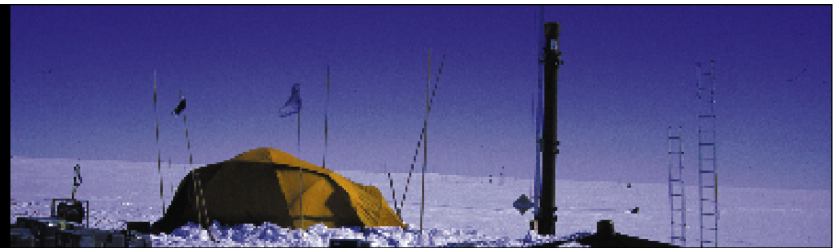


A Fast Low-Cost Mechanical "Access" Drill for Polar Glaciology

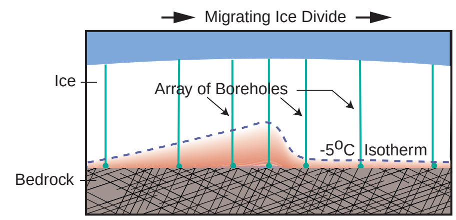
Background: NSF's Polar Glaciology Program currently has two types of deep drills available, ice-coring drills and hot-water drills. These drills are excellent tools for ice-coring projects and for projects that seek to investigate conditions at the bed of ice-sheets. A third type of drill which exists only as a design concept, would significantly benefit a number of scientific projects. The benefits would be immense for projects that do not require ice core and/or require low thermal disturbance (e.g. high-precision temperature measurements, determining horizontal ice-velocity profiles, . . .). Such a drill could be sled- or vehicle-mounted for easy operation. Without the need to periodically bring the drilling head to the surface, a mechanical system could drill 1000-m per day. Due to the reduced logistical requirements, an access drill based on mechanical drilling technology would be much cheaper to operate than an ice-coring drill. With greatly reduced fuel requirements, we believe it would also be cheaper to operate than a hot-water drill.

Drills	Strengths	Drawbacks
Ice Core	• maximizes recovery of large volumes of high quality ice • leaves a semi-permanent access hole • uniform hole diameter	• slow • expensive • holes too large for some experiments • holes thermally disturbed
Hot Water	• quick, "one-time only" access (e.g. to ice/bed interface) for emplacement of instruments that must be frozen in place	• can't recover sensors for calibration checks or redeployment • no repeated logs (temperature, tilt) • variable hole diameter • large thermal disturbance
Mechanical Access	• fast, light • low cost • low fuel requirements • leaves a semi-permanent access hole • sensors can be repositioned within hole or recovered for periodic recalibration • uniform hole diameter • little thermal disturbance	• firn layer must be cased

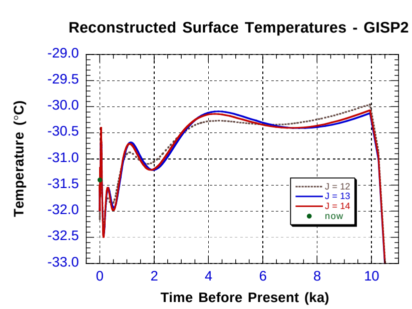
Drill Description: The mechanical "access" drill is similar to a drill commonly used by the mining industry; nearly all the parts are "off-the-shelf" items. The drill basically consists of a pump, hose, and downhole hydraulic motor. A non-freezing (environmentally safe) drilling fluid is pumped down the hose to power the motor. The ice chips are then returned to the surface via the annulus surrounding the hose with the return flow of the drilling fluid. Various cutting heads can be attached to the motor, including cutters optimized for ice or rock. Given the dimensions of off-the-shelf downhole motors, the minimum hole diameter appears to be about 7.5 cm (3 in). Larger diameter holes can be drilled by attaching a larger diameter cutting head; holes much larger than 7.5 cm would also require a larger pump and hose.

Mechanical Access Drill

- **"Long-term" Access to Great Depths Within an Ice-Sheet (or to ice/bed interface):**
  - Would allow multi-year experiments (e.g. horizontal strain, seismic, thermal, ...).
  - Instrumentation could be retrieved for reconfiguration or periodic recalibration.
- **Ice-Divide Migration:**
  - Ice divides are favorite targets for deep ice-coring projects. However, ice divides can migrate with time. Temperature measurements made in an array of holes can be used to constrain the ice dynamics history in the vicinity of a proposed ice-coring site. For example, a moving ice divide leaves a trail of relatively warm ice at depth along its path. An understanding of the dynamic history of an ice divide would be useful for ice-core site selection and for interpreting existing ice cores. [ice-core site selection; ice dynamics]

