Recent investigations of the Greenland Ice Cap.

By Børge Fristrup.

In 1954 *Albert Bauer* published the results of a planimetric investigation of the American World Aeronautical Chart 1: 1.000.000, and according to him the total area of Greenland is 2.186.000 sq.km., of which the area of the Ice Cap covers 1.726.400 sq.km., and smaller glaciers outside the Ice Cap have a total area of 76.000 sq.km. Consequently, the radio between the glacierised area and the ice-free area in Greenland is 5/6, and Greenland is the largest and most important glacier region outside the Antarctic. Therefore, glaciological studies are naturally very important for most geographical work in Greenland. The modern technical facilities and instruments have changed the character of the Arctic expeditions. During the last few years many expeditions have worked on the Greenland Ice Cap and have acquired much new knowledge about the nature and the physical conditions for the large ice sheets in Greenland.

The object of the present paper is to give a summary of the work which has been carried out, especially in the 1950'ies.

I. Expeditions.

The modern geographical exploration of the Greenland Ice Cap started with the German *Alfred Wegener Expedition* 1929—31; during this expedition the first wintering on the interior of the Ice Cap was organized with the establishment of the station »Eismitte« at 70° 54'N., 40° 42'W. in the central part; further, the first attempts to determine, by seismic soundings, the thickness of the ice were carried out. The results were published by *Kurt Wegener* (1933—40). Almost at the same time the *University of Michigan Greenland Expeditions* under *William Herbert Hobbs* 1926—31 and

R. L. Belknap 1932—33 investigated the marginal zone especially around SøndreStrømfjord, and from Camp Scott in Upernavik Fjord. Studies on the Ice Cap itself with wintering farther south than that of the Wegener Expedition were conducted by the *British Arctic Airroute Expedition* 1930—31 under *Gino Watkins* (1932), where *Courtauld* from 8th September — 26th April carried through the wintering alone on the Ice Cap at an altitude of 2.500 m. at 67° 03'N., 41° 49'W. Results were also obtained by the *British Oxford University Expedition* 1938 under *J. G. S. Sugden* and *P. G. Mott* from the Sukkertoppen Ice Cap, where *E. Etienne* (1940) made some studies of the snowstratification in pits and also studied the mass balance of the Ice Cap.

During the second world war airbases were established in Greenland; however, no scientifical activities took place on the Ice Cap proper. Of special importance for the work on the Ice Cap are now the bases: The Thule Air Base (established in 1951), and Søndre Strømfjord (BW 1) and Narssarssuaq (BW 8), of lesser importance are the East Greenland air-strips at Mesters Vig and Íkáteq, from 1958 also on Kulusuk, near Angmagssalik. The war brought many new inventions for the technique of Arctic exploration and travelling, among other things especially the weasels, the snocats and the tractors. The mechanical transportations in co-operation with airplanes and helicopters have now made scientifical investigations on the Ice Cap possible on a much larger scale than in the past.

The geographical explorations in Greenland after the war started with the *Danish Pearyland Expedition* 1947—50 under the leadership of *Count Eigil Knuth;* the main object of the expedition was an investigation of the northernmost part of Greenland: Peary Land. A reconnaissance expedition 1947 brought knowledge of the ice-conditions, and the site for the wintering-station was found in the icefree Jørgen Brønlund Fjord, 82° 10'N. and 30° 30'W. In 1948 the station was established, and from 1948 to 1950 scientists worked in Peary Land with the station as a base for long sledge journeys. Geographical and some glaciological investigations were carried out by *B. Fristrup* (1951) in the region around Academy Gletcher and Navy Cliff at the head of Independence Fjord and on the smaller ice cap Chr. Erichsens Iskappe on Heilprin Land.

In 1948 *Expéditions Polaires Françaises, Missions Paul-Emile Victor,* started their work in Greenland. This organization was established the 27th of February 1947 by *Paul-Emile Victor,* as he »recevais du Conseil des Ministres la mission d'organiser, réaliser

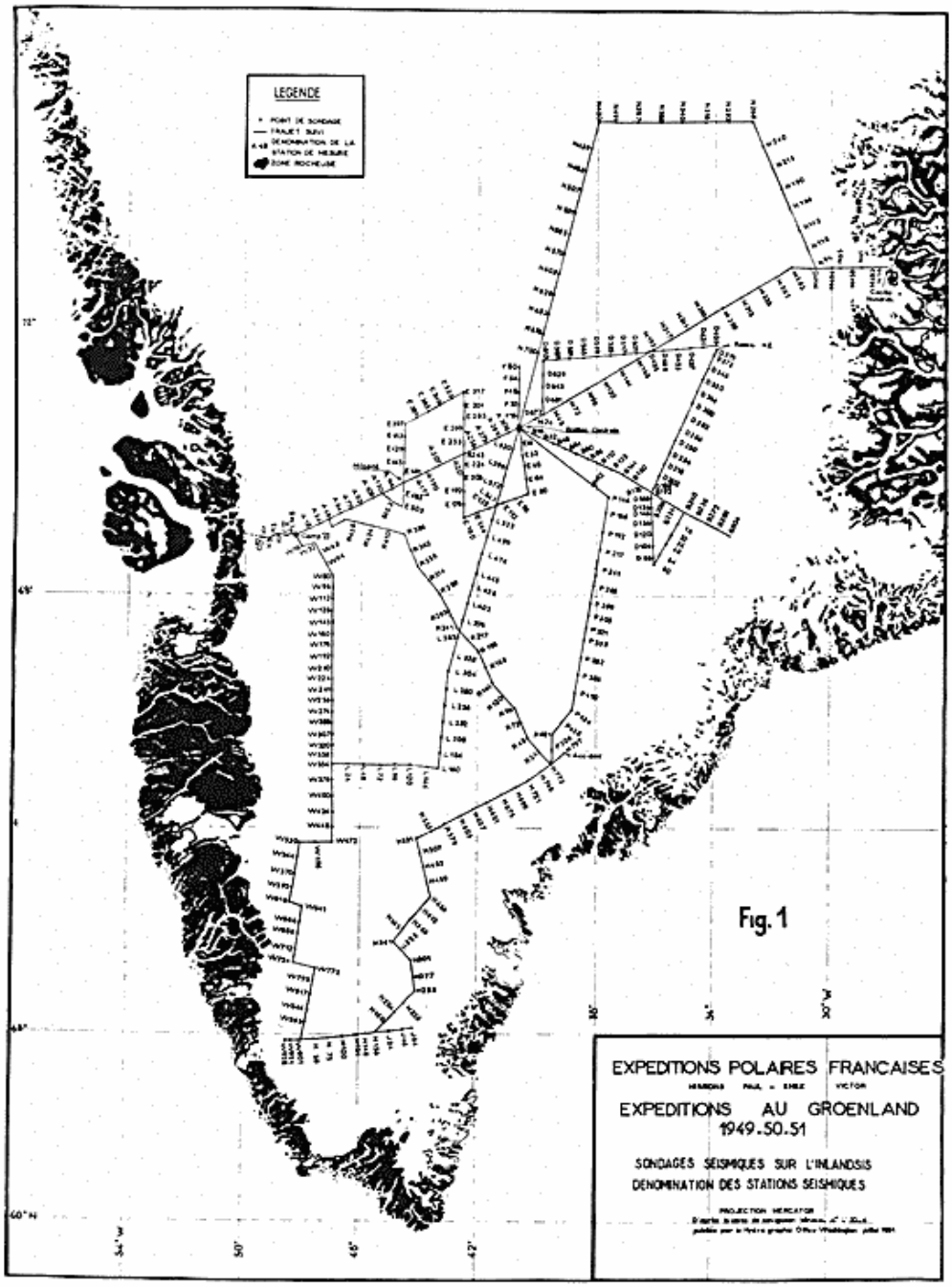

Fig. 1. Seismic surveyings of the Expèditions Polaires Françaises 1949-51. (Holtzscherer 1954).

et diriger des expéditions de recherche scientifique dans l'Arctique au Groenland et dans l'Antarctique en Terre Adélie«. (Rapports d'Activités p. 5). In 1948 the first campaign started with reconnaissance of the access route to the Ice Cap from de Quervains Havn a Eqip sermia. In order to get the weasels to the Ice Cap it was necessary to construct a road 11 km. long from the coast and to prolong it by a 700 m. long cable-way. In 1949 the wintering station »Station Centrale« was constructed in the central part of the Ice Cap at 70° 55'N. and 40° 38'W. in the vicinity of the old Eismitte Station, which in the meantime had been completely covered by snow and could not be found. The altitude of the Station Centrale was 2.994 m.; the supplies to the station were partly effected by weasels transport, and partly and mainly by airdrop — especially by free drop without parachute. 8 men spent the winter 1949— 50 on glaciological studies and meteorological surface observations as well as aerological investigations. In 1950 a summer-expedition relieved the winter-group, and a new team of 9 men continued the work. Different summergroups worked on the Ice Cap with geodetic, gravimetric and seismic surveyings; several traverses of the Ice Cap from Disko Bugt to Cecilia Nunatak and back were accomplished. The glaciological investigations were carried out by measuring accumulation and ablation along ablation markers and registration of snow profiles etc.; further, deep drillings with core sampling were taken at Camp VI (69° 42'N. and 48° 16'W., altitude 1.598 m.); here a depth of 126 m. was reached, and at Station Centrale to a depth of 151 m. At this place a hole was excavated by means of a special one-ton plunger down to 30,5 m. It had a diameter of 80 cm., which allowed a man to be lowered down and study the stratigraphy. *J. C. Heuberger* (1954) was in charge of the drilling operations. The seismic work this summer was very intensified in order to construct a map of the substratum of the Greenland Ice Cap. In 1951 a fourth expedition relieved the group from Station Centrale, whereafter the station was closed in August 1951. The seismic group worked this year on long trails on the Ice Cap, and the ice thickness was measured from 74° N. down to J. A. D. Jensens Nunutakker at 63°N. and from the western border of the Ice Cap to the Cecilia Nunatak at the east coast. In 1952 different geodetic and glaciological observations were continued, and a new, though small, expedition worked on the Ice Cap to bring the equipment back to the coast, from where it was shipped back to France. These observations were continued in 1953.

