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A Reconnaissance Survey of the Environmental Chemistry in East-Central Ellesmere Island, N.W.T.

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ABSTRACT. Snow-pack and surface water samples were collected from east-central Ellesmere Island near Cape Herschel between May and August in 1979-81 to ascertain whether anthropogenic pollution was detectable in a remote "pristine" arctic environment. Snow-pack samples were analyzed for organochlorine pesticide residues, polynuclear aromatic hydrocarbons, and chlorophenoxy acid herbicides. Precipitation and surface water samples were analyzed to determine whether the region has been subjected to "acid rain". In addition, the surface water samples were analyzed for as many as 35 inorganic parameters to provide background data on the water quality of the region.

Measurable concentrations of Lindane (γ-BHC) and its isomer α-BHC, HEOD (dieldrin), and DDT were detected at a number of sites, but no polynuclear aromatic hydrocarbons (PAHs) or chlorophenoxy acid herbicides were detected. The pattern of pesticide residues observed in arctic snow-pack is similar to that present in precipitation in southern Canada, although the concentrations are lower. The presence of a variety of pesticide residues in this remote area of the Arctic is presumptive evidence that the residues are globally dispersed through the atmosphere. Only copper and the lithophilic metals aluminum and iron were consistently detectable in the snow-pack and surface water samples; all other metals were at or below their detection limits. Thus anthropogenic inputs of metal contaminants such as arsenic, cadmium, lead, mercury, selenium, and vanadium, via atmospheric deposition, were not detected in this region. Although "acid rain" was not in evidence in the study area, the surface waters of the local ponds and lakes, many of which are ombrogenic, are potentially susceptible to changes in the acidity of the atmospheric aerosol of the high Arctic.

Key words: snow-pack, precipitation, pesticides, PAHs, acid rain, water chemistry, metals, Arctic, Ellesmere Island

RÉSUMÉ. Des échantillons du manteau nival et de l'eau de surface ont été recueillis à l'est du centre de l'île d'Ellesmere près du cap Herschel entre mai et août en 1979-81, en vue de vérifier s'il est possible de relever des preuves de pollution anthropogène dans un milieu arctique "virginal" et éloigné. Les échantillons du manteau nival furent analysés pour des résidus de pesticides organochlorés, des hydrocarbures aromatiques polynucléaires et des herbicides acidiques chlorophénoxiques. Les échantillons de précipitation et d'eau de surface furent analysés en vue de déterminer si la région a été proie aux pluis acides. De plus, les échantillons d'eau de surface ont été analysés pour jusqu'à 35 paramètres inorganiques afin d'obtenir des données fondamentales sur la qualité de l'eau dans la région.

Des concentrations mesurables de Lindane (γ-BHC) et de son isomère α-BHC, de HEOD (dieldrine) et de DDT furent relevées à plusieurs des sites, mais aucune hydrocarbure aromatique polynucléaire (HAP) et aucun herbicide acidique chlorophénoxique ne furent décelés. La distribution de résidus de pesticides observée dans le manteau nival arctique est semblable à celle dans la précipitation du sud du Canada, bien que les concentrations sont moins élevées dans l'Arctique. La présence d'une variété de résidus de pesticides dans cette région éloignée de l'Arctique est une preuve qui laisse à présumer que les résidus sont dispersés partout sur le globe à travers l'atmosphère. Seuls les métaux lithophiles (l'aluminium et le fer) et le cuivre apparaissaient de façon consistante dans les échantillons d'eau de surface et de neige; tous les autres métaux ne figuraient qu'à leurs limites minimales de détection ou en-dessous de celle-ci. Des entrées anthropogènes de contaminants métalliques tels l'arsenic, le cadmium, la plomb, le mercure, le sélénium et le vanadium par dépôt atmosphérique ne furent donc pas décelés dans cette région. Bien qu'il n'y avait aucune évidence de pluis acides dans la région d'étude, l'eau de surface des étangs et des lacs locaux, dont bon nombre sont ombrogènes, peut être susceptible à des changements d'acidité d'aerosol atmosphérique du nord de l'Arctique.

Mots clés: manteau nival, précipitation, pesticides, HAP, pluis acides, chimie aquatique, métaux, Arctique, l'île d'Ellesmere

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INTRODUCTION

Global pollution from the industrial activities of man has been well documented, but most of the information has come from the low to mid-latitudes of the northern hemisphere and very little information has been available from the Arctic. In mid-1979 an opportunity to collect environmental samples from the high Arctic was used to supplement our meagre arctic data base. The objective of the study was to ascertain whether anthropogenic pollution was detectable in a remote "pristine" arctic environment. Snow-pack samples were collected and analyzed for synthetic organic residues and metals. Precipitation samples and surface water samples were collected and analyzed to determine whether the region was susceptible to, or had already been influenced by, "acid rain". In addition, because so little is known about most of the high Arctic, the surface water samples were analyzed for a wide variety of parameters to provide background data on the water quality of the region.

The global nature of industrial pollution has been emphasized in recent literature and there has been an increasing awareness of global contamination by Long-Range Transport of Air Pollutants (LRTAP) (Glotfelty, 1978; Rahn and McCaffrey, 1979a; Kerr, 1979, 1981). The dispersal of many types of synthetic organic compounds through the atmosphere to contaminate regions remote from their original sources has been documented (Harvey and Steinhauer, 1974; Gummer, 1979). Compounds such as DDT have been detected all over the world including Antarctica and most recently in an isolated walrus population from West Greenland (Born *et al.*, 1981).

