Future hot water drilling on Rutford Ice Stream 2004/05

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Introduction

Ice streams are major drainage routes, through which much of the ice in Antarctica flows from the continent. They flow at speeds of up to two orders of magnitude greater that the rest of the ice sheet and are believed to rest on beds of soft, water-saturated sediments. As sliding and sediment deformation processes affect the ice stream dynamics, understanding them is essential to future predictions of ice sheet variations. Rutford Ice Stream provides one such example of a fast flowing glacier constrained by a deep bedrock trough and is one of a number of ice streams that drain the West Antarctic Ice Sheet into the southwestern Ronne Ice Shelf (Figure1). Extensive fieldwork has been conducted on this ice stream over the past 25 years with measurements of strain, velocity and elevation. Also, ice sounding radars and seismic techniques have been used to measure the ice thickness and examine the nature of the bed at several locations [*Doake et al.*, 2001; *Smith*, 1997]. Many of these measurements have been made in an area approximately 40 km upstream of the grounding line. Here, the aim is to access the bed of Rutford Ice Stream at least twice through almost 2200 m of ice using a hot water drill. Ice cores will be retrieved from selected depths using a hot water ice core drill based on the Caltech design [*Engelhardt et al.*, 2000] and samples of basal sediment will also be recovered. The hole will then be instrumented to measure basal sliding, bed and ice column deformation, basal water pressure and ice temperature. In situ optical images of the bed and any sediment within the ice may also be taken.

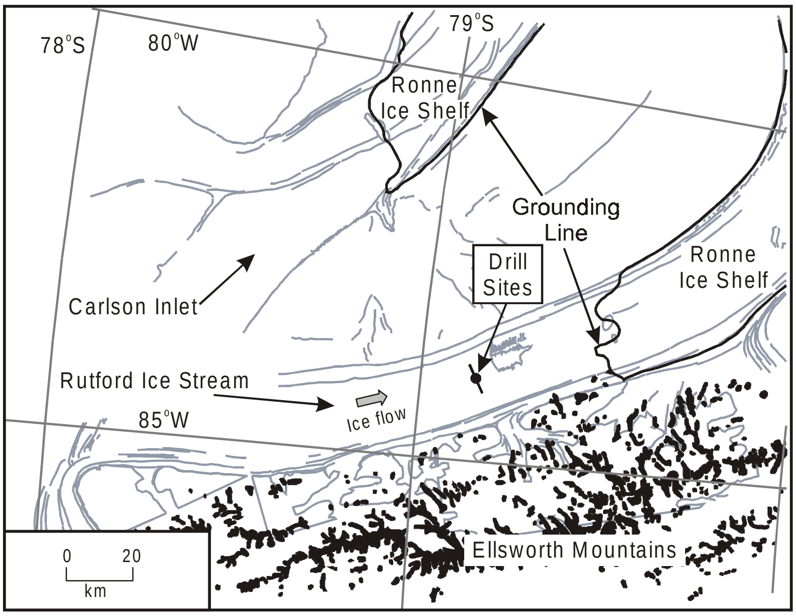

Figure 1. 2004-05 field work area

Hot water drill upgrade

The present hot water drilling system operates at up to 76 l min^{-1} (two pumps), 80°C (eight heaters) and using a ¾″ drilling hose. This system has been used to penetrate ice almost 1000 m thick, creating holes about 0.3 m in diameter. In order to efficiently drill to 2200 m the system requires a significant upgrade. Ideally the hole should be drilled instantly, thus only melting the ice in the hole and not warming the surrounding ice. Clearly this is not possible, therefore it is best to make the hole as fast as is practical (ie high flow rate and water temperature) to achieve the best fuel efficiency, with drilling rates set by the flow rate, water temperature at the drilling nozzle and the size of the required hole. The new system will have roughly double the heating and pumping capacity in order to achieve at least 152 l min^{-1} at 90°C, giving a heat output approaching 1 MW with the option of increasing the flow to 190 l min^{-1}. Adding further heating and pumping capacity to the existing system is relatively easy but it is not possible to deliver such high flow rates down a ¾″ hose and remain within the system pressure rating of 2000 psi. As the flow rate is increased the hose pressure losses increase with the square of the water velocity and Table 1 shows that 1.25″ hose can accommodate the required higher flow rates within the rated pressure.

