Drilling glacial deposits in offshore polar regions

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Abstract

High latitudes are of fundamental importance in the Earth's climate system—they house ice sheets that govern global sea level heights, influence how much solar energy is reflected back to space, and create deep and bottom waters that drive the ocean's ability to circulate energy and nutrients across the globe.

Not surprisingly, understanding future climate change requires knowledge of how past rapid climate changes influenced high latitudes. Under what conditions did ice streams advance and retreat? Did deep and bottom water formation ever slow down or stop and why? What was the precise timing of these changes, and how rapidly are the interacting components in the polar system responding?

To help answer these questions, scientists seek to drill into the seafloor within high latitudes. The depositional succession in sediment cores recovered may be able to tell the story of how high latitudes evolved through past climate changes—knowledge that could help us anticipate how the high latitudes will respond to or push future climate changes.

However, ocean drilling in high latitudes is no easy task. The physical characteristics of glacial tills and related marine deposits, with a highly consolidated cohesive matrix, hinder successful sediment coring because the sticky, clayey material of these deposits clogs the rotating drilling mechanisms. To overcome this challenge, scientists are investigating how drilling systems can be tailored for use on the high- latitude seafloor. One, developed by Germany's MARUM—Center for Marine Environmental Sciences, is a specialized drill rig. Nicknamed MeBo, from Meeresboden- Bohrgerät (German for "seafloor drill rig"), the device can drill into soft sediments, hard rocks, and a combination of the two. Most important, it is portable, meaning that it can be deployed from scientific research vessels, reducing the need for specialized and expensive drilling vessels.

MeBo was recently used on the CORIBAR expedition, which took place on the R/V Maria S. Merian. In 2013, the device drilled two boreholes, each longer than 35 meters, through tills and

