Workshop Advances Interdisciplinary Polar Science and Fast Ice Sheet Drilling

Over the last 50 years, the polar ice sheets covering Antarctica and Greenland have become natural scientific laboratories. Thanks to their unique environments, they yield discoveries that advance different geophysical disciplines and capture the imagination of the general public. The scientific community interested in sampling polar ice sheets and their substrata has been growing recently, and now incorporates biologists, geologists, geophysicists, glaciologists, and paleo-climatologists. This multidisciplinary interest is opening new research frontiers. Significantly advancing our scientific understanding along many of these frontiers will require targeted sampling strategies and the acquisition of data from arrays of deep access holes on spatial scales ranging from local to continent-wide.

With this challenge in mind, more than 50 polar researchers and drilling engineers convened at a workshop to discuss scientific opportunities and technological challenges of fast-access ice sheet drilling. The overarching goal of the workshop was to begin the process of matching specific drilling and sampling technologies to broad objectives of interdisciplinary polar sciences. For convenience, the planned technological platform has been dubbed FASTDRILL. All scientific disciplines represented at the workshop identified several top-level questions that can be addressed with aid of the FASTDRILL platform. Biologists are interested in investigating life in icy environments as a potential analog for extraterrestrial life, and to better understand the origin and evolution of life on our planet. Interactions between tectonic processes and ice-sheet evolution are of primary importance to geologists and geophysicists.

The glaciological community is very interested in the stability of modern ice sheets and in extending the ice core record of paleo-climate further back in time. Specific future applications of a FASTDRILL system may include: sampling of sub-glacial sediments and bedrock, direct investigation of ice sliding, geothermal heat flow measurements, access to sub-glacial lakes, detection of life in deep ice through sampling and borehole logging, site selection for deep ice cores, logging climate proxies with geophysical instruments, borehole paleo-thermometry, and ice rheology studies.

The multidisciplinary FASTDRILL workshop provided an opportunity to recognize the high degree of commonality in scientific objectives and targets across the different disciplines represented at the workshop. For instance, biologists, geologists, and glaciologists have a common interest in sub-glacial hydrology. Extremophiles, an emerging target of biological investigations, may preferentially concentrate in sub-glacial lakes and water-filled channels.

Availability of sub-glacial water controls the rate of ice motion and its changes. At the same time, spatial distribution of sub-glacial water production is largely determined by geothermal heat flux, a quantity of primary importance in interpretations of sub-glacial geology. Hence, borehole surveys of regional- or continental-scale variability in geothermal heat flux and sub-glacial hydrology would provide key observational constraints on top-level scientific questions posed by several different disciplines.

Another excellent example of a multidisciplinary FASTDRILL target of great importance would be the search for old ice (~1 m.y.?). Discovery of such old ice would have obvious significance for ice-core paleo-climatology. It would also provide biologic material for investigating long-term microbial survivability in ice. Specific geographic locations that were frequently mentioned as possible targets of multidisciplinary fast-access drilling included the West Antarctic Ice Sheet, Lake Vostok, the Gamburtsev Mountains, and putative sub-glacial volcanoes in West Antarctica and Greenland. Workshop participants put considerable effort into defining the technological parameters of a FASTDRILL that would satisfy the discussed scientific goals. Such a drill would have to be easily deployable, fast, and mobile, so that several deep boreholes (1–4 km) could be accomplished within one season along a transect with a length of up to hundreds of kilometers. This implies portability of drilling and sampling equipment on a transport plane (LC-130) and on sleds. Rapid recovery of short, ~10 m cores of ice, sub-glacial sediment, and bedrock, as well as acquisition of sub-glacial water samples, must be possible.

Also of great importance is the ability to perform geophysical borehole logging and to install long-term geophysical observatories—for example, seismometers— in ice and beneath ice, <10 m beneath the ice base. Borehole diameters can be narrow for some applications, such as borehole logging, but they should be as large as possible for core recovery and deployment of remotely operated vehicles in sub-glacial water bodies. Many participants expressed interest in having directional drilling capabilities with a horizontal reach of up to a few kilometers. This would permit acquisition of multiple samples or cores along a horizontal transect without having to drill multiple deep access holes. In addition, some important targets—for example, shear margins of fast ice streams—cannot be accessed with strictly vertical boreholes because of the high density of surface crevasses. Directional drilling may provide a solution to this problem. All of the drilling and sampling equipment should be engineered to work at low temperatures (down to –50°C).

Safety and environmental concerns related to fast ice sheet drilling figured prominently in workshop discussions focused on technology issues. Whenever heavy and complicated drill rigs are deployed, there is the danger of physical injury. Researchers accessing sub-glacial sedimentary basins could encounter pressurized natural gas. In addition, drilling into large sub-glacial lakes may trigger depressurization and catastrophic degassing of water. Finally, sub-glacial environments are pristine and fragile, and the top priority should be to avoid contaminating them with drilling fluids.

Fortunately, in many of the proposed applications of ice sheet drilling, clean hot water would be the drilling fluid of choice. Only in a few specific cases, more traditional drilling fluids must be used, such as butyl acetate for optical borehole logging. The preferred strategy, then, would be to pump the fluid out of the borehole and replace it with water before abandoning the site. Drilling engineers from academia and industry provided crucial feedback on the availability and known capabilities of relevant drilling and sampling/coring technologies.

Three main alternatives for drilling were considered: hot-water ice drilling, wire-line rotary drilling, and coiled-tube drilling (CTD). Hot-water ice drills are used widely for making shallow, <1 km access holes in polar ice sheets. Fast thermal energy loss from an uncased borehole increases rapidly the fuel requirements when holes are deeper than ~1 km. Wire-line rotary drill rigs are heavy and best suited for acquiring continuous core records during long-term occupation of a single site.

CTD technology appears to offer the best match to the key requirements of fast drilling capabilities and mobility in the field. It also provides directional drilling capabilities, real-time borehole telemetry during drilling, and a closed borehole fluid system. The latter is important in minimizing the environmental impact of drilling. CTD rigs can use hot water to drill, replicating the ease of use and environmentally friendly nature of hot-water ice drills. At the same time, they offer the option of employing other drilling fluids when completing deep boreholes or in specialized applications.

Although CTD has been used commercially in cold environments, its suitability for conditions that will be encountered in FASTDRILL applications needs to be further investigated. One of the primary outcomes of the FASTDRILL workshop is a plan for further feasibility studies to be conducted jointly by a group of polar scientists and drilling engineers. The paramount goal is to outline the process, which will yield a detailed definition of needs for FASTDRILL hardware, as well as for related logistical and human resources. The desired FASTDRILL platform must meet high expectations in terms of mobility and flexibility, and must be capable of further development to meet future needs.

These are significant challenges. However, these challenges are matched by the high level of scientific interest in acquiring the capability for fast and mobile ice sheet drilling and sampling. The scientific payout of such investment will last for decades and will do much to advance the polar sciences and geophysics in general.

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