jects are scheduled for a more distant date, after strings of hydro stations have been completed along the middle reaches of the Yenesey and on the Angara.

The natural resources of the enormous tracts of land from Norilsk to the Angara have not yet been surveyed thoroughly, but in this region are located the Tunguski and other coal fields, the largest in the U.S.S.R. Their reserves exceed the coal resources of the Kuznetsk coal deposits in West Siberia and those of the Donets coal basin in the European part of the U.S.S.R. However, this wealth will have to wait for exploitation, because Siberia still has large quantities of cheaper coal in more accessible places.

Rich deposits of iron ore have been found in the lower reaches of the Nizhnyaya Tunguska, but they will not be tapped in the foreseeable future for the same reason. Before the more valuable and easily accessible forests in the Angara region and along the middle reaches of the Yenesey have been opened up the commercial exploitation of timber to the north of the river Podkamennaya Tunguska would not appear to be economically feasible.

Thus, except for minor scattered centres of industry, the establishment of which will be encouraged on the Kureika and Nizhnyaya Tunguska rivers for the mining of graphite and other valuable minerals, industrial development will be limited to the area between the Angara and the Podkamennaya Tunguska, 1,500 to 2,000 km. (1,000 to 1,250 mi.) from Norilsk and Igarka.

Water-power stations, as well as thermal stations, which will burn coal mined by the open cast method, are being built in the Angara-Yenesey area. The amount of electric power, the cheapest in the U.S.S.R., to be generated here, will equal in time the present total power output in the Soviet Union. The Irkutsk, Bratsk, and Krasnoyarsk hydro-power plants are to be the first in this construction effort. Three of the industrial centres, which will be created on this basis, belong to the northern zone. They include the Bratsk area, the Ust-Ilim area on the Angara, and the Osinovsky area on the Yenesey. The Bratsk water-power station has already gone into operation. It will reach its projected output of 4 million kw. within the next few years, and will generate eventually 20,000 million kw.-hrs. of electricity per year. An industrial centre, with plants for the production of aluminium, and various other power-consuming enterprises, is being built there. Preparations have been started for the erection of the Ust-Ilim station, which will be even larger than the Bratsk plant. The Bratsk timber combine will supply the project with building materials. There are rich forests on the right bank of the Angara and between the Angara and the Podkamennaya Tunguska. Several large timber combines are being established there and a railway line will be extended towards this area shortly.

Creation of the world's largest centre for the production of cheap electricity and the building of an aggregate of power-consuming industries in the Angara-Yenesey region will provide a springboard for further advance to the north. Widely used in the process will be the timber resources and useful minerals of the vast area from the Podkamennaya Tunguska to the lower reaches of the Yenesey.

Since the natural resources of North Siberia are not yet fully known, it is not possible to predict the future development of these lands in greater detail. However, the ground is being broken in the Ob and Yenesey basins for large-scale industrial construction and the building of an extensive transportation system, which will get under way within the next decade or so.

SAMUIL V. SLAVIN

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STRATIFIED WATER OF A GLACIAL LAKE IN NORTHERN ELLESMERE ISLAND

Antoinette Bay constitutes the central arm of Greely Fiord and extends

40 km. east-northeastward from its junction with Tanquary Fiord in about 80°50′N. 79°W. A large tidewater glacier, flowing northwestward from the Mer de Glace Agassiz to the southeast, has blocked off the head of the bay (or, more properly, fiord) and separates it from the long narrow lake that is the natural extension of the fiord to the east (Fig. 1).

the glacier is bounded by an ice-cored moraine, indicating recent recession of up to about 100 m. On its western or fiord side the glacier calves from an active ice cliff, which appears to be in part floating and in part grounded below sea-level. The glacier has been damming the lake at least since 1883, when J. B. Lockwood of the Lady Franklin Bay Expedition (under A. W.

