DESIGN AND DEVELOPMENT OF RAPID ICE SAMPLING EQUIPMENT

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Tere Tīpako Tio: Rapid Extensive Ice Sampling

The physical properties of glacial ice are critical for robust ice sheet models that predict sea level rise. Traditional ice sampling systems are expensive, time-consuming, and logistically demanding, limiting the number of ice samples that have been collected.

Hot water drilling provides rapid access to ice at depth, but results in irregular internal diameter profiles. Thus, hot water drilled boreholes are currently not compatible with ice sampling tools.

This project focuses on the design, development, and testing of two novel, low-cost, rapid ice sampling systems:

1. A bottom hole ice sampler for collecting samples from the base of a borehole.
2. A sidewall ice sampler for collecting samples from borehole walls.

Project Objectives

- Design and build rapid, lightweight, and field-deployable ice sampling tools to operate within dry hot water drilled boreholes.
- Quantify the mechanical forces, torques, and operational limits for ice sampling in hot water drilled boreholes.
- Conduct Antarctic field testing to evaluate performance, identify limitations, and guide future improvements.

To maximise the scientific value of samples collected, the testing location on the McMurdo Ice Shelf was determined based on preliminary geophysical survey results.

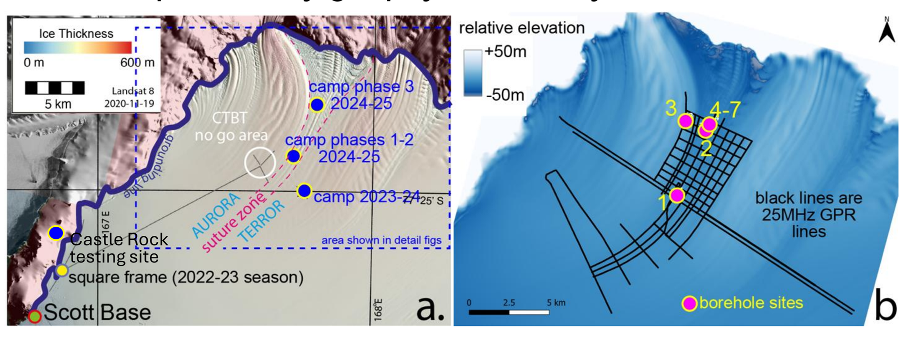


Figure 1: *Field testing locations of the ice sampling equipment at Castle Rock testing site, Ross Island and Windless Bight, McMurdo Ice Shelf.*

Sampling System Design

Sidewall Ice Sampler

The sidewall ice sampler was designed to mechanically cut and retrieve ice samples 50 mm in diameter up to 100 mm long from the sidewall of dry hot water drilled boreholes. Linear actuators extend circular plates to clamp the system into the borehole. A second set of linear actuators drive a rotating core barrel in the sidewall to cut a sample.

