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A GLACIOLOGICAL RECONNAISSANCE OF THE COLUMBIA GLACIER, ALASKA

Introduction

The Columbia Glacier is in the Chugach Mountains between Valdez and Anchorage, Alaska. The terminus of the glacier has a 4-mile front on Prince William Sound, and its giant ice cliffs are a famous tourist attraction. However, most of the glacier lies in one of the least explored areas in Alaska and no scientific study of the area except near the terminus had been made before 1955.

The Columbia Glacier has four large branches; the largest has a length of 41 miles. It has an area of approximately 440 square miles and it covers a range of altitudes from sea-level to 12,000 feet. The Columbia Glacier is very active and its terminus has remained in the same position for over half a century in spite of the great erosive action of the sea on the terminal ice cliffs.

The Chugach Mountains west of Valdez comprise an area of about 6000 square miles. The numerous expeditions that have visited the terminal areas of many of the glaciers of this area include the Harriman Expedition of 1898[1] and the American Geographical Society's expeditions of 1931[2] and 1935[3]. Two expeditions made attempts to penetrate to the interior of this region before 1955. The first of these was the unsuccessful expedition of Dora Keen[4] to the Harvard Glacier. The second was that of Bradford Washburn[5] to the Matanuska Glacier and Mt. Marcus Baker. Very bad weather curtailed the scientific work of this party. In 1955 the Arctic Institute of North America sponsored the Chugach Mountains Expedition, the first to explore the region of the upper Columbia Glacier. In 1957 a second expedition visited the region and made additional observations. Since no adequate map has been published of the Columbia Glacier, a sketch map is given here as Fig. 1. Most of the altitudes shown are based on corrected altimeter and level readings of the 1955 and 1957 expeditions.

The highest peaks of the Chugach Mountains surrounding the Columbia Glacier reach altitudes in excess of 12,000 feet. During the summer numerous exposures of rocks can be found on the lower peaks, but above 7000 feet exposures are generally accessible only on nearly vertical cliffs or on steep slopes swept clean by avalanches. Dark shales were found at 11,000 feet or higher on the south ridge of Mt. Elusive, on the west ridge of Mt. Witherspoon, and on the south ridge of Mt. Valhalla. Dark siltstones and argillites were found at 9000 feet on Mt. Sharkfin 3 miles northeast of Mt. Einstein. At 8500 feet on the east ridge of Mt. Powder Top (9.5 miles east of Mt. Witherspoon) black sandy shale and fine siltstone are exposed. At 5500 feet on Pandora Peak shales, fine siltstones, greywacke, phyllite, black argillite, and slates are exposed. Rocks found at still lower levels on a supra-glacial moraine on the east branch of the Columbia Glacier (2.5 miles southeast of Pandora Peak) were more highly metamorphosed than the folded sedimentary rocks at higher altitudes to the west. The only samples of igneous rock were porphyritic dacite found at 8500 feet on Mt. Powder Top

