A pilot project for shallow drilling in the Arctic

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Abstract

Further advances in unravelling the paleoceanographic history of the polar basin depend on geological sampling beyond the capability of the conventional gravity and piston coring techniques. Given the demonstrated positioning capabilities of Oden in heavy sea ice, we made an attempt at shallow drilling on the Lomonosov Ridge. A riser was successfully set in 962 m water depth, but deployment of the drill string was impeded at 250 m depth and the attempt had to be aborted. A total of 5.5 days were spent on the drilling operation.

The aim of the project

O. B. Bøggild, who was entrusted with examination of the first four sediment samples ever recovered from the deep Arctic Ocean basin during Nansen's drift with Fram, published his results "in the hope that a tolerably clear idea thereby be obtained of the lithology of the bottom of the North Polar Sea". One hundred years later, after more than 600 sediment cores, mostly 2–5 m long, have been recovered and analyzed, we are still totally missing a stratigraphic representation of a 40 million year interval in the Cenozoic which holds the clue to the paleoceanographic response of the Arctic Ocean to Cenozoic global cooling.

A breakthrough in Arctic Ocean geoscientific exploration was made in 1991 by the Swedish icebreaker Oden and the German research vessel Polarstern. Multichannel seismic data of good quality were acquired by R/V Polarstern from the North Pole to Svalbard, including two transects across the Lomonosov Ridge. The lines across the ridge demonstrated that a 500 m thick section of flat-lying sediments (v= 1.5–2.2 km/s) on top of the ridge were unconformably overlying older strata (v>4 km/s). The upper section, which is considered to represent late Eocene and younger rocks, was cut by erosion at the ridge perimeter and presented potential targets for an offset shallow geological sampling approach.

Target oriented sampling on the sea floor requires position-keeping capabilities, and Oden demonstrated that it could hold position to within 50 m in 2.5 m thick sea ice drifting at several hundred m per hour.

These accomplishments provided the basis for definition of a geological sampling programme with a spectrum of tools ranging from a pilot attempt at shallow diamond drilling to the use of a piston corer and a hydrostatic corer.

A concept for shallow diamond drilling

A vessel in the ice-covered Arctic Ocean will experience no heave motion except for motion related to the breaking of ice in order to hold its position. This fact prompted the concept of using a small land exploration wire line rig for shallow diamond drilling on the sea floor, in a cooperative project between the University of Bergen and Geo Drilling A/S, Namsos. The drill string is guided by a tensioned riser anchored by a bottom frame. Variation in the tension of the riser and of the drill string related to the ships lateral deviation from the initial location is compensated by separate tension controlled winches.

In preparation for the Arctic Ocean challenge, two full scale drilling tests were carried out in 1995 and successful drilling was achieved on the continental shelf in Antarctica in 212 meter water depth during the Nordic Antarctic Research Expedition in February 1996.

The work onboard

The shallowest known area of the ridge (842 m depth) was the first alternative target for a drilling location, and the search for a drilling location started as the ship turned on a course nearly perpendicular to the ridge at 86°21'N (0800 hours on 4 August, 1996) during seismic reflection profiling. After intervening station work for other programs, the profile was terminated on the upper slope of the Lomonosov Ridge facing the Makarov Basin. A subsequent 12 hour high resolution seismic survey with chirp sonar (2–6 kHz) showed an irregular bottom topography with chaotic sub-bottom reflectors except in a small area where layering was conformable. It was felt that more advantagous geological conditions would be present 80 nautical miles (n.m.) farther north at the end of seismic line 91090 (87°39′N, 145°E), which was the original proposed target for an attempt at shallow drilling.

