Rapid Access Ice Drill

A Drilling System Equipped for Rapid Transit over Glacial Ice, Equipped for On-the-Fly Ice Coring and Subglacial Rock Coring, and Suitable for Regional Geological Mapping and Glaciology

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ICE DRILLING DESIGN AND OPERATIONS
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Summary

The IDPO led an Ice Drilling Science Community Planning Workshop in April 2011 in order to identify compelling emerging science and associated drilling needs. From that workshop, an interdisciplinary goal was articulated that spanned a wide range of science targets, including understanding the Mid-Pleistocene transition from 40 kyr to 100 kyr climate cycles (by sampling ice as old as ~1.5 Ma), documenting the presence of Eemian-age ice to test models of ice sheet collapse in West Antarctica (~125 Ka), exploring the deep interior geology of Antarctica for the first time, evaluating the bed conditions at the base of the ice sheets, characterizing geological features that have been imaged with geophysical data, and testing models of cratonic growth related to supercontinent assembly in the Mesoproterozoic (~1 Ga). Based on a convergence of science goals, a general conceptualization of a rapid-access ice- and rock-coring drill was outlined by an *ad hoc* working group. The IDPO Science Advisory Board subsequently identified

in the IDPO Long Range Science Plan 2011 a need to move forward with plans to develop a so-called *R*apid *A*ccess *I*ce *D*rill (RAID).

Beginning in October 2011, a series of discussions between representatives of IDPO, IDDO, industry and academia culminated in a feasibility study of a drilling technology that would simultaneously allow for ice coring, rock coring and borehole observation. Several drilling technologies were considered, but it was determined that a RAID system based on a mineral-exploration-industry "diamond-drilling" rig design provides the most suitable, technically feasible, and cost-effective approach. Several commercially-available drilling rigs have been identified that, with appropriate modification, have sufficient capacity to complete the drilling anticipated for the RAID project.

With the development of new drilling tools adapted to a 'wireline coring' system, it will be possible to:

- Bore rapidly through glacial ice without coring, to a depth up to about 4000 meters
- Obtain ice cores of relatively small diameter (~4-7 cm) and up to 3 or 6 meters in length by "on the fly" wireline retrieval—that is, without necessitating the removal of the drill "string" from the bore and subsequent change-over to a completely different drill-head assembly
- Obtain rock and sediment cores by the same wireline process, following coring by diamond drill bit.

Drilling will require a fluid to lubricate the system and provide floatation for cuttings. A liquid drilling fluid with a density approaching that of ice (i.e., $\rho \sim 0.92$ g/cc), and with viscosity similar to water, has been identified as ideal. Several different fluids have been used previously in ice-coring operations, and the fluids considered most appropriate for a RAID platform include n-butyl acetate and other fluids based on a kerosene-like petroleum solvent. Although hydrocarbon solvents typically have somewhat lower densities ($\rho = 0.75$ to 0.8 g/cc), the lower density is partially offset by the fact that:

- The RAID casing will be set above the present-day snow surface, and the casing is filled to its very top, whereas the zone consisting of firn and glacial ice to a depth of a few hundred meters, has a density that is *less than* 0.92 g/cc.
- Fluid is pumped into the bore and flows through the annulus between the rods and the ice bore, from bottom to top. This flow and the pressure gradient that drives it, is interrupted only briefly while new rods are added, and while core is being retrieved. The pressure, which amounts to a few hundred pounds per square inch near the bottom, also supplies compensation against bore collapse.

In cold ice, relatively shallow bores, and rapid drilling while circulating fluid under pressure for most of the boring operations, it will be possible to drill with a fluid that does not provide perfect, static, hydrostatic compensation.

A simple fluid-recirculating and chip-removal system, to be built from commercially available “off the shelf” components, consists of:

1. fluid pumps capable of handling a dilute slush (probably centrifugal pumps);
2. a continuous-filtering centrifuge with a scroll-type ejector for the chips;
3. a chip-moving screw auger;
4. several filter-bags in multiple housings fitted with valves to allow on-the-fly cleaning, for removal of fine particles that escape from the centrifuge.