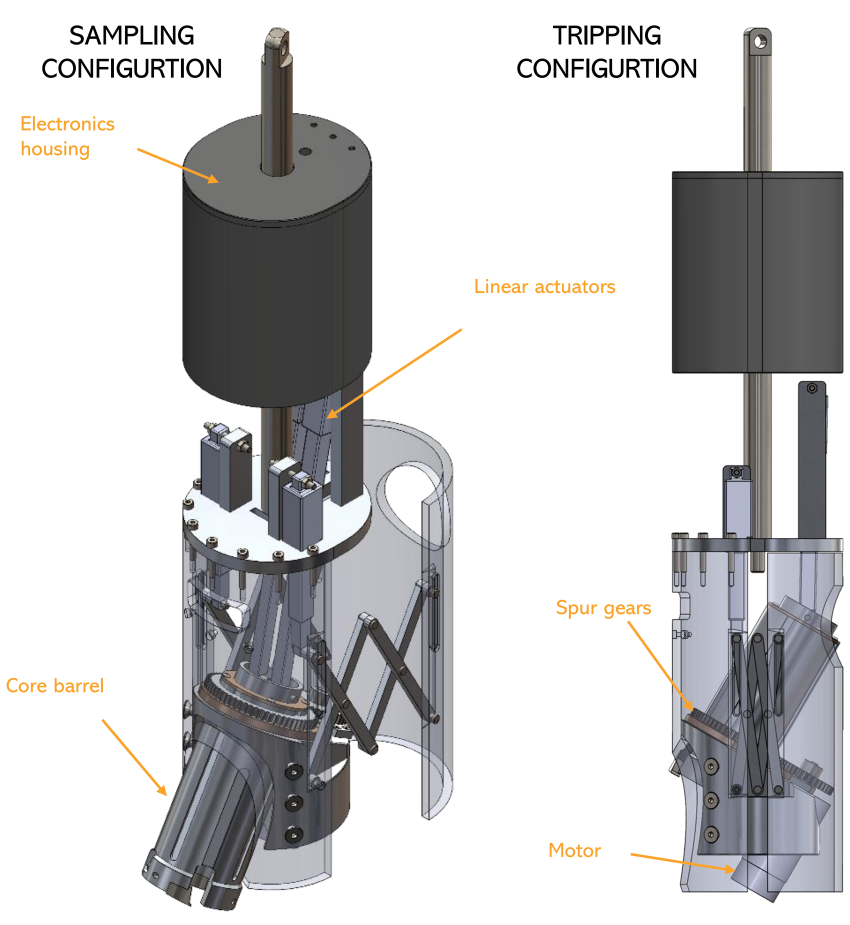


Figure 2: *Sidewall ice sampler assembly in fully extended position (left) and fully retracted position (right).*

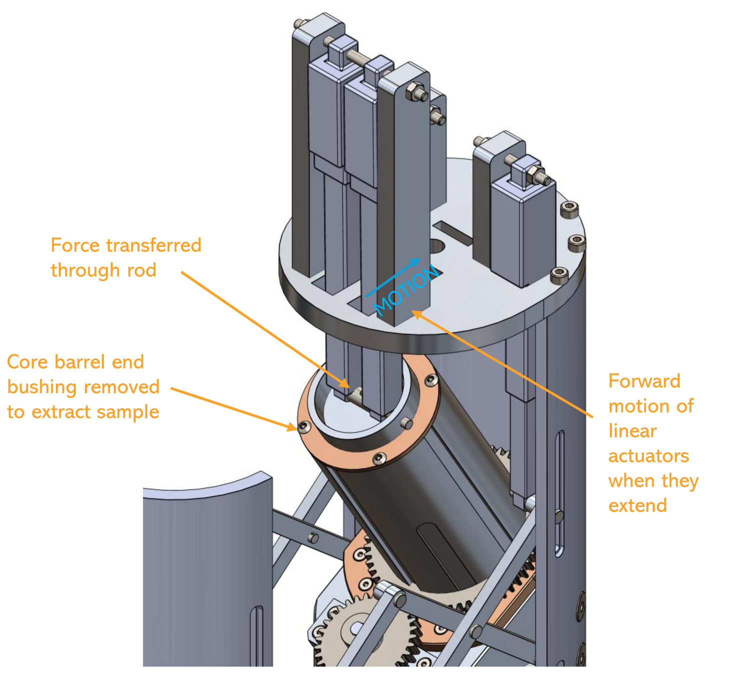


Figure 3: *Sidewall ice sampler linear actuator extension assembly.*

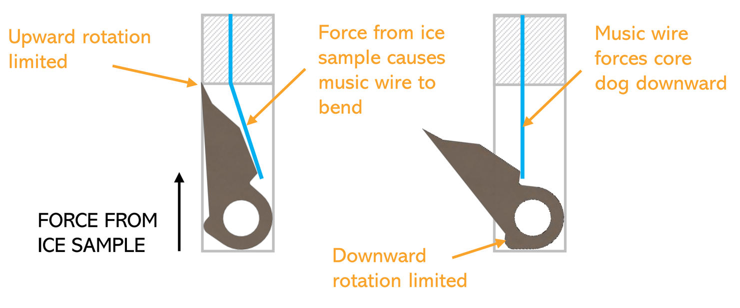


Figure 4: *Schematic representation of core dog rotation when forced by ice sample and music wire lever spring.*

