OUTLINE OF THE DRILLING OPERATION AT MIZUHO STATION*

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Abstract: Ice drillings were carried out in 1971, 1972 and 1974–75 at Mizuho Station (70°41′53″S, 44°19′54″E) as a part of the Glaciological Research Program in Mizuho Plateau of Japanese Antarctic Research Expedition. Four holes, 41.9 m, 75.0 m, 147.5 m and 145.4 m deep, were drilled and 350 m of cores from them were sent to Japan. Two winches, two electrodrills, and five thermal drills were made for the operation. The operation is chronologically outlined from the embryo stage of its planning, with emphasis being laid on its technical aspect.

1. Introduction—Birth of the Drilling Project in Retrospect—

The idea of deep core drilling by the Japanese Antarctic Research Expedition (JARE) dates back as early as May 1965, when a group of glaciologists at Hokkaido University proposed a program of Antarctic glaciological studies to be carried out from March 1968 through February 1972. In the program were stated that an inland depot to be set by JARE-8 in 1967 to support the South Pole Traverse 1968–1969 by JARE-9 should be enlarged to a permanent inland station and that three glaciological projects, year-round glaciological observations and deep core drilling down to 100 m at the inland station (Inland Station Project), extensive traverse snow surveys (Traverse Project) and sea ice studies in Lützow-Holm Bay (Sea Ice Project), should be carried out by JARE-10 (1969), -11 (1970) and -12 (1971), requiring 6 to 7 glaciologists each year.

Unable to allocate so many members to the glaciological projects, the JARE scientific committee asked the glaciologists to set the order of priority among the three. The traverse project having been given the first priority, the Glaciological Research Program in Mizuho Plateau, in which extensive oversnow traverse surveys by JARE-10 and -11 and resurveys along the same routes by JARE-14 and -15 were scheduled, was proposed in September 1967. The program was approved by the JARE scientific committee in May 1968, who recommended, however, that in JARE-12 and -13 geology and geography should have priority over glaciology.

Since the program required a temporary depot around 71°S and 45°E, glaciologists appealed to the JARE scientific committee to maintain the depot in JARE-12

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and -13 with minimal number of glaciologists and continue routine observations and hopefully do some tests of core drilling. Meanwhile, in November 1968, those who were interested in deep core analysis formed a group* with the intention of performing systematic analysis of deep cores already obtained by the U.S. Cold Regions Research and Engineering Laboratory (CRREL) and by the Australian National Antarctic Research Expedition (ANARE) as well as those to be drilled by JARE. While they were asking CRREL and ANARE to supply the cores and information of the drilling techniques, they appealed to the JARE scientific committee to begin core drilling as early as possible.

With these circumstances in background, a program to maintain the depot to be opened by JARE-11 and use it as a drilling site by JARE-12, -13 and -16 (Drilling Project) was submitted to and approved by the JARE scientific committee in May 1969 as a part of the above-mentioned Glaciological Research Program, which thus came to cover JARE-10 through JARE-16.

2. Technical and Historical Remarks on Ice Core Drilling

Drilling is an operation to remove a part of material so as to leave a hole in the material. In simple drilling where only the hole is needed, the part to be removed may be transformed into an easily removable form, or "chips", by melting, by dissolving in solution, or by literally chipping. In core drilling where samples of intact material are required, however, only an annular portion of the part is allowed to change, and a finite length of core must be taken out carefully at intervals. This makes core drilling more time-consuming than simple drilling.

Except in the wire-line method, core drilling is done with a drill-head capable of both penetrating the material by transforming its annular portion into "chips" with an annular bit and holding a certain length of core in a core-barrel. The "chips" are transported either directly to the surface or temporarily to a storage of the drill-head. In each run, the drill-head is lowered to the bottom of the hole. After penetrating some length of the material, the drill-head is pulled up to the surface with a drilled core (and "chips", if any). Hence, the total time T needed to core-drill a hole of a depth D comprises the penetrating time T_p, the traveling time T_t required for lowering and hauling of the drill-head, and the surface time T_s spent at the surface to prepare for the next run. For estimating T, the traveling rate V, the penetrating rate v, the length L of a core taken in a run and the time s required on surface in a run are all assumed constant. Then, a simple calculation yields that

$$T = D/v + s\,D/L + D^2/L/V. \qquad (1)$$

* They later proposed a project titled "Physical and chemical studies on ice of polar ice sheet", which was carried out from fiscal 1971 through 1974 under the financial support from Special Research Fund of the Ministry of Education, Science and Culture, Japan (KUROIWA, 1974).

The three terms in the right-hand side are T_p, T_s and T_t respectively (UEDA and GARFIELD, 1969b).

The development of ice core drilling system is attributed mainly to the longtime efforts of U.S. CRREL, formerly Snow Ice Permafrost Research Establishment (SIPRE), to drill through polar ice sheets. They first used a rotary drilling system where a drill-head was suspended with a string of rods through which power was transmitted mechanically and where chips were transported to the surface by compressed air. With the system, they drilled a 305-m hole in 1956 and a 411-m hole in 1957 at Site 2, Greenland (LANGWAY, 1967), a 309-m hole in 1957–58 at Byrd Station, Antarctica (PATENAUDE *et al.,* 1959), and a 254-m hole in Ross Ice Shelf in October–December 1958 (RAGLE *et al.,* 1960).

The system, however, had two inherent drawbacks in use in remote and cold regions; slow performance and heavy weight. As for the former, the traveling velocity V in eq. (1) became very slow in effect because in hauling or lowering of the drill-head the rods had to be removed from or added to the string one by one. For the latter were responsible again the rods as well as the method of chip-removal: Not only the rods were heavy in themselves but in turn required a strong and hence heavy hoist, while a heavy compressor was necessary to circulate compressed air between the surface and the bottom of hole. Thus, though intended to drill to only 450 m, the system used by SIPRE weighed as heavy as 2.6×10^4 kg (PATENAUDE *et al.,* 1959).

The two drawbacks can be remedied by a cable-suspended system, where a drill-head is suspended with an electric cable through which power is transmitted electrically and where chips are transported to a built-in storage of the drill-head. CRREL adopted this system since 1960, when they made a winch and a thermal drill. Equipped with a 3600-m cable, the winch weighed 1.9×10^4 kg. The thermal drill had an annular heater 124 mm in inner diameter (I.D.) and 162 mm in outer diameter (O.D.). "Chips", now melt-water, were transported to a built-in tank by a water pump. Capable of taking a 3-m core, the drill was 9 m long and 400 kg in dry weight.

The winch and the thermal drill were immediately sent to Camp Century, Greenland. After several trial drillings in three summers, CRREL started in 1963 their plan of drilling through the ice sheet there. By the end of that summer, CRREL drilled a 264-m hole, which was then filled with a mixture of diesel fuel and trichlorethylene mixed to a density of 920 kg/m^3 to prevent closure of the hole. CRREL resumed drilling in 1964 with the thermal drill in the liquid-filled hole and reached 535 m by the end of summer. However, the thermal drill was found so inefficient that CRREL decided to adopt an electro-mechanical drill (electrodrill, for short) in further drilling in a liquid-filled hole.

A commercially available electrodrill, whose main components were a cable suspension, an anti-torque device, a bailer, a submersible electric motor, a water pump, and a double-tube core barrel with a cutting bit, was purchased and adapted by CRREL for use in a liquid-filled hole in ice. The main adaptation was the use of concentrated glycol as drilling fluid, which was circulated by the pump between the bailer and the bit. Before lowering the drill, the bailer was filled with concentrated glycol, which diluted in circulation by dissolving ice chips. A bailer full of dilute solution was removed to the surface on each return trip of the drill. In the final version, the drill weighted 1.2×10^3 kg and was 25 m long.

The drilling with the electrodrill started in 1965 in the 535-m hole, and the bottom of the ice sheet, 1356 m from the surface, was finally reached by July 1966 (UEDA and GARFIELD, 1968).