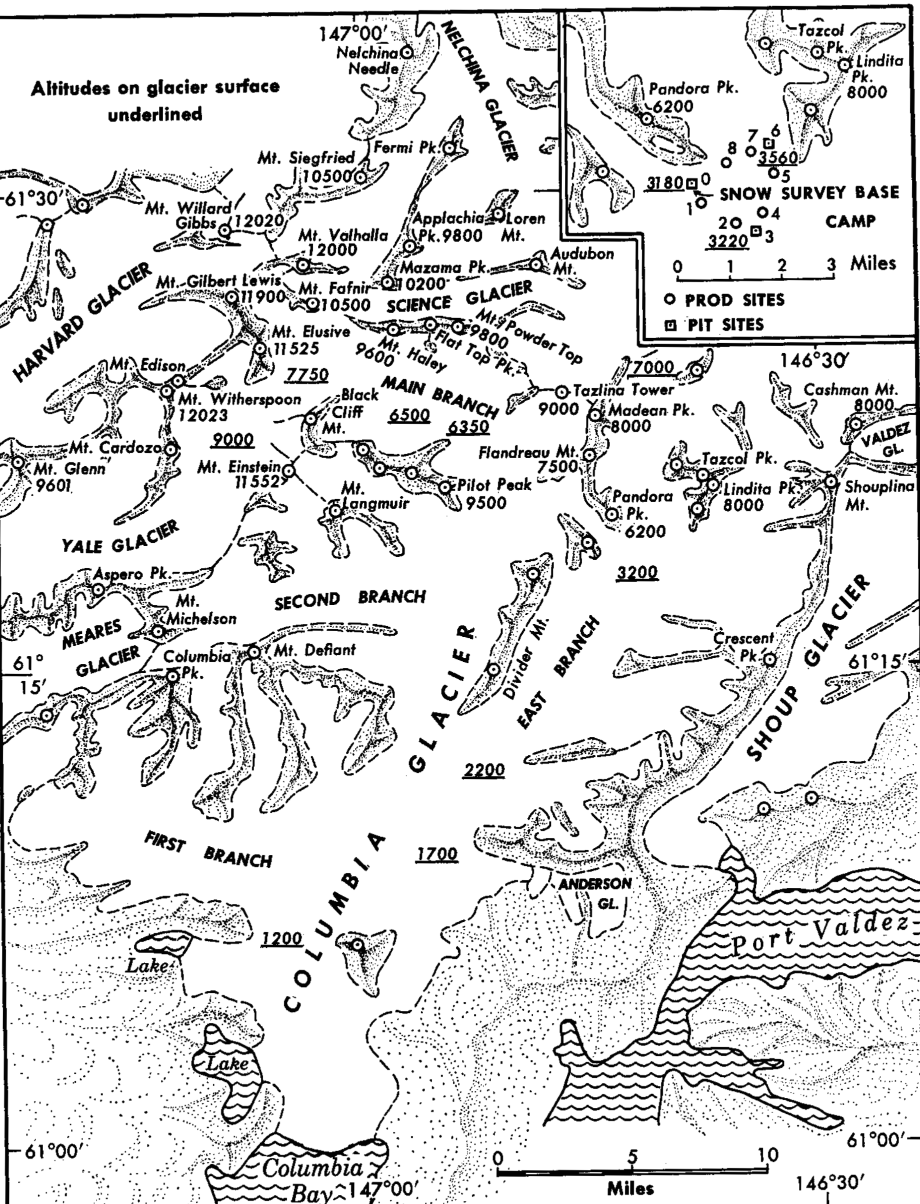

Fig. 1. Sketch map of Columbia Glacier.

and at 3200 feet on the glacier moraine of the east branch[6].

Most of the accumulation area of the Columbia Glacier is above 4500 feet, probably over 50 per cent of it is above 6000 feet, and some accumulation takes place up to at least 12,000 feet. It was the purpose of the 1955 expedition to explore the Columbia Glacier and to make various scientific investigations including meteorological observations and snow accumulation studies, especially at greater altitudes. In 1955 observations were concentrated at 3180 feet on the east branch, at 6340 feet and at 9300 feet on the main branch. In 1957 additional studies were made on the main branch at 6500 feet, 7700 feet, at 8600 feet a mile northeast of the summit between the Columbia and Yale glaciers, and at 9300 to 9500 feet on the east slopes of Mt. Witherspoon and Mt. Edison.

feet[7] and where the highest snow line for the 1954 ablation season was at about 2800 feet[8]. Meteorological observations show that the snow accumulation along the coastal regions of Alaska was also greater than normal during the winter of 1954-5. In spite of this the depth of snow on most of the Columbia Glacier was much less than expected.

Table 1. Snow depth on east branch of Columbia Glacier.

Locality	*Altitude feet*	*Snow depth cm.*	*Date*	*Remarks*
0* (pit 1)	3180	251†	June 17, 1955	pit and prod site
0	3180	208	June 30, 1955	pit and prod site
1	3185	168	June 30, 1955	prod site
2	3195	264	June 30, 1955	prod site
3 (pit 2)	3220	335	June 30, 1955	pit and prod site
4	3290	396	June 30, 1955	prod site
5	3355	389	June 30, 1955	prod site
6 (pit 3)	3560	264	June 30, 1955	pit and prod site; wind blown
7	3490	343	June 30, 1955	prod site
8	3380	211	June 30, 1955	prod site

* base camp
† density of snow approximately 0.5

Snow accumulation studies

On June 10, 1955 the snow line on the Columbia Glacier was just back of the terminus, probably at an altitude of about 400 feet. By June 15 it was still near the terminus, whereas on the nearby retreating Valdez Glacier the snow line was approximately 1200 feet above sea-level. By July 1 the snow line on the Columbia Glacier had retreated about 6 miles to a prominent nunatak at an altitude of nearly 1200 feet.

