depth as shallow as 50 meters, but the ultrasonic velocities are significantly higher than the field measurements at all greater depths. The maximum velocity from the refraction shooting, 3,805 ± 10 meters per second, is typical of other refraction shooting on the Ross Ice Shelf (Robertson, 1975; Crary *et al.*, 1962). When corrected to the temperature in the lab van this velocity would be only 3,770 meters per second.

The ultrasonic velocities, on the other hand, although relatively high (mean for 150 to 155 meters is 3,879 ± 13 meters per second) are more in accord with those from other antarctic ultrasonic measurements (Bennett, 1972; Bentley, 1972), refraction shooting on ice sheets (summary in Kohnen, 1974), and laboratory measurements (summary in Roethlisberger, 1972). The low maximum velocities from refraction shooting on ice shelves have long been known (see, for example, Thiel and Ostenso, 1961), but never well explained. The present study, at least so far, only heightens the mystery, since the difference of some 100 meters per second between the maximum velocities measured is too great to be explained in terms of the anisotropy detected by the ultrasonic measurements.

There appear to be some variations in average velocity around a smooth average curve between 65 and 105 meters depth. Whether these variations are real is difficult to say because of the large scatter in the individual velocity measurements. A suggestion of a similar variation appears in the density depth curve (also plotted in figure 3, from Chiang and Langway, personal communication, 1977) but is far too poorly defined for any quantitative discussion.

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References

Bennett, H.F. 1972. Measurements of ultrasonic wave velocities in ice cores from Greenland and Antarctica. *U.S. Army Cold Regions Research and Engineering Laboratory. Research Report*, 237. Hanover, N.H.

Bentley, C.R. 1972. Seismic wave velocities in anisotropic ice: a comparison of measured and calculated values in and around the deep drill hole at Byrd Station, Antarctica. *Journal of Geophysical Research*, 77: 4406-4420.

Carslaw, H.S., and J.C. Jaeger. 1959. *Conduction of Heat in Solids*, 2nd ed. Oxford Univ. Press, London. 510 p.

Chiang, E., and C.C. Langway. 1976. Physical properties of the 100-meter ice core from J-9, Ross Ice Shelf, Antarctica. Paper presented at Symposium of SCAR Specialist Group on Ice Shelf Drilling Projects. Mendoza, Argentina, October 1976.

Crary, A.P., E.S. Robinson, H.F. Bennett, and W.W. Boyd, Jr. 1962. Glaciological studies on the Ross Ice Shelf, Antarctica, 1957-60. *I.G.Y. Glaciological Report No. 6.* American Geographical Society, N.Y.

Gow, A.J. 1963. The inner structure of the Ross Ice Shelf at Little America V, Antarctica, as revealed by deep core drilling. *General Assembly of Berkeley, International Association of Scientific Hydrology. Publication*, 61: 272-284.

Gow, A.J. 1969. On the rates of growth of grains and crystals in south polar firn. *Journal of Glaciology*, 8: 241-52.

Kohnen, H. 1974. The temperature dependence of seismic waves in ice. *Journal of Glaciology*, 13: 144-47.

Robertson, J.D. 1975. Geophysical studies on the Ross Ice Shelf, Antarctica. *Ph.D. Thesis*, University of Wisconsin. 214 p.

Roethlisberger, H. 1972. Seismic exploration in cold regions. *U.S. Army Cold Regions Research and Engineering Laboratory. Cold Regions Science and Engineering Monograph, II-A2a.* 138 p.

Thiel, E., and N.H. Ostenso. 1961. Seismic studies on antarctic ice shelves. *Geophysics*, 26: 706-715.

Thomas, R.H. 1976. Thickening of the Ross Ice Shelf and equilibrium state of the west antarctic ice sheet. *Nature*, 259: 180-183.

Ross Ice Shelf Project drilling, October - December 1976

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On 27 October the drilling crew and cargo arrived at site J-9 on the Ross Ice Shelf. The team consisted of John Rand, James Morse, Robert Bigl, and Gerard Sheldon from the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL); B. Lyle Hansen from the Ross Ice Shelf Project Management Office, University of Nebraska-Lincoln; Henry Rufli from the Physics Institute, University of Bern, Switzerland; and Steven Quarry from the State University of New York-Buffalo.