The transit north was made and a four hour chirp sonar survey was initiated in water depths around 1070 m at the edge of the plateau. Sub-bottom layers were planar and regular, but the increase in water depth was not considered comfortable for a first attempt at deployment of the drilling equipment. The vessel returned south and we located an area of 6 n.m.x3 n.m. centered at 87°08′N in water depths 9609–80 m deemed acceptable for drilling. A sub-bottom unit of 8–12 m thickness was conformably draping underlying acoustically stratified, planar units in the southern part of the area, but unconformably in the northern part of the area. The peak-to-peak amplitude of sea floor undulations was up to 3 m.

To assess geological conditions in the drilling area, we acquired a total of 26.5 km of high resolution chirp sonar seismic data and two piston cores with 7.8 m and 4.7 m recovery, respectively.

A first positioning test was made in open water on 8 August at 20:30 hours. Wind speeds were 8–10 m/s. The vessel kept well within 50 m from an arbitrary location, but drifted off 100–150 m after midnight and the test was terminated.

The second test was started on 13 August at 18:10 hours at the designated drilling location in 8–9/10 of ice cover. The wind was 5–7 m/s from the north. The ice thickness was around 2.5 m and floe sizes 500–1000 m across. Initially the vessel deviated to 100 m off location, but later maintained position well within 50 m. At 23:00 hours, the vessel again drifted more than 100 m off location and the test was declared ended.

It was clear that Oden had the capacity to maintain position under the current environmental conditions, but the demanding task in hand required in-depth knowledge of vessel response.

Our concern to protect the relatively fragile drill string from the large forces created by blocks of sea ice prompted construction of a well extending from deck level through the hull on the starboard side next to the forward end of the superstructure. Inside the well was a heavy duty pipe 60 cm in diameter which could be lowered to project 2.5 m below the hull.

To get a feeling for how frequently blocks of ice choked off the moon pool entrance below the hull, we suspended a weight at the end of a riser pipe through the well several meters below the hull while the vessel was breaking heavy ice. After a short while the wire and riser pipe were severed by ice and the weight lost.

During the second positioning test, the extension pipe was lowered and a section of the riser suspended about 4 m below the entrance to the extended moon pool. Sharp kicks were heard several times while the vessel was breaking ice to maintain position, and at one point the extension pipe jerked 5 cm up from its seat. However, subsequent inspection did not reveal any visible damage to the pipe.

The drilling operation

Deployment of the 3.5 ton bottom frame through the moon pool started 14 August at 15:00 hours. The upper half of the 2 m high cylindrical frame folded out to become a 4 m diameter four-legged structure as the frame exited below the moon pool. The bottom frame was suspended by a 14 mm wire and the riser pipes, 9 m in length were clamped to the wire. At 21:00 hours, about 500 m of riser was in the water. At 567 m one of the clamps hooked itself onto the upper edge on the extension pipe in the moon pool and the riser above the waterline became displaced relative to the wire. We then attempted partial recovery of the riser, but the wire angle was unfavourable and the riser clamps hooked themselves against the lower edge of the extension pipe. Disjointed sections of riser pipe were observed along the side of the vessel, and the situation had to be remedied with the assistance of divers. Eventually, the whole riser had to be recovered after 24 hours of work.

Before a second attempt at deployment of the riser, a compensation test was successfully carried out by lowering the bottom frame to rest on the sea floor at 960 m water depth in the early morning of 16 August and the gear recovered. Subsequently, deployment of the riser started at 06:00 hours. Three hours later, 396 m of riser were out when we again observed a relative displacement between the riser and the supporting wire. A discontinuity in the riser was detected at 18 m below the drill floor, and the riser was recovered to remedy this break. At 15:30 hours, the vessel started breaking ice to maintain position. Other possible riser discontinuities had been detected and recovery continued. At 19:45 hours, the main wire suddenly broke at the lower exit of the extension pipe for ice protection. The bottom frame and more than 300 m of riser were lost. The event was diagnosed as related to interference with an ice floe.

A new bottom frame was fabricated and loaded with 2 tons of lead. On 19 August at 02:00 hours it was lowered to the sea floor in 970 m water depth to tension up the wire and subsequently hoisted back into the moon pool.