After slight modifications, the thermal drill and the electrodrill were sent to Byrd Station together with the winch, and were used in the 1966–67 and 67–68 austral summers to drill through the ice sheet. The bottom was reached by January 29, 1968 at 2164 m depth (UEDA and GARFIELD, 1969a).

Meanwhile, since the usefulness of a thermal drill in dry drilling had been fully appreciated, CRREL designed a light-weight cable-suspended system capable of core drilling to 450 m (UEDA and GARFIELD, 1969b). Consisted of a winch with a 450-m cable, a thermal drill (CRREL Mk II), and a 5-kW gasoline generator, the system had a gross shipping weight of only 1180 kg, a tremendous reduction from 2.6×10^4 kg mentioned before of the rotary system of similar capability. Being a shortened version of the large thermal drill, the new drill, CRREL Mk II, was 4.6 m in length, 80 kg in dry weight, and capable of taking a 1.8-m core instead of a 3-m core, while it had an annular heater of the same dimension. In the new drill, melt water was sucked to the tank evacuated by an air pump.

CRREL made the first of this system in 1963 for the Canadian Department of Mines and Technical Surveys, who drilled a 121-m hole on Meighen Island (80°N, 90°W) in 22 days in July 1965 (PATTERSON, 1976). Two more were made in 1966 for the United States Antarctic Research Program and for the Australian National Antarctic Research Expedition. The former drilled a 335-m hole at Byrd Station in 260 hours in 1967–68 austral summer (UEDA and GARFIELD, 1969b) and the latter a 310-m hole in Amery Ice Shelf in five months in 1968 (BIRD, 1976).

3. Planning, Preparation, and Performance of JARE Drilling Operation

3.1. Planning and preparation for JARE-12 and 13

The transportation capability of JARE-12 limited the total weight of drilling equipments to around 1000 kg. According to the available information summarized in the preceding chapter, a cable-suspended system was the only choice. Since no light-weight electrodrill had been known, a thermal drill was considered for JARE-12.

Though glaciologists had hoped to winter at an inland drill-site, it was determined because of a limited logistic support available that a three-man drilling team including one glaciologist would stay from October to December 1972 at the drill site, which would have been completed in the previous austral fall. The maximum available drilling time was considered 70 days, or 420 hours with 6 drilling hours per day.

For the use of eq. (1) in the planning, the following values were assumed: $v=2$ m/h, $V=1200$ m/h, $s=0.25$ h, and $L=1$ m. Then, the depth attainable in 420 hours was calculated as 390 m. A target depth of 400 m was thus assigned to JARE-12 and JARE-13, the latter's operation being considered as a backup.

CRREL having already drilled to the bottom at Byrd Station, Japanese glaciologists hoped JARE-16 could attain at least to 1200 m. That depth would certainly require an electrodrill. Hence, an additional plan was assigned to JARE-12 and -13 to test proto-types of a light-weight electrodrill to be used in JARE-16. From experiences of various hand augers, a penetration rate exceeding 5 m/h was supposed easily attainable by an electrodrill with the power as small as 0.4 kW. With $s=0.25$ h and possible increased values of $V=1800$ m/h, $L=1.5$ m and $v=5$ m/h, eq. (1) showed that the time needed to drill to 1200 m was 973 hours, not an unresonably long time for a wintering party.

In the summer of 1969, a full set of blue prints of a winch and a drill, CRREL Mk II, was supplied to JARE by CRREL with their courtesy, and feasibility studies of adapting them to JARE were started.

The most serious item was an electric cable. In response to JARE's request, Furukawa Denki Kogyo K.K. (Furukawa Electric Co., Ltd.) made a sample length of cable similar to CRREL's one. Extensive laboratory tests of the sample proved that it would be quite usable in expected cold temperatures.

In CRREL's design, the winch was driven directly by a gasoline engine of the generator. An electric motor was adopted in our design for easy control of the winch. In the early stage of planning, a 5-kW 200-V single-phase gasoline generator had been considered as a general power source of the drill site because in JARE-12 only three persons would stay for two or three months. Hence, a single-phase 1-kW commutator motor had been considered for the winch. However, the JARE logistic committee decided to install a larger 12-kVA three-phase diesel generator at the drill site from the beginning, expecting that the drill site would be expanded and permanently occupied from JARE-13 on. Therefore, a three-phase 1.5-kW induction motor was adopted for the winch.

The drill design was considerably changed mainly because of difficulties in obtaining thick plastic and aluminum pipes in CRREL's design. Moreover, for the sake of easy handling, the weight and length of the drill was reduced at the sacrifice of the length and diameter of core: The drill, capable of taking a core 1 m long and 103 mm in diameter, would be 2.5 m in length and 30 kg in dry weight. The drill was named JARE 140 because it would make a hole of about 140 mm in diameter.

Besides the winch and the thermal drill designed by one of the authors (Y.

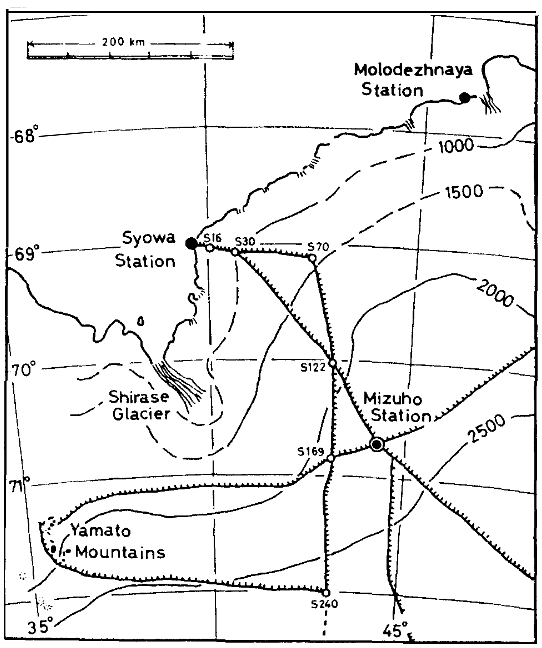

Fig. 1. Location of Mizuho Station (70°41′53″S, 44°19′54″E; 2230 m above sea level; Ice thickness 2095 m).

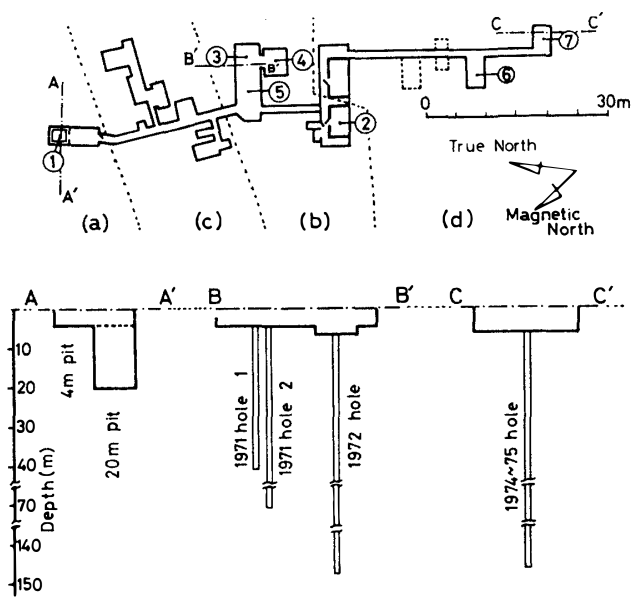

Fig. 2. Plan of Mizuho Station as of January 1975 and vertical sections of the drilling sites and the 20-m pit; ① Refuge hut, ② Living guarters, ③ Drilling site, ④ Glaciological laboratory, ⑤ Generator-site, ⑥ New generator-site, ⑦ New drilling site, (a), (b), (c) and (d) indicate the areas constructed by JARE-11, -12, -13 and -15, respectively.

SUZUKI), a simple electrodrill, consisting of an anti-torque device, a 100-W induction motor with a built-in gear reducer, and a single-tube core auger, was designed by T. KIMURA, chief of the JARE-12 drilling team.