Bottom Hole Ice Sampler

The bottom hole ice sampler was designed to mechanically cut and retrieve ice samples 70 mm in diameter up to 1 m long from the base of dry hot water drilled boreholes. The sampler can operate in two configurations: directly coupling the core barrel to motor housing, or using an outer barrel and chip management system.

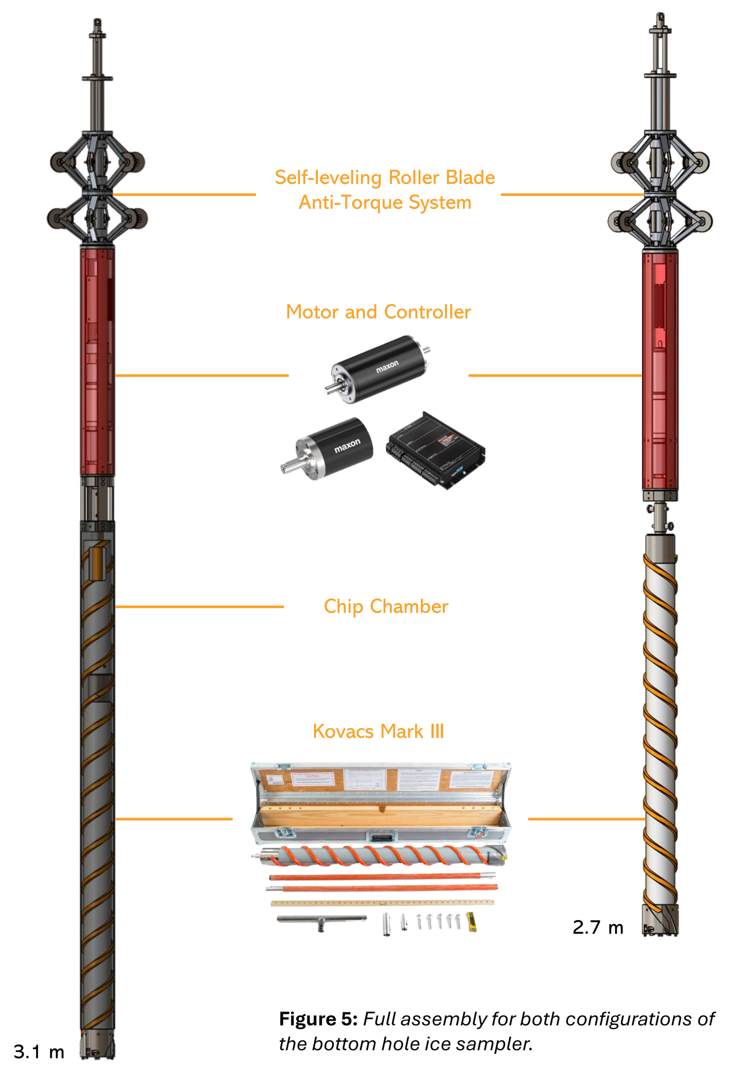
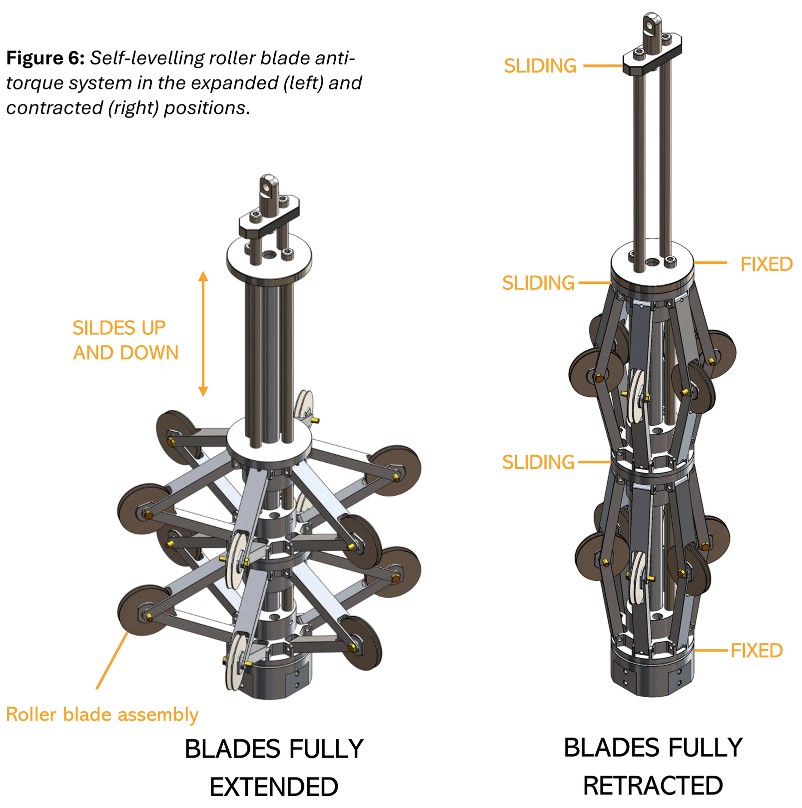