After 10 years of research on the Juneau Ice Field[7] it had been expected that the average firn line (snow line on the glacier at the end of a normal summer) would be at 3400 feet or less. However, our snow survey studies show that the snow line on the east branch of the Columbia Glacier for the summer of 1954 was above 3600 feet even though the winter of 1953-4 had been one of abnormally large snowfall. These results can be compared with data from a climatically similar area, the Taku Glacier on the Juneau Ice Field, where the average firn line is at about 3400

An area of the east branch of the Columbia Glacier near our base camp at 3180 feet was used to study how the snow depth varied at the end of June with altitude and with location on the glacier. This area is shown as an insert in Fig. 1. Three snow pits were dug down to solid ice. In addition, the depth of the snow was determined at nine sites by the use of a prod rod made from ⅜-inch pipe, 20 feet long. The sites are shown in Fig. 1 and the results of the measurements are given in Table 1. Maximum snow depths were found in the centre of the glacier (pit 2) and much less snow was found near the edge of the glacier (pit 1). Although pit 3 was the highest, the snow depth there was considerably less than at several of the lower test points. The area around pit 3 is exposed to the north and probably much of the snow falling there is blown to less exposed sites farther south. Thus, in the small area studied the snow depth depends more on topographical features and on wind conditions than on moderate changes in altitude. All the snow down to solid dirty ice was the accumulation of only one winter. Although several prominent ice bands were found in the pits, there was no evidence that they marked the boundary between the snowfall of two different years. The snow density was estimated to be 0.5 ± 0.1 g./cm.^{3}.

to measure the depth of annual snow accumulation, so it is fortunate to find such a distinct marker as the ash layer. Another volcanic eruption of Mt. Trident and Mt. Martin in August 1960 should give an additional ash band on the glaciers of this area.

Fig. 2. Ash layer in the face of a small ice cliff at the base of Mt. Elusive at 7750 ft.

No pit studies were made in the high area of the main branch of the Columbia Glacier. However, a very convenient marker for snow depths was found in the form of a prominent dark band in crevasses, on ice cliffs, and on seracs. This dirt layer undoubtedly came from the dust of the violent volcanic eruption of Mt. Spurr on July 9 and 10, 1953[9]. This ash band can be of great help to workers on many glaciers in this part of Alaska during the next few years. At great altitudes it is generally difficult

The ash layer was observed at many places on the Columbia Glacier. It showed up best on ice cliffs and on vertical faces of seracs in icefalls. It was also seen at times in crevasses. Fig. 2 shows the ash layer in the face of a small ice cliff at the base of Mt. Elusive at an altitude of 7750 feet. In this area the position of the band varied from 12 to 25 feet below the surface in 1955. This does not indicate as great an accumulation for two years at this altitude as compared with that observed on the

Juneau Ice Field[7,10]. Possibly part of the snow at this locality was blown away to lower levels. However, on the walls of a crevasse below the icefall the depth of snow was even less. At most other localities the snow depth was also less than expected. However, on a giant ice cliff on Black Cliff Mountain (north of Mt. Einstein) at an altitude of over 10,000 feet the ash band appeared to be at least 50 feet (15 m.) below the surface of the snow. No actual measurements were taken, so the above figure may be quite inaccurate.

In 1957 the ash layer was again observed at many points. At 10,800 feet on the south face of Mt. Elusive it was exposed on an ice cliff. Its greatest depth was measured as 35 feet (10.7 m.). At other points on the cliff the depth was only 25 feet (7.7 m.) or less. At 10,000 feet on the east side of Mt. Witherspoon the ash layer was found about 40 feet (12.2 m.) down in a crevasse. In the centre of the main branch of the Columbia Glacier at 6500 feet altitude are some giant crevasses. From a low-flying plane it was estimated that the layer was certainly less than 50 feet below the surface, probably closer to 25 feet. It is difficult to say if these exposures give representative depths of accumulation for the period between 1953 and 57. However, if they do, the depths are much less than expected for a glacier as active as the Columbia when compared with measurements on the Taku Glacier and with the snowfall at sea-level near Juneau and Valdez.

During June 1955 there was a considerable accumulation of snow at altitudes over 4500 feet. For instance, at 6340 feet a blizzard from June 20 to 22 deposited about 4 feet of snow. This gave about 2 feet of snow with a density greater than 0.3 after settling in the bright sun for a day. At 9300 feet only about 8 inches of powdery snow appeared to have fallen during this storm.

Another storm occurred from June 24 to 29. There was continuous fog, and up to 2 feet of snow fell at 9300 feet. Measurements made on June 27 near 8000 feet showed that between 9 and 10 inches of snow (density about 0.20 to 0.25) had accumulated between June 24 and 27.

