A Limnological Survey of the Ablation Point Area, Alexander Island, Antarctica

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A limnological survey of the Ablation Point area, Alexander Island, Antarctica

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[Plate 1]

The ice-free area around Ablation Point (70° 49′ S, 68° 25′ W) is of particular limnological interest. Numerous ponds and pools lie on coastal moraines and large, permanently ice-covered lakes lie in the valleys. Two of the lakes are unusual in that they are in contact with seawater from George VI Sound which is covered by an ice shelf, 100–500 m thick, and which separates Alexander Island from the Antarctic mainland. Evidence for the existence of a marine biome, 100 km from the open sea, was obtained from one lake. Freshwater biological samples added new genera to Antarctic lists, extended the known range of species, and illustrated the important rôle of isolation in the determination of antarctic biocoeneses.

Introduction

In the 1960–1 austral summer, a chain of unusual lakes were discovered in the Schirmachervatna (70° 45′ S, 11° 20′–11° 55′ E). Although the lakes contain only freshwater, they are tidal; levels rising and falling over irregular semi-diurnal periods (Simonov 1963). The freshwater is apparently in contact with seawater under the 500 m thick ice shelf which stretches for 90 km to the north. Geomorphologists, geologists and glaciologists have published detailed descriptions of the water bodies. However, the flora and fauna were apparently not investigated although the unusual situation affords possible colonization of brackish and fresh waters by marine forms.

In 1966 C. W. M. Swithinbank, British Antarctic Survey, predicted the presence of similar lakes near Ablation Point, Alexander Island (70° 49′ S, 68° 25′ W) after detecting tide cracks in aerial photographs (personal communication). Confirmation by glaciologists in the field promoted a general limnological study of the area in the austral summer, 1973–4.

Methods

Lakes were surveyed by prismatic compass and leadline. Sounding and sampling stations were bored with a ‘Jiffy’ ice drill (Feldmann Engineering and Manufacturing Co., Inc., Wisconsin, U.S.A.). The underwater penetration of light was measured with a selenium rectifier photocell, microammeter and glass filters. Temperature, oxygen and salinity were measured *in situ* by probe (Mackereth oxygen probe, Lakes Instruments, Windermere; Oceanographic Salinity and Temperature Bridge Model MC5, Electronic Switchgear (London) Ltd, Hitchin). Water was obtained with a hand-operated suction pump and rigid polyethylene tubing. Alkalinity was measured in the field by titration to pH 4.5 with standard acid: chloride and sulphate + nitrate by titration to pH 4.5 with standard alkali after conversion to acids by ion-exchange (Mackereth 1963). Field colorimetric measurements were made of pH (bromocresol purple indicator), silicates (Mullin and Riley molybdenum blue method), phosphates (molybdenum blue method using ascorbic acid as reducing agent), nitrites and nitrates (Griess Ilosvay method and spongy cadmium as reducing agent for nitrates) using a Lovibond 1000 comparator and Nessler attachment. Limits of detection for nutrient salts were lowered to approximately 0.001 mg l^{-1} by making comparisons with standard solutions instead of Lovibond disks. Samples were preserved by the addition of Spectrosol concentrated nitric acid and analysed for sodium, potassium, magnesium and calcium by atomic emission spectrophotometry in the U.K. Sea and brackish water samples were preserved by freezing at −20 °C without prior filtration for analysis of a wide range of cations by spark source mass spectrometry in the U.K. Chlorophyll *a* was measured after the hot methanol method described in Vollenweider (1969) and carbon fixation rate after the radiocarbon method outlined by Goldman (1963) using a 24 h incubation period. Plant material was preserved in Lugol's iodine, 70% alcohol or by drying. Animal samples were preserved in 70% alcohol directly or after narcotization and relaxation in tetrasodium pyrophosphate.

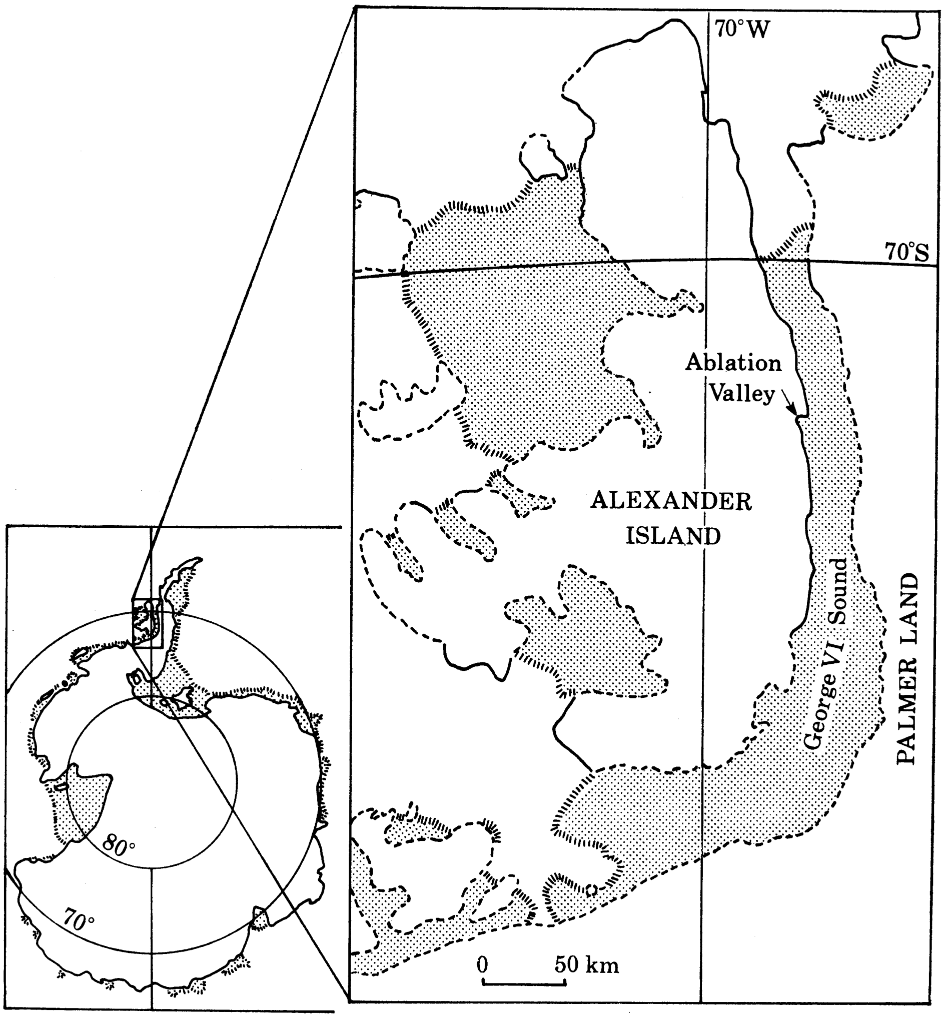

FIGURE 1. Outline map of Alexander Island and its position in Antarctica. Ice shelf, stippled area.

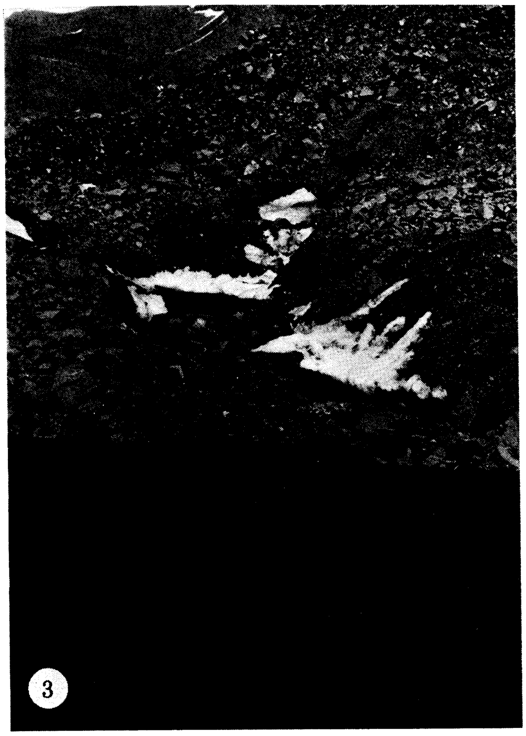

Figure 2. Aerial photograph of Ablation Point area. George VI Sound lies in the foreground. (Photography flown by the U.S. Navy for the U.S. Geological Survey.)

