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Review

SCIENTIFIC RESEARCH COLLABORATION EFFORTS FOR GREENLAND ICE CORE STUDIES

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Abstract: In the central parts of the polar ice caps, the yearly precipitation in the form of snow is piled on top of the precipitation of the previous year. These snow layers are not subject to any disturbances like *e.g.* melting and run-off. The snow, which is compressed to glacier ice by the burden of the overlaid snow, contains a multitude of information of past environmental conditions such as temperature, rate of accumulation and volcanism. In vertically drilled ice cores from the polar regions, this information can be obtained by various techniques of analysis. Since 1989, glaciological research collaboration has been established in the field of ice core drilling between Japan and Denmark. The collaboration includes the fields of logistics, ice core drill development and science performed on the recovered ice cores.

1. Introduction

Since the first deep ice core was drilled to bedrock and recovered at Camp Century (Fig. 1), NW Greenland (77.2°N, 61.1°W), 1963–66 (UEDA and GARFIELD, 1968), study of ice cores has been an important tool for investigations of palaeo-climate. The potential of ice cores in this science is described in numerous publications since the 1960's, and a compilation, which presents the state of the art in ice core studies can be read in *e.g.* AGU Monograph #33 (LANGWAY *et al.*, 1985), Dahlem Konferenz 1988 (OESCHGER and LANGWAY, 1989) and NATO ASI Series I #30 (DELMAS, 1995).

However, before all this interesting science can be performed on the ice cores, these cores must be recovered. The technology of ice core drilling has been, and still is, a challenge, and involves, besides the drilling technology itself, a major effort in form of logistics. The logistic part of a drilling operation in remote polar regions makes the project very expensive, and by far, most of the invested funds are used for logistics. A compilation of the state of the art in ice drilling technique and the connected logistics can be read in the Proceedings of the Fourth International Workshop on Ice Drilling Technology, Tokyo, 1994 (WATANABE, 1994).

2. Established Collaboration

The collaboration between Japan, represented by National Institute of Polar Research (NIPR), Tokyo, and Denmark, represented by Department of Geophysics, Uni-

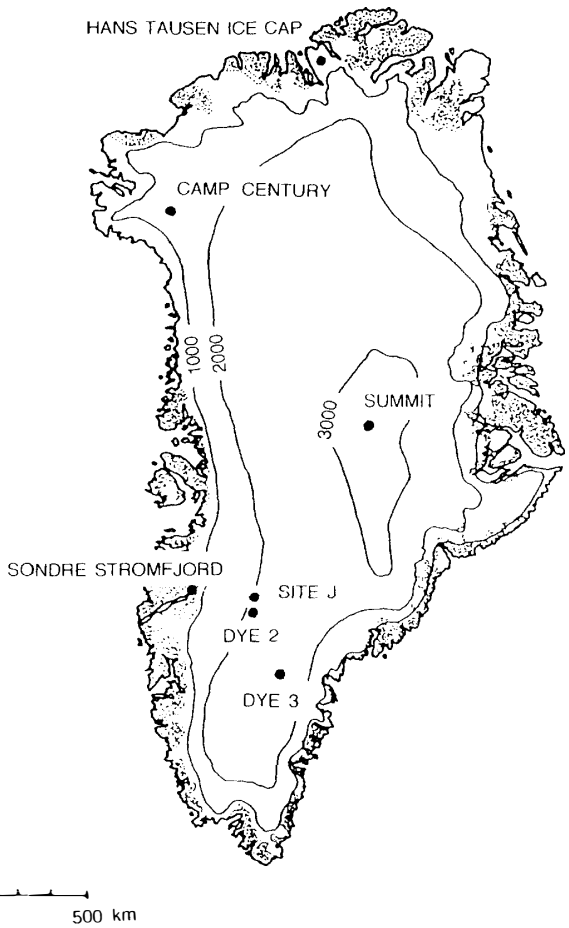

Fig. 1. Positions of the Greenland sites mentioned in the text.

