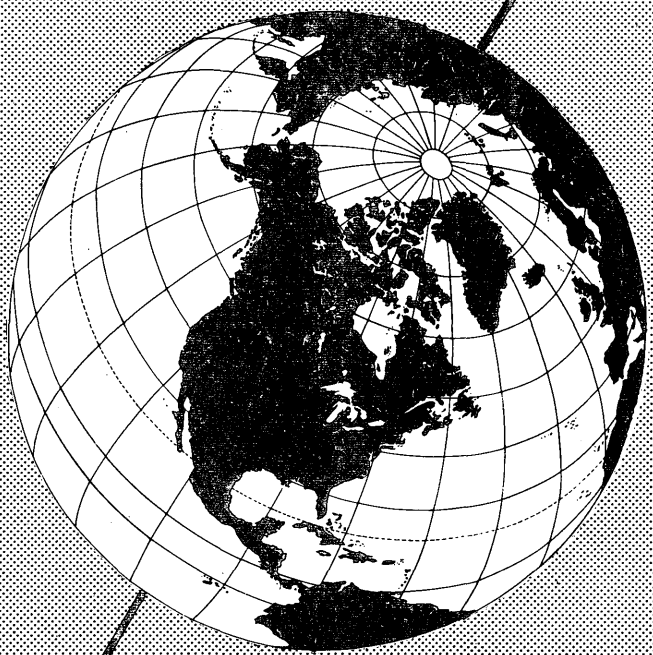
Technical Report 70

JUNE, 1960

Deep Core Drilling in the Ross Ice Shelf, Little America V, Antarctica



U. S. ARMY
SNOW ICE AND PERMAFROST
RESEARCH ESTABLISHMENT
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Deep Core Drilling in the Ross Ice Shelf, Little America V, Antarctia

by R. H. Ragle, B. L. Hansen, A. Gow and R. W. Patenaude

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Wilmette, Illinois

PREFACE

This is a preliminary report on work performed on the final phase of USA SIPRE Project 022.01.033, Antarctic deep drilling core investigations and IGY activities and IGY Project 4.7, Antarctic drilling. Drilling operations were carried out under USA SIPRE Project 22.4-13, Drilling in the Antarctic. Work was carried out during October-December 1959. A preliminary report on similar work at Marie Byrd Station has been published as USA SIPRE Technical Report 60. The purpose of these investigations is to obtain and study ice cores from Antarctica.

The field work on this project was performed by the following personnel:

Mr. Richard H. Ragle, Basic Research Branch, Glaciologist and Field Project Leader
Mr. Robert Patenaude, Applied Research Branch, Engineering Geologist and Ass't Field Project Leader
Mr. B. Lyle Hansen, Technical Research Branch
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Pfc Edward Kokozska (USA PRDC), Driller
Pfc Ruble M. Simpson (USA PRDC), Driller
Pfc Philip T. Walsh (USA PRDC), Driller
Pfc Robert G. Williams (USA PRDC), Driller.

The section on drilling operations was prepared by Mr. Patenaude. The report on core and drill hole investigations at Little America V was prepared by Mr. Ragle and Mr. Gow. The section on drill hole measurements at Byrd Station was prepared by Mr. Hansen. Work on this project was performed for the Basic Research Branch, Mr. J. A. Bender, chief, with the support of the Applied Research Branch, Mr. W. K. Boyd, chief.

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

Henry J. Manger
HENRY J. MANGER
Acting Director

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SUMMARY

Drilling operations and core and drill hole investigations at Little America V in Oct. — Dec. 1958, as well as measurements at Byrd Station in Dec. 1958 are discussed. The hole at Little America V reached 836 ft, and core recovery was 98% of the footage drilled. No saline ice was found in the bottom core, indicating that the bottom ice is melting. In detailed stratigraphic studies made to a depth of 53 m, summer snow deposits were coarse-grained and often associated with icy crusts, ice layers, and glands. Winter deposits were finer-grained, more homogeneous, and lacked the soaked appearance of summer snow. Periods of 2-3 consecutive years at more or less regular intervals of 10-20 yr showed intense ice formation. Layers of foreign material, tentatively identified as volcanic ash, were observed at 172.1 m, 219.4 m, and 222.8 m. The depth-density curve steepened between 20.7 and 36.5 m. If annual precipitation is estimated as 21 cm of water, Little America V rests on about 1225 yr of accumulated snow. Data (some of a preliminary nature) are tabulated and graphed: the depth-density profile to a depth of 53 m, the nature of ice at various depths, spot densities below 53 m, and the annual increments at depth and corresponding water equivalents at Little America V; ice temperature at various depths at both stations; and depth-inclination measurements as well as the diam-vs-depth curve at Byrd Station. The future research program at Little America V is outlined.

