VARIATIONS IN IONIC COMPOSITION BETWEEN HIGH ARCTIC LAKE AND LAND SNOWPACK

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ABSTRACT

The premelt snowpacks beside and on Colour Lake, Axel Heiberg Island, NWT., proved to be similar in terms of water equivalent and stratigraphy but distinct in terms of concentration of major ions. The base of the lake snowpack showed a marked concentration of most major ions. Because of the distinctive chemical "signature" of Colour Lake, it is evident that the origin of these ions is lake water. It is suggested that the lake water was incorporated into the snow during slushing and white ice formation early in the development of the 1.5m ice sheet. It is also suggested that the incorporation of lake-derived ions into snowpack may be a normal feature of the white ice forming process. It is apparent in this case because of the distinctive chemistry of the lake and because horizontal, as well as vertical, snow samples were used.

Study Area

The Colour Lake drainage basin (Fig. 1) is situated in the west-central region of Axel Heiberg Island (79°25'N, 90°35'W), at an elevation of 176m a.s.l. Colour Lake is, with two headwater ponds called the Crusoe Lakes, the only non-ice dammed lake on the 1:50,000 map sheet of the Expedition Fiord area. Morphometric and physiographic indices of the Lake and its surrounding drainage basin are given in Table 1. The lake is located at the boundary of the Heiberg, Savik and Awingak formations. The first and last of these consist mainly of sandstones and shales, the Savik formation also contains some limestones and calcareous shales. Glacial deposits occur at several locations within the basin. Gypsum domes and sulfur springs are also found within or near the catchment area. (Fricker 1963a, 1963b).

Axel Heiberg's climate is cold and semi-arid. Weather observations at the lake compared with those at Isachsen and Eureka, are generally warmer, (1-2°C warmer than Eureka, 3.5-4.5°C warmer than Isachsen), considerably wetter (twice the precipitation), much less windy, (less than half the mean speed) with about the same amount of daily overcast (Caflish, 1970). The snowcover is usually very thin, 5-50 cm., w.e., with numerous exposed ridges. Much of the land surface is bare at the end of the winter and a great deal of the snowpack is found in small hollows and lee locations. Snow depth can therefore vary greatly over great distances (Young 1972).

Methods

Standard methods were used to determine depth and water equivalence. Snow stratigraphy, from pits on land and lake, was determined using techniques from Adams and Barr 1974. Premelt snow samples were collected bi-weekly at three sites on land and lake (Fig. 2). A vertical profile of samples from fresh pit faces was collected, using a plastic scoop, in plastic bags. On melting, some of the sample was placed in nalgene bottles for later analysis, 150ml. was used for onsite conductance and pH measurement. A Barnstead conductivity bridge, model PM 7CCB corrected to 25°C, was used for conductance, an Orion Mk.111 digital pH meter, standardized to buffers of pH4 and 7, for pH. Samples were kept cool for no longer than three weeks prior to analysis at the M.O.E. Laboratory, Toronto, using techniques from Outlines for Analytical Methods (M.O.E. 1981). The ice cover of Colour Lake was sampled with a SIPRE corer (Crocker, 1984). The white and black ice thickness and hydrostatic water level at each site were determined by methods outlined in Adams, 1984. Ice cores were transferred to plastic bags and treated in the same manner as snow samples. Lake water samples were obtained with a peristaltic pump.

Results

Snow depth, water equivalence and density did not differ significantly between the land and the lake snowcourses (Mann-Whitney U, $p=0.5$), (Table 2). Snow stratigraphy profiles from May 9 are remarkably similar at the two sites. Both exhibit an underlying 11cm 2g/cm), large crystal (4mm) basal depth hoar layer overlain by a smaller grained (1-2mm), denser, (.38-.42g/cm^3) layer of wind crust approximately 2cm thick. The terrestrial site was overlain by a further 9cm of wind crust while the lake was overlain by 7cm of broken, wind eroded depth hoar crystals. The surface layer of both snowpacks consisted of a layer of newly deposited, fine grained (.5mm), low density(.2g/cm^3), snow crystals (Fig. 3).

