White paper

Ice Core Drilling Technical Challenges

Introduction
Our ability to continue to build our knowledge of the Earth's climate systems through the wealth of information accessible from ice cores depends on our continued ability to meet the technical challenges associated with successful recovery of good-quality ice cores in a variety of glaciological settings.

IPICS, through the four identified joint projects described in the IPICS white papers, has articulated a suite of requirements for drilling and coring capabilities to support their scientific goals. Although many of these requirements can be met with currently available technology, some will require the extension of current technologies or the development and testing of new ones.

Further requirements have been articulated by communities outside of the current scope of planned IPICS activities. These communities have articulated requirements such as drilling and recovering rock cores from the bottom of the ice core borehole, clean-drilling requirements to preserve the integrity of biological material in the core (including the approaches to sub-glacial lakes), the development of successful strategies for coring and recovering ice charged with varying percentages of particulate material (e.g. silty ice, rock glaciers), development of a rapid access technology, and better utilization of the borehole once coring operations are completed (e.g. various logging methods or the emplacement of instrumentation in the hole).

Planning for the capacity to meet these requirements will be a key component for the future success of IPICS and other programs that depend upon ice drilling technology to meet their scientific goals.

Drill trench

The Technical Issues
Technical requirements identified in the four proposed IPICS projects fall naturally into two sets – those related to the two deep-drilling projects (the 1.5 million year (1.5Ma) and Northwest Greenland deep ice (NWG) core projects) and those related to the shallower (40,000 year (40ka) and 2k (2ka) array) projects.

The deep drilling projects 1.5Ma and NWG will require addressing improvements in drilling fluids, applying successful strategies for recovering good quality cores through the brittle ice zone, institutionalizing successful approaches to core recovery in warm ice and developing methodologies for obtaining replicate samples. All these requirements need to be met without adding large overheads in either logistical requirements or the time required to acquire the core.

The 40ka and 2ka projects require the identification and standardization of a lightweight, 500 – 1,000 m capable, wet drilling system with simple logistical requirements and short setup and breakdown requirements. These projects also have the need for an improved drilling fluid.

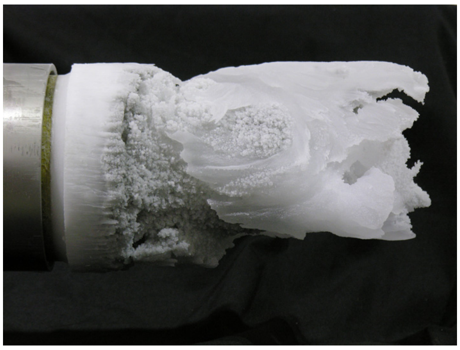
The Challenges
Specific challenges related to the requirements of the four IPICS project proposals include:

- The requirement to identify an acceptable, appropriate, inert drill fluid with no undesirable physical or chemical characteristics;
- The ability to successfully core and recover basal ice close to or at its pressure melting point in a deep, fluid-filled hole;

- The ability to produce good-quality core through the brittle ice zone in polar ice caps and to handle, transport and store it without inducing additional damage;
- The ability to acquire replicate ice samples at specific depths or intervals of interest;
- Creating successful strategies for encountering pressurized water at the bed;
- Sampling bedrock at the bottom of the hole;
- Identifying and standardizing a reliable lightweight, portable dry/wet drill system capable of reaching from several hundred to a thousand meters.
- Developing procedures to handle, transport and store core in a way that it preserves as much of its initial information as possible.

Meeting the Challenge – Current State of Technology

Drill fluid identification: Several new drilling fluids have been proposed in the past three years. Thorough testing of these fluids still remains to be performed in order to fully characterize the temperature dependence of miscibility behaviour (for multi-component fluids), viscosity, and the nature of fluid/chip interactions under an appropriate range of temperatures and pressures.


Refrozen sub-glacial water

Drilling warm ice: Successful strategies for recovering warm ice utilizing ethanol-water solutions and sufficient fluid circulation have been explored and optimized at North GRIP, Dome C and Dronning Maud Land (DML). Utilization of a thermal head to complete deep electro-mechanically drilled holes through the warm basal section has also been identified as a supportable solution, but has not yet been utilized in practice.

Core recovery in the brittle ice zone: Experiences from the current Dome Fuji (DF) and DML drilling projects indicate that a well-tuned drill with sufficient fluid circulation and the minimization of thermal or mechanical shock during drilling, handling, and storage can significantly improve core quality in the brittle zone. Promulgation of the lessons learned during these projects should result in overall improvement in brittle ice recovery in future work.

Replicate sampling: A variety of possible methods for replicate sampling are currently being discussed, (e.g. deviation drilling, sidewall coring, etc.) but no forum has yet been convened to identify a subset of potential solutions that deserve more complete development and eventual testing. All proposed solutions require design and field testing for applications in ice, but some have received extensive development in the oil and gas industry.

Encountering pressurized water at the bed: The presence of liquid water at the base of an ice sheet or glacier presents unique challenges for current electromechanical drilling techniques. Additionally, the sub-glacial environment in the presence of water is vulnerable to contamination. The development of geophysical methods to detect the presence and extent of sub-glacial water and the development of commonly agreed upon procedural guidelines for minimizing contamination when penetrating into a wet bed needs to be pursued.