An atmospheric fallout rate of 0.6 tonnes polynuclear aromatic hydrocarbons (PAHs) per annum was estimated on a global basis for the early 1970s (NAS, 1972) and PAHs have been detected in marine sediments from Greenland and the Mackenzie River–Beaufort Sea areas (Suess, 1976; Stich and Dunn, 1980). Although PAHs tend to degrade rapidly in the atmosphere in intense sunlight (Bjorseth *et al.*, 1979), the rate of photochemical breakdown of any PAHs deposited in snowfalls during the arctic winter should be substantially reduced because of the low intensity of UV-radiation and cold temperatures. Hence winter snow-pack could provide the best

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opportunity for detecting whether anthropogenic PAHs and pesticides are being deposited in this region. Although precipitation samples have been collected and analyzed for synthetic organic compounds from monitoring sites across southern Canada under the Canadian Network for Sampling Organic Compounds (CANSOC) program (Whelpdale and Barrie, 1982), none have been collected from the Arctic.

Special studies on arctic aerosols have been carried out at Mould Bay and Igloolik in the Canadian Arctic (Barrie *et al.*, 1981); on the north coast of Alaska (Rahn and McCaffrey, 1979b); and in northern Greenland (Flyger and Heidam, 1978). Environment Canada maintains two atmospheric sampling stations in the Northwest Territories, one at Inuvik (Mackenzie River delta) and another at Mould Bay (Prince Patrick Island, western Arctic), in support of the Canadian Network for Sampling Precipitation (CANSAP) program which is concerned primarily with the phenomenon of acidic precipitation (Berry, 1979; Whelpdale and Barrie, 1982). As the extent of this phenomenon becomes clearer the identification of potentially sensitive regions increases in importance. Although the majority of environmental studies in arctic North America have been carried out in Alaska and the Mackenzie River–Beaufort Sea areas, some studies have been done on the Queen Elizabeth Islands. Two major International Biological Programme projects have been undertaken in the high Arctic: one at Char Lake near Resolute, Cornwallis Island (Schindler *et al.*, 1974), on an aquatic ecosystem; the other on the Truelove Lowland, Devon Island, on the Tundra Biome which included some limnological studies (Bliss, 1977). Ivarson (1975) has carried out studies in the Lake Hazen area, and Toth and Lerman (1975) have studied lakes on northern Ellesmere Island.

Because most regions of the Arctic are remote from the production and use of virtually all synthetic organic compounds, samples from this pristine environment provide useful information concerning the extent of global contamination via the atmospheric transport of pollutants. This study also provides background information on metals and general water chemistry relevant to LRTAP, on regional sensitivity to acid rain, and on high-arctic ecosystem research.

STUDY AREA

The study area consists of approximately 8300 km² on the east-central coast of Ellesmere Island (Fig. 1), at the southern extremity of the Kane Basin, just north of Baffin Bay. Baird Inlet delineates its southern margin (78°30′N) and Bache Peninsula and Flagler Bay the northern margin (79°10′N). The study area (Fig. 2) extends inland as far as the heads of Beitstad and Jokel Fiords (79°W). The coastal terrain is rugged with local relief of more than 1900 m; along much of the coastline vertical cliffs rise 200-300 m out of the sea.

At least 65% of the landmass within the study area is covered by glaciers; many valley glaciers extend to sea level (e.g., Ekblaw Glacier in Baird Inlet). Blake (1978, 1981, 1982) has investigated the glacial history of the area and Watts (1981) has described some of the weathering phenomena in the Alexandra Fiord and Buchanan Bay area.

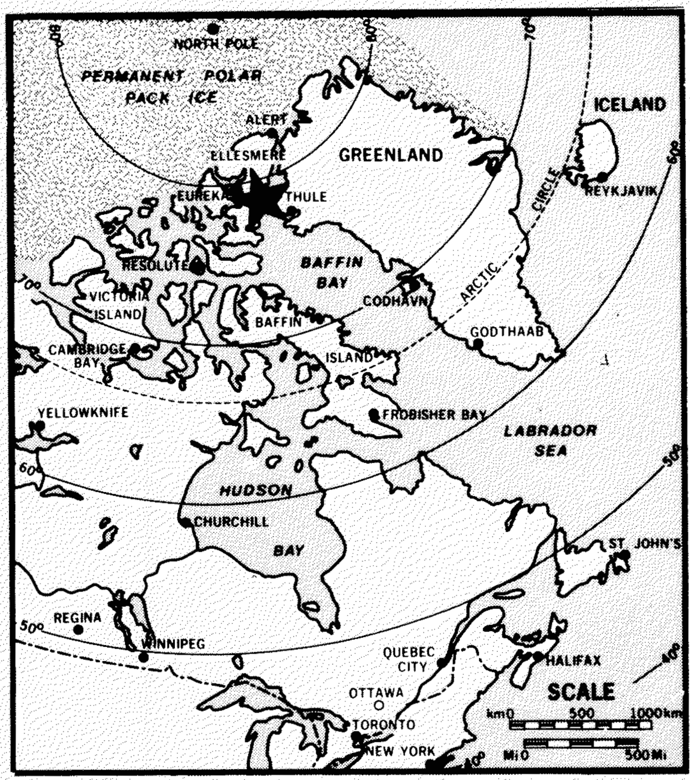

FIG. 1. Index map of the study area.