Ionic composition of both lake and land snowcover was quite variable (Table 3). The lake snowcover was significantly enriched in all major ions except Cl^-. Profiles of both conductance and pH indicate that the lake's depth hoar layer contained substantially higher concentrations of ions than overlying layers. Conductance and pH profiles of the terrestrial snowpack were relatively uniform (Fig. 3). The ice cover had a mean total thickness of 151.5cm (Table 4). Ninety three percent, or 142.4cm., consisted of black ice with an 8.35cm layer of white ice. Major ion concentrations from three ice cores indicate a disproportionate concentration of major ions in the white ice layer (Table 4). The ionic concentrations in the upper water stratum are presented in Table 5. The lake water is extremely hard (249-260mg/l as $CaCo_3$), yet with a very low pH (3.75-3.85). The sulfur spring activity in the region may afford some explanation for this apparent contradiction.

Discussion

The relative similarity of land and lake snowpacks in terms of physical measures may be due to the location of the land snowcourse in a slight hollow. There was more variance on land than lake (Table 2). Both packs resembled Benson et al's (1975) generalized high latitude stratigraphy. The depth hoar layer is typical of High Arctic packs where high temperature gradients result in high vapour gradients (see Bergen 1978, Giddings and LaChapelle 1962, Santeford 1978, Woo 1982a). Such gradients are also typical of lake snow environments (Adams et al 1985).

White ice is not a common component of High Arctic lake ice cover because of the low snowfall, high wind speeds and rapid black ice growth (Rigler 1978). A snowfall in the fall or early winter of 1983, on a thin ice cover, must have caused flooding of the snow through cracks in the ice cover (Shaw 1965). The distinctive chemical "signature" of Colour Lake water is reflected strongly in the white ice (Table 3) and lake snow cover (Table 2). From pH and conductance profiles of the lake snow pack it is evident that the depth hoar layer has a disproportionate share of major ions as compared to the overlying layers of the snowpack (Fig. 3). It is likely that when the lake water flooded upwards into the overlying snowpack, white ice was formed in the saturated lower pack, while residual lake water, above this layer, became incorporated into the snowpack and underwent constructive metamorphism, forming the depth hoar crystals. It is well documented that the white ice component of a winter lake cover often has higher ion concentrations than the relatively dilute black ice component (Adams and Lasenby 1985, Kingsbury 1984, Barica and Armstrong 1971), but the influence of white ice formation on the portion of the snowpack that does <u>not</u> form white ice has not been documented. The effect, which is likely a general one, is apparent here because of the distinctive chemistry of the lake.

There are three major implications of this phenomenon. The higher ionic strength of the lake snowcover leads to a disproportionate loading rate from this source as compared to the terrestrial snowcover. This must be taken into account, particularly on lakes of high ionic strength and where lake surface/catchment area and lake surface/volume rations are large. Lake snowcover in some studies has been assumed to reflect truer atmospheric loadings than terrestrial snowcover (Shewchuk 1984) where canopy and microbiological effects alter the snowpack chemistry (Jones 1985, Jones and Showchanska 1985). The influence on the snowcover of lake slushing events, incorporating a portion of the snowpack as white ice and chemically altering the remaining snowpack, places this assumption in some doubt. A third and final implication of this phenomenon, particularly in the Arctic, is a sampling consideration. An intact vertical profile must be obtained if a true measure of the accumulated ions of a snowpack is to be realized. Because of the relatively fragile nature of the basal depth hoar layer, crystals are often lost from the bottom of sampling tubes (H.E. Welch, personal communication, C. Allan, personal observation). Because of the disproportionate ionic strength of the lake's depth hoar layer, this could lead to a significant error in calculating the accumulated ion loading from a winter's snowcover. The snow must be sampled so that each layer is properly represented. A device such as that described by Crocker and Lewis (1985) would be useful.

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TABLE 1

Morphometric values for the Colour Lake drainage basin*

Drainage Basin Area	0.8	km^2
Lake Surface Area	10.21	ha
Lake Volume	1,034,570	m^3
Mean Depth	10.1	m
Maximum Depth	24.0	m
Maximum Width	650	m
Mean Width	157	m
Shoreline Length	1,500	m
Shoreline Development	1.3	
Drainage Basin/Lake Surface Area	7.8	
Volume Development	.72	

*From Caflish, 1972.