Figure 5: *Full assembly for both configurations of the bottom hole ice sampler.*

Anti-Torque System

The anti-torque system is designed to operate in boreholes where the diameter varies between 125 – 250 mm with depth. Extension springs force circular blades onto the borehole wall. Tension in the load bearing cable overcomes the spring force, retracting the blades.

Figure 6: *Self-levelling roller blade anti-torque system in the expanded (left) and contracted (right) positions.*



Field Testing Results

Testing was conducted in firn and fully dense glacial ice. The linear actuators and 55 RPM motor provided sufficient force to drive the core barrel into the sidewall while annular cutting.

Motor vibration resulted in entire system oscillation, aided by insufficient friction and clamping force between the expansion plates and borehole wall in dense ice. As a result, ice samples were fractured during sampling and could not be retrieved.

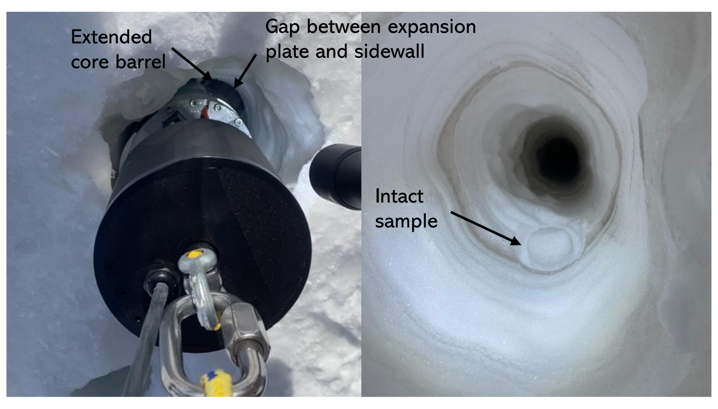


Figure 7: *Sidewall ice sampler at top of hot water drilled borehole in firn (left), intact sample from testing on borehole wall (right).*