The Ross Ice Shelf Project (RISP) wire line core drilling system, designed and constructed at CRREL, incorporates various industrial components and rotary drilling techniques. It is described by Hansen (1976):

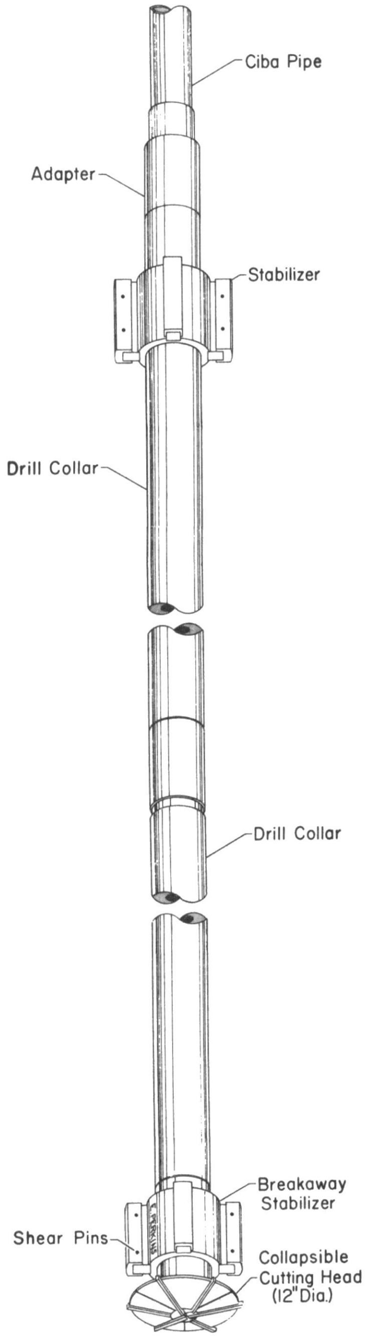
> A wire line core drilling system consists of a coring bit attached to the core barrel outer tube assembly which is rotated by the string of drill pipe, the non-rotating core barrel inner-tube and core lifting assembly, a wire line hoist with an overshot attached to its cable which is used to retrieve the core laden inner tube through the inside of the drill pipe, a means of supporting and rotating the drill string, and a means of circulating the drilling fluid which removes the cuttings from the bore hole, cools the coring bit, and stabilizes the hole.

The two drill strings used are shown in figure 1.

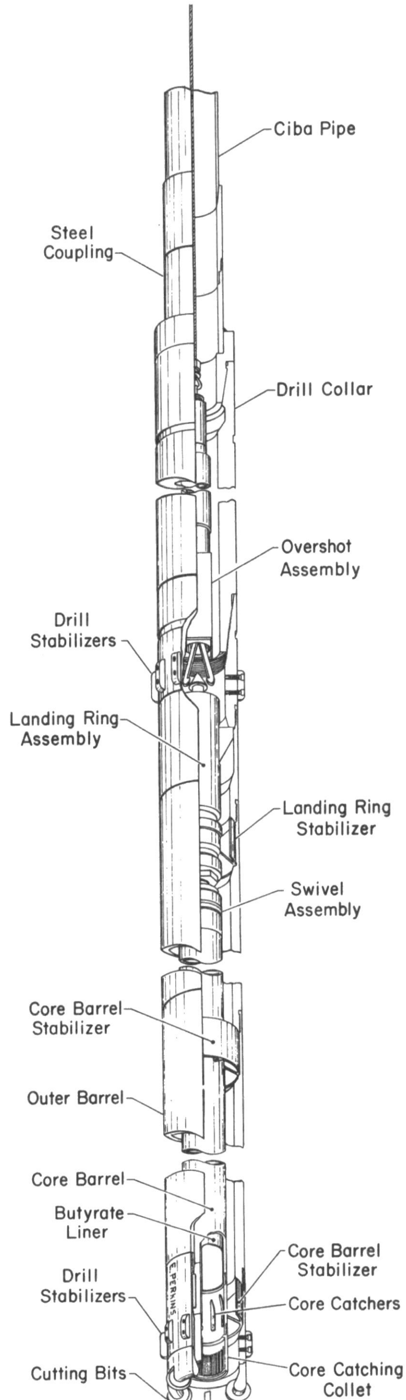
The proposed drilling was to include four holes: the water well hole, the Bern hole, the core hole, and, finally, the access hole.

The water well was drilled between 1 and 4 November. The 12-inch-diameter hole was drilled to 48.2 meters. The generally very cold and windy weather had adverse effects on the drilling operations. Water well operation started on 12 November and ceased on 21 December. During the 39 days of operation, water was produced and stored in the well at a rate of approximately 50 gallons per hour.

Many problems arose during the drilling of the Bern hole between 5 and 20 November. In addition to the poor weather already mentioned, problems developed due to the operators' lack of experience. However, the major problem was the overshot, the tool used to lower an empty inner core



RISP ACCESS HOLE DRILL



WIRE LINE CORE DRILL

barrel and retrieve the core-filled inner core barrel. On three separate occasions this tool released accidentally, causing damage to the cutting bit.

Core was obtained to 103 meters before the third uncontrolled release of the inner tube resulted in a decision to terminate all attempts to recover core with the wire line system until improvements could be made to the overshot assembly. On 22 November, open hole (no core being retrieved) was drilled from 103 to 147 meters. The wire line system was then moved to the access hole location. The CRREL thermal drill was set up at the Bern hole to attempt to drill to a depth of at least 250 meters. The hole was advanced to a depth of 152 meters where the thermal drill became stuck. All attempts to recover the drill failed, and the cable was cut to enable radio propagation studies to take place.

