Technical Report 60

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SNOW ICE AND PERMAFROST
RESEARCH ESTABLISHMENT
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by R. W. Patenaude, E. W. Marshall, and A. Gow

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Wilmette, Illinois

PREFACE

These two preliminary reports present a description and some results of the IGY Glaciological Project 4.7, Antarctic drilling. These reports cover work at Marie Byrd Station, Antarctica, November 1957 to January 1958. More detailed reports, also covering work accomplished in Greenland will be published subsequently.

The investigations were a joint project of the Glaciology Panel, U. S. National Committee, International Geophysical Year (IGY) and U. S. Army Snow Ice and Permafrost Research Establishment (USA SIPRE). Within USA SIPRE the responsibility for procurement of the core samples rests with the Applied Research Branch as a service to the Basic Research Branch, which is in responsible charge of the project and the analysis of the core samples.

Project personnel for the 1957-58 season were as follows:

Mr. E. W. Marshall, Project leader, Basic Research Branch
Mr. R. W. Patenaude, Assistant project leader, Applied Research Branch
Mr. Anthony Gow, glaciologist, Arctic Institute of North America
Mr. Jack V. Tedrow, drill operator, Applied Research Branch
SFC Harlan J. Coffman
SP3 Lupe A. Gooday
SP3 John M. Hamilton
SP3 Adolf K. Kryger
SP3 William R. Tiniski
} drill helpers, U. S. Army Polar Research and Development Center

Part I of this report was prepared by Mr. Patenaude. Part II was prepared by Mr. Marshall and Mr. Gow. The work was done under the direction of Mr. W. K. Boyd, branch chief, Applied Research Branch, and Mr. J. A. Bender, branch chief, Basic Research Branch.

This report has been reviewed and approved for publication by the office of the Chief of Engineers.

Walter H Parsons

WALTER H. PARSONS, JR.
Colonel, Corps of Engineers
Director

Part I manuscript received 19 May 1958.
Part II manuscript received 18 June 1958.

SUMMARY

The preliminary results of core examinations and drill-hole temperature studies from November 1957 - January 1958 are reported, and the drilling equipment and techniques are described. Drilling was accomplished with a Failing model 314 rotary skid-mounted well-drilling rig with a 38-ft mast, powered by a 43-bhp Buda gasoline engine. Two types of bits, both cutting a 3 7/8-in. core and a 5 3/4-in. hole, were used. The speed of rotation was varied from 40-75 rpm, and the rate of penetration ranged from 2.5-10 in/min. Compressed air was used as the drilling fluid. Good quality cores were obtained down to 1013 ft with a 98% recovery. Examination of the cores revealed the presence of a detailed stratigraphic sequence down to a depth of 400 ft, consisting of alternating layers of coarse and fine-grained snow associated with ice bands 4 mm thick, which appeared singly or in closely spaced groups at regular intervals. Below this depth the ice was very homogeneous, except for thin ice bands which persisted to the bottom. The mean densities for meter increments to a depth of 150 ft, densities determined from spot samples at 5 points from 400-721.5 ft, and drill-hole temperatures down to 1000 ft are tabulated.