Actual making of the drilling equipments began in May 1970 after a budget of some four million yen had been allocated to them. The completion of them was hence so delayed that they had to be shipped without any test.

Meanwhile, in July 1970, JARE-11 opened a depot*, Mizuho Station, at a position approximately 270 km southeast of Syowa Station. The ice thickness there measured with ice-radar was reported 2095 m.

As soon as JARE-12 left Japan in November 1970, preparation of drills for JARE-13 was begun. It had been hoped to develop a practical electrodrill, but a thermal drill was adopted again, because no adequate gear reducer was found (the 100-W motor with a gear reducer used before was considered too weak for a practical electrodrill). A new thermal drill, JARE 140 Mk II, easy to disassemble in case of troubles, was designed by Y. SUZUKI and H. NARITA, chief glaciologist of JARE-13. The drill was about 3 m in length, 35 kg in dry weight, and capable of taking a core 1.2 m in length and 106 mm in diameter. The increase in core diameter was due to thinning of the wall of annular heater: The thinning was attempted because it would reduce the area to be melted and, hence, the power required for the same penetrating rate.

As mentioned before, JARE-13 drilling operation was considered as a backup to JARE-12 operation. But, because the failure of JARE-12 in reaching to the target depth had been reported just before the departure of JARE-13 (see next paragraph), it was decided to turn a considerable part of glaciological activities of JARE-13 to drilling operation.

The details of the equipments were given elsewhere (SUZUKI, 1976) and also will be described later in Section 4.

3.2. Drilling operation in 1971 (JARE-12)

On June 28, 1971, JARE-12 personnel arrived at Mizuho Station, where a refuge hut made of corrugated steel sheet had been left. They stayed there for two weeks to construct living and drilling quarters and to install a 12-kVA generator. They returned to Mizuho on September 28 with the drilling equipments. The winch was assembled by October 16 and drilling was started with the electrodrill from the floor of the drilling quarters, which was at a depth of 4.3 m from the surface at that time. (Hereafter, all depths relating to the operations in 1971 and 1972 will be referred to an imaginary surface defined with this depth of the floor. Namely, a depth of z m will mean a level $(z-4.3)$m below the floor. As for depths relating to the 1974–75 operation, see Section 3.5.)

* The depot had been called Mizuho Camp until March 1978, when it was officially renamed Mizuho Station. The new name is used throughout this issue. The officially adopted coordinates of Mizuho Station are: 70°41′53″S, 44°19′54″E and 2230 m above sea level.

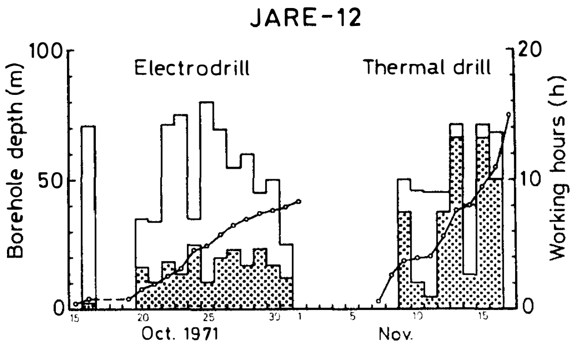

Fig. 3. Progress diagram of drilling in 1971: Dotted area indicates the actual drilling hours and blank area the hours spent for maintenance.

Difficulties were felt in adjusting the anti-torque device of the drill. When the device worked well, the drill could penetrate 50 cm in 10 to 15 minute, that is, with the penetration rate of 2 to 3 m/h. Though the drill had been designed to take a 1-m core, the longest core obtained was 50-cm long, because the helical fins could not transport chips as high as expected.

On November 1, the drill stuck at a depth of 41.9 m. Recovery effort ended on November 6, when the cable slipped out from the connector of the drill.

With no elaborate machine tool available, a make-shift connector was made of

Table 1. Summary of drilling activities.

Year	1971 (JARE-12)	1972 (JARE-13)	1974–75 (JARE-15 and -16)
Personnel	Tsuneyoshi KIMURA, Yoshimasa SHIMAZAKI, Tomomi YAMADA, Masayoshi NAKAWO	Hideki NARITA, Fumio OKUHIRA, Susumu HAYASHIDA, Kazunori UMEDA, Asao MASUKAWA	(JARE-15) Okitsugu WATANABE, Takashi IKARASHI, Kazuhide SATOW, Masayuki INOUE, Isao FUJII (JARE-16) Takatoshi TAKIZAWA, Takeshi KUROKAWA
Drill/depth /drilling period	Electrodrill /4.3 m–41.9 m /Oct. 16–Nov. 1 JARE 140 /4.3 m–75.0 m /Nov. 8–17	JARE 140 Mk II /6.0 m–147.5 m /July 28–Nov. 14	JARE 160A /5.2 m–142 m /Dec. 6–Jan. 19 JARE 160B /106.7 m–145.4 m /Jan. 21–28
Length/depth-range of cores sent to Japan	37 m/4.3 m–41.9 m 45 m/26.0 m–75.0 m	139 m/6.0 m–147.5 m	105 m/5.2 m–142 m 5 m/140 m–145.4 m
Core designation	JARE-12 cores	JARE-13 cores	JARE-16 cores

thick wires at hand, and drilling of a new hole was begun on November 8 with the thermal drill. The drilling proceeded rather smoothly with a penetration rate up to 1.8 m/h, after the initial troubles which occurred mainly in the water suction system had been fixed. The shock necessary to break a core was so large that the winch, weighing some 800 kg, was jerked. The method of core-breaking was hence changed at the sacrifice of the diameter of core at its end. Namely, before the cable was pulled up, the drill was stopped for 2 to 3 minutes with the heater on so as to thin the core and lower the breaking shock. The make-shift connector had to be checked and replaced often, because the breaking shocks, even weakened, loosened the connection in several runs. Despite such precautions, the cable slipped off the connector and the drill was lost at 75 m on November 17.

Core recovery was good but cores taken from shallow depths with the thermal drill were considerably infiltrated with melt-water and those above 26 m in depth were discarded. In total, 37 m of cores taken with the electrodrill from between 4.3 m and 41.9 m, and 45 m of those taken with the thermal drill from between 26 m and 75.0 m were sampled. They were cut lengthwise into halves at Mizuho Station, where one halves were used for various measurements. The other halves were sent to Japan.

3.3. Drilling operation in 1972 (JARE-13)

Mizuho Station, evacuated on January 19 by JARE-12 drilling team, was occupied by JARE-13 inland wintering party on as early as April 27. Several weeks were spent for construction of new buildings and installation of meteorological and glaciological instruments before preparation of drilling began; the winch was displaced several meters; a shallow pit was dug in front of the winch; the new drill, JARE 140 Mk II, was assembled, connected to the cable, and tested. Then, drilling of a new hole was started on July 28 from the bottom of the pit at a depth of 6 m from the surface. The pit was necessary because the height of the mast designed for the JARE 140 drill was short for the new drill.

Low ambient temperatures in the drilling quarters, −25°C on the average during the operation, caused many troubles in every part of equipments. The most vulnerable was the diaphragm pump of the drill, which often failed to start because of stiffening of its diaphragm and had to be warmed by hot air from an oil burner for as long as one hour until it functioned normally.

On September 14 the depth of the hole reached 110.1 m, where the drill stuck. No hose, long enough to reach the bottom, having been available, a hand-made container with a valve at its bottom was made to pour antifreeze to the bottom of the hole. In total, 50 liters of hot antifreeze had been poured by September 22, when the drill was finally recovered, but only with severe damages to the pump.