The bedrock geology was mapped by Christie (1967) and later in more detail by Kerr (1972a, b) and Frisch *et al.* (1978). The Precambrian-Palaeozoic boundary trends east-west across the northern third of the study area (Fig. 3). Precambrian granites and gneissic metasediments crop out along the southern coasts of Bache and Knud peninsulas, whereas Palaeozoic carbonates and clastics lie above and to the north of the Precambrian outcrops. All of the sites sampled lie to the south of this contact, except for sites 9 and 22. A few additional sites are close to and below the Palaeozoic contact and therefore are influenced by the marked change in lithology.

METHODS AND MATERIALS

Study Methods

Samples were collected during May, June, and July in 1979, 1980, and 1981 as an adjunct to a study of glacial history being carried out by the Geological Survey of Canada in the Cape Herschel area (Blake, 1982). The sites sampled are illustrated in Figure 2. In late May and June 1979, snow-pack samples were collected from five sites; samples of fresh snow from three sites; and rime frost from an additional two sites. Precipitation samples, including fresh snow, rain, and rime frost, were collected at two sites in 1981. Surface water samples were collected from ponds, lakes, and streams within the study area. Bodies of standing water < 1-2 m deep, which freeze to the bottom during the winter and which were of no consequence in area, were called ponds, and those several metres deep, not frozen to the bottom during winter, or of considerable areal extent were considered lakes in this study (cf.

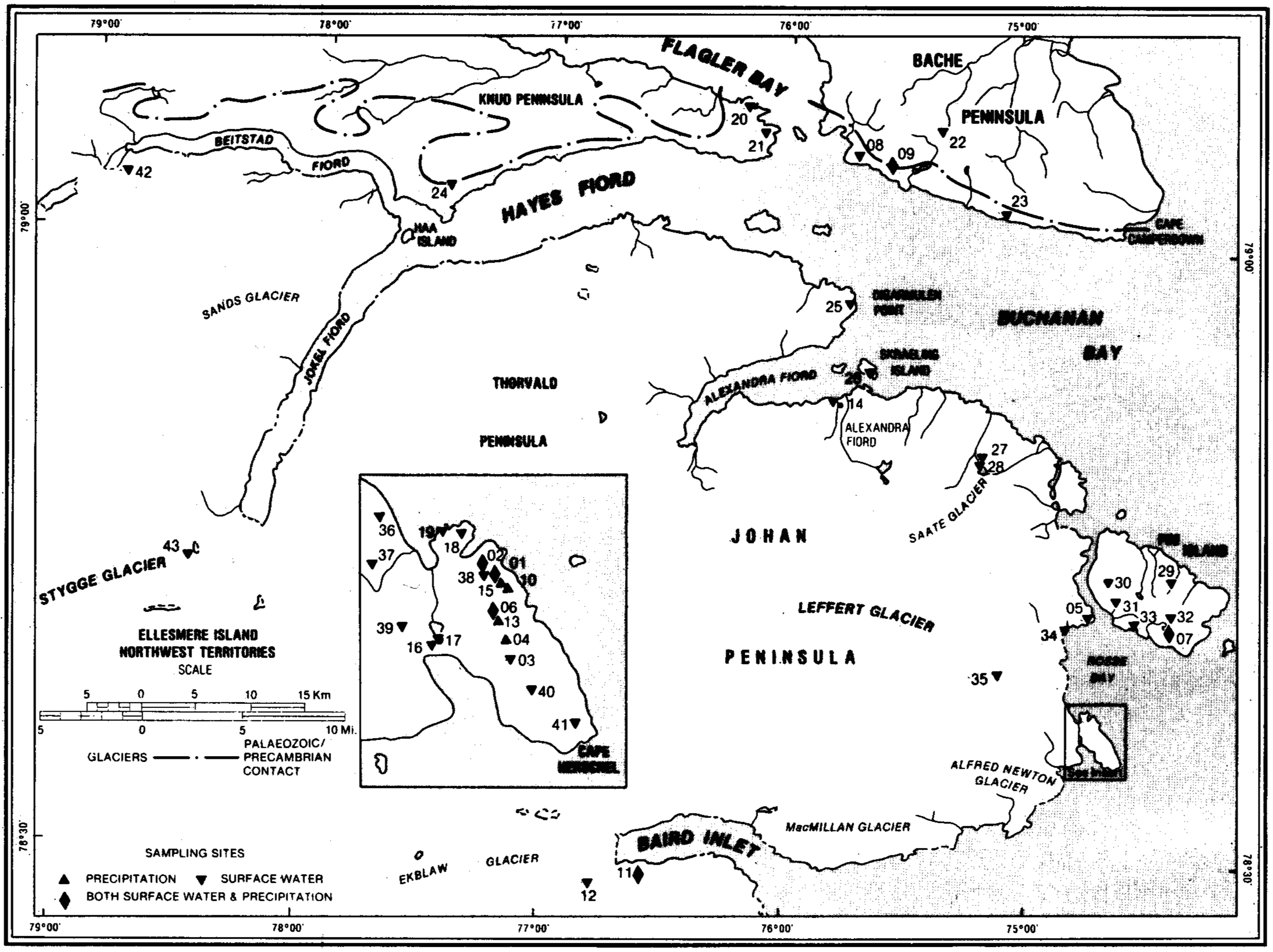

FIG. 2. Location map of sampling sites.