In co-operation with the Danish Pearyland Expedition Commander

C. J. W. Simpson in 1950 started a reconnaissance of the Dronning Louise Land from the air with a view to establishing a *British Expedition to North Greenland.* In 1951 a British reconaissance expedition landed at Sælsøen in Dronning Louise Land, and in 1952 the proper expedition started; a base was established at Britannia Sø, 77° 09' N., 23° 36' W., and another base, Northice, was constructed on the Ice Cap at 78° 04' N., 38° 21' W., at an altitude of 2.343 m. In spring 1953 the glaciological work was commenced on the outlet glaciers from the Ice Cap, while seismic and gravity teams worked between Northice and Britannia Sø. During the second wintering 1953/54 the observations were continued, and in 1954 a traverse from Northice to Thule was accomplished. It had been planned to measure the thickness of the ice sheet by seismic soundings, but no reflections from the ice-bedrock interface were recorded at any point between Dronning Louise Land and Northice and east of a separating line running approximately 330° through 77° N., 45° W. Markers were erected on the inland ice, and their positions were determined, thereby making it possible by a resurveying to obtain information about the movement of the ice sheet and the net accumulation of snow *(W. S. B. Paterson,* 1858). A pit at Northice down to 14 m. allowed the determination of the annual accumulation back to the year 1878. Snow studies on the Ice Cap were carried out by *C. Bull* (1958). The regime of the outlet glaciers was studied as well as the heat balance of the glacier surface. Reports on the expedition and the scientifical results have been published by *C. J. W. Simpson* (1955, 1957) and *R. A. Hamilton* (1958).

After having established the Arctic bases in Alaska, Canada and Greenland, the Canadian and US military organisations have been interested in the Arctic problems, especially the climatology, glaciology and periglaciology. In 1946 the *Arctic Institute of North America* was founded, and in 1949 the chief of engineers US Army created a special *Snow, Ice and Permafrost Research Establishment.* The studies of snow classification and basic research of mechanics of snow compaction acquired in a rather short time so great an importance that the Research Establishment erected its own laboratories at Wilmette, where a great organization with numerous scientists, both Americans and foreigners, has worked for SIPRE. The scientifical investigations in the field have for the greater part been carried out in Greenland and especially in the vicinity of Thule Air Base. Members of the SIPRE group have been working in Alaska and in co-operation with the Canadian Defense Board on the projects

of Arctic shelf ice, at T 3 and in the Antarctic; however, they have especially organized expeditions to the Greenland Ice Cap and to the marginal areas of the ice sheet. Many expeditions have worked on the Greenland Ice Cap, some of them only with military problems; but many of them have accomplished very important scientifical investigations, of which only the most important will be cited below:

In 1952 a small expedition of 9 men with *R. Guillard* and *Victor Layton* as leaders crossed the Ice Cap from Thule to Kap Georg Cohn. Seismic soundings were taken by *Jean Jacques Holtzscherer* (1954) in collaboration with the University of Georgetown (*Victor* 1955). The snow studies were carried out by *Carl S. Benson.*

In 1953 the Americans started the *Operation Icecap* in the Thule region for studies of the physical characteristics of the Greenland Ice Cap and its marginal zones. Four groups of scientists were working in different areas: group 1 called *Ramp* under the leadership of *Richard P. Goldthwait* studied the edge of the Ice Cap on the Nunatarssuaq peninsula at the head of Wolstenholme Fjord; studies were carried out by *Laurence Nobles* (1954) and by *S. E. White* (1956), among others. Group 2 called *Solo* under *Coleman C. Fischer* studied the access route to the Ice Cap near Thule, and seismic soundings and snow studies were made along a route on the Ice Cap to a point 300 miles east of Thule. Group 3, the *Norcut,* under *Robert L. Nichols,* carried through a traverse to Inglefield Land, studying the ice cliffs and the ice-free areas in front of the Ice Cap. Seismic work on the Ice Cap was here carried out by *Holtzscherer* (1954). The fourth group studied the geology of the Thule region, independently of the Ice Cap investigations. A preliminary report of the results was published by *Howard B. Hutchinson* (1953), who was the co-ordinator of the research programme for the Stanford Research Institute.

At the same time another American expedition *Project Mint Julep* worked in Southwest Greenland. In 1947 a military ground operation »Snowman« found a smooth ice area approximately 100 miles southeast of Søndre Strømfjord at 66° 16' N., 47° 46' W. at an altitude of about 1650 m; the whole area was very close to the firn-line*), and it will be possible to use some of the areas for air-strips, necessitating but little care and maintenance; therefore, a research programme was sponsored by the *Arctic Desert Tropical Information Center* together with the *American Geographical Society.* In May

*) These hard, smooth areas of glacier ice, free of crevasses, are found at many places along the firn-line.

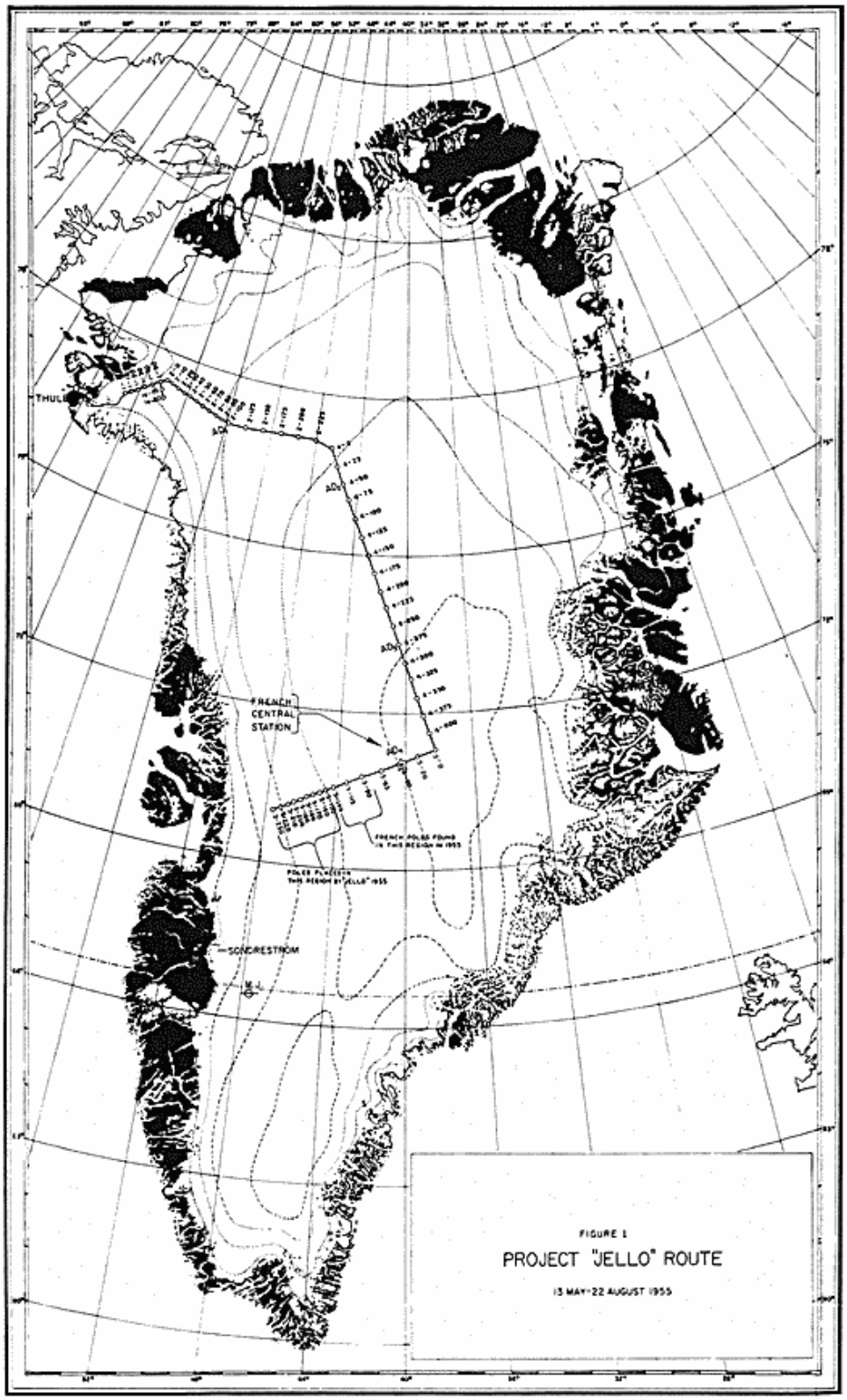

Fig. 2. Snow studies made by Expedition „Jello" 1955.
(C. S. Benson & R. H. Ragle, 1956).