DEEP CORE DRILLING IN THE ROSS ICE SHELF, LITTLE AMERICA V, ANTARCTICA

by

R. H. Ragle, B. L. Hansen, A. Gow, and R. W. Patenaude

INTRODUCTION

A method was developed for drilling in ice and obtaining cores down to depths of over 300 m during the summers of 1956 and 1957 in Greenland. A deep drill hole was successfully made and good quality cores obtained at Marie Byrd Station during the Antarctic 1957-58 summer season. Preliminary reports on this aspect are available in USA SIPRE Technical Report 60 and the IGY Glaciological Report Series, No. 1. As part of IGY Project 4.7 - Antarctic drilling, the program also included drilling in the Ross Ice Shelf near Little America and this preliminary report represents the final phase of the project.

PART I. DRILLING OPERATIONS

The drilling equipment was transported from Byrd Station to Little America V by tractor-train in February 1958 after completion of the Byrd Station drilling program. The drill party arrived at Little America Station on 13 October 1958 to complete the second phase of USA SIPRE deep core drilling in the Antarctic, to core through the ice shelf at Little America.

The equipment was unloaded from sleds, the prefabricated compressor and rig shelters were erected, a Jamesway was set up for use as a tool house and working area, and an undersnow core laboratory and storage vault were constructed to the rear of the drill shelter to receive the cores (Fig. 1).

Drilling commenced at 1630 hours on 31 October 1958. Open hole was drilled to 22 ft, where coring was attempted. Circulation could be maintained for no more than short distances in the upper permeable snow. Casing was initially set to 39 ft. It became necessary to advance the casing four times to a total depth of 130 ft before it was possible to maintain air circulation. As at Byrd Station, the bit designs used at Little America Station cut a $3^7/_8$-in. core and a $5^3/_4$-in. diam hole. Also as at Byrd Station, the casing ID was $6^1/_{16}$ in.

Cooled compressed air was used as a drilling fluid from the surface to 818 ft. The compressed air was furnished by two 315 cfm reciprocating compressors and cooled by a tube and fin air-to-air heat exchanger. The air pressure at the drill was 50 to 60 psi near the surface and 60 to 75 psi at depth while using the core barrel. Moisture condensing and freezing in the air cooler accumulated in the tubes and caused a gradually increasing constriction of the flow of compressed air. The amount of ice accumulating in the cooler varied with the humidity. However, the cooler was generally thawed and drained once a day in order to prevent the air pressure at the drill from dropping below 50 psi. The temperature of the drilling fluid varied as the ambient air temperature and was generally 4-8F warmer. Drilling was not attempted during the infrequent times that the temperature of the fluid exceeded 25F at the drill. While drilling with air, the drill string was rotated from 50 to 60 rpm and advanced at the rate of 5 to 6 in/min.

Apparently some incipient hole closure existed toward the bottom of the shelf. A 10-ft run had been made to 808 ft and, on retrieving the core barrel, bit B413J unscrewed at a point estimated to be 40 ft above bottom. This bit has inclined teeth (see Technical Report 60, Fig. 2) and had been used frequently on several different projects without difficulty. Return circulation had been good, but the drilling had progressed slowly during the preceding several days because of frequent temperature measurements

