GLACIOLOGICAL DATA

REPORT GD-8

ICE CORES

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May 1980

Published by:
WORLD DATA CENTER A FOR GLACIOLOGY
[SNOW AND ICE]
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University of Colorado
Boulder, Colorado 80309 U.S.A.

Operated for:
U.S. Department of Commerce
National Oceanic and Atmospheric Administration
Environmental Data and Information Service
Boulder, Colorado 80303 U.S.A.

DESCRIPTION OF WORLD DATA CENTERS[1]

WDC-A: Glaciology (Snow and Ice) is one of three international data centers serving the field of glaciology under the guidance of the International Council of Scientific Unions Panel of World Data Centers. It is part of the World Data Center System created by the scientific community in order to promote worldwide exchange and dissemination of geophysical information and data. WDC-A endeavors to be promptly responsive to inquiries from the scientific community, and to provide data and bibliographic services in exchange for copies of publications or data by the participating scientists.

1. The addresses of the three WDCs for Glaciology and of a related Permanent Service are:

World Data Center A
INSTAAR
University of Colorado
Boulder, Colorado, 80309 U.S.A.

World Data Centre C
Scott Polar Research Institute
Lensfield Road
Cambridge, CB2 1ER, England

World Data Center B
Molodezhnaya 3
Moscow 117 296, USSR

Permanent Service on the Fluctuations of
Glaciers - Department of Geography
Swiss Federal Institute of Technology
Sonneggstrasse 5
CH-8092 Zurich, Switzerland

2. Subject Matter

WDCs will collect, store, and disseminate information and data on Glaciology as follows:

> Studies of snow and ice, including seasonal snow; glaciers; sea, river, or lake ice; seasonal or perennial ice in the ground; extraterrestrial ice and frost.
>
> Material dealing with the occurrence, properties, processes, and effects of snow and ice, and techniques of observing and analyzing these occurrences, processes, properties, and effects, and ice physics.
>
> Material concerning the effects of present day and snow and ice should be limited to those in which the information on ice itself, or the effect of snow and ice on the physical environment, make up an appreciable portion of the material.
>
> Treatment of snow and ice masses of the historic or geologic past, or paleoclimatic chronologies will be limited to those containing data or techniques which are applicable to existing snow and ice.

3. Description and Form of Data Presentation

3.1 General. WDCs collect, store and are prepared to disseminate raw[+], analyzed, and published data, including photographs. WDC's can advise researchers and institutions on preferred formats for such data submissions. Data dealing with any subject matter listed in (2) above will be accepted. Researchers should be aware that the WDCs are prepared to organize and store data which may be too detailed or bulky for inclusion in published works. It is understood that such data which are submitted to the WDCs will be made available according to guidelines set down by the ICSU Panel on WDCs in this Guide to International Data Exchange. Such material will be available to researchers as copies from the WDC at cost, or if it is not practicable to copy the material, it can be consulted at the WDC. In all cases the person receiving the data will be expected to respect the usual rights, including acknowledgement, of the original investigator.

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[1] International Council of Scientific Unions. Panel on World Data Centers. (1979) Guide to International Data Exchange Through the World Data Centres. 4th ed. Washington, D.C. 113 p.

[+] The lowest level of data useful to other prospective users.

This Guide for Glaciology was prepared by the International Commission on Snow and Ice (ICSI) and was approved by the International Association of Hydrological Sciences (IAHS) in 1978.

3.2 Fluctuations of Glaciers. The Permanent Service is responsible for receiving data on the fluctuations of glaciers. The types of data which should be sent to the Permanent Service are detailed in UNESCO/IASH (1969)*. These data should be sent through National Correspondents in time to be included in the regular reports of the Permanent Service every four years (1964-68, 1968-72, etc.). Publications of the Permanent Service are also available through the WDCs.

3.3 Inventory of Perennial Snow and Ice Masses. A Temporary Technical Secretariat (TTS) was recently established for the completion of this IHD project at the Swiss Federal Institute of Technology in Zurich. Relevant data, preferably in the desired format**, can be sent directly to the TTS or to the World Data Centers for forwarding to the TTS.

3.4 Other International Programs. The World Data Centers are equipped to expedite the exchange of data for ongoing projects such as those of the International Hydrological Project (especially the studies of combined heat, ice and water balances at selected glacier basins***), the International Antarctic Glaciological Project (IAGP), the Greenland Ice Sheet Project (GISP), etc., and for other developing projects in the field of snow and ice.

4. Transmission of Data to the Centers

In order that the WDCs may serve as data and information centers, researchers and institutions are encouraged:

4.1. To send WDCs raw[+] or analyzed data in the form of tables, computer tapes, photographs, etc., and reprints of all published papers and public reports which contain glaciological data or data analysis as described under heading (2); one copy should be sent to each WDC or, alternatively, three copies to one WDC for distribution to the other WDCs.

4.2. To notify WDCs of changes in operations involving international glaciological projects, including termination of previously existing stations or major experiments, commencement of new experiments, and important changes in mode of operation.

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*UNESCO/IASH (1969) Variations of Existing Glaciers. A Guide to International Practices for their Measurement.

**UNESCO/IASH (1970a) Perennial Ice and Snow Masses. A Guide for Compilation and Assemblage of Data for a World Inventory; and

Temporary Technical Secretariat for World Glacier Inventory. Instructions for Compilation and Assemblage of Data for a World Glacier Inventory.

***UNESCO/IASH (1970b) Combined Heat, Ice and Water Balances at Selected Glacier Basins. A Guide for Compilation and Assemblage of Data for Glacier Mass Balance Measurements; and

UNESCO/IASH (1973) Combined Heat, Ice and Water Balances at Selected Glacier Basins. Part II, Specifications, Standards and Data Exchange.

[+] The lowest level of data useful to other prospective users

FOREWORD

As part of the Data Center's long-term program to establish data bases on global snow and ice parameters, a two-year project relating to ice core data has been carried out with funding from NOAA-EDIS. The objectives of this work, as initially described in Glaciological Data, Report GD-3, were to locate and index information about world-wide ice core research as part of the larger effort to identify and consolidate "proxy" climate data.

To date, deep ice cores to bedrock have been obtained from a 1390 m hole at Camp Century in northern Greenland and a 2100 m hole at Byrd Station in Antarctica. Numerous intermediate cores of 100-400 m in depth have also been collected from these ice sheets, as well as in various other parts of the world. Recently, shorter cores have been obtained from glaciers on mid-latitude and even equatorial mountains. The value of paleoclimatic information from ice cores is widely recognized. Paleotemperature trends, atmospheric turbidity, snow accumulation rates, and volcanic activity are among the more frequently studied climatic parameters using ice core material. Annual values can be determined in some cases for several millenia, and the total time-scale spans more than 100,000 years for the deep cores.

This report documents most of the ice cores so far collected on a world-wide basis, as well as providing information on literature sources and on the current status of research activities which may affect the types of data that can be archived. The characteristics and structure of the WDC's data base system for ice core data are also described. Our project and this particular issue of Glaciological Data derived considerable benefit from the expertise of the participants in the Workshop on the Status and Future of Ice Core Research and Ice Core Data held at the WDC, 24-26 September, 1979. We thank all concerned for their help in making that gathering a success, particularly the meeting coordinator, Peter MacKinnon, who has also been responsible for the compilation of this issue.

R. G. Barry
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World Data Center-A
for Glaciology (Snow and Ice)

PREFACE

This issue on ice cores combines several elements: the recommendations derived from the Workshop on the Status and Future of Ice Core Research and Ice Core Data; the results of the inventory of North American sponsored ice core programs; and invited contributions from scientists working in the field.

The work of a number of people went into preparing this issue. We are grateful to Peter K. MacKinnon, who coordinated the entire Ice Core Project, and Claire S. Hoffman, who edited the bibliography. Our thanks also to Anne Gensert, Margaret Strauch and Carol Weathers for their efforts on data entry and typing of the text.

Ann M. Brennan
Technical Editor

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The Status and Future of Ice Core Data

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Introduction

The collection of glaciological data has undergone rapid change in recent years with the establishment of large-scale national and international programs such as AIDJEX, GISP, IAGP, POLEX*, each designed to develop basic information on cryospheric parameters. Improved data management practices are evolving to cope with the growth and diversification of data, aided in some instances by the establishment of specific data management positions. In the case of ice core material, a U.S. National Ice Core Facility (ICF) has been established by the National Science Foundation at the State University of New York, Buffalo, under the direction of Dr. C.C. Langway, Jr., Department of Geological Sciences. The ICF evaluates requests for ice core samples and coordinates their distribution to interested scientists.

Ice core-related data involve a wide variety of types of measurement, including the physical and chemical properties of the ice and of enclosed constituents, minerals and trace metals, ice stratigraphy and radiometric dates, information on the borehole and site characteristics, and core site location. Different parameters may be analyzed by workers in a number of institutions in various countries over a period of years following collection of each core.

The importance of ice core data for fundamental research on global paleoclimate is widely recognized (United States Climate Program Plan, 1977; World Meteorological Organization, 1975 and 1977), but no system yet exists for assembling these multi-faceted data and making them conveniently available to the user community. Accordingly, the World Data Center-A for Glaciology (Snow and Ice) (WDC-A) with NOAA-EDIS support has undertaken to identify and inventory existing core data as the first step towards facilitating digital data exchange and the development of a computerized data base. As part of this activity, WDC-A convened a three-day Ice Core Workshop to bring together representatives of various international groups involved in ice core drilling, core research, and data management. Twenty participants from seventeen organizations gathered in Boulder, Colorado, September 24-26, 1979, to discuss the status and needs of the ice core community, the role of WDC-A for Glaciology, and the interactions between data generators and data users. Other related WDC-A activities have included the inventory of cores and core data, described in a following article, and the development of a test data base.

Data Exchange: Status and Problems

Data exchange constitutes an interchange process between a supplier and a recipient. This may be in the conventional mode of scientists exchanging data, or as data flow through a data center. The present stage of ice core data exchange is dependent upon various national ice core funding and research activities and upon the development of operational policies to facilitate data exchange, including the mechanisms provided by the data center system. Data centers operate both as data repositories and as information clearing-houses. Each facet of operation may be suitable for particular types of data.

Ice core research in the countries represented at the Workshop (Canada, France, New Zealand, Switzerland, United States) is funded by government agencies and, in the case of Canada, France and New Zealand, is largely conducted within particular government departments or research institutions. In Switzerland and the United States, research on the core material is primarily carried out by university scientists. In the United States, where drilling is now conducted by the Polar Ice Coring Office (PICO) in Lincoln, Nebraska, policy on specimen and core sample distribution developed by the National Science Foundation (NSF) (see page 69) stipulates the need for prompt publication of results and annual letter reports. There are at present no requirements or schedules for investigators

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*See ACRONYMS, p.

to make ice core data available to other scientists or to a data center, although specific guidelines for marine, geological, and geophysical data have been established by the International Decade of Ocean Exploration, an NSF-sponsored program.

A central theme of the Workshop was the interplay between data management and data exchange. Using the international criteria for glaciological data acquisition and exchange as a guide (International Council of Scientific Unions, 1979, p. 65-66), basic philosophical and practical concerns were discussed. An attempt is made here to summarize these issues which are represented in the Workshop Recommendations.

Data Management and Data Exchange

1. When should ice core data be sent to a data center?

Scientists are concerned that first results are not necessarily final, in view of interpretative problems, and may not be suitable for archiving. A first step would be to deposit ice core data relating to published work in the WDC-A. An exhaustive list of published studies could be developed, together with at least selected data from cores of recognized paleoclimatic significance. This would facilitate the maintenance of a computerized ice core inventory while assisting in developing standardization. Under the NSF Deep Sea Drilling Project, for example, investigators receiving samples are required to indicate what analyses are to be performed on the samples and to furnish copies of both the analyses and published results in a timely manner.

At a minimum, data should be archived permanently when a project terminates, but this involves the risk of inadequate documentation or loss of data as individuals previously involved in the work leave.

2. What are the advantages/disadvantages in having a central ice core data base?

Many scientists are concerned that a data set may be misinterpreted by another user, unless there is close contact with the originator of the data. There is also concern that the effort required to document a data set consumes resources that are better devoted to further research; and also, that submission of the information to a data center may prevent the scientist from benefiting fully from the initial data analysis, notably, in terms of credit for research publications.

These types of concern are common to many areas of science but, for most geophysical data, they have been successfully overcome by the data center system. The purpose of a data center is not to circumvent the conventional exchange of information and data among scientists, but to ensure continuity and security for valuable records that may be 'lost' or inadequately documented if left in a scientist's files. Moreover, through the development and promotion of standardized data recording procedures, a data center can help to reduce duplication of effort in data processing.

The cost of formating data for archiving appears to be inadequately recognized by funding agencies. This problem is part of the much wider issue of geophysical data policy currently under study in the U.S. National Academy of Sciences.

The scientist is also concerned with the question of receiving credit and recognition for archiving data. A data center can help to alleviate this concern by notifying data suppliers when information and/or access has been generated with respect to their materials held within the center. This would also serve to allay concern about the possible misinterpretation or misuse of the data by others by enabling direct contact to be made between individual scientists.

It is important to recognize that new scientific interpretations and ideas will inevitably emerge when several individuals examine the same data in different ways. The release of data is a matter of normal scientific practice, and under these circumstances, of maximum return on the investment of public money in science.

It is also worth stressing the role that a national or world data center can play in assisting the scientist individually--by services such as provision of other data sets and products, literature searches and information, opportunities for guest workers--and collectively, by wider publicity for the subject among the community of potential data users.

The existence of a central archive will assist research groups in meeting requests for their data. The experience of the Ice Core Facility indicates that a large proportion of user requests for ice samples are not followed through beyond a preliminary state of enquiry.

3. What data should be archived?

What are raw and processed data? The sample of ice (or water) itself can be regarded as level 0; calibrated measurements of physical quantities are level 1; parameters at the highest level of resolution extracted from level 1 data under strictly controlled and documented procedures are level 2; combinations of different parameters, possibly averaged in space or time, represent level 3 data. For WDC-A purposes in general, raw data are represented by level 1.

Primary ice core data are logged in depth-parameter pairs (level 2). Separate arrays are often available for each depth-time sequence that is evolved for a particular core. Their combination would represent a level 3 data set.

There is need to assess the potential value of data relative to their reproducibility, as well as to the cost of their acquisition and storage. Where a well-documented and -managed archive exists, it may be sufficient to hold a data catalog in the data center. The availability of an inventory of data sources may also serve to increase the interest of potential new users in obtaining specific items of data or information.

There is also a question of ancillary data sets. In the case of ice core data, these might relate to meteorological records from the ice core site. Should these be archived with the ice core data or sent to the disciplinary center?

4. What formats and standards should be used for data submitted to a data center?

As a result of the nascent stage of ice core research, no standardized data formats have yet evolved. The establishment of such formats is clearly dependent on interactions between data generators and a data center on a case-by-case basis. The data center can assist in coordinating and promoting such activity. For computerized data bases, some specific guidelines can be prepared relating to existing computer systems in a data center network. WDC-A for Glaciology has a staff programmer to assist scientists in preparing data formats. However, data are better submitted in the format most convenient to the individual scientist than not submitted at all.

The Role of WDC-A for Glaciology

The Data Center is responsible under the ICSU guidelines for collecting, storing, and disseminating unprocessed, analyzed, and published data relating to all forms of snow and ice, their occurrences, properties, processes, and effects. In the acceptance of new data sets, a data center needs to consider the appropriate media for archival, the amount/level of data to be retained, the requirements of potential users (media, format and volume of data, any special processing/graphic displays, etc.), and quality control. Another key consideration is the cost of establishing and maintaining a particular data base or archive. The linkages between the U.S. national centers provide a means of capitalizing on the available experience in modern data processing techniques, while the WDC system facilitates international connections between scientists and foreign data centers. The WDC can also inventory actual and potential world-wide suppliers of data and thereby develop a directory of ice-core (or other) data sources.

National and world data centers provide continuity and security for valuable records and can assist the scientist by facilitating access to other sources of data, and by promoting the value of research to a wider audience. Contact between data collectors, data users and the data center is an essential element in establishing widely accepted and practical operating policies. The exposure of Workshop attendees to data management questions, and of data managers to data collector's concerns is obviously mutually beneficial. While needs and concerns differ between individuals, and perhaps between function for any one individual, the general objective of maintaining interchange of data is a common element. The question of translating general and occasionally divergent philosophies into practical operating policies is then up to the Data Center, its formal advisory bodies, and interested scientists.

References

International Council of Scientific Unions. Panel on World Data Centers. (1979) Guide to International Data Exchange Through the World Data Centres. 4th ed. Washington, D.C., 113 p.

United States Climate Program Plan (1977) Washington, D.C., Federal Coordinating Council for Science, Engineering, and Technology, Interdepartmental Committee for Atmospheric Sciences, 82 p.

World Meteorological Organization (1975) The Physical Basis of Climate and Climate Modelling, Global Atmospheric Research Program, GARP Publication 1. World Meteorological Organization and International Council of Scientific Unions. Geneva, Switzerland, 265 p.

World Meteorological Organization (1979) World Climate Conference. Proceedings. World Meteorological Organization. Publication No. 537. Geneva, Switzerland, 791 p.

WORKSHOP ON THE STATUS AND FUTURE OF ICE CORE RESEARCH AND ICE CORE DATA (BOULDER, COLORADO, 24-26 SEPTEMBER 1979)

1. RECOMMENDATIONS

WORKING GROUP: CORE AND CORE DATA MANAGEMENT

INTRODUCTION

How can the ice core community achieve effective and efficient transfer of core samples and core data to all who need to use them, while giving appropriate protection to the interests of the scientists who collected the samples and/or generated the data? Discussion of this question resulted in the following conclusions and recommendations.

Conclusions and Recommendations

1. Management of Existing Core Samples

There is an unsatisfied demand for deep ice cores. If there were enough deep ice core, there would be no problem of allocation by core managers.

There are two opposing and unreconciled viewpoints regarding the management of existing deep core. One is that until the acquisition of new deep core is assured, existing deep core should not be used up. New analytical techniques, such as the anticipated near term availability of accelerator absolute dating, will enable future extraction of information that cannot now be obtained.

The other view is that the existing inventory of stored core should be made available in its entirety for study. This would increase our knowledge derivable from existing cores, further improve the methods of ice core analysis, and help define the best sites for collection of new deep core.

With regard to shallow (less than 100m) cores, the Working Group concurs with the existing policy of the Greenland Ice Sheet Program (GISP) and State University of New York - Buffalo which makes core liberally available without retention of archival sections. Intermediate depth dry hole cores (400 to 1000m, depending on location) were considered, but no recommendation was made. Consideration was also given to the storage of cores. It was pointed out that the storage of core on an ice sheet could be reliable and cost effective for the long term. Access to core would be maintained through routine field visits.

2. Management of Ice Core Data

The Working Group concurs with the WDC-A plan to determine the needs, the concerns, and the constraints of the ice core community before embarking on further acquisition of core-related data. The Data Center should develop and enunciate the principles of ice core data exchange, taking account of scientific need both within and outside the ice core community and the objectives and constraints of funding agencies. The NSF/DPP Specimen and Core-Sample Distribution Policy is a step along these lines (see page 69). For new core collection and analysis projects, the funding agency and the principal investigator should negotiate, as a part of the requirements of the grant, a scheme to make available both excess core material and data sets to the research community as a whole. A key feature of this scheme is the provision of a fixed time interval after collection of the core during which the principal investigator has exclusive use of the material.

The Working Group concurs with the WDC-A plan to notify original data contributors that their data have been provided to others. In this way the donor and the recipient can exchange information necessary to develop a detailed understanding of the data.

Published papers using a particular ice core-related data set should footnote the availability of those data, whether at WDC-A or elsewhere.

WDC-A should compile a set of maps showing the places where cores have been drilled (and if feasible, locations where drilling is planned) and noting the institution at which the core is being studied and/or stored. These maps should be updated at suitable intervals and made widely available to the ice core and other research communities. At a minimum, WDC-A should obtain summary data on field locations of all ice cores. For some existing sets of ice core-related data, WDC-A may best serve as an information clearinghouse, rather than as a repository. WDC-A should also seek to ensure that geophysical data collected at or near drill sites are held in an appropriate data center.

WORKING GROUP: THE APPLICATION OF ICE CORE RESEARCH TO CLIMATE STUDIES

INTRODUCTION

Ice core measurements can potentially provide information about past climatic conditions, including atmospheric composition and circulation, precipitation, and air temperature. In addition, ice core studies can be used to investigate past ice sheet geometry and flow, as well as related time scales. All of these are necessary for climatic interpretation of ice core records.

Climatic records can be classified into two categories: the instrumental period (early 1700's to present) which implies shallow and intermediate core work associated with pit studies; and long paleoclimatic records which imply intermediate and deep cores.

The interpretation is first made for local conditions and this can then be extended by correlation with other cores to hemispheric and global interpretations.

Recommendations

1. Need for Ice Cores

There is a need for a relatively large number of cores from selected areas covering the instrumental period. Site selection must take meteorological knowledge into account.

Ice cores corresponding to this period are considered important for determining the existence and source of ice core signals and local noise levels, and for estimating climatic change over the historical period by comparison with instrumental records.

For paleoclimatic records extending further in the past, it is recommended that, in addition to isolated cores in well defined climatic zones, a series of intermediate or deep cores be taken along selected flow lines to determine the effect of flow (e.g., surging) on ice core signals. These studies are needed in order to make a faithful reconstruction of past ice sheet geometry and flow, and consequently, an inference of the paleoclimate.

2. Data Bank

The Working Group recommends the establishment of a data bank containing: an inventory of basic data on existing cores, including location, depth, drilling procedure, atmospheric and surface data at the drilling site, and measurements and observations performed during the recovery of the core. Investigators should be encouraged to provide such data in a standardized format. WDC-A would be an ideal focus for such a project.

3. Additional Notes

a. Climatic interpretation of ice core measurements requires knowledge of various parameters at the surface and in the borehole. Consequently, the above recommendations are also relevant for borehole measurements and related surface measurements.

b. Criteria for the collection and storage of samples for specific measurements should be prepared. For example, crystal size, trace elements, gas content, and gas composition analyses require particular core and handling conditions. WDC-A should coordinate this type of project.

c. Greater effort should be given to the study of rheological parameters which are essential to flow modeling of the ice sheets in order to understand the response of ice sheets to climatic changes.

WORKING GROUP: ICE CORE DATING

INTRODUCTION

Ice core dating is a vital key for reconstructing and comparing both paleoclimatic and ice sheet evolutionary characteristics. Current dating methods are reviewed and recommendations are made with respect to: accelerator dating, correlation dating, and stratigraphic standardization.

Dating Methods

1. Flow Model Calculations

   Ages established by flow model calculations may be accurate for shallow depth to the same degree as the stratigraphically estimated mean annual precipitation in the past. At greater depth, where layer thinning caused by ice deformation is considerable, additional uncertainties arise that can produce significant errors.

2. Stratigraphic Methods

   Under favorable conditions, the stratigraphic method gives the most accurate ages. At certain locations, it is possible to count annual layers back for several thousand years.

   The dating accuracy increases if different parameters showing seasonal variations are simultaneously measured and compared. Parameters with seasonal variations which are caused by well-understood processes are to be preferred. Any stratigraphic feature will smooth with increasing depth and time due to diffusion. The diffusion is different for different signals and may be very slow for certain signals, such as microparticles.

3. Geochronological Methods (including radioisotopes)

   Geochronological methods assume that the initial activity or initial concentration can be estimated. By measuring the concentration at a given depth, the age can be calculated if the kinetic process is known, as in the case of radioactive decay.

   New counting techniques, such as accelerator spectrometers, will give accurate measurements of concentrations of radioisotopes in ice core samples. The accuracy of the estimates of the concentration at the time of precipitation varies from one radioisotope to another.

   Dating with ^{14}C on several kg of ice back to 20,000 years before present with an accuracy of several percent will be possible within the near future.

Recommendations

Comparison between chronological horizons, e.g. volcanic acid or ash layers, and stratigraphic methods should be made whenever possible.

Where the counting of annual layers in a continuous sequence is not feasible, the measurement of the mean annual layer thickness in certain depth ranges may allow corrections to be made in flow model calculations, thereby increasing the accuracy of the ages calculated by this method.

Redating of ice cores already dated by other methods should be carried out as accelerator methods become available.

Establishing a time scale by correlation with extraregional (terrestrial or marine) records is not advisable.

Efforts should be made to conform to the principles of stratigraphic classification described in Hedberg, H.D., ed. (1976) International Stratigraphic Guide: A Guide to Stratigraphic Classification, Terminology and Procedure, New York, Wiley-Interscience.

If results of ice core studies are reported in relation to a time scale, they should always be presented on a depth scale as well.

WORKING GROUP: DRILL TECHNOLOGY AND THE INTERFACE WITH ICE CORE RESEARCH NEEDS

INTRODUCTION

Past experience has shown that drill designers, logistics planners, drill operators, and core researchers should jointly establish criteria to optimally satisfy technological and practical constraints in meeting scientific needs. The Working Group established three major topics which, it was felt, concerned all four drilling interests:

1. Drill operational requirements and capabilities
2. Logistical requirements for drill operations
3. Present drill status and development plans.

1. Drill Operational Requirements and Capabilities

Basic factors which, directly or indirectly, concern drill designers, logistics planners, drill operators, and scientists include the nature of the material to be drilled, requisite depth, accuracy of depth measurements, core size, core quality, core orientation, hole diameter, geophysical measurements in the borehole, and use of drilling fluids.

a. Material to be Drilled

Materials which may be encountered during ice drilling operations include firn, ice, dirty ice, permafrost, and unconsolidated subglacial material. These materials directly influence drill design in such areas as method of drilling, chip removal, drill head or cutter design, etc. Operators must be aware of the possible materials to be encountered in order to select proper drills and drill components.

b. Depth

Scientists normally provide their depth requirements to designers, operators, and logistics coordinators. Depth requirements are essential when designing or selecting a winch, selecting cable, calculating hole fluid quantities and core shipment requirements.

c. Accuracy of Depth Measurements

Information concerning the accuracy of depth measurements is normally supplied by the designer or operator and assists the scientist in validating his/her data and in correlating these data with results of other investigations.

d. Core Size

Both core diameter and core length are of interest. Core diameter influences the types of scientific analyses that can be performed, as well as the techniques used to perform these analyses. Core diameter and length requirements affect drill design, and also concern the logistics planner responsible for core containers and core shipment. A drill operator may select a specific drill based upon the scientists' core size requirements.

e. Core Quality

Scientists are mainly concerned with the degree of fracturing and core contamination. Some scientists may require unfractured core, while others may require melt samples and are not concerned with fractures. Drill operators are concerned with fracturing since this may influence the ability to retrieve core. Certain analyses require that the core be as free from contamination as possible. This may dictate design and/or selection of a drill fabricated from special materials, as well as requiring special core-handling techniques.

f. Core Orientation

In the past, core orientation was not generally considered in drill design. However, core orientation features have been incorporated in non-rotating thermal drills, but not in rotary ice drills. Scientists were able to orient core from the Byrd Station, Antarctica, deep drill hole indirectly, by considering the inclination and direction of deviation of the borehole, assuming that the ice layers were horizontal.

Technically, it is feasible to incorporate core orientation features on any drill, but the cost has been a major deterrent.

g. Hole Diameter

Hole diameter is a consideration in drill system design, design of hole logging instruments, casing selection, and in determining the quantity of drilling fluid required for deep holes.

Scientists with existing hole-logging instruments need to know if their equipment is compatible with planned or existing drill holes.

h. Geophysical Measurements

Borehole geophysical studies include, among others, inclination and temperature measurements, sonic logging, and dielectric measurements. Scientists must consider the effects that drilling techniques may have on design or selection of logging instruments. Drill designers may also consider incorporating certain sensors into the drill. In the latter case, drill operators may be required to make specific borehole measurements during drilling.

i. Drilling Fluids

Drilling fluids are required in deep holes to maintain hydrostatic equilibrium and counteract hole closure due to plastic flow of ice. Types of fluids used have included diesel fuel/trichlorethylene and Jet A/tetrachlorethylene mixtures. These mixtures not only degrade certain drill components such as seals, but may also contaminate the ice core to the extent that it is unusable for certain studies. In addition, use of drilling fluids greatly increases the logistics requirements for drilling operations.

2. Logistical Requirements

Logistical considerations include: proposed site location, equipment, manpower, fuel and other power requirements, available transportation, and the time schedule for proposed drilling activity.

a. Site location includes not only geographic location, but also consideration of terrain, altitude, and local weather conditions.

b. Required information on equipment includes weights and dimensions of the total drill package, plus those of individual pieces, particularly the largest and heaviest.

c. Manpower requirements must be known to plan for transportation, food supplies, living accommodations, etc.

d. Fuel and other power requirements depend upon many other factors, including the type of equipment, manpower and living accommodations, duration of field activity, and local transportation requirements.

Logistical considerations may outweigh scientific and engineering considerations in selecting suitable drill sites. Therefore, the above factors should be thoroughly investigated before deciding upon a particular site.

3. Drill Status and Development

Current drill capabilities and developments in drill technology are important to both the drill operator and the scientist. Both would like to know what drills are available, who can furnish them, performance capabilities of available drills, and the cost to rent or purchase a drill.

Recommendations

The Working Group encourages drill designers to investigate the feasibility of standardizing drill components whenever possible. Suggested areas for standardization include drill diameters, cutting bits, and electromechanical connections between the drill and cable.

The Group also recommends that drill designers keep the glaciological community informed of new developments in drill technology.

Finally, the Working Group recommends that the WDC-A undertake a survey of drill designers and operators in order to obtain information on present drill capabilities, as well as future plans. The results of this survey should be assembled and made available to all interested users. This information should be updated yearly. Suggested survey questions include:

1. Drill name ______________
2. Operating principle ______________
3. Capable of drilling in:

   _______firn _______ice _______dirty ice

   _______permafrost _______unconsolidated subglacial material
4. Core Size _______diameter _______length
5. Core quality ______________
6. Can core be oriented? _______yes _______no
7. _______Dry hole _______Fluid-filled hole
8. Hole diameter_______
9. Depth capability ______________
10. Accuracy of depth measurement ______________
11. Drilling rate _______instantaneous _______average daily
12. Electrical power requirements

    _______volts _______Hz _______KW

    _______single phase _______3 phase
13. Is electrical generator included? _______yes _______no

    If yes, Fuel type _______

    Fuel consumption _______

    Altitude restrictions _______

    Lubricants _______
14. Weight of entire drill assembly _______
15. Volume of entire drill assembly_______
16. Heaviest component_______weight

    _______x_______x_______dimensions
17. Largest component _______weight

    _______x_______x_______dimensions
18. Special requirements ______________

2. PROGRAM

Introduction

P.J. Webber, INSTAAR, University of Colorado
A.H. Shapley, NGSDC, NOAA
Welcome and Introduction to Institute of Arctic and Alpine Research, University of Colorado, and WDC-A for Glaciology (Snow and Ice).

R.G. Barry, WDC-A, INSTAAR, University of Colorado
Workshop objectives

P.K. MacKinnon, Workshop Coordinator
Meeting structure

A. DRILL TECHNOLOGY AND THE INTERFACE WITH ICE CORE RESEARCH NEEDS

Chairman: C. Bentley, University of Wisconsin

B. Koci, University of Nebraska-The Role of the Polar Ice Coring Office

B. Koci, University of Nebraska-Drill Technology

D. Garfield, CRREL-CRREL Drill Development Program

B. DRILLS AND ICE CORE SAMPLING

Chairman: C. Bentley, University of Wisconsin

G. Holdworth, Environment Canada-A New Canadian Ice Core Drill (Paper presented by R.M. Koerner, PCSP, Ottawa)

A. Gow, CRREL-Priority Studies of an Ice Core at the Drill Site and After Returning to the Laboratory

B. Stauffer, University of Bern-Data from an Alpine Ice Core

C. ICE CORE ANALYSES AND APPLICATIONS

Chairman: E. Mosley-Thompson, Ohio State University

D. Raynaud, CNRS, Grenoble-Total Gas Content of Polar Ice Cores

M. Herron, SUNY at Buffalo-Ice Chemistry

E. Zeller, University of Kansas Sequential Nitrate Analyses from the Antarctic Ice Sheet

B. Stauffer, University of Bern-CO_2 Analysis of Ice

A.T. Wilson, Waikato University, New Zealand-Chemical Stratigraphy

D. DATING TECHNIQUES: PROBLEMS AND PROSPECTS

Chairman: M. Stuiver, University of Washington

E. Mosley-Thompson, Ohio State University-Dating by Microparticles

R.M. Koerner, PCSP, Ottawa-Particle and Acid Layer Dating

B. Stauffer, University of Bern - Dating by Radioactive Isotopes

U. Radok, NOAA - University of Colorado-Dating Problems and Prospects

M. Herron, SUNY at Buffalo-Chemical Dating

E. NATIONAL AND INTERNATIONAL ICE CORE DRILLING PROGRAMS - RELATIONSHIPS TO CLIMATE STUDIES

Chairman: Guy Guthridge, NSF-DPP

J.T. Andrews, University of Colorado Need for Ice Core Derived Paleoclimate Comparisons with the Terrestrial and Marine Records

R.M. Koerner, PCSP - Ottawa-Ice Core Derived Paleoclimatic Studies, Arctic Canada

L. Thompson, Ohio State University - IPS-Tropical Ice Core Studies and Past Climate

D. Raynaud, CNRS - Grenoble-Ice Core Research Performed at Grenoble.

F. CORE AND CORE DATA HANDLING AND STORAGE

Chairman: R.M. Koerner, PCSP - Ottawa

M. Herron, SUNY at Buffalo-The Role of the Ice Core Facility at SUNY

M. Stuiver, University of Washington
Oxygen Isotope Data Management at the University of Washington

M. Herron, SUNY at Buffalo-The Management of Ice Chemistry Data

R. Hooke, University of Minnesota
Use of Cores for Rheological Purposes

G. DATA MANAGEMENT, EXCHANGE AND STANDARDIZATION

Chairman: R.G. Barry, WDC-A

P.K. MacKinnon, WDC-A-World Data Center-A Ice Core Inventory

Discussion Themes

1. Need for consolidation of data derived from international glaciology projects
2. Types and process levels of data suitable for archiving
3. Problems of data exchange
4. Need for standardization
5. The community's view of the role of WDC-A

H. WORKING GROUP ORGANIZATIONAL MEETING

Structure of Working Groups:

Drill Technology and the Interface with Ice Core Research Needs -
Holdsworth, Koci, Garfield, Hooke -
Chairman: Garfield

The Application of Ice Core Research to Climate Studies -
Koerner, E. Mosley-Thompson, Radok -
Chairman: Raynaud

Core and Core Data Mangement -
Herron, Stuiver, L. Thompson, MacKinnon -
Chairman: Guthridge

Ice Core Dating -
Gow, Johnsen, Hollin, Andrews, Wilson -
Chairman: Stauffer

Objectives: Each group will develop a set of recommendations pertinent to the theme of the working group for presentation at a Plenary Session.

I. PLENARY SESSION: REPORTS OF WORKING GROUPS

Chairman: D. Garfield
Drill Technology and the Interface with Ice Core Research Needs

Chairman: D. Raynaud
The Application of Ice Core Research to Climate Studies

Chairman: G. Guthridge
Core and Core Data Management

Chairman: B. Stauffer
Ice Core Dating

Summary Recommendations: R.G. Barry and P.K. MacKinnon

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ICE CORE INVENTORY

1. SURVEY OF NORTH AMERICAN ICE CORE STUDIES

The first phase of the World Data Center A for Glaciology (Snow and Ice) Ice Core Project has been to review glacial ice core research activities sponsored in whole or in part by North American agencies. The components of this review included a literature search of past and present ice core investigations, documentation of core sites, identifying the groups currently involved in ice core drilling and the principal centers conducting ongoing ice core analyses, and identifying the availability of core and data. This paper reports on the current status of these findings. Pit studies, shallow cores (generally less than 5 m), and ice core boring without core recovery are excluded.

