dogs. We found it best to drill with a core barrel with no core dogs, then pull the drill out of the hole and collect the core with a second core barrel with core dogs.

Penetration rate

When drilling through ice, better core quality can be achieved if the drill penetrates quickly (Table 3). Penetrating too slowly produces fine chips that pack inside the core barrel. The core then sticks inside the barrel and snaps off. But when drilling in rocky ice, too fast a penetration rate will likely result in broken inserts.

Heat

Care should be taken to minimize the heat generated in the hole since this can cause the drill to freeze into the hole.

Table 2. Cutters used in different kinds of ice, sand and rock

Type of ice	Expected cutter/bit to be used	Cutter/bit used
Clean ice	Crucible V 10 steel or tungsten carbide	Crucible V 10 steel or tungsten carbide
Ice with sand	Tungsten carbide	Tungsten carbide
Ice cement	Tungsten carbide	Tungsten carbide
Ice with small rocks	Crucible V 10 steel	Tungsten carbide
Rock	Rock core bits	Rock core bits and tungsten carbide

Table 3. Feed rates used in different kinds of ice

Material	Drill speed	Penetration rate	Weight on bit
	rpm	mm min^{-1}	kg
Ice	50–80	100–120	10–20
Ice cement	50–80	50–80	10–25
Rock or ice and rock	25–35	1–10	10–500

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If the drill starts to freeze, the drill motor requires more power. If the drill stops turning, it will freeze instantly. When drilling through large rocks (any rock that covers >120° of the cutting circle) the heat generated will melt the ice. We used a shop vacuum cleaner to remove the water and chips from the hole each time we pulled the drill out of the hole. Once through the rock, we let the hole cool overnight to refreeze the meltwater before continuing to drill the ice below the rock.

These problems will all be addressed in designing and constructing the next-generation Koci drill.

ACKNOWLEDGEMENTS

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A special note of recognition

In response to a suggestion by D. Marchant, Ice Coring and Drilling Services named the drill in honor of Bruce Koci who passed away in November 2006. Bruce was heavily involved in its development, and much of the success of this drill can be attributed to his advice and support.

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