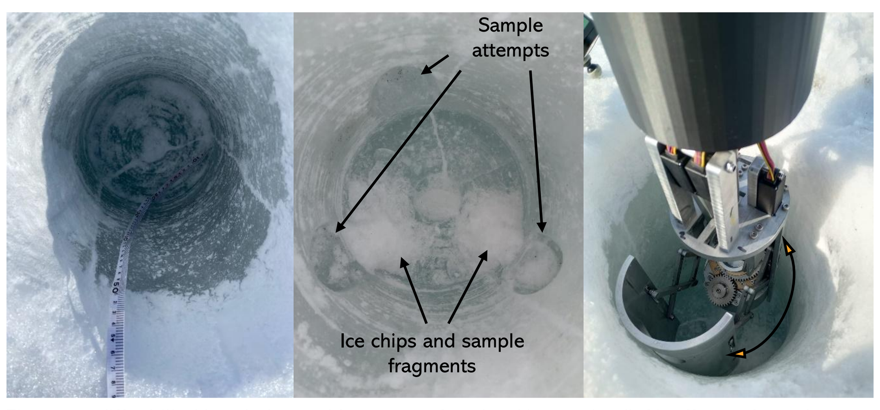


Figure 10: *Jiffy-drilled borehole used for near surface hard ice testing (left), effects of annular cutting on borehole wall with sample fragments at the base (middle), sidewall sampler clamped into the borehole with oscillation observed in direction of arrow (right)*

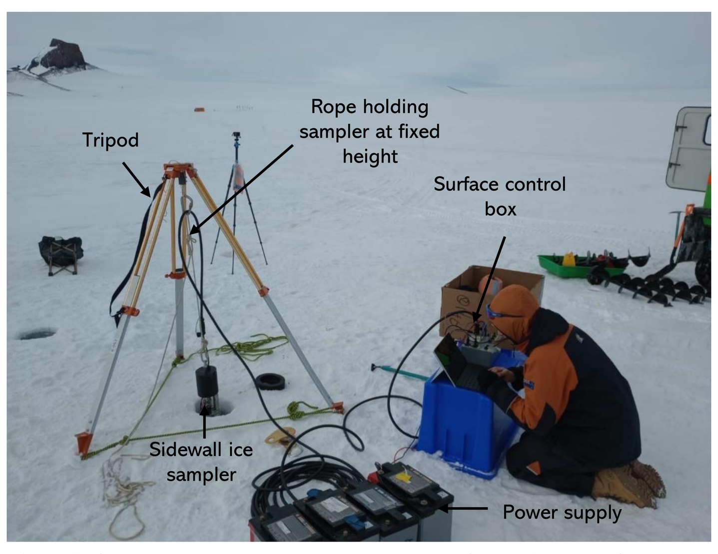


Figure 8: *Sidewall ice sampler testing set up at the Castle Rock Test Site.*

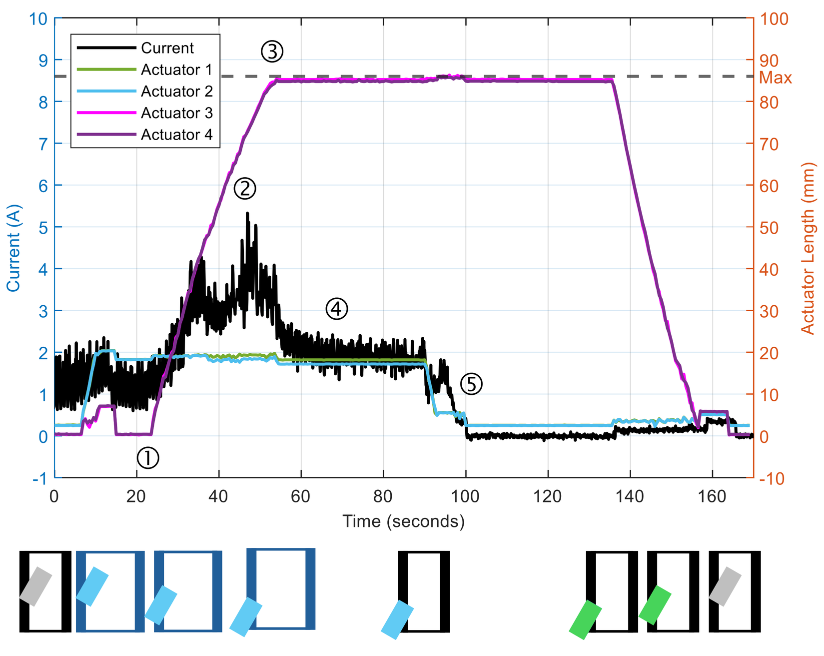


Figure 11: *Extended length of the sidewall ice sampler linear actuators during the Test 1 on 16th December (Figure 10). Actuators 1 and 2 control the motion of the expansion plates; actuators 3 and 4 control the extension of the core barrel. Where (1) is the start of core barrel extension, (2) is the peak in current draw during sampling, (3) is the end of core barrel extension, (4) is the current draw when the motor is rotating during full extension, (5) is the current draw from retracting the linear actuators 1 and 2.*