This fluid circulation and chip-extraction system is anticipated to run virtually unattended. Using centrifugation, the amount of drilling fluid being abandoned (adhering to chips) at each drill site is likely to be on the order of a couple of hundred liters, distributed in tens of cubic meters of chips. Chips will be conveyed directly into a trench dug at the site, compacted, and buried under the snow removed to dig the trench, as part of the site-abandonment process.

The RAID system being considered will store and handle large quantities of pressurized, flammable liquids. Some of these will be pumped at very high flow rates. There are real environmental and safety hazards associated with use of such materials. The RAID conceptualization identifies technologies that are believed capable of providing safe operation given the hazards, equipment specifications, staffing levels and skills, and environmental conditions, and to minimize both the environmental and safety risks. Fire hazard mitigation technologies are arranged into two ‘tiers’ of response.

The RAID system as conceived will require minimal staffing. However, the staff will require a number of members with experience in deep diamond drilling operations and skills necessary to troubleshoot and repair diesel engines, hydraulic systems, and electrical systems. Staff will also have to meet the “normal” polar region project requirements of being able to work effectively as a team in extreme cold weather in isolated, remote regions, etc. Staffing projects utilizing RAID, therefore, can be expected to be more challenging and more expensive than most polar projects.

Operating conditions of -20° C are normally expected. Start-up temperatures as low as -40° are practical, and engineering changes required for these conditions have been tentatively planned. Strength-of materials-issues (particularly, the peculiarities of mild steel), must be explicitly considered.

A time-line for the development and fielding of the conceptualized RAID has been constructed. The time for final completion of all tasks is expected to take about 5 years, including development, acquisition, integration and testing. As conceptualized, the RAID system would be ready for a first field test no earlier than about 2.5 years after the project is started.

Science Requirements: Rapid Access Ice Drill

From a planning meeting organized by IDPO in October 2011 and follow-up teleconferences, discussions with the research community and with IDDO staff, the following are science requirements defined for the Rapid Access Ice Drill:

1. Produce 3300 m bore to base of ice in ≤ 200 hours of drilling operation, including drilling and retrieval of at least one 50 cm-long ice core and at least 25 m of sub-glacial rock and / or unconsolidated, frozen sediment core.

2. Minimize bore-fluid and rod weight requirements by producing ≤ 3” diameter ice borehole, and ideally 2.75" diameter ice borehole (nominal BQ size). Minimize complexity by avoiding stepped borehole diameter.

3. Ice drilling through dry, frozen-bed conditions (i.e., “clean access” system not required).

4. Retrieve short ice cores (~50 cm long) of ≥ 1.4" diameter at up to 3300 m depths.

5. Retrieve at least 25 m of bedrock cores of ≥ 1.4” diameter (nominal BQ size).

6. Borehole walls must be left clean and essentially free of debris for borehole logging measurements.

7. System is equipped with drilling-fluid recirculation, chip-removal and disposal system.

8. Stand-alone, traverse-capable, over-ice system (not reliant on a fixed support camp).

9. Minimal staff for drilling operations in the field, with an objective of 24-hour-per day operations; 3 shifts per day; each shift consisting of 2 or 3 dedicated and experienced drillers; other field staff in support of drilling operations to be provided separately.

10. Keep borehole open for up to 5 years, allowing for some deformation and/or decrease in diameter; tolerances will be determined separately for each borehole as determined by ice conditions and fluid density requirements.

11. Completion of bore, including the provision of a suitably dense, bore-filling fluid, to allow for logging:

a) immediately after ice drilling is complete and before rock coring is initiated (requiring the removal of the drill string so as not to interfere with borehole logging), and
b) subsequent to rock coring for purposes of logging *only*, as determined in item 10 above.

12. Non-freezing, non-ice-reactive (“hydrophobic”) drilling fluid will have a density similar to water ice and provide pressure stabilization, but this fluid system need not provide perfect hydrostatic compensation (consistent with materials and safety requirements covered elsewhere, and consistent with long-term observation requirements).

13. Drilling fluid or a fluid “system” (to be determined) will be compatible with borehole logging (i.e. transparent; ideally has a refractive index similar to that of water ice, for the light wavelength(s) of observation).