The third attempt at riser deployment started the same day at 06:45 hours while the vessel was drifting with the pack ice. Distinct reflections from top of the bottom frame and from the sea bed showed the riser to be 18 m off the bottom at 17:30 hours. The vessel and the suspended riser were drifting about 0.5 knots with heading 207 degrees at 87°09.46′N, 146°21.19′E. Position-keeping started at 18:23 hours; the riser successfully landed on the sea bed and was under tension by 19:08 hours.

To check the condition of the riser, we lowered a three meter long gravity corer with two additional weight sections (120 kilo) into the riser, but met an obstruction in the riser at 814 m below the drill floor and subsequently retrieved the corer. A shorter probe in the riser successfully reached the sea bed and returned covered with mud.

Work started at 02:45 hours the following day to run the drill string (BWL, 51 mm I.D) into the riser. Two hours later, 250 m of drill string was out when an obstruction was detected. We attempted to lubricate by pumping mud, but the drill string had to be retrieved. As the riser was lifted to the problem area, problems developed due to interference between the riser clamps and the lower edge of the moon pool. The television camera of a remotely operated vehicle was extremely useful in guiding the disconnected and bent riser sections into the moon pool. Also clear indications of wear on the surface of the entrance into the moon pool were observed.

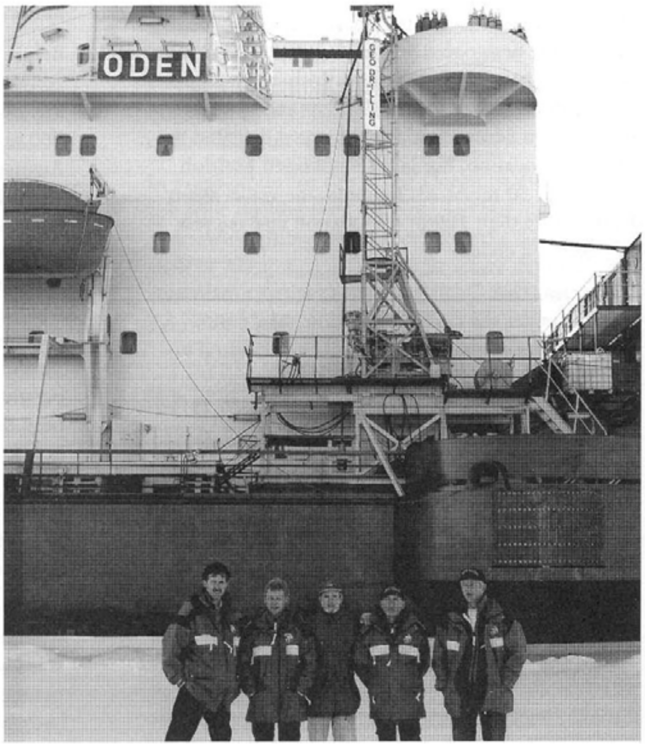
The problem area was cleared and the continuity of the riser rechecked, but a second obstruction was found at 456 m below the drill floor. At this point the riser had to be retrieved completely and all equipment was on deck in the early hours of 21 August.

A final scenario was discussed wherein the bottom frame and the drill string, guided by distributed short sections of riser pipe, would be deployed simultaneously. The chance of success with this approach was considered high by us, but permission was not granted.

A total of 5.5 days had been spent on the drilling operation including the time for the position-keeping tests.

Preliminary results

Clearly, the challenges were many. Several details such as a flared moon pool exit and more stream-lined attachments for clamping the riser, played a major role in the course of events. However, we find good reasons to consider the feasibility of shallow diamond drilling with a single-ship operation under favourable ice conditions to have been demonstrated by this endeavour. The need for a new generation geological sampling technique was demonstrated by the problems encountered in penetrating the youngest sediment drape using piston or hydrostatic corers following the unsuccessful attempt at drilling.



The drill rig mounted on Oden on the starboard side.