Figure 3. Exposed ice of the moraines.

Figure 5. Ridges of ice along the shore of Ablation Lake pushed up by pressure from the ice shelf tongue.

(*Facing p*, 40)

Topography and geology

Ablation Point area, 700 km², lies between the Grotto and Jupiter Glaciers on the east coast of Alexander Island, 70° 49′ S, 68° 25′ W (figures 1 and 2, plate 1). It consists of three main valleys separated by almost sheer, 650 m high ridges. Ablation and Moutonée valleys trend eastward and descend to sea level. The third, and unnamed valley, trends southward and descends to the Jupiter Glacier, 150 m above sea level. Alexander Island is separated from the Antarctic mainland (Palmer Land) by George VI Sound; the waters of which are covered by a 100–500 m thick ice shelf. The surface of the shelf lies 30 m above sea level. The Sound receives glacier ice from both Palmer Land and Alexander Island. The resultant force is towards the northwest and rows of pressure ridges, 10–15 m high, and associated moraines, lie along the east coast of Alexander Island in the Ablation Point area. Ablation and Moutonée valleys are sealed by tongues of pressure ice. A small amount of permanent ice and snow forms ice fields and decaying glaciers at the head and on northern walls of the valleys. Elsewhere the ground is covered with coarse to fine scree which extends in steep (30°) slopes up the valley walls.

Table 1. Values for some chemical factors of mineral soils from the Ablation Point area

		extractable		total (%)				
		Cl	S					
code	sample detail	parts/10^6		Si	P	K	Mg	Ca
A	moraine	50	790	27.9	0.067	1.71	1.13	1.94
B	moraine	330	2500	28.0	0.098	1.53	1.68	2.70
C	moraine	130	1000	28.0	0.070	1.91	1.25	1.99
D	moraine	<25	180	28.6	0.088	1.50	1.18	1.89
E	moraine	76	590	30.4	0.099	2.50	1.73	1.81
F	moraine	1400	4300	26.9	0.071	1.42	1.14	2.62
G	moraine	25	120	26.5	0.086	1.30	1.29	3.45
H	moraine	990	2800	24.4	0.077	1.58	1.49	2.19
I	Ablation Valley, South Ridge	—	400	29.7	0.098	1.70	1.45	1.87
J	ridge above moraines	—	81	28.7	0.100	1.59	0.93	2.16
K	dirt cones	—	180	28.7	0.102	1.92	1.22	2.44
L	N.W. Valley, West Ridge	<25	80	28.8	0.065	1.97	1.14	1.66
M	Ablation Valley, outwash plain	—	140	29.0	0.089	1.99	1.17	1.89
N	Ablation Valley, South Ridge	—	170	29.8	0.086	2.15	1.50	1.94
O	Ablation Valley, South Ridge	—	140	30.2	0.093	2.00	0.95	1.80
P	Moutonée Valley, South Ridge	<25	120	28.4	0.081	1.42	1.25	1.85
Q	Moutonée Valley, floor	<25	230	28.4	0.092	1.38	2.98	2.05
R	Moutonée Valley, floor	<25	81	28.8	0.076	1.66	0.84	1.49
S	Moutonée Valley, North Ridge	<25	140	26.5	0.071	1.48	0.92	1.46
T	Moutonée Valley, limestone	<25	100	28.3	0.078	1.45	1.87	1.64

—, not measured.

The rocks are largely sedimentary and cover a wide time range (Upper Jurassic to lower Cretaceous) because of the steep dip of a large anticline which bisects the area from north to south. All the sediments were deposited in a shallow-water marine basin not far from their source, a deeply eroded plutonic and metamorphic terrain. There is evidence of some volcanic activity continuing throughout the period of deposition. Rock types range from andesite eruptions, and their erosional equivalents, to arkoses, conglomerates and mudstones. Hydrothermal alteration and low grade metamorphism have caused extensive mineralogical changes.

Minerals known to be present are plagioclase, augite, chlorite, quartz, calcite, sphalerite, sericite, epidote, prehnite and iron ore (Elliott 1974). The mineral soils examined had high levels of extractable sulphate and silicate (table 1).

Climate

The climate of the area is largely determined by the interaction of dry polar winds and oceanic weather systems from the Bellingshausen Sea. During the period of study (November 1973 to January 1974) the following climate data were recorded at a nearby (27 km) glaciological, semi-automatic weather station; mean air temperature -2.3 °C, mean wind speed 1.66 m s^{-1}, mean relative humidity 73.5%, total incoming solar radiation 640161 W m^{-2} (A. C. Wager, personal communication). It is reasonable to assume that the mean summer temperature of the Ablation Point area was 1–2 °C higher because of longwave back radiation from the greater area of bare rock. The relative humidity would be correspondingly lower. The annual mean air temperature is approximately -9 °C. Precipitation is not measured at the weather station but net accumulation over a glacier has averaged 11.4 cm water equivalent over the winter months (February to October) of the past 4 years. Little snow falls during the summer. Allowing for drift, it is reasonable to assume that the annual precipitation is less than 20 cm water equivalent a year. The climate is therefore cold and arid but not as extreme as continental inland ice-free areas (Heywood 1972).

Terrestrial vegetation

About 40 km^2 of ice-free ground was searched on foot. Extensive terrestrial plant cover is restricted to seven discrete patches of moss, lichen and algae, totalling 2300 m^2. The patches are on north-facing slopes where groundwater wells up continuously during the summer. Widely scattered, very small moss cushions also occur between and beneath stones in a few other damp and wet places. Lichens, especially *Usnea sulphurea*, are widespread, but sparse, on bedrock and scree to 1000 m above sea level. Aerial reconnaissance confirmed that most of the Ablation Point area is bare of vegetation. Lack of water, soil instability and wind erosion seem to be the most important restricting factors. Localized but sometimes large areas of mineral soil and small patches of moss were found covered with accretions of salt, presumably deposited from groundwater during ablation/evaporation. Crystals collected were 95% calcium sulphate. High salt concentrations in the surface soil layers are also a probable limiting factor, therefore.

Freshwater bodies

Many small pools lie on moraines bordering the ice shelf along the east coast of Alexander Island. They are particularly numerous in the Ablation Point area where 600 were found over a distance of 3 km. A few pools also lie between the mountains and the Grotto and Jupiter Glaciers, and on dirt cones of glaciers at the head and in a side arm of Ablation Valley. The pools vary from 1 to 250 m^2 in surface area and are up to 1 m deep. Ponds, 500–10000 m^2 in area, lie between the mountains and the moraines of the ice shelf. The maximum recorded depth is 6 m.