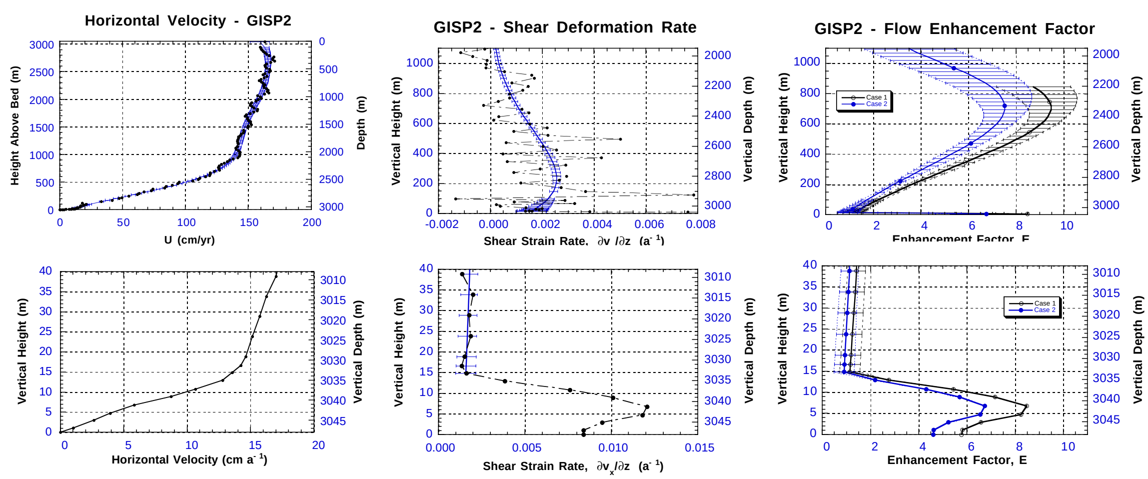


- **Borehole Paleothermometry:**
  - Temperature measurements from deep access holes can be used to reconstruct past climatic changes using "borehole paleothermometry". At present, the temperature measurements are acquired in large-diameter holes created by deep ice-coring drills. Although this works, it is not ideal due to the thermal disturbance caused by ice coring operations and the fluid convection that occurs in large-diameter holes. To circumvent these problems, temperature measurements presently need to be made over a 3-year period, beginning one year after hole completion. In contrast, temperature measurements made in a small-diameter access hole drilled adjacent to deep ice-core hole could be made during a single field season and would be of higher quality. In addition, the borehole temperature data needed to calibrate the δ^{18}O paleothermometer for the ice core could be available by the time the ice core is completed, instead of four years later. [paleoclimate reconstruction, calibration of δ^{18}O paleothermometer]



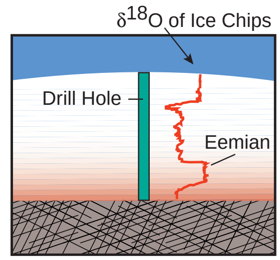
- **Geothermal Heat Flow:**
  - There are only a few geothermal heat flow measurements in Antarctica and nearly all these are restricted to the McMurdo Dry Valleys. Geothermal heat flow measurements are important for forecasting the stability of the West Antarctic Ice Sheet and for understanding the recency of tectonic activity, particularly in West Antarctica. The availability of a fast mechanical access drill would allow geothermal heat flow measurements to be made at an array of sites across Antarctica. [forecasting the stability of the WAIS, tectonics]

- **Borehole "Tilt" Experiments:**
  - Precise measurements of the changing geometry (inclination, azimuth) of a borehole over several years can be used to determine the horizontal velocity profile above the bed in an ice sheet. This provides an important constraint for regional ice dynamics models. Analysis of the horizontal velocities also yields information about: a) shear-strain rates, b) and how soft the ice is to shear deformation with height above the bed. Borehole tilt experiments require a relatively uniform access hole that remains open for several years. [ice dynamics, ice rheology]



- **Ice Fabric Anisotropy:**
  - Sonic logs made in access holes can be used to determine how the alignment of ice crystal c-axes change with depth at a given site. This information can be used to improve ice dynamics models; vertical c-axis clustering inhibits vertical strain and enhances bed-parallel flow. Sonic logs require straight uniform boreholes such as those provided by a mechanical access drill. [ice rheology, ice dynamics]

- **δ^{18}O of Ice Chips:**
  - δ^{18}O could be measured on the ice chips pumped out of a mechanically drilled access hole, providing a low-resolution (in time) climate record at a drill site. δ^{18}O measurements from an array of access holes could prove useful in delineating the boundaries between climatic zones in Antarctica and how they may have changed with time (e.g. At present, there is a persistent incursion of warm air masses into West Antarctica from the Amundsen Sea. Did this pattern persist at the LGM despite a different ice sheet configuration, different ocean circulation, etc. ?). It could also prove useful in determining if a specific target (e.g. the Eemian) is sufficiently far off the bed to warrant drilling a deep ice core. [climatic zones, ice-core site selection]