1953 eight Jamesway huts were brought in by planes; a camp site was constructed, and investigations were carried out in the area until August. Snow-stratification was studied by *Robert L. Shuster* (1954), the ablation by *R. L. LaChapelle* (1954), while the sastrugi and the »nieves penetente« especially were studied by *L. R. Wilson* (1954); the hydrology of the meltwater streams was measured by *G. William Holmes* (1954).

In 1954 several projects were started in the Thule region and on the Greenland Ice Cap. *Carl S. Benson* (1955) was the leader of a small mobile scientific expedition *Party Crystal* with weasels working on the Ice Cap eastward of Thule Air Base. The work included measuring of elevation, snow accumulation, summer melting and snow properties. *George P. Rigsby* (1955) carried out the first studies of ice fabrics from a polar glacier, taking samples from the ice fronts at Nunatarssuaq and from the Moltke Gletscher. Extensive studies of the accumulation, the ablation, the glacial meteorology and the superimposed ice were conducted by *Valter Schytt* (1955) on the Thule Ramp of the Ice Cap. In connection with this project *Barry C. Bishop* (1957) started a study of the well developed shear moraines at the edge of the Ice Cap at Thule. Of special importance for the glaciological studies are the investigations carried out under the direction of *Henri Bader* at a test site established 320 km. east of Thule Air Base at an altitude of 2.134 m.; the latitude of the place, which was called Site 2, is very near 78° N. In 1954 a pit was excavated here to a depth of 30 m, and a 18 m core drill hole was sunk by hand drilling from the bottom of the pit to a total depth of 48 m. The stratigraphic study of the snow in the deep pit permits dating of the annual layers back to 1908. Investigations of the density, viscosity and all other physical properties of the snow were conducted at Site 2 and on the basis of samples brought to the cold laboratory at Wilmette (*Bader* 1955). Studies of snow — with a view to examining the traficability of snow and the possibilities of using it for constructions — were carried out by *R. Waterhaus* (1955) and others. The investigations of the Nunatarssuaq were continued under *Laurence Nobles* and a study of the glacier crevasses was started by *R. L. Schuster* and *F. A. Small* in Blue Ice Valley, one of the big tributaries to the Moltke Gletscher at the head of Wolstenholme Fjord. 1954 was a very warm summer, perhaps the warmest in North Greenland for the last 30 years; the melting on the Ice Cap was bigger than normal, a fact which makes the 1954 surface a very distinct feature for snow pit studies in the future.

In 1955 the SIPRE work from the preceding years was continued; studies of the aspects of geometry, mechanics and thermodynamics of processes for the developing of crevasses were this year conducted by *Mark F. Meier* (1957) at Blue Ice Valley, while the studies of the ramp at Tuto were continued by *Thomas M. Griffiths* (1957), and *Laurence Nobles* worked in the Nunatarssuaq region. Of special interest this year was the expedition »*Jello*« under the leadership of *Carl S. Benson* and *R. H. Ragle* (1956). The expedition started from Thule Air Base; one of the objects was snow studies along the route from Thule to a point on the Ice Cap at 77° 06' N., 43° 00' W., from here along the crest of the inland ice down to 71° 28' N., 37° 15' W., and further on to the French Station Centrale and along the French trail to Victor's old camp VI at 69° 45' N., 48° 15' W., where the members of the expedition were evacuated by plane. Another purpose of the expedition was to extend all the markers and to measure the accumulation of the French prominent markers as well as their displacement since 1951. A resurveying of Station Centrale was carried out by *George Wallerstein,* who found the position to be 70° 54' N. and 40° 37' 57" W., and a calculation made by *L. Tschaen* and *A. Bauer* (1958) showed a displacement of 170 m. per year in a southwestern direction, a fact which was rather astonishing.

Another important investigation in 1955 was the studies at Site 2; here the deformation of excavations in the névé was measured by *J. K. Landauer* (1957), glacial meteorological observations were executed by *M. Diamond* and *R. W. Gerdel* (1956), who especially studied the global and net radiation, the conditions for the white-out and the occurrence of blowing snow on the Ice Cap. At the edge of the Ice Cap, near Tuto, the construction of a tunnel 152 m long and 1,7×2.0 m wide in the ice was started; in 1956 the tunnel was extended over a distance of 32 m, and a room 18×18 m and 8 m high was excavated. It is the first time that such big rooms have been excavated in the glacier ice. The tunnel was made partly for engineering purpose, partly with a view to scientifical studies, especially for measuring of the shearplanes and as control of the seismic and gravimetric determinations of the thickness of the ice. The tunnel started from a vertical ice cliff, and the excavations were directed by *Donald O. Rausch* (1958). A smaller ice tunnel was excavated on Nunatarssuaq in connection with the studies of the vertical ice cliffs of the North Ice; here *Richard P. Goldthwait* (1956, 1957) carried out comprehensive studies of the conditions for the position and the balance of the vertical ice cliffs.

In 1956 the SIPRE studies continued at the Site 2 and at other places on the Ice Cap, and a special expedition under *Norman Goldstein* made seismic soundings with a new type of instrument in the area where no reflection was recorded by the British Simpson Expedition; this time the investigations were successful, and the thickness of the ice was determined. Another expedition under *Robert Frost* reconnoitred the access routes to the Southern Greenland Ice Cap, especially in the Narssarssuaq and the Ivigtut areas and along Frederikshåb Isblink. In many respects this year was a preparation for the IGY, and an international glaciological course was held in the Thule area under the leadership of *Henry Bader* and *B. Fristrup*. Experiments with deep core drilling were made at Site 2, and a depth of nearly 1.000 feet was reached; the core from this depth represented real glacier ice, the age of which is estimated to go back to 1500. A very careful examination was carried out, and analyses of grain size, density, particulates, rati $0^{16}/0^{18}$, volcanic ash horizons, gas content, deuterium etc. were executed. The HIRAN stations on the Ice Cap were also established in connection with the IGY, and simultaneously with the construction of the sites very detailed snow studies were carried out. A 10 m. high steel-tower of a special SIPRE construction was erected, making it possible to find the stations even after they had been covered by snow; in spring 1959 at least one of the stations has been completely covered, and its presence is only revealed by the steel tower. The positions of the stations are according for the »Manuel d'Operations« of the International glaciological Expedition.

station	26:	68° 15' N., 36° 30' W.
»	27:	69° 23' N., 35° 55' W.
»	28:	70° 37' N., 36° 10' W.
»	29:	68° 04' N., 42° 20' W.
»	30:	69° 33' N., 43° 10' W.
»	31:	70° 55' N., 40° 48' W.

A resurveying of the French Station Centrale showed the position to be 70° 54' 43" N. and 40° 37' 21" W. and, consequently, overthrew the theory of displacement of the Station Centrale as put forward by *Tschaen* and *Bauer* (1958). A new calculation of the position af Station Centrale have been published by L. Tschaen (1959).

In 1957 the SIPRE programme still continued. The deep drilling this year started with a new equipment, and a hole was drilled down

to 411 m. The diameter of the core was 10 cm., and a continued core was taken up from a depth of down to 300 m.; from below this depth only some separate cores were brought up; 160 m. of selected half-cores were transported by air in dry ice to the SIPRE Laboratory at Wilmette for further detailed investigations: stratigraphy, pressure in the enclosed air bubbles, shape and size distribution of the bubbles, porosity and permeability, snow structure, metamorphism and ice fabrics, content of particles, isotopic analyses (e. g. $0_{16}/0_{18}$, deuterium, tritium), grain-size distribution and content of bacteria. A preliminary report has been given by *Langway* (1958). The studies at the Thule Ramp under *M. Griffiths* were continued and achieved. At Site 2 the investigations of the snow drift were carried on, and studies of the snow structure were also executed. In South Greenland a surveying with a view to an access route to the Ice Cap was carried out in the region of Narssarssuaq.

In 1958 the studies in the Thule region were continued, and an American reconnaissance expedition named *Operation King Dog* worked in the Søndre Strømfjord region, studying the access to the Ice Cap and the marginal zone; glaciological investigations were carried out.