Investigations of ice cores have been based mainly on the establishment of stratigraphic interpretations of atmospheric events, natural or anthropogenic in origin. In order to interpret such climatic signals, it is essential also to understand the physical and thermodynamic processes which transform snow to ice and cause ice to deform under load. Table 1 illustrates a suite of basic data sets that have been selected as keys for identifying and aiding in the study of paleoclimatic and anthropogenic signals, and ice mass modeling.

Table 1. Basic data sets for: paleoclimatic reconstructions, identifying anthropogenic signals, and ice sheet modeling.

ICE CORE	BOREHOLE	RELATED STUDIES
Stratigraphy	Temperature	Accumulation
Stable Isotopes	Inclination	Surface Elevation
Radioactive Isotopes	Closure	Ice Thickness
Particulates:	Vertical Strain Rate	Bedrock Topography
Organic	Ice-Bedrock Interface	10 M Temperatures
Inorganic		Horizontal Strain Rates
Chemistry:		Ablation
Soluble		
Insoluble		
Conductivity		
Fabric		
Density		
Bubble Gas Pressure, Composition		
Bubble Geometry		

The practical application of ice coring techniques only span the past thirty years. Early work sponsored by North American agencies included drillings on Ice Island T3 (Crary, 1958) and the Penny Ice Cap, Baffin Island (Ward, 1952).

The literature review was used to identify core drilling work to assist in compiling core site data from North American investigators, and to identify published data. A substantial number of these publications have been included in the Ice Core Bibliography beginning on page 111. Table I lists 421 cores obtained through funding to North American investigators. Columns eleven and twelve of table I identify the agencies responsible for core procurement and curating.* This table begins on page 26. Selected published data sets along with pertinent references will form part of the Ice Core Project data and information storage and exchange system (see page 59).

Over the years numerous research groups have had an interest in ice cores. A great impetus for ice core studies came as a by-product of American military investigations on the Greenland Ice Sheet. Under the technical auspices of the U.S. Army's Cold Regions Research and Engineering Laboratory (CRREL), both the Greenland and Antarctic Ice Sheets were penetrated to bedrock (Garfield and Ueda, 1968; Ueda and Garfield, 1969). Today, the bulk of American ice coring operations are coordinated and carried out by the Polar Ice Coring Office at the University of Nebraska - Lincoln (PICO). Most of the cores drilled by the PICO group are stored by the Ice Core Facility (ICF) at the State University of New York at Buffalo. Both PICO and ICF operate as services to the glaciological community and they are sponsored by the Division of Polar Programs of the National Science Foundation (see articles on PICO and ICF on pages and respectively). Several research groups also have their own drilling equipment. For example, the University of Minnesota has coring equipment which has been used for several seasons on the Barnes Ice Cap on Baffin Island (Hooke, 1976), and the University of Washington developed thermal coring equipment for temperate glacier ice (Taylor, 1976). Table 2 is a list of current research teams involved in core drilling and routine ice core analysis. An attempt has been made to identify the types of analyses routinely performed at each laboratory. In addition, numerous researchers have occasion to require selected ice samples for special purpose projects. Although these forms of analyses are not reported here, it should be noted that there are diverse and increasing interests in using the sedimentary column from ice by researchers outside the traditional bounds of glaciology. A number of specialized researches are documented in the Ice Core Bibliography.

The identification from the literature of groups currently conducting ice core drilling and ongoing core analyses was supplemented by a combination of interviews and visits and by a questionnaire concerning scientific and institutional queries regarding ice core drilling, analyses, and the availability of core and data for other investigators. This phase of the project produced a number of representative data sets from thirty sites scattered over Antarctica, Arctic Canada, East Africa, Greenland, and Peru. Site details and the present data holdings are listed in Table 3. These data are typical of the routine analyses being performed on ice cores.

In Canada, ice core drilling and core research have been primarily supported by the federal government through in-house facilities at the Defense Research Board, the Polar Continental Shelf Project, and the Department of the Environment. Finally, the Arctic Institute of North America has played a role in sponsoring ice core research in Canada, Alaska, Greenland, and Antarctica.

Core samples are available from groups in both the United States and Canada. Cores under the curatorial responsibility of ICF are subject to the NSF core sampling policy reprinted on pages 69-70. Information on available cores from other agencies can be obtained by contacting the organization of interest. The Polar Ice Coring Office provides a core drilling service, dependent on logistics and equipment, to accredited researchers on the basis of proposal peer-review. Details are available from the Polar Ice Coring Office or the Division of Polar Programs of the National Science Foundation.

In summary, the first phase of the WDC-A Ice Core Project has produced a comprehensive list of North American sponsored core drillings and associated references. The tabulation of core drilling and principal research centers, along with their analysis facilities, has been designed to provide an overview of current operational activities. Finally, it is hoped that this report will lead to new research efforts through an increased awareness of core availability and ice core data sets.

It should be noted that many authors over the years have neglected to furnish adequate information about specific core site, the drilling equipment and/or the

Table 2. North American research teams involved in ice core drilling and routine ice core analysis.

Organization	Drilling Equipment	Routine Core Analyses
United States:		
Browning Engineering	Jet and hot water	
CRREL	Thermal, electromechanical, and SIPRE corer	Physical properties*, trace chemistry
Ohio State University		Microparticles, bubble gas, stratigraphy
United States Geological Survey	Developing a hot water coring drill	
University of Colorado		Pollen
University of Kansas-Lawrence Virginia Polytechnical Institute		NO_x chemistry
University of Minnesota	Thermal	Physical properties*, contract for 0-18
University of Nebraska-Lincoln Polar Ice Coring Office	Thermal, electromechanical, hot water and SIPRE corer	
University of New York at Buffalo	SIPRE corer	Physical properties*, trace chemistry
University of Washington	Thermal (on loan to USGS)	
University of Wisconsin-Madison		Electromagnetic wave propogation in ice
Virginia Polytechnical Institute University of Kansas-Lawrence		NO_x chemistry
Canada:		
Department of the Environment	SIPRE corer and a new combination thermal-electromechanical (field trials spring 1980)	Physical properties*, contract for pollen, 0-18
McGill University in association with ETH Zurich	SIPRE corer	Stratigraphy, contract for stable and radioisotopes
Polar Continental Shelf Project	SIPRE corer, thermal	Physical properties*, trace chemistry, microparticles, contract for 0-18, radioisotopes, pollen

*Physical properties include: stratigraphy, density, load, fabric, and bubble geometry

Table 3. Ice core sites and associated core data currently available from the WDC-A Ice Core Project.

Site	Year	Latitude ° '	Longitude ° '	Depth Range (m)	No. Samples	Data	Remarks	Data* Source
Camp Century	1966	77 10N	61 08W	30 intervals between 80.47 - 1354.86	685	number of particles in each of 15 classes from 0.5 to 16.0 μm		16
Byrd	1968	80 01S	119 31W	24 intervals between 180.00 - 2139.61	1553	number of particles in each of 15 classes from 0.5 to 16.0 μm		16
Devon 72	1972	75 18N	82 18W	continuous 0.04 - 298.89	1934	(depth, δ0-18) pairs	bedrock	8
Devon 73	1973	75 18N	82 18W	continuous 7.40 - 299.35	1970	(depth, δ0-18) pairs	bedrock	8
Milcent	1973	70 18N	44 33W	6.82 - 398.01	~3500 variable	(depth, δ01-18, time) tuples (from 1965 - 1173 AD), stratigraphy, density, load, temperature in hole		3
Crete	1974	71 07N	37 19W	0.315 - 246.04	~4100 variable	(depth, δ0-18, time) tuples (from 1974 - to 1160 AD), stratigraphy, density, load, temperature in hole		3
Dye 2	1974	66 23N	46 11W	0.0 - 99.93	variable	stratigraphy, density, load		3
J-9	1974	82 22S	168 40W	0.03 - 100.07	variable	stratigraphy, density, load, temperature in hole		3
South Pole	1974	90 00S	-	0.6 - 100.30	variable 840	stratigraphy, density, load, NO_x chemistry		3 39
South Dome	1975	63 33N	44 36W	0.0 - 79.58	variable	stratigraphy, density, load		3
Dye 3	1975	65 11N	43 50W	0.0 - 93.80	continuous	stratigraphy		3
C-7-2	1976	78 20S	179 51E	0.0 - 20.25	continuous	stratigraphy, density, load		3
C-7-3	1976	78 20S	179 51E	0.0 - 49.99	continuous	stratigraphy, density, load		3
Roosevelt Dome	1976	79 22S	161 80W	0.0 - 51.56	variable	stratigraphy, density, load		3

*See page

Table 3. (continued)

Site	Year	Latitude ° '	Longitude ° '	Depth Range (m)	No. Samples	Data	Remarks	Data Source
Quelccaya	1976	13 56S	70 50W	0.0 - 14.95	183	number of particles in each of 15 classes from 0.5 to 16.0 μm	pit-core	16
Quelccaya	1976	13 56S	70 50W	0.0 - 16.10	161	number of particles in each of 15 classes from 0.5 to 16.0 μm		16
Quelccaya	1976	13 56S	70 50W	0.0 - 15.07	140	number of particles in each of 15 classes from 0.5 to 16.0 μm	pit-core	16
Quelccaya	1976	13 56S	70 50W	0.0 - 1.37	10	number of particles in each of 15 classes from 0.5 to 16.0 μm		16
Quelccaya	1977	13 56S	70 50W	0.0 - ~2.5	85	number of particles in each of 15 classes from 0.5 to 16.0 μm	from 3 summit pits	16
C-16	1977	81 05S	172 45E	0.0 - 100.18	variable	stratigraphy, density, load, temperature in the hole		3
Q-13	1977	78 57S	179 55E	0.0 - 100.00	variable	stratigraphy, density, load, temperature in the hole		3
South Pole	1978	90 00S	-	0.0 - 111.49	variable	stratigraphy, density, load, temperature in the hole, NO_x chemistry		3 39
Quelccaya	1978	13 56S	70 50W	0.0 - ~3	126	number of particles in each of 15 classes from 0.5 to 16.0 μm	from 3 summit pits	16
Lewis Glacier Site 1	1978	0 10S	37 19E	0.0 - 13.4	111	number of particles in each of 15 classes from 0.5 to 16.0 μm	pit-core 3.5 m void at site	16
Lewis Glacier Site 2	1978	0 10S	37 19E	0.0 - 11.4	65	number of particles in each of 15 classes from 0.5 to 16.0 μm	pit-core	16

diameter and continuity of core. Consequently, this report was made easier by many researchers who willingly provided first hand information. Thanks is also due to the organizations that have kindly supplied data as part of their contribution to the World Data Center system.

References

Crary, A.P. (1958) Arctic ice islands and ice shelf studies. Arctic, v. 11(1), p. 3-42.

Garfield, D.E.; Ueda, H.T. (1968) Drilling through the Greenland Ice Sheet. U.S. Army. Cold Regions Research and Engineering Laboratory. CRREL Special Report no. 126.

Hooke, R. Le B. (1976) University of Minnesota ice drill. (In: Splettstoesser, J.F., ed., Ice Core Drilling. Lincoln, Nebraska, University of Nebraska Press, p. 47-57.)

Taylor, P.L. (1976) Solid-nose and coring thermal drills for temperate ice. (In: Splettstoesser, J.F., ed., Ice Core Drilling. Lincoln, Nebraska, University of Nebraska Press, p. 167-177.

Ueda, H.T.; Garfield, D.E. (1969) Core drilling through the Antarctic Ice Sheet. U.S. Army. Cold Regions Research and Engineering Laboratory. CRREL Technical Report no. 321, 19 p.

Ward, W.H. (1952) The glaciological studies of the Baffin Island expedition, 1950. Part III: equipment and techniques. Journal of Glaciology, v. 2(12), p. 115-121.

2. INTERNATIONAL SUMMARY

Although a number of national and international glaciology programs related to ice core research exist, for example, the program of the Centre Nationale de Recherche Scientifique (see page 103) and the International Antarctic Glaciology Project (Radok, 1977), there is no process which provides for an organized multilateral flow of ice core data and information among all interested scientists. In order to fill this gap, the World Data Center A for Glaciology (Snow and Ice) considers it important to identify, to assemble, and to prepare for dissemination viable data sets relevant to the identification of short- and long-term climatic change, as well as data appropriate to the basic understanding of physical processes in glaciers and ice sheets.

Following assessment of North American ice core and ice core data holdings (see page 15), WDC-A established a two-phase program to determine the needs, concerns, and constraints of the international ice core community regarding the development of an ice core data base. First, the Center convened an ice core workshop, with international representation, in order to provide recommendations addressing a wide range of key technical, scientific, and data management problems. See the Ice Core Workshop Recommendations, beginning on page 5. As a result of this meeting, the Data Center identified some concerns and a series of objectives which a representative selection of the ice core community considered important issues. This included a recognized need for, and support of, an ice core inventory. Table 1 summarizes the seven principal steps in the organization and function of such an inventory.

Table 1. Ice core information and data inventory

1. Identify, collate, and index descriptive information about ice cores.
2. Assemble, where possible, comprehensive data sets in (depth, parameter) sequences.
3. Identify (time, depth) equivalents.
4. Integrate available data into a standardized format in a computer data management system.
5. Disseminate available information and data.
6. Encourage standardization.
7. Serve as an information clearing house for selected data sets.

The second phase of the program involved working visits to researchers in England, Denmark, Switzerland, France, and Canada in October and November, 1979. The principal purposes of these visits were to present first-hand the conceptual plan for an international ice core inventory, to broaden the international support for this program, and to assess the range, quantity, and availability of ice core and core related data. At every stop there was an affirmative response to the concept of an international ice core data inventory. Furthermore, each organization expressed a willingness to contribute data. What is now being developed is an institutional mechanism that will permit effective and efficient transfer of data from a central repository while giving appropriate protection to the interests of the scientists who generated the data.

Prior to the trip, a literature search was completed. This was used to locate information on European ice core drilling experience and to provide a general overview of alpine and polar drilling activities for the Ice Core tables beginning on page 26.

References

Radok, U. (1977) International Antarctic Glaciology Project: past and future. Antarctic Journal of the United States, v. XII (1-2), p. 32-38.

3. ICE CORE TABLES AND CORE SITE MAPS

The ice core tables and associated maps document almost all of the ice cores reported in the literature since the first French core drilling in Greenland in 1949 and the drilling effort of the Norwegian-British-Swedish Antarctic Expedition to Maudheim, 1949-52. Sites were selected on the basis that core, generally greater than 5 m in length, was recovered for firn/ice studies and/or the identification of proxy atmospheric data.

The tables, listing 414 individual cores, contain a geographical descriptor and information on each ice core from that region. Cores are ordered within geographical areas according to the year of recovery (column 3), site name (column 2), latitude column 4), longitude (column 5), and elevation (column 6). Where a specific core name was not found, a general descriptor has been used. The sequence number (column 1) is unique to each core within each geographical area. This number is used for core identification on the appropriate map. In addition, the largest core number in each geographical area identifies the total number of cores recovered from the region. Core depth (column 7), core diameter (column 8), and drill type (column 9) provide some basic characteristics for each core. In a few cases a core hole is re-entered with a different drill or at a later date. In order to provide yearly progress in core recovery, re-entry is identified as a separate core with the appropriate depth range noted in column 7. The mean annual air temperature or 10 m firn temperature has been included when available (column 10). The drilling agency (column 11) and the curating agency (column 12) are number coded in accordance with the Drilling/Curating Agency table key preceding the tables. A unique number identifies each agency involved in core drilling and/or core curating. In most cases the cores without a curating agency identification have not been returned from the field or stored beyond a limited period of time. Any additional comments are listed under Remarks (column 13).

Four maps for Arctic Canada, Greenland, the world between 80°N and 60°S latitudes, and Antarctica depict the distribution of cores identified in the tables. The numbers appearing on each map are specific to the core sequence number for each geographical area. These areas are:

A. North America
   1. Canada
   2. United States

B. Greenland

C. Iceland

D. Spitzbergen

E. Western Europe
   1. Alps
   2. Scandinavia

F. Asia, including the Caucasus

G. Southern Hemisphere, excluding Antarctica
   1. Africa (Kenya)
   2. New Guinea (Irian Jaya)
   3. New Zealand
   4. South America (Peru)

H. Antarctica

Each region above identified by an alphabetical code has separate numbering on the appropriate map. This is of particular importance on the world map, where repetition of numbers occurs. However, each set of numbers is geographically specific. Finally, core recovered on traverses in Antarctica, where site coordinates could not be found, have the core code marked adjacent to the appropriate traverse section. The position of the arctic ice islands, T-3 and North Pole 19, has been omitted from the Arctic map since these changed over time.

A summary of the tabulated core data is given in table 1. Each core hole is counted only once; the additional cores identified on the Antarctic traverse are included.

Table 1. The number and percentage of cores within specific depth ranges.

Depth Range (m)	Number of Cores	Percentage of Cores
To 10	125	30.2
10-20	93	22.5
20-50	66	15.9
50-100	44	10.6
100-200	37	8.9
200-300	16	3.9
300-400	17	4.1
400-500	10	2.4
500-800	0	-
800-900	1	0.2
900-1000	3	0.7
1000-1500	1	0.2
1500-2100	0	-
2100-2200	1	0.2
Total	414	100

The depth intervals in table 1 reflect the general range of penetration for different drilling systems. The majority of shallow cores, less than 20 meters, have been obtained with manually operated corers. Power-assisted manual corers and light thermal drills have provided most of the core in the 30 to 200 m range. Intermediate thermal corers and some mechanical drills have generated most of the core in the 200 to 1000 meter range. To date, only electro-mechanical drills have exceeded 1000 m depth.

On a geographical basis, core sites can be divided into four broad categories shown in table 2.

Table 2. The number and percentage of cores on a geographical basis.

Region	Number of cores	Percentage of Cores
North Polar	147	35.5
Temperate alpine	69	16.7
Tropical alpine	16	3.9
South Polar	182	44.0

Key to Table I - Drilling/Curating Agency

1 - Cold Regions Research and Engineering Laboratory (CRREL), Hanover, New Hampshire, USA

2 - Greenland Ice Sheet Program (GISP), Denmark, Switzerland, United States

3 - Ice Core Facility, State University of New York at Buffalo, USA

4 - University of Copenhagen, Denmark

5 - Expéditions Polaires Francaises

6 - State University of New York at Buffalo, USA

7 - University of Bern, Switzerland

8 - Polar Continental Shelf Project, Canada

9 - University of Minnesota, USA

10 - Australian National Antarctic Research Expedition

11 - Japanese Antarctic Research Expedition

12 - Laboratoire de Glaciologie, Centre National de Recherche Scientifique, France

13 - Expédition Antarctique Belge

14 - Norwegian-British-Swedish Antarctic Expedition

15 - Soviet Antarctic Expedition

16 - Institute of Polar Studies, Ohio State University, USA

17 - Science Institute, University of Iceland

18 - University of Washington, USA

19 - Australian Universities Expedition to New Guinea

20 - University of East Anglia, Great Britain

21 - Snow, Ice and Permafrost Research Establishment (SIPRE), USA

22 - University of Innsbruck, Austria

23 - Ross Ice Shelf Project (RISP), University of Nebraska, USA

24 - Polar Ice Coring Office (PICO), University of Nebraska, USA

25 - Arctic Construction and Frost Effects Laboratory, U.S. Army

26 - Expédition Glaciologique Internationale au Groenland II (EGIG)

27 - North Water Project, Eidgenössiche Technische Hochschule (ETH), Zurich, Switzerland, McGill University, Montreal, Canada

28 - Arctic Institute of North America

29 - United States Air Force Cambridge Research Laboratory, USA

30 - Hokkaido University, Japan

31 - University of Alberta, Canada

32 - Nagoya University, Japan

33 - Department of the Environment, Canada

34 - University of California, USA

35 - American Geographical Society, USA

36 - University of Alaska, USA

37 - University of Wisconsin, USA

38 - University of Michigan, USA

39 - University of Kansas/Virginia Polytechnical Institute, USA

40 - United States Antarctic Research Program

41 - International Antarctic Glaciology Project

42 - British Antarctic Survey

43 - Institute of Geography, USSR Academy of Sciences

44 - Arctic and Antarctic Institute, USSR

45 - Central Asian Hydrometeorological Institute, USSR

46 - Institute of Low Temperature Science, Japan

47 - Cambridge University Expeditions to Svartisen, Norway

48 - Norwegian Antarctic Expedition

49 - Argentine Antarctic Expedition

50 - University of Stockholm, Sweden

51 - Geographical Institute, Academy of Sciences, People's Republic of China

52 - New Zealand Geological Survey

Table I. ICE CORES
A. NORTH AMERICA
1. CANADA

NO.	SITE NAME	YEAR	LATITUDE ° '	LONGITUDE ° '	ELEVATION (m) asl	CORE DEPTH (m)	CORE DIAMETER (cm)	DRILL TYPE	MEAN ANNUAL TEMPERATURE (°C)	DRILLING AGENCY	CURATING AGENCY	REMARKS
1	Hole 1	1952	∿85 30N#	∿90 00W#	∿4	15.8	8	manual rotary	-19.9	29		T3
2	Penny Ice Cap	1953	∿65 30	∿67 00	∿1800	9.75	3.8	mechanical rotary		28		
3	Penny Ice Cap	1953	∿65 30	∿67 00	∿1800	9.75	3.8	mechanical rotary		28		
4	Penny Ice Cap	1953	∿65 30	∿67 00	∿1800	18.0	3.8	mechanical rotary		28		
5	Hole 2	1953	∿85 30 #	∿90 00 #	∿4	15.8-32.5	8	manual rotary	-19.9	29		T3
6	Hole 3	1953	∿85 30 #	∿90 00 #	∿4	28	8	manual rotary	-19.9	29		T3
7	A1	1953	66 58	65 29	2080	21	7.6	SIPRE		28		Penny Ice Cap
8	Hole 4	1955	∿83 30 #	∿88 00 #	∿4	12	8	manual rotary	-19.9	29		T3
9	Hole 5	1955	∿83 30 #	∿88 00 #	∿4	17	8	manual rotary	-19.9	29		T3
10	Hole 6	1955	∿83 30 #	∿88 00 #	∿4	15	8	manual rotary	-19.9	29		T3
11	Hole 7	1955	∿83 30 #	∿88 00 #	∿4	15	8	manual rotary	-19.9	29		T3
12	Hole 8	1955	∿83 30 #	∿88 00 #	∿4	21	8	manual rotary	-19.9	29		T3
13	Hole 9	1955	∿83 30 #	∿88 00 #	∿4	25	8	manual rotary	-19.9	29		T3
14	Trough	1960	83 11	74 23	∿3	35	7.6	SIPRE	∿-18.5	6		Ward Hunt Ice Shelf

drifting ice island

Table I (A-1). Canada, continued.

NO.	SITE NAME	YEAR	LATITUDE ° '	LONGITUDE ° '	ELEVATION (m) asl	CORE DEPTH (m)	CORE DIAMETER (cm)	DRILL TYPE	MEAN ANNUAL TEMPERATURE (°C)	DRILLING AGENCY	CURATING AGENCY	REMARKS
15	Ridge	1960	83 10N	74 22W	7	35	7.6	SIPRE	∿-18.5	6		Ward Hunt Ice Shelf
16	Reentrant	1960	∿83 07	∿71 47	∿3	11.25	7.6	SIPRE	∿-18.5	6		Ward Hunt Ice Shelf
17	Rise	1960	∿83 08	∿74 05	27	52.25	7.6	SIPRE	∿-18.5	6		Ward Hunt Ice Shelf
18	Site Q	1960	∿82 20	∿96 00	3.7	34.7	7.6	SIPRE	-19.9	30	30	T3, grounded
19	Site T	1960	∿82 20	∿96 00	0.6	7.5	7.6	SIPRE	-19.9	30	30	T3, grounded
20	Auger Hole 1	1963	60 44	139 42	2520	7	7.6	SIPRE		31	31	Kaskawulsh Glacier
21	Auger Hole 2	1963	∿60 47	∿139 45	2650	3.5	7.6	SIPRE		31	31	Kaskawulsh Glacier
22	Meighen Ice Cap	1965	79 54	99 06	260	121.2	12.2	thermal	∿-17	8	8	bedrock
23	Devon 71	1971	75 18	82 18	∿1800	230	12.2	thermal	∿-23**	8	8	drill stuck
24	BO	1971	∿69 43	∿71 58	∿590	10	9	thermal	∿-10	9	9	Barnes Ice Cap
25	B1	1971	∿69 43	∿71 58	∿600	17	9	thermal	∿-10	9	9	base of core opens into a horizontal shaft
26	B1	1971	∿69 43	∿71 58	∿590	8	9	thermal	∿-10	9	9	continuation of B1 below shaft floor
27	B2	1972	∿69 43	∿71 58	∿610	22	9	thermal	∿-10	9	9	Barnes Ice Cap
28	Devon 72	1972	75 18	82 18	1800	298.9	12.2	thermal	-23**	8	8	bedrock
29	Devon Camp	1972	75 18	82 18	1800	10	7.6	SIPRE	-23**	8		

** 10m firn temperature

Table I (A-1). Canada, continued.

NO.	SITE NAME	YEAR	LATITUDE ° '	LONGITUDE ° '	ELEVATION (m) asl	CORE DEPTH (m)	CORE DIAMETER (cm)	DRILL TYPE	MEAN ANNUAL TEMPERATURE (°C)	DRILLING AGENCY	CURATING AGENCY	REMARKS
30	T3	1973	Various#	Various#	∿4	30	25.0	thermal	∿-20	32	32	test for JARE[1]
31	T3	1973	Various#	Various#	∿4	31	13.5	thermal	∿-20	32	32	test for JARE[1]
32	Devon 73	1973	75 18N	82 18W	1800	299.4	12.2	thermal	-23**	8	8	bedrock
33	Devon	1974	75 18	82 18	1800	12	7.6	SIPRE	-23**	8		
34	South Cape	1974	76 52	86 05	1402	12	7.6	SIPRE		8		
35	Saddle	1974	76 38	79 25	902	12	7.6	SIPRE		8		
36	Parrish Glacier	1974	79 50	76 40	1760	12	7.6	SIPRE		8		
37	Central 1	1974	78 03	81 00	1266	12	7.6	SIPRE		8		
38	Central 2	1974	78 34	79 30	1688	12	7.6	SIPRE		8		
39	Mer de Glace	1974	80 46	73 30	1820	12	7.6	SIPRE		8		
40	Axel Heiberg	1974	79 46	91 13	1840	12	7.6	SIPRE		8		
41	Site 1	1974	78 25	80 00	1387	25.6	7.6	SIPRE		27	27	Ellesmere Island
42	Site 2	1974	77 33	80 20	1346	22.2*	7.6	SIPRE		27	27	Ellesmere Island
43	Site 3	1974	76 38	78 22	658	10.0*	7.6	SIPRE		27	27	Ellesmere Island
44	Site 4	1974	76 35	79 45	903	3.9*	7.6	SIPRE		8	27	Ellesmere Island
45	T0975$_3$	1975	69 52	72 05	508	52.5	9	thermal	∿-10	9	9	Barnes Ice Cap - core taken at selected intervals

\# drifting ice island

* pit-core

** 10m firn temperature

[1] JARE - Japanese Antarctic Research Expedition

Table I.(A-1). **Canada, continued.**

NO.	SITE NAME	YEAR	LATITUDE ° '	LONGITUDE ° '	ELEVATION (m) asl	CORE DEPTH (m)	CORE DIAMETER (cm)	DRILL TYPE	MEAN ANNUAL TEMPERATURE (°C)	DRILLING AGENCY	CURATING AGENCY	REMARKS
46	NW Col	1975	60 34N	140 24W	5339	15.8*	7.6	SIPRE	-28.9**	33	33	Mt. Logan 2 m pit
47	NW Col	1976	60 34	140 41	5339	7.6	7.6	SIPRE	-28.9**	33	33	Mt. Logan
48	T061	1976	69 48	72 07	745	223	9	thermal	∿-10	9	9	Barnes Ice Cap
49	T081	1977	69 51	72 06	∿643	∿160	9	thermal	∿-10	9	9	Barnes Ice Cap
50	Mer de Glace Agassiz	1977	∿80 46	∿73 30	∿1820	337.4	12.2	thermal		8	8	Ellesmere Island
51	Mer de Glace Agassiz	1977	∿80 46	∿73 30	∿1820	20*	7.6	SIPRE		8		Ellesmere Island 10m pit
52	Mt. Logan	1978	60 34	140 24	5339	18.7	7.6	SIPRE	-28.4**	33	33	
53	T020	1978	69 45	72 09	862	300	9	thermal	∿-10	9	9	Barnes Ice Cap
54	Mer de Glace Agassiz	1979	∿80 47	∿73 30	∿1850	149	12.2	thermal		8	8	Ellesmere Island - core still on ice cap

*pit-core

**10m firn temperature

Table I. ICE CORES
A. NORTH AMERICA
2. UNITED STATES

NO.	SITE NAME	YEAR	LATITUDE		LONGITUDE		ELEVATION (m) asl	CORE DEPTH (m)	CORE DIAMETER (cm)	DRILL TYPE	MEAN ANNUAL TEMPERATURE (°C)	DRILLING AGENCY	CURATING AGENCY	REMARKS
			°	'	°	'								
55	Taku Glacier	1950	58	33N	134	08W	1110	91	~4	mechanical rotary		35		
56	Mt. Wrangell	1961	~62	00	~144	00	~4200	10*	7.6	SIPRE	~15.7	36		
57	Mt. Wrangell	1961	~62	00	~144	00	~4200	10*	7.6	SIPRE	~15.7	36		
58	Mt. Wrangell	1961	~62	00	~144	00	~4200	10*	7.6	SIPRE	~15.7	36		
59	Mt. Wrangell	1961	~62	00	~144	00	~4200	9.7*	7.6	SIPRE	~15.7	36		
60	Blue Glacier	1962	47	49	123	41	~1325	137	2.5	thermal		34	34	bedrock
61	Blue Glacier	1971	47	49	123	41	~1325	40	15.2	thermal		18	18	
62	Blue Glacier	1971	47	49	123	41	~1325	90	15.2	thermal		18	18	

* pit-core

There have been few ice cores recovered from the Western Cordillera of North America. However, hot point drills have been extensively used for englacial deformation and temperature studies.

Table I. ICE CORES
B. GREENLAND

NO.	SITE NAME	YEAR	LATITUDE		LONGITUDE		ELEVATION (m) asl	CORE DEPTH (m)	CORE DIAMETER (cm)	DRILL TYPE	MEAN ANNUAL TEMP (°C)	DRILLING AGENCY	CURATING AGENCY	REMARKS
			°		°	'								
1	CAMP IV	1949	69	40N	49	31W	1098	50	8.0	Thermal		5		
2	CAMP VI	1950	69	42	48	16	1598	47	8.0	Thermal		5		
3	CAMP VI	1950	69	42	48	16	1598	126	4.8	Rotary		5		
4	Milcent	1950	61	10	45	15	2450	52	8.0	Thermal	-22.2**	5		
5	Station Centrale	1950	70	55	40	38	2994	55	8.0	Thermal	-27.0	5		
6	Station Centrale	1950	70	55	40	38	2994	151	4.8	Rotary	-27.0	5		
7	Station Centrale	1950	70	55	40	38	2994	30.5	80.0	Mechanical	-27.0	5		
8	FD-32	1953	66	16	47	46	1828	10.2	7.6	SIPRE				
9	SITE 2	1954	76	59	56	04	2100	31	1.5m^2	Manual	-25.4**	21		hand dug pit, inclined 15° from vertical
10	SITE 2	1954	76	59	56	04	2100	31-48	7.6	SIPRE	-25.4**	21		
11	SITE 2	1956	76	59	56	04	2100	305	9.8	Rotary	-25.4**	21	3	drilling fluid of compressed air
12	SITE 2	1957	76	59	56	04	2100	411	9.8	Rotary	-25.4**	21	3	drilling fluid of compressed air 19m to top of core
13	Camp Century	1961	77	10	61	08	1885	186	12.4	Thermal	-24.5	21	3	fluid fill after drilling
14	Camp Century	1962	77	10	61	08	1885	238	12.4	Thermal	-24.5	21	3	fluid fill after drilling
15	Camp Century	1963	77	10	61	08	1885	264	12.4	Thermal	-24.5	21	3	fluid fill after drilling
16	Camp Century	1963	77	10	61	08	1885	535	12.4	Thermal	-24.5	21	3	fluid fill after drilling
17	Camp Century	1964	77	10	61	08	1885	535-1002	10.8	Electro-mechanical	-24.5	21	3	fluid fill
18	Camp Century	1964	77	10	61	08	1885	12	7.6	SIPRE	-24.5	1	1	
19	Camp Century	1966	77	10	61	08	1885	1002-1387.4	10.8	Electro-mechanical	-24.5	21	3	16.9m silty ice at the base,plus additional 3.55m till

Table I(B). Greenland, continued.

NO.	SITE NAME	YEAR	LATITUDE ° '	LONGITUDE ° '	ELEVATION (m) asl	CORE DEPTH (m)	CORE DIAMETER (cm)	DRILL TYPE	MEAN ANNUAL TEMP (°C)	DRILLING AGENCY	CURATING AGENCY	REMARKS
20	HOLE 1	1966	77 55N	39 14W	2402	60.0	top 18m, 20.0 12.5	Electro-mechanical	-30.4	28/29	4	Inge Lehman
21	HOLE 2	1966	77 55	39 14	2402	60.2	top 18m, 20.0 12.5	Electro-mechanical	-30.4	28/29	4	Inge Lehman
22	HOLE 3	1966	77 55	39 14	2402	51.0	top 18m, 20.0 12.5	Electro-mechanical	-30.4	28/29	4	Inge Lehman
23	HOLE 4	1966	77 57	39 11	2402	60.0	top 18m, 20.0 12.5	Electro-mechanical	-30.4	28/29	4	Inge Lehman
24	Carrefour	1967	69 49	47 26	1849	20	7.6	SIPRE	-16.4	26		
25	Carrefour	1967	69 49	47 26	1849	1-10	7.6	SIPRE	-16.4	26		1 m pit
26	Carrefour	1968	69 49	47 26	1850	22	7.6	SIPRE	-16.4	26		
27	Milcent	1968	70 18	44 33	2450	10.5	7.6	SIPRE	-22.2	26		
28	Station Centrale	1968	70 55	40 38	2994	35	7.6	SIPRE	-27.0	26		
29	Crête	1968	71 07	37 19	3174	30	7.6	SIPRE	-30.0	26		
30	Jarl Joset	1968	71 21	33 29	2867	12	7.6	SIPRE	-28.0	26		
31	Depot 420	1968	72 14	32 20	∿2750	12	7.6	SIPRE	-28.8	26		
32	Depot 480	1968	72 06	30 00	2500	20	7.6	SIPRE	-22.4	26		
33	Dye 3	1971	65 11	43 50	2480	25	12.4	Thermal	-18	2	17	core consumed for tritium analysis
34	Dye 3	1971	65 11	43 50	2480	372	12.4	Thermal	-18	2	3	
35	North Site	1972	75 46	42 27	2842	15	7.6	SIPRE	-31	2		
36	Milcent	1973	70 18	44 33	2450	398	12.4	Thermal	-22.2**	2	3	6.8 m to top of core
37	Summit	1974	72 17	37 56	3244	31	7.5	Electro-mechanical		2		drill test
38	Crête	1974	71 07	37 19	3174	23	7.5	Electro-mechanical	-30.0	2		drill test
39	Crête	1974	71 07	37 19	3174	50	7.5	Electro-mechanical	-30.0	2		drill test
40	Crête	1974	71 07	37 19	3174	405	12.4	Thermal	-30.0	2	3	

**10m firn temperature

Table I(B). Greenland, continued.