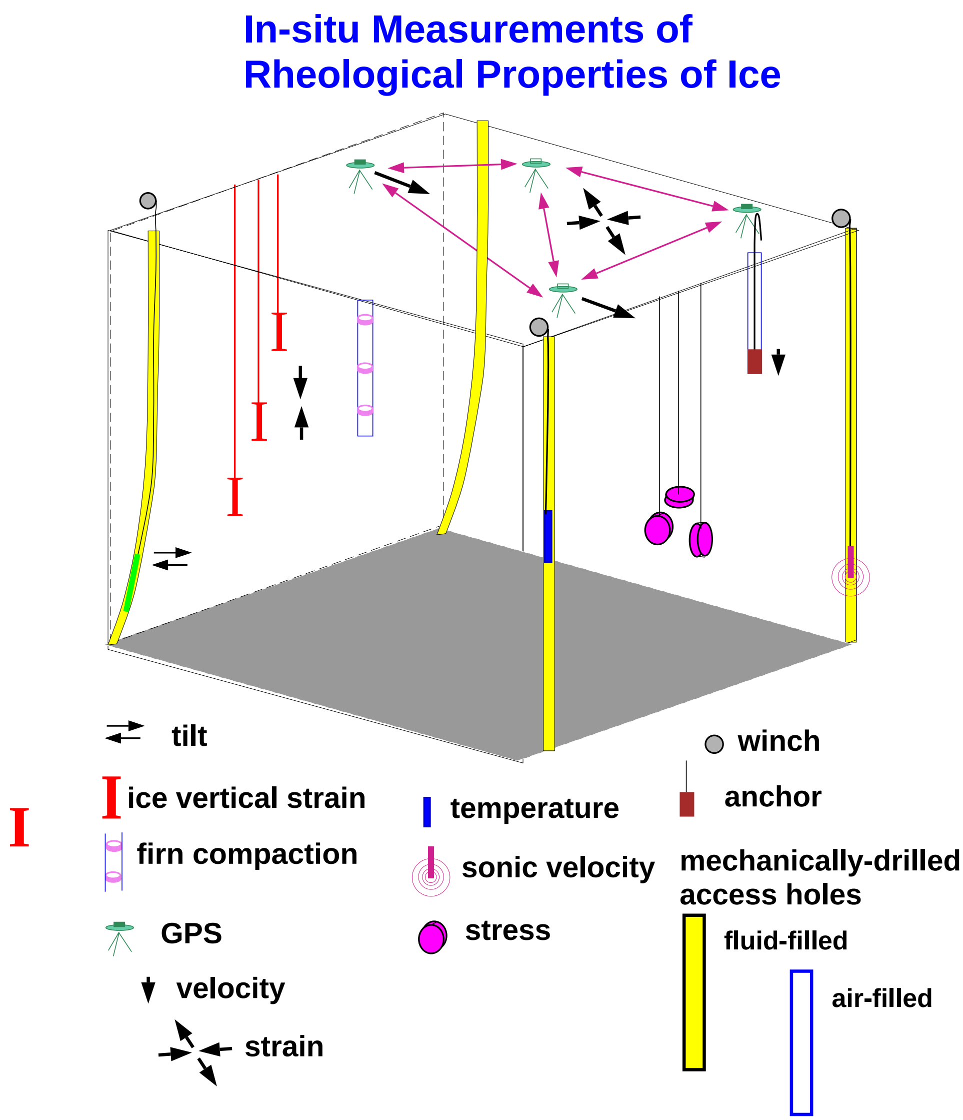
- **In-Situ Ice Rheology Experiments:**
  - For some research activities (e.g. interpretation of ice cores), very detailed knowledge of ice flow is essential. Practically, this can be accomplished only with flow models. The most reliable results are obtained when some or all of the relevant rheological parameters can be determined from stress, strain rate, temperature, and crystal fabric measurements at a specific site. The rheology experiments would include some or all of the following: GPS measurements on the surface (horizontal strain-rates on the surface), repeat measurements of band locations in shallow air-filled holes (vertical strain rates in the firn layer), vertical strain sensors frozen into the ice, 3-axis stress sensors frozen into the ice, borehole "tilt" experiments (horizontal strain rates, strength for shear stresses), temperature logs, sonic logs (anisotropy). While some instruments require hot-water drilled holes for permanent emplacement, other experiments such as temperature, tilt, firn vertical strain, and fabric (sonic) logging need uniform holes with semi-permanent access.

For more information, contact:

Gary Clow, USGS/Global Change & Climate History Program, 303-236-5509, clow@usgs.gov

Ed Waddington, Univ. of Washington/Geophysics Program, 206-543-4585, edw@geophys.washington.edu

(23 March, 1998)


In-situ Measurements of
Rheological Properties of Ice
tilt
winch
ice vertical strain
temperature
anchor
firn compaction
sonic velocity
mechanically-drilled
access holes
GPS
stress
fluid-filled
velocity
air-filled
strain