The Danish glaciological investigations under the IGY were executed under the leadership of *Fristrup* (1958); however, all the stations were local glaciers outside the Ice Cap, and only the measurements at the Hurlburt Gletcher in the Thule district have some relation to Ice Cap studies, especially as a control and reference for the ramp studies at Thule Air Base.

At the International Congress of the Geophysical Union in Rome in 1954 the plans were made public for an *International Glaciological Expedition to the Greenland Ice Cap,* usually called *E.G.I.G.,* under the patronage of the International Association for Scientifical Hydrology, and a co-operation between Denmark, France, Germany, Switzerland and Austria was established with the object of studying the mass balance of the Greenland ice sheet. In April and May 1957 a reconnaissance of the access route was carried out, and an air reconnaissance of the Kangerdlugssuaq region and of some of the outlet glaciers to Umanak and Disko Bugt was made in July the same year. The possibility of using air photogrammetry for determination of the velocity of ice movements in glaciers was discussed on the basis of some air photos taken in July 1957, see *Finsterwalder* (1958), *Baussart* (1958) and *Hofmann* (1958). Preliminary plans for the geodetic work of the expedition were published by *Lichte* (1957)

and *Hofmann* (1958). In 1958 a ground reconnaissance was carried out, and a remeasuring of some ablation markers was put into work; *Bauer* found that some of the old markers in the Eqip sermia region from the French work in 1949—53 seem to indicate a lowering of the firn-line, and superimposed ice up to 2 metres was covering some of the markers originally put up. On the basis of observations in 1958 *Bauer* estimates the line of equilibrium to have lowered 200 m. from 1950 (rapport interne d'E.G.I.G. 1958).

In connection with the E.G.I.G. a French expedition under *Dumont* established a base on the Ice Cap at 71° 21' N., 33° 55' W. by parachuting all the equipment and the members of the expedition. Meteorological investigations were carried out, and during the winter time a glaciological pit was excavated down to 42 m. below the surface. At the evacuation of the station in spring 1957 the pit was closed very carefully. A detailed investigation of the stratigraphy and other snow studies will be carried out during the wintering of the E.G.I.G. expeditions at the same place 1959/60. The meteorological results have not been published.

In 1958 The *British West Greenland Expedition* under *O. Henry* and *White* worked on the Lyngbræen descending from the Sukkertoppen Ice Cap; the main object was to study the formation of ogives.

An expedition to the West Greenland waters was organized in 1958 by the Arctic Institute of North America under the leadership of *David Nutt* and *Per F. Scholander;* however, although this expedition did not include the Ice Cap proper it is possible that it will give the answer to the problems of the age of the Ice Cap and also to other problems. The object of the expedition was to investigate the gas content in glacier ice; to this purpose a continuation of investigations was carried out on samples from icebergs from Labrador waters (»Blue Dolphins«, *Labrador Expedition* 1954). Previous investigations had been devoted to studies of the air pressure in the bubbles in glacier ice; from the Ice Cap measurings have been made by *Chester C. Langway* (1958), among others. According to some preliminary results published by *Scholander, Kanwisher* and *Nutt* (1956), *Coachman, Hemmingsen, Scholander, Enns* and *de Vries* (1958) it is possible to determine the age of the gas content by Carbon 14 analyses of the carbon dioxide in the gas bubbles and, thereby, to determine the age of the ice. According to investigations made by *Epstein* (1956), by *Robert P. Sharp* and *Epstein* (1958) and by *Dansgaard* (1954, 1958), the ratio of the common isotopes of

oxygen 0^{18} to 0^{16} in snow is influenced by the temperature at which the precipitation takes place and, therefore, by the altitude of the place where the snow is deposited; consequently, the 0^{18} content most likely decreases with increasing distance from the coast. *Epstein* found a decrease in the H_2O^{18} content in the precipitation at increasing altitude. *Dansgaard* is of opinion that on the basis of these preliminary results it will be possible to determine not only the age of the ice in the icebergs produced by the Greenland Ice Cap, but also the region of the Ice Cap from which the ice originates. Only a preliminary report has yet been published.

In spring 1959 the International Glaciological Expedition started the work from Søndre Strømfjord.

II. Scientific Results.

Since the first crossing of the Greenland Ice Cap carried through by *Nansen* in 1888 many geographical problems in this region have been solved; however, many researches still remain to be carried out before we know the age, the origin of the ice sheet, the total regime and the balance of the whole Ice Cap, and at present we know very little about the geophysical conditions of the ice in the interior part of the Ice Cap. During the last years many papers concerning the glaciology of the Greenland Ice Cap have been published, among them some summaries, see *Kayser* (1928), *Milthers* (1953), *Bauer* (1954) and *Sharp* (1956); further, a number of publications from the recent American and British investigations have appeared; therefore, the following summary will be of some interest:

Topography:

The general topography of the Ice Cap is well known from the maps; a picture of the altitudes is given by the following maps:

1. *Grønland 1 : 5.000.000* published by *the Geodetic Institute, Copenhagen;* the latest edition from 1957.
2. *Géographie Glaciaire du Groenland* par *Paul-Emile Victor,* carte révisée au 31er janvier 1955; a) étendue probable de la fonte d'été et b) altitudes.
3. *Altitudinal map of part of North Greenland and North-East Greenland* in Meddelelser om Grønland 143, no. 1, 1950.
4. *World Aeronautical Chart* 1 : 1.000.000 published by *Aeronautical Chart Service, U.S. Air Force, Washington.*

As it appears from the maps, the predominant topographic feature is the division of the Greenland Ice Cap in two domes, a smaller southern summit with altitudes up to 2.700—2.800 m. and a larger, very uniform northern dome with altitudes up to 3.200—3.300 m. Between the two domes is a broad depression running approximately from the Disko Bugt to south-west of Angmagssalik. The greater part of the depression has an altitude of 2.200 m. The highest point of the Ice Cap has not been exactly determined; however, it seems to be very near 3.300 m.; the highest part of the ice sheet is situated west of Scoresby Sund, and over a distance of more than 800 km. the Ice Cap has altitudes above 3.000 m. The highest part of the Ice Cap with the crest or the surface ice-divide is much nearer the east coast than the west coast; this makes the Ice Cap very asymmetrical. The reason why and the development of the ice crest have been the subject of much speculation. According to *Wager* (1933) the crest represents the region of the greatest ice thickness, while *Sorge* (1933) supports the view that the ridge is the result of a maximum accumulation, to all probability not from recent time, but from an earlier date, the ridge thus being a relict of a former climatic condition. In 1943 *Demorest* published as his opinion that the crest reflects an elevation in the subglacial topography. The numerous traverses across the Ice Cap have made it clear that the surface is rather uniform over big areas, and a study of the region on both sides of the crest has been published in a preliminary report from *Benson* (1955); according to him the slopes near the crest are very gentle, only 5—50 feet per mile, and the surface of the ice sheet is relatively smooth and featureless; however, more detailed surveying has revealed several relief features with numerous hills, basins and other topographic features; the majority of the slopes averaged 0,3 %, and the steepest slope measured was 1,9 %. Further, a very characteristic undulation of the surface has been reported from many expeditions. The micro-relief is most probably the result of local meteorological conditions and, consequently, is dynamic and liable to change from time to time. Many of the sastrugi patterns have a very close resemblance to the ripple marks in sand dunes at the coasts and in the deserts, while other sastrugi forms are erosion forms and have no related patterns in dune-landscapes; the whole problem of the sastrugi forms and the developing of one from another has not been studied in Greenland; however, such studies would probably explain some of the features of the micro-relief.

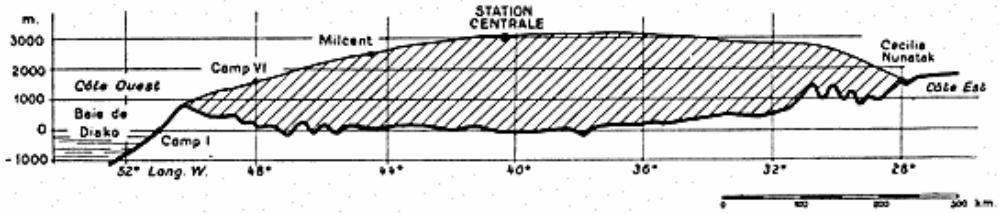

Fig. 3. Cross section through the Ice Cap from Disko Bugt to Cecilia Nunatak (Exp. Pol. Franc., Rapp. prél. 16, 1953).