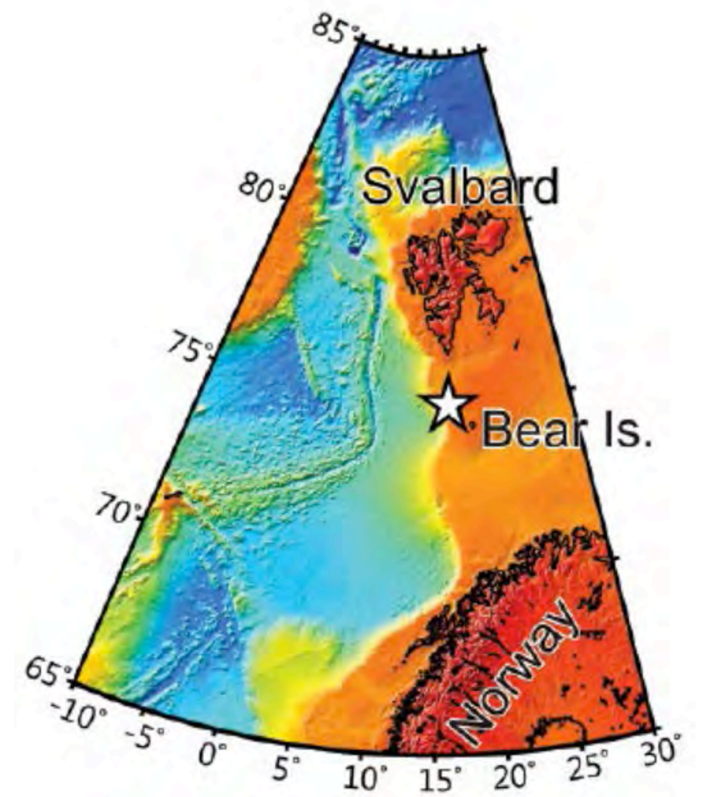

Figure 1: *Location of the Kveithola Trough in the Norwegian Sea (star).*

glacigenic deposits in the Kveithola Trough of the western Barents Sea, south of Svalbard (Figure 1). The project showed that obtaining marine sediment cores and borehole logs from glacial deposits remains technologically challenging. Nevertheless, this first- ever deployment of MeBo in the Arctic region has given scientists a basic idea of the climaterelated glacial history of the region.
The Kveithola system consists of an eastwest trending, 100- kilometer- long, 12-kilometerwide, 300- meter- deep glacial trough. Inside the trough, the advance of an ice stream sometime in the past produced large parallel lineations that are overlain by a series of convex ridge-like depositional structures perpendicular to the trough's axis.
These structures are interpreted to be grounding zone wedges (GZWs), formed by subglacial sediment supply at the front of the ice stream—somewhat similar to a terminal moraine—during times when ice stream advance or retreat temporarily halted. Existence, dynamics, and timing of GZW emplacement after the Last Glacial Maximum reflect an episodic retreat of the ice stream interrupted by periods of no motion. GZWs are believed to be key morphological elements responsible for stabilizing and counteracting the collapse of ground-based ice streams on continental shelves when sea level rises.
MeBo's task was to core these GZWs as well as a succession of unsorted glacially derived sediments that were dumped over the continental shelf's edge by the ice stream that formed the lineations. Coring these features should reveal the dynamics of the local ice stream's sensitive responses to past rapid regional climatic changes.
To use MeBo, researchers must lower the 10-ton drilling rig to the seabed with a special umbilical. This cable also facilitates remote control of the rig. On board MeBo, standard core barrels and drill

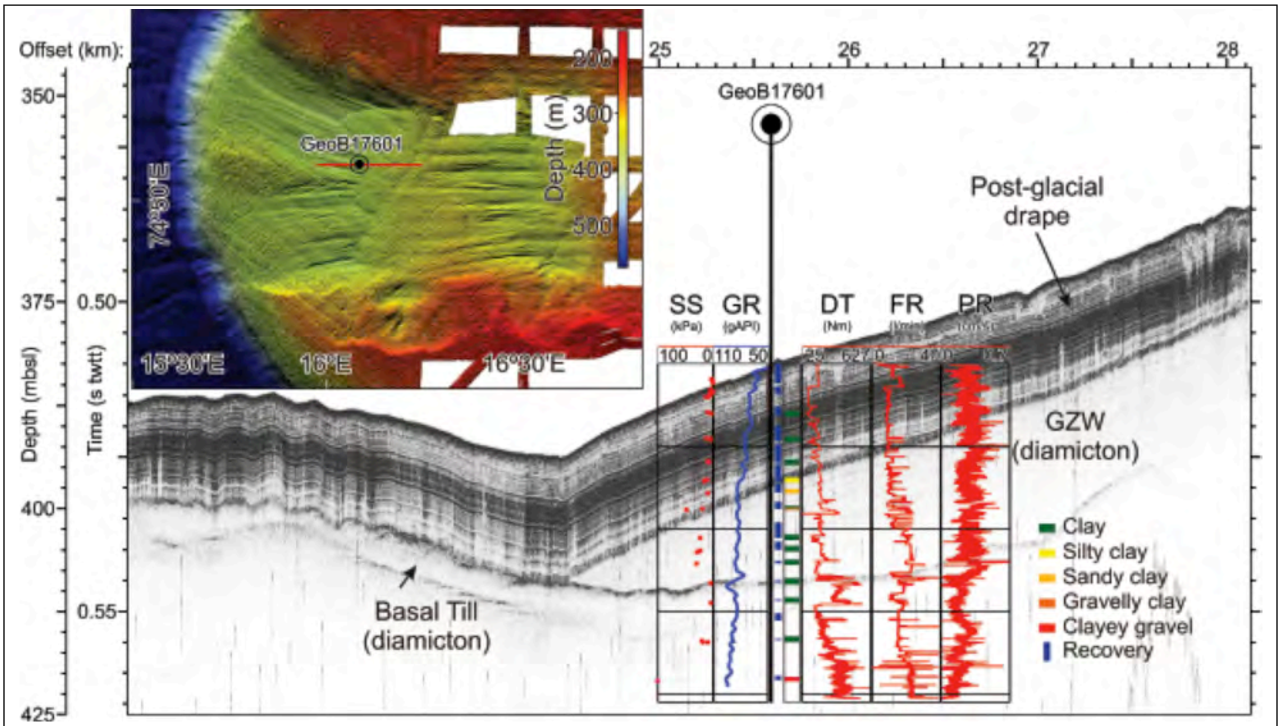

Figure 2: *Subbottom echosounder (Parasound) profile (red line in multibeam map inset shows location) across a grounding zone wedge inside the Kveithola Trough from MeBo Site GeoB17601 (black dot). Superimposed on the subbottom profile are logs of shear strength (SS, measured in kilopascal (kPa), from pocket penetrometer measurements), natural gamma ray (GR, measured in gamma ray American Petroleum Industry (gAPI) units), sediment recovery (blue dots), and lithology from barrel core catchers (see legend). Also included are logs of physical drilling parameters: drill head torque (DT, measured in newton meters (Nm)), flush rate (FR, measured in liters per minute (l/min)), and penetration rate (PR, measured in centimeters per second (cm/s)). Logs and lithological information are converted to time using a 1500-meter-per-second sound speed velocity (s twtt is two-way travel time in seconds; mbsl is meters below sea level; horizontal scale is in kilometers (km). The vertical scale is the same for the Parasound profile and the logs.*