versity of Copenhagen (UCPH), in the field of glaciology started in the summer of 1989, when a team of Japanese scientists, Japanese Arctic Glaciological Expedition (JAGE89), (WATANABE and FUJII, 1990) recovered a 205 m shallow ice core at Site J (67.5°N, 43.5°W, 2000 m a.s.l.) 100 km East of Sondre Stromfjord, in West Greenland (Fig. 2). Sondre Stromfjord has during the summer season 5 weekly commercial flight connections to Copenhagen and housed in 1989 the field operation facility for an European ice core drilling project (EUROCORE) at the summit of the Greenland ice sheet (72.5°N, 37.4°W, 3232 m a.s.l.). The operation facility provided JAGE89 with daily radio communications, assistance in Twin Otter operations to the JAGE89 camp and temporary freezer storage for the ice core samples before shipment to Japan. Besides the collaboration on the logistic side, a scientific collaboration evolved on the retrieved JAGE89 ice core and other Greenland shallow ice cores in the field as well as in laboratories for the study of stable isotopes (past temperature and rate of accumulation, SHOJI *et al.*, 1991), ECM measurements (acidity and volcanism) and physical properties (crystal size and ice deformation, LANGWAY *et al.*, 1993; KAMEDA *et al.*, 1994).

During the years 1990–92 an European ice core drilling program, Greenland Ice Core Program (GRIP), involving 8 European countries and EEC, drilled a 3029 m ice core to the bottom of the Greenland ice sheet at the summit site (Fig. 3) mentioned

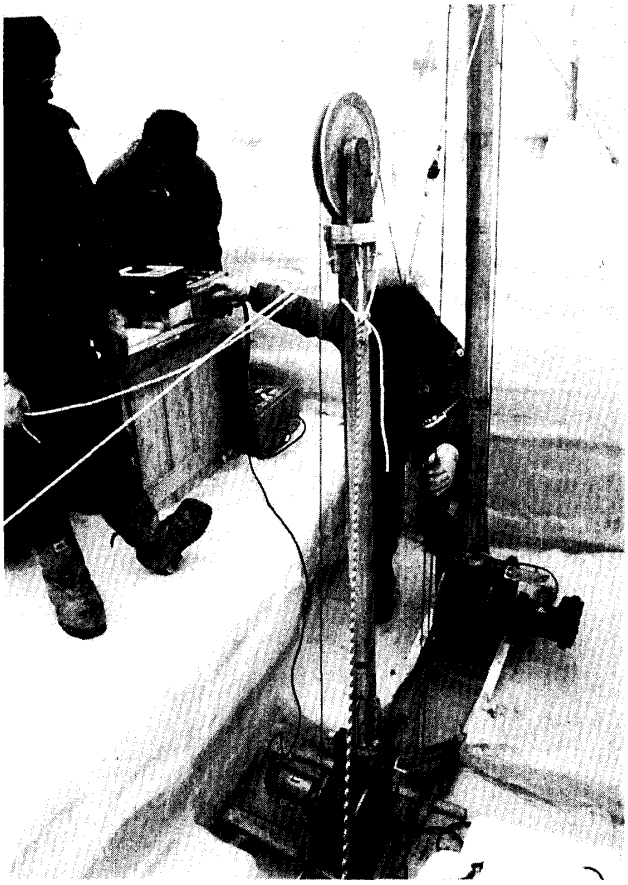

Fig. 2. JAGE drilling oprations at Site J, Greenland.

above. The drill used during the GRIP operation was a modified version of the ISTUK drill (GUNDESTRUP *et al.*, 1984), that penetrated the Greenland ice sheet at DYE3 (65.2°N, 43.8°W) in 1979–1981 and recovered a 2037 m continuous ice core from top to bottom (DANSGAARD *et al.*, 1982). Japanese/Danish/GRIP research collaboration was also made on the GRIP deep ice core (GRIP MEMBERS, 1993). For the GRIP drilling project a camp for up to 50 persons was created on top of the Greenland ice sheet at the summit site. The GRIP program operated from Kangerlussuaq, as Sondre Stromfjord is called today, because this site with its frequent flight connections makes it an excellent staging point for work on the ice sheet.