The macro-relief with the two domes and the asymmetrical shape of the Ice Cap is very complicated. According to the seismic soundings by *Holtzscherer* (1954) the southern dome overlies a high part of the subglacial substratum; however, this is not the case of the northern dome. Here the substratum is formed as a large saucer, the central part of which is extending below sea level to a maximum depth of —250 m.; a system of subglacial valleys is coming from the Disko Bugt reaching far in below the Ice Cap. No such valleys have been found draining off to the east coast; the bed-rock surface under the ice is higher at the east coast than at the west coast. Consequently, according to *Holtzscherer,* the crest has no direct relation to the subglacial topography; therefore, he advanced the opinion that the ice crest is due to a restraining of the easy outflow eastward caused by the high eastern mountains. As pointed out by many authors, among them also *Victor,* a predominant feature of the ice dynamics of the Greenland Ice Cap is the occurrence of »ice streams«, i.g. the ice streams flowing in a colder and therefore more solid ice. Ice streams are predominant in several regions of Greenland and especially in the region around Disko Bugt and Umanak Fjord; here many glaciers are descending to the sea, many of which are very active with high velocities, up to 25—30 m. a day, and with a big production of icebergs. Such glaciers seem not only to follow subglacial valleys in the bed-rock floor, but also appear as ice streams draining a larger area than the one corresponding to the subglacial bed-rock topography. The depression between the two domes therefore can be explained as a result of the rapid outflow of the ice to the Disko Bugt which lowers the ice surface. The easy glacial outflow to the west as compared with the restrained outflow to the east may be interpreted as follows: the mass of ice moving west is bigger than the mass moving east, and the result of this is that the ice-divide is pressed to the east of the centre-line. In this connection it should be pointed out that in North Greenland the ice-crest is nearer to the centre-line than farther south, and according to the general topography and to the seismic results

obtained by *Holtzscherer* there is no great difference in this region between the possibilities of outflow of ice to the east and to the west.

The difference in the accumulation has been studied by *Benson and Ragle* (1956), who found a decrease of accumulation towards higher elevation; the 4-year accumulation established on the basis of the resurveying in 1955 of the French markers indicates an approximate eastward decrease of 5 cm. per 20 miles. The results obtained are only from central Greenland; in North Greenland *Benson* (1955) found that the greater part of the accumulation comes from the Melville Bugt, and the areas to the south and to the east of the expedition routes act as catchment-basins; in addition a considerable portion of the new snow was blown off the ridge, and there was no variation of any importance of the annual accumulation according to the longitude. From the British North Greenland Expedition *Bull* (1958) and *Hamilton* (1958) report as a result of their investigations that the mean annual accumulation was almost constant at the altitudes between 1850 and 2500 m.; along the whole traverse-route where the gravity had been examined and near the coast the accumulation was less, due to a presumably increased ablation. The general direction of the winds above the Ice Cap was found to be south-westerly, and there is a considerable asymmetry in the surface wind-system in North Greenland, as mentioned by *Bull*. In the area above the ridge the south-westerly winds are predominant, whereas farther to the east catabatic winds are ruling; therefore, *Bull* supports, though with a certain reservation, the point of view that the change in accumulation is more associated with the wind-pattern than with the differences of precipitation. *Bull* is of opinion that the results of the Koch und Wegener Expedition (1930), which found the accumulation along the western part of their route to be more than twice the accumulation along the eastern half, the demarcation line coinciding with the north-south ridge, must have their origin in an exceptional year with precipitation very far from the normal conditions. After having compared his investigations with *Benson*'s results, *Bull* has come to the conclusion that in the area north-east of Baffin Bay, bounded by the main north-south ridge and by the ridge of the lobe extending west and south towards the Thule Air Base, the annual accumulation is about 35 g./sq.cm. and greatly exceeds that to the north and to the east, where it has been found to be 15 g./sq.cm.; the difference of accumulation is obviously due to a concentration of the differences of precipitation and of the deflation in the areas situated to both sides of the ridge.

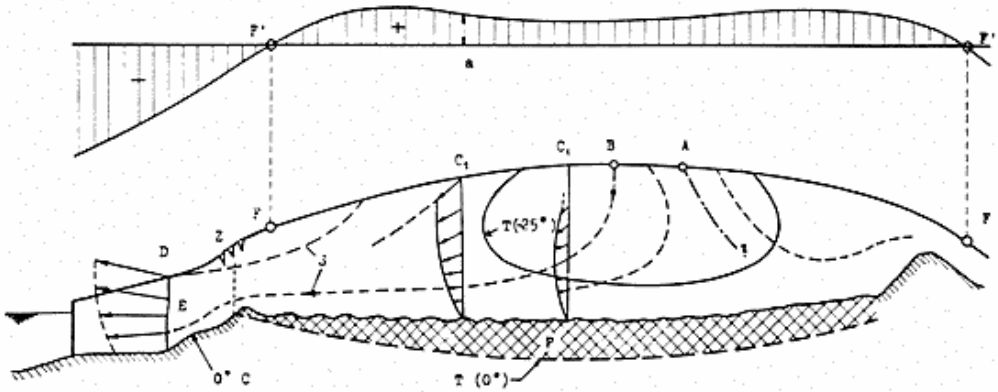

Fig. 4. A rough sketch of the Ice Cap. *Above:* Accumulation and ablation. *Below:* Ice streams and temperature conditions (hypothetic). F (snow line) S (shear lines) C_1, C_2, D (profile of velocity of the glacial drift) E (ice streams) Z (zone of crevasses) A (hydrographical ice-divide) a (accumulation of snow) B (cinematical ice-divide) T (÷ 25°) (isotherm ÷ 25° C (Robin)) T (0°) (isotherm 0° C) P (permafrost). (Haefeli 1957).

The influence of the wind and of the blowing snow has been emphasized by many authors, see *Ljungner* (1944), and as pointed out by *Bauer* (1955) the Ice Cap is very sensitive to all accumulation fluctuations; therefore, it is evident that even if the crest is a result of differences of meteorological conditions a change of climate may have the result that at present the crest is not situated at the place of greatest accumulation; and, according to the above-mentioned observations, it is most probable that the crest is not in the proximity of the region of greatest accumulation, at least not under the present conditions, and there is no direct relation between the crest and the topography of the substratum; however, a certain relation may be sought in the restraining of the outflow of the ice to the east exercised by the high mountains at the east coast of Greenland, culminating in Gunnbjørns Fjeld, 3.700 m.

Another cause of the surface-form of the Greenland Ice Cap must be brought into discussion: the historical factor, which has not been much mentioned in literature. As pointed out by previous authors, the Ice Cap has a very great age. According to *L. R. Wager* (1933) and *Lauge Koch* (1950) the Greenland Ice Cap has existed since Miocene time, and ice coming to the surface to-day is possibly many thousand years old. Consequently, the Ice Cap not only reflects the existing conditions, but also the conditions which were prevailing many thousand years earlier. We must also take into consideration that the present Ice Cap has not originally developed as a single, rather uniform glacier; until a few years ago the normal opinion among the geologists was that the Ice Cap might have developed as a high-

land glacier and from the central part spread out over the surrounding lower land; however, judging from the knowledge obtained by the seismic soundings this supposition cannot hold good; it may be true of the southern dome, whereas the whole northern dome must have developed not as a single glacier, but by fusion of several glaciers descending from the coastal mountain range; how fast, at which plane and at which place the fusion has taken place, we do not know. When taking into consideration the difference in climate between the humid West-Greenland and the continental East-Greenland, there is all probability that the fusion has taken place at a rather long distance to the east of the centre-line of Greenland. After the fusion of the glaciers, which most likely were of the type Piedmont glaciers, the building-up of the Ice Cap took place and thus completely changed the whole system of movement and shear-planes etc. It seems rather natural to think that in the interior part of the ice still certain features remain which have more relation to the older rheology of the ice than to the existing and, therefore, also may influence the present shape of the Ice Cap. In this connection it is of the greatest importance that according to several glaciologists, cf. *Haefeli* (1957), it ist probable that part of the deepest ice does not contribute to the general ice movement, and at present we do not know if the whole Greenland Ice Cap is in equilibrium or not.

The total area of the Greenland Ice Cap has been calculated by several authors. Official Danish statistics have been based on a planimetry of the Danish maps from 1920, according to which the total area of Greenland is 2.182.000 sq.km. and that of the Ice Cap 1.869.000 sq.km. *Bauer* (1955) found by a planimetry based on the 15 World Aeronautical Chart US AF in the scale 1: 1.000.000 covering Greenland that the area of the Ice Cap was 1.726.400 sq.km. and that of the other glaciated areas 76.200 sq.km., while the total area of Greenland was found to be 2.186.000 sq.km. Considering the greater scale of the map, *Bauer*'s figures are most probably quite correct. The highest point was found by the French expeditions to be at 72° N. lat. 37° 30' W. long., and according to a hypsometric curve calculated by *Bauer* (1954) the mean height was 2.135 m.

