LANGWAY, C.C., Jr. 2008. *The history of early polar ice cores.* Hanover, NH, US Army Corps of Engineering. Engineer Research and Development Center/Cold Regions Research and Engineering Laboratory, ERDC/CRREL TR-08-1, 57pp. Technical report available as hard copy from NTIS, Springfield, Virginia 22161, USA, and as free download from the Cold Regions Research and Engineering Laboratory website: www.crrel.usace.army.mil/library/technicalreports/ERDC-CRREL-TR-08–1.pdf

In this report, readers are taken on a grand tour around early efforts to probe the third dimension of glaciers; how this was achieved and what startling scientific discoveries ensued. The tour starts with the early pit studies of Ernst Sorge at station Eismitte, central Greenland, and Carl Benson in northwest Greenland. This is followed by the early drilling work by the US Army Snow, Ice and Permafrost Research Establishment (SIPRE) during the International Geophysical Year (IGY; 1957/58) in Greenland and Antarctica, the Cold Regions Research and Engineering Laboratory (CRREL) drilling to bedrock at Camp Century, northwest Greenland, and Byrd Station, Antarctica, and finally the Greenland Ice Sheet Program (GISP) Dye-3 drilling from 1978 to 1981. As a research scientist and principal investigator, our tour guide Chet Langway was a highly active participant in all of these ice-coring and scientific efforts, which makes the report a most authentic historical document.

This most interesting report starts poetically with a quote from Henri Bader: 'Snowflakes fall to Earth and leave a message'. The nine sections cover wide ground, under the headings 'Pit studies', 'Previous ice core research', 'International Geophysical Year', 'Post-IGY bedrock cores', 'Laboratory analyses', 'Greenland Ice Sheet Program', 'Paleo-environmental data', 'Conclusions' and 'Summary'. The text is embellished with 26 pictures of historic significance which help to make the reading even more informative and enjoyable. Two tables list the main pit and ice-coring efforts to date. Table 1 covers early pit studies and ice-core drilling projects and the appendix lists the main polar ice drilling efforts between 1956 and 2006. An error is found in the appendix: the NorthGRIP 1999 drilling extended from the surface to 1750 m (probably a world record), not from 1300 to 1750 m as stated. Some projects that drilled shallower cores to bedrock are missing from the appendix, such as the Greenland Renland and Hans Tausen cores, as well as the Antarctic Law Dome and Berkner Island cores.

Three ingredients that were essential for the happy outcome of this highly successful glaciological venture are laid out and discussed:

1. The supportive scientific administration of the US research community, the US National Science Foundation (NSF), cooperating with the US Army Corps of Engineers' directors of SIPRE and CRREL. The active role of the US military in these early efforts is amazing. The names of about 40 of the individuals involved are listed in this context.

2. The enthusiasm of the drilling and drill development community was inspired by the visionary foresight of SIPRE's director, Henri Bader, and the technical inventiveness of B. Lyle Hansen, the chief mechanic at SIPRE and CRREL, and his associates. The dedicated support of A.P. Crary, the chief of NSF's Office of Polar Programs, was vital for these efforts.

   The leading role of the US community in deep ice-core drilling was taken over by the Danes with support from the Swiss during GISP, which resulted in the Dye-3 core to bedrock in 1981. How this came about is left out of the report, in contrast to the detailed reporting on earlier drilling efforts. I was deeply involved in this exercise and add a few facts below concerning this missing issue.

3. The continued development of methods for logging, dating and analyzing the ice cores includes the study of crystal structure and firnification in the earliest cores. The stable-isotope profiles, along with ion chemistry and atmospheric composition from the bubbles in the ice, provided a wealth of environmental parameters relating to climatic change and the forcing factors involved.

The initial drilling projects in the 1950s were mostly based on modified rock drills that produced broken cores. The famous SIPRE hand auger was an exception, being designed for drilling in firn and ice down to 50 m depth. The SIPRE drilling efforts at Site 2, northwest Greenland, and in Antarctica during the IGY were based on a commercially modified, mechanical rotary rock drill equipped with heavy 20 ft (6.1 m) long end-threaded steel pipes as the drill stem. The core quality was fair to good, but at greater depths the removal of the drill string during each run was very inefficient, and proved to be a major drawback. In 1957 Henri Bader tasked Lyle Hansen to develop a 'thermal' drill (Cox, 2005, p. 43) to melt instead of cut the ice around the core. The drill was cable-suspended and the meltwater was stored in a heated tank above the core barrel. Even though core quality was quite good, the thermal shock introduced internal fractures in the core, thus degrading core quality. Several copies of this drill were built for the international community and used in dry drilling operations by Australian, Canadian and Japanese researchers, but never by Icelandic researchers as stated on page 17 in the report. In 1961 a lightweight, shallow-depth (300–500 m) thermal drill was deployed to start the deep drilling operation in Camp Century. The drill team had to solve a wealth of problems using this new drill. The core quality became very poor after drilling liquid was pumped into the hole. In 1965 a new commercially available, cable-suspended rock drill, ingeniously modified for ice drilling, was installed. The cuttings were dissolved in an ethylene glycol water solution circulated between a tank in the drill and the drill head. After final tuning, the drill could deliver 4.5 m of good core in each run and became a most efficient deep ice-core drill. With this drill, the Camp Century core was completed in 1966 and the Byrd Station core in 1968, a most amazing feat. Unfortunately the drill was lost, as well as the technology involved, in 1968 attempts to recover the hole that became blocked by refrozen water from the ice–bedrock interface. The use of thermal drilling has now mostly been abandoned due to better core quality delivered by rotary drills.