NO.	SITE NAME	YEAR	LATITUDE °	'	LONGITUDE °	'	ELEVATION (m) asl	CORE DEPTH (m)	CORE DIAMETER (cm)	DRILL TYPE	MEAN ANNUAL TEMP (°C)	DRILLING AGENCY	CURATING AGENCY	REMARKS
41	Dye 2	1974	66	23N	46	11W	2200	25	7.5	Electro-mechanical	-16.6	2	3	drill test
42	Dye 2	1974	66	23	46	11	2200	45	7.5	Electro-mechanical	-16.6	2		drill test
43	Dye 2	1974	66	23	46	11	2200	101	10.2	Electro-mechanical	-16.6	2	3	drill test
44	V	1974	77	04	70	25	1173	7.0	7.6	SIPRE		27	27	North Water site 1.7 m pit
45	VI	1974	76	46	64	35	1560	22.1	7.6	SIPRE		27	27	North Water site 2.4 m pit
46	Dye 3	1975	65	11	43	50	2480	95.2	7.6	Electro-mechanical	-19.6	2	3	drill test
47	Dye 3	1975	65	11	43	50	2480	378	7.6	Electro-mechanical	-19.6	2	3	
48	South Dome	1975	63	33	44	36	2854	79.6	7.6	Electro-mechanical	-21.5	2	3,4	drill test
49	South Dome	1975	63	33	44	36	2854	30	7.6	Electro-mechanical	-21.5	2		drill test
50	Hans Tausen	1975	∿82	30	∿38	20	1200	60	7.6	Electro-mechanical		2	3,4	drill test
51	D 6	1975	65	12	43	47	2488	10.5	7.6	SIPRE	-20.2**	2	4	
52	DS-1	1975	63	36	44	55	1847	11.0	7.6	SIPRE	-21.5**	2	4	
53	DS-2	1975	63	33	44	56	2503	11.0	7.6	SIPRE	-22.3**	2	4	
54	DS-3	1975	63	42	44	32	2488	11.0	7.6	SIPRE	-22.4**	2	4	
55	South Dome	1975	63	33	44	36	2854	11.0	7.6	SIPRE	-22.2**	2	4	
56	ST-1	1975	65	18	43	47	2476	12.0	7.6	SIPRE	-20.5**	2	4	
57	SDS-1	1975	65	42	44	46	2620	11.0	7.6	SIPRE	-20.8**	2	4	
58	SDS-2	1975	65	32	44	07	2618	11.0	7.6	SIPRE	-20.5**	2	4	
59	SDS-3	1975	65	50	44	07	2640	11.0	7.6	SIPRE	-20.8**	2	4	
60	SAS	1975	65	40	44	19	2637	11.0	7.6	SIPRE	-20.9**	2	4	

**10m firn temperature

Table I(B). Greenland, continued.

NO.	SITE NAME	YEAR	LATITUDE °	'	LONGITUDE °	'	ELEVATION (m) asl	CORE DEPTH (m)	CORE DIAMETER (cm)	DRILL TYPE	MEAN ANNUAL TEMP (°C)	DRILLING AGENCY	CURATING AGENCY	REMARKS
61	SN	1975	66	11N	43	40W	2574	11.0	7.6	SIPRE	-21.2**	2	4	
62	SNS-1	1975	66	28	44	50	2457	11.0	7.6	SIPRE	-20.5**	2	4	
63	SNS-2	1975	65	55	42	43	2365	11.0	7.6	SIPRE	-18.0**	2	4	
64	A-1	1975	67	27	41	59	2670	11.0	7.6	SIPRE	-22.7**	2	4	
65	A-1-S-1	1975	67	02	41	51	2563	11.0	7.6	SIPRE	-21.0**	2	4	
66	A-1-S-2	1975	67	51	43	07	2606	11.0	7.6	SIPRE	-22.8**	2	4	
67	D-4	1975	~65	12	~43	47	2490	11.1	7.6	SIPRE	-20.5**	2	4	
68	D-5	1975	~65	12	~43	47	2490	11.0	7.6	SIPRE	-20.7**	2	4	
69	BDS	1975	64	30	44	20	2760	11.0	7.6	SIPRE	-22.2**	2	4	
70	D-2	1975	~65	12	~43	47	2504	11.0	7.6	SIPRE	-20.2**	2	4	
71	D-3	1975	~65	12	~43	47	2488	11.0	7.6	SIPRE	-20.1**	2	4	
72	Dye 2	1975	66	23	46	11	2200	20	7.6	SIPRE	-16.6	2	4	
73	Dye 3	1976	65	11	43	50	2480	93	10	Electro-mechanical	-19.6	2	4	drill test
74	Hans Tausen	1976	~82	30	~38	20	1200	~50	10	Electro-mechanical		2		drill test, poor quality core, drill stuck
75	Dye 2	1977	66	23	46	11	2200	84	7.6	Electro-mechanical	-16.6	2	3	
76	Camp Century	1977	77	11	61	05	1890	100.2	7.6	Electro-mechanical	-24.5	2	3	2.1m to top of core
77	Camp Century	1977	77	11	61	05	1890	101	7.6	Electro-mechanical	-24.5	2	4	2.0 m to top of core - 10 km up-stream from Camp Century
78	Camp Century	1977	77	13	60	48	1922	78	7.6	Electro-mechanical	-24.5	2	3	
79	Camp Century	1977	77	13	60	48	1922	71	7.6	Electro-mechanical	-24.5	2	4	
80	North Central 1	1977	74	37	39	36	2941	100	7.6	Electro-mechanical	-31.7	2	3	2.2 m to top of core

**10m firn temperature

Table I(B). Greenland, continued.

NO.	SITE NAME	YEAR	LATITUDE °	'	LONGITUDE °	'	ELEVATION (m) asl	CORE DEPTH (m)	CORE DIAMETER (cm)	DRILL TYPE	MEAN ANNUAL TEMP (°C)	DRILLING AGENCY	CURATING AGENCY	REMARKS
81	North Central 2	1977	74	37N	39	36W	2941	∿109	7.6	Electro-mechanical	-31.7	2	3	
82	North Central	1977	74	37	39	36	2941	102	7.6	Electro-mechanical	-31.7	2	4	
83	Dye 3	1978	65	11	43	50	2480	∿90	10	Electro-mechanical	-19.6	2	4	drill test
84	Camp III	1978	69	43	50	08	615	48	7.6	Electro-mechanical		2	7	bedrock
85	Camp III	1978	69	43	50	08	615	90	7.6	Electro-mechanical		2	7	water layer at the bottom
86	Dye 3	1979	65	11	43	50	2480	80	12.4	Thermal	-19.6	2	3	80 m cased
87	Dye 3	1979	65	11	43	50	2480	80-∿220	9	Electro-mechanical	-19.6	2	3	fluid fill, drill test

Table I. ICE CORES
C. ICELAND

NO.	SITE NAME	YEAR	LATITUDE ° '	LONGITUDE ° '	ELEVATION (m) asl	CORE DEPTH (m)	CORE DIAMETER (cm)	DRILL TYPE	MEAN ANNUAL TEMP (°C)	DRILLING AGENCY	CURATING AGENCY	REMARKS
1	Langjökull	1968	∿64 40N	∿20 10W		30	4.5	Thermal		17	17	drill test
2	Bardarbunga	1968	∿64 36	∿17 36	1800	42	4.5	Thermal	∿-8	17	17	drill stuck
3	Bardarbunga	1969	∿64 36	∿17 36	2000	104	4.5	Thermal	-8	17	17	hole to 108 m
4	Bardarbunga	1970	∿64 36	∿17 36	1800	27*	7.6	Rotary mechanical SIPRE	∿-8	17	17	10 m pit
5	Bardarbunga	1972	∿64 36	∿17 36	2000	415	9	Rotary mechanical	-8	17	17	30 tephra layers, core dates to 1650 AD

*pit-core

Table I. D. SPITSBERGEN

NO.	SITE NAME	YEAR	LATITUDE ° '	LONGITUDE ° '	ELEVATION (m) asl	CORE DEPTH (m)	CORE DIAMETER (cm)	DRILL TYPE	MEAN ANNUAL TEMP (°C)	DRILLING AGENCY	CURATING AGENCY	REMARKS
1	Ice Divide	1967	∿78 30N	∿14 25W	450	8.1		Manual rotary		44		Grenfiord and Fritöf Glaciers
2	Ice Divide	1975	∿78 30	∿14 25	450	211	8.4	Thermal		44		Grenfiord and Fritöf Glaciers, Bedrock, samples melted
3	Ice Divide	1975	∿78 30	∿14 25	450	10	8.4	Thermal		44		Grenfiord and Fritöf Glaciers
4	West Spitsbergen	1976				211		Thermal		43		New drill
5	Lomonosov Glacier	1977				210		Thermal		43	43	West Spitsbergen

Table I. ICE CORES
E. EUROPE
1. ALPS

NO.	SITE NAME	YEAR	LATITUDE ° '	LONGITUDE ° '	ELEVATION (m) asl	CORE DEPTH (m)	CORE DIAMETER (cm)	DRILL TYPE	MEAN ANNUAL TEMP (°C)	DRILLING AGENCY	CURATING AGENCY	REMARKS
1	Vallee Blanc	1963	~45 53N	~06 56E	~3550	55	7.6	SIPRE		12		
2	Vallee Blanc	1966	~45 53	~06 56	~3550	36	7.6	SIPRE		12		
3	L 67	1967	~46 50	~10 47	3240	17	7.6	SIPRE		22	22	Kesselwandferner Ötztal Alps
4	J I	1967	46 33	07 58	3489	8	7.6	SIPRE		22	22	Jungfraujoch
5	J II	1967	46 33	07 58	3489	8	7.6	SIPRE		22	22	Jungfraujoch
6	JZ I	1968	46 33	07 58	3471	6.5	7.6	SIPRE		22	22	Jungfraujoch
7	JZ II	1968	46 33	07 58	3472	5.75	7.6	SIPRE		22	22	Jungfraujoch
8	JZ III	1968	46 33	07 58	3470	5.1	7.6	SIPRE		22	22	Jungfraujoch
9	JZ IV	1968	46 33	07 58	3473	7.5	7.6	SIPRE		22	22	Jungfraujoch
10	JZ V	1968	46 33	07 58	3480	9.5	7.6	SIPRE		22	22	Jungfraujoch
11	JZ VI	1968	46 33	07 58	3487	9.0	7.6	SIPRE		22	22	Jungfraujoch
12	JZ VII	1968	46 33	07 58	3471	4.5	7.6	SIPRE		22	22	Jungfraujoch
13	Saint Sorlin	1968	45 11	06 10	2800	60	10	Rotary mechanical		12	12	Test thermal drill, 10 cm core
14	Saint Sorlin	1968	45 11	06 10	2800	60	10	Rotary mechanical		12	12	
15	Saint Sorlin	1968	45 11	06 10	2800	60	10	Rotary mechanical		12	12	
16	K I	1970	~46 50	~10 47	~3350	12.58	7.6	SIPRE		22	22	Kesselwandferner Otztal Alps
17	K II	1970	~46 50	~10 47	~3285	14.88	7.6	SIPRE		22	22	Kesselwandferner Otztal Alps
18	K III	1970	~46 50	~10 47	~3275	14.97	7.6	SIPRE		22	22	Kesselwandferner Otztal Alps
19	K IV	1970	~46 50	~10 47	~3225	16.01	7.6	SIPRE		22	22	Kesselwandferner Otztal Alps
20	K V	1970	~46 50	~10 47	~3175	16.13	7.6	SIPRE		22	22	Kesselwandferner Otztal Alps
21	K S	1970	~46 50	~10 47	~3125	11.06	7.6	SIPRE		22	22	Kesselwandferner Otztal Alps

Table I(E-1). Alps, continued.

NO.	SITE NAME	YEAR	LATITUDE °	'	LONGITUDE °	'	ELEVATION (m) asl	CORE DEPTH (m)	CORE DIAMETER (cm)	DRILL TYPE	MEAN ANNUAL TEMP (°C)	DRILLING AGENCY	CURATING AGENCY	REMARKS
22	K VII	1970	∿46	50N	∿10	47E	∿3082	6.60	7.6	SIPRE		22	22	Kesselwandferner Otztal Alps
23	Vallee Blanc	1970	∿45	53	∿06	56	∿3550	33	7.6	SIPRE		12		Mer de Glace
24	Vallee Blanc	1971	45	53	06	56	3500	40	10	Rotary mechanical		12	12	Mer de Glace
25	Vallee Blanc	1971	45	53	06	56	3500	40	10	Rotary mechanical		12	12	Mer de Glace
26	Vallee Blanc	1971	45	53	06	56	3500	187	10	Thermal		12	12	Mer de Glace bedrock
27	Col du Dome	1973	∿45	50	∿07	00	4280	24.5	7.6	SIPRE	-13.2**	12		Mont Blanc
28	P 1	1972	∿46	33	∿08	00	3470	∿9	7.6	SIPRE		7	7	Jungfraujoch
29	P 2	1972	∿46	33	∿08	00	3470	∿10	7.6	SIPRE		7	7	Jungfraujoch
30	Col du Dome	1973	45	50	07	08	4785	16.7	7.6	SIPRE	-13.2**	12	12	Mont Blanc
31	PM 1	1974	∿46	24	∿07	32	2750	>3.5	7.6	SIPRE		7	7	Plaine Morte
32	PM 2	1974	∿46	24	∿07	32	2750	>1.45	7.6	SIPRE		7	7	Plaine Morte
33	PM 3	1974	∿46	24	∿07	32	2750	>1.45	7.6	SIPRE		7	7	Plaine Morte
34	P3	1974	∿46	33	∿08	00	3470	∿19	7.6	SIPRE		7	7	Jungfraujoch
35	Col du Dome	1976	∿45	50	∿07	08	4250	30.6	7.6	SIPRE	-13.2**	12	12	Mont Blanc
36	Colle Gnifetti	1976	45	56	07	46	4450	33	7.5	Electro-mechanical	-14.8**	7	7	
37	Ewigsch-Neefeld	1976	∿46	33	∿08	03	3370	29.0	7.5	Electro-mechanical		7	7	
38	Ewigsch-Neefeld	1977	∿46	33	∿08	03	3370	35.0	7.5	Electro-mechanical		7	7	water table ∿31 m
39	Ewigsch-Neefeld	1977	∿46	33	∿08	03	3410	36.4	7.5	Electro-mechanical		7	7	water table ∿31 m
40	Ewigsch-Neefeld	1977	∿46	33	∿08	03	3440	38.5	7.5	Electro-mechanical		7		Core not recovered for study

**10m firn temperature

Table I(E-1). Alps, continued.

NO.	SITE NAME	YEAR	LATITUDE ° '	LONGITUDE ° '	ELEVATION (m) asl	CORE DEPTH (m)	CORE DIAMETER (cm)	DRILL TYPE	MEAN ANNUAL TEMP (°C)	DRILLING AGENCY	CURATING AGENCY	REMARKS
41	Ewigsch-Neefeld	1977	∿46 33N	∿08 03E	3440	35.0	7.5	Electro-mechanical		7		Core not recovered for study
42	Colle Gnifetti	1977	45 56	07 46	4450	55	7.5	Electro-mechanical	-14.8**	7	7	
43	Colle Gnifetti	1977	45 56	07 46	4450	65	7.5	Electro-mechanical	-14.8**	7	7	

Table I(E). EUROPE
2. SCANDINAVIA

1	Svartisen	1964	∿66 40N	∿14 00W	1368	16.76*	7.6	SIPRE		47		Norway, 3.2m pit
2	Svartisen	1964	∿66 40	∿14 00	1322	7.73	7.6	SIPRE		47		Norway
3	Svartisen	1964	∿66 40	∿14 00	1121	17.26	7.6	SIPRE		47		Norway
4	Tarfala Glacier	1973	∿67 25	∿18 20		20	7.6	SIPRE		50	50/4	Sweden

* pit core

** 10m firn temperature

Table I. ICE CORES
F. ASIA, INCLUDING THE CAUCASUS

NO.	SITE NAME	YEAR	LATITUDE ° '	LONGITUDE ° '	ELEVATION (m) asl	CORE DEPTH (m)	CORE DIAMETER (cm)	DRILL TYPE	MEAN ANNUAL TEMP (°C)	DRILLING AGENCY	CURATING AGENCY	REMARKS
1	Shokalsky Glacier	1957	76 30N	62 00E	∿1000	30				44		Novaya Zemlya ice divide
2	Elbrus	1963	∿44 12	∿44 08	∿4000	200	9.4	Percussion cable		43		Recovers 2-7cm ice chips
3	Alaty	1965	∿50 00	∿87 30	∿4000	200	9.4	Percussion cable		43		Recovers 2-7cm ice chips
4	Taisetsu Mts.	1966	∿43 30	∿143 00	1730	24		Manual rotary		46	46	Yukikabe Firn Hokkaido, Japan
5	Besengi Glacier	1966	∿44 12	∿42 40	2700	150	9.4	Percussion cable		43		Caucasus 2-7cm ice chips
6	Rongbuk Glacier	1966	28 05	86 52	5400	12		Manual rotary		51	51	People's Republic of China
7	Abramov Glacier	1972	∿39 00	∿72 00		110		Thermal		45		Pamir Mts.
8	Abramov Glacier	1973	∿39 00	∿72 00	4400	50	10	Thermal				Pamir Mts.
9	Abramov Glacier	1974	∿39 00	∿72 00	4400	106	10	Thermal				Pamir Mts.
10	Pamirs	1974	∿39 00	∿72 00	∿3000	137	8.4	Thermal		45		
11	Obruchev Glacier	1974	∿65 00	∿60 00	∿600	87	8.4	Thermal		44		Polar Urals
12	Obruchev Glacier	1974	∿65 00	∿60 00	∿600	64	8.4	Thermal		44		Polar Urals
13	North Pole 19	1974	Various #	Various #	∿5	34	8.4	Thermal		44		
14	North Pole 19	1974	Various #	Various #	∿10	11	8.4	Thermal		44		
15	Vavilov Dome	1978	∿80 00	∿96 00	∿780	450	10	Thermal		44	44	Severnaya Zemlya
16	Vavilov Dome	1978	∿80 00	∿96 00	∿780	459	10	Thermal		44	44	Severnaya Zemlya

#drifting ice island

Table I. ICE CORES
G. SOUTHERN HEMISPHERE EXCLUDING ANTARCTICA
1. AFRICA
KENYA

NO.	SITE NAME	YEAR	LATITUDE ° '	LONGITUDE ° '	ELEVATION (m) asl	CORE DEPTH (m)	CORE DIAMETER (cm)	DRILL TYPE	MEAN ANNUAL TEMP (°C)	DRILLING AGENCY	CURATING AGENCY	REMARKS
1	Lewis Glacier	1975	0 09S	37 18E	4880	6	5	Thermal	∿0	20	20	To bedrock
2	Lewis Glacier	1977	0 09	37 18	4880	11	5	Thermal	∿0	20	20	To bedrock
3	Lewis Glacier Site 1	1978	0 10	37 19	∿4980	13.4	7.6	SIPRE	∿0	16	16	On the summit, 3.5m void at site
4	Lewis Glacier Site 2	1978	0 10	37 19	∿4980	11.5	7.6	SIPRE	∿0	16	16	On the summit

Table I(G). SOUTHERN HEMISPHERE EXCLUDING ANTARCTICA
2. NEW GUINEA
IRIAN JAYA

1	Meren A	1972	∿04 06S	∿137 20W	4470	9.31	7.6	SIPRE	-0.15**	19		
2	Meren B	1972	∿04 06	∿137 20	4523	10.16	7.6	SIPRE	-0.15**	19		
3	Meren D	1972	∿04 06	∿137 20	4365	10.05	7.6	SIPRE	-0.15**	19		
4	Meren E	1972	∿04 06	∿137 20	4417	9.83	7.6	SIPRE	-0.15**	19		
5	Meren X	1972	∿04 06	∿137 20	4595	9.93	7.6	SIPRE	-0.15**	19		
6	Carstensz K	1973	∿04 04	∿137 20	4495	∿10	7.6	SIPRE	-0.15**	19		
7	Carstensz L	1973	∿04 04	∿137 20	4536	∿10	7.6	SIPRE	-0.15**	19		
8	Carstensz M	1973	∿04 04	∿137 20	4595	∿10	7.6	SIPRE	-0.15**	19		

**10m firn temperature

Table I(G). SOUTHERN HEMISPHERE EXCLUDING ANTARCTICA continued
3. NEW ZEALAND

NO.	SITE NAME	YEAR	LATITUDE ° '	LONGITUDE ° '	ELEVATION (m) asl	CORE DEPTH (m)	CORE DIAMETER (cm)	DRILL TYPE	MEAN ANNUAL TEMP (°C)	DRILLING AGENCY	CURATING AGENCY	REMARKS
1	Tasman Glacier	1970	∿43 30S	∿170 15E	2340	12	7.6	SIPRE		52		

Table I(G). SOUTHERN HEMISPHERE EXCLUDING ANTARCTICA continued
4. SOUTH AMERICA
PERU

1	Summit	1975	13 56S	70 50W	5650	6.8*	7.6	SIPRE	-4	16	16	3.8m pit
2	Middle Dome	1976	13 56	70 50	5650	15.07*	7.6	SIPRE	-4	16	16	3m pit
3	South Dome	1976	13 56	70 50	5650	16.10	7.6	SIPRE	-4	16	16	
4	Summit	1976	13 56	70 50	5650	14.95*	7.6	SIPRE	-4	16	16	3m pit

*pit-core

Table I. ICE CORES
H. ANTARCTICA
1. ARGENTINA

No.	SITE NAME	YEAR	LATITUDE °	'	LONGITUDE °	'	ELEVATION (m) asl	CORE DEPTH (m)	CORE DIAMETER (cm)	DRILL TYPE	MEAN ANNUAL TEMP (°C)	DRILLING AGENCY	CURATING AGENCY	REMARKS
1	James Ross Island	1977/ 1978	∿64	20S	∿57	30W	∿1628	10	7.6	SIPRE		49	49/12	
2	James Ross Island	1977/ 1978	∿64	20	∿57	30W	∿1628	10	7.6	SIPRE		49	49/12	

Table I(H). ANTARCTICA
2. AUSTRALIA

3	G1	1968	∿69	00S	∿71	00E	∿50	310	12	Thermal	-20**	10	10	Amery Ice Shelf
4	SGA	1969	∿66	08	∿110	55	375	320	12	Thermal		10	10	Law Dome Cape Folger
5	SGD	1969	∿66	39	∿112	50	1390	385	12	Thermal		10	10	Law Dome Summit
6	SGJ	1972	∿65	50	∿113	13	400	112	11.75	Thermal		10	10	Law Dome, Cape Poinsett
7	SGB	1972	∿66	17	∿111	30	575	73	11.75	Thermal		10	10	Law Dome
8	SGP	1972	∿66	13	∿111	15	600	113	11.75	Thermal		10	10	Law Dome
9	S1	1972	∿66	17	∿110	44	262	53	11.75	Thermal	-10.7	10	10	Law Dome
10	GL1	1974	72	31	65	19	1148	10	7.6	SIPRE	-28.1**	10	10	Lambert Glacier Drainage Basin
11	GL2	1974	72	16	63	58	1607	10	7.6	SIPRE	-30.3**	10	10	Enderby Land
12	GL3	1974	72	48	62	09	1808	10	7.6	SIPRE		10	10	Enderby Land
13	GL4	1974	73	15	61	00	2020	10	7.6	SIPRE	-36.5**	10	10	Enderby Land
14	GL5	1974	73	43	61	11	2000	10	7.6	SIPRE	-35.8**	10	10	Enderby Land
15	GL6	1974	74	03	62	00	1889	10	7.6	SIPRE		10	10	Enderby Land
16	GL7	1974	74	14	64	13	1556	10	7.6	SIPRE	-33.2**	10	10	Enderby Land
17	GL8	1974	74	59	66	06	1763	10	7.6	SIPRE	-34.7**	10	10	Enderby Land
18	GL9	1974	74	45	67	58	1710	10	7.6	SIPRE		10	10	Enderby Land
19	GL10	1974	74	04	68	23	1109	10	7.6	SIPRE		10	10	Enderby Land
20	GL11	1974	73	44	70	37	1462	10	7.6	SIPRE	-27.8**	10	10	Enderby Land
21	SGF	1974	∿66	09	∿111	00	375	348	11.75	Thermal		10	10	Law Dome
22	GE2 to GE9	1976	Various		Various		∿2000	∿8	7.6	SIPRE		10	10	8 cores on Enderby Land Traverse

**10m firn temperature

Table I(H-2). Australia, continued.

No.	SITE NAME	YEAR	LATITUDE ° '	LONGITUDE ° '	ELEVATION (m) asl	CORE DEPTH (m)	CORE DIAMETER (cm)	DRILL TYPE	MEAN ANNUAL TEMP (°C)	DRILLING AGENCY	CURATING AGENCY	REMARKS
23	BHQ	1977	∿66 21S	∿111 48E	940	419	11.75	Thermal		10	10	Law Dome
24	BHD	1977	∿66 39	∿112 50	1390	475	11.75	Thermal		10	10	Law Dome Summit
25	GM Series	1977	Various	Various	Various	10	7.6	SIPRE		10/15	10	8 cores on Mirnyy -Dome C Traverse
26	GM	1977	69 50	95 30		10	7.6	SIPRE	∿-37**	10/15	10	Pionerskaya
27	GM10	1977	71 38	101 50	2977	10	7.6	SIPRE	∿-47**	10/15	10	
28	GM7	1977	70 27	97 51	2758	10	7.6	SIPRE	∿-38**	10/15	10	
29	GM13	1977	73 14	110 27	2961	10	7.6	SIPRE	∿-53**	10/15	10	
30	GM23	1977	74 39	124 10	3240	10	7.6	SIPRE	-53.5	10/15	10	Dome C
31	Mirnyy	1977	66 33	93 01	∿200	10	7.6	SIPRE	-14.6	10/15	10	
32	Vostok	1977	78 28	106 48	3500	10	7.6	SIPRE	-55.6	10/15	10	
33	Vostok 1	1977	72 08	96 35	2940	10	7.6	SIPRE		10/15	10	
34	Komsomolskaya	1977	74 01	97 22	∿3400	10	7.6	SIPRE		10/15	10	

Table I(H). ANTARCTICA continued
3. BELGIUM

35	Base Roi Baudouin	1961	70 26S	24 19E	39	115.72	7.6	Power SIPRE		13	13	
36	P64A	1964	71 58	24 19	1500	9.7*	7.6	SIPRE		13		2.7m pit
37	P64B	1964	71 58	24 19	1500	9.7*	7.6	SIPRE		13		2.7m pit 50cm from P64A
38	M185	1964	86 45	58 36	3110	11.3*	7.6	SIPRE	-51.5**	13		SPQMLT1^2 2.4m pit
39	M275	1964	86 38	30 36	2860	12.2*	7.6	SIPRE	-47.9**	13		SPQMLT1^2 2.6m pit
40	M370	1964	85 46	8 42	2690	10.5*	7.6	SIPRE	-50.0**	13		SPQMLT1^2 2.6m pit
41	M415	1965	85 10	1 36	2630	12.2*	7.6	SIPRE	-48.6**	13		SPQMLT1^2 2.2m pit
42	M496	1965	84 58	17 54	2680	10.3*	7.6	SIPRE	-49.0**	13		SPQMLT1^2 2.4m pit
43	M620	1965	84 10	37 36	3170	10.2*	7.6	SIPRE	-48.8**	13		SPQMLT1^2 2.4m pit
44	M363	1966	82 00	9 35	2510	10.2*	7.6	SIPRE	-46.7**	13		SPQMLT2^2 4.2m pit
45	M455	1966	81 30	20 30	2870	10	7.6	SIPRE		13		SPQMLT2^2 4m pit

*pit core

**10m firn temperature

^{2}SPQMLT South Pole - Queen Maud Land Traverse 1, 2, 3

Table I(H-3). Belgium, continued.

NO.	SITE NAME	YEAR	LATITUDE ° '	LONGITUDE ° '	ELEVATION (m) asl	CORE DEPTH (m)	CORE DIAMETER (cm)	DRILL TYPE	MEAN ANNUAL TEMP (°C)	DRILLING AGENCY	CURATING AGENCY	REMARKS
46	M248	1967	78 19S	23 22E	3360	10.0	7.6	SIPRE	-49.5**	13		SPQMLT3[2] 3m pit
47	M500	1968	76 22	9 32	3230	10.0	7.6	SIPRE	-48.5**	13		SPQMLT3[2] 3m pit
48	M750	1968	77 53	1 55W	2540	9.0	7.6	SIPRE	-41.5**	13		SPQMLT3[2] 3m pit

Table I(H). ANTARCTICA continued
4. FRANCE

49	Pioner-skaya	1964	69 44S	95 31E	2740	10		Manual rotary		5		
50	Pioner-skaya	1964	69 44	95 31	2740	7		Manual rotary		5		
51	G1	1964/1966	66 41	139 55	86	97.7		Electro-mechanical	-12**	5	12	Drilling fluid compressed air
52	A3	1964/1966	66 43	139 54	220	106		Electro-mechanical	-13.5**	5	12	Drilling fluid compressed air
53	G2	1964/1966	66 42	139 55	112	105.9		Electro-mechanical	-12.5**	5	12	Drilling fluid compressed air
54	D100	1971/1972	71 34	131 59	2810	~12	7.6	SIPRE		12		
55	D120	1971/1972	73 04	128 44	3010	~12	7.6	SIPRE		12		
56	D10	1972	66 42	139 55	270	44	10	Thermal		12	12	
57	Dumont d'Urville to Vostok	1972/1973	Various	Various	Coast to 3500	17	7.6	SIPRE	Various	5/15		3 cores along traverse
58	Dumont d'Urville to Vostok	1972/1973	Various	Various	Coast to 3500	25	7.6	SIPRE	Various	5/15		5 cores along traverse
59	D10	1974	66 42	139 55	270	304	10	Thermal		12	12	Bedrock
60	South Pole	1974/1975	90 00		2912	17	7.6	SIPRE	-51.1	12	12	
61	Dome C	1977/1978	74 39	124 10	3240	905	10	Thermal	-53.5	12	12	Initial 130m drilled with electromechanical 10cm core

**10m firn temperature

[2] SPQLMT South Pole - Queen Maud Land Traverse 1, 2, 3

Table I(H-4). France, continued.

NO.	SITE NAME	YEAR	LATITUDE ° '	LONGITUDE ° '	ELEVATION (m) asl	CORE DEPTH (m)	CORE DIAMETER (cm)	DRILL TYPE	MEAN ANNUAL TEMP (°C)	DRILLING AGENCY	CURATING AGENCY	REMARKS
62	Dome C	1978/ 1979	74 39S	124 10E	3240	180	10	Electro-mechanical	-53.5	12	12	20m from 905m hole

Table I(H). ANTARCTICA continued
5. GREAT BRITAIN

63	Detroit Plateau	1974/ 1976	64 05S	59 35W	1806	10	7.6	SIPRE		42	42/4	
64	Bruce Plateau	1974/ 1976	66 25	64 57	1937	10	7.6	SIPRE		42	42/4	
65	Peninsula Plateau Crest	1974/ 1976	67 32	66 00	1750	10	7.6	SIPRE		42	42/4	
66	Adelaide Island	1974/ 1976	67 46	68 55	377	10	7.6	SIPRE		42	42/4	
67	Stowington Island	1974/ 1976	68 11	67 00	380	10	7.6	SIPRE		42	42/4	
68	Gipps Ice Rise	1974/ 1976	68 46	60 56	290	10	7.6	SIPRE		42	42/4	
69	Fleming Glacier	1974/ 1976	69 30	66 16	870	10	7.6	SIPRE		42	42/4	
70	Peninsula Plateau Crest	1974/ 1976	70 01	64 29	2131	10	7.6	SIPRE		42	42/4	
71	Dolleman Island	1974/ 1976	70 37	60 44	396	10	7.6	SIPRE		42	42/4	
72	Murrish Glacier	1974/ 1976	71 07	62 20	1050	10	7.6	SIPRE		42	42/4	
73	Peninsula Plateau	1974/ 1976	71 14	63 22	1752	10	7.6	SIPRE		42	42/4	
74	Peninsula Plateau Crest	1974/ 1976	70 50	64 27	1987	10	7.6	SIPRE		42	42/4	
75	Peninsula Plateau Crest	1974/ 1976	71 15	64 30	2010	10	7.6	SIPRE		42	42/4	
76	Snow Field	1974/ 1976	71 18	67 29	290	10	7.6	SIPRE		42	42/4	

Table I(H-5). Great Britain, continued.

NO.	SITE NAME	YEAR	LATITUDE		LONGITUDE		ELEVATION (m) asl	CORE DEPTH (m)	CORE DIAMETER (cm)	DRILL TYPE	MEAN ANNUAL TEMP (°C)	DRILLING AGENCY	CURATING AGENCY	REMARKS
			°	'	°	'								
77	Elliot Hills	1974/76	71	23S	65	30W	1547	10	7.6	SIPRE		42	42/4	
78	Thomson Rock	1974/76	71	29	66	58	946	10	7.6	SIPRE		42	42/4	
79	Charcot Island	1974/76	70	00	75	20	595	10	7.6	SIPRE		42	42/4	
80	Peninsula Plateau Crest	1974/76	71	42	64	05	1886	10	7.6	SIPRE		42	42/4	
81	Monte-Verde Peninsula	1974/76	72	30	72	50	488	10	7.6	SIPRE		42	42/4	
82	Peninsula Plateau Crest	1974/76	72	47	64	30	1797	10	7.6	SIPRE		42	42/4	
83	Spoatz Island	1974/76	72	50	64	30	539	10	7.6	SIPRE		42	42/4	
84	Peninsula Plateau Crest	1974/76	73	42	64	47	2007	10	7.6	SIPRE		42	42/4	
85	Butler Island	1974/76	72	12	60	20	130	10	7.6	SIPRE		42	42/4	
86	Peninsula Plateau	1974/76	70	53	64	57	1835	10	7.6	SIPRE		42	42/4	
87	Graham Land	1974/76	67	32	66	00		5	7.6	SIPRE		42	42	
88	Graham Land	1974/76	67	32	66	00		5	7.6	SIPRE		42	42	
89	Rossini Point	1974/76	72	30	72	50	1600	9.75	7.6	SIPRE		42	42	top 75 cm missing
90	Rossini Point	1974/76	72	30	72	50	1600	9.79	7.6	SIPRE		42	42	top 75 cm missing
91	Horse Point	1974/76	71	18	67	29	1100	9.78	7.6	SIPRE		42	42	
92	Horse Point	1974/76	71	18	67	29	1100	9.85	7.6	SIPRE		42	42	

Table I(H). ANTARCTICA, continued.
6. JAPAN

NO.	SITE NAME	YEAR	LATITUDE ° '	LONGITUDE ° '	ELEVATION (m) asl	CORE DEPTH (m)	CORE DIAMETER (cm)	DRILL TYPE	MEAN ANNUAL TEMP (°C)	DRILLING AGENCY	CURATING AGENCY	REMARKS
93	Syowa To South Pole Traverse	1968/69	69 00S to 90 00	39 35E	~40 to 2912	10	7.6	SIPRE		11	11	10m core every 100 km
94	Mizuho	1970	70 42	44 18	2230	20	7.6	SIPRE	-33	11		
95	Mizhuo	1971	70 42	44 18	2230	41.9*	10.8	Electro-mechanical	-33	11	11	4.3m pit
96	Mizuho	1971	70 42	44 18	2230	74.9*	10.3	Thermal	-35**	11	11	4.3m pit
97	Mizuho	1972	70 42	44 18	2230	147.5*	10.6	Thermal	-35**	11	11	6m pit
98	Mizuho	1974	70 42	44 18	2230	10	7.6	SIPRE	-32.7**	11	11	
99	Mizuho	1974/75	70 42	44 18	2230	142*	13.2	Thermal	-32.8**	11	11	5.2m pit, drill stuck
100	Mizuho	1975	70 42	44 18	2230	106.7-145.4	13.2	Thermal	-33	11	11	Re-entered 142m hole in an attempt to detach stuck drill
101	Mizuho	1977	70 42	44 18	2230	46.3		Manual rotary	-33	11		

Table I(H). ANTARCTICA
7. NORWAY

NO.	SITE NAME	YEAR	LATITUDE ° '	LONGITUDE ° '	ELEVATION (m) asl	CORE DEPTH (m)	CORE DIAMETER (cm)	DRILL TYPE	MEAN ANNUAL TEMP (°C)	DRILLING AGENCY	CURATING AGENCY	REMARKS
102	Camp Norway 3	1976/77	72 19S	16 14W	~510	10	7.6	SIPRE		48	48/4	
103	Camp Norway 3	1976/77	72 19	16 14	~510	11	7.6	SIPRE		48	48/4	
104	Camp Norway 3	1976/77	72 19	16 14	~510	11	7.6	SIPRE		48	48/4	
105	Camp Norway 3	1976/77	72 19	16 14	~510	13	7.6	SIPRE		48	48/4	
106	Camp Norway 3	1978/79	72 19	16 14	~510	13	7.6	SIPRE		48	48/4	

*pit core
**10m firn temperature

Table I(H). ANTARCTICA, continued.
8. NORWEGIAN-BRITISH-SWEDISH EXPEDITION.