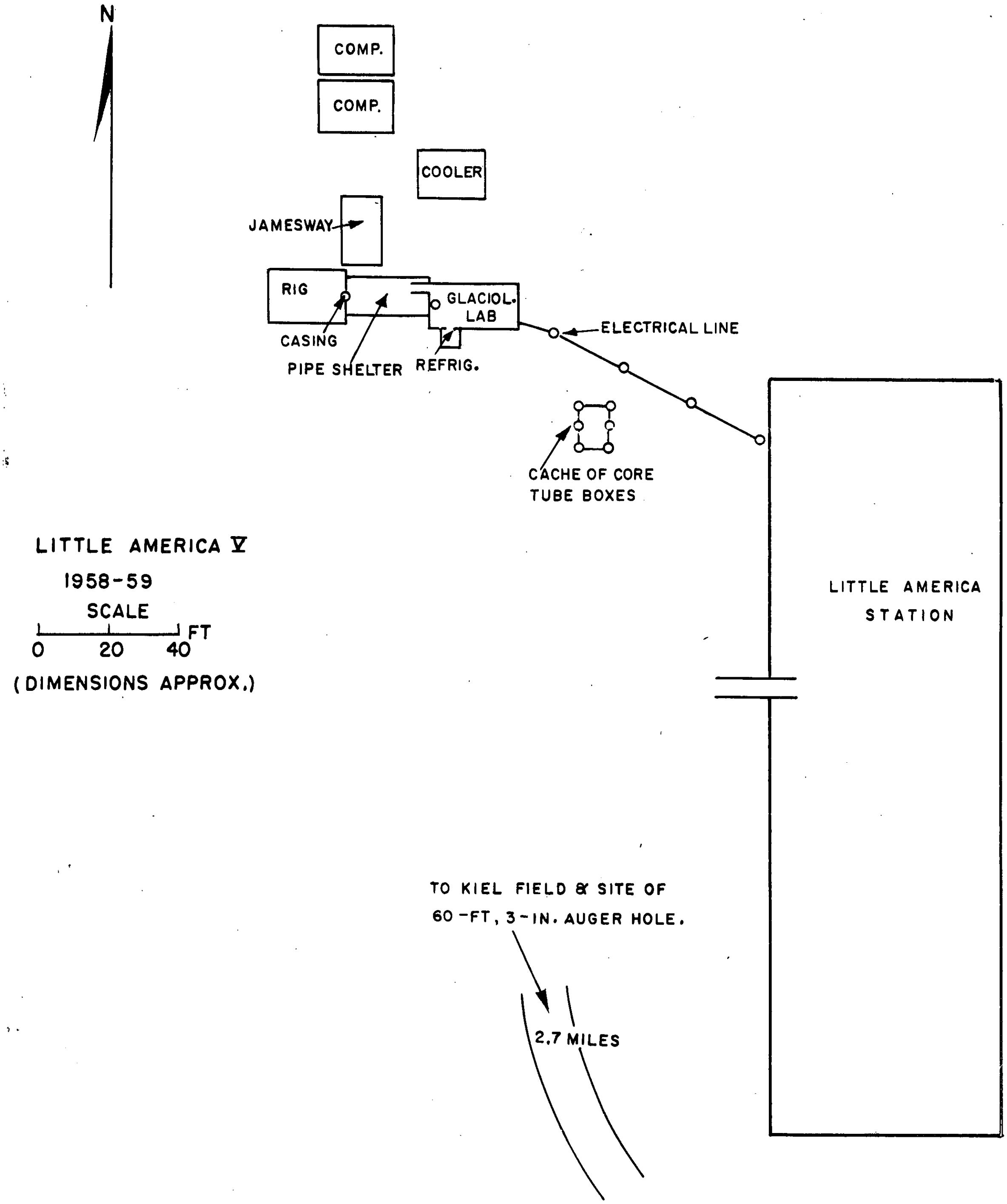

Figure 1. Plan of drilling site, Little America V, 1958-59.

and the driller reported a tight hole for the bottom 200 ft. The bit was recovered by running a four-fingered grapple made from sections of two turnbuckles down through the bit on the sand line. For the remainder of the drilling, this bit was replaced by bit B413E, which is similar except for vertical teeth, and therefore less likely to unscrew in a similar situation.

When the drilling had advanced to 818 ft, the rising temperature curve of the ice, together with seismic evidence, indicated the possibility of encountering the bottom of the shelf in another 20 or 30 ft. It was decided to drill through the bottom of the shelf with diesel fuel as a drilling fluid so that the hydrostatic head of the diesel column might, in part, balance the salt water head. The possibility of losing part of the hole to salt water encroachment was realized, as the collar of the hole was 140 ft above sea level and about 700 ft of salt water (density 1.025 at 0C) would weigh more than 840 ft of Arctic diesel fuel (density about 0.813 at 5F). Preparations were made to load the hole with diesel fuel on the assumption that it would be possible to drill out any resulting salt ice plug.

The Moyno pump was put in service. It is model 3L6-CSQ of the progressing helical type, which is designed for use with liquids carrying a high percentage of solid material. It weighs 150 lb and is rated at 5.2 gpm/100 rev at 225 psi. A slush pit was fabricated of three diesel drums cut in half lengthwise and welded end to end to form a six-compartment tank. Filter screens of common house screening were placed in each compartment.

The hole was drilled to 836 ft using diesel fuel. During the coring run, the drill string was rotated from 60 to 65 rpm and advanced at 6 in/min. The pump pressure averaged 100 psi and the circulation averaged 50 gpm. The temperature of the diesel fuel was 6F. While retrieving the drill string from the hole, a return flow of diesel fuel, roughly equivalent to the previous pump circulation, continued while the first five or six joints were in the slips. This flow ceased while the string was being raised between joints. When the core barrel was recovered, about four inches of core projected below the bit, and to this was frozen an irregular, diesel-fuel-contaminated layer of salt ice $\frac{1}{2}$ to $\frac{3}{4}$ in. thick.

The diesel fuel head in the drill hole was measured shortly after removal of the core and was found to be 32 ft from the surface. The computed volume loss due to removal of the tools was 82 ft. A weight was run down the drill hole on the sand line and a semi-firm zone was encountered between 600 and 620 ft. The weight was recovered with ice particles on it that tasted strongly of salt. As the bottom of the core terminated in a clean break, it would appear that a fracture was encountered or developed in the bottom of the shelf providing access for the salt water. It was decided to wait several days for the salt water to freeze and then to redrill the hole.

The coring run with diesel fuel was made on 5 December and progress was not resumed until 15 December, principally because of a storm that made drilling impracticable. By the evening of 16 December, the hole had been redrilled to 760 ft using a $5\frac{5}{8}$ in. drag bit. The cuttings from 600 to 760 ft consisted almost entirely of thin, flat, transparent plates as large as a centimeter in diameter. They appeared to be crystal fragments, indicating that the salt water had frozen into a crystal mush. The circulation while drilling averaged 50 psi and 50 gpm and the temperature of the diesel fuel was 5F. The drilling tools were rotated at 60 and 70 rpm and advanced about 6 in./min.