A pump of a different type was obtained from Syowa Station on October 28. Fortunately, the pump could be fitted to the drill, and the drilling was restarted

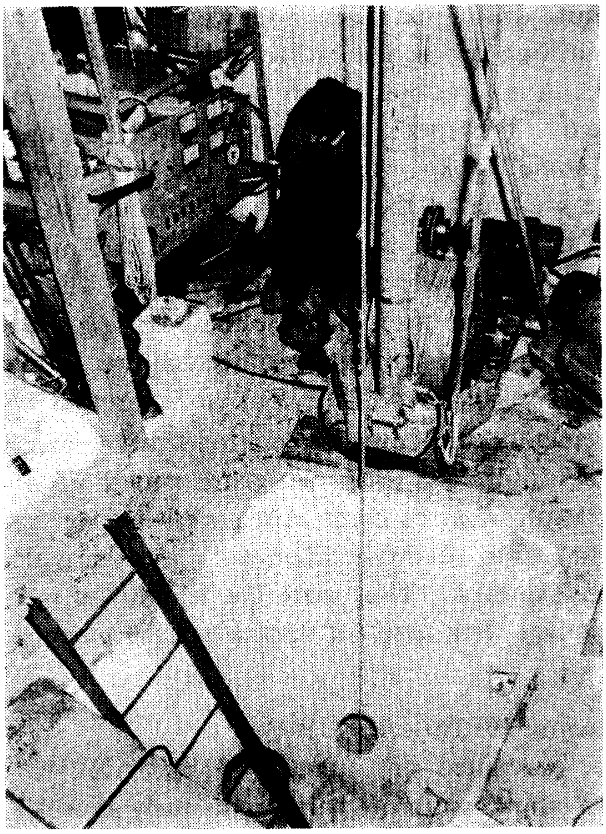

Fig. 4. The 400-m winch in operation in 1972.

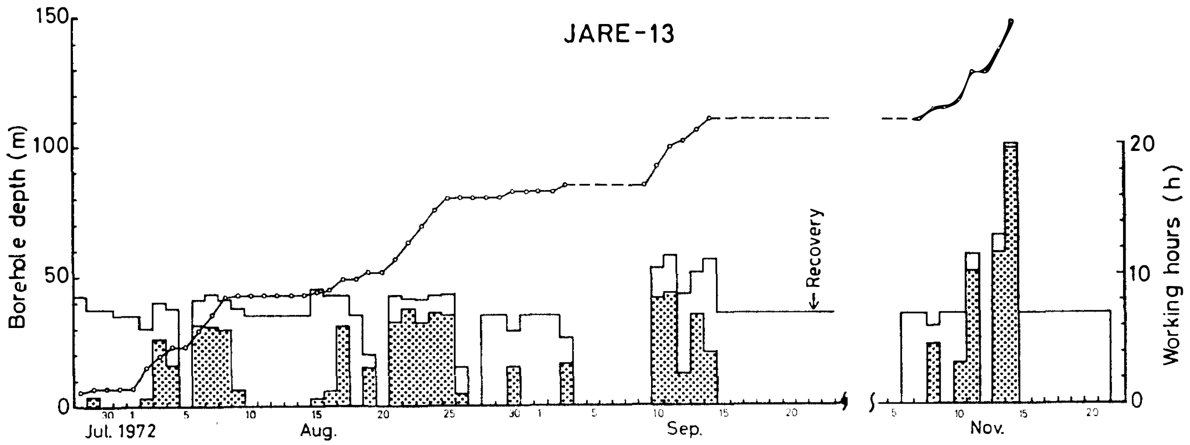

Fig. 5. Progress diagram of drilling in 1972: Dotted area indicates the actual drilling hours and blank area the hours spent for maintenance.

on November 6. The depth of the hole reached 147.5 m on November 14. The drill stuck in the next run. Recovery effects ended on November 21, when the cable was pulled with a lever-block, resulting in the breakage of the drill between its pump housing and its tank.

Meanwhile, the work to deepen a 4-m pit dug by JARE-11 in 1970 was begun on October 9 and continued until December 7 when the depth of the pit reached 20 m.

The average penetrating rates of the JARE 140 Mk II were 1.3 m/h for firn and 1.1 m/h for ice. The core-recovery rate was about 98%; cores totaling 139 m in length were obtained from a depth-range between 6.0 m and 147.5 m.

3.4. Planning and preparation for JARE-15 and -16

In spite of failures of JARE-12 and -13 in attaining the target depth of 400 m, the drilling project of JARE-16 was never abandoned but was reduced somewhat. Instead of the original plan of the operation starting in July 1976 by several wintering members, it was decided that the operation would be done for a maximum of 40 days in January-February 1975, with two JARE-16 members flown to Mizuho Station directly from the icebreaker FUJI. Equipments would have been transported to Mizuho Station in the previous year by JARE-15 traverse party who, after finishing the traverse, would join the drilling operation, or desirably start the operation before the arrival of the JARE-16 personnel. When the both parties joined, the drilling would be done round the clock by three teams. Available working time was estimated at 1000 hours in maximum.

No reliable electrodrill had yet been developed and experiences by JARE-12 and -13 suggested that it would be very difficult, if not impossible, for a thermal drill to penetrate at the rate of 2 m/h. Furthermore, in order to get a traveling velocity of 1800 m/h with a longer and hence heavier cable, one would need an electric motor too strong to be started by the 12-kVA generator available. Therefore, in using eq. (1) realistic values would be $v=1.5$ m/h, $V=1200$ m/h, $L=1.5$ m and $s=0.25$ h. With these values, the attainable depth in 1000 hours was calculated as 787 m. A target depth of 800 m was hence set for JARE-16 operation. It was hoped that dry drilling would be possible to that depth. Preparation was begun in early 1973 of a winch with a 800-m cable and two 3-kW thermal drills of a new type, JARE 160.

As a winch motor, a 1.5-kW induction motor was again used, though it was too weak to ensure a hauling rate of 1200 m/h for a winch with a longer cable. Use of a more powerful induction motor was difficult because of the large starting current in an induction motor. A DC motor would have been used if a rectifier mentioned below had been adopted earlier. The JARE 160 drill, designed to take a core 1.5 m long and 130 mm in diameter, was 3.4 m long and would drill a hole 170 mm in diameter (the misleading naming was due to a hole diameter of 162 mm in the early stage of planning).

Since the cable had only two power conductors, the drills had been previously powered from one phase of the generator and in order to prevent a severe imbalance dummy loads had been connected to other phases, increasing fuel consumption considerably. Based on a suggestion by mechanicians of JARE-15, a converting system to convert 200-V three-phase AC into 0-to-230-V DC was adopted.

The drilling operation by Nagoya University on the ice island T-3 in the fall of 1973 should be mentioned here. It was hoped to test a JARE drill there, while Nagoya University planned to take a large core at least 250 mm in diameter. A final technical plan was so worked out that the JARE 160 drill would drill a pilot hole 170 mm in diameter in advance and a large thermal drill, simply a core barrel with a large annular heater at its bottom and a guide pipe at its side, would take large cores along the pilot hole in which the guide pipe would advance and into which melt water would be allowed to flow: A core-cutting mechanism to be activated by a messenger dropped from the surface was installed in the guide pipe.

The Nagoya party arrived at Barrow, Alaska, in September 1973 with one of the JARE 160 drills, the large thermal drill, and a 400-W electrodrill, the test of which had been later added to the operation. Poor weather prevented them from getting to T-3 until the end of October, but by the end of November, they succeeded in taking 30 m of cores 250 mm in diameter and 31 m of cores 132 mm in diameter.

Based on the interim report from T-3, the other JARE 160 drill was modified into the JARE 160A, which was brought by JARE-15 together with the 800-m winch. As a backup to JARE 160A in case of its loss, an elongated version, JARE 160B, was made in 1974 and brought by JARE-16.

3.5. Drilling operation in 1974–75 (JARE-15 and -16)

Mizuho Station, which had been only temporarily visited by JARE-14 a few times, was occupied by JARE-15 four times; in 1974 from January 19 to February 2, from March 13 to September 4, and from October 10 to 14, and in the austral summer 1974–75 from November 17 to February 5. The first stay was to support the JARE-14 traverse, the second to expand the station, the third a short visit by a traverse party heading southward (the Highland traverse party) and the fourth to carry out drilling.