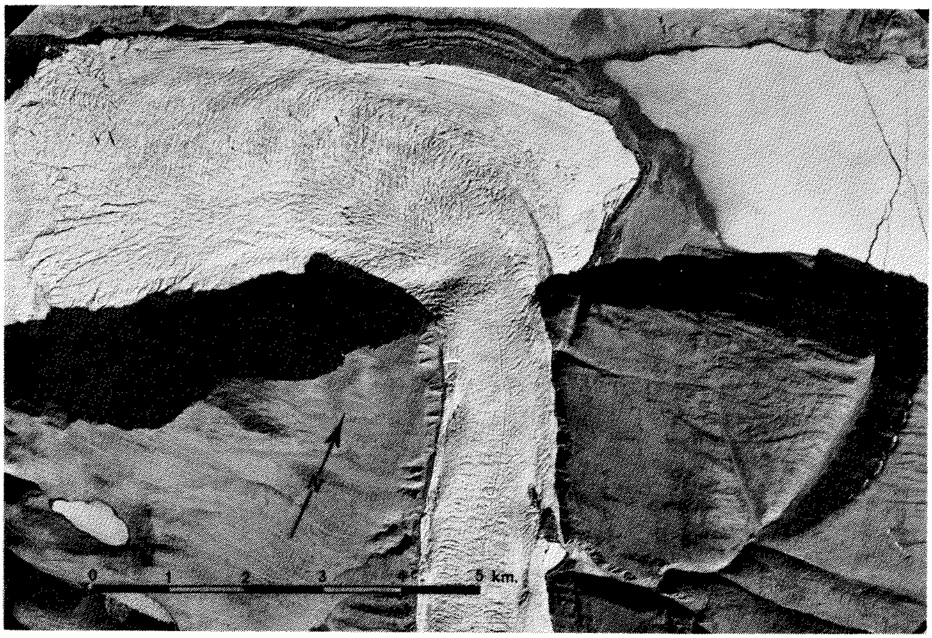

Photo: R.C.A.F., July 27, 1959.

Fig. 1. Western end of glacial lake (right) at the head of Antoinette Bay (left).

We visited Antoinette Bay and the lake on June 2 and 3, 1963 during the course of an oceanographic traverse over the sea-ice from the field station of the Defence Research Board at the head of Tanquary Fiord. Antoinette Bay is a typical steep-sided fiord; a single sounding, taken 10 km. from its mouth, showed no bottom at 240 m. The lake, which is unnamed, was visited on the chance of finding interesting structural and temperature conditions in the lake water. An easy passage was found along the northern margin of the glacier by following the frozen and snow-drifted bed of the river that drains the lake. On its northern and eastern sides

Greely) discovered it[1], and in all probability for a very much longer period.

The lake is 20 km. long and in its western two-thirds averages 3 km. in width, it narrows to about 1 km. in the eastern one-third. An active glacier at the eastern end calves occasional small icebergs into the lake. Readings from a pocket aneroid indicated that the level of the water in the lake was 10 to 12 m. above sea-level. This altitude precludes any possible connection with fiord water under the glacier at the present time; indeed the glacier (except near the seaward edge) shows every appearance of being grounded below sea-level. The level of the lake is not an indication of land uplift, for it is strictly controlled by the glacier dam, which permits only a limited drainage down the marginal river. At the eastern end of the lake ice-rafted boulders and a low wave-cut silt bank indicate a seasonal rise in lake level of about 1 m., caused by summer run-off. There are also signs of a former level 20 to 25 m. higher than the present. The snow cover during our visit consisted of hard drifts from 25 to 75 cm. deep, with wide areas of glare ice, particularly near the western end where there was only 50 per cent snow cover.

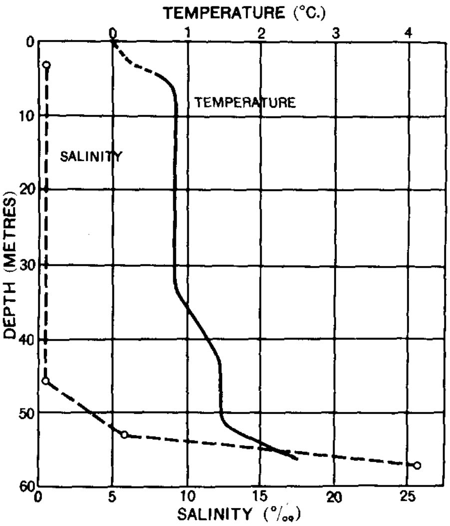

Fig. 2. Temperature and salinity of the glacial lake.

About 3 km. from the western end of the lake an 8-inch (20-cm.) diameter hole was drilled through 2.7 m. of ice and a sounding gave a depth of 60 m. A 78-m. bathythermograph was lowered to a depth of 59 m. and recorded a temperature-depth curve shown in Fig. 2, with depths given below the ice surface. Below a depth of 6 m. the water was isothermal at approximately 0.8°C. down to 33 m. At 44 m. the temperature had risen to approximately 1.4°C. and remained steady to a depth of 50 m. below which point there was a steep rise in temperature to 2.5°C. at 56 m. Unfortunately, reversing thermometers were not carried to the lake and no absolute check on the bathythermograph record is available, but the temperatures are probably accurate to ±0.1°C. Water samples were collected in a "Knudsen" bottle at depths of 3, 45.5, 53, and 57 m. The salinities at these depths, from analyses at the Bedford Institute of Oceanography under the supervision of Dr. A. E. Collin, were respectively 0.46, 0.46, 5.75, and 25.594 ‰ (the last the mean of four samples), Fig. 2. The sharp rise in salinity appears to correspond to the sharp rise in temperature near the bottom.