TABLE 5

1984 Colour Lake Water Chemistry

Depth*	Cond at 25°C (umhos cm)	pH	Ca^{+2} (mg/l)	Mg^{+2} (mg/l)	Na^{+} (mg/l)	K^{+} (mg/l)	Cl^{-} (mg/l)	$SO4^{-2}$ (mg/l)
0	615.53	3.75	72.2	18.6	10.8	4.54	.80	245.4
1	601.75	3.85	70.4	18.3	7.56	4.52	.81	224.7
2	633.71	3.8	71.0	18.7	6.1	4.36	.73	238.5

*Depth in metres below ice cover

TABLE 4

1984 Colour Lake Ice Data

Total Ice (n=37), $\bar{x}$= 151.1cm, Std.Dev.=10.87 White Ice (n=47), $\bar{x}$= 8.35cm, Std.Dev.=3.2

Black Ice (n=37), $\bar{x}$= 142cm, Std.Dev.=9.76

Ice Core	Depth[1]	Cond 25°C (umhos/cm³)	pH	Ca^{+2} (mg/l)	Mg^{+2} (mg/l)	Na^{+} (mg/l)	K^{+} (mg/l)	Cl^{-} (mg/l)	$SO4^{-2}$ (mg/l)
Ice Core A8	* 0-10	378.64	3.50	40.2	5.62	6.46	1.56	.36	242.30
	10-22.3	23.44	4.75	2.1	.56	.40	.28	.27	6.33
	22.3-40	44.04	4.00	.7	.14	8.36	.12	.07	9.07
	40-58	4.61	4.85	.7	.10	5.56	.14	.21	1.16
	58-80	5.00	4.80	.4	.10	.20	.14	.19	1.91
	80-92	5.48	4.80	.2	.00	1.16	.06	.14	5.36
	92-108.5	7.51	4.80	.5	.12	.10	.06	.25	2.29
	108.5-128.5	14.91	5.40	1.3	.32	.30	.14	.15	11.07
Ice Core B4	* 0-11	247.85	4.20	26.5	6.58	1.60	1.52	.26	98.10
	11-30	24.61	4.49	1.2	.24	3.70	.22	.25	5.50
	30-50	3.06	4.90	.5	.06	.16	.10	.22	1.07
	50-74	5.24	4.75	.3	.04	.26	.20	.29	.83
	74-95	8.04	4.75	.4	.06	.56	.38	.41	3.25
	95-118	11.56	4.45	.2	.04	2.26	.14	.41	1.83
	118-148	13.48	5.10	.9	.16	.76	.18	.41	3.60
Ice Core B5	* 0-11.5	114.95	4.40	12.3	2.88	2.30	.66	.18	45.86
	11.5-42.5	28.05	4.70	2.6	.60	.26	.20	.24	9.47
	42.5-66.5	3.39	4.90	.2	.00	4.40	.06	.25	2.14
	66.5-84.5	3.75	4.75	.6	.10	8.00	.06	.13	3.07
	84.5-102.5	11.93	4.55	.2	.04	7.56	.04	.31	10.01
	102.5-122.5	3.17	4.90	.0	.06	.40	.04	.17	1.38
	122.5-154.5	9.39	4.80	1.0	.18	.20	.14	.25	1.82

*White ice layer [1]Depth in cm.

TABLE 2 May 9, 1984 Snow survey results from the Gordon Creek terrestrial snow course and the Colour Lake snow course

Gordon Creek (n = 7)

Snow Depth (cm)		Water Equivalence (cm)		Density (g/cm^3)	
$\bar{x}$ =	27.61	$\bar{x}$ =	6.04	$\bar{x}$ =	.21
Range =	63.5	Range =	16.76	Range =	.15
Max =	63.5	Max =	16.76	Max =	.26
Min =	0.0	Min =	0.0	Min =	.11
Std.Dev.=	21.67	Std. Dev. =	5.53	Std. Dev.=	.067

Colour Lake (n = 12)