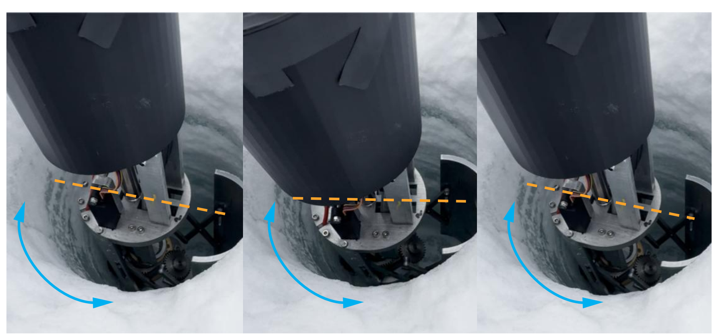


Figure 9: *The observed oscillation of the sidewall ice sampling system. The orange line provides a reference for system oscillation.*

Eight ice samples at depths between 8 m and 40 m were collected from hot water drilled boreholes at Windless Bight. Ice sampler performance was contingent on borehole properties and HWD processes.

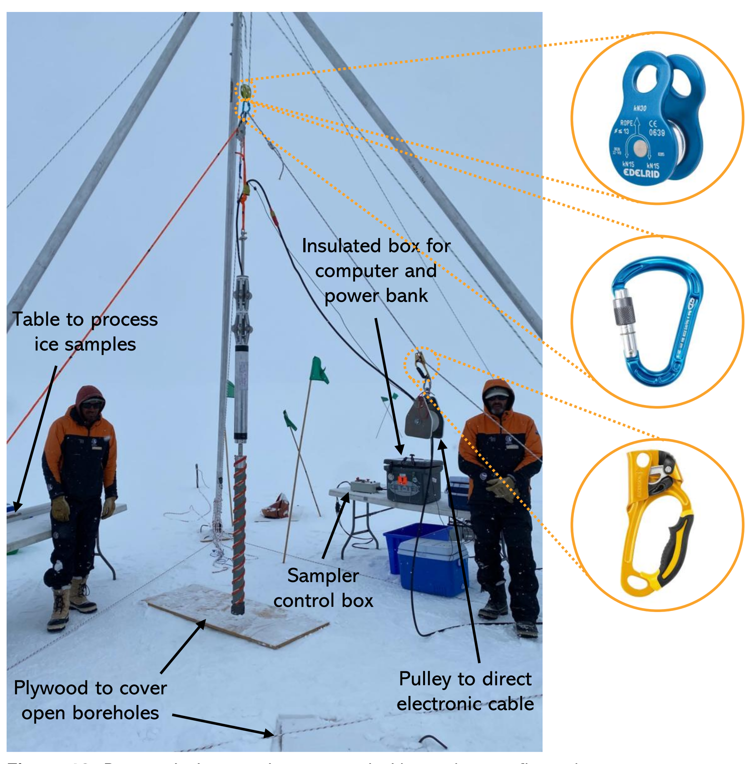
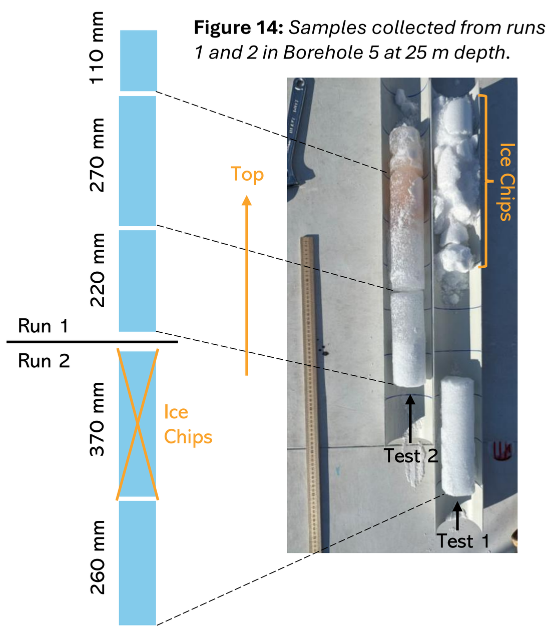