It seems probable that the saline water near the bottom of the lake was originally sea-water trapped by the advance of the glacier across the fiord, but considerations of density and temperature relationships indicate that quite complex processes may have determined the subsequent history of the waters of the lake. The upper isothermal layer of 27 m. strongly suggests an overturning of the water, probably in the summer of 1962, which was unusually warm. Because this layer had a temperature of only 0.8°C., there can only be limited surface heating after the ice cover melts, for, if there were substantial heating, a temperature of near 4°C. could be expected in this layer of virtually fresh water. It is possible that the lower isothermal layer, from 44 to 50 m., represents a remnant of an overturn in a previous summer. These deductions are necessarily speculative, but they point to the need for detailed investigations of temperature, salinity, and also oxygen content of the water. Carbon-14 dating of the bicarbonate in the highly saline bottom water might provide information on the date of advance of the glacier across the fiord. It is notable that this highly saline layer lies about 45 m. below sea-level, for which there is no ready explanation.

We are most indebted to Dr. W. L. Ford of the Defence Research Board for advice on the interpretation of the temperature and salinity profiles. We also acknowledge with thanks the as-

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G. HATTERSLEY-SMITH*
H. SERSON*

[1]Report of the Proceedings of the United States Expedition to Lady Franklin Bay, Grinnell Land. Washington, 1888, Vol. 1, pp. 274-9.

*Defence Research Board, Ottawa.

ICE TRANSPORT IN THE EAST GREENLAND CURRENT AND ITS CAUSES*

Introduction

When water freezes, about 80 cal./gm. are liberated and the same amount is taken up when the ice melts. As long as these processes happen at the same place, heat gains and losses cancel in the course of a year and can therefore be disregarded. However, if freezing takes place in one area and melting of the ice in another, then the area of freezing will represent a heat source and the melting area a heat sink.

Large quantities of ice are exported from the Arctic Ocean, mostly between Greenland and Spitsbergen. An energy budget for the Arctic Ocean cannot disregard this energy source, as has been shown by Mosby[1], and Vowinckel and Orvig[2]. In the area of melting, the Greenland Sea and directly south of it, a corresponding amount must be found on the negative side of the energy balance.

The available estimates of the ice export all go back, directly or indirectly, to Russian investigations. The best value seems to be the one by Gordienko and Karelin[3] of 1,036,000 km.^{2} as an annual average for the period 1933-1944. No details are given about the method by which this value was obtained, and such information is not available to the present author. However, as the period used by Gordienko and Karelin lies before and during World War II, the data available for this estimate cannot have been especially plentiful. It therefore seems appropriate to re-examine the ice export and, if possible, to obtain some estimates about its variations.

Ice transport in the ocean is effected in two ways:

(a) Ice is carried along by the ocean current on which it floats, the transport being directly proportional to the current speed.

(b) Ice is moved, independently of the current, by the wind.

The relation between wind and ice drift was evaluated by Zubov and Somov[4]. Their results were confirmed by Zubov[5], Gordienko[6], and Crary[7]. The ice movement was found to be parallel to the surface isobars, the speed given by the empirical formula:

$$V = 13{,}000\ p$$

where V: ice movement (km./month)
and p: pressure gradient (mb./km.)

Daily synoptic weather maps for the area under consideration covering a long period are available from different sources. There is, therefore, no difficulty in determining the wind component of the ice export by this formula.

For the East Greenland Current, however, estimates of flow are not satisfactory. Oceanographic soundings are only few in number for the summer and there are none for the winter. Therefore, indirect methods have to be used to obtain the ice export by currents.

The only sets of observations for such an indirect approach are the ice charts published each year (for the months April to August) by the Danish Meteorological Service[8] and the monthly mean ice charts by the U.S. Hydrographic Office[9] and the German Seewetteramt[10]. The Danish charts are based on all ice information available for a particular month. The amount of information varies greatly, with the result that the reliability of the charts is quite different from year to year. However, the analysis is carried out by assuming that the ice limit is near its

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