NO.	SITE NAME	YEAR	LATITUDE ° '	LONGITUDE ° '	ELEVATION (m) asl	CORE DEPTH (m)	CORE DIAMETER (cm)	DRILL TYPE	MEAN ANNUAL TEMPERATURE (°C)	DRILLING AGENCY	CURATING AGENCY	REMARKS
107	Maudheim	1950 1951	71 03S	10 56E	37.5	99.75	8	Rotary mechanical	-17.4	14		Norwegian-British-Swedish Expedition

Table I(H). ANTARCTICA
9. SOVIET UNION

NO.	SITE NAME	YEAR	LATITUDE ° '	LONGITUDE ° '	ELEVATION (m) asl	CORE DEPTH (m)	CORE DIAMETER (cm)	DRILL TYPE	MEAN ANNUAL TEMP (°C)	DRILLING AGENCY	CURATING AGENCY	REMARKS
108	Mirnyy	1956/58	66 33S	93 01E	∿200	371		Rotary mechanical	-14.6	15		7 km S of Mirnyy
109	Mirnyy	1969	∿67 00	∿93 30	∿1000	250	12.4	Thermal	∿-14	15		Test 50 km S of Mirnyy
110	Penta 3	1969	74 01	97 22	∿3400	7		Manual rotary		15/5	15	Komsomolskaya
111	Penta 4	1969	∿74 30	∿97 19	∿3125	11		Manual rotary		15/5	15	Vostok-1
112	Penta 5	1969	70 53	95 57	∿3300	15		Manual rotary		15/5	15	Zhelob
113	Vostok	1970	79 28	106 48	3500	506.9	12.4	Thermal	-55.6	15		
114	57 km	1971/72	∿67 00	∿93 30	∿1000	50.5	12.4	Thermal		15		Mirnyy-170 km traverse
115	153 km	1971/72	∿68 00	∿94 00	∿1600	56.6	12.4	Thermal		15		Mirnyy-170 km traverse
116	Vostok	1972/73	78 28	106 48	3500	506.9-952	12.4	Thermal	-55.6	15		Re-entered 1970 hole
117	Vostok	1974	78 28	106 48	3500	905	12.4	Thermal	-55.6	15		
118	Vostok	1974	78 28	106 48	3500	105	12.4	Thermal	-55.6	15		Test hole, fluid fill
119	Novolazarevskaya	1974/75	70 46	11 50	∿500	330	12.4	Thermal		15		
120	Vostok 1	1974/75	72 08	96 35	2940	105	12.4	Thermal		15		For sterile microbiology
121	Lazarev Ice Sheet	1975	69 58	12 55	40	357		Thermal		15		Ice floating

Table I(H-9). Soviet Union, continued.

NO.	SITE NAME	YEAR	LATITUDE ° '	LONGITUDE ° '	ELEVATION (m) asl	CORE DEPTH (m)	CORE DIAMETER (cm)	DRILL TYPE	MEAN ANNUAL TEMP (°C)	DRILLING AGENCY	CURATING AGENCY	REMARKS
122	Lazarev Ice Sheet	1975	69 58S	12 55E	40	447		Thermal		15		Hit rock
123	Dome C	1975	74 39	124 10	3240	10*	7.6	SIPRE	-53.5	15/5	15/5	5.4m pit
124	Dome C	1975	74 39	124 10	3240	12*	7.6	SIPRE	-53.5	15/5	15/5	5.4 m pit
125	Dailey Island	1975	77 53	165 06		6.5	7.6	SIPRE		15/40		
126	Koettlitz Glacier	1975	78 17	164 00	5	7.5	7.6	SIPRE		15/40		
127	McMurdo Ice Shelf	1975	78 21S	166 41E	~50	6.6	7.6	SIPRE		15/40		
128	McMurdo Ice Shelf	1975	78 21	166 41	~50	5.9	7.6	SIPRE		15/40		
129	Novolazar-evskaya	1976/77	70 46	11 50	~500	810	12.4	Thermal		15		
130	Vostok-1	1977/78	72 08	96 35	2940	180	12.4	Thermal		15		
131	Vostok-1	1977/78	72 08	96 35	2940	180-300	12.4	Thermal		15		
132	J-9	1978	82 22	168 40W	60	416.04	8	Thermal		15/40		
133	Vostok-1	1978/79	72 08	96 35E	2940	300-430	12.4	Thermal		15		
134	Shackle-ton Ice Shelf	1978/79	~65 50	~96 30	~50	200	12.4	Thermal		15		

*pit core

Table I(H). ANTARCTICA, continued.
10. UNITED STATES

NO.	SITE NAME	YEAR	LATITUDE ° '	LONGITUDE ° '	ELEVATION (m) asl	CORE DEPTH (m)	CORE DIAMETER (cm)	DRILL TYPE	MEAN ANNUAL TEMP (°C)	DRILLING AGENCY	CURATING AGENCY	REMARKS
135	Wilkes S-2	1957	66 31S	112 13E	1139	61.2*	7.6	SIPRE	-19.4**	16/28		35.2 m pit
136	Byrd	1958	80 00S	120 00W	1524	308	9.8	Rotary mechanical	-28.6**	21		Drilling fluid compressed air
137	Byrd	1958	80 00	120 00	1524	48.8*	7.6	SIPRE	-28.6**	21	21	Pit 'Snow Mine' 27.2 m
138	Little America V	1958	78 11	162 10	42	256	9.8	Rotary mechanical		21		Drilling fluid compressed air, within several m of base of ice shelf
139	Little America V	1958	78 11	162 10	42	18.0	7.6	SIPRE		21	21	
140	Byrd and Marie Byrd Traverse	1958/59	Various	Various	Various	∿10	7.6	SIPRE	Various	16		10 core holes
141	Marie Byrd Traverse	1958/59	Various	Various	Various	20	7.6	SIPRE	Various	16		3 core holes
142	Pit 4	1959	∿78 34	∿163 57	20	21.6*	7.6	SIPRE		28/38	38	Crevasse Fox 2.6 m pit, Camp Michigan
143	Pit 5	1959	∿78 34	∿163 57	25	18.6*	7.6	SIPRE		28/38	38	Crevasse Fox 2.4 m pit, Camp Michigan
144	Ski-Hi (Eights)	1961	75 15	77 07	452	21	7.6	SIPRE	-24.8**	16	16/37	APT[3]
145	Eight Station	1961/62	75 15	77 07	452	21.95	7.6	SIPRE	-24.8**	16	16	
146	C-Site	1961/62	75 00	73 00		7.91	7.6	SIPRE		16	16	
147	M 796	1962	74 27	67 08	2150	25	7.6	SIPRE	-25.4**	16	16/37	APT[3]
148	Whitmore Mountains Traverse	1962/63	Various	Various	Various	10	7.6	SIPRE	Various	16		9 core holes
149	Plateau	1966/67	79 15S	40 30E	3624	71	12.2	Thermal	-58.4**	1/16		
150	Byrd	1966/67	80 00S	120 00W	1524	35	12.2	Thermal	-28.6**	1		

*pit core **10m firn temperature [3]Antarctic Peninsula Traverse

Table I(H-10). United States, continued.

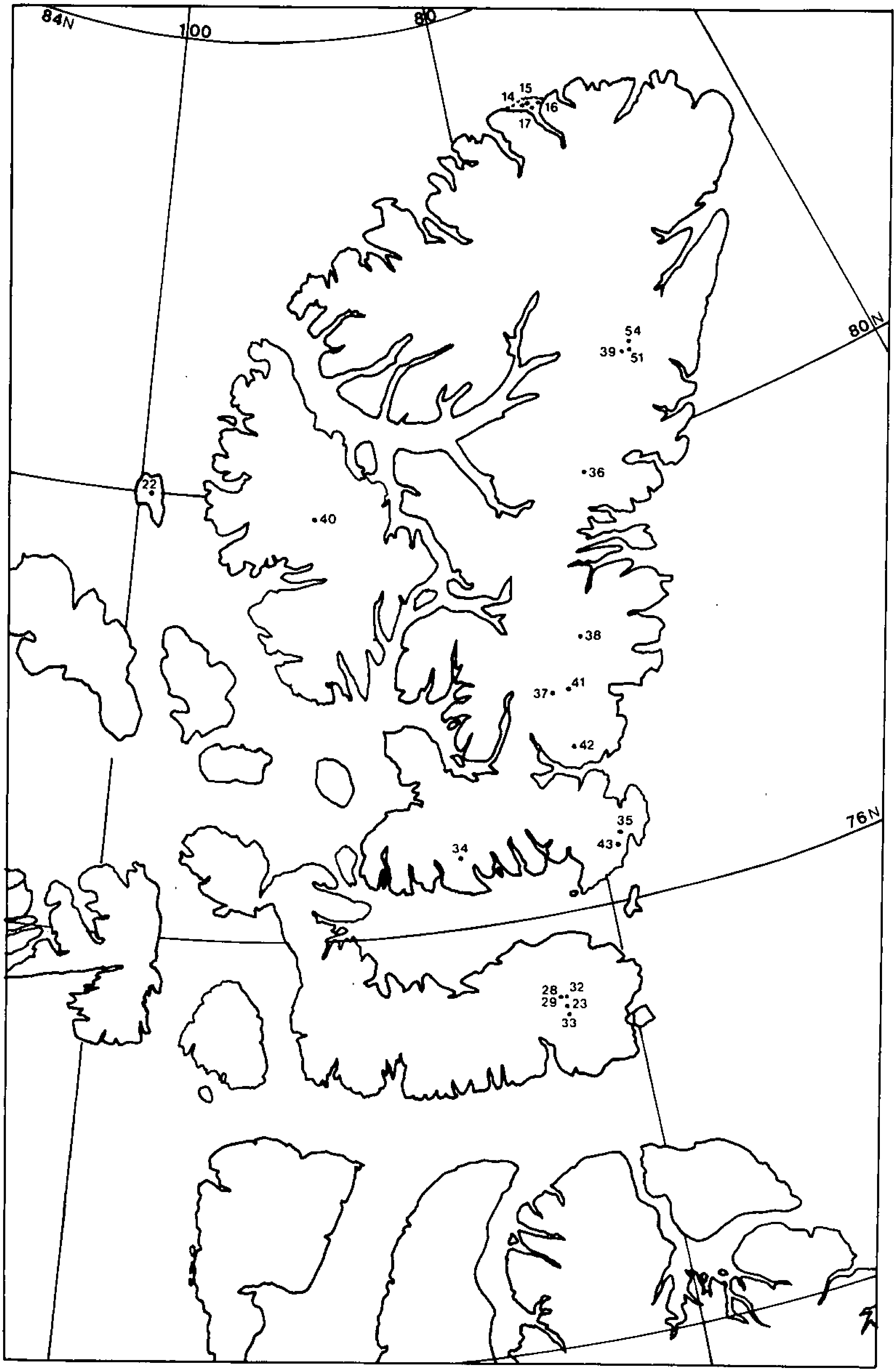
NO.	SITE NAME	YEAR	LATITUDE ° '	LONGITUDE ° '	ELEVATION (m) asl	CORE DEPTH (m)	CORE DIAMETER (cm)	DRILL TYPE	MEAN ANNUAL TEMP (°C)	DRILLING AGENCY	CURATING AGENCY	REMARKS
151	Byrd	1966/67	80 00S	120 00W	1524	35	12.5	Thermal	-28.6**	1		
152	Byrd	1966/67	80 00	120 00	1524	75-227	10.8	Electro mechanical	-28.6**	1		
153	Byrd	1967/68	80 00	120 00	1524	57	12.2	Thermal	-28.6**	1		4 core holes
154	Byrd	1967/68	80 00	120 00	1524	335	12.2	Thermal	-28.6**	1		
155	Byrd	1968	80 00	120 00	1524	2164	10.8	Electro mechanical	-28.6**	1	3	2141 vertical depth
156	Byrd	1969/70	80 00	120 00	1524	50	12.2	Thermal	-28.6**	1		
157	Byrd	1969/70	80 00	120 00	1524	82	12.2	Thermal	-28.6**	1		
158	Byrd	1969/70	80 00	120 00	1524	354	12.2	Thermal	-28.6**	1		
159	Byrd	1971/72	80 00	120 00	1524	366	12.2	Thermal	-28.6**	1		
160	Ross Ice Shelf	1973/74	Various	Various	∿60	10	7.6	SIPRE	Various	23/4	4/1	37 core holes
161	Byrd Flow Line	1974	Various	Various	Various	10	7.6	SIPRE	Various	16	16	∿16 core holes
162	J-9	1974	82 22	168 40	60	100.07	10.2	Electro mechanical	-28.0**	23/24	3	
163	South Pole	1974	90 00		2912	100.03	10.2	Electro mechanical	-51.1	24	3	All of core used
164	C-7-3	1976	78 20	179 51E	∿60	50	7.6	Electro mechanical	-25.8**	24	3	
165	Roosevelt Island	1976	79 22	161 40W	∿500	51.56	7.6	Electro mechanical	-22.7**	24	3	
166	C-7-2	1976	78 20	179 51E	∿60	20.3	7.6	Electro mechanical	-25.6**	24	3	
167	C-7	1976	78 30	177 00W	∿60	11	7.6	Electro mechanical		24		
168	J-9	1976	82 22	168 41	60	147	5.4	Wireline	-28.0**	24	3/7	103-147 open bore
169	J-9	1976	82 22	168 41	60	147-152	12.7	Thermal	-28.0**	24	3/7	Drill stuck
170	J-9	1976	82 22	168 41	60	330	5.4	Wireline	-28.0**	24	3	Drill stuck
171	Q-13	1977	78 57	179 55E	∿60	100.01	10.2	Electro mechanical	-27.2**	24	3	

**10m firn temperature

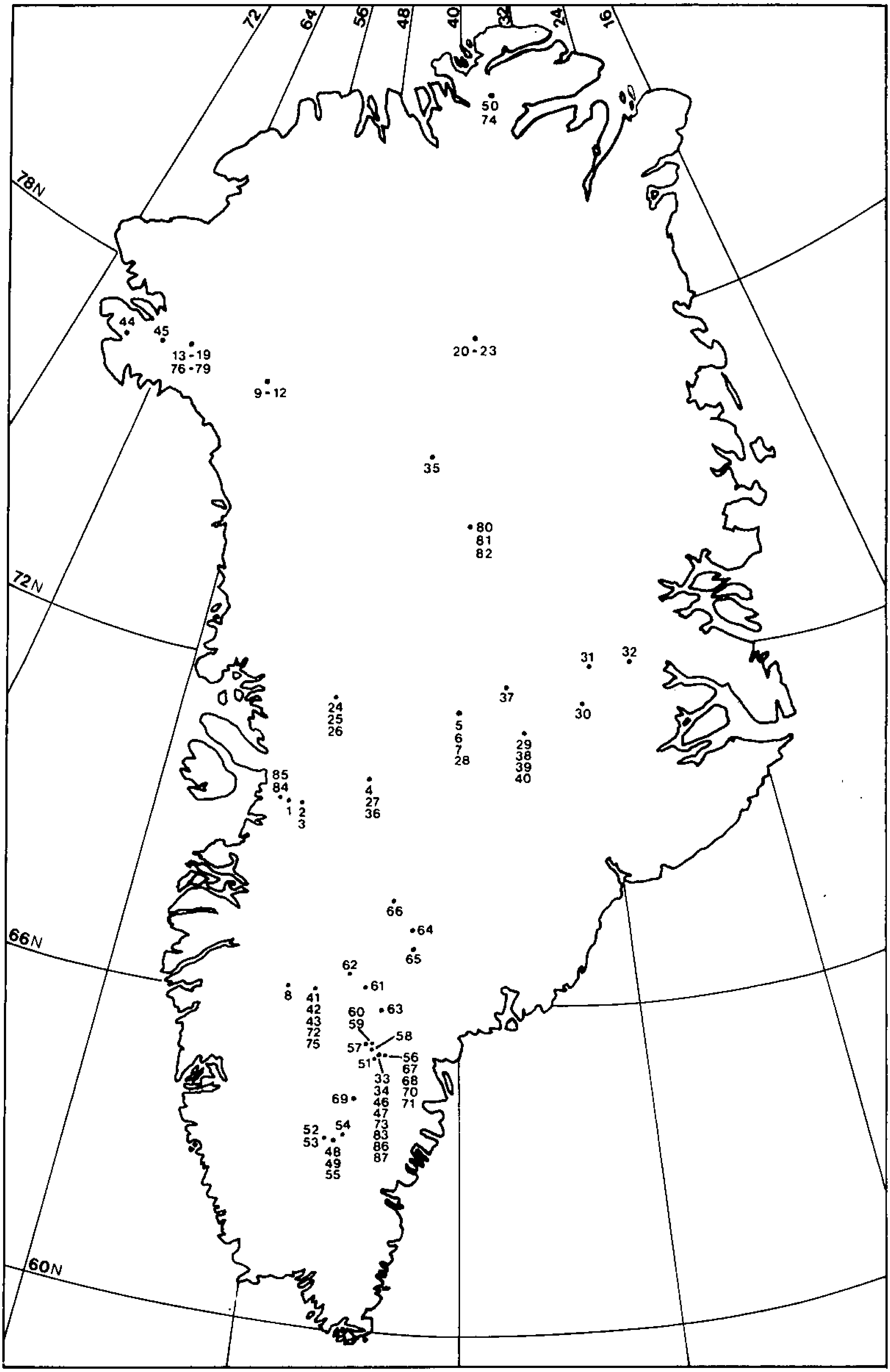
Table I(H-10)United States,continued

NO.	SITE NAME	YEAR	LATITUDE °	'	LONGITUDE °	'	ELEVATION (m) asl	CORE DEPTH (m)	CORE DIAMETER (cm)	DRILL TYPE	MEAN ANNUAL TEMP (°C)	DRILLING AGENCY	CURATING AGENCY	REMARKS
172	C-16	1977	81	12S	170	30E	~60	100.18	10.2	Electro mechanical	-26.9**	24	3	
173	J-9	1977	82	22	168	40W	60	170.8	5.4	Wireline	-28.0**	24	3	Drill stuck
174	Erebus Tongue	1977 78	77	41	167	00E		11	7.5	SIPRE		33/40		
175	South Pole	1978	90	00			2912	111.49	10.2	Electro mechanical	-51.1	24	3	
176	South Pole	1979 80	90	00			2912	44	10.2	Electro mechanical	-51.1	24	39	
177	South Pole	1979 80	90	00			2912	32	10.2	Electro mechanical	-51.1	24	39	
178	Vostok	1979 80	78	28	106	48	3500	104	7.6	Electro mechanical	-55.6	24	6/3	
179	Vostok	1979 80	78	28	106	48	3500	104	7.6	Electro mechanical	-55.6	24	6/3	
180	Vostok	1979 80	78	28	106	48	3500	100	7.6	Electro mechanical	-55.6	24	39	
181	Vostok	1979 80	78	28	106	48	3500	60	10.2	Electro mechanical	-55.6	24	39	Drill test
182	Vostok	1979 80	78	28	106	48	3500	25	10.2	Electro mechanical	-55.6	24	39	Drill test

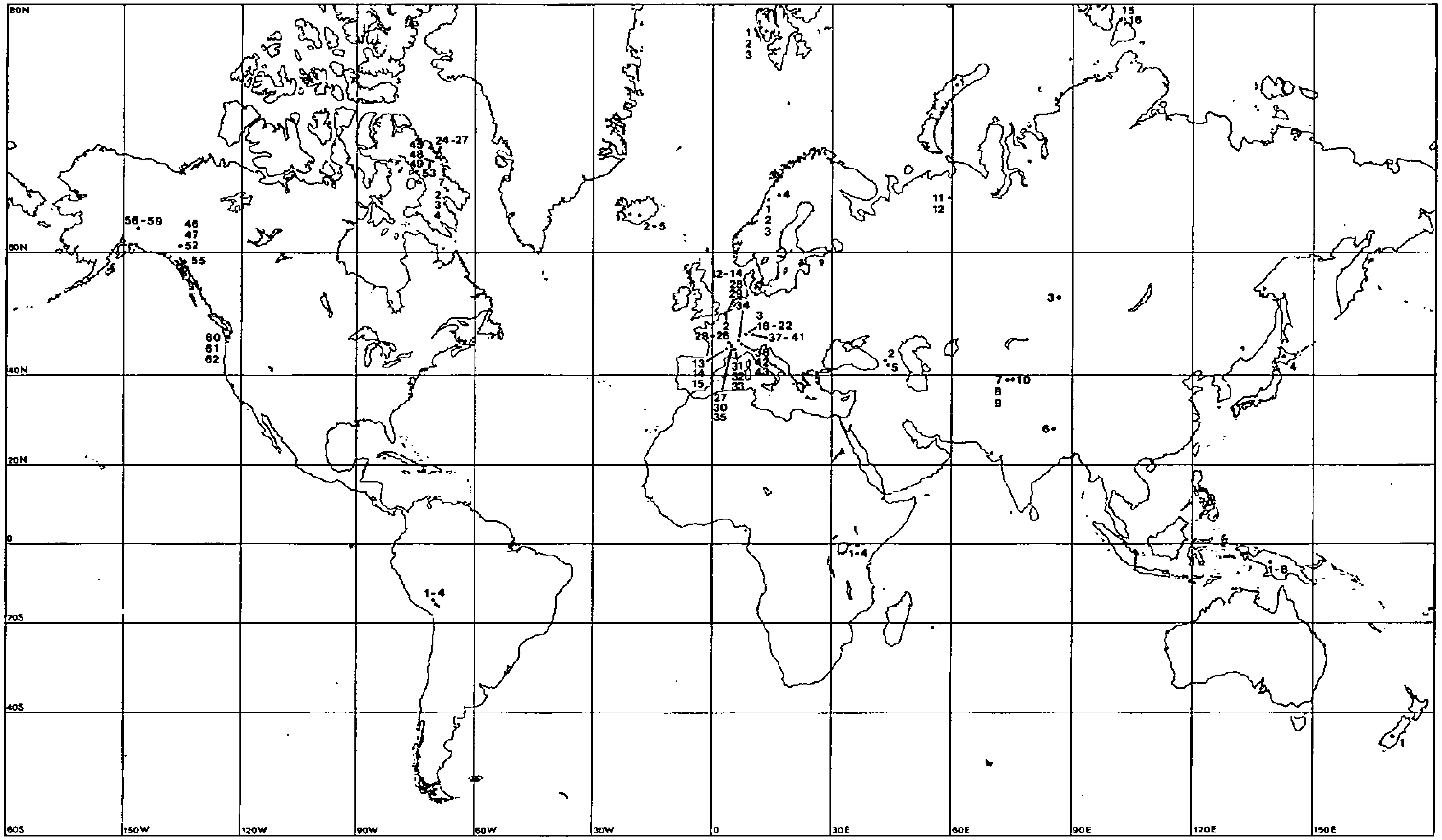
**10m firn temperature



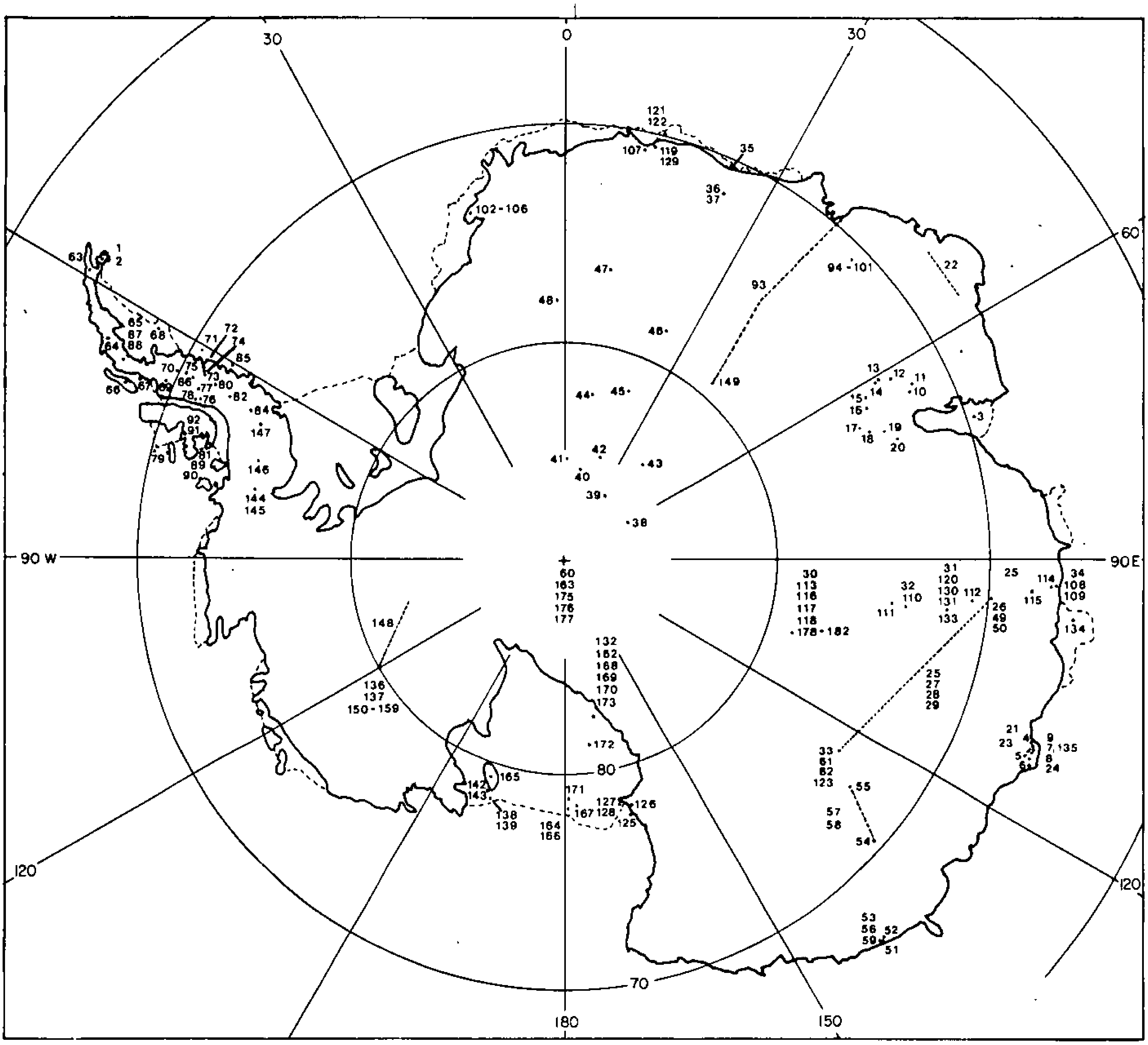
Map 1. Ice core sites in the high Eastern Arctic, Canada.



Map 2. Ice core sites on the Greenland Ice Sheet and associated ice caps.



Map 3. World map of ice core sites between 80°N and 60°S latitude, excluding the high Eastern Arctic, Canada and Greenland.



Map 4. Ice core sites in Antarctica.

An Ice Core and Information Storage and Exchange System

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Introduction

This paper presents an overview of a data and information storage and exchange system (DISES) developed by the World Data Center A for Glaciology (Snow and Ice) for the management of ice core and related data. The design of this system consists of specifications for the data file structure, the computer programs necessary to obtain the proposed operational capabilities, and procedures to use the programs and data files within the host computer facility. Elements of this design have been shaped by the nature of ice core data sets and by suggestions received from the glaciological community.

File Structure Design

Two categories of data, passport data and evaluation data, are used to describe ice core analyses. Passport data consist of a standardized set of core related information such as location, core recovery reference horizon, drilling agency, analysis team, and data supplier (see table 1). It should be noted that bibliographic citations in the passport data are accession numbers from a separate Data Center bibliographic reference file. The ice core bibliography appearing in this issue is a sample of this file. Evaluation data comprise the results of analyses on a core. These data are recorded for one or more dependent variables cross-linked with depth as the independent variable.

Table 1. The content of the passport data record.

Passport Data

core name
latitude
longitude
geographical area
surface elevation
ice thickness
drill date(s)
total core length
drill hole depth
depth reference horizon
core diameter
average core length
core quality
initial borehole diameter
drill type(s)
drilling fluid
post-drill fluid fill
drill site strain net(s)
principal investigator(s)
funding institution/ agency
data supplier
data abstract
bibliographic citation number(s)
access notification flag
data release date (will not be printed)

The file structure for each core site includes fields in which to record all passport data, names of and formats of the evaluation data variables, and the evaluation data. Passport and evaluation data form a data transfer unit. In summary, this structure provides internally documented data files and, consequently, allows generalized computer programs to access any file.

System Design

Design goals for this system include data security and notification of use, accommodation of new evaluation data as they arise, flexible output formats, smooth interfacing with data manipulation packages, and portability of program and data. The most efficient method of attaining these goals is to combine the general capabilities of a computer system with specific functions of custom designed programs and prescribed clerical procedures to track the activity of the system.

The system must be secure from loss of data through magnetic tape failures or accidental corruption of file contents. The conventional approach of keeping duplicate or triplicate copies of data in separate locations provides adequate protection against these possibilities. Management of duplicate files is one area in which detailed clerical procedures are necessary in order to monitor system activity. For example, when alterations are applied to a working copy of a data file, the backup must also be updated.

The system must also be secure from release of specific data sets prior to the designated public release date. This situation arises when a principal investigator, project, or funding agency submits data for archival purposes prior to the expiration of a fixed period of time deemed reasonable for first rights to the data. Securing the data against premature release can be achieved through a data release date within each file which can be compared with the computer clock date. It is possible to override this condition if the need arises.

Upon a data transfer, a notification procedure informs the data supplier of the type and quantity of data requested and the requestor's identity. This notification and the information in the data transfer unit allows direct contact between parties. In addition, the flow of data sets can be monitored.

The organization of the evaluation data file will permit variation in data formats and the addition and deletion of data as needed. These can be accomplished, without rewriting programs, through the use of internal documentation in the evaluation data file.

Flexible output formats can be provided in hard copy or on magnetic tape. The file structure allows programs to construct output page formats for the various data files. The evaluation data's variable names and formats are used to generate column headings and set up appropriate column spacing. Data tapes can be written in a format best suited to the requestor's computing system.

The design of DISES allows a smooth interface with conventional software packages, systems library routines, and customized modules for further data manipulation. This interface provides for in-house and external data processing.

Program and data portability permits inter-machine compatability within the Data Center's automated data processing environment. In addition, this portability provides the option of transferring the programs to a data generator's computing facilities where it could be used for in-house data management. Portability is enhanced by maintaining all files in ASCII code.

DISES is a composite of data flow steps. Following the submission of data, a formating standard is applied and the passport and evaluation files are constructed. Routine computer and clerical procedures are invoked in response to data requests. Output procedures tailor the data transfer unit to the requestor's needs. Notification of use and shipment of the data constitute the final steps of DISES. The data are then available for user processing and interpretation. This flow is illustrated in figure 1.

Entering Data in DISES

It is envisaged that data sets received by the Data Center will be in a variety of formats. This will require some reformating of the data. Once a standardized format has been reached, one of the programs in the data management package will initialize the internal file structure with the correct passport data and evaluation data description.

In principle, it is unwise to have more than one point at which data are entered or changed within a system of this type. To do so invites problems in controlling the status of the data. For this reason, DISES cannot be open for interactive entry outside of the Data Center. However, procedures could be established to allow for remote read-only access to selected files.

In order to meet an acceptable level of standardization, the data formats in table 2 are recommended as a guide for data entered into the DISES system. Most of these data are likely to be level 2 (see page 3). In all cases a complete description of data is necessary. The Data Center can assist in preparing data set formats and descriptions.

Summary

The ice core data and information storage and retrieval system has purposely been kept simple and versatile. While the file structure is fairly static in design, the contents can be expanded to include additional passport and evaluation data. The

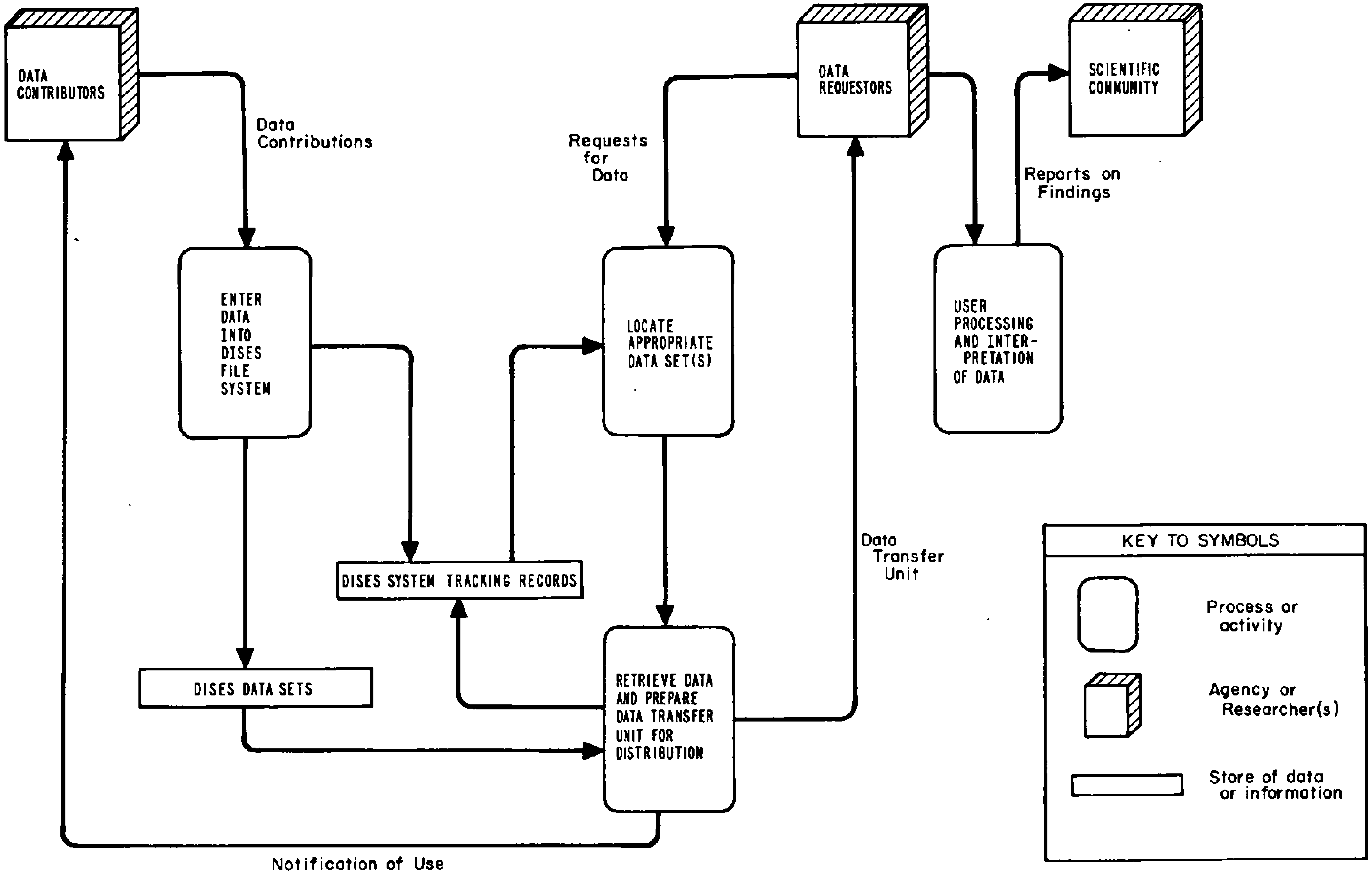

Figure 1. Data flow diagram of the Data and Information Storage and Exchange System (DISES).