Snow Depth (cm)		Water Equivalence (cm)		Density (g/cm^3)	
$\bar{x}$ =	23.89	$\bar{x}$ =	5.67	$\bar{x}$=	.23
Range=	20.32	Range=	7.87	Range=	.13
Max =	34.54	Max =	10.16	Max=	.29
Min =	14.32	Min =	2.29	Min=	.16
Std.Dev.=	6.24	Std. Dev. =	2.41	Std. Dev.=	.044

TABLE 3 1984 Axel Heiberg Snow Chemistry

Site	Date	Condat 25°C (umhos cm^3)	pH	Ca^{+2} (mg/l)	Mg^{+2} (mg/l)	Na^{+} (mg/l)	K^{+} (mg/l)	Cl^{-} (mg/l)	SO_4^{-2} (mg/l)
Terrestrial Snow Samples									
GC1	May 4	4.92	5.25	0.60	.040	.200	.060	.27	1.26
GC5	"	8.63	5.00	1.70	.140	.400	.220	.42	1.91
GC3	"	4.73	5.34	0.60	.080	.500	.080	.22	2.94
GC5	May 9	*	5.09	0.90	.080	.200	.100	.41	3.47
GC3	"	29.27	5.34	0.60	.140	.000	.060	.13	2.40
GC1	"	35.44	5.65	0.50	.060	.000	.000	.11	1.21
GC1	May 18	6.63	5.20	0.71	.110	.190	.050	.20	1.35
GC3	"	*	*	0.52	.080	.130	.055	.15	1.00
GC5	"	*	*	0.81	.135	.235	.050	.30	2.00
GC5	May 29	9.07	5.35	1.06	.100	.330	.130	.33	1.80
GC1	"	5.56	5.05	0.34	.060	.090	.050	.12	1.05
GC3	"	7.34	5.40	1.08	.155	.150	.170	.94	4.65
x =		12.40	5.27	.79	.098	.202	.085	.30	2.09
std dev =		11.52	.19	.37	.038	.150	.061	.23	1.12
Colour Lake Snow Samples									
A10	May 4	47.62	4.35	3.10	.600	.460	.180	.33	10.17
A8	"	18.21	4.50	1.50	.380	.200	.120	.32	9.66
A6	"	238.19	3.95	22.30	11.500	2.800	.268	.77	96.70
A9	May 18	235.88	4.05	18.50	8.880	2.320	2.000	.72	93.00
A7	"	34.88	4.70	3.30	.775	.515	.165	.31	14.70
A8	"	51.61	4.81	2.95	.725	.700	.245	.34	19.20
A8	May 29	24.60	4.95	2.19	.600	.265	.175	.23	8.05
A7	"	86.95	4.50	7.30	2.500	.810	.875	.59	32.00
A9	"	43.00	4.65	3.25	1.200	.510	.330	.26	33.24
X =		86.77	4.50	7.15	3.018	.953	.484	.43	35.19
Std. Dev.		87.39	.33	7.74	4.166	.938	.612	.21	35.05