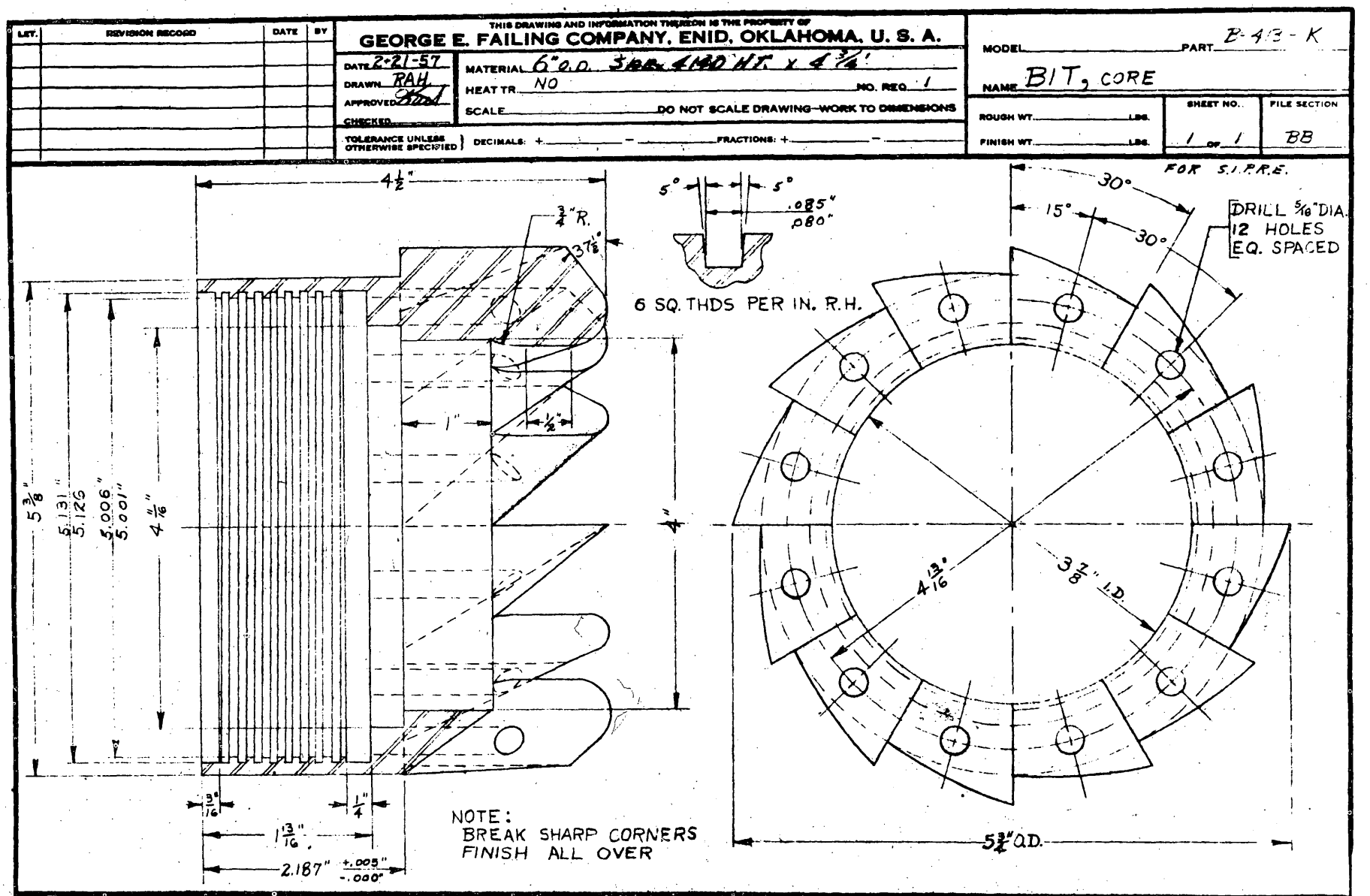

Figure 1. Bit B-413-K.

DEEP CORE DRILLING IN ICE, BYRD STATION, ANTARCTICA

Part I. Drilling Techniques

by

R. W. Patenaude

Planning of the drilling program and procurement of the equipment for modification and of the special items was initiated in 1955. A preliminary drilling program was conducted on the ice cap in Greenland in 1956 and was followed by a second operation in Greenland in the summer of 1957. The experience gained during these two seasons of work contributed greatly to the success of the Antarctic program.

This report very briefly reviews the equipment used in the drilling operation, the logistics of supply, and the method used to secure the ice cores.

Equipment

The drill rig was a Failing model 314 rotary well-drilling skid-mounted rig equipped with a 38-ft mast and powered by a 43 BHP Buda gasoline engine. The rig was mounted on a 10-ton Otaco sled with the mast legs and break-out table supported by a cribbing of 8 x 8-in. and 12 x 12-in. wooden blocking erected in the snow beneath the rig floor. The drill pipe was 2 3/8-in. x 20-ft external upset with API IF tool joints and 1 3/4-in. bore. The core barrel was a standard 4 x 5 1/2-in. DCDMA swivel-type double-tube barrel especially modified for use with air. The bits were bottom discharge type fabricated of soft steel and especially designed for use in ice.