Sampling bedrock at the bottom of the hole: There is a general consensus that if the recovery of rock from the bottom of the core is motivated by glaciological or climatological questions, the drilling community needs to be prepared to do this. Several potential approaches exist, (e.g., rapid access drilling to the bed and the utilization of a rock drill or a drill-specific rock-drilling attachment for the ice drill) but no consensus has emerged. The solution still requires design and testing of potential configurations.

Lightweight dry/wet drill system: Several variations of the same drill have been utilized for this type of application (e.g. Hans Tausen, Berkner Island, Talos Dome). This capability will benefit from standardization of components and the promulgation of this drill system as a demonstrated success for the requirement. The limiting factor for deployments of this type is likely to be the logistical requirements related to the amount of fluid required to fill the hole if maintaining hydrostatic balance is required.

Core handling, transport and storage: The physical properties of cores change fundamentally when it is stored at warm temperatures. For the different properties, such as electrical, elastic and structural properties, procedures for handling and storage should be standardized and the temperature history of the core should be carefully documented. The aim is to have a history of handling for each core after it has been taken from the ice sheet. Projects should be encouraged to use temperature loggers for each step of the process and provide "certified samples".

Drillers meeting Sep. 2004, Zugspitze, D

Identification of Field Safety and Environmental Best Practices:
Large-scale drilling projects present unique challenges in the areas of workplace safety and environmental soundness. Different nations have differing requirements in these areas. The identification of a common set of best practices on the drill site that will ensure worker safety and promote environmental stewardship is a highly desirable outcome of international collaboration within the drilling community.

The International Dimension

Specific opportunities for international collaboration in the area of drilling technology include:

- Expansion of international exchange of technical personnel.
- International participation in regular field testing and training opportunities.
- Following the example of the satellite community, establish mechanisms for development of shared international responsibility for designing and testing specific technical solutions.
- Establish an international forum for the exchange of ideas and information, the promulgation of best practices, and the promotion of standardization.

The Next Steps and Schedule

A significant proportion of the challenges require the development of consensus around proposed solutions, convergence on a standardized configuration or procedure, the promulgation of successful strategies, and/or the opportunity for field testing. The commonalities among these requirements are the need for a regular forum for discussion, a mechanism for reaching consensus, and the opportunity to develop, test, and promulgate solutions. Specific actions that can be immediately undertaken to begin the realization of these next steps include:

- Provision of the opportunity to gather frequently and exchange experiences and ideas, including some travel funds to support experts that have no other means to participate. This includes support for attendance at the next International Drilling Technology Workshop scheduled September 2006.
- The facilitation of expanded international exchange of technical personnel through a high-level international memorandum of understanding that will permit simplified processes for such exchanges.
- Formalization of the drilling technology community to permit the establishment of mechanisms for maintaining regular discourse throughout the community and disseminating information on best practices.
- Developing international support for annual testing and training seasons through a formalized agreement among participating nations to support a summer testing camp in the northern polar region.

International Partnerships in Ice Core Sciences (IPICS) is a group of scientists, engineers and logistics experts from the leading laboratories and national operators carrying out ice core science. At the first IPICS meeting, in Washington, DC in 2004, participants identified several high priority international scientific projects to be undertaken over the next decade or more. At the second IPICS meeting, in Brussels, Belgium, in October 2005, these projects were further defined, and routes to implementation were discussed. The 2005 meeting also placed IPICS on a more formal footing. It now has an international steering committee including representatives of 18 nations, planning groups are being formed around each of the scientific projects, and an additional international group of drillers and engineers has been organized. IPICS has been officially approved as an IPY project by the International IPY Committee.
The current document complements the four that describe the science proposals; this one looks at some of the technical challenges and drilling needs for implementing the IPICS plans. The five documents are entitled:

1. The oldest ice core: A 1.5 million year record of climate and greenhouse gases from Antarctica.

2. The last interglacial and beyond: A northwest Greenland deep ice core drilling project.

3. The IPICS 40,000 year network: a bipolar record of climate forcing and response.

4. The IPICS 2k Array: a network of ice core climate and climate forcing records for the last two millennia.

5. Ice core drilling technical challenges.

For more information about IPICS or any of these projects please contact the IPICS co-chairs:

Edward Brook
Department of Geosciences
Oregon State University
Corvallis, OR 97330
USA
brooke@geo.oregonstate.edu

Eric Wolff
British Antarctic Survey
High Cross, Madingley Road
Cambridge CB3 0ET
United Kingdom
ewwo@bas.ac.uk

Drafting committee for this document:

Frank Wilhelms, Alfred Wegener Institute for Polar and Marine Research (AWI), D
Jakob Schwander, University of Bern, CH
Bill Mason, Ice Core Drilling Services (ICDS), University of Wisconsin, USA
Laurent Augustin, Laboratoire de Glaciologie et Géophysique de l'Environnement (LGGE), F
Nobuhiko Azuma, Nagaoka University, J
Steffen Bo Hansen, University of Copenhagen DK
Joan Fitzpatrick, United States Geological Survey, USA
Pavel G. Talalay, St. Peterburg State Mining Institute 2, 21 Line, St. Petersburg 199026, Russia