It appeared that the loose salt ice structure might continue to the bottom of the hole, and might not be of sufficient strength or impermeable enough to contain the sea water. For this reason, it was decided to cease drilling open hole and to attempt to take a sample of this ice plug with the core barrel, after which the drilling would be stopped and the hole would be left loaded with diesel fuel.

When the attempt was made to take a core, it was found necessary to ream the redrilled portion of the hole with the core barrel. During the morning of 17 December, the hole was reamed from 600 to 660 ft. From this point onward, ice repeatedly lodged within the narrow clearances of the core barrel and blocked off the fluid circulation. It was evident that a much larger settling pit would have to be constructed to allow the fine ice particles to settle out of the fuel oil. Since it was late in the season and the supply of diesel fuel had been depleted, the drilling was discontinued. The drill hole was measured and bottom indicated at 727 ft. The loss from 760 ft represented cuttings that had fallen to the bottom of the hole while reaming with the core barrel. To secure the drill hole for possible future use, three joints of casing totaling 15 ft were added above snow level to the original 27 joints of casing in the hole and a cap inserted.

Results

Variations in drilling techniques in the upper snow, especially rate of penetration and rpm, appear to be less critical than in the deeper ice. These rates can be varied widely without affecting the snow core. During the coring from 38 to 138 ft, the rotation was varied from 50 to 110 rpm and the rate of penetration from 6 to 12 in/min without apparent alteration in the condition of the core. A symetrical spiral faceting of the core was observed in two runs at 75 rpm from 138 to 165 ft, which may have been due to resonance developing in the lengthening string of tools. Beyond 165 ft, the rotation was maintained at 60 rpm and the rate of penetration at 6 in./min.

The core from 150 to 300 ft was infrequently broken, with unbroken segments often in excess of 15 ft long. Beyond 300 ft, the increasing brittleness of the ice resulted in increasingly shorter segments of unbroken core down to 600 ft, where the segments averaged 1 ft in length. Beyond 600 ft, the core condition gradually improved, i.e., the length of unbroken segments increased, possibly because of the increasing temperature and resulting increasing plasticity of the ice. At depths greater than 500 ft, most core breakage was actually separation along pre-existing cracks on removal from the core barrel. Cracks normal to the axis of the core, which are characteristic of cores taken with air from depth, became pronounced by 500 ft, and there were perhaps a dozen fractures per foot of core length by 600 ft. The number of fractures per unit length increased with depth down to 818 ft, where air was no longer used as a drilling fluid. These cracks are probably caused by release of static pressure.

The core from 818 to 836 ft, drilled using diesel fuel as a drilling fluid, did not contain the normal cracks characteristic of the cores taken with air at this depth, but rather contained small irregular superficial cracks that did not penetrate more than a centimeter into the core.

Core recovery amounted to 98% of the footage drilled. A major part of the core loss resulted when 4.5 ft of a 19 ft coring run from 320 ft was lost and the remainder badly fragmented because a bit of improper design was used.

PART II. CORE AND DRILL HOLE INVESTIGATIONS

The first 4-in. (10.16 cm) diam core was taken at a depth of 6.7 m and continuous core was obtained to a depth of 254.8 m (835.7 ft) with less than a 1 % loss of the 814 ft of possible core.

Although no saline ice was found in the bottom core, proximity to the bottom of the shelf was evident when salt water seeped into the hole up to the 188.2 m level. Since no saline ice was found, it is possible that fresh ice continues to the ice-water interface which, from existing seismic information and temperature measurements, is between 256 m and 259 m (840-850 ft). This seems to indicate that the ice at the bottom is melting rather than in a stationary state or in the process of forming new sea ice.

Stratigraphy

Detailed stratigraphic studies were made to a depth of 53 m. To facilitate glaciological studies in the upper 3 - 4 m of snow and firn, three shallow pits were excavated some distance from the Little America V camp site. Detailed studies of the pit walls were made in order to supplement data from the mechanically drilled and hand-augered cores. As a result, a complete stratigraphic profile, in addition to the depth-density profile, will be obtainable for the Ross Ice Shelf in the vicinity of Little America V.

Summer snow deposits appeared as coarse-grained and frequently were associated with icy crusts, ice layers and glands. Winter deposits were finer-grained, more homogenous, and lacked the "soaked" appearance of summer accumulation. Periods of two or three consecutive years through the stratigraphic sequence showed intense ice formation. These periods appear to have occurred at more or less regular intervals which were approximately 10 to 12 years apart (Table I). Though icy crusts and ice lenses persist to greater depths, visual annual stratigraphic increments become obscure below 30 m.

Layers of foreign material were observed at 172.1 m, 219.4 m, and 222.8 m. Microscopic examination of the first layer revealed aggregates of glassy, markedly angular material identified tentatively as volcanic ash. The second and third layers have not been examined microscopically but will be studied in detail at USA SIPRE.