Individual pools appear to exist for only short periods of time. There is considerable evidence of pools having drained through fissures, in the process of being filled in, and having recently

TABLE 2. SUMMER VALUES FOR SOME CHEMICAL, PHYSICAL AND BIOLOGICAL FACTORS OF POOLS AND PONDS

	date	soil sample	pH	alk mmol l^{-1}	mg l^{-1}										trans-parency	benthic flora
					Cl	SO_4	Si-SiO_3	N-NO_2	N-NO_3	P-PO_4	Na	K	Mg	Ca		
moraine pools	24. 1. 74	A	6.4	1.22	7.10	134.40	1.18	—	—	n.d.	48.55	5.04	10.00	14.90	+ + +	+ + +
	24. 1. 74	B	6.7	0.93	24.85	388.80	2.17	—	—	n.d.	54.00	5.66	85.00	24.25	+ + +	+ +
	22. 1. 74	C, D	6.4	0.73	1.42	15.36	1.27	n.d.	n.d.	n.d.	14.91	0.91	3.54	12.90	+ + +	+ + +
	22. 1. 74	C, D	6.6	0.92	0.97	13.96	1.27	n.d.	n.d.	n.d.	16.36	1.42	4.07	13.85	+ +	+
	22. 1. 74	C, D	6.7	0.55	0.97	8.16	1.49	0.02	n.d.	0.17	15.45	4.09	4.49	3.32	+	+ + +
	22. 1. 74	C, D	6.6	0.55	0.97	12.00	1.72	n.d.	n.d.	0.05	16.18	0.51	3.83	4.25	+	+
	22. 1. 74	C, D	6.6	0.89	1.42	15.84	1.42	n.d.	n.d.	0.08	21.64	3.83	5.34	5.45	+	+ + +
	22. 1. 74	C, D	6.6	0.92	0.97	13.92	1.27	n.d.	n.d.	n.d.	17.28	2.08	4.70	12.90	+ +	+
	24. 1. 74	E	6.4	0.84	7.10	316.80	3.26	—	—	n.d.	68.18	15.38	9.65	20.07	+ + +	+ + +
	24. 1. 74	F	6.4	0.99	17.75	225.60	1.18	—	—	n.d.	53.09	6.22	9.39	20.07	+ + +	+ + +
	24. 1. 74	G	6.6	0.77	1.07	15.84	1.81	—	—	n.d.	19.10	2.52	5.30	5.62	+	+ + +
	24. 1. 74	H	6.4	1.44	113.60	254.40	1.18	—	—	n.d.	78.55	18.05	10.30	21.30	+	+ + +
Camp Pond	4. 1. 74	I	6.3	0.50	2.84	9.60	1.83	—	n.d.	n.d.	14.36	0.69	3.58	5.30	+ + +	+ + +
Skua Pond	14. 1. 74	B, J	6.4	0.25	1.07	27.82	0.36	n.d.	n.d.	n.d.	18.00	1.13	3.94	4.35	+	+
Clear Pond	14. 1. 74	E, J	6.4	0.94	35.50	372.00	1.09	n.d.	n.d.	n.d.	69.82	21.30	10.24	24.25	+ + +	+ + + M
Moss Pond	14. 1. 74	F, J	6.4	1.02	2.13	111.36	1.27	n.d.	n.d.	n.d.	21.64	0.95	8.69	20.04	+ + +	+ + + M
Pressure Pond	14. 1. 74	G	6.6	0.25	3.55	5.76	0.36	n.d.	n.d.	n.d.	17.09	1.35	2.62	1.88	+ + +	+
Ice Pond	14. 1. 74		6.0	0.04	1.42	n.d.	n.d.	n.d.	n.d.	n.d.	14.18	0.51	0.45	0.26	+ + +	none
Dirt Cone Pond	30. 12. 73	K	6.3	0.23	1.07	4.32	0.50	n.d.	n.d.	—	11.27	0.44	1.26	3.20	+	+
N.W. Valley pond	30. 12. 73	L	6.4	0.30	2.84	5.76	0.10	n.d.	n.d.	—	11.82	0.44	1.16	4.50	+	+

n.d., not detectable. —, not measured. Transparency/benthic flora: +, low/poor; + +, medium; + + +, high/rich. M, moss.

formed. The moraines and dirt cones are ice-cored and extremely unstable. Ice under the moraines is moving under pressure from the ice shelf, and buckling against the bedrock of the land. Layers of overlying insulating debris are being thinned or lost (figure 3, plate 1). Consequent melting of ice during the summer causes further movement. Dirt cones are subject to ice melt only, because the glaciers are retreating. In both areas there is a constant rattle of falling debris throughout the summer. Individual pools probably only exist for 3–5 years. Although the ponds are less effected by moraine movement, they are also subject to infill from steep scree slopes. Size alone will, however, ensure a longer existence than the pools.

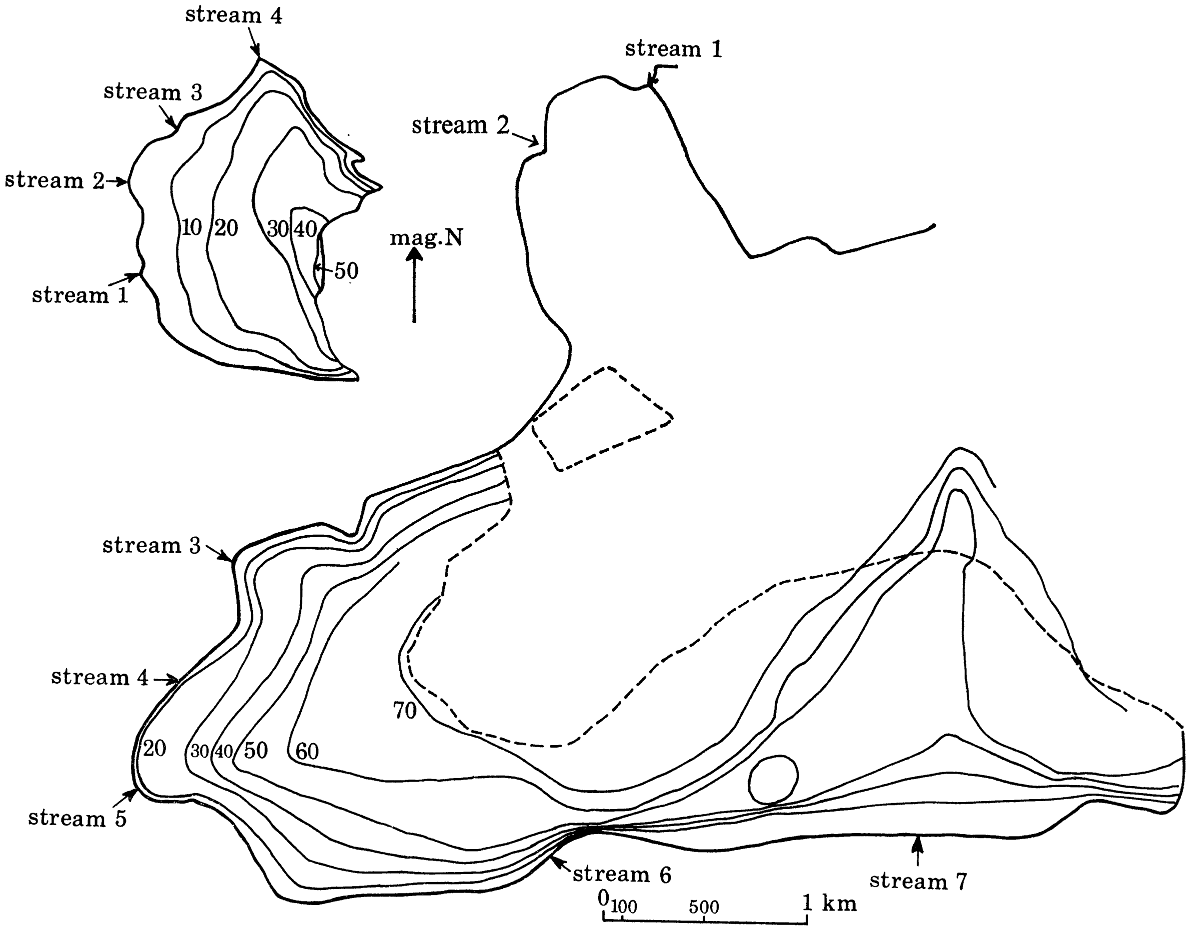

FIGURE 4. Outline of Ablation Lake and Moutonée Lake, showing bathymetric contours (m). The dotted line marks the edge of the ice shelf tongue.

The turbidity of the waters varies from less than 10 to more than 90% transmission per metre (estimated during Scuba dives) as a result of suspended glacial clay. All the pools were free of ice during the summer but some of the ponds remained partly ice-covered; the combined effect of greater volume and, in some cases, the proximity of an adjacent snow field. Temperatures as high as 15 °C were recorded in the pools and 7.5 °C in the ponds. All but the deepest ponds must freeze solid for a considerable part of the winter.

The chemical composition varies considerably even between waters of adjacent pools or ponds (table 2). This clearly reflects the mixed and exotic nature of the rocks forming the moraines.