Two bit designs were used, both of which cut a 3 7/8-in. core and a 5 3/4-in. hole. From 60 ft to 180 ft, bit B413K was used. This bit had 12 wedge-shaped teeth 2 1/4 in. long on the outside diameter and 1 1/4 in. long at the inside diameter. The teeth were vertical in the direction of rotation and had a 30-deg slope to the rear. A vertical 5/16-in. air hole was positioned in the center of the slanted back of each tooth (Fig. 1).

From 180 ft to 1013 ft, bit B413J was used. This bit had eight rounded disk-shaped rearward-inclined teeth that were 1 1/2 in. long on the outside diameter and 1/2 in. long on the inside diameter. Two 5/16-in. air holes were spaced between each tooth at the bottom of the bit for a total of 16 holes. This bit appeared to have a milling action and was very effective in the denser snow and in ice (Fig. 2).

The core catcher was of a modified split ring variety with inward projecting teeth, developed by the driller, Mr. J. V. Tedrow.

The drilling fluid was air, compressed by two Joy Company Sullivan model WK-80-315 cfm reciprocating compressors powered with Hercules DRXC diesel engines. The compressors were each mounted separately on 10-ton sleds. To prevent melting the ice, the compressed air was cooled to within 4 to 6 F of the ambient air temperature by passing it through a tube and fin air-to-air heat exchanger manufactured by the Happy Co. of Tulsa, Oklahoma. Moisture which accumulated in the tubes in the form of ice as the air was cooled was removed by heating the cooler between coring runs with a Herman Nelson BT-400-10 heater. A 6-in. centrifugal blower driven by the rig engine was utilized in conjunction with 6-in. hose to draw the cuttings as they emerged from the casing and eject them beyond the working area.

No accurate determination was made of the amount of air used. The two 315 cfm compressors ran continuously during drilling operations and maintained 68 psi at the drill head at maximum depth.

To provide a uniform rate of drilling into the ice a core feed device was provided which consisted of a winch, electric motor, and hydraulic transmission. This unit was specially designed and built by the George E. Failing Company of Enid, Oklahoma.

The rig, compressors, and working space in front of the rig were protected by a Langdon tubular steel and plastic impregnated prefabricated shelter. This made it possible to work in all but extreme weather conditions.

A Lincoln combination 200 amp welder and 4 KVA standby AC power unit were used for emergency power and for welding requirements.

Short Notes

(a) Description of drilling Rig
(b) Drilling details
(c) Core recovery & core quality
(d) Duration of drilling

Logistics

The drilling program at Byrd Station was scheduled on the premise that personnel and equipment would be at the drilling site by the middle of October. The personnel were in New Zealand at the end of September, and the driller and driller's helpers arrived at Byrd Station 7 November 1957.

Twenty-six tons of basic equipment consisting of drill rig, two compressors, air cooler, drill pipe and casing had arrived at Little America by ship in December of 1956. This equipment was transferred to a tractor train and arrived at Byrd Station by 26 October 1957. In addition, 13 tons of supplemental drilling equipment was forwarded from the United States to Christchurch, New Zealand, by ship in 1957, arriving in late October; and finally 3700 lb of equipment used in the 1957 Greenland operation was flown direct from Thule, Greenland, to Christchurch by Military Air Transport Service. About 5000 lb of this material, which was flown to NAF McMurdo by USAF Globemasters, was landed at Byrd Station by ski-equipped R4D (U. S. Navy). The remainder, consisting of 72 separate items, was air dropped by Globemasters at Byrd Station on 1 and 4 December 1957.