* Missing

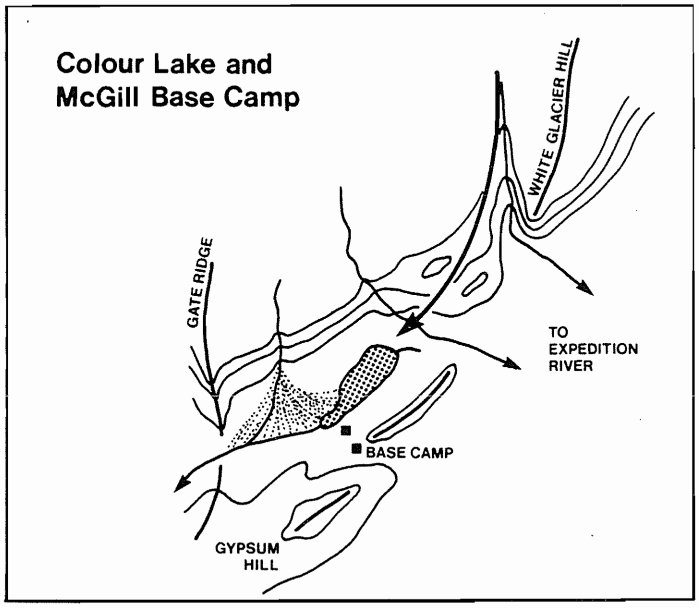
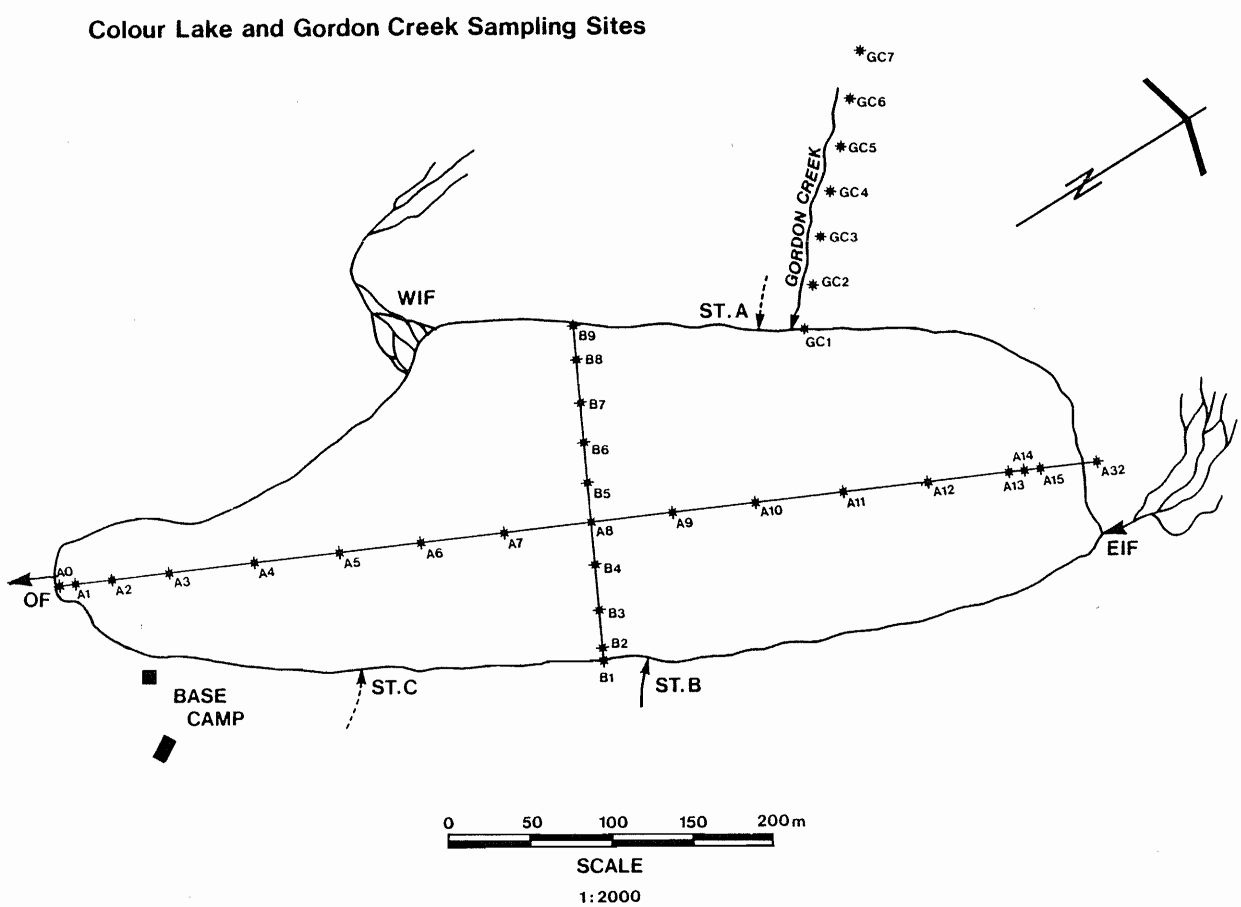


Figure 1
Location of Colour Lake, Expedition Fiord, on the western side of Axel Heiberg Island, N.W.T. (after Caflish, 1972).