Measurements at the end of June at ablation stakes between 5200 and 6300 feet showed that the two storms mentioned gave a net accumulation of 18 inches or more of settled snow with a density of at least 0.35.

Residents of Valdez, including the local weather observer, said that June 1955 was stormier than usual. In contrast June 1957 was unusually free from long or violent storms. Between June 13 and 30, 1957, 2 feet of wet snow fell during the course of five storms. During the first 2 weeks of July at least 3 feet of wet snow fell. These values apply to altitudes between 7500 and 9000 feet. However, warm periods between storms must have reduced net accumulation during this time to near zero or actually caused a loss. It seems probable that during a normal year the upper Columbia Glacier receives much of its snow during the summer months. Possibly during the winter most of the precipitation falls as snow at levels below 5000 feet, whereas the higher altitudes receive little snow. A detailed study of the amount and kind of precipitation as a function of altitude and time of year is needed on a glacier such as the Columbia with its great variation in altitude.

At the 1955 base camp at 3180 feet there was continuous loss of snow during the observation period in June and July, no snowfall was recorded. The ablation results are given in Fig. 3. On account of the cool and cloudy weather from June 17 to 30 it can be assumed that the ablation during this period was rather less than normal.

On calm, cloudy days there was not much ablation, on sunny days there was a moderate amount of ablation and on warm, windy days the ablation was great. For instance, on July 1 (a sunny day with a 35-mile wind and a temperature of 49° F.) there was 1 inch of ablation in 2 hours, whereas during the night of June 16 (clear sky, calm 24° F.) there was only about 0.12 inch of ablation during 8 hours. These figures illustrate the importance of warm winds in causing ablation. Solar radiation by itself seems to be less important than wind. For instance, on June 30 (warm, partly sunny, very little wind) there was only 1.37 in. of ablation in 13 hours. These figures agree with the much more extensive results obtained by workers on the Juneau Ice Field[10].

of a number of years, it is possible to detect changes that occur in the regimen of the various branches. Fortunately, enough information is available to show some interesting changes in the Columbia Glacier during the past 40 years. The map of Valdez and Vicinity (Alaska Sheet No. 29, used in locating mining

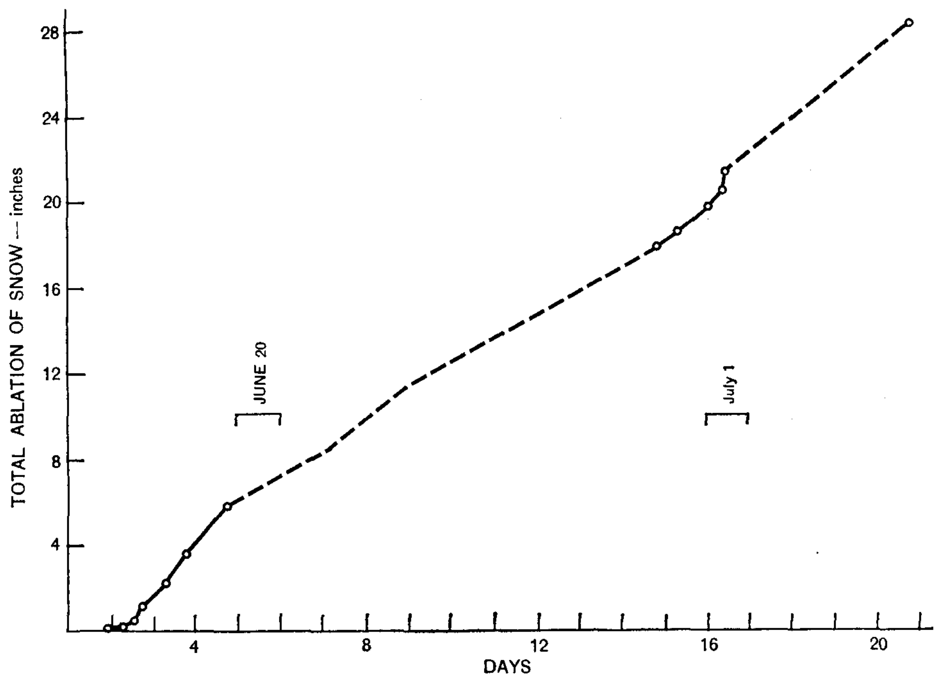

Fig. 3. Ablation at base camp in 1955, 3180 ft. altitude.