Figure 12: *Bottom hole sampler suspended in testing configuration before tripping, with climbing hardware used for lowering indicated.*

Figure 13: *Anti-torque system engaged with borehole wall at 25 m. Borehole diameter variation with depth due to hot water drilling can be observed.*

Figure 14: *Samples collected from runs 1 and 2 in Borehole 5 at 25 m depth.*



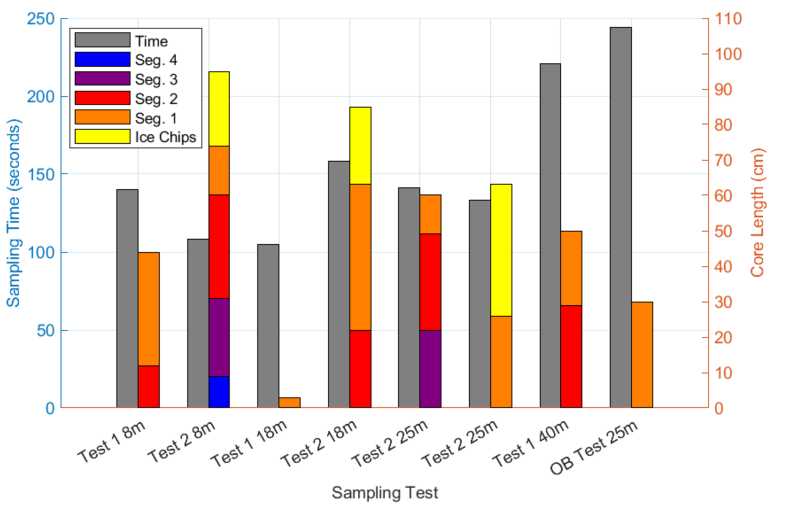


Figure 15: *Summary of all the ice samples collected during bottom hole sampler testing at depth at Windless Bight compared to their tested sampling time*

Table 1: *Results from all field testing conducted with the direct core barrel configuration in dry hot water drilled boreholes at Windless Bight.*

	Test 1 8 m	Test 2 8 m	Test 1 18 m	Test 2 18 m	Test 1 25 m	Test 2 25 m	Test 1 40 m
Average cutter head torque (Nm)	12.8	14.9	14.6	14.6	15.6	14.1	15.9
Total Sample length (mm)	450	970	30	1100	600	630	500
Number of sample segments	2	5	1	3	3	2	2
Compacted ice chips in core barrel	No	Yes	No	Yes	No	Yes	No

Conclusions and Future Work

The sidewall sampler needs further development to reliably retrieve ice samples due to undesired oscillation, but the functionality showed promise.

Future development of the sidewall ice sampler should focus on the design of oscillation damping mechanisms and improving reliable data acquisition.

The bottom hole ice sampler successfully retrieved eight ice samples from dry hot water drilled boreholes.

Future development priorities of the bottom hole ice sampler include integration with a winch and load bearing electronic cable, and comprehensive testing of the outer barrel configuration.

This research demonstrates the feasibility of retrieving ice samples from dry, hot-water-drilled boreholes using purpose-built, lightweight sampling devices.

Acknowledgements

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Figure 16: *Hot water drilling set up at Windless Bight.*