Table 2. Guidelines for transfer of numerical data to World Data Center-A for Glaciology (Snow and Ice)

Numerical data sets to be transferred to WDC-A Glaciology should be accompanied by the following items:

- types of data
- the location at which the data were collected
- a brief statement of the purpose of the collecting agency
- names of researchers or agencies responsible for the data collection or analysis
- references to any published articles which include interpretations or descriptions of the data and, if possible, a reprint of each article.

The preferred medium for data transfer is magnetic tape; however, punched cards are also acceptable. The following specifications, where applicable, should be adapted to cards. Alternative acceptable options are listed in parentheses.

Tape preferences:

- 9 track tape (7 track)

  1600 bpi (800 bpi, 800 or 556 bpi for 7 track)

  ASCII coded (EBCDIC, BCD for 7 track)
- blocked format

  logical record length not to exceed 5120 characters

  block size an even multiple of logical records

  maximum block size not greater than 5120 characters
- no internal label on tape (ANSI label).

All data fields should be defined, indicating:

- variable name
- format
- data type (alpha-numeric, integer, real)
- unit of measurement, e.g. meters, ppb, grams water equivalent, etc.
- location of any implied decimal point
- identification of an implied minus sign
- brief description, or name, of analysis technique for evaluation results, level of precision.

Any header records on the tape should also be explained.

When a tape contains two or more files of different record structure, each should be described.

The make and model of the originating computer, its word size and operating system, a listing of the control statements which wrote the tape, and a listing of the first few records are also very helpful.

major goals of accepting diversified input and producing standardized output, maintaining adequate documentation, ensuring that the identity and origins of each data set are not lost, meeting reasonable security standards, allowing for software package interfacing, and providing system portability have all been met. Furthermore, this system can also serve as a multi-group operational data management service and later as a permanent repository for the final data sets.

Each data set entered into DISES is also indexed in the U.S. National Oceanic and Atmospheric Administration's (NOAA) Environmental Data Base Directory (EDBD). EDBD is a directory of data bases. It does not contain data sets but indicates where environmental data can be obtained.

Central Ice Core Storage Facility and Information Exchange

C. C. Langway, Jr.
E. Chiang
State University of New York — Buffalo
Amherst, New York, U.S.A.

Our facility is responsible for processing, cataloging, and distributing ice cores drilled in Antarctica, Greenland, and other polar and sub-polar regions to approved recipients in accordance with National Science Foundation ice core sample distribution policy. Under this arrangement a commercial freezer facility stores most of the cores, with some storage capacity located at the State University of New York, Buffalo. A curator handles and arranges for redistribution and shipment of the ice cores. A data bank is maintained for each core recovered in the field and the data bank is routinely updated (Langway, 1974; Langway and Chiang, 1976). See p. 67 for the Central Ice Core Storage Facility - Ice Core Sampling Procedures.

The objective of maintaining central core storage facilities is to centralize and to maintain an accurate inventory of the ice cores and other snow surface samples recovered in National Science Foundation polar core drilling operations in both the Northern and Southern Hemispheres and to make portions of these samples available to approved recipients at worldwide locations for various physical and chemical investigations. Prior to sectioning and redistribution of the core samples, preliminary physical measurements are made. These and other data from other investigations on each core are contained in a computerized data bank. Pertinent information is available to participating scientists either by print-out sheets or by responding to specific requests.

All computer programs related to data analysis, the data bank, and information exchange activities (Langway and Chiang, 1976) were improved and translated from BASIC language (DTSS) to FORTRAN (KRONOS). This included an updated data bank for all the 400 meter and shallow cores obtained in Greenland and Antarctica since 1971 (Dye-3, Milcent, Crete, South Dome, Dye-2 and Dye-3, South Pole, C-7-1, C-7-2, and C-7-3, Roosevelt Island dome, and J-9). A technical note (Miller and Chiang, 1976) and 12 new Ice Core Laboratory Data Bank Report Series (computer printouts of the data bank storage) were written describing this effort. Data plotter computer programs were developed for depth/density, bubble pressure, and chemical property studies for standardization of a data treatment and analysis (Miller and Chiang, 1976).

This work is supported by National Science Foundation contract C-1010.

References

Langway, Chester C., Jr. (1974) Ice core storage facility. Antarctic Journal of the United States, v. IX(6), p. 322-325.

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Miller, K.J.; Chiang, E. (1976) Technical computer manual: introduction to the design and operation of the ice core data bank. Ice Core Laboratory (ICL) Report Series. Amherst, State University of New York at Buffalo, Department of Geological Sciences,15p.

Miller, K.J.; Chiang, E. (1976) Technical computer manual: hydrostatic determination of glacier ice density. Ice Core Laboratory (ICL) Report Series. Amherst, State University of New York at Buffalo, Department of Geological Sciences, 7 p.

Miller, K.J. (1976) Technical computer manual: plotting Schmidt stereographic projections. Ice Core Laboratory (ICL) Report Series. Amherst, State University of New York at Buffalo, Department of Geological Sciences, 4 p.

*Reprinted from the Antarctic Journal of the United States, v. XII(4), p. 154-156.
**Currently, National Science Foundation, Division of Polar Programs, Washington, D.C. 20550.

DIVISION OF POLAR PROGRAMS
NATIONAL SCIENCE FOUNDATION

WASHINGTON, D.C. 20550

CENTRAL ICE CORE STORAGE FACILITY — ICE CORE SAMPLE REQUEST FORM

Principal investigator and institution ______________________ Date of request ________

Tel. ( ) ________

Location of laboratory research ______________________

Purpose of research ______________________

Funding source (if funding required) ______________________

SAMPLE REQUIREMENTS*

1. Type of samples (frozen/melted; snow/firn/ice) ______________________
2. Sample site location(s) ______________________
3. Number of samples ______________________
4. Volume required per sample ______________________
5. Preferred cross-sectional configuration ______________________
6. Depth/age intervals required ______________________
7. Is research destructive? ______________________
8. Date requested for U/B visit and sampling ______________________
9. Shipping destination ______________________

Return form to: Curator, Ice Core Storage Facility
Department of Geological Sciences
State University of New York at Buffalo
4240 Ridge Lea Road
Amherst, New York 14226 U.S.A.
Tel. (716) 831-1819

*Use additional sheets if necessary

Curatorial remarks Date ________

National Science Foundation

☐ Approved

☐ Disapproved

By ________

Title ________

Date ________

August 25, 1978

DIVISION OF POLAR PROGRAMS
NATIONAL SCIENCE FOUNDATIONS

Washington, D.C. 20550

CENTRAL ICE CORE STORAGE FACILITY - ICE CORE SAMPLING PROCEDURES

The curator of the Ice Core Storage Facility is charged with meeting the objectives of National Science Foundation, Division of Polar Programs, outlined in the Specimen and Core-Sample Distribution Policy (Revised March 1977). These objectives are to assure (1) maximum availability of samples to qualified investigators, (2) analysis over a wide range of research disciplines without unnecessary duplication, and (3) prompt publication of results.

Some investigators with a valid interest in ice cores have not previously studied them. A program has been developed to familiarize potential core users with current and planned studies and with problems associated with ice core research, and to aid in evaluating their applicability of new techniques. Ice cores are difficult and expensive to collect, and the scientific return must be maximized.

Three stages of close interaction are required between the new researcher and the curator. First, the planned research and possible application to previous investigations are discussed.

Second, the researcher is briefly introduced to glaciology and its relationship to the proposed study. Core recovery and processing methods that may influence the sampling procedure are discussed. The curator and the researcher decide which cores should be involved and agree on sample volume, sampling interval, and depth/time-scale. Pilot studies may be recommended.

The researcher submits an Ice Core Sample Request Form to the curator, coordinating with the curator to determine sample availability.

The curator immediately forwards the forms, with his recommendations, to the Chief Scientist, Division of Polar Programs, who gives approval or disapproval. The researcher is free to discuss this decision with the Chief Scientist.

Third, low-priority core is tested to determine if the desired data may be detected and to confirm the techniques. At this stage, the researcher has the opportunity to minimize the volume requirement per sample so that the core may be analyzed by the greatest number of researchers.

Upon National Science Foundation approval, the samples are distributed along with auxiliary data, such as depth and age of the samples, when available. The researcher provides data, reprints, and reports when they become available to the Ice Core Storage Facility for inclusion in the annual data bank and sample distribution report. He acknowledges the National Science Foundation in any publication resulting from study of the ice core samples received.

Following is a detailed checklist of ice core sampling procedures.

DETAILED OUTLINE

1. Preliminary Discussions (Researcher and Curator)
    a. Description of study (R)
    b. Anticipated results (R)
    c. Summary of previous work in other media (R)
    d. Summary of similar work in ice (R,C)
    e. Preliminary feasibility determination (R,C)

2. Orientation and Feasibility Discussions (R,C)
    a. Glaciology (C, if necessary)
        -Snow, firn and ice
        -Ice sheet zones
        -Greenland/Antarctica comparison
        -Snow-aerosol relation
        -Firn-ice transition
        -Diagenesis and metamorphism
        -Ice core dating techniques
        -Thinning of annual layers
        -Ice, air, impurities
        -Fractures, wafering

- b. The Ice Core Storage Facility (C)
  - -Drilling techniques
  - -Field logging and processing
  - -Initial laboratory examination
  - -Ice core data bank
- c. Methods of Core Preparation (C, if necessary)
  - -Thin and thick sections
  - -Firn cleaning
  - -Ice core cleaning, "wet" and "dry"
  - -Surface sampling
- d. Sample and Data Requirements (R,C)
  - -Detection limits (R)
  - -Observed/estimated values (R,C)
  - -Volume requirement minimization
  - -Detail desired (R)
  - -Time scales (R,C)
    - ..Seasonal
    - ..Post-Industrial Revolution
    - ..Little Ice Age
    - ..Volcanic events
    - ..Holocene
    - ..Wisconsin
    - ..Sangamon
  - -Auxiliary data required (R,C)
    - .. ^{18}O-isotope
    - .. Sea spray
    - .. Dust
    - .. Crystal fabric/texture
    - .. Other
  - -Other considerations (R,C)
    - .. Special field sampling
    - .. Bi-polar sampling
    - .. Multi-core analysis
    - .. Latitude of site
    - .. Elevation of site
    - .. Temperature of core profile
- e. Submission of Ice Core Sample Request Form (R)

3. Preliminary Investigation (R)

- a. Detection
- b. Confirmation of Core Suitability and Cleanliness
  - -Comparison with results from other media
  - -Comparison with results from other methods
  - -Comparison with results from other laboratories
  - -Interior/exterior comparison
  - -Detection of seasonal variations
- c. Minimization of volume requirement per sample
- d. Maximization of scientific yield
- e. Identification of auxiliary data required

4. Final sampling (R,C)

- a. Date of sampling (R,C)
- b. Inclusion of results in Ice Core Data Bank (R)
- c. Resampling, if necessary (R,C)
- d. Publication (R)
- e. Further work (R)

DIVISION OF POLAR PROGRAMS
NATIONAL SCIENCE FOUNDATIONS

Washington, D.C. 20550

SPECIMEN AND CORE-SAMPLE DISTRIBUTION POLICY

The Division of Polar Programs supports collection and analysis of polar ice, sediment, and rock cores and biological specimens. This statement establishes policy and procedures for distributing these materials to investigators for research use.

The State University of New York at Buffalo provides a storage facility and a curator for ice cores. The Florida State University provides a storage facility and a curator for sediment and rock cores. The Smithsonian Oceanographic Sorting Center provides a storage facility, a sorting service, and curators for biological specimens. The Division of Polar Programs funds operation of these facilities.

General provisions

The Foundation's objective is to assure (1) maximum availability of samples to qualified investigators, (2) analysis over a wide range of research disciplines without unnecessary duplication, and (3) prompt publication of results.

To obtain samples, an investigator first contacts the appropriate curator to determine that the needed material is available. The curator sends the investigator a form to be filled out or otherwise indicates the exact procedure to be followed. (For some specific types of samples see further instructions below.) The investigator sends the completed request for samples to the curator. The request must specify type and amount of samples required, purpose of research, and source of funding if funding is needed. The Division of Polar Programs or a designated advisory group authorizes distribution if warranted. Normally, a Division of Polar Programs grant for sample research automatically authorizes access to samples. Samples are not provided to investigators unless funding for the proposed research either is forthcoming or is not needed.

Investigator responsibilities

Investigators are responsible for:

1. Prompt publication of significant results, with acknowledgment of the National Science Foundation as the source of materials.
2. Submittal of annual letter reports to the curator citing publications resulting from the research and enclosing copies of the publications. If the investigator has not published in a particular year, he or she sends the curator a letter describing, very briefly, his progress over the last year.
3. Provision of a copy of the letter noted in item 2, and two copies of all published results, to the appropriate program manager in the Division of Polar Programs--whether or not the investigator has a grant from the Division.
4. Notification to the curator, with a copy to the program manager, of any proposed change from tasks stated in the orginal request.
5. Return to the curator of the remainders of samples or any residue in good condition, unless otherwise authorized by the curator.

Investigators may not distribute residue samples to other investigators without prior approval. Investigators receiving residue samples become subject to the reporting procedures outlined in this section. The objective of this provision is not to restrict research; on the contrary, the objective is to insure that the best possible use is made of the samples and that the curator is fully informed as to their use and disposition.

The curation facility may charge investigators to recover freight or mailing expenses involved in filling requests. The curator will estimate charges, if required, before processing the request.

Ice cores

Glacier ice cores have been taken at several locations in Antarctica and Greenland. Deep cores (to bedrock) were taken at Byrd Station and Camp Century. Several 100-meter and 400-meter cores have been obtained from other ice sheet locations. The curator of the ice core storage facility at the State University of New York at Buffalo keeps a record of core locations. A data bank exists for each core, and annual reports on use of core are available.

Sediment cores

Sediment cores and bottom samples have been taken from numerous locations in the southern ocean using the research ship *Eltanin* (now *Islas Orcadas*) and other ships. Published core logs are available from the curator of the Florida State University facility. Before publication of logs, preliminary logs generally are available.

Piston core material is apportioned as follows:

--1/4 for permanent reference, to be held in the core facility for future investigation as authorized by the Division of Polar Programs
--3/4 for research use

Gravity cores, trigger cores, grab samples, dredge samples, and other samples are apportioned as follows:

--1/3 for permanent reference, as above
--2/3 for research use

Ross Ice Shelf Project marine sediment cores

RISP cores are logged visually in the field, then shipped to the Florida State facility. The logs are available from the curator at Florida State. Researchers wishing to obtain samples should get a request form from the project coordinator or from the curator at Florida State, then apply to the Division of Polar Programs as described earlier. Normally, core will not be available until after publication of the logs. However, investigators wishing to study ephemeral properties may request that the waiting period be waived. The curator keeps a record of sample requests, indicating investigators and subjects of study. The record is available on request.

Dry Valley Drilling Project cores

Preliminary core descriptions prepared by site geologists have been published in *DVDP Bulletins*, available from the Department of Geology, Northern Illinois University, DeKalb, Illinois 60115. The Dry Valley Drilling Project staff at Northern Illinois University keeps a record of sample requests, indicating investigator and subjects of study, that is available on request. Frozen and unfrozen core samples are kept at the Florida State University facility. Igneous rock core, including basement and massive basalts, is at Northern Illinois University, but may be moved to Florida State.

Distribution is made after joint approval by the project sponsors: the Antarctic Division, Department of Scientific and Industrial Research, Christchurch, New Zealand; the Japan National Institute for Polar Research, Tokyo; and the Division of Polar Programs. To request samples, researchers use a form available from a DVDP coordinator in Japan, New Zealand, or the United States or from the curator at Florida State University. To aid in choosing samples for study, new researchers may examine cores at the Florida State or Northern Illinois University facilities.

Biological samples

To obtain samples/specimens from the Smithsonian Oceanographic Sorting Center, contact the Director, who will advise on availability of specimens and provide a request form. All requests are reviewed by an appropriate peer Advisory Committee established by SOSC. The DPP is advised of all requests and subsequent action. After study, specimens provided by SOSC must be handled as follows: holotypes and a representative series of nontype specimens should be deposited in the U.S. Museum of Natural History; remaining identified specimens may be deposited in other repositories on approval from SOSC curators.

Addresses and telephone numbers

Curator, Ice Core Facility
Department of Geology
State University of New York at Buffalo
Amherst, New York 14226
(716) 831-1852

Curator
Antarctic Marine Geology Research Facilty and
Core Library
Florida State University
Tallahassee, Florida 32306
(904) 644-2407

Director
Smithsonian Oceanographic Sorting Center
Smithsonian Institution
Washington, D.C. 20560
(202) 381-5643

Project Coordinator
Dry Valley Drilling Project
Department of Geology
Northern Illinois University
DeKalb, Illinois 60115
(815) 753-0284

Chief Scientist
Division of Polar Programs
National Science Foundation
Washington, D.C. 20550
(202) 632-4162

Ice Core Sampling

U. Radok
Cooperative Institute for Research in Environmental Sciences
University of Colorado
Boulder, Colorado, U.S.A.

ABSTRACT

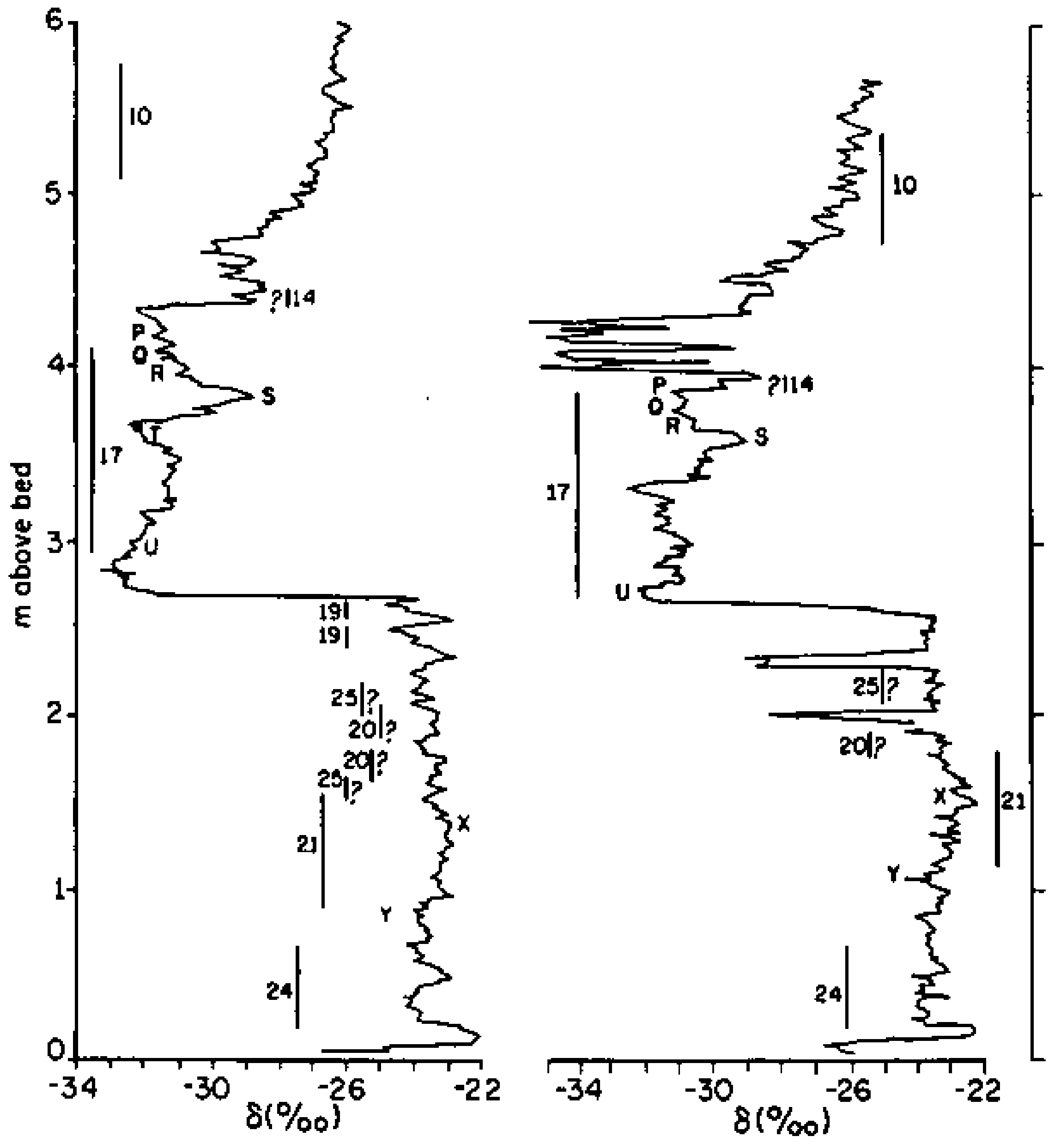
Before fine details of ice core records can be accepted as significant, it will be necessary to compare the features of neighboring cores as a function of their separation. Once the local variability of such features has been established, the way is open to sampling the essential features of major catchments in the Antarctic and Greenland ice sheets. It is suggested that, in the first place, further deep cores are needed on the Byrd flow line, and on flow lines from Dome C towards Casey and Dumont d'Urville, in the regions of relatively fast flow (defined by flux rates exceeding 20-30^{3}km /100 km/year). Together with the existing core data and improved models, these new data will define, at least in outline, the thermodynamics and dynamics of two major Antarctic catchments. Concurrent intermediate and shallow sampling programs are needed to complete the material from which their histories could be reconstructed. It is conceivable that the same could be achieved for the remainder of the two large ice sheets by analogy and modeling based primarily on intermediate core data.

The concept of a surface sampling task force is outlined. This would collaborate with aerial radar sounding, deep drilling, and computer modeling teams in a coordinated program for completing the task of describing the polar ice sheets as physical systems.

The sampling problem of ice cores consists of two main questions: 1) how many cores are needed, or worthwhile, to define the internal ice properties of a region, and how should they be spaced? 2) assuming that a characteristic local variability of ice core features can be defined, how many cores are needed to describe, in the limits set by that variability, a major catchment in the ice sheets of Antarctica or Greenland, and where should these cores be obtained?

The first problem has been studied in an important paper by Paterson, et al. (1977), in which comparisons were made between $^{18}0/^{16}/0$ ratios (δ) of two cores 27 m apart in the Devon Island ice cap, and between their combined features and those of the Camp Century deep core, some 600 km away. For ease of reference, some of the illustrations of the paper are reproduced here (figure 1). The correlations quoted in the paper appear to have been computed without allowance for the long trends in the data and therefore, are difficult to assess in terms of significance. Careful inspection, however, makes it doubtful whether the fine structure of such cores means anything at all, beyond defining the local uncertainty of the isotope ratios and of the palaeotemperatures deduced from them. It might be added that ocean cores, which are becoming popular as collateral evidence for the reality of ice core features, (Lorius, et al., 1979) suffer from similar sampling uncertainties (figure 2).

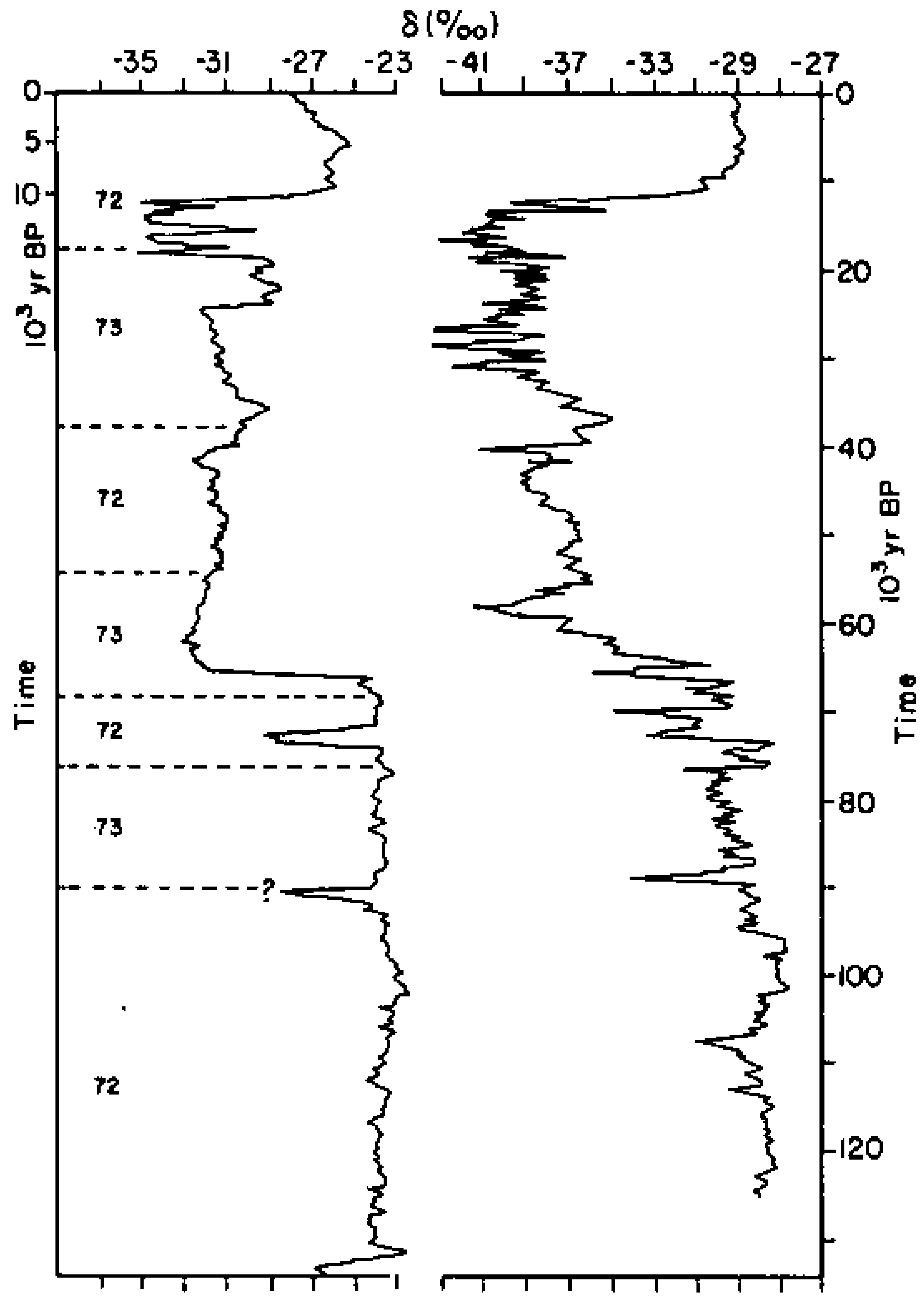
A thorough study of the local variability in ice core features should be made for cores at different distances. The full potential for such a study will become clearer once the World Data Center A for Glaciology [Snow and Ice] has completed its survey of existing ice cores. Evident candidates for comparative study are the Vostok cores started from a common opening, the Australian cores on Law Dome spaced at approximately 15 km, and the two Byrd cores separated by 11 km. The dating of any prominent excursions in δ and other core features will be a crucial part of all these



a. DEVON 73 b. DEVON 72

Figure 1(a,b). Profile of δ near the bed for Devon Cores.

Values of δ for samples 10 mm long against distance above bedrock for lowest few m of each core. Sections and features marked with the same number or letter are considered to be equivalent. The isotopic shift at 2 m in Core 72 is doubtful; it may result from a sampling error. Gaps up to 50 mm long are apparent in both cores.



c. DEVON COMPOSITE d. CAMP CENTURY

Figure 1(c,d). Composite profile of δ from Devon cores and the equivalent δ profile for Camp Century.

The pre-Holocene profile was obtained by combining the records from the lowest few meters of the two cores - see figure 1(a,b). While more nearly complete than either record, the combined one probably still has gaps.

Figure 1 a,b,c,d. (Adapted from Paterson, W.S.B.; Koerner, R.M.; Fisher, D.; Johnsen, S.J.; Clausen, H.B.; Dansgaard, W.; Bucher, P.; Oeschger, H. (1977) An oxygen-isotope climatic record from the Devon Island ice cap, arctic Canada. Nature, v. 266, p. 508-511.)

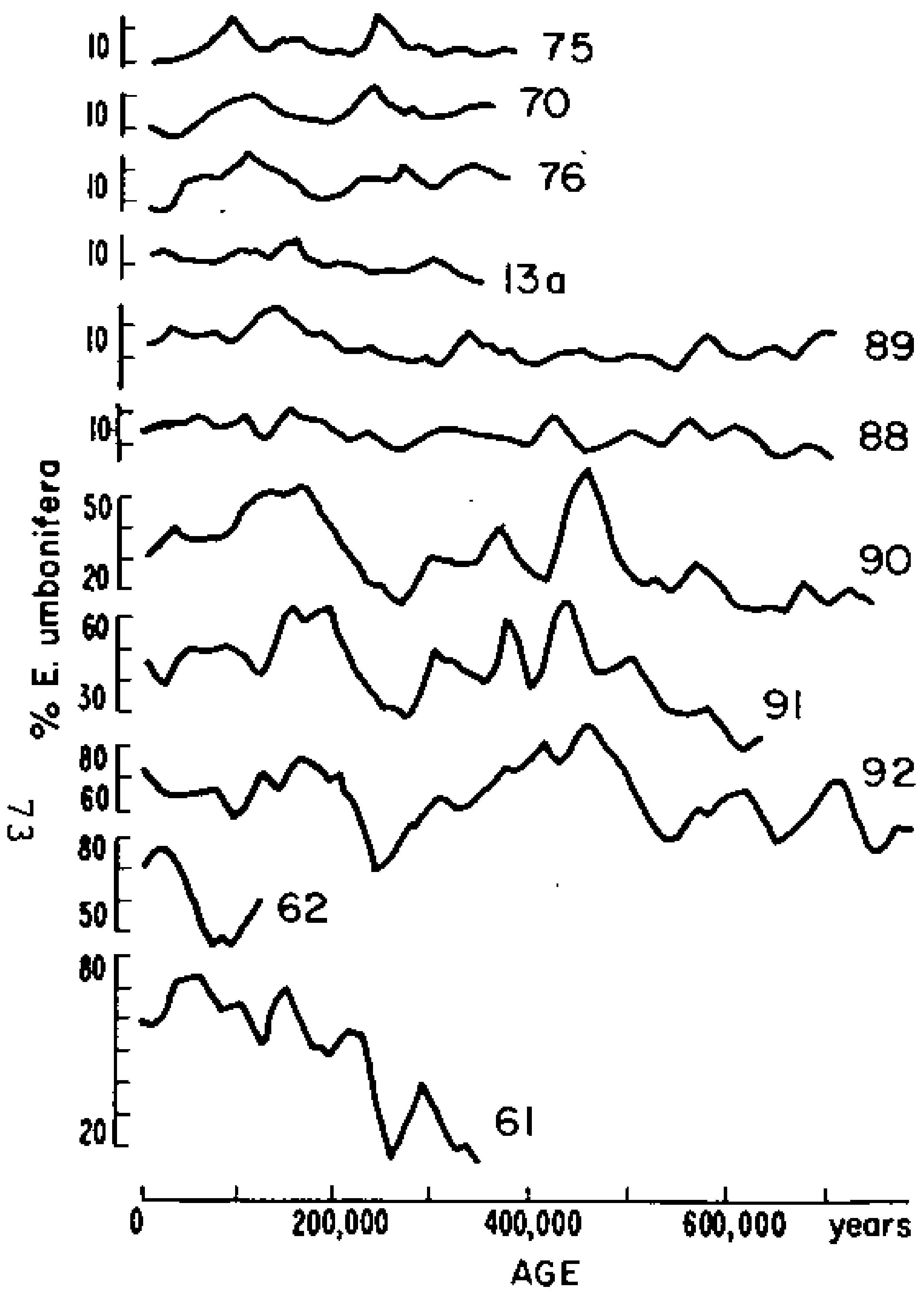


Figure 2a. Variations in abundance of Epistominella umbonifera, an indicator of the Antarctic Bottom Water, in sediment cores from the west flank of the Rio Grande Rise. (Adapted from Lohman, G.P. (1978) Oceanus, v. 21(4), p. 58-64.

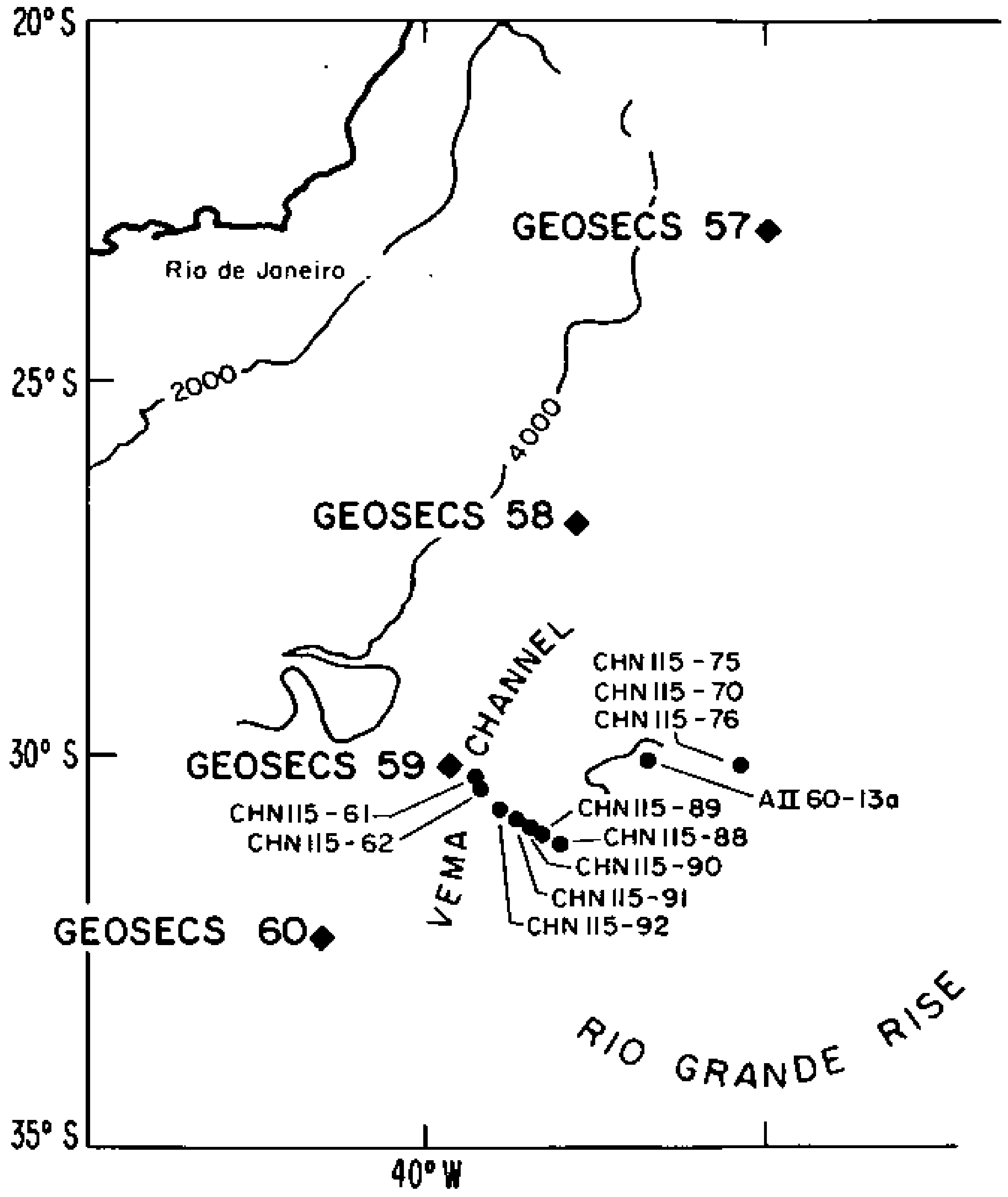


Figure 2b. Core sites for foraminiferal data displayed in figure 2a. (Adapted from Lohman, G.P. (1978) Journal of Foraminiferal Research, v. 8, p. 6-34.