Density measurements

Approximately 500 density measurements were made in the field. Average length of core for density determination was 12 to 15 cm. The depth-density profile from the surface to 53 m has been completed, and spot densities have been made to 155 m. Average densities for meter increments show a steepening of the depth-density curve between 20.7 and 36.5 m. Densities calculated in the field are given in Tables II and III and Figure 2.

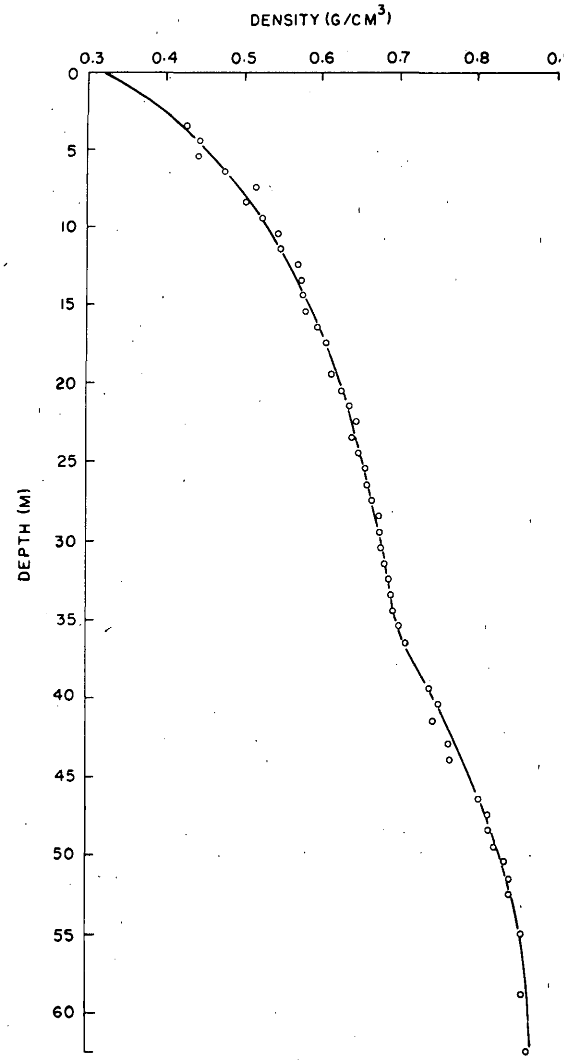

Figure 2. Depth-density curve for deep drill hole, Little America V, 1958-59.

To obtain some estimate of the annual precipitation of Little America V, several sections of ice core were drilled out by hand auger from beneath the floor of the glaciological laboratory. Water equivalents have been calculated, and the results are presented in Table IV. These results are intended to give only a general indication of the annual precipitation, but it would appear from the preliminary studies that: (a) 21 cm of water is a fair average value; and (b) snow now 18 m below the surface was originally deposited on the Ross Ice Shelf about 40 years ago. Assuming that the ice shelf in the vicinity of the drill site is composed entirely of depositional strata (melting at the bottom having eliminated the original basement of the shelf), and assuming a constant annual accumulation of 21 cm of water, then it may be said that Little America V rests upon approximately 1225 years of accumulated snow.

Petrofabrics

Eight thin sections of the core from 62 m to 249 m have been examined on the Rigsby Universal Stage. Although too few crystals have been measured on each slide to allow for a completely adequate analysis, these preliminary studies indicate that some pattern of preferred orientation exists in the lower levels of the Ross Ice Shelf and that the fabric becomes more strongly developed with increasing depth.

Future investigations

It is hoped that the detailed examination of the deep cores from Little America V

Table I. Years of predominant ice occurrence in cores

Depth (m)	Ice character	Age of formation*
5.07 - 5.55	Lenses and pellets	1947 - 48
** 9.85 - 10.05	Lenses and pellets	1935 - 36
10.25 - 10.45	Thick lenses and pellets	1934 - 35
**14.85 - 15.20	Chunky ice and lenses	1922 - 23
16.10 - 16.40	Thick ice layer	1920 - 21
21.30 - 21.45	Chunky ice and lenses	1908 - 09
**25.35 - 25.40	Chunky ice and pellets	1895 - 96
25.95 - 26.00	Pellets	1893 - 94
**29.50 - 29.70	Chunky ice and pellets	1881 - 82
30.50 - 30.65	Chunky ice and pellets	1879 - 80
**40.25 - 40.35	Lenses	1846 - 47
40.60 - 40.70	Ice gland (8 cm thick)	1845 - 46
46.65 - 49.00	Sporadic layer and pellets	1815 - 24
51.10 - 51.35	Lenses	1806 - 07

*The years have been reckoned on the assumption that the rate of accumulation has remained constant (21 cm water). The earlier dates (below 21.45 m) should be considered approximate only.