When the Japanese Antarctic Research Expedition (JARE) in the late 1980's decided to evaluate the possibility for a deep drilling at Dome Fuji Station in Antarctica (77.3°S, 39.7°E), one of the many problems was to manufacture a drill, capable of penetrating 4 km of ice at temperatures down to –58°C. Because of the limitations in logistics and the difficulties due to the environment, the drill had to be lightweight, robust and simple to operate without sacrificing the core quality. One option was to modify the Danish ISTUK drill (GUNDESTRUP *et al.*, 1984). Due to its double curved elastomeric seals and the delicate mechanics of this drill, JARE decided to develop a new type of deep drill. Based on laboratory experiments, which involved a 15 m thick artificial ice sheet, two different drill designs seemed promising. In 1990, it was decided to extend

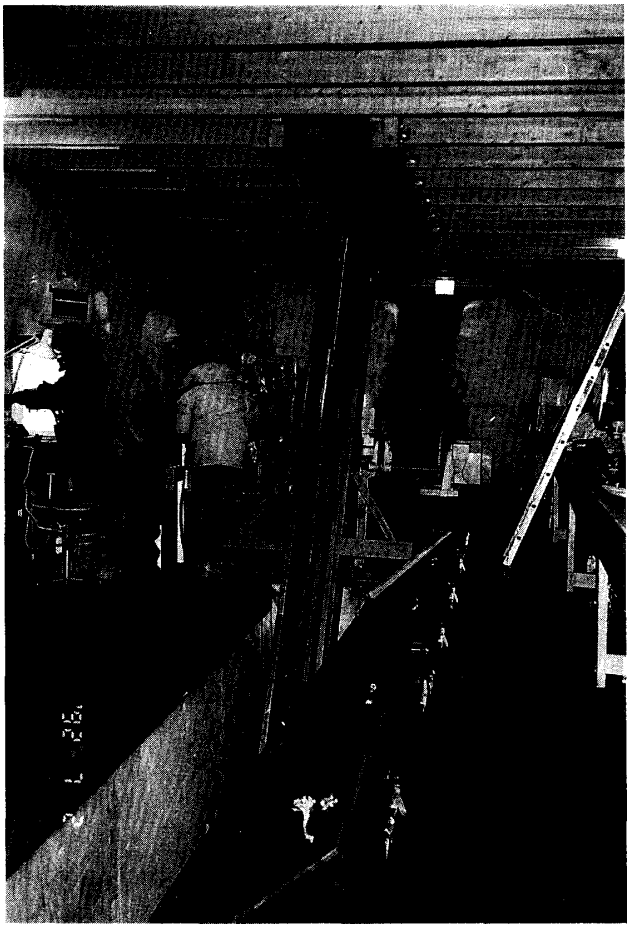

Fig. 3. GRIP drilling operations at Summit, Greenland.

the GRIP drilling with a collaboration with JARE/JAGE. Based on this cooperation, JARE/JAGE established a small satellite camp at the GRIP site for testing of the JARE deep drills. GRIP provided logistic support for the JARE/JAGE drilling. Also, Japanese drillers participated in the Danish deep drilling group. This strengthened the drilling group, and provided direct and informal exchange of information between the two groups. The concept worked well. In 1991, JARE/JAGE tested the two different drill designs at GRIP. Based on this test, a type was selected and tested again in 1992. The tests resulted in several changes and refinements to the original design before the drill was sent to Dome Fuji Station. The resulting design was presented at the International Drilling Symposium in Tokyo 1993.