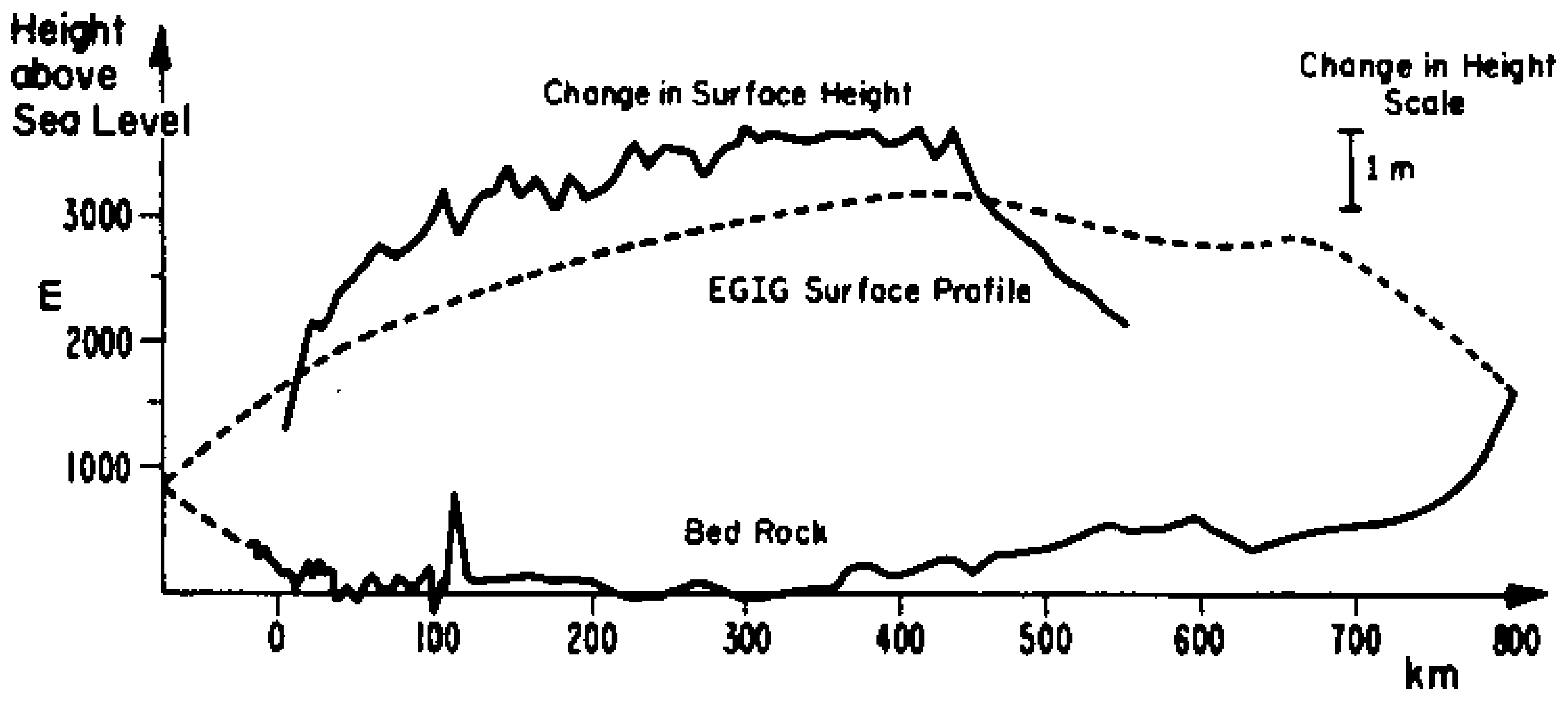


Figure 3. Change in the height of the Greenland ice sheet surface along the EGIG profile, 1959-1967. (Adapted from Mälzer, H.; Seckel, H. (1975) Zeitschrift für Gletscherkunde, v. XI(2), p. 252.)

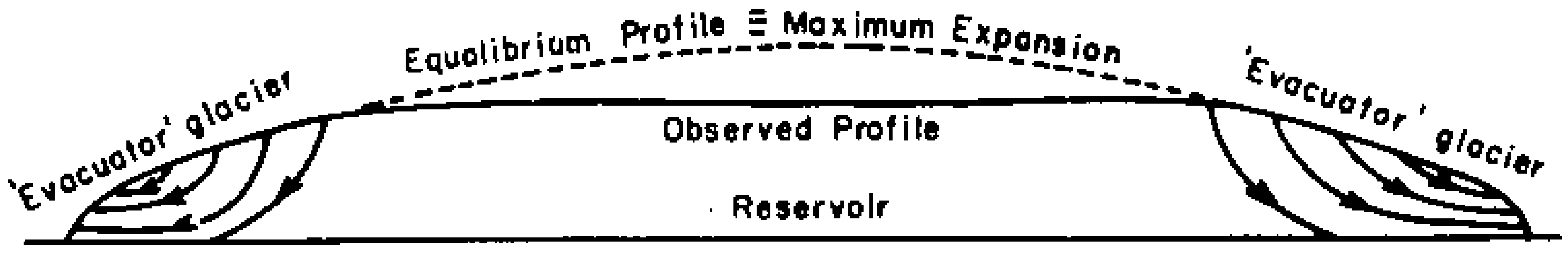


Figure 4. Profile of the ice sheet in northern Greenland where the ice movement near the edge is not appreciable. (Adapted from Lliboutry, L. (1965) Traite de Glaciologie, p. 459, Paris, Masson and Cie., v. 2.)

analyses but must await the perfection of the new particle accelerator and laser techniques.

The outcome of such a systematic study of local variability cannot be firmly predicted. It may well be found that even in cores very close together only the broad trends agree, and that the "embroidery" merely provides rms errors to be applied to all core measurements. In that case, the local sampling could simply be carried out at a single site, by coring two holes a few meters apart to establish the broad changes with depth and local rms errors. However, reducing that error by averaging a number of core profiles is worthwhile for the surface layer, less than 200 m thick, because that layer contains the climatic record of the instrumental era and is now readily penetrated with several available shallow coring systems. An operational framework for such a shallow coring program is suggested at the end of this note.

The second problem of core sampling is that of deciding the number, locations, and depths of cores needed to provide inputs to and checks of models of large polar ice sheets. It cannot be emphasized too strongly that direct inferences from a single core profile are, at best, inspired guess work. Only a consistent synthesis of the records from several cores in a quantitative model of at least the same flow line, and preferably an entire catchment, can provide reliable clues to the past, present, and future behavior of an ice sheet.

Even then, the assumption must be made that the major catchments of Antarctica and Greenland, although reacting with considerable lag to general climatic anomalies in the surrounding atmosphere and oceans, act out their own dynamics and can be regarded as largely independent of one another. An example of this may be provided by the vertical displacements between 1959 and 1967 along the Expedition Glaciologique Internationale au Grönland (EGIG) line (figure 3). Note the implied shift in the location of the ice divide. Similar information for other parts of Greenland and for Antarctica is now starting to be constructed with the help of Doppler satellite techniques. Indirect evidence already exists that the ice surface is rising along the Casey-Vostok line and in the Lambert Glacier catchment. Moreover, coastal climatic anomalies observed at the coastal stations appear to move around the Antarctic continent in a manner that would give rise to opposing effects in different catchments.

However, both observations and model results suggest that each of the major catchments contains two basic flow regimes - sheet flow, due mainly to internal deformation, and stream flow, involving a substantial amount of basal sliding. Although broadly typical of the inner and outer parts of a catchment respectively, Lliboutry's "reservoir" and "evacuator" glaciers (figure 4), regimes may also exist side by side over extensive regions. A large-scale sampling program must provide at least representative core data for both regimes.

The flow boundaries approximately coincide, according to a very important paper by Budd and McInnes (1979), with the mass flux isopleth of 20 km^3/100 km/year. Figure 4b shows its location as derived from the steady-state balance model of Antarctica. The corresponding information for Greenland is being prepared by W. Budd and F. Jacka.

Antarctic catchments predestined for detailed core sampling are those already containing deep holes, sectors issuing from Dome C and from the ice divide above Byrd Station. The Byrd cores should be matched with one of the deep core pairs mentioned earlier on the same flow line and just upstream of the Ross Ice Shelf. The Dome C should be matched with a pair of deep cores on one of the flow lines converging toward the major ice streams near Casey, the Vanderford and Totten glaciers, as well as another pair from the flow lines diverging from the ridge extending towards Dumont d'Urville. The flow and temperature fields in between the sets of cores must be constructed with numerical models including both thermodynamic and dynamic effects and using real, rather than idealized, surface topographies, temperature, and accumulation rates.

The information on the last two of these basic model inputs is now lagging behind that obtainable from aerial radar sounding. This underlines the need for supplementary intermediate and shallow core sampling. Shallow cores have become a major source of information on recent climatic trends on the Antarctic ice sheet. An example of results obtained by French workers is shown in figure 5. Together with data provided by intermediate cores (from dry holes extending to the depth where the hole closure rate becomes appreciable), shallow cores may yet prove to contain all the information that is needed to extrapolate from closely sampled catchments to the remainder of the two ice sheets.

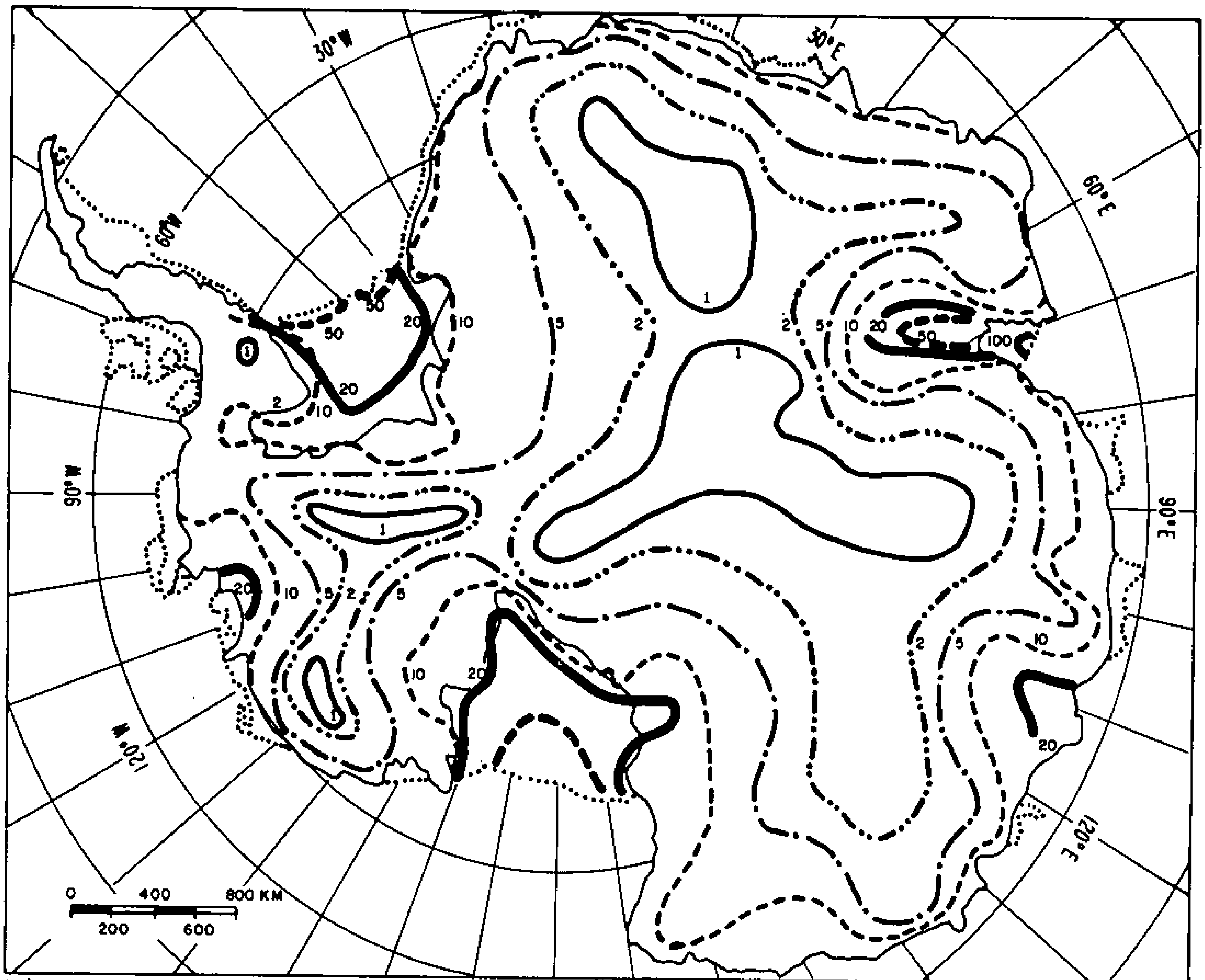


Figure 5. Steady-state mass flux in the Antarctic Ice Sheet. The heavy line marks the critical flux of 20 km^3/100 km/year. (Adapted from Budd, W.F.; Jenssen, D.; Radok, U. (1971) Derived physical characteristics of the Antarctic Ice Sheet, University of Melbourne Meteorology Department. Publication no. 18.)

Thinking of the decade ahead, it is tempting to visualize what might be done with new technologies already available or in the making. Systematic shallow, and perhaps, even intermediate, core sampling of Antarctica and Greenland, might be based on a moderate-size airplane, equipped as a geophysical and geochemical laboratory and capable of open-field landings. Work to be carried out during a few days at each site of a grid covering the ice sheet would include: 1) Doppler satellite location; 2) remote sensing by radar and newer techniques of ice thickness and internal layering, crystal sizes and orientations, and temperature; 3) shallow and intermediate coring and core measurements, sampling for subsequent or on the spot stable and radioactive isotope and trace element analyses, determination of mechanical properties, and crystal fabrics. The capability to carry out some of these tasks is still to be developed. Although most of the necessary expertise can be found in the United States, it is attractive to visualize this program in terms of an international task force.

In cooperation with radar echo sounding and deep coring programs and computer modelers, a surface sampling task force could round off the information needed for a full understanding of the polar ice sheets and for reconstructing their history.

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Lorius, C.; Merlivat, L.; Jouzel, J.; Pourchrt, M. (1979) A 30,000 years isotope climatic record from Antarctic ice. Nature, v. 280, p. 644-648.

Paterson, W.S.B. et al. (1977) An oxygen-isotope climatic record from the Devon Island ice cap, Arctic Canada. Nature, v. 266(5602), p. 508-511.

Polar Ice Coring Office Ice Drill Status Report

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Bruce R. Koci
Richard A. Tillson
Polar Ice Coring Office
University of Nebraska
Lincoln, Nebraska, U.S.A.

Introduction

This report has been prepared by the Polar Ice Coring Office (PICO) for the National Science Foundation, Division of Polar Programs (NSF-DPP). The purpose of the report is to review the capabilities and present status of ice drilling equipment developed for use in the Antarctic, Arctic, and other alpine localities. The report is limited to a discussion of drilling equipment developed through funding by the NSF-DPP, and currently under the custodianship of the Polar Ice Coring Office.

A brief background statement is followed by individual discussions of the seven ice drilling and coring devices currently in the NSF-DPP inventory.

Background and Terminology

Over the last 30 years, results of measurements in boreholes and analyses of ice cores have shown that the vast Greenland and Antarctic ice sheets, smaller polar ice caps, and alpine glaciers are storehouses of information on glaciology, climatic history, and changes in the composition of the earth's atmosphere. Ice core drilling is the technique used to obtain those samples necessary for studies by glaciologists, climatologists, atmospheric modelers, and environmentalists.

"The wide variety of equipment and techniques that have been used can be classified on four bases: 1) whether the means of penetration is thermal or mechanical, 2) the disposition of the meltwater or cuttings formed during penetration, 3) coring or non-coring, and 4) whether hole closure, or opening, due to plastic flow of the ice was controlled. The temperature of the ice, temperate or cold, is an obvious constraint on the equipment and technique that can be used." (Hansen, 1976).

In this report, ice drilling and coring devices are classified on the basis of depth capability, for which the classifications, 10-meter, shallow, intermediate, and deep are used. Ten-meter depths are usually obtained with a hand-driven SIPRE coring auger that collects 7.6 cm diameter core. Shallow cores refer to depths from the surface to a maximum depth of 100 m. Shallow drills are usually lightweight, easy to transport, and capable of drilling through firn and ice densities ranging from approximately 0.4 to 0.85 g cm^{-3}. Intermediate-depth drilling is considered to be from the surface to a maximum depth of 1000 m. The depth is limited by the hole closure that occurs as a result of the plastic flow of the ice caused by the overburden pressure. This depth is temperature-dependent, ranging from 400 to 1000 m at ice temperatures of -20°C to -50°C respectively. Deep drilling is considered to be to any depth where fluid must be added to the hole to retard or prevent hole closure. Deep core usually extends to the bottom of the ice and into the sub-ice material.

For those who are interested in the history of drilling and coring in ice, a summary and bibliography are provided by Langway (1970). In addition, excellent background material is provided in Ice Core Drilling (Splettstoesser, 1976) which presents the proceedings of the Symposium on Ice Core Drilling held at the University of Nebraska-Lincoln in August 1974, and emphasizes the technological developments and accomplishments of ice core drilling projects prior to that time.

References should also be made to other ice core drills developed through funding by sources other than NSF-DPP: the Danish shallow drill (Johnsen, et al., in press); the Canadian Rufli-Rand ice core drill (Holdsworth, 1979); the Icelandic drill (Arneson, et al., 1974); the French electrothermal coring drill (Gillet, et al., 1976); and the USSR electrothermal-alcohol coring drill described in a personal communication from I. Zotikov (1979).

The following sections describe the capabilities and present status of the ice drilling and coring equipment currently in the NSF-DPP inventory. Table 1 provides a summary of drills, their depth capability, core diameter, system weight and location as of October 1979.

The NSF-Swiss Shallow Drill

This is a downhole electromechanical drill supported by an electromechanical cable that raises and lowers the drill and transmits electrical power to it. The cable is spooled on a winch that is used to raise and lower the drill. Mechanical penetration is accomplished by rotating a cutting bit driven by an electric motor through a gear reducer. The cuttings formed during penetration are removed by augering them into a storage space above the ice core. The core and cuttings are removed at the surface after each length of core has been cut downhole. The core diameter is 7.6 cm and the core length is 1 m per run. The drill is limited to a depth of about 100 m.

The drilling equipment packs into 10 boxes, weighing approximately 1050 kg with a total volume of 3.1 m^3. A 100-m core weighs about 350 kg without core tubes, or 433 kg with tubes. The volume of core with tubes is about 1.3 m^3. Fuel consumption for one 100-m hole is approximately 55 gallons of gasoline. For logistical planning purposes, food, shelter, and fuel are required for three men for a five-day period at each location for one hole in the 100-m range. This is the only drill in the NSF inventory currently suitable for helicopter or small aircraft transport.

Two of these drills were procured by PICO for use in NSF-funded projects. Prototype drills were tested in Greenland and have been used to recover core for scientific analysis since 1974 (Rufli, et al., 1976). The two current units were designed and manufactured at the Physics Institute, University of Bern in 1978. They were used by PICO during the U.S. Antarctic Research Program (USARP) 1978-79 field season to collect one 100-m core from Amundsen-Scott South Pole Station, a 56-m core from Dome C, and a 96-m core from Siple Station. Unfortunately, one of these drills was stuck at a depth of 60 m at Dome C.

Modifications have since been made in preparation for the 1979-80 Antarctic field season, and include: 1) replacement of the 3.5 kW DC generator with a 6 kW AC generator in order to compensate for the high-altitude power loss; 2) installation of new control circuits that incorporate Silicon Controlled Rectifiers (SCRs); and 3) remachining of the drill head inlet ring to include mechanical core-catching devices to supplement the existing tapered inlet ring. This drill will be used by PICO during USARP 1979-80 at Amundsen-Scott South Pole Station and at the USSR's Vostok Station. It is anticipated that the drill stuck downhole at Dome C can be recovered using the PICO hot water system, described later in this report.

The USA CRREL Shallow Drill

The CRREL shallow drill is an electromechanical drill that takes continuous firn and ice core 10 cm in diameter to a depth of 100 m. The cuttings move up a spiral auger flight and are deposited in the inner barrel above the core. Core and cuttings are removed from the drill after completion of a drill run. The downhole portion is supported by and powered through a 7-conductor electromechanical cable. Surface components include a winch and tower hoist system mounted in a ski-equipped frame, and a 3-phase, 220V, 5 kW gasoline generator. The total weight of the system is 1227 kg, with a volume of 5.1 m^3.

This drill was used to collect 100-m core in both Greenland and Antarctica during four field seasons (Rand, 1975; Langway, 1975). In 1978-79, a PICO drill team used it to collect four cores to depths up to 60 m. Unfortunately, this recent field season might well have been the drill's undoing. Its age and extensive use were apparent as the spiral auger flights became separated from the barrel; the aluminum frame suffered considerable structural damage in being towed behind oversnow vehicles; and the generator deteriorated to an unusable condition.

The CRREL shallow drill has performed very well over the last four years, but it is in need of a major overhaul and rebuilding or replacement of most components before it can be used again with any degree of reliability. The complete drill system is

QUANTITY	DRILL	TYPE	DEPTH CAPABILITY (M)	CORE DIAMETER (CM)	APPROXIMATE WEIGHT (KG)	CURRENT LOCATION
2	NSF-Swiss Shallow Drill	Electromechanical	100	7.6	1,057	1 at PICO-Lincoln, NE 1 at Dome C, Antarctica
1	CRREL Shallow Drill	Electromechanical	100	10	1,227	PICO-Lincoln, NE
1	PICO Shallow Drill	Electromechanical	100	10	1,237	PICO-Lincoln, NE
1	CRREL Intermediate Drill	Electromechanical	1000	7.62	4,310	CRREL-Hanover, NH
1	RISP Wireline Drill	Wireline	600*	6	13,000	McMurdo-RISP Cargo Yard
1	Browning Flame-Jet Drill	Flame Jet	300	No Core	9,100	McMurdo-RISP Cargo Yard
1	Browning Hot Water Drill	Hot H_2O	400*	45.7	25,000	McMurdo-RISP Cargo Yard
1	PICO Hot Water Drilling System	Hot H_2O	150*	No Core	1,662	McMurdo-RISP Cargo Yard

*Depth capability could be increased with purchase of new components.

currently at PICO's Lincoln office, but in the near future it will be returned to CRREL for their continued use.

PICO Shallow Drill

The PICO shallow drill is an electromechanical drill that is compatible with the NSF-Swiss winch, cable, and tower system. This drill incorporates several features designed by the PICO engineering technician, Mr. John Litwak. These include the cable termination, drill hammer, drill shoe and cutters, and drill motor. The antitorque system is similar to that of the CRREL shallow drill, and the barrels are similar to those of the NSF-Swiss shallow drill. Other features include the use of a 3-phase AC winch motor and SCR control circuit that converts 1-phase AC to variable 3-phase AC power.

The PICO shallow drill takes 10 cm diameter core and 1 m per run to a depth of 100 m. A 100-m core weighs about 600 kg without core tubes and 800 kg with tubes. The volume of core with tubes is about 1.5 m^3. The PICO shallow drill packs into 12 boxes with a total weight of 1237 kg, and a total volume of 3.67 m^3. This drill will be used at USSR's Vostok Station and at South Pole Station during the Antarctic 1979-80 field season. See figure 1.

CRREL Intermediate Drill

The CRREL intermediate drill system consists of a downhole electromechanical core drill, the electromechanical cable which supports the drill and carries power to it, the hoist that raises and lowers the drill in the hole, an hydraulic drive that provides a 2.4-m slow-speed (0- to 1-m per minute) feed for the core drilling, and an auxiliary winch used to place the core drill on a bench where the core and the cuttings are removed for processing (Rand, 1976, personal communication).

The drill bores an 11.6-cm diameter hole while obtaining a 7.6-cm diameter core at penetration rates up to 1 m per minute in -20°C ice. The core size is the same as the NSF-Swiss shallow drill and the SIPRE coring auger. The core barrel is designed to recover 2 m of core per run. The drill is capable of drilling to a maximum depth of 1000 m in an open hole. The winch is spooled with 1000 m of cable.

The winch section is skid-mounted, incorporating the cable and winch, the gear drive section, the control and operator station, and the sheave support structure. To eliminate the requirement for a heavy structural tower, the cable is passed horizontally over the snow surface to a reaction sheave, and returns to the winch section where it goes over the sheave and support structure, then down hole. A light-weight tubular tower beside the hole enables the drill to be raised up and out of the hole for core removal. During normal operations, the resulting force developed in the drilling operation reacts through the sheave support structure and not the tower.

Rand (1976, personal communication) provides the following estimates and description of components for logistics planning purposes. The downhole portion of the CRREL intermediate drill weighs approximately 110 kg, and the winch, cable, and tower weigh a total of 2200 kg with a volume of 14 m^3. The power required for the drilling operation is 10 kW, however, camp operations and related project equipment require that the drill system include a 30 kW diesel generator. The weight and cube of the generator are 1600 kg and 3 m^3, and the fuel consumption is 3 gallons per hour at full rated load. The estimated fuel requirement for a one-month operation is 30 drums of arctic diesel fuel (DFA) weighing 5454 kg with a volume of 10 m^3. The drill system includes a WeatherPort shelter that encloses the downhole portion of the drill, the tower and winch unit, and provides an area for core removal and processing. The shelter size is approximately 5 m wide by 16 m long, and its shipping weight is about 400 kg. Because of the material-handling problems associated with a drill of this size, it is necessary to include a Caterpillar 931 Traxcavator with forklift capability. The 931 Cat weighs approximately 7300 kg and has a cube of 24.4 m^3. The estimated fuel consumption for one month's operation of this unit , weighing 5454 kg at 10 m^3, is 30 drums of DFA. The weight and cube for 1000 m of core are 5020 kg and 10.4 m^3.

The drilling performance has been calculated to take four men, drilling in two twelve-hour shifts, seven days to drill the first 500 m, and a total of 21 days to drill all 1000 m. For planning purposes, a one-month field program should be adequate to obtain a 1000-m core.

Figure 1. Polar Ice Coring Office shallow drill, South Pole, 1980.

The drill was tested at Dye-2 Greenland during July 1977. The test showed that all components of the system met the design criteria except the downhole electromechanical core drill which could not meet the criteria of 2 m core per run. Runs were limited to 1.3 m because the drill cuttings were not entering the space provided for them above the core. With the exception of this deficiency, the performance of the core drill was outstanding. There was 100 percent recovery of excellent quality core at penetration rates of up to 1 m per minute all the way through the extremely variable firn and on into the impermeable ice.

Due to other demands placed upon the CRREL engineering staff, the necessary modifications and subsequent testing of the intermediate drill have not been completed. It is anticipated that these modifications and tests, and a training session for the PICO drill operators, can be accomplished by March 1980. If so, then the drill will be used during 1980-81 to drill an intermediate-depth hole at the Amundsen-Scott South Pole Station.

RISP Wireline Core Drilling System

This is a unique system that utilizes components and techniques from both the diamond core drilling and rotary drilling industries, and is intermediate in size between the rigs typical of those industries.

The wireline core-drilling system "consists of a coring bit attached to the core barrel outer-tube assembly which is rotated by a drill pipe, a non-rotating core-barrel inner-tube and core-lifter assembly, a wireline hoist with an overshot attached to its cable which is used to retrieve the core-laden inner-tube through the inside of the drill pipe, a means of supporting and rotating the drill string, and a means of circulating the drilling fluid which removes the cuttings from the hole and prevents its closure by plastic flow of the ice due to the overburden pressure." (Hansen, 1976, p.29).

The system was developed to take 6-cm diameter core using reverse air-vacuum circulation to the depth where hole closure becomes a problem. Below that depth, the hole is filled with a mixture of DFA and trichlorethylene (TCE) whose density is nearly that of ice. This mixture is pumped down through the drill pipe and carries the cuttings up through the annulus to a separator on the surface. The clarified fluid is recirculated through the drill string.

The wireline system developed for use on the Ross Ice Shelf Project (RISP) was designed for a maximum depth of 1000 m. It was also intended, but never used, as a subsea sediment corer for RISP. During the 1977-78 season, the wireline system was used to core to a depth of 170 m at the RISP Drill Camp J-9. It was also used to drill an access hole to a depth of 313 m into, but not through, the Ross Ice Shelf.

Problems with the separation of ice chips from the drilling fluid at the surface must be remedied before this system can be used again. The system cannot be used in its present form to meet any of the projected deep drilling requirements in either Greenland or Antarctica.

The RISP wireline drill with 600 m of composite drill pipe is currently in storage at McMurdo Station, Antarctica. The large and complex nature of the wireline system reduces the potential for future use, especially when similar depths could be reached using the CRREL intermediate drill. However, the wireline is the only system currently capable of recovering core into the sub-ice sediment and bedrock beneath an ice sheet.

Browning Flame-Jet Drill

This system uses compressed air and DFA delivered to a combustion chamber at the end of hoses to produce a high-temperature supersonic jet of exhaust gases, making a usable but soot-contaminated access hole in the ice. Drilling speeds vary between 0.75-m and 2-m per minute, depending on the desired hole diameter. The system was used in the RISP 1977-78 field season to obtain the first access hole (Browning, 1978).

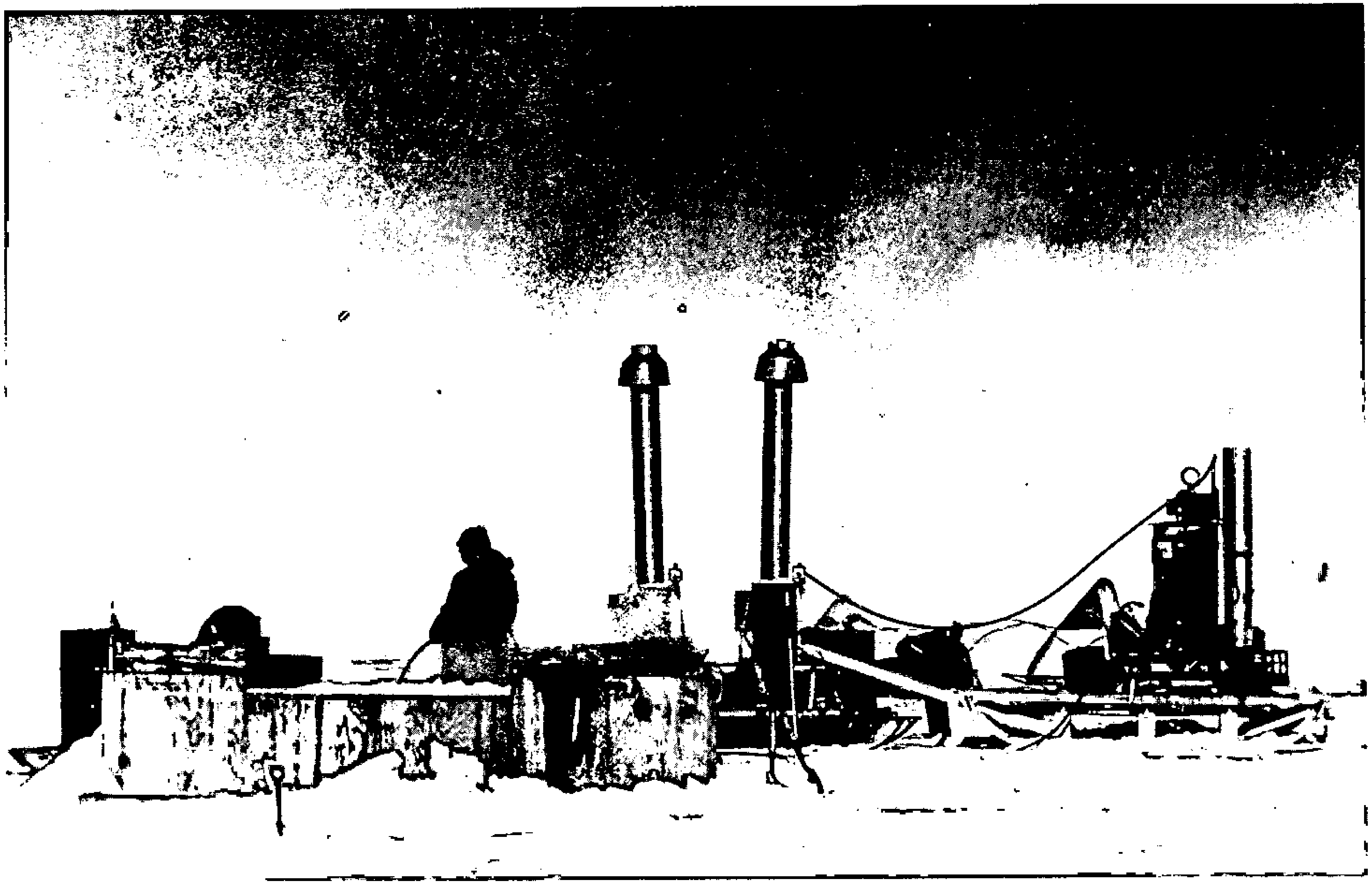

Figure 2. Polar Ice Coring Office Hot Water Drilling System, Dome C, 1980.

During the 1978-79 Antarctic field season, the flame-jet drill was tested with an air-cooled burner replacing the water-cooled burner. The use of a larger-diameter nozzle eliminated the need for a larger booster compressor to deliver 600 psi air. Therefore, the system was lightened and simplified, but also eliminated as a contending intermediate-to-deep drilling system because the booster compressor was shipped back to the United States. The air, water, and fuel hoses of the Browning system were damaged by the reel assembly during the 1977-78 season, and should be inspected before any future use, and then used only in low-pressure applications. A new fuel pump and different nozzles would be needed before the flame-jet could be used again.

Considering the excessive fuel consumption, weight, danger to personnel, and contaminated hole produced by this system, further use of the flame-jet drill is not anticipated.

Browning Hot Water Drill

This drilling system consists of a boiler, heat exchanger, downhole pump, booster pump, and reels of hose with a long 2-inch diameter pipe and nozzle. It was used during the 1978-79 season to drill three access holes at the RISP Drill Camp J-9, and to obtain large-diameter, approximately 45 cm, ice core. The penetration rate in ice is roughly half that of the flame-jet system, but the large, 76 cm, hole produced stays open longer because of the increased heat input (Browning 1979, personal communication).

The hot water system is stored at McMurdo and would be ready for further use after some minor repairs to the boiler. Current depth capability is about 400 m due to the length of the hose, but with a new pump, hose, capstan, and after-heater, it may be capable of drilling to greater depths.

PICO Hot Water Drilling System

This is a noncoring shallow-depth hot water drill consisting entirely of off-the-shelf items. The drill should be capable of producing irregular diameter holes to a depth of 100 m. See figure 2.

Two Malsbary hot-water heaters are used together to melt, heat, and circulate water in a 500-gallon reservoir. Once the water reaches 100°-150°F, it is pumped through a larger water heater where it reaches a temperature of 175°F. The water then flows through a synflex hose and out through a nozzle to melt the hole. Use of some ethylene glycol or DFA is necessary for each set-up of this system. The time required to set up and drill one 100-m hole is estimated at about 12 hours.