The 800-m winch was installed by August 18 at the new drilling site, a roofed pit 6 m by 3.2 m in area and 5.2 m in depth. (Hereafter, all depths relating to the 1974–75 drilling will be referred to an imaginary surface 5.2 m above the pit floor. See Section 3.2.) The JARE 160A drill was brought to the station on November 17 together with the controller in which the current converting system previously mentioned was incorporated. It was found on arrival that a heavy transformer in the controller had been loosened and severely damaged the controller. Despite such an accident, drilling was begun by T. IKARASHI, who was responsible for the JARE-15 drilling operation, together with K. SATOW, glaciologist, and I. FUJII, medical doctor, both from the Highland traverse party which had returned to Mizuho on November 29. The number of drilling personnel increased to four on January 8 when I. FUJII was replaced by O. WATANABE and M. INOUE, both glaciologists of

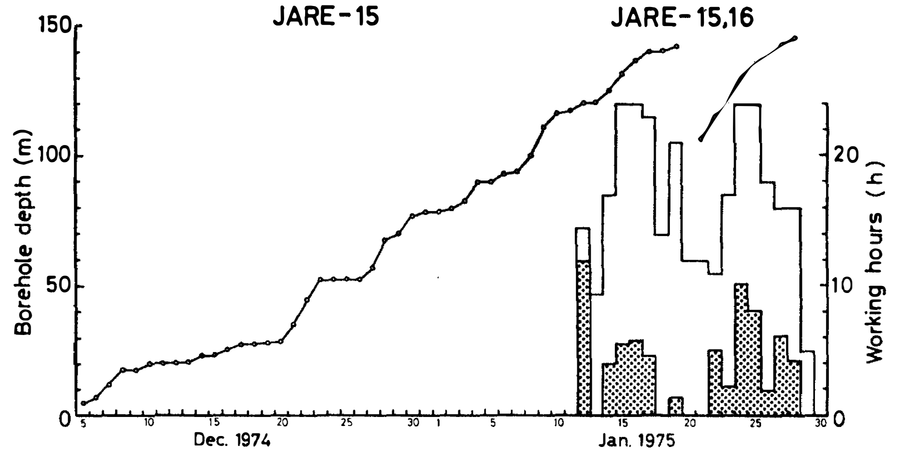

Fig. 6. Progress diagram of drilling in 1974–75: Dotted area indicates the actual drilling hours and blank area the hours spent for maintenance.

the Sandercock traverse party which had left Mizuho on December 14 and returned on January 7.

Having worked six to nine hours daily, they reached 116 m on January 10, when T. TAKIZAWA and T. KUROKAWA of JARE-16 joined. Daily working time was now increased up to 22 hours.

Dispite the hard work, the hole advanced very slowly. The slow advance might be partly attributed to the inadequate design of the 160 type drill which necessitated of detaching its core barrel to take out a core. It was troublesome to reattach the barrel to the swinging drill. Moreover, electric and water piping connections had to be carefully examined every time the barrel was reattached.

Below 120 m, the drill often caught the wall of the hole when it was slowly nearing the bottom (Trouble A in Fig. 7). In such cases, the drill was either pulled up for some length and then lowered a little faster or operated with reduced power in a few minutes to melt supposed obstacles. Sometimes, a few repeated cycles of these two procedures were necessary for the drill to reach the bottom. Another trouble was that the drill did not advance though it had certainly reached the bottom (Trouble B in Fig. 7). The reason being unclear, this trouble was overcome only by chance in repeated runs. Anyway, the advance of the drill and the power supply had to be carefully monitored lest the heter should have burned out in poor contact with ice.

By the midnight of January 17, the hole reached 142.6 m. In the next run, the drill stopped 2.7 m above the bottom. The relief procedures did not work, so the drill was pulled up to the surface for inspection. Several runs were tried in vain in the afternoon of January 19. A sudden stop of the winch in rapid lowering of the drill in the last run caused the cable slip off the drill suspension and the drill was lost. The screw clamp in the cable suspension must have been loosened.

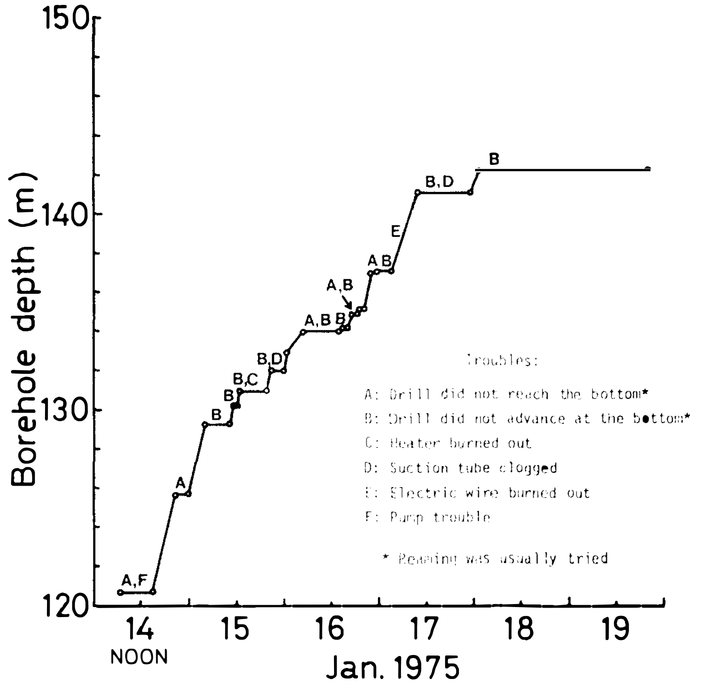

Fig. 7. Detailed progress diagram from January 14 to 19, 1975.

Work to detour the lost drill with the JARE 160B drill began on January 21. The drill was lowered in the hole slowly to catch the wall at an appropriate depth. It caught the wall at the depth of 106.7 m. Then it was operated with the power supply of 1.5 kW, half the rating power. The drill advanced 1.6 m in one hour. No core was recovered in this run. The next run recovered a core having a crescent cross-section. In the subsequent runs, the shape of the recovered core became better and better and finally in the run to 124.7 m a completely cylindrical core 80 cm long was recovered. The subsequent runs were then operated with the rated power supply to the heater. Between 135.8 m and 137.1 m, the cores lacked up to 10% of a circle in their cross-section, showing that two holes touched there. In the evening of January 27, the depth of the new hole exceeded that of the old hole.

The success of the detour, however, was followed by failures. In the morning of January 27, the rectifier burned out in a run to 145.7 m. The power supply was then changed to AC. In the first AC-powered run, the drill advanced 50 cm in 67 minutes and recovered a thin core of 118 cm long. In the next run, the drill stopped at 20 cm above the bottom, and advanced 50 cm in 59 minutes to 146.5 m, where the drill was stopped for 3 minutes with a heater on to thin the core for easy break. After this routine operation, it was found that the drill stuck, the reason being unknown.

On January 29, sixty litres of hot antifreeze was poured into the hole with a

140-m long rubber hose. Several pulling efforts were made in vain. Meanwhile, a fire broke out in the generator room, ruining the generator. With little time left in the summer season, the drilling operation was terminated.

Sampled cores totaling 110 m were transported to Japan, of which 105 m were taken from a depth-range of 5.2 m to 142 m in the first hole and 5 m from that of 140 m to 145.5 m in the detouring hole.

3.6. Core management

3.6.1. Naming

For convenience' sake, the cores obtained in 1971, 1972 and 1974–75 will be named JARE-12 cores, JARE-13 cores and JARE-16 cores, respectively. The general name will be JARE Mizuho cores, or, simply, Mizuho cores. If necessary, JARE-12 cores will be divided into JARE-12A cores, which were taken with the electrodrill, and JARE-12B cores, which were taken with the thermal drill.

3.6.2. Transportation and storage

The halved JARE-12 cores were wrapped with aluminum foil and put in polyethylene bags. Then, they were packed in cartons lined with PSF (polystyrenefoam) boards. The container for JARE-13 cores was a carton of $0.52\times0.6\times0.4\,m^3$ in inner dimensions. Several specially shaped PSF boards served as spacers as well as insulators. Six 0.5-m long JARE-13 cores, each put in a polyethylene bag, were put in one container. Since such PSF spacers became too bulky, they were not used for JARE-16 cores 0.132 m in diameter. The JARE-16 cores, each put in a polyethylene bag, were placed in ordinary cartons with snow as insulator and spacer.