claims) by the U.S. Geological Survey gives the location of some of the medial moraines of the lower Columbia Glacier in about 1911. Comparison of this map with trimetrogon aerial photographs taken in the 1940s shows some remarkable changes. For instance, the moraine between the main branch and the east branch of the Columbia Glacier has shifted at least 0.75 mile to the east toward the Anderson Glacier. In view of the accurate detail shown on the map of land adjacent to the glacier and of the nunataks of the lower Columbia Glacier there is no reason to question the accuracy of the location of the moraines shown on the map. Therefore, this is additional evidence that the east

Medial moraines of the Columbia Glacier

The medial moraines of a glacier give considerable information about the past history and the state of health of the glacier. For instance, if one branch of a glacier is in a very good state of health compared with adjacent branches, the medial moraines bordering the healthy branch will be forced outward at the expense of the width of the unhealthy branches. Thus, the relative spacing of moraines across a glacier gives some indication of the past accumulation in the upper areas of the various branches.

In addition, if the transverse position of moraines is plotted over the course branch is losing and the higher main branch is gaining strength.

The regimen of the Columbia Glacier

Not nearly enough data are available to make good calculations of the regimen of the Columbia Glacier, only some rough estimates can be made for the glacier and its various branches. Table 2 gives approximate areas of accumulation and ablation and the ratio of these areas for various other Alaskan glaciers.

The table shows in general that if the ratio of the accumulation area to the ablation area is about two or greater, then the glacier will be near equilibrium or even advancing. If this ratio is less than two the glacier will retreat. The use of this ratio of areas is a crude measure of the state of health of a glacier. More exact relations have been derived[11], but in general not enough data are available to make use of the more exact relationships.

If one assumes that the ablation of ice at the terminus of the Columbia Glacier is the same or slightly less than that found at the termini of glaciers on the Juneau Ice Field[7] then Table 3 can be constructed.

Knowing the areas between various altitudes it is possible to estimate the total ablation of ice per year. For the Columbia Glacier this gives about 4.5 to 6.0 $\times 10^{10}$ ft.^{3} (1.27 to 1.70 $\times 10^9$ m.^{3}) per year. To maintain a steady state of equilibrium this amount of ablation requires an average of from 12 to 17 ft. (366 to 518 cm.) of snow of density 0.5 over the whole accumulation area at the end of each ablation season, which is roughly twice the amount of snow indicated by our observations.

Table 2. Accumulation and ablation areas of various Alaskan glaciers.

Glacier	*Accumulation area km.²*	*Ablation area km.²*	*Ratio of areas*	*Remarks*
Columbia Glacier (total)	678	466	1.45	stationary
Columbia Glacier (main and 2nd west branch)	396	174	2.28	active
Columbia Glacier (1st west branch)	153	93	1.64	stationary
Columbia Glacier (east branch)	129	199	0.65	dying
Taku Glacier	582	117	5.0	advancing
Norris Glacier	—	—	0.75	retreating
Lemon Glacier	—	—	1.8	nearly stationary
Mendenhall Glacier	—	—	0.84	slowly retreating
Nelchina Glacier	158	111	1.4(?)	retreating
Tazlina Glacier	243	132	1.8(?)	retreating
Valdez Glacier (main branch)	80	73	1.1	retreating

Table 3. Ablation of bare ice below the firn line. (estimated water equivalent)

Altitude interval on glacier	*Ablation — cm./year*	
	minimum	*maximum*
0 — 1000 feet	550	770
1000 — 2000 feet	365	455
2000 — 3000 feet	180	245
above 3000 feet	60	90

If similar calculations are applied to the main branch and the second west branch of the glacier only, from 9 to 13 feet (274 to 396 cm.) of snow (density 0.5) are required each year to maintain a steady state. This amount is still slightly greater than that observed. Obviously more data will have to be obtained to decide whether or not our values for ablation of ice are too high or our accumulation values too low. However, in view of the limited data, the agreement between the observed values of snow depth and the calculated values is good enough to indicate that the main branch of the glacier is in a healthy state. Certainly, the general appearance of the main glacier leads one to believe that it is healthy and active.

Unusual glaciological phenomena

The 1957 expedition had the good fortune of being able to study two rare glaciological phenomena: the birth of a crevasse and a great ice avalanche across a frozen glacier surface.