**Consecutive years which show heavy melt.

will add considerably to our knowledge of the structure, origin, and glaciological history of the Ross Ice Shelf. Further research at USA SIPRE will include:

a. Completion of the depth-density profile
b. Estimation of annual accumulation from the stratigraphic record and study of variations in the rate of accumulation inasmuch as they reflect changes in topographic and/or climatological conditions on the Ross Ice Shelf.
c. Grain size and crystal area studies
d. Petrofabric studies
e. Studies of bubble structure and bubble pressures
f. Entrapped gas analysis
g. Particulate and salt analysis
h. Oxygen isotope analysis, etc.

Deep drill hole temperatures, Little America V

Temperature measurements were made in the bottom of the deep drill hole as it was cored, and recorded to 0.001C. A temperature probe containing four thermistors and a Leeds and Northrup platinum resistance thermometer, S/N 1063033 was used. The thermometer was calibrated by the National Bureau of Standards and used to calibrate the thermistors before and after measuring temperatures in the hole. The thermistor used was Veco No. 41A1 4-56. Resistance was measured with a Leeds and Northrup 4735 Guarded Wheatstone Bridge, S/N 6656 (SIPRE 1695), and a Leeds and Northrup Cat. No. 9834 D.C. Null Detector. Table V gives temperatures to the nearest 0.01C. No corrections have been made for bridge temperatures and, therefore, hole temperatures should be considered preliminary. Corrections will be less than 0.1C.

Hole diameter and inclination

The diameter of the hole at Little America V was measured at the 300 ft level. The mean of three measurements recorded was 5.759 in.

No attempt was made to make measurements of inclination.

Table II. Densities for meter increments in deep drill hole, Little America V, 1958 (0 - 53 m)

Depth (m)	Density (g/cm^3)	Depth (m)	Density (g/cm^3)	Depth (m)	Density (g/cm^3)
0	0.360	18	-	36	0.078
1	0.390	19	0.611	37	-
2	0.402	20	0.624	38	-
3	0.426	21	0.635	39	0.738
4	0.442	22	0.644	40	0.750
5	0.441	23	0.638	41	0.743
6	0.476	24	0.644	42	0.763
7	0.515	25	0.655	43	0.764
8	0.501	26	0.657	44	-
9	0.522	27	0.664	45	-
10	0.541	28	0.673	46	0.800
11	0.548	29	0.673	47	0.812
12	0.569	30	0.675	48	0.811
13	0.572	31	0.680	49	0.820
14	0.574	32	0.687	50	0.834
15	0.579	33	0.690	51	0.840
16	0.595	34	0.692	52	0.840
17	0.601	35	0.699	53	
18		36			

Table III. Spot densities below 53 m in the deep drill hole, Little America V, 1958 (±0.005)

Depth (m)	Density (g/cm^3)	Depth (m)	Density (g/cm^3)
54.35	0.839	79.30	0.886
55.85	0.852	80.50	0.889
57.35	0.849	82.10	0.889
58.85	0.854	83.50	0.890
60.85	0.858	84.95	0.890
61.65	0.868	86.50	0.887
63.15	0.866	87.86	0.888
64.28	0.873	89.30	0.894
66.12	0.878	90.87	0.892
69.03	0.878	92.40	0.894
70.20	0.879	95.15	0.895
71.10	0.887	106.50	0.901
73.42	0.885	108.70	0.894
74.59	0.882	111.72	0.903
76.41	0.887	154.82	0.906
77.85	0.887		

Measurements at Byrd Station, December, 1958

Temperatures. The same temperature recording equipment was used in the drill hole at Byrd Station as had been used at Little America V. Temperatures were taken every 50 ft to the 200-ft level and then every 100 ft to the 1000-ft level. (Total depth of the hole is 1013 ft.) Steel casing extends down the hole 115 ft and has apparently influenced surrounding snow temperatures down to at least 150 ft (Fig. 3). No corrections have been made on the existing data, but preliminary examination indicates that temperatures are within 0.18C of those recorded in February 1958 by Mr. E. W. Marshall (Technical Report 60).

Hole diameter. The diameter of the drill hole was measured every 50 ft from the top of the casing by means of an electric caliper which varies a resistance as a function of the diameter. Resistance was measured with the same Wheatstone bridge and null indicator used for measuring temperatures.

Closure of the hole is shown by Figure 4. Measurements were repeated wherever points appeared to depart greatly from the mean curve. Total closure 1000 ft from the top of the casing was approximately 1.1 in.