Core transportation from Mizuho to Japan by each party was done in a similar manner: Cores packed into the containers were transported by sledge to a depot, S16 (Fig. 1), then by helicopter to the icebreaker FUJI where they were kept in a refrigerated room. Upon arrival at Tokyo, the containers were immediately transferred to a refrigerated truck, which transported them to Sapporo. The cores have been stored in the cold rooms of the Institute of Low Temperature Science, Hokkaido University, at temperatures of around −15°C occasionally rising up to −5°C.

3.6.3. Distribution

After registration, the cores were distributed in parts to scientists participating in the Glaciological Research Program. The JARE-13 cores had been divided as shown in Fig. 8 before they were distributed, while the halved JARE-13 cores and JARE-16 cores were distributed without any further division. The remaining cores have been offered for public scientific investigations. As of May 1978, there remained 68.85 m of the halved JARE-13 cores and 53.63 m of the JARE-16 cores in Sapporo. They are now in the custody of the Department of Glaciology, National Institute of Polar Research, Tokyo.

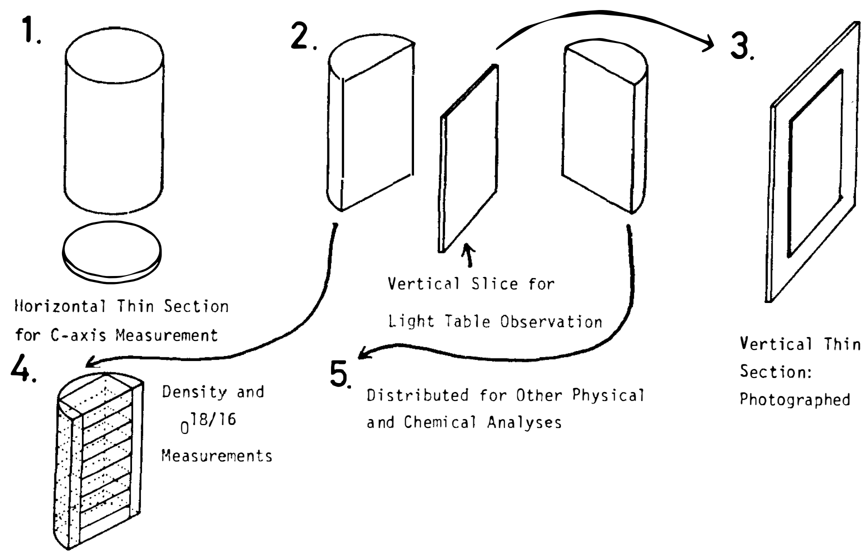

Fig. 8. Cut of JARE-13 cores.

4. Details of Equipments

4.1. Cable and winch

The specifications of the cables are shown in Table 2. Both are of CRREL-type, having seven control conductors and one power conductor, the latter together with double armors intended to transmit large direct or single-phase alternating current. In order to reduce load on a winch, unit weight of the 800-m cable was decreased at the sacrifice of the tensile strength and the conductivity of power conductor and armors. The designed value of 3×10^4 N of the tensile strength seems enough to break a core 0.132 m in diameter and the power conductor and the armors can safely transmit 30 A.

The power trains are similar for both winches (Fig. 9). The 800-m winch drum had a cylindrical slip-ring assembly, instead of a planar one used in the 400-m winch, because the former was easy to make and maintain.

4.2. Thermal drills

Specifications of the JARE drills are given in Table 3 together with those of the CRREL Mk II drill (UEDA and GARFIELD, 1969b). Every drill except the JARE 140 drill consisted of five blocks: suspension block, air pump block, water tank block, core barrel block, and main heater. The third and fourth blocks were structurally combined in one block in the JARE 140 drill.

4.2.1. Suspension block

A cable suspension with a tension indicator is necessary for a thermal drill for two reasons: First, there is an optimum value of pressure against ice to maximize the penetration rate of a drill and usually a thermal drill is too heavy to give that

Table 2. Specifications of cable.

	JARE-12 (400 m)	JARE-15 (800 m)
Plain copper: Number/dia.	7/0.23 mm	7/0.23 mm
Thickness of nylon insulation	0.23 mm	0.23 mm
Diameter of one conductor	1.15 mm	1.15 mm
Diameter of seven conductors	3.45 mm	3.45 mm
Thickness of mylar tape layer	0.15 mm	0.15 mm
Plain copper: Number/dia.	12/1.18 mm	15/0.9 mm
Diameter up to power conductor	6.1 mm	5.55 mm
Thickness of polyethylene	0.85 mm	0.8 mm
Thickness of braid	0.3 mm (Nylon)	0.3 mm (Polyester)
Galvanized steel: Number/dia.	12/1.0 mm	14/0.8 mm
Tinned hard copper: Number/dia.	12/0.99 mm	14/0.8 mm
Diameter up the first armor	10.4 mm	9.35 mm
Galvanized steel: Number/dia.	27/1.20 mm	25/1.20 mm
Diameter of cable	12.8 mm	11.8 mm
Resistance: Control conductor	$<65\ \Omega/\text{km}$	$<70\ \Omega/\text{km}$
Power conductor	$<1.4\ \Omega/\text{km}$	$<2.0\ \Omega/\text{km}$
Armor	$<1.9\ \Omega/\text{km}$	$<2.5\ \Omega/\text{km}$
Tensile strength	$>4\times10^4$ N	$>3\times10^4$ N
Weight	650 kg/km	450 kg/km

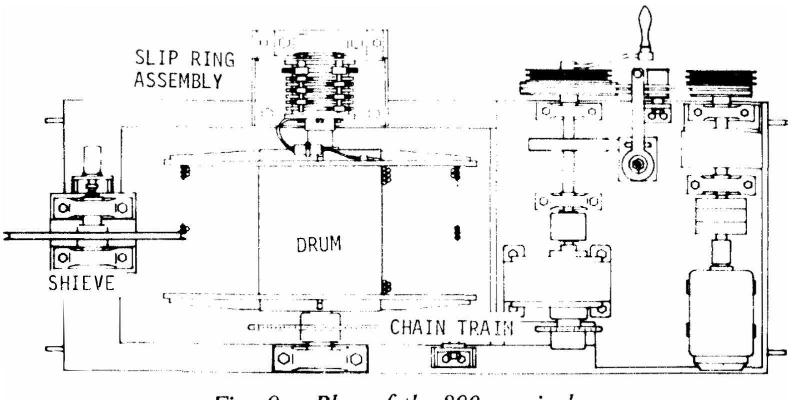

Fig. 9. Plan of the 800-m winch.

optimum value. Secondly, a drill must be partly supported by a cable to make a plumb hole. A telescopic type suspension whose height depends on cable tension was used in every drill with a micro-switch assembly to monitor the height. Three ranges of tension—small, normal, and large—were indicated on the controller by signals from the micro-switch assembly.

The cable was fixed to the inner cylinder by clamping spread armors with

Table 3. Specifications of thermal drills.

Type	Length (mm)	Weight (kg)	Core size diameter/length (mm)	Heater ring O.D./I.D./height (mm)	Heater elements	Estimate melting area (m^2)	Power per unit area (kW/m^2)
140	2500	35	103/1000	142/105/75	100 V 1.2 kW × 2	80×10^{-3}	300
140 Mk II	3050	35	105/1200	142/108/75	100 V 1.0 kW × 2	75×10^{-3}	270
160 160A	3420	43	132/1500	168/134/70	200 V 1.5 kW × 2	90×10^{-3}	330
160B	4000	48	132/1500	168/134/65	100 V 1.5 kW × 2	90×10^{-3}	330
New heater for Type 160A and B				168/134/50	200 V 3 kW × 1	90×10^{-3}	330
CREEL Mk II	4600	80	122/1500	162/124/51	215 V 625 W × 18		
					Used at 115 V	90×10^{-3}	360
					ca. 3.2 kW		

a screw clamp, instead of cementing them with epoxy cement as in CRREL's design.