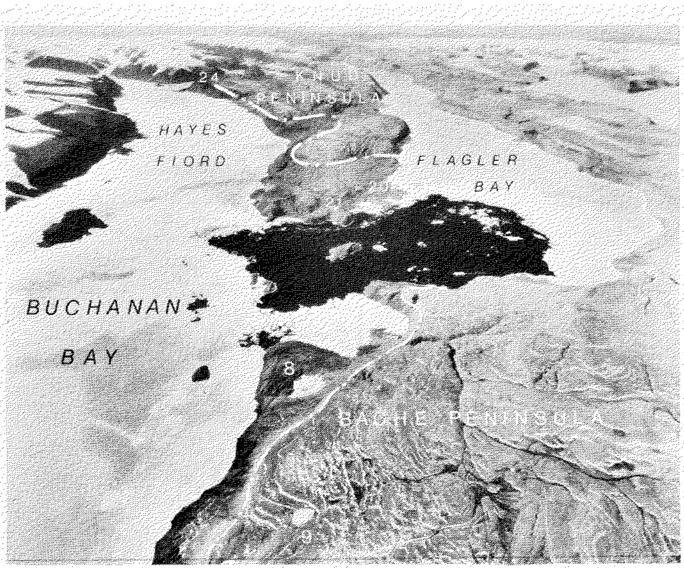

FIG. 3. A view looking westward from Bache Peninsula towards Knud Peninsula in the northern part of the study area. The Palaeozoic/Precambrian contact extends westward with the calcareous Palaeozoics above and to the north (right) of the boundary. Only site 9 lies on Palaeozoic bedrock; sites 8, 20, 21, and 24 lie on Precambrian basement yet are strongly influenced by the overlying Palaeozoic lithologies. The Arctic Institute's base camp is at site 20 on the western edge of a polynya at the mouth of Flagler Bay.

Hobbie, 1973). In 1973, 15 sites were sampled; two lake sites were sampled in 1980; and in 1981, five sites were revisited and 19 new sites sampled. More than one type of medium (e.g., snow-pack and water) was sampled at some sites.

Sampling Methods

Before sample containers were shipped to the field they were prepared as follows: both stainless steel and glass snow-pack sampling containers were washed in detergent and water, rinsed with demineralized water, and then rinsed twice with hexane. The containers were oven-dried and sealed with hexane-rinsed aluminum foil and a cap or lid. Glass bottles for the synthetic organic samples were washed with detergent and water in a dishwasher. The final rinse was demineralized water. The bottles were then rinsed with acetone and then hexane, dried overnight in an oven at 350°C, and sealed with hexane-rinsed aluminum foil and a teflon-lined cap. Polyethylene and Teflon bottles and caps were washed in "Nochromix" cleaning solution and rinsed four to five times with demineralized water. Glass and "sovirel" bottles were cleaned with a 5% sulphuric acid solution and then rinsed four to five times with demineralized water.

When sampling snow-pack on ponds and lakes, we cleared a trench to the ice surface using a shovel. The snow face to be sampled was then cut and cleaned with a stainless steel knife and scoop which had been rinsed in hexane (pesticide residue grade) and stored in hexane-cleaned aluminum foil. The snow-pack samples were collected in either a stainless steel bucket (20 × 20 × 40 cm) or a large-mouth glass bottle (20 cm dia. × 40 cm) by pushing these sampling containers into the snow face and then trimming off the front (top) edge of the snow with the stainless steel knife. When sampling snow cornices we pushed the containers directly into the snow after cleaning the cornice face with the scoop and knife. To eliminate the possibility of cross-contamination between samples the snow-pack sampling containers were used only once. Rime frost samples were hand-picked from their attachment surfaces with polyethylene gloves, and allowed to melt in a polyethylene, glass, or styrene bottle.

Snow-pack and fresh snow samples were stored at sub-zero temperatures, in the dark, until it was convenient to melt them at room temperature. The volume of water derived from the original 10-15 dm^3 of snow was variable and depended on the granularity (porosity) and "wetness" of the original sample. The water equivalent of the snow samples was 30-40% and therefore sufficient sample was usually available for the chemical analyses. The melted snow was poured into either a one-gallon amber-glass solvent bottle or 4 to 5 clear-glass 40-oz bottles. Sample transfer was accomplished using separate hexane-rinsed glass funnels for each sample. The funnels were wrapped in hexane-cleaned aluminum foil and stored in separate sealed plastic bags until used. Samples taken for organochlorine pesticide residues, PAHs, and PCBs were not preserved, whereas the samples for chlorophenoxy herbicides were preserved with sulphuric acid (5 ml conc. per 40-oz bottle). If sufficient sample volume was available, subsamples were taken for major ions (1-litre polyethylene), total phosphorus (50-ml glass "sovirel"), metals (1-litre Teflon), and mercury (250-ml Teflon) analyses.

A precipitation (snow) sample was collected at the base camp (site 15) in 1979 using a standard copper rain gauge (12.5 cm dia.) which had been thoroughly rinsed with distilled water. In 1981 precipitation samples were collected both in the standard rain gauge and in stainless steel trays (collector areas of 123 and 2400 cm^2, respectively). All sampling containers were thoroughly rinsed with distilled water before sampling each event. A portion of each rain or melted snow sample was transferred to a distilled-water-rinsed polyethylene bottle to be analyzed for physical parameters and major ions.