Three large (1.5–6.5 km^2), deep (50 to more than 117 m), ice-dammed lakes lie in the main valleys. All are proglacial, the waters being held back by the ice of the Jupiter Glacier (Upper Lake), or the ice shelf (Ablation and Moutonée Lakes) (the names are unofficial). Bathymetric surveys were carried out on Ablation and Moutonée Lakes (figure 4) but not Upper Lake where difficulty of access prevented the use of the ice drill. The lake basins had obviously been scoured out by glacial action. The surface waters are permanently frozen, ice cover ranging from 4.0 to 4.5 m thick in winter, 2.5 to 3.0 m thick in summer. Ice from George VI Sound pushes into Ablation Lake along the 70 m depth contour for 3.4 km. Waves of pressure ridges can clearly be seen along the ice tongue, the ridges becoming more widely separated by lake-ice-infill as the tongue moves further into the lake. The ridges also decrease in height presumably as a result of melt. The ice tongue is grounded over most of its length and does not rise with the tide (see p. 46). Shelf ice does not penetrate into Moutonée Lake but forms impressive 30 m cliffs over what appears to be a sublacustrine, corrasion-resistant sill at the entrance to the valley.

At the height of the summer, a narrow (1–2 m) moat forms along part of the landward shores of Moutonée and Upper Lake. This does not happen on Ablation Lake because pressure from the ice shelf tongue piles the lake ice on to the shore (figure 5, plate 1) and Scuba dives revealed that ice along the shoreline is still 5 m thick at the end of the summer.

Snow and ice are removed from the lakes by ablation and melting. Melt occurs at sub-zero temperatures through the solar-radiation warming of rock-dust particles which have been blown onto the ice cover. Melt water drains into the lower snow layers, and, while the snow cover is over 30 cm deep, the surface remains crisp and firm. Thinner snow layers form a slush which ablates away or drains into the now porous upper ice layers. The ice surface remains smooth and transparent for only a brief period before ablation erodes it into sharply angular, plate-like ridges, 10–20 cm high and orientated northeastwards. These frequently collapse to form a white, hard, granular surface. The snow cover lay in increasing depth from north to south across Ablation Lake and throughout the summer the various stages of ablation/melting formed distinct bands slowly moving southwards. Snow cover, and therefore the various ablation/melting zones, were irregularly distributed over Moutonée Lake. The snow surface appeared uniformly firm on Upper Lake (150 m higher) when visited on 3 January. From mid-December, water drained into holes being drilled into even snow and slush-free ice indicating that melting was occurring within the ice sheet.

Light penetration profiles were obtained for only Ablation Lake water, which is very transparent (table 3). However, only 20% (13 Jan.) to 15% (4 Feb.) of incident light penetrated a snow-free ice cover. Snow cover would reduce this amount considerably. The area is subject to effectively 2 months polar night because of the mountains, and the annual input of solar energy to the lake water must be very low.

Water temperature remained almost constant throughout the period of investigation. The profile of Ablation Lake ranged from +0.10 °C (surface) to −1.60 °C (below 67 m) and of Moutonée Lake from +0.30 °C (surface) to −1.0 °C (below 48 m) (figure 6). Evidence of small localized thermal cells within the upper 2 m of water was obtained from temperature profiles measured along transects. The maximum temperature recorded was only +1.10 °C. Heat gain by the water must be restricted by the high latent thermal capacity of the lake and Sound ice.

Salinity measurements revealed that the top 55 m of Ablation Lake water are fresh (0.1 to 1.0 part/10^3 but below 66.5 m the salinity is 32 parts/10^3). The halocline is very steep and between 66.00 m and 66.25 m the salinity rises from 18 parts/10^3 to 31.5 parts/10^3 (figure 6). The lake surface moves up and down with an irregular diurnal rhythm. Maximum recorded tidal range is 1.65 m. Variation in salinity profile with tidal movement indicated that the saline layer is in direct contact with the seawater of the sound. The seawater extends 4.0 km into the lake and is a further heat sink preventing the freshwater layer attaining higher temperatures. In Moutonée Lake the salinity gradually increases from 1 parts/10^3 at 30 m to 24.5 parts/10^3 at 50.5 m (bottom). Variation in salinity profile with tidal movement indicated that the water layer between 36 m and 39 m (10 to 12 parts/10^3) flows in and out of Moutonée Lake while the more saline lower layers remain stationary. This phenomenon is caused by the sublacustrine bar at the valley entrance.

TABLE 3. VERTICAL EXTINCTION COEFFICIENTS CALCULATED FOR ABLATION LAKE

		In units $\mathrm{m^{-1}}$				
date	depth of water	375 nm	460 nm	540 nm	580 nm	630 nm
13. 1. 74	upper metre	.	0.05	0.09	0.18	0.41
	upper 10 m	.	0.08	0.09	0.16	0.37
4. 2. 74	upper metre	0.35	0.48	0.33	0.42	0.76
	upper 10 m	.	0.07	0.08	0.15	0.34

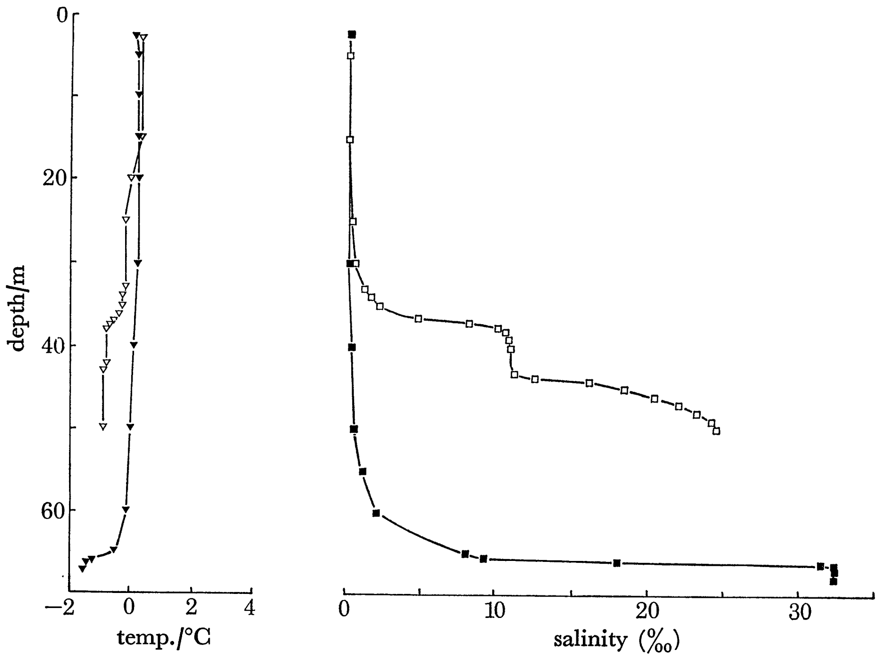

FIGURE 6. Temperature and salinity profiles for Ablation Lake (▼, ■) and Moutonée Lake (▽, □).