4.2.2. Air pump block

A diaphragm-type 20-W air pump, Model AP-220, Iwaki Co. Tokyo, capable of producing a vacuum of -450 mm Hg at sea level, was used throughout, with modifications to fit in a cylinder 0.13 m (for the 140 type) or 0.15 m (for the 160 type) in diameter. The pump was a little weak for a tall drill, the JARE 160B.

The pump housing of the JARE 140 drill was a stainless-steel cylinder with an inner flage on top while a female screw threaded at the bottom. The suspension was bolted to the top flange, while a male coupler, glued to an FRP (fiber-reinforced plastics) casing of the tank and barrel block, fitted in the female screw (Fig. 10).

The pump housing of every other drill was a "cage" made of four shafts planted on a basal disk. The cage was covered by an FRP pipe, which was not a tensile structural member. The suspension was fixed to the shafts, and the tank to the basal disk (Figs. 11, 12, 13).

4.2.3. Water tank block

Every tank was made of a 2.1-mm-thick stainless-steel pipe, of either 114.3 mm O.D. (the 140 type) or 139.8 mm O.D. (the 160 type). A simple water gauge using a buoy and a micro-switch was mounted in every tank. The 160B tank had an electromagnetic valve to recover its inner pressure quickly so as to make water in the suction tubes flow down rapidly when the pump stopped.

Every tank was covered with foam plastic, and inserted in a 4.5-mm-thick FRP pipe of 139 mm O.D. (the 140 type) or 159 mm O.D. (the 160B) or covered with

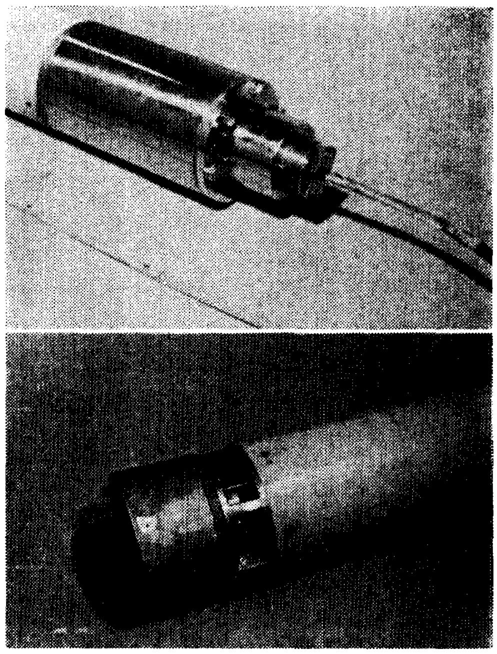

Fig. 10. JARE 140 thermal drill.

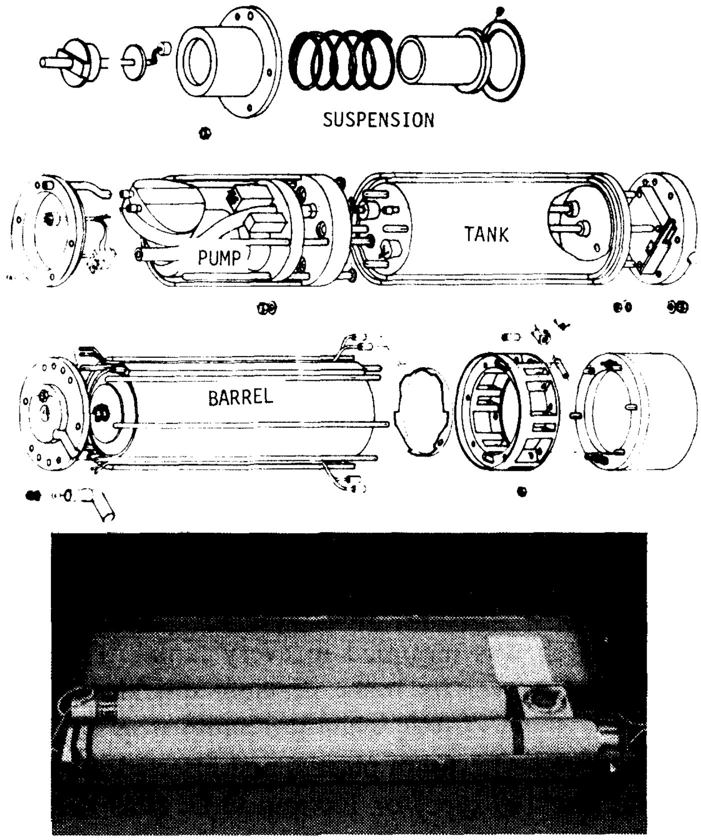

Fig. 11. JARE 140 Mk II thermal drill.

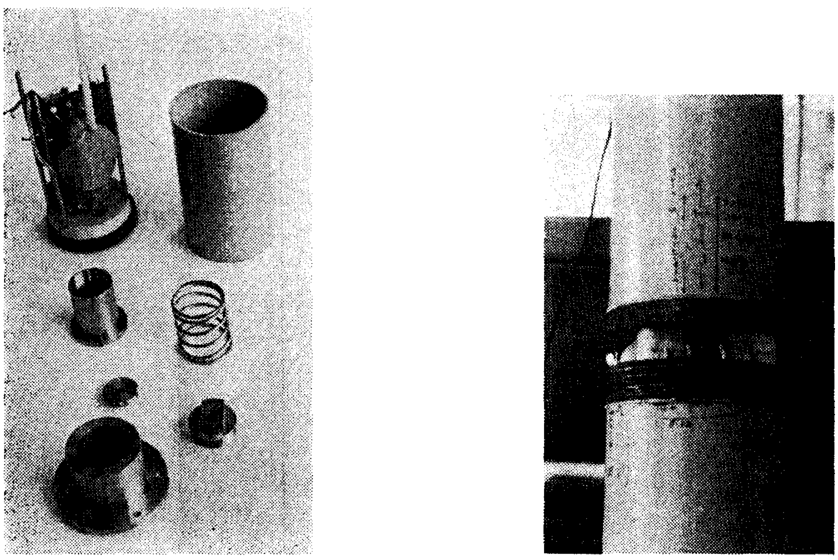

Fig. 12. JARE 140 Mk II: Suspension and pump (left), connection between tank and barrel (right).

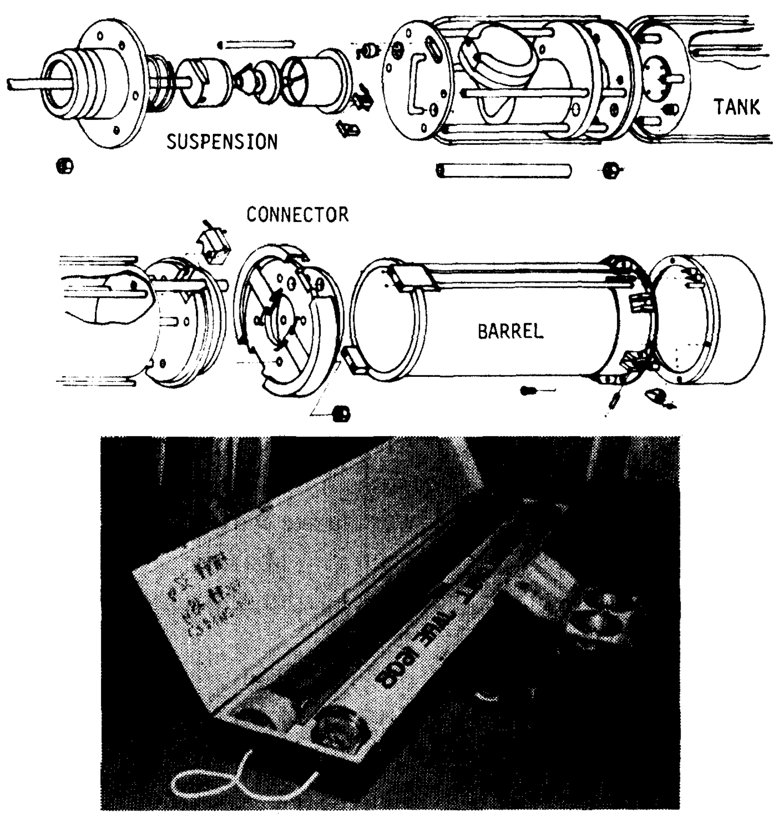

Fig. 13. JARE 160B thermal drill.