Figure 2 The 1984 Gordon Creek snow course and Colour Lake sampling sites



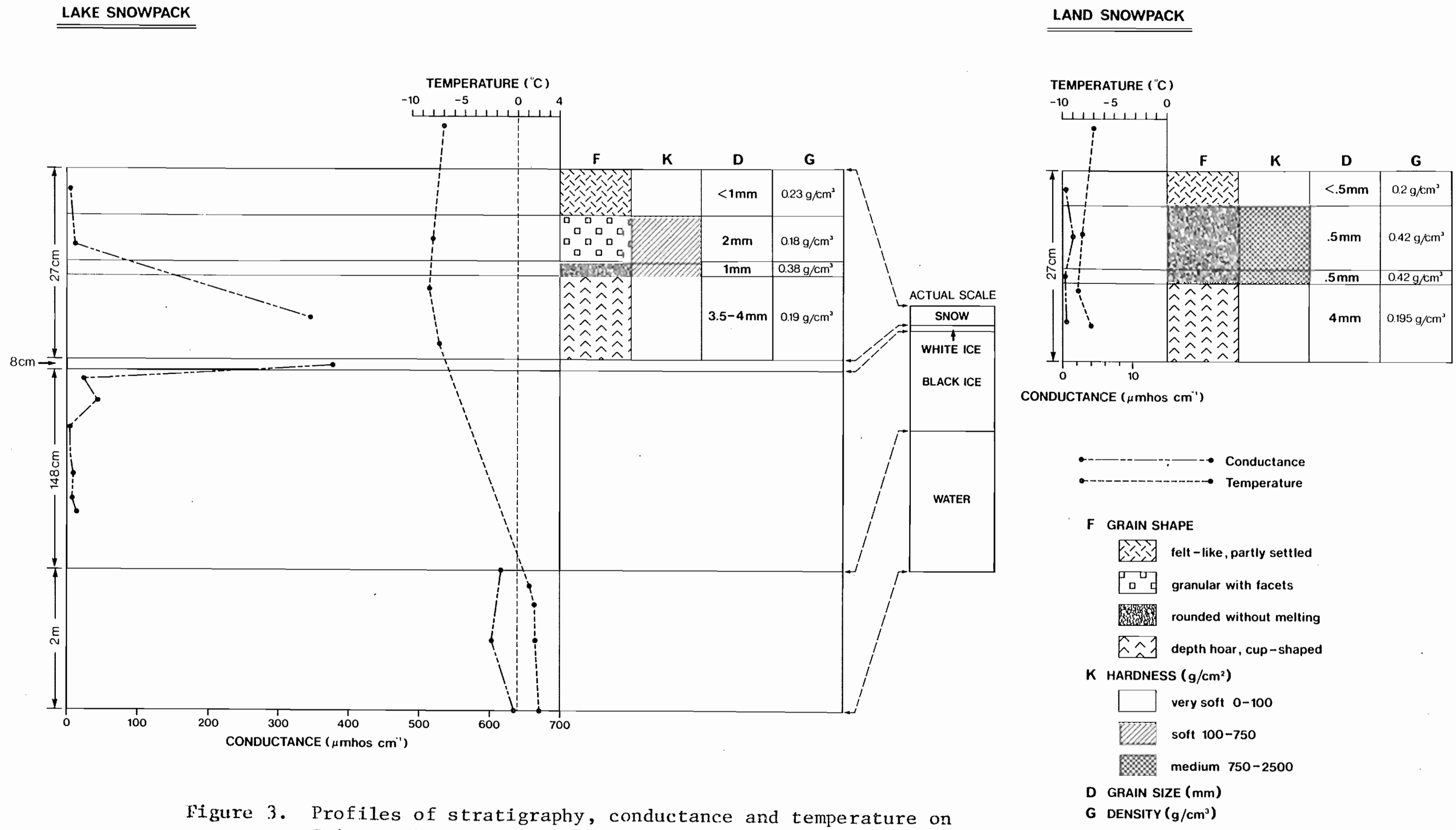


Figure 3. Profiles of stratigraphy, conductance and temperature on Colour Lake and on nearby land, May 1984. Note that white ice and snow thicknesses are exaggerated on the lake to bring out the main point of the paper.