This system will be used at Dome C during the 1979-80 Antarctic field season in an attempt to recover the stuck NSF-Swiss shallow drill and in drilling shot holes for the University of Wisconsin-Madison geophysics program.

Acknowledgment

The Polar Ice Coring Office is supported by the National Science Foundation, Division of Polar Programs under contract no. NSF-C-DPP74-08414.

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Nomenclature Applied to Ice Cores: a Geological Viewpoint

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Introduction

Glaciologists working on ice cores frequently wish to compare their direct physical records or their interpreted "climate" records with other types of stratigraphic evidence presented by other workers from terrestrial regions or from the ocean floor. In doing so it is often useful to employ such commonly accepted terms as: Wisconsin Glaciation, Older Dryas, Holocene, et cetera. These correlations are usually made on the basis of some conceptual model of climate and its effect on glaciation and ice core parameters. Unfortunately, such correlations may be misleading because they are based on a misunderstanding of the definitions of the various stratigraphic units that geologists employ in characterizing Quaternary deposits and the Quaternary system. This note is intended to point out some of the drawbacks of using certain existing names, and to suggest an appropriate strategy that, if followed, would foster better communication between glaciologists and Quaternary geologists.

Stratigraphic Units

The American Stratigraphic Code (1961) recognizes a variety of stratigraphic units. In contrast, the International Stratigraphic Guide (Hedberg, 1976) proposes that only three formal stratigraphies be recognized, namely, lithostratigraphy, biostratigraphy, and chronostratigraphy. The Quaternary part of the American Stratigraphic Code is now being reconsidered, and although no formal announcements have been made, it is reasonable to assume that the Code will move closer to the concepts of the Guide. From the glaciologist's viewpoint, it is important to stress that the so-called geologic-climate units (glaciation, interglaciation, stade, and interstade) are in fact, events interpreted from the physical record (i.e., from the lithostratigraphy - tills, soils, outwash, loess, et cetera).

In Europe, events of glaciation and interglaciation are often called climatostratigraphic events (Mangerud, et al, 1974). An important point about these stratigraphic units is that their boundaries are time-transgressive. Thus, the Wisconsin Glaciation of Hudson Bay is several times longer in duration than the Wisconsin Glaciation of southern New York State. Therefore, geologic-climate units do not uniquely define a period of time. In addition, glaciations are frequently interpreted as "cold" periods, and in this case, there is no conflict between the North American usage and the Northwestern European use. However, recent work on deep-sea cores and INSTAAR'S work on Baffin Island indicate that glaciation occurred during a time of "warm" seas. Thus, it was possible to have interglacial conditions from a biotic point of view, at the same time that land areas were experiencing glaciation (e.g., Miller, et al, 1977; McIntyre, et al, 1979). In view of these problems, it is recommended that terms such as Wisconsin Glaciation be avoided when labelling sections of ice cores.

Chronostratigraphic units represent "... a body of rock strata that is unified by being the rocks formed during a specific interval of geologic time" (Hedberg, 1976, p. 67). The Pleistocene and Holocene constitute units of series rank. The boundaries of these units are considered by definition to be globally time-parallel. In practice, these units should be defined by boundary stratotypes at internationally accepted sites. Thus, the type site for the Pleistocene/Tertiary boundary lies near North Calabria, Italy. A boundary stratotype for the Pleistocene/Holocene boundary has not yet been agreed on (see Mörner, 1976) in a physical sense. Nevertheless, the cart has been placed before the horse and the international Quaternary community, by and large, agrees that the Holocene begins at 10,000 radiocarbon years before present. It is critical to note that changes in ice core parameters prior to an estimated 10,000 years date (Lorius, et al, 1979) occur in late Pleistocene time. The Holocene is not a comparable unit to Wisconsin Glaciation. The end of the latter does not have any significance for the definition of the Holocene/Pleistocene boundary.

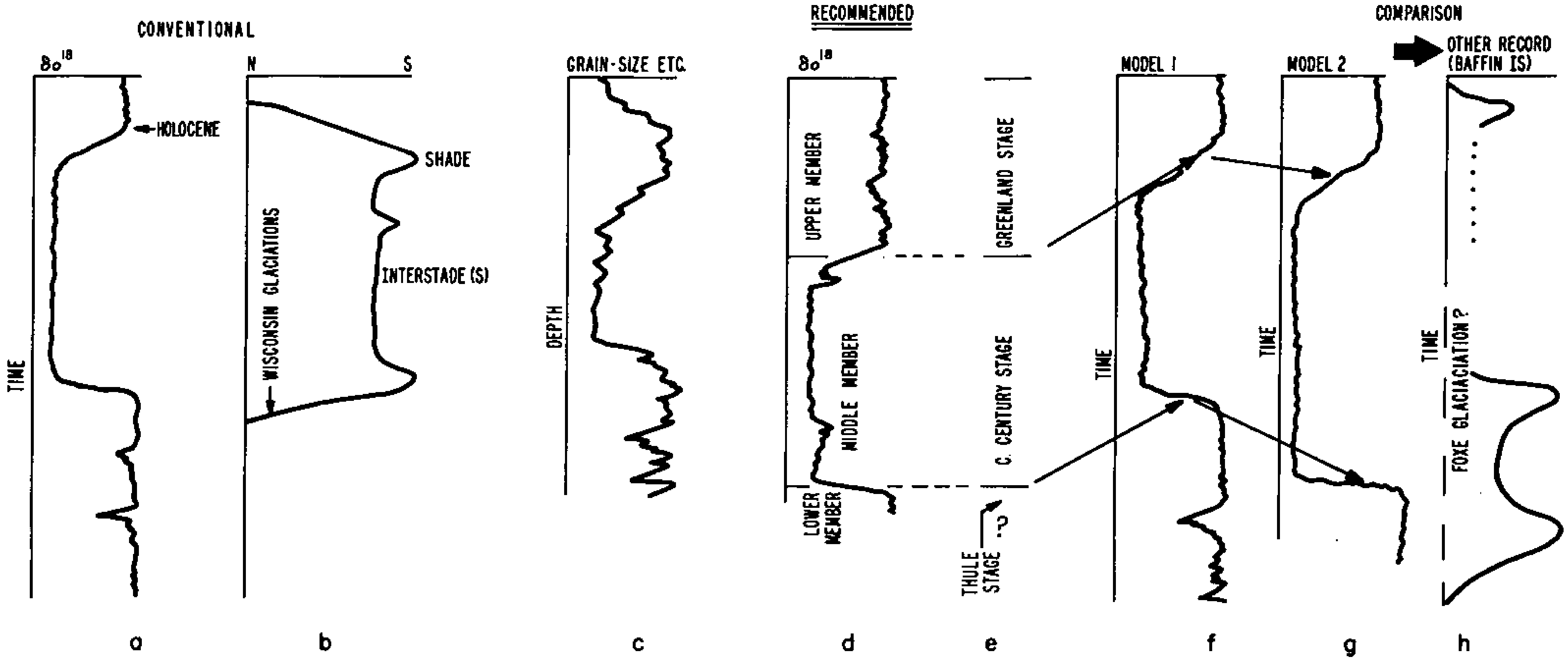

Figure 1. Diagram to illustrate conventional approaches to ice core stratigraphic nomenclature. Columns a and b represent conventional approaches. Column c represents an example of the physical attributes of a core associated with depth. Column d represents members being defined in terms of depth in the core; and names associated with chronostratigraphic units (stages) defined by the contacts between members are shown in Column e. Columns f and g represent interpretations based on different models of the relationship between depth and age; and finally, Column h stresses the comparison link between the ice core interpretations and other proxy records.

Recommendations

Ice core data and interpretations should have a nomenclature system that is independent. Ideally, it should follow conventional geological practices. The fundamental boundaries must be defined by depth in the core. In this way, the age of the boundary will vary as dating methods develop and progress. In establishing chronostratigraphic boundaries for each ice sheet/cap, it must be kept in mind that, in detail, these boundaries are not likely to be isochronous (see figure 1 for a general illustration). The following steps might be used in establishing chronostratigraphic boundaries:

1. Measure the physical properties of the ice core - grain size, electrical properties, crystal orientation, $^{18}O/^{16}O$ ratios, microparticle content, et cetera.
2. Define the major physical or lithologic units of the cores. These can be called "members" and be given a descriptive or geographical name for reference.
3. Use the depths at which various properties of the members change to define boundary stratotypes for chronostratigraphic units. These units should have a proper name followed by "Stage," such as "Camp Century Stage," or if defined solely on ^{18}O, then "Isotope Stage A."
4. Date the boundaries of the chronostratigraphic units by whatever means are available. Updating the ages of the boundaries is common and should cause no trouble.
5. Compare the nature of the physical changes between and within the chronostratigraphic units with other stratigraphic records from adjacent and distant land, ocean, and ice core records. Interpret the findings in terms of climate.

Following this procedure, the naming of the major physical properties of the ice core is independent of other records. Consequently, the names will retain their fundamental raison d'être, despite changes in the interpretation of the physical data (see Bowen, 1978 for useful discussions, chapters 4 and 10).

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Time-Priority Studies of Deep Ice Cores

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Introduction

In considering the kinds of measurements that should be performed on deep ice cores, one can do little better than reiterate the list of studies advocated by Henri Bader (1962) in CRREL Special Report 58, "Scope, problems, and potential value of deep core drilling in ice sheets." Since this document is as valid today as it was in 1962, that portion of Bader's report dealing with the essential aspects of ice core and borehole analysis is reproduced at the end of this article (Appendix I).

Since the publication of Bader's report in 1962, both the Greenland and Antarctic ice sheets have been successfully core-drilled to bedrock, 1390 m at Camp Century, Greenland in 1966 and 2164 m at Byrd Station, Antarctica in 1968. Core and borehole studies at both sites have revealed a wealth of interesting results, especially at Byrd Station where extensive studies of cores were begun as soon as they were pulled out of the drill hole. Continuing investigations of these Byrd Station drill cores, including recent observations of apparent widespread recrystallization in certain sections of ice core, further confirm the importance of initiating as many studies as possible at the drill site. Most of the comments that follow are based on the experience obtained with deep ice cores from Byrd Station.

Any attempts to establish a list of the studies that should be conducted on deep ice cores must recognize two kinds of research: 1) those studies of a time-priority nature that must be initiated as soon as cores are pulled to the surface and, 2) other essential studies in which relaxation of the ice is not a factor. These latter studies can generally be deferred until cores are transported to more permanent storage facilities outside Antarctica.

Time-Priority Studies

Time-priority studies include those that are affected by, or are directly related to, relaxation processes in the ice cores. Several different mechanisms are known to contribute to this relaxation including microcracking, decompression of pre-existing air bubbles, and void formation. At Byrd Station, this relaxation, manifested as a density decrease of the ice with time, could still be detected nine years after the cores had been drilled. The nature and extent of this relaxation is indicated in figure 1. Greatest relaxation, amounting to a volume increase of the ice of nearly 1 percent has occurred in cores with the most highly pressurized air bubbles from near the bottom of the brittle core zone (figure 2). Some generalized profiles of the physical and mechanical properties of the Byrd Station ice cores are also given in figure 2. Cores from the top 400 m contained only superficial cracks, whereas, cores in the range 400-900 m exhibited brittle fracture that increased in intensity with depth. The mechanical condition of the core improved rapidly below 900 m. With the exception of occasional cracks, which appeared to follow the boundaries of large crystals in very deep cores, cores from below 1100 m were raised in essentially unfractured condition.

All ice cores should be examined for visual stratigraphy as soon as they are pulled from the core barrel. Particular attention should be paid to stratigraphic features such as volcanic dust bands which, because of their diffuse nature, tend to be obliterated in deep ice by microcracking of the cores as they relax. It was discovered that circulating ethylene glycol, used downhole to remove drill chips, over the ice core during the drilling process "polished" the cores and rendered them sufficiently transparent to facilitate identification of even the faintest of dust bands. Of the more than 2000 dust bands recorded in cores at Byrd Station, it is doubtful if more than a few percent would have been observed during routine examination if glycol had not been used to polish the cores. It is also imperative that all core be logged carefully to ensure that the correct top-bottom orientation of

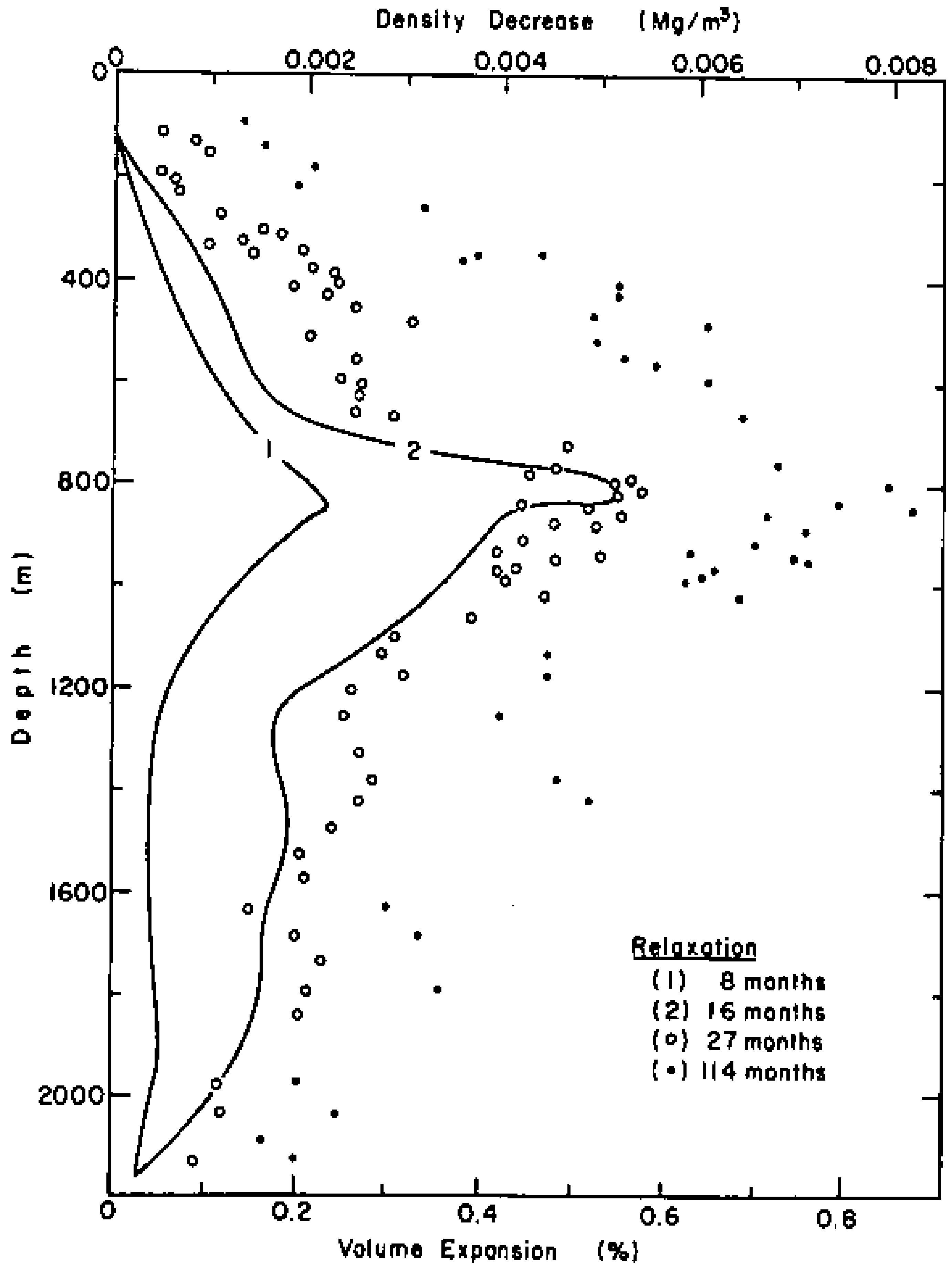

Figure 1. Relaxation behavior (density decrease with time) of deep ice cores from Byrd Station, Antarctica.

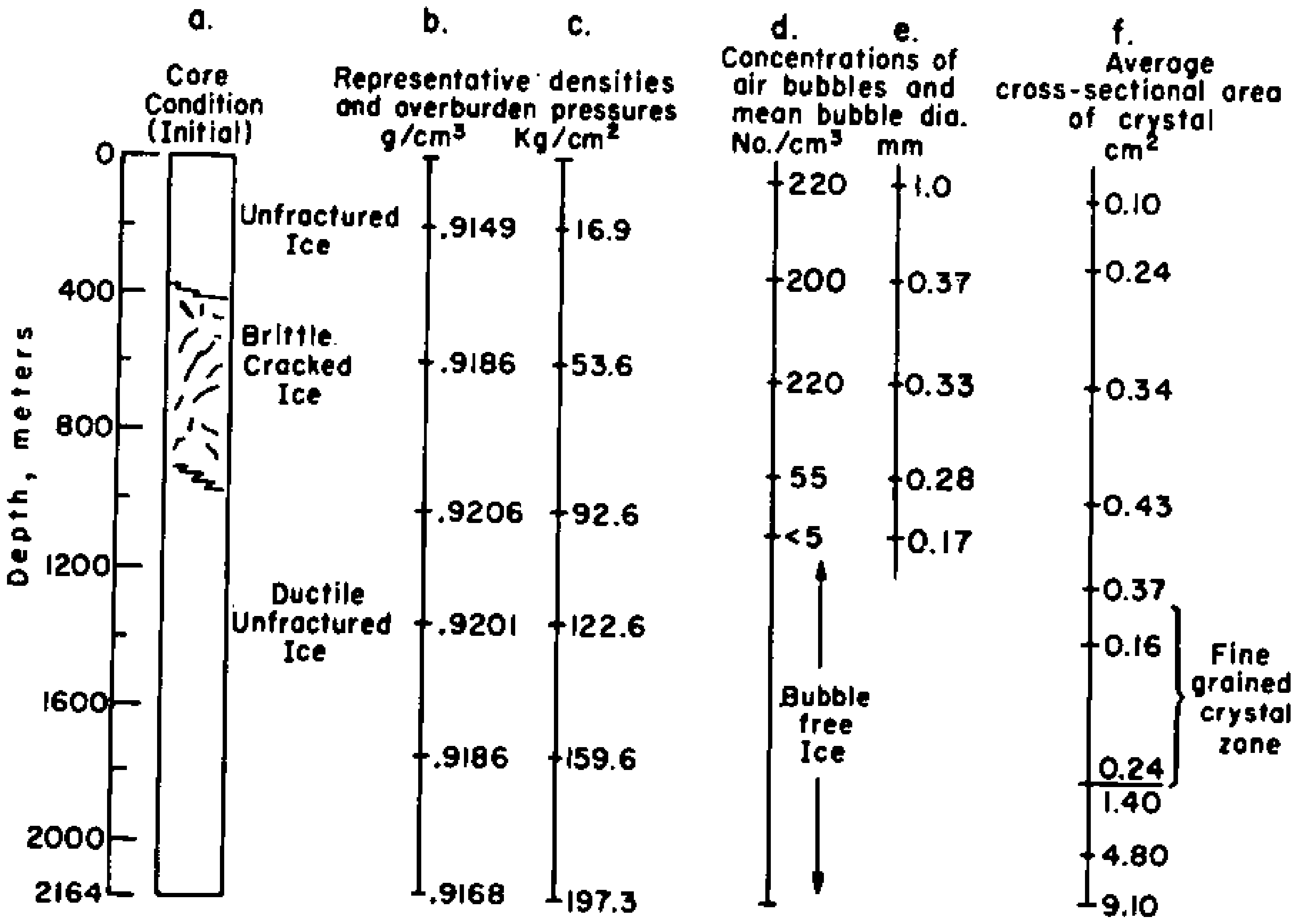

Figure 2. Some physical property profiles (based mainly on data from freshly drilled cores) of the Antarctic Ice Sheet at Byrd Station. (Adapted from Gow (1971)).

ice cores is maintained at all times. This is especially important in studies requiring long-range continuity of core, e.g., studies of crystal fabric, stable isotope, and microparticle records.

Any cracking of cores due to relaxation, in conjunction with the use of drill hole fluids, must be very carefully considered in regard to measurements of chemical consitutents in the ice cores. In addition to ethylene glycol, a mixture of trichlorethylene and diesel oil was added to the drill hole to restrain closure of the drill hole walls. Since any fracturing of the ice will tend to transfer these drill fluid contaminants to the interior of the cores, the preparation of samples for chemical analysis should be initiated as early as possible in order to minimize problems with cracking and drill fluid contamination. Such contamination will remain a vexing problem to chemists, since it does not seem likely in the light of existing drilling technology, that deep core holes can be drilled successfully without using fluids to restrain closure.

Bubbles of air trapped in the ice are a characteristic feature of most cores. Such bubbles undergo significant changes in size, shape, pressure, and distribution in response to stresses associated with increasing depth of burial in the ice. Additionally, analysis of the entrapped gas can be used to investigate the chemical composition of the air at the time of its entrapment, which in deeper cores may reach back 100,000 years or more. Since these properties of air bubbles can change drastically with relaxation of the cores, investigations of them should be initiated during visual examinations of core stratigraphy and in conjunction with observations of crystal structure of the ice in thin sections.

On-site examination of freshly drilled cores at Byrd Station revealed the unexpected occurrence of completely bubble-free ice below 1100 m. However, this disappearance of bubbles was not accompanied by any significant loss of air from the ice. When cores were reexamined five to six months after drilling, numerous gas-filled inclusions or cavities had begun to form in cores that originally lacked all trace of bubbles. The disappearance of bubbles is now attributed to pressure-induced diffusion of gas molecules into the ice, possibly to form a clathrate or gas hydrate. Such a hydrate would be stable only as long as the pressure on the ice equals or exceeds the dissociation pressure of the hydrate. As soon as pressures are released by drilling, the hydrate should begin to decompose and the formation of new gas-filled cavities is consistent with such a process. This diffusion of air molecules into the ice should apply generally to the Antarctic and Greenland ice sheets, with the depths to formation of bubble-free ice decreasing as the in situ temperature decreases.

Thin section photographs of crystal-bubble relationships in freshly drilled cores are shown in figure 3 and characteristic features of bubbles and gas-filled cavities are demonstrated in figure 4. The relationship of relaxation trends in ice cores to bubble and cavity abundances measured 16 months after the cores were drilled is indicated in figure 5. This relaxation increases fairly abruptly with the first appearance of cavities in the same section of core exhibiting maximum decompression of original air bubbles.

Other time-priority studies that should be initiated at the drill site or at nearby facilities set up for this purpose include bulk density measurements, spot sample studies of crystalline texture and fabrics, ultrasonic velocity measurements, and bubble pressure and total gas content determinations. Measurements of total gas content constitute a valuable tool for evaluating past changes in the elevation and thickness of the ice sheet. Density, an easily determined and fundamental index property of ice cores, not only furnishes information on the distribution of density with depth, it also permits calculations of: 1) variations of ice load with depth, 2) freeboard estimates for floating ice shelves, and 3) provisional estimates of bubble pressures. In addition, periodic redeterminations of density constitute the simplest way of measuring bulk relaxation in the ice (figure 1). Ice load data and depth density profiles measured at the drill site and approximately nine years later are included in figure 6.

Measurements of ultrasonic velocities parallel and perpendicular to the vertical axis of representative core samples provide for rapid determination of gross crystal anisotropy in ice sheets. However, supplementary thin section studies should also be performed at the drill site to assess crystal size bias and to furnish spot checks of the precise nature of the c-axis fabric.

Serious consideration should be given to pressurizing representative samples of ice as soon as cores are pulled to the surface. Portable pressure chambers fitted with windows should be fabricated for this purpose. A see-through chamber of this

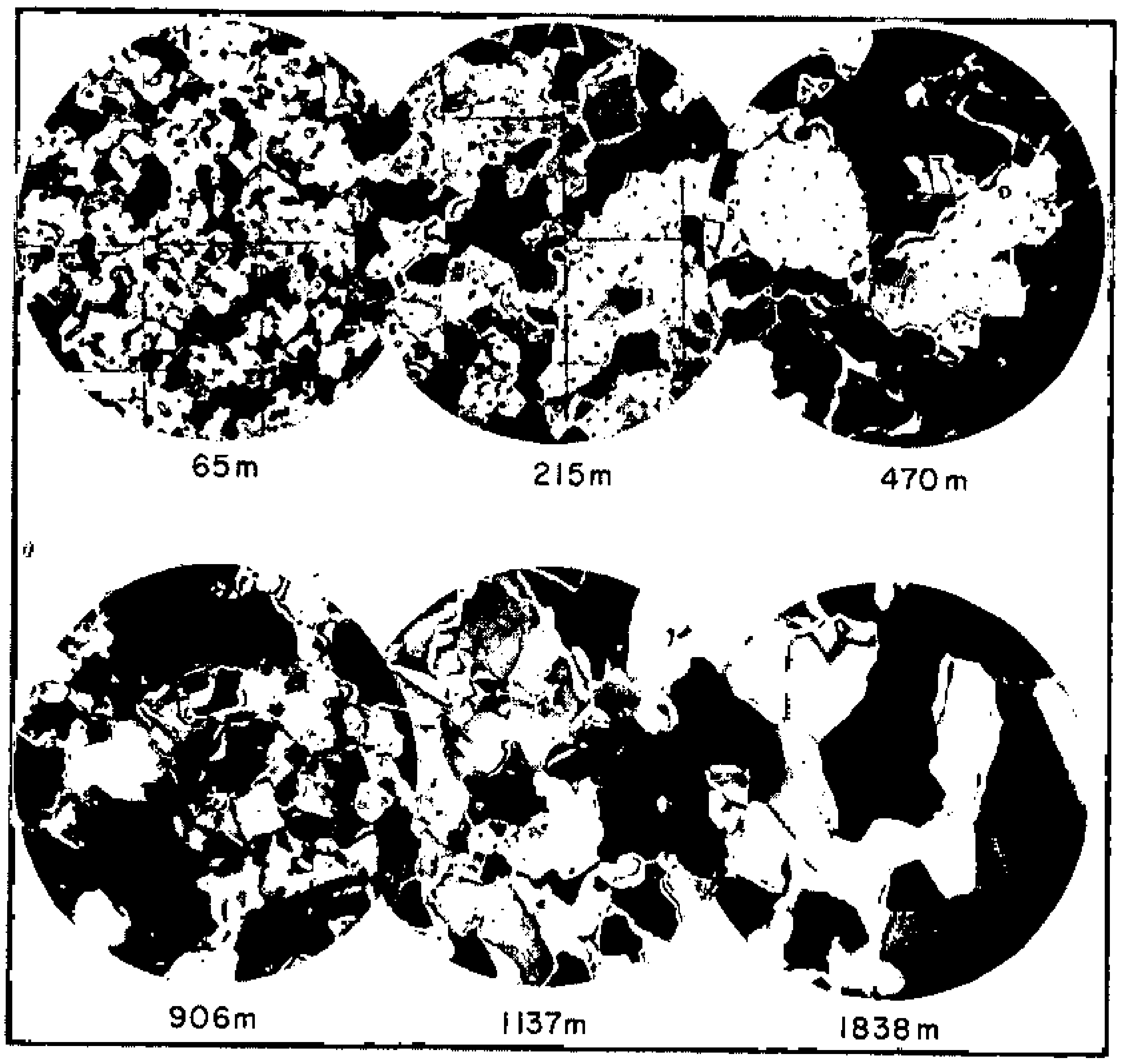

Figure 3. Crystal-bubble relationships observed in thin sections of freshly drilled ice cores from Byrd Station, Antarctica. Air bubbles, that occur abundantly in the upper part of the ice sheet, could not be detected in ice below 1100 m. (Adapted from Gow and Williamson (1975)).

kind, designed to withstand hydrostatic pressures of up to 400 bars has been used extensively by the author to measure gas pressures in individual bubbles for determining the isothermal linear compressibility of ice.

Other Essential Studies

Of other essential studies not materially affected by relaxation per se, those investigations aimed at furthering our understanding of the dynamics and climatological aspects of ice sheets are perhaps the most important. These studies should include paleoclimatic investigations based on stable isotope analyses. Such studies have generated much useful paleoclimatic data, but a completely rational interpretation of results obtained on deeper and older cores tends to be hampered by a lack of absolute dating techniques. Currently, interpretations are determined, to a greater or lesser degree, by the researcher's choice of a time scale. Such scales are invariably derived from simplistic flow models that either ignore or gloss over major physical and structural variations within the ice sheet. In short, current knowledge of the factors affecting age-depth relationships in ice cores is still too limited to furnish reliable time scales much beyond 20,000 years.

Crystalline texture and fabrics (c-axis orientations) are most readily investigated with the aid of thin sections. At Byrd Station, these sections were prepared and photographed soon after cores were taken from the core barrel. These sections, together with the samples from which they were prepared, were returned in 1968 to CRREL where they have been stored for most of the time at a temperature of -35°C. Recent re-examinations of these sections together with observations on several new thin sections of the parent samples have revealed no detectable changes in the crystalline texture or fabrics of any of these sections. However, the bulk of the Byrd Station cores have been stored in a separate facility at temperatures ranging from -18°C to -10°C and suspicions that portions of this core may have undergone recrystallization during storage have now been confirmed. Particularly extensive recrystallization has occurred in the section of fine-grained, deformed ice from 1200-1800 m depth. Recrystallization of this ice has led to the formation of a very

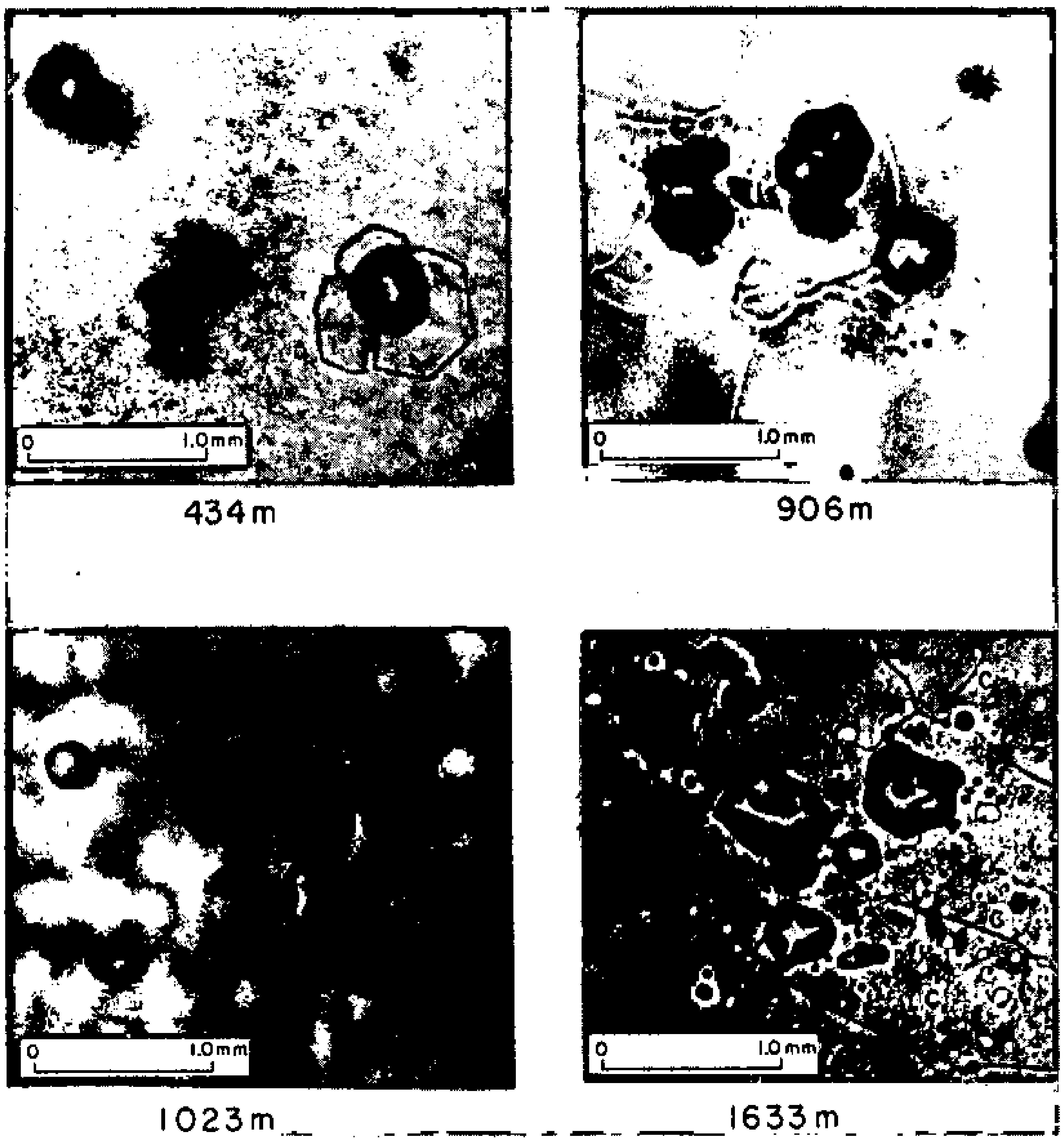

Figure 4. Photomicrographs of ice thick sections showing characteristic features of the various types of inclusions observed in Byrd Station deep ice cores. 434 m-pressure cracked bubble; 906 m-cavity cluster; 1023 m-bubbles (rounded) and cavities; 1633 m-cavities and cleavage cracks [c] (Adapted from Gow and Williamson (1975)).

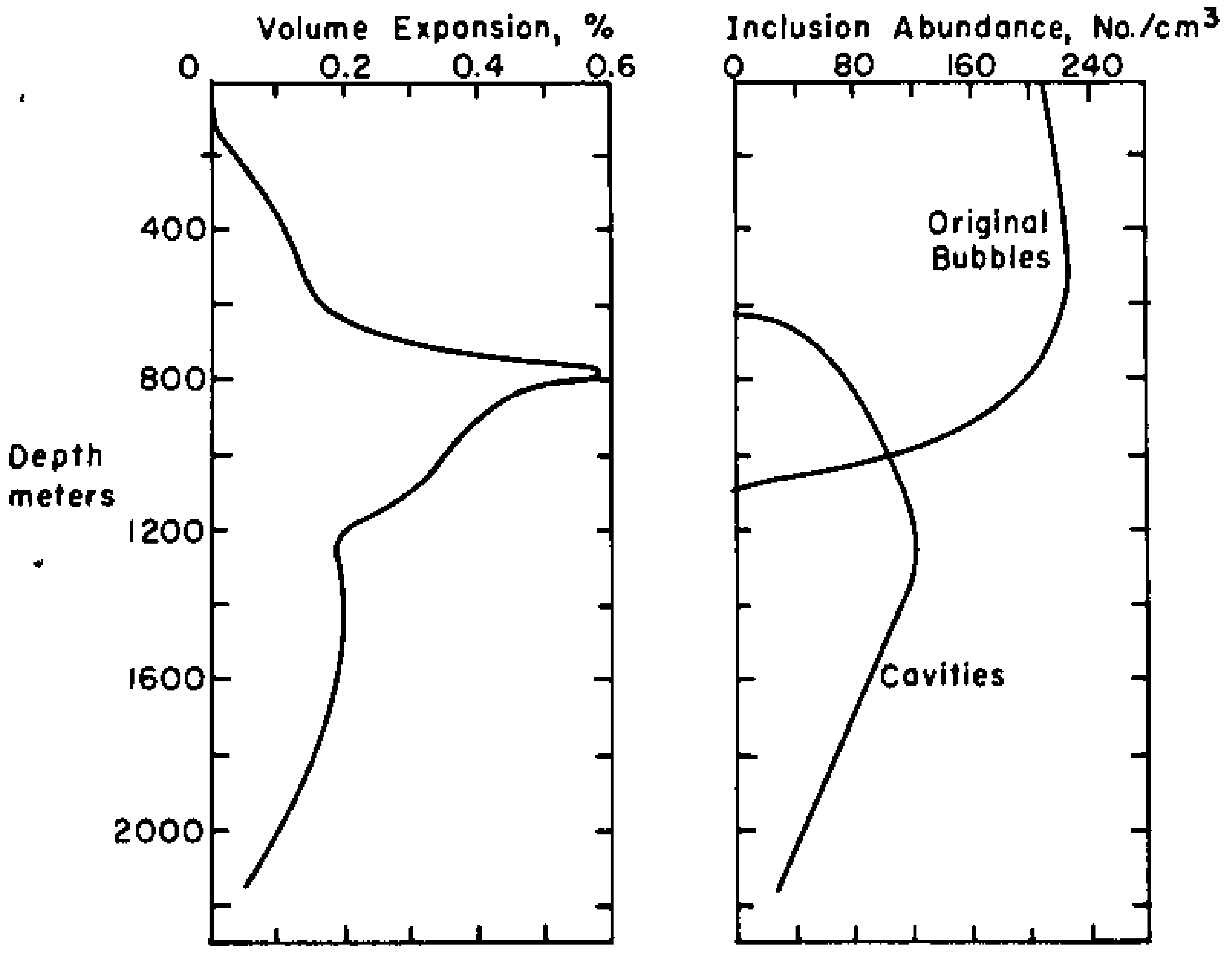

Figure 5. Relationship of relaxation trends (volume expansion based on density measurements) to bubble and cavity abundances measured 16 months after ice cores were drilled at Byrd Station, Antarctica. (Adapted from Gow (1971)).