On June 22 we had a camp at 9450 ft. at the top of an icefall between Mt. Edison and Mt. Elusive. At 2 p.m. we experienced a single violent jerking motion like the shaking due to an earthquake. The motion was accompanied by a sharp cracking sound. A crack several hundred yards long with widths from a hairline to half an inch ran through the camp area. Two days later the width of the crack had grown to 2 to 4 inches. At the same time the downhill side of the new crevasse had risen till it was 3 inches higher than the other. The main crevasses of the icefall were several hundred yards away. No other open crevasses were found near the new one, but one small snow-bridged crevasse was 75 ft. farther uphill and another was 120 ft. below in the direction of the icefall. The new crevasse appeared in a tension area where the surface slope increases towards the icefall. If the ice goes over the icefall mainly as blocks rather than as deformable material the relative uplift of the lower side of the crevasse would be caused by the tilting of an ice block on a surface of increasing slope.

A great ice avalanche came down the south face of Mt. Edison probably during the cold night of June 21, 1957. The glacier surface had a hard frozen crust 2.5 inches thick at the time, so the avalanche slid for about a mile on the gentle surface of the Columbia Glacier after falling a thousand feet or more down the cliffs of Mt. Edison. The main avalanche consisted of eight or nine wide streams of ice 10 to 25 feet in thickness. The great streams fanned out in different directions and some made sweeping curves. Several streams of ice tore through piles of fresh avalanche debris leaving behind them a smooth track like a giant bobsled run up to 50 ft. wide. Along the sides of these tracks were piles of ice up to nearly 15 ft. high with the inner surface smooth and nearly vertical. At the ends of the tracks were great piles of ice the size of several freight cars. The main glacier surface was not greatly disturbed as most of the avalanche stayed on the surface. The ice streams did, however, pile the crust up in front of them or along their sides in some areas. A rough estimate gave an amount of 10^7 ft.^{3} (2.8 $\times$ 10^5 m.^{3}) of ice in the avalanche.

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PROMOTING THE DECAY OF SEA-ICE

Some attention has been paid to hastening the decay of sea-ice along inshore navigation channels; dusting the ice with dark materials has been considered and is being investigated. More practical than dusting might be hosing the ice surface with normal sea-water in the spring. This suggested itself when difficulties arose at McMurdo Sound in 1962, following flooding a runway on perennial sea-ice with sea-water to smooth the surface. The consequent increase in surface salinity (from less than 1‰ for the old ice to 17 to 31‰ for the flooded surface) led to a wet surface layer while air temperatures were still as low as −15°C.

The surface salinity of annual sea-ice in the Arctic is commonly less than 5‰. Covering the surface with sea-water pumped from below would increase surface salinity to 20 to 30‰. Hence the volume of liquid brine at any given temperature would be increased by a factor of 4 to 6. This should decrease the albedo (possibly by a factor of 2 at temperatures above −10°C.) so that a higher proportion of the incident solar radiation would be absorbed. The water transfer would also contribute sensible and latent heat at the surface. Surface heat transfer might be aided by convection in the layer of meltwater, and ultimately the surface brine should drain down through the natural ice as its original brine cells expand under rising temperatures. The advantages of increased absorption of radiation might be slightly offset by increased long-wave emission and higher evaporation from the liquid phase. The net result of these processes should be to reduce the treated ice to a low-strength porous condition comparatively early in the season.

Pumping sea-water on the ice should be appreciably cheaper than delivering and spreading dusting materials. Submersible pumps run from a portable generator could be lowered through holes made in the ice by drilling or blasting. Field tests of the method would be inexpensive.

The above considerations should also have some bearing on the use of the free-flooding technique for thickening runways on sea-ice. If runway surfaces are not to deteriorate by slushing and pitting in the spring, there should be some provision for brine drainage and a snow cover should be maintained on the runway.

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Dr. Helge Larsen, the former Director of the Institut, has succeeded Captain Ejnar Mikkelsen as Chairman of the Board, and Colonel J. Helk has been appointed Director.

Twentieth International Geographical Congress

The Second Circular of the 20th International Geographical Congress, which will be held from July 6 to August 11, 1964 in the United Kingdom, has just been published. Copies of this circular can be obtained from:

The Secretariat,
20th International Geographical Congress,
c/o Royal Geographical Society,
London, S.W.7.

Corrections

In *Arctic* Vol. 16, No. 1, p. 30: the lettering for the ordinate in Fig. 4 should read feet instead of inches.

On p. 55 in the second line of the heading under O. C. S. Robertson read R. D. for R. B. and C. D. for C. B.