Hose internal diameter (mm / inch)	Flow rate (l min^{-1})	Water Velocity (m s^{-1})	Hose pressure loss over 2200 m (psi)
25.4 / 1.0	152	5.0	3200
31.75 / 1.25	152	3.2	1050
31.75 / 1.25	190	4.0	1650

Table 1. Drilling hose pressure losses for different flow rates

The large increase in hose diameter gives larger bend radii and the greater depths mean that it is no longer possible to store all the hose on a single drum. Therefore, a large diameter (1.5 m) driven capstan and two storage drums able to hold at least 300 m of hose are required for drilling on Rutford Ice Stream (Figure2).

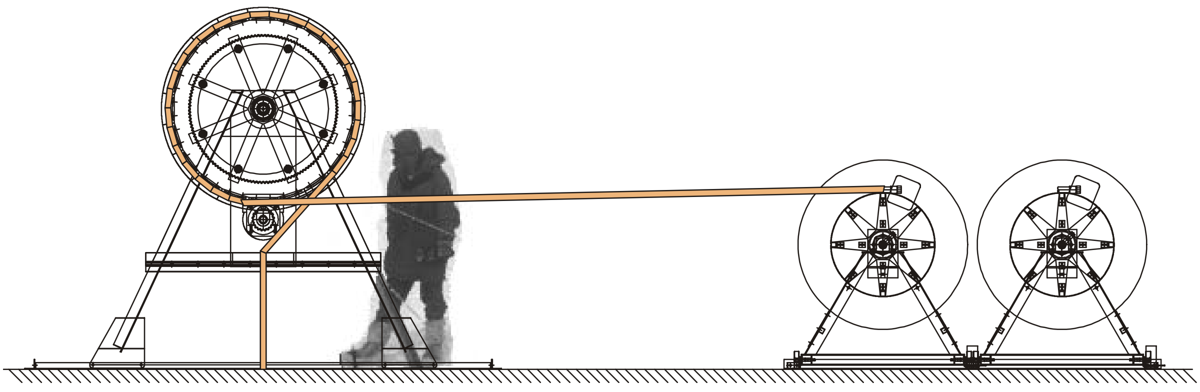

Figure 2 Drawing of the new hot water drill winch to be used with the 1.25" hose. Two hose drums are required to add 200 m lengths of hose during drilling. The large capstan wheel is used to power the hose up and down the hole and all the units are hydraulically powered.

During drilling, 200 m sections of hose will be preheated and added as the drilling progresses. However, a significant problem occurs during the addition of hose lengths. Throughout the drilling process the hose water pressure inflates and shortens the hose, when the pressure is released the hose deflates and lengthens. The danger is that when extra hose is added during drilling, the hose will lengthen and the nozzle could freeze to the base of the hole or restart drilling a none vertical hole. The size of this effect will be determined in forthcoming field tests and the results used to modify the drilling operation.

In order to drill efficiently it is essential to recirculate the water used for drilling. This is achieved by using electrically powered submersible borehole pumps. These pumps return the water from a cavity at a depth of 100 m, to the surface, where it is reheated and used for drilling or reaming the hole [*Makinson*, 1994]. However, 40 km upstream from the Rutford grounding line the elevation is 327 m [*Smith*, 1997], indicating that once a hydraulic connection is made at the base of the ice stream it will not be possible to maintain a water recirculation system. Two effects may raise the water level in the hole. Firstly, if the till and drainage system are similar to the Siple Coast conditions [*Engelhardt and Kamb*, 1997], it may offer a back pressure that can support about 30 m of water. Secondly, the hydraulic connection is ultimately linked to the seawater at the grounding line. This density difference between fresh and salt water may support an additional 49 m of water, suggesting a water level in the range of 248–327 m below surface. The highest possible water level would be around 245 m below the surface if the ice were just at floatation. Table 2 shows the range of submersible pumps available and numbers require to maintain a recirculation system.

Sub-pump power (HP)	Number of pumps required to recover 152 l min^{-1}	Operational depth (m)
2	4	120
3	4	170
11	1	250
11	2	275

Table 2. Submersible borehole pump specifications

The 11 HP submersible pumps appear to meet the recirculation requirements but there are numerous difficulties with such large equipment and the Twin Otter aircraft would unable to transport the generator required to power the pump. The first option is practical and has been used in the past, but there is no opportunity to recirculate water once the hydraulic connection has been made at the bed. Some water is available in two surface reservoirs but pumping at 152 l min^{-1} will empty these in 2.5 hours, at least one hour before the drilling nozzle is recovered to the surface.