Water samples from ponds, lakes, and streams were collected at the surface of open water or through an augered hole in the ice. In all years, samples for major ion chemistry and physical parameters were taken in 1-litre polyethylene bottles. In 1979, 1-litre samples for metal analyses were taken in Teflon bottles and preserved (2 ml conc. HNO_3); 250 ml of sample was taken in Teflon bottles for mercury analyses and preserved (2 ml conc. HNO_3 or H_2SO_4 + 2 ml 5% $K_2Cr_2O_7$); and in 1979 and 1981 samples for total phosphorus analyses were collected in either a 50-ml glass "sovirel" bottle without preservation or in a 125-ml glass bottle, preserved with sulphuric acid (1 ml, 30%). All sample bottles were rinsed with the ambient water prior to filling.

Analytical Methods

Field Parameters. During 1979, a number of field observations were made and noted. These included temperature of the air, snow, and water; type of snow; method of sampling; and collector material. Ambient specific conductance, pH, and dissolved oxygen were measured on many ponds, lakes, and streams in 1979. In 1980 and 1981 pH was the only parameter measured in the field but it was measured on all media — rain, snow, and surface water (ponds and lakes).

Laboratory Analyses. Snow-pack samples (7) and fresh snow samples (4) taken in 1979 were analyzed for synthetic organic residues which included 17 polynuclear aromatic hydrocarbons, 18 organochlorine pesticides, 6 chlorophenoxy acid herbicides, and polychlorinated biphenyls, either as the Aroclor (-1248, -1254, and -1260) components or as total PCBs (Table 1).

Major ions and "physical" parameters, metals including mercury, and nutrients were measured on most of the samples. Table 2 identifies the parameters measured on samples from each site and on each type of medium. The selection of parameters depended on the quality of sample available for analy-

TABLE 1. Synthetic organic parameters analyzed

Polynuclear Aromatic Hydrocarbons (PAHs)	DL[†]	Organochlorine Pesticides (OCs)	DL
acenaphthene	0.02	aldrin	0.001
acenaphthylene	0.02	α - BHC	0.001
anthracene	0.02	γ - BHC (Lindane)	0.001
benzo (a) anthracene	0.02	α - chlordane	0.003
benzo (b) fluoranthene	0.02	γ - chlordane	0.002
benzo (k) fluoranthene	0.02	pp′-DDD (pp′-TDE)	0.002
benzo (g,h,i) perylene	0.02	pp′-DDE	0.001
benzo (a) pyrene	0.02	op′-DDT	0.001
2-chloronaphthalene	0.02	pp′-DDT	0.004
chrysene	0.02	α - endosulfan	0.001
dibenzo (a,h) anthracene	0.02	β - endosulfan	0.003
fluoranthane	0.02	endrin	0.002
fluorene	0.02	HCB	0.001
indeno (1, 2, 3-cd) pyrene	0.02	HEOD (dieldrin)	0.002
naphthalene	0.02	heptachlor	0.001
phenanthrene	0.02	heptachlor epoxide	0.002
pyrene	0.02	methoxychlor	0.01
		mirex	0.001

Note: The average recovery for the above compounds is 80.4% with a coefficient of variance of 25.3%.

Chlorophenoxy Acid Herbicides	DL	Polychlorinated Biphenyls (PCBs)	DL
dichlorprop (2,4-DP)	0.004	PCB fractions	
fenoprop (Silvex)	0.004	Aroclor - 1248	0.002
MCPA	0.2	- 1254	0.002
2,4-D	0.004	- 1260	0.005
2,4-DB	0.009	Total PCB	0.02
2,4,5-T	0.002		

Note: The average recovery for the herbicides is 85% with a coefficient of variance of 20%

Note: The average recovery for PCBs is 80.4% with a coefficient of variance of 25.3%

[†] DL = Analytical detection limit ($\mu g \cdot l^{-1}$)

sis and on the availability of technically qualified personnel to perform the in-field sample treatment.

The analytical methods for all the physical and inorganic parameters measured on the samples are given in the Analytical Methods Manual of the Water Quality Branch (Environment Canada, 1979). Special precautions must be exercised when analyzing trace levels of environmental contaminants such as metals. Interlaboratory quality control and sample blanks should be included in the program. In this study all of the metals (Table 2) were analyzed by atomic absorption spectroscopy (AAS). Arsenic, boron, and selenium were analyzed only in the Calgary laboratory, whereas the other metals were analyzed in both Burlington and Calgary. Most of the metals (Cd, Co, Cu, Fe, Pb, Ni, V, and Zn) were analyzed using solvent extraction (APDC/MIBK), but barium was done by direct aspiration and aluminum required hydroxy quinoline/chloroform extraction. Arsenic (arsine conversion) and selenium were analyzed by flameless AAS, and mercury required cold vapour AAS analysis. The analytical precision of specific metals is noted in the Analytical Manual for a single laboratory–single operator, and the interlaboratory precision (coefficient of variation) for most metals near their detection limits (low $\mu g \cdot l^{-1}$ levels) is ±30% (Cheam and Chau, 1981).