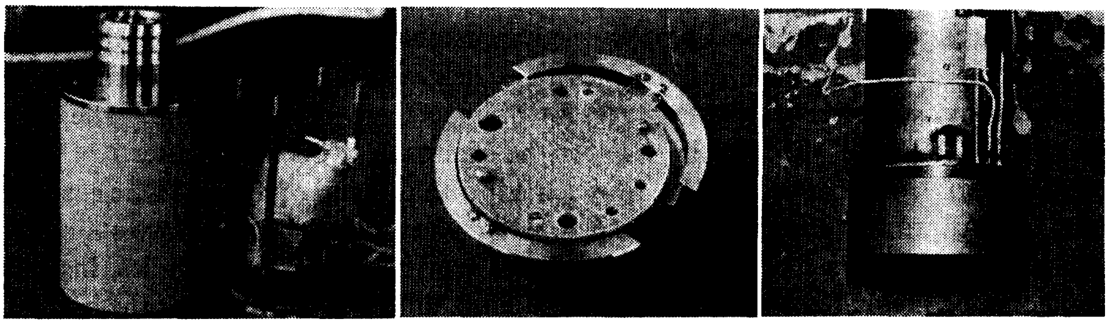

Fig. 14. JARE 160B: Pump (left), connector (center), lower part of barrel with heater (right).

thin sheet steel lined with a rubber sheet heater (the 160A). The heater was intended for emergency use when the drill froze in the hole.

Every tank except that of the JARE 140 was a structural member with four bolts welded on each end panel. The upper four fastened the basal disk of the pump housing and the lower four a connector for the barrel. The connector of the 140 Mk II was a simple disk, while that of the 160 type was a sophisticated device with two semi-circular arms to grip the flange of the barrel. The arms can be closed or openned instantly with a special tool.

4.2.4. Core barrel block

The barrel of the JARE 140 was an extension of the FRP tank casing, with a core-cutting ring glued to its lower end. A special feature of the ring is its catcher-releaser, turning of which can instantly release all catchers from the core so that the core is easily taken out downward.

The structural member of the 140 Mk II barrel block was six 6-mm-diameter stainless-steel shafts with a male screw threaded on both ends. The shafts were planted on a core-cutting ring similar to that of the JARE 140. An inner case was inserted among the shafts. Water piping and electrical wiring were fastened to the inner case, as were the shafts. A 139-mm O.D. FRP pipe covered them for protection. The shafts were fastened with nuts to the connector disk of the tank block.

The barrel of the 160 type was a 2.1-mm-thick stainless-steel pipe, 139.8 mm in outer diameter, with core catcher bearings and a flange welded at the lower end and a flange at the upper end. The lower flange was to support the heater while the upper flange to be gripped by the connector. The barrel had no catcher-releaser. Core was taken out by detaching the barrel from the tank block and turning it upside down.

Water tubes were of stainless (6 mm or 8 mm O.D.). Siliconerubber lead heaters were used for warming the tubes, except those of the 160B, which were hoped to have no freezing problem because of the pressure release valve of the tank.

4.2.5. Main heaters

To avoid the fine machining required by the CRREL design, where cartridge heaters were inserted in an aluminum ring, we adopted molded aluminum alloy heaters throughout. The heating element was made of stainless steel sheath heater of 8 or 9 mm O.D. In the original design, a heater had two heating elements to give clearances for vertical water holes to be machined after molding. The new heaters, made in late 1974 just in time for the departure of JARE-16 after ANARE design (BIRD, 1976), had a spiral heating element with one end of resistive wire earthed to the sheath, so that they had only one apparent electric connector. Two stainless-steel tubes of 1.5 mm I.D. were molded in the new heater for water holes, instead of machining them afterward. Several horizontal holes were drilled near the bottom and/or a groove pattern was machined on the bottom face of some of the heaters as water channels.

4.3. Electrodrills

As described in Section 3, one drill made in 1970 was used by JARE and another made in 1973 was tested on the ice island T-3 for JARE.

The 1970 drill consisted of four components; a suspension, an antitorque device, a power unit and a barrel with cutters. The suspension was common with the thermal drill, JARE 140. The anti-torque device was of a pantagraph-type with four pairs of arms expanded by adjustable springs. The power unit was a

100-W 100-V single-phase 4-P induction motor with a 20: 1 gear reducer. Thus, at 50 Hz the drive shaft rotated at 75 rpm. The barrel was a 1.5-m long steel pipe of 114.3 mm O.D. and 108.3 mm I.D., with a cutter shoe welded at the lower end and triple helical fins welded all over the length. The cutter shoe was of 150 mm O.D. and 105 mm I.D. and three cutters were fixed to it with hexagonal bolts. The pitch of each fin was a uniform 150 mm. Hence, two adjacent fins were 50 mm apart vertically. The upper half of the barrel was the reservoir for ice chips, which the fins were expected to transport up to the upper openning of the barrel. In the actual operation, the fins did not work as expected. The anti-torque device was also ineffective. The power was slightly insufficient.

In the 1973 drill, a 200-V 400-W single-phase 2-P motor (3000 rpm by 50 Hz) was mounted on the upper base of an anti-torque device, which was of the panta-graph-type with three pairs of arms without "skates". A 39: 1 gear reducer was fixed under the lower base of the anti-torque device and cuppled with the motor by a spline mechanism to accomodate the change of the height of the device. The barrel was a 2.2-m long stainless-steel pipe of 139.8 mm O.D. and 134 mm I.D., on which a cutter shoe of 165 mm O.D. and 131 mm I.D. was welded at the lower end and double helical fins of a 240-mm uniform pitch were welded over the length. Two cutters were fastened on the lower face of the cutter shoe, each by one hexagonal bolt, while two claws for core-breaking, each with a vertical rotational axis, were planted on the upper face of the cutter shoe. The two claws struck and caught the core, when the motor rotated reversely. Some results from the test at T-3 were that (1) the drill usually stuck after penetrating 50 to 60 cm, showing ineffectiveness of the fins to transport chips; (2) as long as the drill advanced smoothly, the imput current was much less than the rated value for 400-W output, showing that the motor had enough power for chipping ice; (3) a penetrating rate of up to 9 m/h was obtained for ice; (4) core breaking craws worked well.

5. Concluding Remarks

The JARE drilling project had two aspects; technical and scientific. The first was represented by drilling operations to drill holes and obtaine cores, while the second by scientific investigations using the drilled holes and the obtained cores. Only the first aspect was outlined in the present report as will be expected from its title, because the second aspect is to be described in the individual scientific papers more adequately than a mere outline.

Now, the drilling operations conducted thrice at Mizuho Station had succeeded in drilling four holes, some down to 145 m, and recover over 300 m of cores and thus had contributed somewhat to the success of the drilling project as a whole. Nevertheless, the drilling operations themselves could be hardly regarded successful. They failed to achieve their targets; the 400-m drilling in 1971 and 1972 and the 800-m drilling in 1974–75.

In retrospect many reasons account for the failures, but, in a word, the failures might be ascribed to the lack of preparation; equipments had hardly been tested and personnel had hardly been trained before actual operations. With no adequate natural environment in Japan to test the equipments and train the personnel for ice drilling, expeditions abroad for technical and logistical training should be seriously considered together with construction of artificial test facilities such as the ice-well at CRREL before the next JARE drilling operation which must be begun as early as possible because deep core samples are urgently needed for various scientific studies, especially for studies of historical trend of world climate.

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