The climate of the Ice Cap

has been studied by nearly all the expeditions crossing the ice sheet. The glacial anticyclone theory advanced by *William Hobbs* in 1910

has been much discussed. The observations from the Wegener Expedition and from the British Arctic Airroute Expedition have shown that the central part of Greenland is not dominated by good weather and high pressure and that calm weather, contrary to the theory, very seldom exists on the Ice Cap; in spite of this, Hobbs and with him many other geographers still have supported the theory of glacial anticyclone. When *Helge Petersen* in 1938 published his volume on the climate of Greenland in Köppens Handbuch der Klimatologie he demonstrated the importance of the cyclonic activities especially in South Greenland; however, his work does not seem to have acquired the expected importance, perhaps because it was written in German and not in English. In 1946 and in 1950 *Matthes* published the results of his study of the anticyclone theory and demonstrated very clearly, based on the observations from the expeditions in the 1930-ies, that there is no glacial anticyclone over the Greenland Ice Cap; his results were confirmed by the observations carried out at Station Centrale by the French expedition. These observations showed that there is a very low catabatic wind draining the slopes of the ice sheet to the coast. This wind is local and is strongest in the marginal zone of the Ice Cap and weak at Station Centrale. Here the mean wind was 7 m./sec. with a maximum speed of 35 m./sec., and real calm weather was seldom; the predominant wind-direction was E.S.E. The mean temperature of the year is –30,3, the mean temperature for January is –47,3 and for July –10,8 (according to *Georgi* 1953/54). The temperature varies very much, and in the course of four days the temperature rose from –62° to –15°, at another occasion from –64,8° to –36° in the course of 24 hours (22–23/2 1950); the minimum temperature for the whole period was –64,8° and the maximum temperature 0,7°. The observations from the Northice have been published by *R. A. Hamilton* and *G. Rollitt* (1957), and they are very similar to those made by Station Centrale; the maximum temperature was found to be –1° and the minimum temperature –66°; the mean wind speed was only 4 m./sec. The observations from Site 2 and from Station Dumont have not yet been published.

Snow studies

and especially studies of the snow stratification were already carried out by *de Quervain* and by *Koch und Wegener;* however, the most important studies were carried out by *Sorge* (1935) at Station

Eismitte; here he found that the grains in the summer layers were slightly larger than those in the winter layers, and that this variation could serve to determine existing boundaries down to 6 m.; below this level it appeared to be difficult to measure the grain size. According to *Sorge* the winter deposits consisted of hard and dense layers, while the softer and less dense firn originates from snowfall during the summer. A study of the snow stratification was made by *Etienne* (1940) on Sukkertoppen Ice Cap, and his conclusion was this: high density identical with summer-layers and low density with winter-layers, which is the opposite of *Sorge*'s conclusions; *Schytt* (1958) is of opinion that this is most probably a misinterpretation of the layers, and *Sorge*'s classification of the layers has been confirmed by the studies carried out by *Schuster* (1954), by the American snow investigations around Site 2 and by *Benson* on the Ice Cap. A comprehensive report on the snow-pit studies is being prepared by *Carl Benson*.

The density variation as a function of depth has been studied by *Heuberger* as a result of the French drilling operation; the results have been much discussed by *Schytt* (1958), who argues that the measurings have been carried out in such a way that the compression of the drilling cores has varied much, thus provoking a wrong calculation of the densities; this is expected to be confirmed or not when the results from the American deep drilling are published.

The temperature in the ice

has been determined at several places. At Site 2 in North Greenland the mean annual temperature was found by *Langway* (1958) to be –25°, and during the deep drilling he found the temperature to decrease with the depth; the temperature gradiant between 250 m. and 400 m. was constantly 0,14° per 100 m., and at 400 m. the temperature was –25,42°. At Northice the temperature was –28° at 15 m. below the snow-surface. At Station Centrale *Heuberger* (1954) found that the mean temperature was –27°, and that the temperature from 90 m. to 100 m. and downwards was constantly –27,78°. At Camp VI the temperature was –12 at a depth of 10 m. decreasing to –16,5 at a depth of 130 m. According to a theory advanced by *Victor* (1956) the Ice Cap should at present have a temperature lower than could be expected from to-day's climatic conditions.

The temperatures at the bottom of the ice and in the substratum have not been measured; however, some informations have been

collected from the geophysical investigations, in the first place from the seismic soundings. From the high speed of the seismic waves found by the French seismic investigations *Holtzscherer* (1954) drew the conclusion that the central part of the Ice Cap was cold down to the bottom; the temperature at the bottom he estimated to be –10°, and below the ice he found evidence of a 200 m. thick layer of permafrost. In 1955 *G. de Q. Robin* published a very fascinating calculation of the distribution of temperature in an ice sheet by making simplified assumptions of the heat flow, and he worked out a quantitative method of estimating the temperature distribution near the centre of the Greenland Ice Cap. Based on a thickness of the ice of 3.000 m., an accumulation of 30 cm. per year and a surface temperature of –29°, *Robin* calculated the bottom temperature to be –12°, which is very close to the figure arrived at by *Holtzscherer. Haefeli and Brentani* (1956) calculated the bottom temperature on a completely different base, the results of a rheological investigation of an approximately 50 m. thick ice cap at the Jungfraujoch were used for calculating the thermal conditions in the Ice Cap and especially the temperatures at the bottom; from the movement and the viscosity conditions they concluded that the Ice Cap in the central part is frozen hard to the base, where the resultant shear stresses are well below the shear strength; this means that the temperature is below zero and, consequently, we will find permafrost; as pointed out by *Haefeli* (1957), this should be interpreted as follows: the movement near the bedrock is insignificant and, therefore, the erosion is inconsiderable. Also at Camp VI *Holtzscherer* found that the velocity of the seismic waves in the layer below the ice was very near the velocity found in permafrost, and he therefore assumed the existence of permafrost at this place too. In North Greenland investigations and calculations have been carried out by *Bull* (1957), who came to the conclusion that near the centre of the Ice Cap in North Greenland the bottom of the ice sheet must be at the melting point (–1,5°), and he advances as his opinion that the result of the melting is a lubrication between the ice and the underlying substratum; consequently, the movement of the ice here should be possible with a smaller stress than in the region of Station Centrale. Along the eastern part of the British traverse the bottom temperature was most probably at the melting point at all places, while in the western side as well as farther south the temperature was presumably so low that permafrost layers existed. According to present informations it seems that the ther-

mal conditions in the Ice Cap itself are far from uniform, and a distinct picture of the conditions for the greater part of the ice sheet can only be obtained by further investigations.

The regime and the balance of the Ice Cap

have been studied from many sides. It is evident from many observations that under the present climatic conditions most of the outlet glaciers from the Ice Cap are retreating. Retreat of the glaciers descending to Independence Fjord and to Hagen Fjord has been found by *Fristrup* (1950, 1951); the retreat of the glacier to Inglefield Fjord has been described by *Fristrup* (1959) and of the glacier to Wolstenholme Fjord by *Wright* (1939). A study of the frontal variations of Upernaviks Isstrøm and of the inland-ice margina around Upernaviks Isstrøm has been published by *Weidick* (1958); glacier oscillations in the Umanak district have been studied by *Ransley* (1952), and the retreat of Eqip sermia has been described by *Bauer* (1955 b). A study of the oscillations of Jakobshavns Isbræ has been carried out by *Meldgaard* (1958) in connection with the archaeological investigations, and he found that during the last 2.500 years the front has not advanced farther than the position in 1850—70; since there has been a retreat. A study of the border of the Ice Cap and of the outlet glacier published by *Weidick* (1959) contains much information based on studies of old photos, maps and so on. Observations of a retreat of the glacier descending from the Ice Cap to the sea in the Angmagssalik district have been carried out by *Fristrup* (1959); retreat of glaciers in NE Greenland has been described by *Foster Flint* (1948) and others and of glaciers from Dronning Louise Land by *H. Lister* (1956); retreat of several glaciers in NE Greenland was also found by *Fristrup* (1951) during the Danish Pearyland Expedition.

From the above mentioned publications it appears that the border and the outlet glaciers from the Ice Cap have been retreating for a long time and, further, that the retreat started earlier in South Greenland than in North Greenland. The very small number of observations carried out — such as the lowering of the equilibrium line in Eqip sermia described by *Bauer* (1959) — seem to indicate that the retreat is possibly diminishing, and that the ice is even slightly growing in somes places. The well developed trim-lines along the greater part of the Greenland Ice Cap have undoubtedly been noticed by most geographers who have flown across Greenland.

The retreat of the marginal zone is not a proof of a diminishing of the whole Ice Cap, and at several occasions *Bader* has supported the theory that at present a construction of the central part of the Ice Cap is going on, tending to a greater and greater height, and when the culminating point has been reached the ice will suddenly spread out over the surrounding low land (see *Lliboutry* 1957). His theory is based on the calculation of the movement velocity for the discharge of icebergs and for the ablation according to the accumulation going on to-day, and he came to the conclusion that the known ice-movement seems to be very insignificant in proportion to the great amount of precipitation falling over the central Ice Cap. Contrary to this *Bauer* (1955) made a calculation by estimating the total accumulation to be 446 sq.km. of water, the ablation to 315 sq.km. and the production of icebergs to 215 sq.km.; accordingly, the deficit for the whole Ice Cap will be about 100 sq.km. of water or nearly a fourth of the accumulation. Previously, several calculations have been carried out, showing other results; however, as all the estimates have been based on very few observations, the results remain uncertain, and it has very little scientifical value to make a calculation on purely estimated figures. A rather interesting problem which may have some relation to the balance of the Ice Cap has been described by *Saxov* (1958), who found that after a long period of sinking of the West Greenland coast a rising has taken place since 1940, and even at a very high speed, on an average around 14 mm. per year; the most probable explanation of this is a diminishing of the Ice Cap and, consequently, an uplift of the land in accordance with the isostasy. Changes in precipitation during the last 30 years have been studied by Diamond (1956).