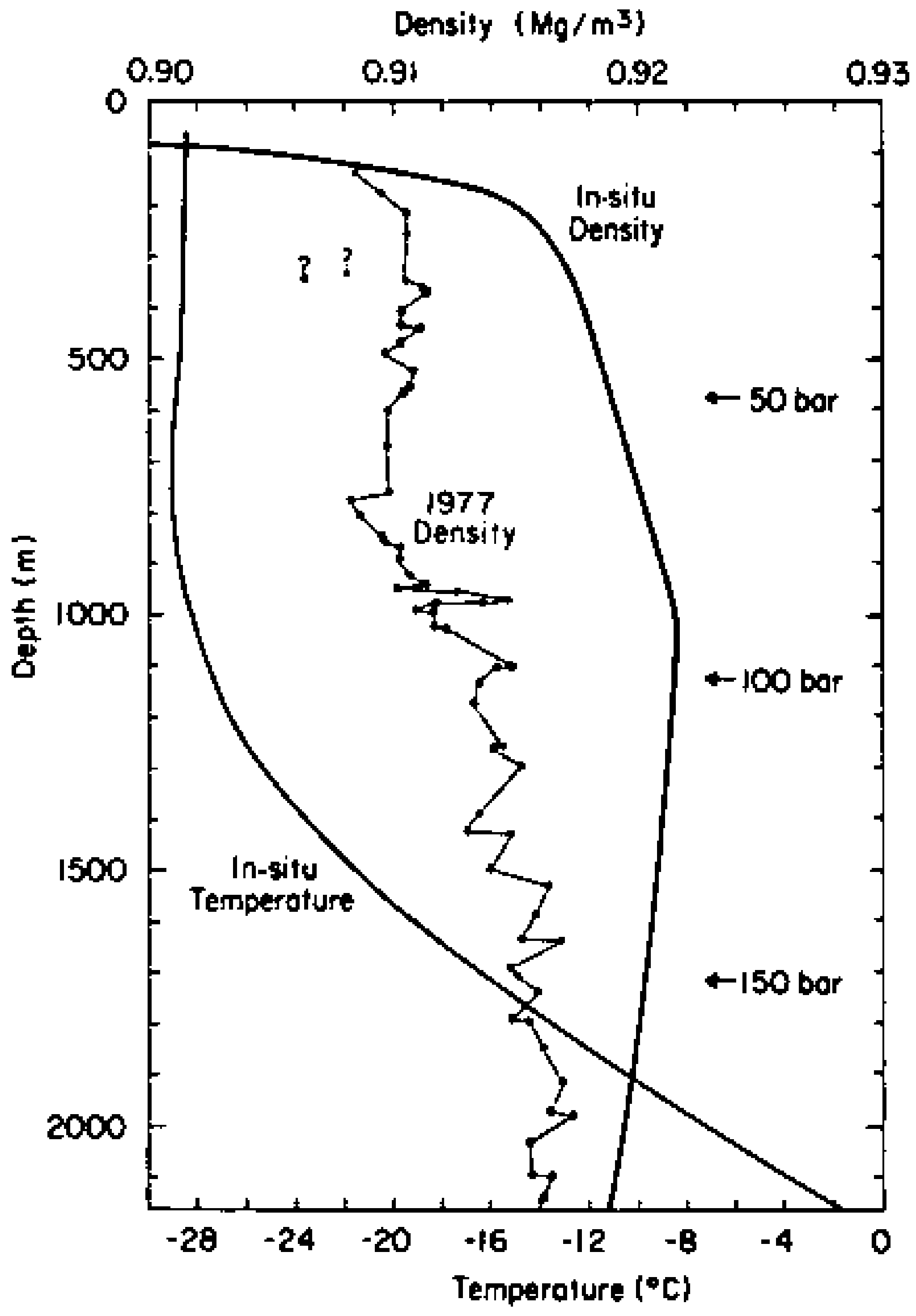

Figure 6. In-situ temperature and density profiles, Byrd Station, Antarctica. Densities remeasured in August 1977 demonstrate the extent to which ice cores have relaxed since drilling in 1967-68. (Adapted from Kohnen and Gow (1979)).

coarse-grained crystal structure that closely resembles the texture and fabrics of naturally annealed ice from the bottom 350 m at Byrd Station. The full extent of recrystallization is still being evaluated, but it may be confined just to the section of core composed of fine-grained deformed ice. An examination of etch patterns on cut surfaces of these cores indicates that recrystallization could have occurred as little as two years after cores were placed in storage. These observations point up two areas of critical concern:

1. The importance of preparing and examining sections of freshly drilled core at the drill site to ensure documentation of the original texture and fabric.

2. The need to store cores at temperatures lower than -20°C. To what extent recrystallization might effect the original distribution of stable isotopes, entrapped gas molecules, and chemical constituents in the ice is not known, but problems could arise if the sampling interval was less than the dimensions of the recrystallized grains. This experience with the Byrd Station cores further reinforces the view that on-site investigations of the cores must include measurements of those properties of the ice that are affected or likely to be substantially modified by relaxation, cracking, or recrystallization.

In summary, a list of essential studies of deep ice cores obtained in future drilling programs must include the following:

1. A thorough examination of all stratigraphic structure in the ice, including debris entrapped at any level in the ice sheet;

2. close monitoring of the mechanical condition of the core, including density measurements and periodic remeasurements of density as a means of evaluating ice core relaxation;

3. air bubble investigations and entrapped gas analysis, including accurate determinations of total gas content;

4. detailed examination of the crystalline texture and c-axis fabrics of the ice, including ultrasonic velocity logging of the cores;

5. stable isotope analysis and geochemical studies related to surface precipitation processes and the climatological history of the ice;

6. microparticle investigations; and

7. determinations of ages of samples by any available means.

Surface geophysical investigations that bear directly on core study interpretation should include radio echo soundings in the immediate vicinity of the drill holes. This would permit direct correlation of geophysical records, e.g., internal reflections with stratigraphic and/or structural characteristics of the ice cores. Down hole measurements, including seismic logging, should also be performed as an essential adjunct to core analysis. It is only through making a reasoned list of priorities such as outlined above, and using the best talent available that we can ever hope to extract the maximum useful information from ice drilling projects.

APPENDIX I*

DEEP CORE DRILLING IN ICE SHEETS

Measurements, etc., to be made on the hole

a. During boring

1) Temperature to 1/10 degree absolute, and to 1/100 degree centimeter differential at appropriate depths.

2) Changes in liquid level between shifts.

3) Fluid pressure, to be checked against load pressure, calculated from core densities.

4) Filter melt water from each run and retain filter and some water samples. This may not be very useful unless the hole-filling liquid is also filtered.

5) Keep appropriate drill log, with special mention on non-routine events.

b. Immediately after hole is finished

1) Register liquid level as function of time. Keep supply of heavy and light liquid ready for corrective action.

2) Rate of horizontal shear deformation at different levels, beginning at bottom or top. Shear rate is larger at bottom but there is also the danger of losing tool. Bottom first is preferable if cable can be pulled loose at inclinometer if it should jam. Knowledge of vertical distribution of horizontal shear strain rate is pertinent to knowledge of flow law of glacier.

3) Change in hole diameter at same time as shear rate. This is per se relatively uninteresting, but is check on hole condition if liquid level changes rapidly. (Danger of pinching off, have casing ready.)

4) Seismic velocities by geophones in hole.

c. If hole can be kept open for longer periods

1) Vertical strain rate at different levels. Pertinent to flow law.

2) Total vertical strain rate, by single wire from top to 200 m, from 200 m to top of high shear rate level (if any) and from there to bottom. Pertinent to general state of ice sheet, i.e., stationary, thickening or thinning.

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*Bader, H. (1962) Scope, problems and potential value of deep core drilling in ice sheets. U.S. Army. Cold Regions Research and Engineering Laboratory. CRREL Special Report no. 58, p. 3-5.

Measurements, etc., to be made on core

a. Immediately after core is pulled

1) Clean off fluid.

2) Accurate spot densities for comparison with later redetermination.

3) Stratigraphy.

4) Observe cracking around air bubbles.

5) Spot checks on structure and texture.

6) Rate of dilation by relaxation.

7) Pack some core pieces in pressurized containers to prevent dilation.

8) Cut core lengthwise into halves, pack both separately for separate shipment. Samples to be used for analysis of enclosed air must be sealed hermetically.

b. Later laboratory work

1) Density, structure and texture.

2) Stratigraphy in detail.

3) Air bubble investigation. Mean pressure, pressure distribution function, chemical and isotopic composition of air.

4) Chemistry of soluble impurities.

5) Isotopic composition of ice.

6) Electrical conductivity of ice and melt water.

7) Radioactivity of ice or residues.

8) Study of insoluble particles. Concentration and size distribution. Nature of particles.

9) Determination of age by all available means.

10) Determination of annual increments and correction for strain (thinning or thickening).

11) Organic content. Biology.

Determination of age of ice

a. By counting of annual layers

Identification of annual layers is always based on some difference between summer and winter layers. All methods, except stratigraphy in snow, are likely to fail in areas of very low accumulation.

1) Stratigraphy. Here the existence of slight summer thaw is a great advantage, as is also a considerable difference in density between summer and winter snows. This method, generally restricted to snow layer, probably fails in ice.

2) Oxygen isotope ratio. Based on summer-winter difference. May fail at greater age if lattice oxygen self-diffusion is high. If it is low, determination of paleosurface temperatures is possible. Requires small samples, but is expensive.

3) Fallout of terrestrial dust. Picked up and transported by wind. There should be a summer-winter difference, easily determined on very small samples. Sampling techniques critical.

4) Specific electrical conductance of melt water. Depends on summer-winter difference in ionic content. Easily measured on small samples. Sampling techniques critical.

5) Ratio of soluble salts. Summer-winter difference not very promising, but worth investigating. Expensive. Samples small, sampling technique critical.

6) Fallout of cosmic material. Possible annual cycle associated with annual meteoric showers. Worth investigating. Necessary sample size unknown.

b. Methods unrelated to counting of annual layers

1) Tritium. Useless for ages larger than a few decades. Requires fairly large samples.

2) Carbon 14 from air in bubbles. Very good for great age but requires samples of the order of tons, possibly obtainable by melting out at selected depths, which may be technically very difficult to do without contamination.

3) Long-lived natural unstable isotopes. Presently no more than a possibility.

4) Fallout of cosmic material. Correlation with historic and cyclic prehistoric events, such as recorded intense meteoric activity and comet approaches. Depends on identification and separation of cosmic material.

c. Determination of recent rate of accumulation in Antarctic low-accumulation areas where stratigraphic counting is unreliable

1) Tritium. Determination of depth of 1954 layer if Castle shot fallout reached Antarctica.

2) Volcanic ash fallout. Determination of 1884 layer (Krakatoa ash) if Antarctic volcanos were quiescent at that time.

Determination of total strain (due to flow deformation) on core ice

1) Structure and texture. Not promising.

2) Air bubble elongation. Worth investigating.

3) Count of particulates. It is possible that some fraction of the insoluble particles, either terrestrial or cosmic, falls out at a constant rate. If this were true, the measured concentration would be inversely proportional to the rate of accumulation. If the thickness of the annual layer can be determined, then the total vertical strain is calculable.

Associated tasks

Much of the glaciological interpretation of measurements on hole and core will depend on a number of things that must be done in the vicinity and upstream from the hole. These are at least:

1) Measurement of rate of horizontal motion of drill site, by accurate astrofixes, trilateration or geodetic satellite.

2) Preparation of a map of surface and bed centered on drill site.

3) Determination of local rate of accumulation by pitwork and snow-stake farm.

4) Measurement of rate of accumulation upstream to divide, by pitwork.

5) Determination of surface and bed profile upstream to divide. We must know ice thickness and surface and bed slopes.

6) Determination of horizontal surface strain rate vectors at several points between drill site and divide.

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Ice Core Work at the Laboratoire de Glaciologie, CNRS, Grenoble

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The Laboratorie de Glaciologie is dedicated to environmental science with its main emphasis on alpine glacier and ice sheet studies. The work done by the Grenoble laboratory includes the recovery and analysis of ice cores in order to obtain a record of past environmental conditions that prevailed near the surface of ice masses.

For this purpose the best conditions have been found on polar ice sheets where large areas are unaffected by surface melting and ice thicknesses provide long time series.

Field work in Antarctica

Most of the field work performed by the Grenoble group in polar regions is done in east Antarctica. During the last few years, near surface sampling (snow sampling in pits and shallow cores from the upper firn layers) has been performed along a traverse route between Dumont-d'Urville and Dome C (figure 1). Deeper ice cores have been recovered in the coastal area near Dumont d'Urville, and at Dome C where a depth of 905 m has been reached (table 1). Field measurements include borehole temperatures and hole closure rates. There are plans to drill deeper and the electrothermal system developed in the laboratory is being modified and tested for use in fluid filled holes (Gillet, Donnou, and Ricou, 1976). Currently, this work is part of the International Antarctic Glaciological Project (Anonymous, 1971; Radok, 1977) and is supported by the Terres Australes et Antarctiques Françaises, the Expéditions Polaires Françaises, and the U.S. National Science Foundation, Division of Polar Programs.

Table 1. Longest cores recovered by the French in east Antarctica.

STATION		Year of recovery	Depth (m)	Drill system	Bedrock reached
G 1	coastal	1965	98	Rotary drill	Yes
G 2	stations	1966	106	Rotary drill	Yes
A 3	near	1966	106	Rotary drill	No
D 10	Dumont	1972	44	Electrothermal	No
D 10	d'Urville	1974	304	Electrothermal	Yes
Dome C		1978	905	Electrothermal	No
Dome C		1979	180	Electromechanical	No

Laboratory work

To obtain a record of the atmospheric conditions at the surface of the ice sheet, samples are analyzed to provide information about the variations during the past in temperature, precipitation, atmospheric composition and circulation, and ice sheet geometry.

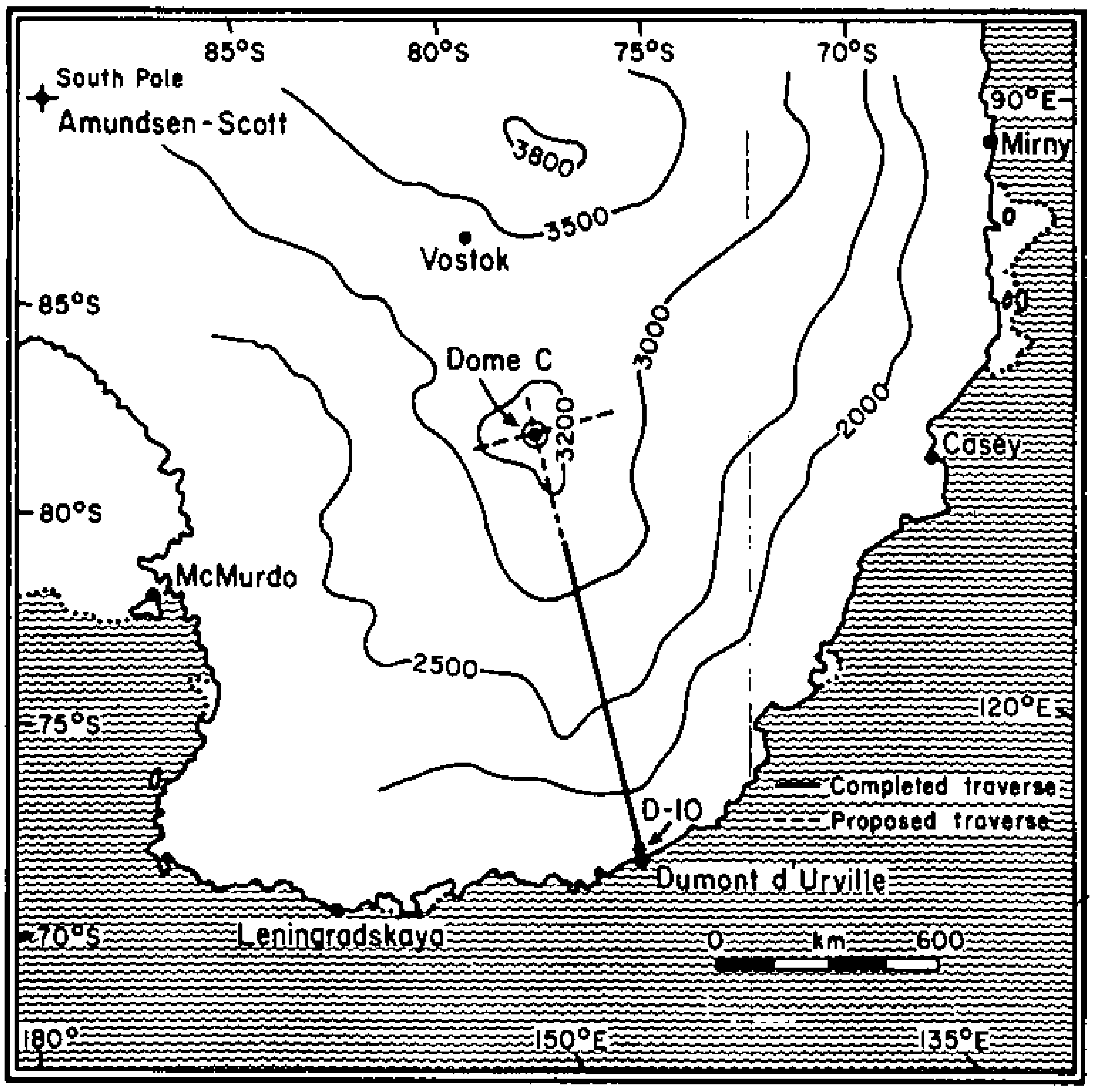

Figure 1. Field locations of the French contribution to the International Antarctic Glaciological Project. Elevation contours are given in meters.

To complete these studies, the measurements performed on snow, firn, and/or ice samples include:

1. stable oxygen and hydrogen isotopic composition
2. ice crystal size
3. gross β, ^{210}Pb and artificial tritium radioactivity
4. ^{10}Be
5. acidity
6. concentrations in trace elements and microparticles
7. total content and composition of entrapped gases

The stable isotope and tritium measurements are performed by the Départment de Recherche et Analyse, Centre d'Etudes Nucléaires du CEA (Saclay). The measurements of ^{10}Be are undertaken by a team from the Laboratoire René Bernas (Orsay) and the Institut des Sciences Nucléaires (Grenoble) using the cyclotron in Grenoble. Measurements of trace elements by neutron activation are conducted at the Centre d'Etudes Nucléaires de Grenoble. The laboratory at Grenoble is equipped for all of the other measurements listed above. The Centre des Faibles Radioactivités (Gif-sur-Yvette) is also measuring ^{210}Pb and gross β radioactivity. All of these laboratories are associated in a Cooperative Research Program headed by C. Lorius, from the Laboratoire de Glaciologie (Grenoble).

The following is a summary of some of the records obtained at Dome C between the surface and a depth of 905 m. This is an example of the research being conducted.

Climatic record

The first indication of the climatic record revealed by the 905 m long core was obtained in the field by measuring ice crystal size. The general trends of this profile with depth are an increase in size of crystal cross-section between 88 and 400 m and between 600 and 900 m, and a marked decrease in crystal size between 400 and 600 m. These important decreases occur in the depth interval where the stable isotopic composition of ice shifts from glacial to interglacial and again to glacial values. Nevertheless, the variations of crystal size associated with climate cannot be explained solely by temperature effects and may be due to the effect of microparticle content or of initial c-axis orientations on the migration rate of grain boundaries (Raynaud, et al, 1979). Microparticle and ice fabric measurements are currently undertaken on the Dome C ice in collaboration with the U.S. colleagues at the Institute of Polar Studies, Ohio State University, and the Cold Regions Research Engineering Laboratory (CRREL). These studies will be useful in determining the cause of the variation in crystal growth rate with climate.

The stable isotopic composition ($^{18}O/16_{0}$) has been continuously measured along the 905 m long core. The discussion of the results by Lorius, Merlivat, Jouzel, and Pourchet (1979) provides a detailed interpretation in terms of a 30,000-year isotope climatic record from Antarctic ice. The major conclusions of this study are:

1. The main characteristics of the stable isotopic profiles (measured at Dome C, Vostok, and Byrd) are similar for east and west Antarctica.

2. Isotopic events observed at Dome C are also seen in the record of sea-surface temperature change in marine sediments.

3. The climatic change at the end of the last glaciation was possibly similar at Dome C, Vostok, and Byrd. A tentative estimate of the difference in the surface temperature at Dome C between the coldest part of the glaciation and the present climate would be on the order of 7°C.

4. By using dated events in a comparable marine core, the Dome C record suggests smaller rates of snow accumulation associated with colder climatic conditions.

The change of the accumulation rate in the Dome C area over the last 25 years has been investigated by identifying 1955 and 1965 surface layers from β radioactivity measurements (Petit, et al, 1979). The results indicate that the rate of snow accumulation after 1965 is about 30 percent higher than during the 1955-65 decade. These authors also obtained accumulation rates over the last century from stratigraphy and ^{210}Pb measurements.

Ice sheet geometry changes

Under certain conditions, the total gas content of polar ice reflects the elevation at which the ice was formed. A large percentage of the 905 m long core obtained at Dome C is unfortunately too badly cracked to obtain a record of past surface elevation. Nevertheless, measurements performed on uncracked samples taken in the upper part of the core have been of great importance in describing the variations in the total gas content of ice that has been formed under present-day conditions (Raynaud and Lebel, 1979). Using these results, the gas content method can now be applied with much greater confidence than before to indicate past changes in surface elevation.

Record of atmospheric composition

The concentrations of 12 trace metals have been measured in snow samples carefully collected from the near-surface layers. The results discussed by Boutron and Lorius (1979) and Boutron (in press) indicate:

1. Na and Mg mainly originate from an oceanic source and Al, Fe, Mn, K, and Ca from a continental crustal source.

2. The remaining elements, Pb, Cd, Cu, Zn, and Ag are independent of both oceanic and continental crustal sources. The variations with depth of these trace metals show that both the concentrations and the enrichment factors, taken with respect to the composition of reference crustal and marine sources, in new snow are comparable to those found in snow about 100 years old. This suggests that the concentrations of Pb, Cd, Cu, Zn, and Ag recorded at Dome C are not strongly influenced by industrial pollution but are related to natural phenomena, probably volcanism. Support for this is provided by the concentrations of sulfate measured at Dome C. The most important sulfate concentrations seem to be linked to major volcanic eruptions in the Southern Hemisphere (Delmas and Boutron, in press).

For a record extending much further into the past, samples from the 905 m long core are being analyzed for microparticles. Preliminary results show that there is a particularly high content of microparticles found in the ice spanning the last stage of the most recent glaciation (Thompson, Mosley-Thompson, and Petit, 1979). This was also observed previously in other long polar ice core records.

^{10}Be concentrations have been measured, using the accelerator technique, in two samples of approximately 10 liters water equivalent taken at depths of about 70 and 240 m. The only other published measurement of ^{10}Be in polar deposits was performed by another technique on a sample of 1.2 x 10^6 liters water equivalent (McCorkell, Fireman, and Langway, 1967). The primary objective of measuring the Dome C samples was to test the use of the accelerator technique for measurement of ^{10}Be on relatively small samples taken from ice cores. The experiment was performed using the Grenoble cyclotron and the results obtained have been discussed by Raisbeck, et al, (1978). This work indicates that the ^{10}Be concentration of polar ice cores can be recorded with sufficient accuracy using the accelerator technique that possible variations with time can be investigated. These variations might be used to describe, in particular, the intensity variations of the geomagnetic field. The present results lead to an estimation of the long-term average for ^{10}Be deposition rate at Dome C.

Exchange of ice core samples and complementary studies

As noted above, pieces of the Dome C long core have been analyzed in laboratories outside of France. In fact, the Laboratorie de Glaciologie exchanges ice samples with several foreign institutions. This kind of cooperation has proven very effective in terms of scientific results.

A reconstruction of the past from studies on ice cores requires a knowledge of the conditions occurring at the surface today and concurrent modelling of the flow of the ice sheet. The Grenoble laboratory has collected numerous surface samples and measured specific parameters at the surface in various locations, especially between Dumont d'Urville and Dome C. In collaboration with the Melbourne group, the flow of the ice from Dome C to the coast near Dumont d'Urville has been modelled. This modelling has been compared with the analysis of the ice core obtained to the bedrock at D 10 (Raynaud, et al, 1979). The results give an indication about climate and ice sheet thickness during the past in this part of east Antarctica.

In conclusion, the ice core program of the Grenoble laboratory is designed to aid in the understanding of past, present, and future environmental changes. A rather large number of problems can now be addressed due to fruitful national and international cooperation. I would like to take this opportunity to emphasize the value of my stay in the United States at the Institute of Polar Studies during 1979, within the framework of the NSF-CNRS, U.S.-France Exchange of Scientists Program.

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ACRONYMS

Because of the large number of acronyms present in this issue, the following list is included to assist the reader:

AIDJEX - Arctic Ice Dynamics Joint Experiment

CEA - Commissariat á l'Energie Atomique (France)

CNRS - Centre Nationale de la Recherche Scientifique (France)

CRREL - Cold Regions Research and Engineering Laboratory (U.S.)

DFA - arctic diesel fuel

DISES - Data Information Storage and Exchange System

DMSP - Defense Meteorological Satellite Program (U.S.)

DPP - Division of Polar Programs (U.S.)

DVDP - Dry Valley Drilling Project

EDBD - Environmental Data Base Directory [NOAA] (U.S.)

EDIS - Environmental Data and Information Service [NOAA] (U.S.)

EGIG - Expédition Glaciologique Internationale au Gronland

GISP - Greenland Ice Sheet Program (Denmark, Switzerland, U.S.)

IAGP - International Antarctic Glaciological Project

ICF - Ice Core Facility (U.S.)

ICSU - International Council of Scientific Unions

INSTAAR - Institute of Arctic and Alpine Research (University of Colorado)

IPS - Institute of Polar Studies (Ohio State University)

NGSDC - National Geophysical and Solar-Terrestrial Data Center [NOAA] (U.S.)

NOAA - National Oceanic and Atmospheric Administration (U.S.)

NSF - National Science Foundation (U.S.)

PICO - Polar Ice Coring Office (U.S.)

POLEX - Polar Experiment

RISP - Ross Ice Shelf Project

SCRs - Silicon Controlled Rectifiers

SIPRE - Snow, Ice and Permafrost Research Establishment (U.S.)

SOSC - Smithsonian Oceanographic Sorting Center (U.S.)

TCE - trichlorethylene

USARP - United States Antarctic Research Program

WDC-A - World Data Center A for Glaciology (Snow and Ice)

WMO - World Meteorological Organization

ICE CORES: A SELECTED BIBLIOGRAPHY

The Ice Core bibliography is a representative collection of international references to ice core drilling and ice core analyses and research. It is the first version of the literature reference file for the Ice Core Project data and information storage and exchange system (DISES) which is described in detail starting on page 59.

The bibliography is divided for reference purposes into nine subject categories. In order, they are:

A. General

B. Drill Technology

C. Stratigraphy and Physical Properties

D. Stable Isotopes

E. Radio Isotopes

F. Chemistry

G. Particulates

H. Bubbles and Gases

I. Miscellaneous Related Topics

Each subject entry has a unique number. Articles appearing under more than one subject heading have separate numbers for each citation. These appear in association with the alphabetized author index on pages 133-136.

The bibliography has been compiled from several different sources, including the automated and manual indexing and abstracting services listed below.

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If any individuals or institutions see their publications in this list without an "≠", the WDC would gratefully appreciate receiving copies of those which are still available.

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INDEX

NOTES

I. WDC-A Data Sets

A. Polar Ice Sounding and Geomagnetic Data Sets

A flier describing ice sounding and geomagnetic data sets from Antarctica and Greenland which are held by the World Data Center is now available on request. Data consist of ice thickness profiles and airborne geomagnetics generated during NSF-funded remote sensing flights in 1977-78 and 1978-79. Over 241,000 km flight-lines of data are available; requestors may obtain complete flights or selected geographic "windows."

Data are available in a combination of digital and/or analog form, on 7- or 9-track magnetic tape, paper listings, strip charts, and 35mm microfilm. Costs are dependent on the amount of data requested and computer processing required.

For further information, request a free copy of Data Announcement 1980(GA) from:

World Data Center A for Glaciology (Snow and Ice)
Institute of Arctic and Alpine Research
Campus Box 450
University of Colorado
Boulder, CO 80309 U.S.A.
Telephone: (303) 492-5171
FTS 323-4311

B. Great Lakes Ice Data

The World Data Center A for Glaciology (Snow and Ice) has begun archiving Great Lakes ice data formerly held by the Great Lakes Environmental Research Laboratory (GLERL) in Ann Arbor, Michigan. Within the next two years data transfer will be complete; at present three data sets are available in Boulder:

1. National Ocean Survey (NOS) Water Level Gage Ice Reports

   Tabulated daily observations of ice conditions at 30 to 40 water level gage sites on the Great Lakes, 1956/57 to the present. Photocopies are available for selected years, months, or stations. A location map is provided, with coordinates of each gage site listed.

2. U.S. Coast Guard (USCG) Surface Ice Reports

   a. Ice conditions and meteorological observations from USCG Great Lakes icebreakers and shore stations, 1979/80 ice season. Photocopies are available for selected dates or locations, as well as for the complete ice season.

   b. Data from 1961/62 - 1975/76 are combined on magnetic tape. Software is presently not available to sort these data in any way; tape copies are available, with format documentation.

3. Air Temperature - Degree Day Climatology, 1897-1977

   Microfilm appendices to Great Lakes Degree-Day and Temperature Summaries and Norms, 1897-1977 (Assel, R.A., NOAA Data Report ERL GLERL-15, January 1980) tabulating maximum, minimum, and mean daily and seasonal values and accumulations of freezing and thawing degree days at 25 stations. Copies of complete or partial rolls are available in paper or 35mm film format.

   These data sets, and others as they become available, will be described in Data Announcements to be distributed to individuals and organizations on our mailing list, and by request. For further information, please contact Claire Hoffman, World Data Center A for Glaciology, Campus Box 450, University of Colorado, Boulder, CO 80309, USA. Telephone (303)492-5171; FTS 323-4311.

C. Defense Meteorological Satellite Program

Beginning in the fall of 1980, Air Force DMSP (Defense Meteorological Satellite Program) imagery with a resolution of 3 nautical miles will be available from the World Data Center A for Glaciology.

The DMSP data being archived are a series of mosaics compiled from several orbits (for example, the Asia mosaic is made from five orbits). The mosaics are corrected for distortion and are gridded with latitude and longitude. The period of coverage is from November 1975 onward. The combination of high resolution and at least twice-daily coverage (globally) in both infrared and visual bands make DMSP an excellent tool for observing snow and ice on the earth's surface.

The University of Wisconsin Space Science and Engineering Center continues to archive DMSP products with 1/3- and 2-nautical mile resolutions.

A formal announcement of the DMSP archive at the Data Center will be made in Glaciological Data, Report GD-9, and in a special data flyer when the data becomes available in the fall of 1980.

In the meantime, further information can be obtained from: Greg Scharfen, World Data Center-A for Glaciology, Campus Box 450, University of Colorado, Boulder, CO 80309, USA. Telephone (303)492-5171; FTS 323-4311.

D. Glacier Photograph Collection

The Data Center is in the process of acquiring the collection of glacier photographs of the American Geographical Society (AGS). The collection is currently in the care of Dr. W. O. Field, director of glaciological research at the AGS. The collection contains a wide variety of prints and negatives, many dating back to the turn of the century, and consists of three main categories: 1) terrestrial photographs, 2) aerial photographs, and 3) miscellaneous negatives and slides.

The terrestrial photographs were taken principally in Alaska. They date back to the International Boundary Commission Surveys in the 1890's and early 1900's. Included in this category are the photographs from Field's work in Alaska beginning in 1926 and continuing to the present. He instigated a long-term project to carry on the observations begun by H. F. Reid of recording glacier changes by photographing and surveying from certain photo stations every few years. Some of the photo stations used were established by early scientists in the area (e.g., Wright, Cooper, Tarr and Martin, and Grand and Higgins), so glacier changes can be compared for many decades. Dr. Field has made 13 scientific expeditions to Alaska to continue this work, which has been supported by the American Geographical Society since 1940.

Vertical and oblique aerial photographs in the collection were taken primarily of Alaskan glaciers and were obtained from various sources, such as those from Bradford Washburn. The collection also includes trimetrogon photographs taken in Alaska and British Columbia in the early 1940's. Most, or all, of the original negatives of these photographs no longer exist.

Miscellaneous negatives and 2 x 2" slides which have been donated over the years are also included in the collection. One example from this category are several hundred of H. F. Reid's glass negatives taken in the Alps in the early 1900's.

The collection is well identified as to location, glacier names, photo station names, photographer, date, and some historical and scientific data. Dr. Field has developed a comprehensive listing of Alaskan glaciers, arranged by mountain range and listed historically for the collection. He is currently working on detailed maps of photo station locations so the sites can be revisited in the future by other scientists.

The AGS collection, as well as that of A. S. Post, U.S. Geological Survey, Tacoma, Washington, is being indexed for the WDC-A by C. Locke in order to provide access to specific photographs by means of a computerized data base.

II. International Glaciological Society Announcement of Annals of Glaciology

In order to maintain the quality of the Journal of Glaciology while keeping rising costs under control, the International Glaciological Society has decided to make some changes in the content and format of the Journal. These plans were presented at the 1979 Annual Meeting of the Society and appeared in Ice, No. 60.

It was decided to remove Glaciological Literature from the Journal and to produce it in a less expensive way. Glaciological Literature will be offered for sale in the new format and will be a separate item on the 1980 subscription renewal form.

The establishment of a new publication series for conference proceedings and other special publications was also recommended. This new series will be called Annals of Glaciology. Members will not receive copies of this series automatically as they do the Journal. Instead, a member will have the option to purchase the volume at a preferred rate at the time it is offered on the subscription renewal form. The Society feels that this new publication series will provide a flexibility to respond on an ad-hoc basis to opportunities as they arise. The first publication in the series will be the Proceedings of the Iceberg Conference to be held in Cambridge, England this spring. The second will be the Proceedings of the Society's Symposium on Glacier Erosion to be held next year in Norway.

Establishing this new publication does not mean that proceedings of conferences cannot, on occasion, be published in the Journal. But as a general policy, adequate guarantees must be made that the cost of publication can be covered either by the Society or other sponsoring bodies. Examples include the Proceedings of The Symposia on Dynamics of Large Ice Masses and in Glacier Beds and the Proceedings of the Symposium on Snow in Motion which will be published as regular issues of the Journal.