The main target of GISP was a deep core at the Dye-3 radar station in South Greenland. The intention was to use a newly developed US wireline drilling system for the task in the late 1970s, but could our US colleagues deliver a well-functioning drill in due time?

Now to the Danish drill developments in the 1970s, so vital for GISP and future coring efforts in Greenland and Antarctica.

I had been inspired by Burt Crary's opening address at the 1968 International Symposium on Antarctic Glaciological

https://doi.org/10.3189/S0022143000200658 Published online by Cambridge University Press

Exploration (ISAGE) in Hanover, NH ('... add the thin dimension... drill, drill and drill some more... a task for the bold and courageous...'). Furthermore, having spent some months with Lyle Hansen in Greenland, listening to his stories forced me to consider Danish drilling capability as an attractive and feasible option. In fact a realistic dream, since we had access to excellent workshops in Copenhagen and our well-functioning group consisted of many highly skilled individuals. Having built a most successful shallow drill in 1975 (Johnsen and others, 1980), our group was ready to start developing a new deep drill in 1977, when problems with the new wireline drill seemed to become overwhelming. In designing, building, testing and deploying the new drill, ISTUK, I worked closely with Steffen Bo Hansen our drill mechanic, Niels Gundestrup our electronic wizard and Niels Reeh our civil engineer and eminent glaciologist. All of the work was financed by Danish funds. During testing and deployment of the drill we received good support from Henry Rufli and Jakob Schwander, two highly skilled members of the Bern group. In order to better cope with this exciting challenge, all my scientific projects were put on hold for 3 years. The performance of the ISTUK drill kept improving during the entire drilling period, and coring at Dye-3 reached bedrock in 1981. The ISTUK drill was also used to penetrate the Greenland ice sheet at the GRIP Summit Camp in 1992 (Johnsen and others, 1994). The drill was copied by Vin Morgan and colleagues at the Australian Antarctic Division, for drilling to bedrock on Law Dome (Morgan and others, 1997). Our accumulated drilling experience was subsequently used to develop a new deep drilling system for upcoming European Greenland and Antarctic deep drilling projects (Johnsen and others, 2007). Looking back, the pioneering spirit of Henri Bader, Lyle Hansen and Burt Crary can be felt through all these successful efforts.

Chet Langway initiated modern ice-core processing and analyses with his early study of the Site 2 core. He continued his efforts by joining forces with Willi Dansgaard and his group in Copenhagen and the late Hans Oeschger and his co-workers in Bern when working on the Camp Century and Byrd Station ice cores. The fingerprints of these three early pioneers can be seen in much of the amazing scientific outcomes of the ice-coring endeavours mentioned above.

For whom is this report intended? Obviously, the ice-core research community should be interested. Also, it is recommended that every user of ice-core data in environmental studies read it to gain a better understanding of the groundwork behind the magic data they often rely so heavily on.

Centre for Ice and Climate Sigfús J. JOHNSEN
Niels Bohr Institute
University of Copenhagen
Juliane Maries Vej 30
DK-2100 Copenhagen
Denmark
E-mail: sigfus@gfy.ku.dk

REFERENCES

Cox, J.D. 2005. *Climate crash: abrupt climate change and what it means for our future*. Washington, DC, Joseph Henry Press.

Johnsen, S.J., W. Dansgaard, N. Gundestrup, S.B. Hansen, J.O. Nielsen and N. Reeh. 1980. A fast light-weight core drill. *J. Glaciol.*, **25**(91), 169–174.

Johnsen, S.J., N.S. Gundestrup, S.B. Hansen, J. Schwander and H. Rufli. 1994. The new improved version of the ISTUK ice core drill. *Mem. Natl Inst. Polar Res.*, Special Issue 49, 9–23.

Johnsen, S.J. *and 16 others*. 2007. The Hans Tausen drill: design, performance, further developments and some lessons learned. *Ann. Glaciol.*, **47**, 89–98.

Morgan, V.I., C.W. Wookey, J. Li, T.D. van Ommen, W. Skinner and M.F. Fitzpatrick. 1997. Site information and initial results from deep ice drilling on Law Dome, Antarctica. *J. Glaciol.*, **43**(143), 3–10.

https://doi.org/10.3189/S0022143000200658 Published online by Cambridge University Press