One item of the 40 odd tons of equipment sent to Byrd Station was lost. This consisted of 575 ft of wire line and was replaced from Navy stocks in McMurdo. A small amount of drilling equipment and the steel frame for the rig shelter was damaged during the air drop. Fortunately the damaged drilling equipment had been duplicated. The metal framing was repaired by straightening and welding. Also damaged was a Herman Nelson heater and the hydraulic transmission for the core feed device. The hydraulic transmission was replaced from the United States and the Herman Nelson was turned in to the base and a replacement borrowed from the Navy.

Methods

The core drilling at Byrd Station was accomplished with drilling equipment and techniques similar to those employed in coring rock. Major exceptions were the bits, core catchers, drilling fluid, and a non-standard core feed device to provide the perfectly uniform rate of feed required at depth in the ice.

Previous experience had shown that very low bit pressures were required. As a result, all of the drilling and coring was done with the drill string in tension. A combination of draworks brake and hydraulic drill head was used for feeding, but the rate of feed became more irregular as the weight of the drilling string increased with depth. To rectify this situation a core feed device was developed that utilized a regulative hydraulic transmission. This made possible a perfectly constant rate of feed, with very fine adjustment by means of a regulating wheel on the hydraulic transmission.

During the course of the drilling, the speed of rotation of the drill string varied from 40 to 75 rpm and the rate of penetration ranged from 2 1/2 to 10 in/min. With increasing depth the speed of rotation and rate of penetration became more critical, with the speed of rotation appearing to be the more critical of the two. For the last several hundred feet a rotation speed of 50-55 rpm and a rate of penetration of 4 in/min seemed the optimum with the bit used. Lower rotation speeds appeared to create resonance in the drill string, and higher speeds resulted in faceting and fragmenting of the core.

To help prevent the ice from shattering during the coring operation, it was necessary to reduce the vibration of the core barrel and bit. This was accomplished by adding a heavy drill collar to the drill string just above the core barrel. A sludge barrel was used above the drill collar in order to catch cuttings that were not carried out of the hole. Two reamers were used 20 and 40 ft above the drill collar to maintain the diameter of the hole by preventing cuttings from adhering to the hole wall.

The drilling fluid was cooled compressed air that averaged 60 psi at the drill head and varied from 0 to 24 F, depending on the ambient air temperature. In an uncased hole the air tends to dissipate into the permeable upper snow, leaving the cuttings to adhere to the hole wall or to fall back down the hole. For this reason it is necessary to case the hole to a depth where, with increasing density, the permeability of snow becomes sufficiently low that it does not interfere with circulation. In the initial

drilling a fishtail bit was used to drill open hole through the porous snow. Coring was begun at 63 ft, and 6 1/16 in. ID casing was eventually advanced by underreaming to 115 ft.

The hole dimensions beneath the casing at the completion of the program were 7 1/2 in. ID from 115 to 123 ft, and 5 3/4 in. from 123 to 1013 ft.

To remove the core the core barrel was laid on blocking with the bit end inclined slightly downwards. The bit was removed and the core slid out and placed in a core trough for delivery to those responsible for the analysis.

Results

Drilling operations were begun 16 December 1957 and completed 26 January 1958. Cores were obtained between 63 and 1013 ft below the surface and recovery was 98% of this distance. An abbreviated drilling log of the work is presented below.

Abbreviated Drilling Log

Dec. 16 Completed setting up the equipment and shelter. Spudded in at 3 p.m. and drilled open hole to 40 ft.

17 Attempted coring at 40 ft but lost circulation. Drilled open hole to 63 ft. Passed through some type of void in the snow from 52 to 58 ft.

20 Casing set to 62 ft. Cored to 95 ft and again lost circulation. Set casing to 84 ft.

23 Bearings went out in the transfer case from the rig engine drive shaft to the mud pump, making it necessary to shut down the rig. Attempted to obtain bearings at NAF McMurdo and Little America.

26 Reassembled the transfer case using a bushed down bearing and improvised oil seals.

30 Cored to 134 ft and lost circulation.

Jan. 1 Set casing to 115 ft.