The specific samples taken for synthetic organic residue analyses were treated in the following manner: the samples were extracted three times with 100 ml benzene or hexane, dried, and reduced in volume to 10 ml. The extract was then split: half the extract was used directly for the analysis of PAHs by capillary, flame ionization detection gas-liquid chromatography (FID-GLC), and then gas chromatography mass spectrometry (GC-MS). The other half of the extract was "cleaned up" by high-pressure liquid chromatography and analyzed by electron capture, gas-liquid chromatography for organochlorine pesticide residues and polychlorinated bi-

TABLE 2. a) Parameters analyzed and concentration levels relative to the detection limits for snow, snow-pack, and rime frost samples

		Snow/Snow-Pack									Rime Frost	
	Site No.	1	2	4	6†	9	10	11	13†	15	7	15
	PARAMETER (‡DL)											
"Physical"	Colour (5 TCU)	+		+	+	+	+	+		+		
	Conductivity (0.2 $\mu S \cdot cm^{-1}$)	+		+	+	+	+	+		+		
	Oxygen, Diss. (0.5 $mg \cdot l^{-1}$)											
	pH (Not applicable)	+		+	+	+	+	+		+	+	+
	Temperature (Not appl.)	+	+	+	+	+	+	+				
	Turbidity (0 JTU)	+		+	+	+	+	+		+		
Major Ions	Alkalinity (1.0)	+		+	*	+	×	×		+		*
	Calcium (0.1)	×		×	*	×	+	+		+		+
	Chloride (0.1)	+		+	+	+	+	+		+	+	+
	Hardness (1.0)											
	Magnesium (0.1)	+		+	+	+	+	×		+		+
	Potassium (0.1)	×		+	+	×	+	×		+		*
	Sodium (0.1)	+		+	+	+	+	×		+	+	+
	Sulphate (1.0)	×		+	*	×	+	×		+	+	+
Nutrients	Carbon, Diss. I. (1.0)	×		×	+	×						
	Carbon, Diss. O. (1.0)	×		×	×	×						
	Nitrate + Nitrite (0.01)	+			+	+						
	Nitrogen, D/P (0.01)	+		+	+	*						
	Phosphorus, Tot. (0.003)	*	×	+	*	+	×	×				
	Silica, Reactive (0.1)	×		×	×	×	×	×		*		×
Metals	Aluminum (0.005)		×					+	+			
	Arsenic (0.5)	×		×	×	×						
	Barium (0.1)		×					×	×			
	Boron (0.02)	×		+	*	×						
	Cadmium (0.001)							×	*			
	Cobalt (0.002)							×	×			
	Copper (0.001)							+	+			
	Iron (0.001)		×					+	+			
	Lead (0.004)							×	×			
	Mercury (0.02)				×		×	×	×			
	Manganese (0.01)		×					×	×			
	Nickel (0.002)							×	×			
	Selenium (0.5)	×		×	×	×						
	Vanadium (0.001)							×	×			
	Zinc (0.001)							×	+			
Synthetic Organics	#PAHS (0.02)	×	×		×	×		×		×		×
	††OCs (0.01-0.001)	*	×	*	*	×	*	×	*	*		×
	Herbicides (0.2-0.002)				×							
	#PCBs (0.02-0.002)	×	*	×	×	+	×	+	*	+		+

phenyls (PCBs).

The samples analyzed for chlorophenoxy acid herbicide residues were extracted twice with 100 ml dichloromethane, dried, reduced in volume, and extracted into a small volume of methanol. The herbicide residues were converted to their methyl esters using BF_3-methanol. The methyl esters were extracted into benzene, "cleaned up" and analyzed by gas-liquid chromatography.

The detection limit was defined as the concentration which produced an instrument response equal to twice the standard deviation obtained on low-level replicate analyses (ASTM, 1983). "Trace" concentrations were sometimes observed below the statistically established criterion noted above and were confirmed by (Multiple Ion Detector) MID-GC-MS (see Table 4). The detection limits for the synthetic organic compounds reported by the Water Quality Branch laboratory in Burlington were adjusted to reflect the equipment sensitivity at the time of the sample analysis. However, they were in the same range as the levels of detection reported by the Water Quality Branch laboratory in Calgary (Table 1).

RESULTS AND DISCUSSION

Because complete data are available from NAQUADAT (Environment Canada, 1982a) and the results also appear in "Detailed Surface Water Quality Data, Northwest Territories" (Environment Canada, 1982b, 1984), only summary data and tables appear in this text.

The parameters analyzed at each site are noted in Table 2 with an indication as to whether the measured concentration was above or below the detection limit of the method used. The synthetic organic compounds are presented in Table 3, except for the PCBs, which although present at some sites were variable in concentration and were suspected to have resulted from contamination of the samples in the field.

The organochlorine compounds (Table 1) are man-made and used primarily as insecticides (McNeely *et al.*, 1979) in the more populated regions of the world. Residues of these compounds are toxic and persistent in the environment. Many of the polynuclear aromatic hydrocarbons (PAHs) can be derived from natural sources such as forest or tundra fires, and vol-

TABLE 2. b) Parameters analyzed and concentration levels relative to the detection limits for pond waters