The chemical composition of both Ablation and Moutonée Lake freshwater appears to result from both the leaching of salts (especially sulphates and silicates) from surrounding rocks and the diffusion of salts from the underlying saline layers (table 4). Analyses of water from several sites and salinity probe transects could only detect the dilution effect of inflowing streams and ice melt in the upper 3–4 m of water. The sharpness of the halocline suggests that diffusion takes place at very low rates in Ablation Lake, probably only through molecular activity. Neither thermal convection currents (p. 45) nor wind-generated currents extend deep into the lake

TABLE 4. SUMMER VALUES FOR SOME CHEMICAL, PHYSICAL AND BIOLOGICAL FACTORS OF STREAMS AND LAKES

	date	soil sample	salinity parts 10^{-3}	pH	alk mmol l^{-1}	oxygen % sat.	Cl (mg l^{-1})	SO_4 (mg l^{-1})	Si-SiO_3 (mg l^{-1})	N-NO_2 (mg l^{-1})	N-NO_3 (mg l^{-1})	P-PO_4 (mg l^{-1})	Na (mg l^{-1})	K (mg l^{-1})	Mg (mg l^{-1})	Ca (mg l^{-1})	source	speed	benthic flora
Ablation Valley																			
stream no.																			
1	19. 12. 73	L	.	6.3	0.25	—	1.42	5.76	0.10	n.d.	n.d.	n.d.	18.00	0.97	8.35	19.10	ice field	+++	0
2	19. 12. 73	L	.	6.2	0.16	—	0.71	3.84	0.10	n.d.	n.d.	n.d.	12.73	0.40	1.31	2.00	glacier	+++	0
3	19. 12. 73	L	.	6.4	0.17	—	1.42	3.74	0.10	n.d.	n.d.	n.d.	11.82	0.42	1.16	2.37	glacier	+++	0
4	19. 12. 73	M	.	6.2	0.25	—	0.71	7.68	1.00	n.d.	n.d.	n.d.	12.00	0.57	2.62	2.70	glacier	+++	+
5	19. 12. 73	N	.	6.2	0.91	—	2.13	99.84	1.40	n.d.	0.04	n.d.	17.27	0.73	7.82	20.00	snowpatch	+++	0
6	19. 12. 73	O	.	6.2	0.60	—	2.13	26.88	2.40	n.d.	n.d.	n.d.	15.64	0.55	4.40	13.61	snowpatch	+	+++
7	12. 12. 73	I	.	6.6	0.88	—	13.49	84.48	2.31	n.d.	n.d.	n.d.	—	—	—	—	upwelling	+	+++
lake (m)																			
3	21. 12. 73	.	0.1	6.2	0.14	103	50.00	17.28	0.17	—	n.d.	n.d.	41.82	1.79	4.34	2.29	.	.	.
5	21. 12. 73	.	0.2	6.2	0.14	100	117.86	24.96	0.17	—	n.d.	n.d.	64.73	3.70	9.33	3.54	.	.	.
20	21. 12. 73	.	0.2	6.3	0.17	93	145.55	28.80	0.17	—	n.d.	n.d.	68.73	4.20	9.60	3.66	.	.	.
40	21. 12. 73	.	0.4	6.3	0.18	96	195.96	34.56	0.17	—	n.d.	n.d.	80.18	5.44	10.10	4.28	.	.	.
55	21. 12. 73	.	1.3	6.4	0.24	90	543.15	91.20	0.33	—	n.d.	n.d.	647.27	21.01	91.00	11.10	.	.	.
67.5	21. 12. 73	.	32.3	6.6	2.26	52	16898.00	2496.00	2.66	—	0.40	0.13	7654.55	501.68	242.00	272.50	.	.	.
Moutonée Valley																			
stream no.																			
1	6. 1. 74	P	.	6.2	0.32	—	3.91	10.08	0.80	n.d.	n.d.	n.d.	13.64	0.51	2.02	4.86	snowfield	+	+++
2	6. 1. 74	Q	.	6.3	0.40	—	2.13	20.16	2.00	n.d.	n.d.	n.d.	15.64	0.62	3.07	6.00	snowfield	+++	+
3	.	R,T	.	6.4	0.33	—	1.42	3.84	1.46	n.d.	n.d.	n.d.	13.45	0.99	1.41	4.00	snowfield	++	+
4	.	S	.	6.5	1.16	—	2.13	24.96	1.08	n.d.	n.d.	n.d.	16.36	0.55	3.94	17.61	snowpatch	++	++
lake (m)																			
3	26. 12. 73	.	0.1	6.2	0.19	—	40.47	12.48	0.10	n.d.	n.d.	n.d.	40,73	1.82	6.45	3.70	.	.	.
5	26. 12. 73	.	0.1	6.3	0.23	94	52.54	17.28	0.10	n.d.	n.d.	n.d.	45.82	2.14	7.68	4.62	.	.	.
20	26. 12. 73	.	0.2	6.3	0.25	85	88.04	26.88	0.50	n.d.	n.d.	n.d.	57.09	3.07	8.78	4.86	.	.	.
40	26. 12. 73	.	11.1	6.4	0.94	72	6656.25	960.00	1.17	n.d.	0.13	0.05	4763.64	137.37	246.00	142.50	.	.	.
50	26. 12. 73	.	24.5	6.4	1.55	44	11396.00	1536.00	1.50	n.d.	0.27	0.10	6218.18	192.59	246.00	212.50	.	.	.
Upper Valley																			
lake east-shore	3. 1. 74	.	.	6.1	0.12	—	4.97	3.84	0.10	n.d.	n.d.	n.d.	16.73	0.47	1.11	1.48	.	.	.
outflow	3. 1. 74	.	.	6.2	0.17	—	12.43	12.00	0.17	n.d.	n.d.	n.d.	24.91	0.69	2.88	3.90	.	.	.

n.d., not detectable. —, not measured. Speed of flow/benthic flora: +, slow/poor; ++, medium; +++, fast/rich.

The maximum seiche recorded on the tide gauge was 8 cm when the oscillation lasted for 6 h. Seawater obviously does not penetrate into the Moutonée Lake basin but tidal flow across the sublacustrine bar generates turbulence which causes considerable mixing of the two waters. Analyses of 17 inorganic elements by spark source mass spectrometry could not detect any significant differences in the proportions present in the Moutonée Lake brackish water, Ablation Lake seawater and seawater collected several kilometres off-shore in Marguerite Bay.

Little can be said of Upper Lake from the few samples taken. It lies approximately 150 m above George VI Sound. Obviously its waters are not in contact with seawater and it is not tidal. When it was visited, vast quantities of water were pouring off the Jupiter Glacier into the lake. How far this water penetrates into and mixes with the main body of lake water is questionable. The outflow stream leaves the lake by the side of the glacier also. It is reasonable to assume that the salinity of the lake is less than the upper waters of Ablation and Moutonée Lakes.

Running waters are of three distinct types. Fast streams, fed by glaciers, ice or snow fields pour through coarse scree in gullies or carve temporary beds out of finer but still unstable rock debris on the valley floors. Seepage water from snow patches drains very slowly over the surface or in very shallow runnels. Small springs feed a few other seepage paths. In general the slower moving waters contain the more salts and are biologically the more interesting (table 4). The freshwaters may receive no salts of marine origin from precipitation. Sodium, potassium and calcium could not be detected by atomic emission spectrophotometric analyses (limit 0.02 parts/10^6) of freshly fallen snow samples collected in November.

Flora and fauna

Antarctic freshwaters seem to offer a more favourable physical environment to plant species than the land. In them plants are not subject to desiccation, wide and rapid diurnal fluctuation in temperature, extremely low temperatures, frequent freeze-thaw cycles and abrasion by wind-driven ice crystals, granular snow and rock particles (Light & Heywood 1973, 1975). In the Ablation Point area, pools, ponds, streams and seepage runnels support a generally rich benthic flora, in sharp contrast to the surrounding arid land (table 5).

Preliminary analysis suggests that the most varied algal communities are present in ponds and pools which have very clear water. Here felts up to several centimetres thick develop, often with an irregular convoluted surface. In the deeper waters of some ponds, the algae form hollow conical structures up to 15 cm tall. The bulk of the felt is formed of filamentous *Phormidium* and/or *Calothrix* spp. (Myxophyceae), only the surface layers of which appear to be living. Many other forms of algae are living on, within and beneath the felt, and often are most numerous a few millimetres below the surface. Diversity of flora is generally directly related to thickness of felt and is indicated by the wide variety of colour recorded – green, orange, red, pink, brown, gray and yellow. In ponds with an estimated light transmission greater than 50% per metre luxuriant moss growth covers large areas from 0.5 to 6.0 m depth. Stems grow 30 cm in length. *Campylium polyganium* and *Dicranella* sp. are dominant. *Distichium capillaceum*, *Bryum algens* and another *Bryum* sp. are also found. Cover was estimated during Scuba dives and varied from 40 to 80% overall. Total moss cover was approximately 3500 m^2 in an area of 10000 m^2 examined. Less luxuriant stands of mosses were also found in a few of the pools.