Table IV. Annual increments at depth and corresponding water equivalent, Little America V. (Ages determined on basis of 21 cm water/yr: approx. only)

Age	Depth below snow surface (m) (Annual Increments)	Water equiv. (cm)
1944 - 45	6.70 - 7.15	21.4
1943 - 44	7.15 - 7.55	18.8
1942 - 43	7.55 - 8.00	22.2
1941 - 42	8.00 - 8.46	20.8
	Core broken and unsuitable for water equivalent determination	
1933 - 34	10.80 -11.17	19.7
1932 - 33	11.17 -11.57	21.6
1931 - 32	11.57 -12.05	26.3
1930 - 31	12.05 -12.45	22.4
	Core broken and unsuitable for water equivalent determination	
1924 - 25	13.96 -14.32	19.9
1923 - 24	14.32 -14.66	19.3
1922 - 23	14.66 -15.05	22.3
1921 - 22	15.05 -15.41	20.5
1920 - 21	15.41 -15.73	18.1
	Core broken and unsuitable for water equivalent determination	
1917 - 18	16.86 -17.14	16.9
1916 - 17	17.14 -17.57	25.6
1915 - 16	17.57 -18.00	25.8

Avg water equivalent = 21.3

Table V. Depth-temperature measurements, Little America V, 1958

Depth (ft)	Temp (C)	Depth (ft)	Temp (C)
140*	-21.68	617	-14.89
200*	-21.54	668	-13.02
276	-21.10	730	-10.30
315	-20.68	765*	- 8.36
347*	-20.22	786*	- 7.05
400	-19.47	798	- 6.00
455	-18.57	808	- 5.17
499	-17.69	818	- 4.44
560	-16.28	836	-

*Temperatures taken in air above the bottom of the hole.

No corrections for bridge temperatures have been made and the results of these measurements should be considered preliminary.

<u>Inclination.</u> Inclination of the hole was taken every 200 ft by a Lane-Wells small photo-record magnetic single-shot instrument. The instrument was mounted in a 10-ft long 2-in. diam aluminum barrel which was made at Little America V and substituted for the 14-ft brass casing lost during an air drop at Byrd Station. Results of the measurements are given in Table VI.

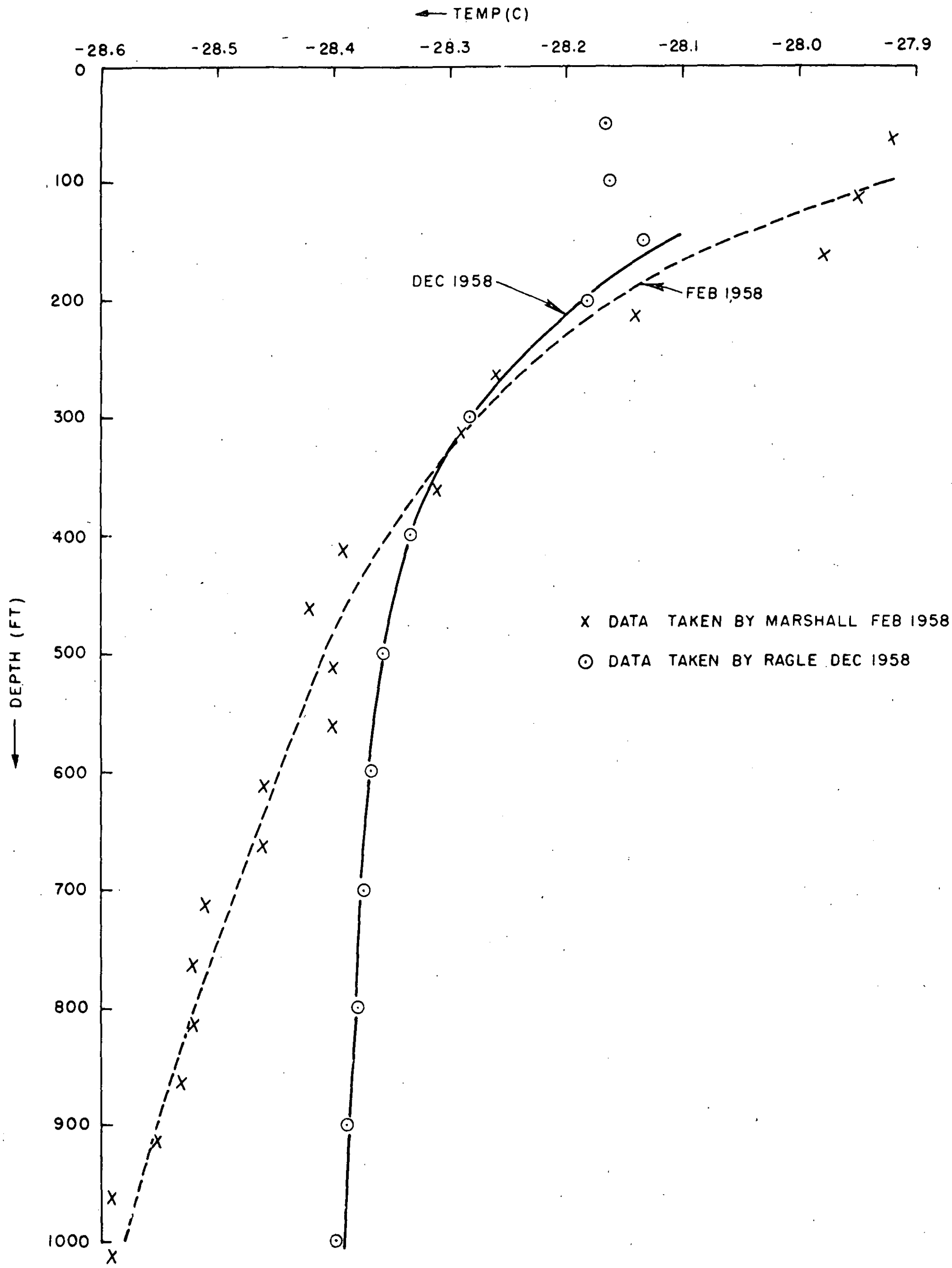

Figure 3. Byrd Station deep drill hole temperatures, 1958.