Only a very accurate levelling across the Ice Cap combined with determinations of the ice thickness along the whole profile and a resurveying of all measurements 10—12 years later will give the answer, and the main object of the EGIG Expedition 1959—60 is to established the first measuring of the profile from the Disko Bugt to Cecilia Nunatak.

LITERATURE

Ahlmann, H. W: son (1948): Glaciological Researches on the North Atlantic Coasts. Roy. Geogr. Soc., Res. Ser. 1.

– (1953): Glacier Variations and Climatic Fluctuations. Amer. Geogr. Soc., Bowmann Mem. Lect., Ser. 3.

Arctic Institute Greenland Expedition 1958: Field Report 1958 by David C. Nutt, Per F. Scholander, Lawrence K. Coachmann, Willy Dansgaard. Oslo.

Bader, H. (1955): Excavations and Installations at SIPRE Test Site, Site 2. Greenland. SIPRE Report 20.

Bauer, Albert (1953): Campagne au Groenland de 1948. Triangulation côtière de la région de l'Eqe. Rapports scientifiques des Expéditions Polaires Françaises N. III: 1. Annales de Géophys. 9: 1.

– (1954): Contribution à la Connaissance de l'Indlandsis du Groenland. IIe partie: Synthèse Glaciologique. Paris.

– (1955, a): The Balance of the Greenland Ice Sheet. Journ. of glaciol. 2: 17.

– (1955, b): Le Glacier de l'Eqe. Glaciologie Groenland II. Expéditions Polaires Françaises, Missions Paul-Emile Victor. VI. Paris.

Baussart, M. (1958): Essai de détermination par photogrammetrie de la vitesse superficielle d'un glacier du Groenland. Symposium de Chamonix. Publ. A.I.H.S. 47.

Benson, C. S. (1955, a): Scientific Work of Party Crystal 1954. SIPRE Report 24.

– (1955, b): Operation and Logistic of Ice Cap Party Crystal 1954. SIPRE Report 25.

Benson, C. S. and R. H. Ragle (1956): Measurements by SIPRE in 1955 on the Accumulation Markers of Expéditions Polaires Françaises in Central Greenland. SIPRE Special Report 19.

Bishop, Barry C. (1957): Shear Moraines in the Thule Area, Northwest Greenland. SIPRE Report 17.

Bull, C. (1957): Observations in North Greenland relating to Theories of the Properties of Ice. Journ. of Glaciol. 3: 21.

– (1958): Snow Accumulation in North Greenland. Journ. of Glaciol. 3: 24.

Carlsson, W. S. (1939): Movement of some Greenland Glaciers. Geol. Soc. Amer., Bull. 50.

Coachmann, L. K., E. Hemmingsen, P. F. Scholander, T. Enns and H. de Vries (1958): Gases in Glaciers. Science 127.

Dansgaard, W. (1954): The 0^{18}-abundance in Fresh Water. Geoch. et Cosmoch. Acta 6: 5/6.

– Nogle meteorologiske og glaciologiske problemer belyst ved målinger af de stabile iltisotoper i vand. Fysisk Tidsskrift 1958 nr. 2–3.

Demorest, Max (1943): Ice Sheet. Geol. Soc. Amer., Bull. 54.

Diamond, M. (1956): Precipitation Trends in Greenland during the past 30 Years. SIPRE Res. Report 22.

Diamond, M. and R. W. Gerdel (1956): Radiation Measurements on the Greenland Ice Cap. SIPRE Res. Report 19.

– (1957): Occurrence of Blowing Snow on the Greenland Ice Cap. SIPRE Res. Report 25.

Epstein, S. (1956): Variation of the O^{18}/O^{16} Ratio of Fresh Water and Ice. Nat. Acad. Sci. Nat. Res. Council. Publ. 400: IV.

Etienne, Erich (1940): Expeditionsbericht der Grönland-Expedition der Universität Oxford 1938. Veröff. des Geophys. Inst. der Univ. Leipzig. Zweite Ser. XIII. Leipzig.

E.G.I.G. (1959): Missiones Aériennes de Reconnaissance au Groenland 1957–58. Rapport interne.

Expéditions Polaires Françaises:

Publications Préliminaires:

(1949) No. 5: Campagne préparatoire au Groenland 1948.
(1949) » 7: Campagne préparatoire au Groenland 1948. Météorologie, Transmission radio.
(1950) » 10: Campagne au Groenland 1949.
(1952) » 15: Campagne au Groenland 1950.
(1953) » 16: Campagne au Groenland 1951.
(1956) » 17: Hivernage au Groenland 1949–50.
(1953) » 19: Ravitaillement aérien des expéditions françaises au Groenland 1949–50–51.
(1953) » 22: Hivernage au Groenland 1950–51.
(1956) » 23: Rapport d'activités.
(1954) » 24: Campagne au Groenland 1952–53.

(1954): Les observations météorologiques de la station française du Groenland. Conditions atmosphériques en surface de 5 septembre 1949 au 20 juin 1950, par M. Bouché. Fasc. I–II.

(1954): Les observations météorologiques de la station française du Groenland. Conditions atmosphériques en altitude du 17 septembre 1949 au 10 août 1951, par B. Bedel.

(1956): Les observations météorologiques de la station française du Groenland. Conditions atmosphériques en surface du 21 juin 1950 au 15 août 1951. Fasc. I, par B. Bedel.

Finsterwalder, R. (1958): Measurement of Ice Velocity by Air Photogrammetry. Symposium de Chamonix. Publ. A.I.H.S. 47.

Flint, Richard Foster (1948): Glaciological Geology and Geomorphology. The Coast of Northeast Greenland. Amer. Geogr. Soc., Special Publ. 30.

Fristrup, Børge (1948/49): Peary Land. Geogr. Tidsskr. 49.

– : Climate and glaciology of Peary Land. U. G. G. I. A. J. H. S. Assemblée genérale de Bruxelles 1951.

– (1952, a): Danish Expedition to Peary Land 1947–50. Geogr. Rev. XLII.

– (1952, b): Die Klimaänderungen in der Arktis und ihre Bedeutung besonders für Grönland. Erdkunde VI.

– (1959): Gletscherundersøgelser i Grønland under det Geofysiske År. »Grønland«.

Frost, Robert E. (1957): A Reconnaissance for a Southern Greenland Ice Cap Access. SIPRE Techn. Report 46.

Georgi, Johannes (1953/54): Bemerkungen zum Klima von Eismitte. Ann. der Meteorol., 6. Jahrg.

Gerdel, R. W. and M. Diamond (1956): White out in Greenland. SIPRE Res. Report 21.

Glen, J. W. (1958): The Flow Law of Ice. Symposium de Chamonix. Publ. A.I.H.S. 47.

Goldthwait, R. P. (1956): Study of Ice Cliff in Nunatarssuaq, Greenland. Ohio State Univ. Res. Found. Report 11, and as SIPRE Report 39.

– (1957): Study of Ice Cliff in Nunatarssuaq, Greenland. Ohio State Univ. Res. Found. Report 17.

Griffith, Thomas M. (1954–56): Glaciological Report, Tuto Area. Univ. of Denver.

Haefeli, R. and F. Brentani (1956): Observations in a Cold Ice Cap. Journ. of Glaciol. 2: 18, 19.

Haefeli, R. (1955/56): Gletscherschwankung und Gletscherbewegung. Schweiz. Bauzeitung 73/74.

– (1957): Le project de la participation de la Suisse à l'Expédition Glaciologique Internationale au Groenland. La Suisse Horlogère 20.

Hamilton, R. A. (1958): The British North Greenland Expedition 1952–54. Scientific Results. Nature 181.

Hamilton, R. A. and G. Rollitt (1957, a): Meteorological Observations at »Northice«, Greenland. Medd. o. Gr. 158, 3.

– (1957, b): Climatological Tables for the Site of the Expedition's Base at Britannia Sø and the Station on the Inland-Ice »Northice«. Medd. o. Gr. 158, 2.

Hansen, B. L. and J. K. Landauer (1958): Some Results of Ice Cap Drill Hole Measurements. Symposium de Chamonix. Publ. A.I.H.S. 47.

Heuberger, Jean-Charles (1954): Forages sur l'Inlandsis. Glaciologie Groenland I. Expéditions Polaires Françaises, Missions Paul-Emile Victor V. Paris.

Hobbs, William Herbert (1941): Reports of the Greenland Expeditions of the University of Michigan I–II. Univ. of Michigan Studies V and VI.