The luxuriance of the benthic flora is particularly remarkable considering the probable brief lives of the pools and perhaps ponds. However, more detailed examination of apparently rich

TABLE 5. PROVISIONAL FRESHWATER FLORA LIST, ABLATION POINT AREA

		wet patches	moraine pools	camp pond	moss pond	slow streams
Chlorophyceae						
Conjugales	*Cosmarium quadratum* (or *Holmiense*)	.	.	*	+	+
	C. globosum	+	.	+	+	+
	Cosmarium sp.	*	.	.	+	.
	Mesotaenium sp.	.	.	.	*	+
	Hormidium, *Desmidium* or *Spondylosium* sp.	+	.	*	+	*
Volvocales	*Asterococcus* sp.	+	*	.	*	.
	Tetraspora sp.?	.	.	*	+	.
	Chlamydomonas sp.	+	.	.	.	.
	Pandorina sp.	.	+	.	.	.
Zygnemales	*Zygnema* sp.	+	*	+	+	*
Ulotrichales	*Chlorhormidium* sp.	+	+	.	*	.
	Binuclearia sp.	.	+	.	+	.
Chaetophorales	*Microthamnion* sp.	.	.	.	*	.
	‘filamentous 9 µm’	+	.	.	.	.
	‘filamentous 4 µm’	+	.	.	.	.
	‘filamentous 1 µm’	.	.	*	.	.
Bacillariophyceae						
Pennales	*Eunotia* sp. 1	+	.	+	.	.
	Eunotia sp. 2	+	.	.	.	.
	Eunotia sp. 3	.	.	.	+	+
	Nitzschia sp.	.	.	.	+	.
	Pinnularia borealis	+	.	*	.	+
	Pinnularia sp. 2	.	.	.	.	+
	Pinnularia sp. 3	.	*	.	*	.
	Pinnularia sp. 4	.	.	.	*	.
	Navicula rhyncocephala	.	.	.	+	.
	Navicula sp. 2	*	.	.	*	.
	Navicula sp. 3	.	+	.	.	.
	Achnanthes sp.	.	.	.	+	.
	Fragilaria sp.	.	.	.	+	.
	Synedra sp.	.	.	.	+	.
	‘diatom’ sp. 7	.	+	.	+	.
	‘diatom’ sp. 9+	.	.	.	*	.
Myxophyceae						
Chroococcales	*Synechococcus*	*	.	.	+	+
Nostocales	*Phormidium* sp. ‘1 µm’	.	*	.	*	.
	Phormidium sp. ‘3–4 µm’	.	*	.	*	.
	Phormidium sp. ‘6 µm’	+	+	.	.	.
	Phormidium sp. ‘8 µm’	+	+	.	.	.
	Lyngbya sp.	.	.	+	+	.
	Nostoc sp.	*	+	*	*	*
	Calothrix sp.	*	+	*	*	.
	Nodularia sp.	.	*	.	.	.
	‘filamentous 12 µm’	+	.	.	+	.
	‘sheathed filamentous’	.	.	.	+	.
Euglenophyceae	‘sp. 1’	+	+	.	*	.
Dinophyceae	‘sp. 1’	.	+	.	.	.
Cryptophyceae	‘sp. 1’	+	*	.	.	.

+, present. *, abundant.

felts from pools with a high suspended silt content may reveal that the felt is largely moribund and that the epiphytic algae have disappeared. A remarkable phenomenon was observed during a Scuba examination of Clear Pond (unofficial name). The water was very clear to a depth of 5 m but below this (max. depth 6 m) the water was very opaque with suspended glacial clay. The benthic flora of this zone was buried in settled clay and dead, but within the clear zone, the moss growth was luxuriant. It seemed to hang in ripples down the steep walls. When a sample was removed, a jet of fine clay streamed in from the wall. Further investigation revealed the tangled mats of moss were holding back a thick layer of silt. This was causing the rippling or bulging effect and clearly the moss would eventually be torn away and buried on the bottom of the pond. A chain of interconnecting ponds nearby, Skua Ponds (unofficial name), contain very opaque water. Visibility recorded on Scuba dives was 15 cm and although a large area was searched in two of the ponds no benthic algal felt was found, nor were there signs that the ponds had once contained luxuriant vegetation.

Phytoplankton samples have not been examined yet. However, measurements of chlorophyll *a* from three ponds, taken late December-early January, were low (0.42 μg l^{-1}, 0.65 μg l^{-1} and 0.75 μg l^{-1}) suggesting that the phytoplankton population is sparse.

Examination of lake flora was hindered by the thick ice cover. Five Scuba dives into Ablation Lake covered an area of about 10000 m^2 extending to 15 m depth. The only vegetation observed was a thin film of algae on occasional rocks jutting out of a silt floor. Colonization of shallow water is probably prevented both by the presence of ice which is 5 m thick along the shore, and by 'ice-push' generated by the ice shelf tongue, which forces the lake ice onto the shore to form ridges 2–3 m high (figure 5). Thin blue-green algal felts were seen below low tide mark in several places along the moat which thawed out round Moutonée Lake. There was also an even cover of green filamentous algae in a small pool which lay isolated at low tide. The intertidal zone does not remain dry for long periods, so perhaps ice scour is the main restricting factor.

Chlorophyll measurements indicate that phytoplankton levels in both lakes are low. On 15 February 0.65 μg l^{-1} were recorded for the ice/water interface (2.5 m) in Ablation Lake and 0.50 μg l^{-1} for other layers down to 20 m. A maximum fixation rate of 6 mg carbon m^{-3} day^{-1} was recorded at 3 m on that date and a total of about 60 mg C m^{-2} day^{-1} was calculated for a 20 m deep zone. Measurements in Moutonée Lake were made on 26 December 1973 when the maximum recorded value was 0.5 μg l^{-1} at 5 m. Light levels in the lakes must be constantly changing and it must be very difficult for the phytoplankton to take advantage of the occasional increases in available energy. However, on 4 February 1974 it may have been a phytoplankton bloom which increased considerably the vertical extinction coefficients in the upper metre of water in a snow-free area of Ablation Lake (table 3).

No observations could be made on the flora of Upper Lake. A value of 0.28 μg l^{-1} chlorophyll *a* was recorded for the outflow, but this was probably diluted considerably by glacial melt.

Algae are abundant in slow-moving streams and seepage runnels. Large wet areas of level ground in Moutonée Valley have particularly rich floras forming over 90% cover for many square metres. Five species of desmids are particularly common, often forming pure masses of many grams. The filamentous green *Zygnema* is also abundant. Only *Nostoc* sp. and *Phormidium* spp. can colonize areas which are drier, less stable and silted. Algae apparently cannot colonize the unstable bed of fast-flowing streams.

Protozoa, Rotifera, Tardigrada and Nematoda form a benthic fauna in pools, ponds and

TABLE 6. PROVISIONAL FRESHWATER FAUNA LIST, ABLATION POINT AREA

	density																												
	Ablation Lake	camp pond 'old' *Phormidium*		camp pond 'new' *Phormidium*		camp pond *Nostoc*		clear pond		moss pond		moraine pool 3		moraine pool 5		moraine pool 7		moraine pool 9		seepage runnel		seepage runnel		stream gently flowing		stream gently flowing		stream gently flowing	
	no. l^{-1}	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Rotifera *Philodina gregaria* *P. antarctica* *Lindia torulosa* n.var. *Notholca verae* *Colurella* sp.	—	571	46	409	51	2826	82	134	8	180	27	935	107	156	8	0	0	48	6	93	29	368	112	8571	505	2865	231	632	89
Tardigrada *Echiniscus* (*Echiniscus*) sp. (*Macrobiotus ambiguus*) *Macrobiotus furciger* *Hypsibius* (*Hypsibius*) *dujardini* *H.* (*Hypsibius*) *oberhaeuseri* *H.* (*Isohypsibius*) *asper* *H.* (*Isohypsibius*) *renaudi* *H.* (*Diphascon*) *alpinus*/*pinquis* *H.* (*Diphascon*) *scoticus* *Milnesium tardigradum*	—	277	22	51	6	870	26	0	0	97	15	332	38	0	0	47	4	96	13	0	0	1388	431	2964	175	2188	177	20	3
Nematoda *Plectus parietinus* *Eudorylaimus antarcticus* *Mesodorylaimus* sp. A *Mesodorylaimus* sp. B *Mesodorylaimus* sp. C	—	69	6	119	15	435	13	0	0	28	4	185	21	0	0	349	32	0	0	120	38	590	179	2964	175	1328	107	79	11
Copepoda *Pseudoboeckella poppei* *Cyclopoid* sp. (marine)	0.50 0.06	abundant in the overlying water																		absent									
Pisces *Trematomus bernacchii* (marine)	+																												

A, numbers per gram of algae
B, numbers per square centimetre of algae } mean of 3 subsamples.
—, not detected.
+, present but density unknown.

streams. They probably occur in the lakes but none were caught. Protozoa could not be examined or preserved under field conditions but the other animals were extracted and preserved for identification and density studies (table 6). The rotiferan genera *Lindia* and *Colurella* were recorded for the first time in Antarctica (the *Colurella* was also recorded in 1974 from the South Orkneys by Dartnall (personal communication)). The *Lindia* and the *Notholca* could be new varieties. The *Mesodorylaimus* nematodes are new to Antarctica and may be new species.