2 Cored to a depth of 180 ft. Recovered the first unbroken core, 18 ft in length.

4 Cored to 338 ft. Recovered the last unbroken core, 19 ft in length.

8 Cored to 509 ft. Recovered unbroken lengths of core up to 8 ft in length at this depth.

11 Completed installation of core feed device (509 ft).

26 Cored to 1013 ft without incident. Recovered core in unbroken segments as great as 2 ft in length at 1000 ft. The cores contained many incipient fractures roughly approximating a horizontal plane that appeared to be tension fractures due to release of overlying pressure. These fractures first became evident at a depth of 600 to 700 ft and became better developed and more frequent with depth.

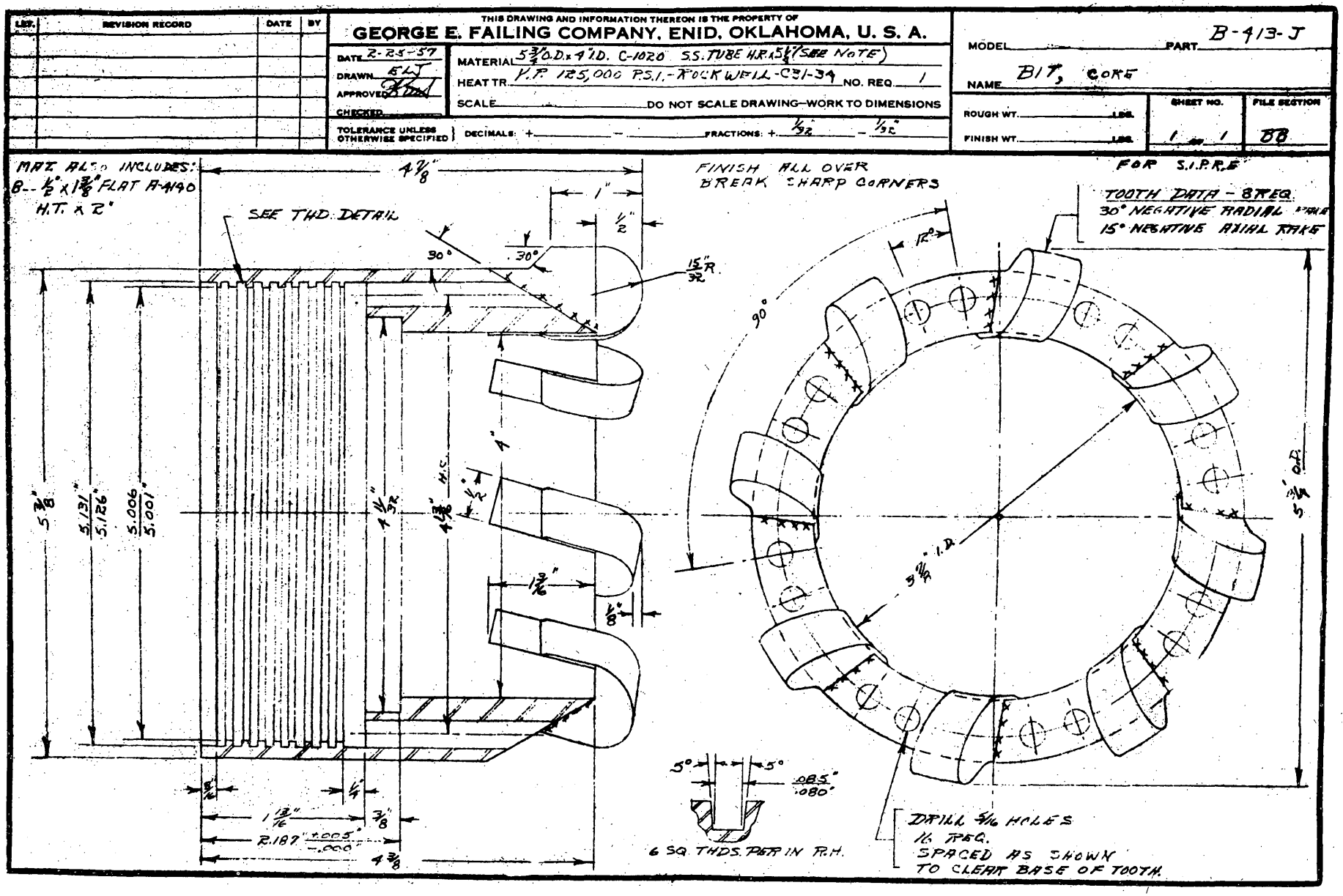

Figure 2. Bit B-413-J.