Accumulated delays in the drilling activities and the problems that had developed in the drilling of the Bern hole resulted in a decision not to attempt the core hole that field season.

Prior to the start of the drilling of the access hole, an auxiliary 7-inch-diameter hole had to be drilled 60 meters deep. A submersible pump was placed in this hole to pump sea water out of the access hole for use in later drilling operations. This operation was accomplished on 26 November, and the drill was then moved 12 inches sideways to start the access hole operation.

Figure 2 shows the general progress of the J-9 access hole operation. On 1 December, the hydraulic motor for the vacuum pump failed. It was repaired in the field and put back into service. An alternate prime mover was obtained in case of further problems with the motor.

On the evening of 3 December, penetration stopped. As the drill pipe was being pulled, the bit had become separated from the drill string. The bit was retrieved, and field repairs were made on it.

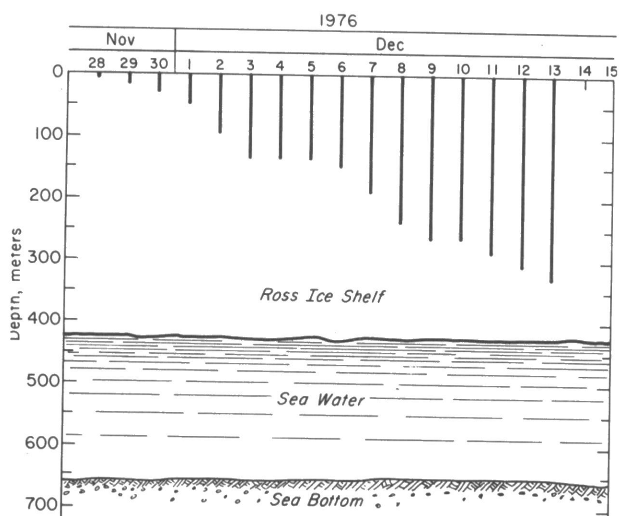
The next stoppage occurred on 9 December. When the drill string was pulled, a section of the top stabilizer was found to be missing. Damage to the bit was also noticed and repaired.

On 12 December, drilling stopped at 310 meters. Again the top stabilizer had been dislodged from its position. The bit was again repaired and new shear pins added to the stabilizers.

Drilling of the access hole stopped at 330 meters on the morning of 13 December. The drill had been lowered down the hole during the evening of 12 December. Drilling had been resumed and a noticeable increase in penetration rate (21 meters in 4.5 hours) and smooth drilling had been experienced. At the end of this crew shift, drilling halted and the drill remained stationary for 30 minutes. At the start of the next shift's operation the drill could not be raised, lowered, or rotated. All attempts to recover the string were unsuccessful. After several days, it was decided that the drill should be left in place and recovery attempts resumed during the next field season when new equipment could be used.

Based upon the experiences of this season's drilling operations it is now known that it is not feasible to drill an open hole through the Ross Ice Shelf due to closure of the drilled hole as a result of the flowing characteristics of ice. Weertman (1973), as a part of this RISP study, calculated the closure rates for a proposed 500-meter hole on the Ross Ice Shelf. Hansen (1976, unpublished) recalculated for an assumed ice thickness of 420 meters and Rand's 100-meter temperature profile at the drill site. Based on these calculations, it had been thought that it would be feasible to drill an open hole to within several meters of the bottom of the ice shelf, but the stoppage at 330 meters disproved this assumption.

Operations this next year will include alternate liquid-filled methods of drilling through the Ross Ice Shelf to obtain an access hole.



J-9 ACCESS HOLE PROGRESS CHART

References

Hansen, B. Lyle. 1976. Deep core drilling in the east antarctic ice sheet: a prospectus in ice core drilling. In: *Ice Core Drilling*, (John F. Splettstoesser, ed.). University of Nebraska Press, Lincoln and London. 29-36.

Hansen, B. Lyle. 1972. Drilling through the Ross Ice Shelf. *U.S. Army Cold Regions Research and Engineering Laboratory. Informal Report*.

Rand, John H. 1975. 100-meter ice cores from the South Pole and the Ross Ice Shelf. *Antarctic Journal of the U.S.*, X(4): 150-151.

Weertman, J. 1973. Anticipated closure rates for a proposed drill hole, Ross Ice Shelf, Antarctica. *U.S. Army Cold Regions Research and Engineering Laboratory. Special Report*, 190.

Polar ice core analysis

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The polar ice core analysis program of State University of New York, Buffalo, began in January 1975. The program is integrated and multidisciplinary with the field portion primarily involved with ice core and surface sample collections and the laboratory portion involved in detailed cold room, warm laboratory, and clean room investigations.

The present emphasis on all studies is designed to establish and characterize the nature of ice sheets during their chronological development in the various geographical locations and geophysical zones on the Greenland Ice Sheet and on the Ross Ice Shelf and other antarctic locations. A