rods for drilling down to 70 meters below seafloor are stored on two magazines. An autonomous spectral gammaray probe serves for borehole logging.
Through CORIBAR, MeBo drilled at five sites: three sites inside the Kveithola Trough, to drill through the GZWs, and two sites on the associated trough mouth fan on the continental slope in front of the Kveithola Trough's opening, to recover landslide deposits.
At Site GeoB17601, MeBo cored through 41 meters, comprising a 15-meter- thick glacimarine sediment drape, 15 meters of GZW sediments, and 11 meters of underlying basal tills (Figure 2). Borehole gamma- ray logging highlighted major lithological changes, particularly evident at the contact between GZW and underlying deformation till. Along the upper clay-rich succession (i.e., the glacimarine sediment drape and the GZW), major changes in gamma- ray data likely relate to sediment consolidation resulting from the loading (or lack thereof) by the ice stream.
The shear strength (measured with a pocket penetrometer at the base of the recovered sections) was relatively low in the overlying glacimarine sediment drape (<12 kilopascals) and increased suddenly within the GZW. Below the GZW, a pebbly diamicton with stiff clayey matrix had shear strengths up to 100 kilopascals, likely indicative of basal deformation tills.
As expected, these stiff glacigenic deposits were a challenge for drilling and core recovery. Average recovery rates were 72% for glacimarine sediment drape and 23% for the drilled diamicton (GZW 43%; basal till 9%).
Valuable experience was gained for MeBo drilling during the CORIBAR expedition. Project scientists were able to test different types of drill bits, core catchers, and controlling drill parameters. Core catcher strength proved to be critical in recovering sections of the soft young sediment drape.
Also important was the rate at which drilling materials were flushed with water while coring. Typically, the system was flushed with about 10–15 liters of water per minute with the rotating drill applying less than 200 newton meters of torque. This allowed for penetration rates around 0.25 centimeter per second for soft deposits. However, the deeper glacigenic diamictons and slope deposits—bound with a cohesive plastic, very sticky, clayey matrix— hampered drilling string rotation.
A flushing rate decrease from 22–23 to less than 20 liters per minute resulted in increased core recovery from 31% to 55% within the GZW, indicating that flush water critically determines recovery in glacial deposits. Especially challenging were basal tills, as indicated by high torque values of more than 350 newton meters despite increasing flushing rates to 25 liters per minute. Glacigenic landslides on the continental slope were as sticky and had similar consistency as GZWs inside the trough. Project scientists allowed torque up to 600 newton meters by keeping the flush water rate below 25 liters per minute and reached recovery rates of 80%.
MeBo's core recovery for the diamictons that form the basal till is comparable to previous Ocean Drilling Program (ODP) expeditions at high latitudes but significantly higher for the firm to stiff GZW sediments. Average recovery in ODP drilling in Antarctica was 10.1% (subglacial till in Leg 178 shelf transect sites) and 7.9% (subglacial and proximal diamicton in Leg 188, Site 1166). Integrated ODP (IODP) Expedition 341 had a recovery rate of 24% for diamictons deposited from suspension settling, gravity flows, and ice rafting (Site U1421). With the technology used in the Shallow Drilling (SHALDRILL) project, which deployed drill/push coring from a special diamond coring rig, recovery was 40% for an 80-centimeter- thick diamicton on the second leg of the cruise (2006) but 0% in preceding attempts during the first leg in 2005. Only the Antarctic Drilling (ANDRILL) project, deploying full drill hole cementation and circulation muds, achieved a recovery of 98%.

References

Hanebuth, T.J.J., Rebesco, M., Urgeles, R., Lucchi, R.G., Freudenthal, T., 2014. Drilling glacial deposits in offshore polar regions. Eos 95 (31), 277-278.