3. Current Collaboration

In addition to the GRIP deep drilling activities, the Danish drilling group had for many years worked on improving the core quality of shallow drills (SCHWANDER and RUFLI, 1994). Although a shallow drill can drill to 325 m in moderate cold ice (CLAUSEN *et al.*, 1989), the core quality below 130 m is not satisfactory for many types of analysis. The problem is the high pressure in the air bobbles, which creates fractures in the core

during the cutting process. The idea was, that if the cutting process could be lubricated by operating in a liquid filled hole, the core quality should improve. However, until the JARE design evolved, it was significantly more complicated to operate a shallow drill in a liquid than to operate in a usual dry hole. Also the surface procedures are more lengthy, compared to a normal shallow drill working in a dry hole. In order to verify the JARE drill system, and to test if a few metres of liquid at the bottom of the hole improved the core quality, the Danish shallow drill was modified to work in a liquid using the JARE design, and tested in Greenland in 1993. This test verified that the JARE design also worked in a shallow drill, and most importantly, that a drill working in a liquid, ensured the same good core quality below 130 m as found in the uppper 100 m of a dry hole. A liquid layer of only 5 m was sufficient to ensure a very good core quality all the way to the bottom of the 225 m deep test drilling.

In 1993, Denmark became involved in the European Project for Ice Coring in Antarctica (EPICA). In this program, Denmark should together with France work on the drill technique. Because the conditions at the first EPICA drill site at Dome C (75.1°S, 123.1°E) is quite similar to those at Dome Fuji Station, the Copenhagen drilling group had to follow the same line of arguments as JARE followed previously. This resulted in a decision to develop a JARE type of drill for the EPICA drilling. The original JARE design could not be used directly: Dome Fuji Station is a year round operation, whereas EPICA plans to drill only in the two summer months. Therefore, the productivity of the EPICA drill is critical, and velocity of the drill in the liquid filled hole must be at least 1 m/s. Based on the JARE drawings, the French and Danish drilling group started to develop the EPICA drill in 1994. The first phase was to test a prototype drill at the 344 m thick Hans Tausen Ice Cap in Pearyland, North Greenland (82.4°N, 38.2°W), where UCPH already had a glaciological program in 1995. The drill developed for this program was a shortened version of the EPICA drill, producing a core with a diameter of 96 mm in a 130 mm hole. Compared to the original JARE design, the most important modifications were the use of active valves in the drill, allowing a velocity of 1 m/s in a liquid filled hole, and the use of a cylindrical filter around the hollow centre shaft to separate the liquid from the cuttings. The drill worked very well and penetrated the ice cap without any major problems or delays. However, it was observed, that further improvements are required in order to obtain the drilling stability which is required at Dome C, *e.g.* to increase the packing of the cuttings inside the drill to prevent them from being washed out when the drill is hoisted to the surface.

4. Future Plans

In 1995, UCPH was funded for another deep drilling in Greenland, the North Greenland Ice Core Program (NGRIP). This program, mainly a Danish/German program, also involves France, Japan, Sweden, Switzerland and USA.

NGRIP will start its field work in 1996, and is expected to run until 1999. The final version of the EPICA deep drill will be tested in the field at NGRIP prior to shipment to Antarctica in the fall of 1996. Due to the collaboration between the Greenland and Antarctica drilling programs, the EPICA drill will be well tested prior to the start of the EPICA drilling in December 1997.

With two different versions of the JARE design working at NGRIP and Dome Fuji Station, a collaboration regarding training of drillers and exchange of knowledge is foreseen. In fact, using the good communication facilities at Dome Fuji Station, there is already a continuous exchange of ideas between NIPR, the drill team at Dome Fuji Station and the Copenhagen drilling group.

At NGRIP, a collaboration between Japanese, German and Danish scientists in the field of physical properties of the ice core, as well as a collaboration regarding the drilling is planned for.

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