Recorded densities vary widely up to 5.0×10^6 m^{-2} Rotifera, 4.2×10^6 m^{-2} Tardigrada and 1.8×10^6 m^{-2} Nematoda, and are generally highest for the slow-running streams. There is no discernible correlation between numbers and water chemistry and clarity. It is reasonable to assume that the governing factors are the quality and quantity of the epiphytes which probably reflect the age of, and the degree of silting taking place in, the pool or pond. The flow of water in the streams keeps the felt generally free from silt.

The copepod *Pseudoboeckella poppei* forms an often abundant plankton in lakes, ponds and pools, but not in the streams. Both male and female show considerable variation in the armature of the 5th pair of legs, features previously considered to be of taxonomic value. This discovery prompted a reappraisal of the previously reported *P. silvestri* on Signy Island, and this was reclassified as *P. poppei* (Heywood 1977).

Ablation Lake provided a remarkable addition to the Antarctic inland waters faunal list. Four specimens of a common Antarctic marine benthic fish, *Trematomus bernacchii* were caught in a trap lying in 70 m of water (Heywood & Light 1975). The fish were in good condition and one female had mature gonads. The morphometric statistics of the fish suggest that they are of a smaller growth form than specimens captured in the open sea off Terre Adelie and in McMurdo Sound. The fish had fed just prior to capture on a variety of marine organisms. Since this species of fish is of sedentary habit, the evidence suggests that there is a marine biome in the lake and under the ice of the Sound, nearly 100 km from the open sea. The productivity of the freshwater layer in Ablation Lake is extremely low and perhaps barely sufficient for the *P. poppei* population (average concentration recorded 0.5 individuals per litre, including naupliar stages). Its contribution in the form of detritus must add little to the budget of the marine biome which must be dependent on detritus carried through the ice-covered Sound. If the current flows north the distance involved is 334 km.

Trematomus bernacchii is not adapted to freshwater and the fish showed signs of acute distress when brought to the surface. However, a cyclopoid copepod was collected from below 40 m over a range of salinity 0.6–32 parts/10^3. The maximum concentration recorded was 0.06 individuals per litre but samples could only be taken from as far down as the fringe of the marine layer where the animals are presumably more numerous. One must conclude that these cyclopoids are marine but able to tolerate both fresh and brackish waters. Unfortunately only immature, and therefore unidentifiable, specimens were obtained.

Discussion

Although approximately 95% of Antarctica is permanently ice-covered, the vast continent contains innumerable water bodies. Organized antarctic limnological research is only of recent origin, however, and knowledge of both environments and biocoenoses is extremely limited. Species lists for any area are likely to reflect the thoroughness of collecting rather than the actual flora and fauna present. This investigation has provided valuable information on a new area. It has proven to be particularly valuable in that unusual environments have been described, and new additions made to the lists of known genera and species. Detailed examination of the flora and fauna samples will show, no doubt, a considerable southward extension of the known range of many species.

Desmids, generally abundant in the Arctic, are rare in Antarctica. In a review (1972), I suggested that the distribution probably reflected the ability of these algae to survive dispersal across wide oceanic areas rather than differences in severity of Arctic and Antarctic environments. Observations on the five species discovered in the Ablation Point area certainly indicate that certain species at least can thrive under the particularly harsh régime of Antarctic streams and seepage runnels.

Littlepage & Pearce (1962) were the first to demonstrate that a relatively rich and diverse benthic fauna could exist under an Antarctic ice shelf. They collected material from under the Ross Ice Shelf 28 km from the open sea. The discovery of a marine biome in the Ablation Point area is still remarkable, however, for the problems of obtaining enough food 100 km (or perhaps 335 km!) from the open sea are far greater than when merely 28 km away.

The discovery of a marine fish in Ablation Lake must not overshadow the importance of finding a freshwater calanoid in the lake as well. The low levels of primary production recorded and the physicochemical evidence (Goldman 1964; Goldman, Mason & Hobbie 1967; Heywood, this paper) suggest that the upper freshwater layers of Ablation Lake and Lake Bonney and Lake Vanda, two ectogenic meromictic lakes in South Victoria Land (77° 39′ S, 162° 52′ E), are environments of similar severity. So copepods (and other crustaceans?) could apparently colonize the McMurdo Sound–South Victoria Land dry valleys area, if they could get there. This is further evidence that the distribution of organisms within Antarctica is largely a function of dispersal difficulties and environmental conditions in particular lakes and not one of latitude.

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REFERENCES (Heywood)

Elliott, M. H. 1974 Stratigraphy and sedimentary petrology of the Ablation Point area, Alexander Island. *Br. Antarctic Surv. Bull.* **39**, 87–113.

Goldman, C. R. 1963 The measurement of primary productivity and limiting factors in freshwater with C^{14}. In *Proceedings of a conference on primary productivity measurements* (ed. M. S. Doty). U.S.A.E.C. publication TID-7633, 103–113.

Goldman, C. R. 1964 Primary productivity studies in antarctic lakes. In *Biologie antarctique* (eds R. Carrick, M. W. Holdgate & J. Prevost), pp. 291–299. Paris: Hermann.

Goldman, C. R., Mason, D. T. & Hobbie, J. E. 1967 Two antarctic desert lakes. *Limnol. Oceanogr.* **12**, 295–310.

Heywood, R. B. 1972 Antarctic limnology: a review. *Br. Antarctic Surv. Bull.* **29**, 35–65.

Heywood, R. B. 1977 The correct identity of a *Pseudoboeckella* sp. (Copepoda, Calanoida) from Signy Island, South Orkney Islands. *Br. Antarctic Surv. Bull.* **45**.

Heywood, R. B. & Light, J. J. 1975 First direct evidence of life under antarctic shelf ice. *Nature, Lond.* **254**, 591–592.

Light, J. J. & Heywood, R. B. 1973 Deep-water mosses in antarctic lakes. *Nature, Lond.* **242**, 535–536.