Hofmann, Walther (1958, a): Lagemessung bei der Internationalen Glaziologischen Grönland-Expedition (EGIG). Zeitschr. f. Vermessungswesen 83: 7–8.

– (1958, b): Bestimmung von Gletschergeschwindigkeit aus Luftbildern. Bildmessung und Luftbildwesen 1958: 3.

Holland, M. F. W. (1958): An Expedition to West Greenland 1956. Geogr. Journ. CXXIV.

Holmes, G. William (1955): Morphology and Hydrology of the Mint Julep Area. Southwest Greenland. Mint Julep Reports II.

Holtzscherer, Jean-Jacques (1954): Contribution à la Connaissance de l'Inlandsis du Groenland. Ière partie: Mesures Séismiques. Paris.

Hutchinson, Howard B. (1953): Preliminary Report on the Scientific Program of Operation Icecap 1953.

Kayser, Olaf (1928): The Inland Ice. Greenland I, ed. by M. Vahl, G. C. Amdrup, L. Bobé and Ad. S. Jensen.

Koch, J. P. und A. Wegener (1930): Wissenschaftliche Ergebnisse der dänischen Expedition nach Dronning Louises Land und quer über das Inlandseis von Nordgrönland 1912–13. Medd. o. Gr. 75.

Koch, Lauge (1950): Report on the Expeditions to Central East Greenland 1926–39. Conducted by Lauge Koch. Medd. o. Gr. 143, 1.

La Chapelle, Edward (1955): Ablation Studies in the Mint Julep Area. Mint Julep Report II. A.T.D.I.C.

Langway, Chester C. (1958, a): A 400 Meter deep Ice Core in Greenland. Journ. of Glaciol. 3: 23.

– (1958, b): Bubble Pressure in Greenland Glacier Ice. Symposium de Chamonix. Publ. A.I.H.S. 47.

Landauer, J. K. (1957): On the Deformation of Excavations in the Greenland Névé. SIPRE Res. Report 30.

Larsen, Helge and J. Meldgaard (1958): Paleo-Eskimo Cultures in Disko Bugt, West Greenland. Medd. o. Gr. 161, 2.

Lichte, H. (1957): Geodätische Messungen auf dem grönländischen Inlandeis. Zeitschr. f. Vermessungswesen, Jahrg. 82.

Lindsay, Martin (1935): The British Trans-Greenland Expedition 1934. Geogr. Journ. LXXXV.

Lister, H. (1956): Glacier Regime in North-East Greenland. Geogr. Journ. CXXII.

Lliboutry, L. (1957): Nos connaissances actuelles sur l'Inlandsis groenlandais. Soc. Hydrotechn. de France. Section Glaciologie. Réunion du 12 Fév. 1957.

Ljungner, Erik (1949): East-West Balance of the Quaternary Ice Caps in Patagonia and Scandinavia. Bull. of the Geol. Inst. of Uppsala XXXIII.

Loewe, F. (1936): Höhenverhältnisse und Massenhaushalt des grönländischen Inlandeis. Gerlands Beitrage zur Geophysik 48: 1.

Matthes, F. E. (1946–50): The Glacial Anticyclone Theory Examined in the Light of Recent Meteorological Data from Greenland I–II. Trans. Amer. Geophys. Union 27: III & 31: II.

Meir, M. F. (1957): Preliminary Study of Crevasse Formation. SIPRE Report 38.

Meldgaard, J. See Helge Larsen & J. Meldgaard.

Milthers, Keld (1953, a): Indlandsisens Oprindelse. »Grønland«.

– (1953, b): Indlandsisens Produktion. »Grønland«.

Mirrild, W. M. (1957): Foliation, Bubble Trends and Dirt Zones and their Relation to Glacier Flow in Part of North Ice Cap, Northwest Greenland. Geol. Soc. Amer., Bull. 68: 12.

Mirrles, S. T. A. (1932): The Weather on a Greenland Air Route. Geogr. Journ. LXXX.

Nakaya, Ukichiro (1958): Visco-elastic Properties of Snow and Ice in Greenland Ice Cap. Symposium de Chamonix. Publ. A.I.H.S. 47.

Neviere, J. (1954): Campagne au Groenland 1948–1949–1950. Nivellement géodésique de l'Inlandsis. Rapports scientifiques des Expéditions Polaires Françaises N. III: 1. Annales de Géophys. 10: 1.

Nobles, Laurence H. (1954): Characteristics of High-polar Type Glaciers in Northwestern Greenland. Geol. Soc. Amer., Bull. 65: 12.

Nutt, David: See Arctic Institute Greenland Expedition 1958.

Paterson, W. S. B. (1958): The Position of Markers on the Greenland Ice Sheet. Journ. of Glaciol. 3: 24.

Project Mint Julep Reports: I. Introduction and General Reports. (1955): A.T.D.I.C. Research Studies Institute Air University, Maxwell Air Force Base, Alabama.
(1955): II. Special Scientific Reports.
(1954): III. Snow Studies SIPRE.
(1954): IV. Report of Arctic Construction and Frost Effects Lab.

Ransley, T. J. (1952): Glacier Studies in the Umanak District, West Greenland, 1950. Medd. o. Gr. 136, 2.

Rausch, Donald O. (1958): Ice Tunnel Tuto Area, Greenland 1956. SIPRE Techn. Report 44.

Rigsby, George P. (1955): Study of Ice Fabrics, Thule Area. Greenland. SIPRE Report 26.

Robin, G. de Q. (1955): Ice Movement and Temperature Distribution in Glaciers and Ice Sheets. Journ. of Glaciol. 2: 18.

Saxov, Svend (1958): Bevægelsen af Vestgrønland. »Grønland«.

Scholander, P. F., J. W. Kanwisher, and D. C. Nutt (1956): Gas in Icebergs. Science 123.

Schuster, Robert L. (1954): Snow Studies. Project Mint Julep. SIPRE Report 19.

Schytt, Valter (1955): Glaciological Investigations in the Thule Ramp Area. SIPRE Report 28.

– (1958): Glaciology II. Snow Studies at Maudheim. The inner Structure of the Ice Shelf at Maudheim. Norwegian-British-Swedish Antarctic Expedition 1949–52. Scientific Results IV, Oslo.

Sharp, Robert P. (1956): Glaciers in the Arctic. Arctic 9.

– *and S. Epstein* (1958): Oxygen-Isotope Ratios and Glacier Movement. Symposium de Chamonix. Publ. A.I.H.S. 47.

Simpson, C. J. W. (1955): The British North Greenland Expedition. Geogr. Journ. CXXI.

– (1957): North Ice, the Story of the British North Greenland Expedition. London.

Sorge, Ernst (1933): The Scientifical Results of the Wegener Expedition to Greenland. Geogr. Journ. LXXXI.

– (1935): Glaziologische Untersuchungen in Eismitte. Wissenschaftliche Ergebnisse der Deutschen Grönlandsexpedition Alfred Wegener 1929 und 1930/31, 3.

Tschaen, L. (1959): Groenland 1948–1949–1950. Astronomie-Nivellement Géodésique sur l'Inlandsis. Noveau Calcul. Expéditions Polaires Françaises, publ. 207.

– *et A. Bauer* (1958): Le Mouvement de la partie Centrale de l'Inlandsis du Groenland. Symposium de Chamonix. Publ. A.I.H.S. 47.

Victor, Paul-Emile (1955): Geography of Northeast Greenland. SIPRE Special Report 15.

– (1956): Wringing Secrets from Greenland's Icecap. Nat. Geogr. Mag.

Wager, L. R. (1933): The Form and Age of the Greenland Ice Cap. Geol. Mag. 20.

Wallerstein, G. (1958): Movement Observations on the Greenland Ice Sheet. Journ. of Glaciol. 3: 23.

Waterhouse, R. (1955): Structures for Snow Investigations on the Greenland Ice Cap. SIPRE Report 27.

Watkins, H. G. (1932): The British Arctic Air Route Expedition 1930–31. Geogr. Journ. LXXIV & LXXX.

Wegener, K. und andere (1933–40): Wissenschaftliche Ergebnisse der Deutschen Grönland Expedition Alfred Wegener 1929 und 1930–31. I–VII. Leipzig.

Weidick, Anker (1958): Frontal Variations at Upernavik Isstrøm in the last 100 Years. Medd. Dansk Geol. Foren. 14: 1.

– (1959): Glacial Variations in West Greenland in Historical Time. Medd. o. Gr. 158, 4.

White, S. E. (1956): Glaciological Studies of two Outlet Glaciers, Northwest Greenland 1953. Medd. o. Gr. 137, 8.

– (1958): Preliminary Studies of Motion of an Ice Cliff, Nunatarssuaq, Northwest Greenland 1955. Symposium de Chamonix. Publ. A.I.H.S. 47.

Wilson, L. R. (1955): Minor Surface Features of the Southwest Greenland Ice Cap. Mint Julep Reports. A.T.D.I.C.

Wrigth, J. W. (1939): Contribution to the Glaciology of North West Greenland. Medd. o. Gr. 125, 3.