Part II. Core Examination and Drill Hole Temperatures

by

E. Marshall and A. Gow

Byrd Station was chosen for the season's operations because of its high polar position and dry cold environment which is somewhat similar to the conditions at Site 2, Greenland where deep coring had been successfully accomplished by USA SIPRE personnel for the previous 2 years.

The project party was assembled in Christchurch, New Zealand by early October. One engineer with 1 assistant left for the Antarctic in advance of the main party to expedite transport of equipment from McMurdo Air Facility to Byrd Station. The drill crew and one engineer arrived at Byrd Station early in November and started work on the erection of the drill rig and the excavation of a core laboratory adjacent to the drill site. The Failing "1500" rotary type rig, compressors, cooling plant and drill pipe had arrived at Byrd Station on 28 October by tractor train from Little America, but because of cargo delays in New Zealand the first airdrop of project equipment at Byrd Station by C-124 type aircraft from McMurdo did not take place until 1 December. Para-drops were completed by 4 December. The two glaciologists did not arrive at Byrd Station until 25 December by which time the drill site had been established and deep drilling commenced. A comprehensive glaciological study of the ice core at Byrd Station had been planned but because of the late start this had to be modified.

Ice cores were obtained down to 1013 ft. With rare exceptions, the quality of the core was excellent throughout, and in several coring runs of the first 600 ft, 19-ft lengths of unbroken core were extracted from the 20-ft core barrel. Less than 1 ft of core was lost by grinding in this interval but a 15-ft loss was recorded over the final 360 ft of drilling. The core recovery amounted to 98.3%.

Close inspection of the early cores revealed the presence of a detailed stratigraphic sequence. The stratigraphy consisted of alternating layers of coarse and fine-grained snows associated with thin ice bands (4 mm) which appeared singly or in closely spaced groups at regular intervals in the cores. Thick bands of ice indicative of a period of pronounced thaw were not recognized and, in the absence of such diagnostic features, a detailed density analysis of successive layers in the stratigraphic sequence was attempted. In this way it was hoped to be able to separate summer and winter snows and to determine the order of magnitude of accumulation from year to year.

Ice cores were placed on a trough and viewed from above in transmitted light from a light source placed under the trough. The exact position of a stratigraphic break was determined by a measuring tape laid along one edge of the trough. This measurement and the nature of the layer (whether coarse, fine, or icy) was carefully recorded. Successive sections of core were then photographed. This combined stratigraphic-photographic procedure was commenced at 60.3 ft (18.36 m) and continued down to 319.5 ft (97.38 m). Strip photographs were mounted in order on cardboard sheets to give a running stratigraphic column over this interval. Distinctive layering in the core could be observed down to 400 ft. Beyond this the ice became very homogeneous and visual stratigraphy disappeared with the exception of the thin ice bands, which persisted to the bottom of the drill hole. Density determinations of the individual layers were started at 60.3 ft (18.36 m) and completed to 154.4 ft (47.06 m) in the time available at Byrd Station. In all, densities were calculated for 700 segments of core ranging in length from 15 cm to slightly less than 1 cm. Mean densities for 1-m increments have also been calculated and are presented in Table I. Three-inch core from a hand-augered hole drilled to 71 ft (21.6 m) adjacent to the main coring site was similarly treated. Densities from 176 segments were determined for the first 30 ft and mean densities for meter increments were calculated (Table II). Densities were also determined for spot samples selected at depths of 123 m, 150 m, 177 m, 200 m, and 222 m (Table III). Thin sections were made from the same samples and examined under the microscope for grain-size differences, but there was insufficient time to carry out detailed fabric studies of the thin sections while at Byrd Station.