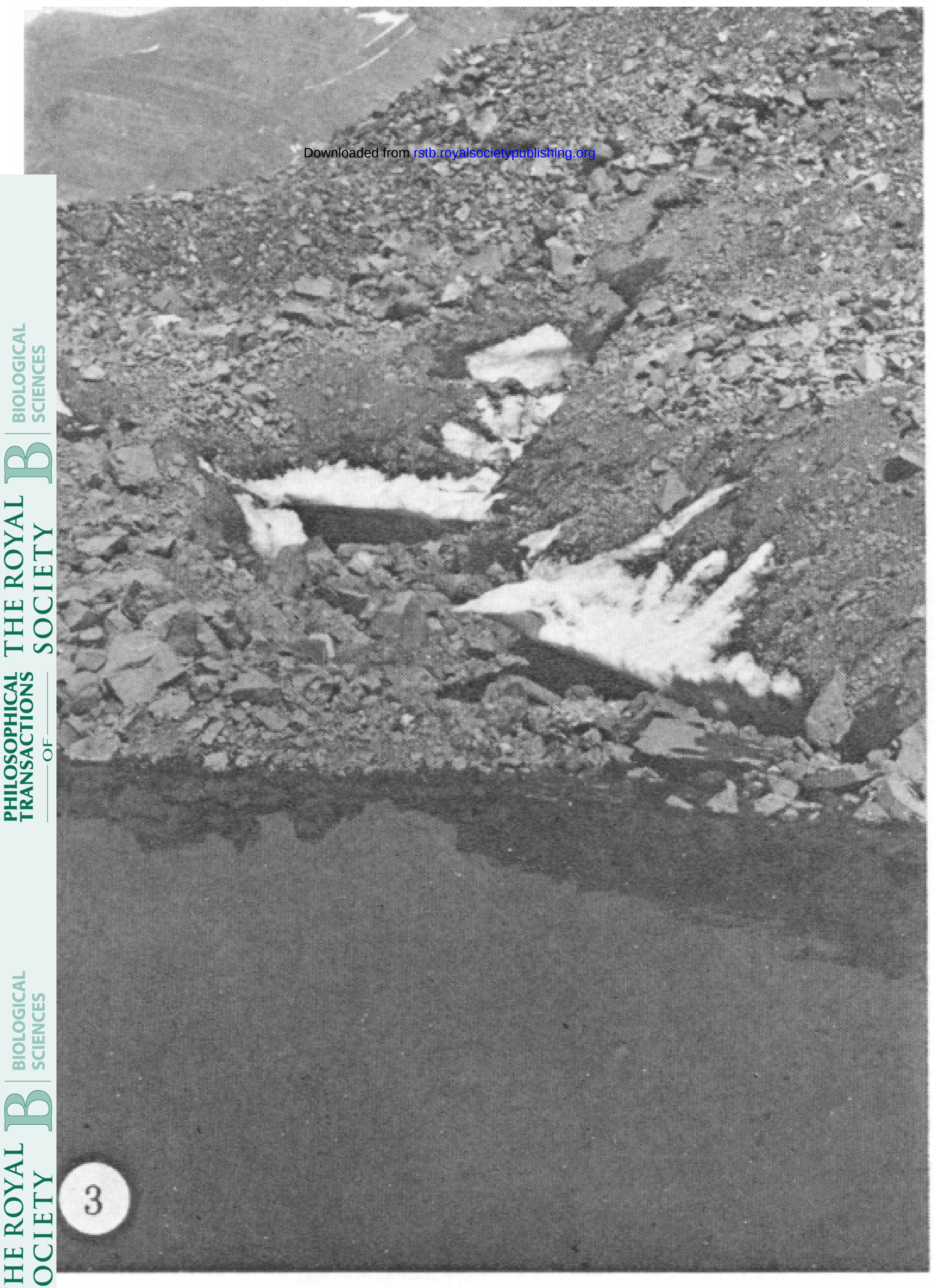
Light, J. J. & Heywood, R. B. 1975 Is the vegetation of continental Antarctica predominantly aquatic? *Nature, Lond.* **256**, 199–200.

Littlepage, J. L. & Pearce, J. S. 1962 Biological and oceanographic observations under an antarctic ice shelf. *Science, N.Y.* **137**, 679–681.

Mackereth, F. J. H. 1963 Some methods of water analysis for limnologists. *Scient. Publs Freshwat. biol. Ass.* No. 21, 70 pp.

Simonov, I. M. 1963 Prilivnyye yavleniya v morskikh zalivakh oazisa Shirmakhera [Tidal phenomenon in the sea inlets of the Schirmacher Ponds]. *Inf. Byull. sov. antarkt. Eksped.* **41**, 25–26. [English translation: **4**, No. 6, 1964, 328–329].

Vollenweider, R. A. 1969 *A manual on methods for measuring primary production in aquatic environments*. IBP Handbook No. 12, pp. 22–25. Oxford: Blackwell Scientific Publications.



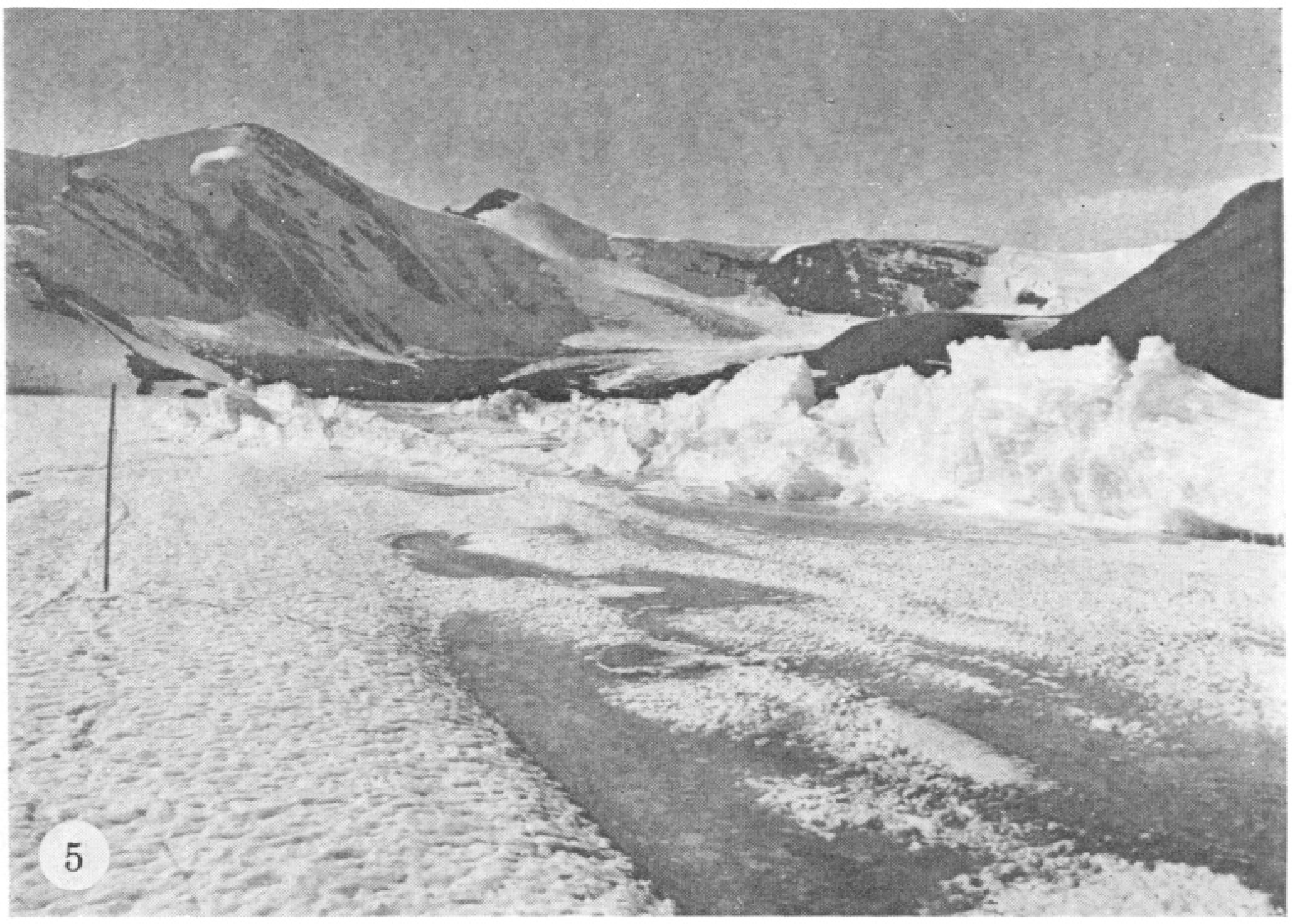


FIGURE 2. Aerial photograph of Ablation Point area. George VI Sound lies in the foreground. (Photography flown by the U.S. Navy for the U.S. Geological Survey.)

FIGURE 3. Exposed ice of the moraines.

FIGURE 5. Ridges of ice along the shore of Ablation Lake pushed up by pressure from the ice shelf tongue.