	Site No.	1†	2	3†	5†	6†	16	18†	19	20†	23	24	25	26†	27	29	34	35	36	37	38	39	40	41	43
	PARAMETER (‡DL)																								
"Physical"	Colour (5 TCU)			+	+						×	×	×	×	×	×	×	×		+	+			×	×
	Conductivity (0.2 $\mu S \cdot cm^{-1}$)	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Oxygen, Diss. (0.5 $mg \cdot l^{-1}$)	+	+			+		+	+	+															
	pH (Not applicable)	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Temperature (Not appl.)	+	+	+	+	+		+	+	+															
	Turbidity (0 JTU)			+	+			+		+				+					+			+	+		
Major Ions	Alkalinity (1.0)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Calcium (0.1)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Chloride (0.1)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	×	+	+	+	+	+	+	+
	Hardness (1.0)	+	+		+					+															
	Magnesium (0.1)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Potassium (0.1)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	×	+	+	+
	Sodium (0.1)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Sulphate (1.0)	+	+	+	+	+	+	*	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Nutrients	Carbon, Diss. I. (1.0)				+																				
	Carbon, Diss. O. (1.0)				+																				
	Nitrate + Nitrite (0.01)				+																				
	Nitrogen, D/P (0.01)				+																				
	Phosphorus, Tot. (0.003)			+	+						+	+	+	+	+										
	Silica, Reactive (0.1)	+	+	+	+	+	+	+	+	+				+											
Metals	Aluminum (0.005)																								
	Arsenic (0.5)				×																				
	Barium (0.1)																								
	Boron (0.02)				×																				
	Cadmium (0.001)	×								×															
	Cobalt (0.002)	×								×															
	Copper (0.001)	+								+															
	Iron (0.001)	+								+															
	Lead (0.004)	×								×															
	Mercury (0.02)																								
	Manganese (0.01)																								
	Nickel (0.002)	×								×															
	Selenium (0.5)				×																				
	Vanadium (0.001)																								
	Zinc (0.001)	+								+															

TABLE 2. c) Parameters analyzed and concentration levels relative to the detection limits for lakes and streams

	Site No. PARAMETER (‡DL)	7†	8	9†	11†	12†	14	17	21	22	28	30	31	32	33†	42
"Physical"	Colour (5 TCU)	+	+	+	+	+	+		+	+		×			+	+
	Conductivity (0.2 µS·cm⁻¹)	+	+	+	+	+	+		+	+	+	+	+	+	+	+
	Oxygen, Diss. (0.5 mg·l⁻¹)	+	+	+	+	+										
	pH (Not applicable)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Temperature (Not appl.)	+	+	+	+	+	+									
	Turbidity (0 JTU)	+	+	+	+	+	+		+	+	+		+	+	+	+
Major Ions	Alkalinity (1.0)	+	+	+	+	+	+	+	+	+	×	+	+	+	+	+
	Calcium (0.1)	+	+	+	*	+	+	+	+	+	×	+	+	+	+	+
	Chloride (0.1)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Hardness (1.0)	+	+	+	+	+										
	Magnesium (0.1)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Potassium (0.1)	+	+	+	*	+	+	+	+	+	×	+	+	+	+	+
	Sodium (0.1)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Sulphate (1.0)	+	+	+	*	*	+	+	+	+	+	+	+	+	+	+
Nutrients	Carbon, Diss. I. (1.0)	+	+	+	+	×										
	Carbon, Diss. O. (1.0)	*	+	+	×	×									+	+
	Nitrate + Nitrite (0.01)	+	+	+	×	+										
	Nitrogen, D/P (0.01)	+	+	+	+	+			+	+			+	+	+	
	Phosphorus, Tot. (0.003)	+	+	+	+	+	+		+	+		+	+	+	+	
	Silica, Reactive (0.1)	+	+	+	+	+	+	+							+	+
Metals	Aluminum (0.005)	+			+	+	+									
	Arsenic (0.5)	+	×	×	×	×										
	Barium (0.1)	×			×	×	×									
	Boron (0.02)	×	+	+	×	×										
	Cadmium (0.001)	+			×	×	×									
	Cobalt (0.002)	×			×	×	×									
	Copper (0.001)	+			×	+	+									
	Iron (0.001)	+			+	+	+									
	Lead (0.004)	+			×	×	×									
	Mercury (0.02)	×		×	×	×	×									
	Manganese (0.01)	×			+	×	+									
	Nickel (0.002)	+			×	×	×									
	Selenium (0.5)	×	×	×	×	×										
	Vanadium (0.001)	×			×	×	×									
	Zinc (0.001)	+			×	+	+									

† = multiple (sub-) samples
‡DL = detection limit (Units: "Physical" as indicated; Major Ions, Nutrients, and Metals - mg·l^{-1}, except for Arsenic, Mercury and Selenium -µg·l^{-1}; Synthetic Organics - µg·l^{-1}.)
blank = not analyzed
\+ = concentration above the detection limit
× = concentration below the detection limit
* = multiple (sub-) samples: some values above, some values below the detection limit

canic activity (Suess, 1976), which accounts for low-level background concentrations. Chlorophenoxy acid herbicides are used primarily for weed and brush control in agricultural crops and pasturage, and in populated areas. Although the degradation rate of these herbicides is relatively rapid in the natural environment, their degradation is slower under cold climatic conditions; thus they have been detected in lakes and streams in the agricultural districts of Canada (Gummer, 1979). Their low volatility militates against long-range atmospheric dispersion and rarely are they detected beyond the areas where they are applied. Polychlorinated biphenyls (PCBs) are used industrially in a variety of ways, e.g., as additives to hydraulic fluids, lubricants, and sealers, and as dielectrics in electrical transformers. These compounds are toxic to biota, do not degrade in the natural environment, and are aerially dispersed with fine particulates (Nisbet and Sarofim, 1972).

Although transition elements (metals) occur naturally, they can also be anthropogenically introduced into the environment by industrial activities. As with many contaminants, including synthetic organic compounds, these metals can be translocated and bioaccumulated in the foodweb and potentially create environmental problems or health risks.