Table I. Mean densities for meter increments of deep core (4-in.) at Byrd Station.

Increment (m from surface)	Mean density (g/cm^3)
18.50 - 19.00 (60.3 ft)	0.599
19.00 - 20.00	0.606
20.00 - 21.00	0.608
21.00 - 22.00	0.613
22.00 - 23.00	0.619
23.00 - 24.00	0.630
24.00 - 25.00	0.638
25.00 - 26.00	0.643
26.00 - 27.00	0.653
27.00 - 28.00	0.655
28.00 - 29.00	0.660
29.00 - 30.00	0.673
30.00 - 31.00	0.676
31.00 - 32.00	0.684
32.00 - 33.00	0.689
33.00 - 34.00	0.695
34.00 - 35.00	0.699
35.00 - 36.00	0.704
36.00 - 37.00	0.710
37.00 - 38.00	0.715
38.00 - 39.00	0.723
39.00 - 40.00	0.724
40.00 - 41.00	0.722
41.00 - 42.00	0.736
42.00 - 43.00	0.738
43.00 - 44.00	0.746
44.00 - 45.00	0.743
45.00 - 46.00	0.750
46.00 - 47.00 (150 ft)	0.757

Table II. Mean densities for meter increments of hand-augured core (3-in.) at Byrd Station.

Increment (m from surface)	Mean density (g/cm^3)
2.32 - 3.00	0.449
3.00 - 4.00	0.405
4.00 - 5.00	0.421
5.00 - 6.00	0.432
6.00 - 7.00	0.487
7.00 - 8.00	0.515
8.00 - 9.00	0.526
9.00 - 9.37	0.536

Table III. Densities determined from spot samples.

Depth (m)	Density (g/cm^3)
123.00 (400 ft)	0.885
150.00	0.890
173.00	0.895
200.00	0.899
222.00 (721.5 ft)	0.905

Table IV. Deep drill hole temperatures.

Depth (ft)	Avg temp (C) ±0.10
50	-27.9
100	-29.9
150	-28.0
200	-28.1
250	-28.3
300	-28.3
350	-28.3
400	-28.4
450	-28.4
500	-28.4
550	-28.4
600	-28.5
650	-28.5
700	-28.5
750	-28.5
800	-28.5
850	-28.5
900	-28.6
950	-28.6
1000	-28.6

At the outset of project operations, it was intended to split the 4-in. cores lengthwise, return one half to USA SIPRE for further research, and retain the other half at Byrd. However, because of the detailed stratigraphy in cores down to 400 ft, it was decided to retain this section of core in its original state. Splitting of the latter 600 ft of core was begun but, as a result of band saw failure at 850 ft, the last 160 ft remained uncut. In addition to both sections of uncut core and half the longitudinally split core, snow cores from the 71-ft auger hole and from two other shallower holes at Byrd were transported from the Antarctic aboard the USS Glacier. The cores were maintained at 0F throughout the trip to Boston, Massachusetts, where they were offloaded on 15 April and transferred by refrigerated truck to the USA SIPRE Laboratory at Wilmette, Illinois. Further research will include completion of the density profile, grain size and petrofabrics, particulates, gas bubble pressure, O^{16}/O^{18} ratio, entrapped gas analysis, and solubles analysis.

GPO 823835-4

Temperature measurements were made in the deep drill hole to a depth of 1000 ft using a 100-ohm copper, four-wire thermohm and a Wheatstone bridge temperature indicator manufactured by Leeds and Northrup.

Thermal conditions in the hole were disturbed by the drilling and the use of cold compressed air as the drilling medium. Temperature measurements were not begun until 3 days after completion of the drilling.

The thermohm was lowered at 50-ft intervals and allowed a minimum of 2 hr to come to equilibrium.

Instrument errors and reading errors allow an accuracy of ±0.1C.

Because of the permeability of the snow, steel casing had to be set to a depth of 115 ft. The temperatures at 50 ft and 100 ft were measured inside the casing.

GPO 823835—1