As the water filled hole begins to refreeze at a rate of between 0.5–1.0 cm hr^{-1} [*Makinson*, 1994], there is a limited number of hours before the hole becomes unusable. Two idealized options are shown in Figure 3 giving an indication of drill speeds, times as well as the initial hole radius and the radius after a period of hours. In scenario (a), a hole with a diameter of up to 0.5 m is made over 53 hours requiring around 10000 litres of fuel. If a minimum hole diameter of 0.2 m is required to instrument the hole, then about 48 hours is available once drilling has stopped. Likewise in scenario (b), a 0.3 m diameter hole is made in under 20 hours, using 3500 litres of fuel, with the hole available for almost 24 hours. In both cases the times and fuel usage are minimums as no account is made for setting up the water recirculation system, adding extra hose every 200 m or breakdowns.

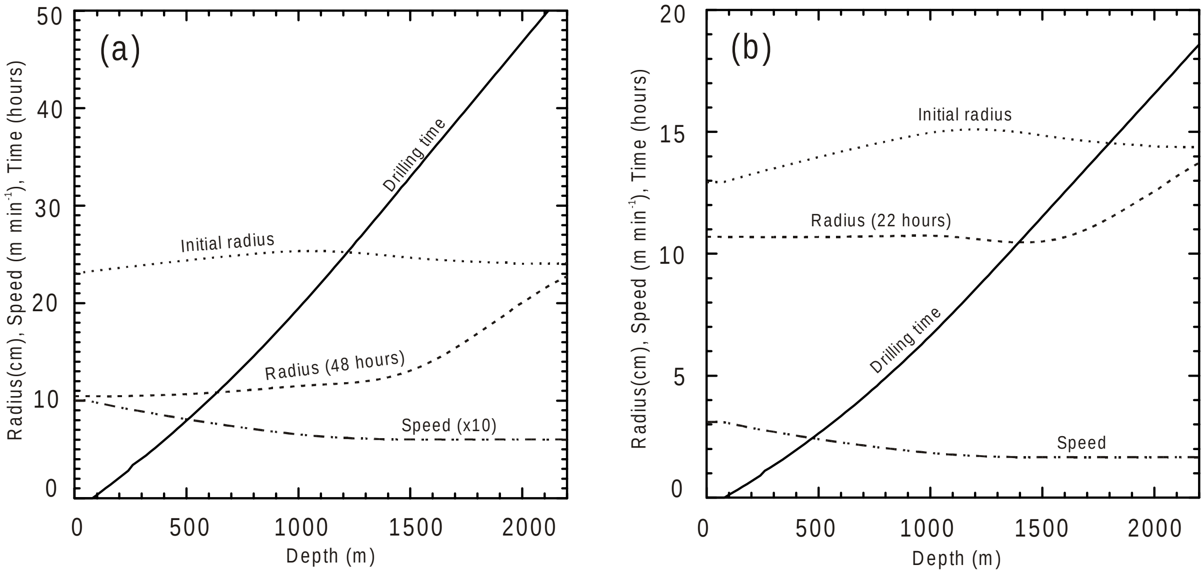

Figure 3 Both plots show the drilling time and drilling speed as well as the initial hole radius and radius after a period of hours once drilling stops. The surface water flow is 152 l min^{-1} at 90^{o}C with the water temperature falling to 52^{o}C at 2200 m. The minimum ice temperature is -27^{o}C.

Instruments and measurements

During the drilling of the two to six holes, ice cores will be recovered from one of the holes at various depths to look at ice rheology and typically where tilt sensors may be placed, around depths with internal seismic reflectors and as close to the bed as possible. Cores of the basal sediments will also be taken to look a rheology, permeability and possible dating. In addition, visual imagery of sediments within the ice and at the bed may also be taken. Once sampling has finished, instrument strings will be deployed. These are likely to include pressure sensors for basal water pressure, tilt sensors and strainmeters for sediment and ice deformation, a tethered stake to measure basal sliding and thermistors to measure temperature. At the surface there will be passive seismic recorders and GPS measurements of the ice motion. The data from these instruments will be recorded locally by a surface data logger and possibly relayed back to the UK via an ARGOS satellite link.

References

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