Table VI. Depth-inclination measurements, Byrd Station, 1958

Depth (ft)	Inclination (mag hdgs)
200	N 100° W $1\frac{1}{4}$°
400	N 043° W $1\frac{1}{2}$°
600	N 045° E (?) $\frac{3}{4}$°
800	N 023° E $\frac{2}{3}$°
1000	N 048° W $\frac{1}{4}$°

(Declination 67° 25'E.)

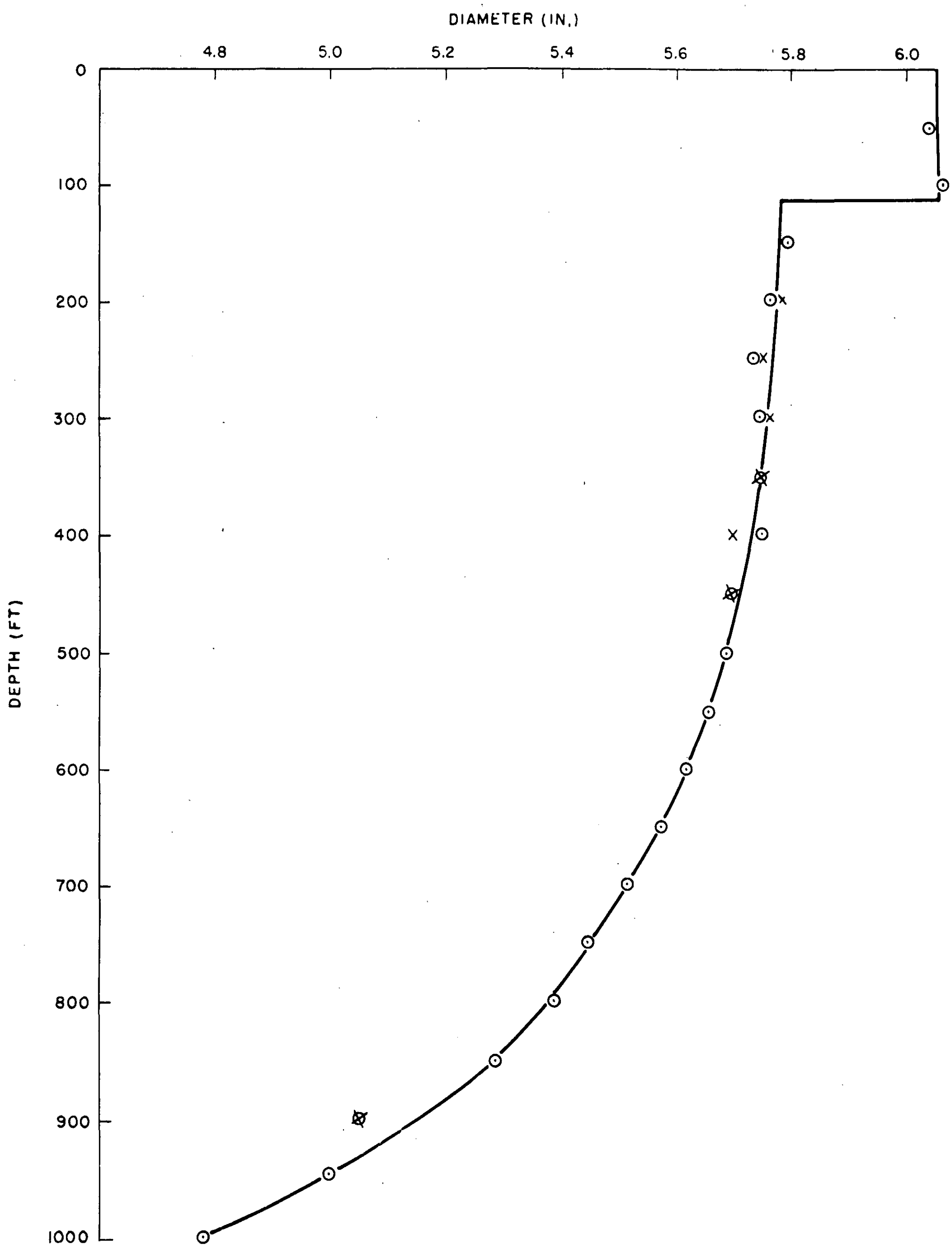

Figure 4. Diameter vs depth curve for deep hole, Byrd Station, December, 1958.