SYNTHETIC ORGANIC COMPOUNDS

Snow and snow-pack samples were analyzed for polynuclear aromatic hydrocarbons, but none was detected. This observation is environmentally encouraging and is consistent with the postulated rapid degradation of PAHs by photo-oxidation in the atmosphere (Bjorseth *et al.*, 1979). Because chlorophenoxy acid herbicides degrade rapidly in the environment and are not transported over long distances (Gummer, 1979), their presence was not expected in samples from the high Arctic. The two samples from site 6 which were analyzed for herbicides contained no detectable concentrations. Larger sample

TABLE 3. Organochlorine pesticide residues in snow-pack and rime frost samples

Site No.	1			2		4	6				9	10	11	13			15		
Replicate Sample No.	1	2	3	1	2	1	1	2	3	4	1	1	1	1	2	3	1	3	6
Number of Analyses	1	3	2	1	2	2	2	2	1	2	1	2	1	1	1	1	1	1	1
PARAMETER																			
aldrin			o		o		o			o									
α-BHC	+	+	o	o	o	+	+	+	+	+		+		+	+	+	+	+	+
γ-BHC (Lindane)		+	o	+	o	o	+	+	+	+		+		o			+		
α-chlordane	o		o						+										
γ-chlordane					o	o		*	+				+	o					
pp′-DDD (pp′-TDE)			o			o													
pp′-DDE							o												
op′-DDT			o		o		o	+	+	o									
pp′-DDT			o				o	+	+	o				o					
α-endosulfan		o						o	+										
β-endosulfan		o	o		o			o											
endrin					o			o											
HCB																			
HEOD (dieldrin)	+	o	o	+	o	o	+	+	o		+		o	o	o				o
heptachlor																			
heptachlor epoxide		o	o		o	o	o	o											
methoxychlor		o	o		o	o													
mirex																			
Laboratory†	B	C	C	B	C	C	C	X	B	C	B	C	B	C	C	C	B	B	B

† = B = Burlington, Ontario; C = Calgary, Alberta; X = Both laboratories
blank = concentration below the detection limit
\+ = concentration above the detection limit
* = "confirmed" trace concentration below the detection limit (cf. Table 4)
o = "unconfirmed" trace concentration below the detection limit (cf. Table 4)

volumes, and possibly even solvent extraction in the field, are advocated for future studies in order to detect very low levels of synthetic organic compounds which might be present.

The persistent nature of many of the organochlorine pesticides, especially DDT, has been well documented and the presence of pesticide residues has been observed in a variety of media (water, sediment, and biota). More recently an atmospheric dispersal mechanism has been recognized and many pesticide residues have been detected at great distances from their sources of production and use. The CANSOC program has shown that pesticide residues are present in precipitation throughout southern Canada; the northernmost site in the CANSOC network is Fort McMurray, Alberta. Virtually all the samples from the 12 CANSOC sites exhibited detectable levels of Lindale (γ-BHC) and its isomer α-BHC (Environment Canada, 1981). Throughout the network 42% of the samples analyzed for p,p′-DDT and 40% of the samples analyzed for HEOD (dieldrin) were at or above their detection limits. There were also less frequent detections of heptachlor epoxide, methoxychlor, endosulfan, DDE, and chlordane. The pesticides identified in snow-pack samples from the high Arctic (Table 4) were similar to those observed in the CANSOC network, but concentration levels were lower. The highest concentration of Lindane observed in the arctic snow-pack was 0.008 $\mu g \cdot l^{-1}$ and the maximum level for α-BHC was 0.018 $\mu g \cdot l^{-1}$, whereas the CANSOC maxima for 1979 were 0.083 and 0.040 $\mu g \cdot l^{-1}$, respectively.

TABLE 4. Summary statistics of pesticide residues detected in snow-pack and rime frost samples

Pesticide Residue	No. of Analyses	Concentration Range ($\mu g \cdot l^{-1}$) Minimum	Maximum	No. of Confirmed* Detections	No. of Unconfirmed** Detections
α-BHC	28	<0.001	0.018	21	5
γ-BHC (Lindane)	28	<0.001	0.008	10	5
α-chlordane	28	<0.001	0.002	1	2
γ-chlordane	28	<0.002	0.002	2	5
op′-DDT	28	<0.001	0.004	2	5
pp′-DDT	28	<0.001	0.002	2	5
α-endosulfan	28	<0.001	0.002	1	2
HEOD (dieldrin)	28	<0.002	0.004	5	12

* Confirmed Detections include both
(i) concentrations above the detection limit (positive values), and
(ii) concentrations below the detection limit confirmed by MID-GC-MS
** Unconfirmed Detections are instrument responses below the detection limit but of insufficient concentration to permit sample "clean-up" and confirmation by MID-GC-MS.
MID-GC-MS: Multiple Ion Detector — Gas Chromatography — Mass Spectrometry

PCBs were found in some samples, but in our judgment, these samples may have become contaminated by the use of petroleum products in and around the sample-transfer area. Consequently, the reliability of these results is suspect and, therefore, they have not been reported.

The significance of finding pesticide residues in the high Arctic is not so much their concentration levels, because the levels were low, but rather their presence which is presumptive evidence that remote northern environments do receive atmospheric deposition containing trace levels of contaminants. Barrie *et al.* (1981) have documented the episodic incursion of mid-latitude air masses from North America, Siberia, and Europe into the Arctic, especially during the winter. Pollution (arctic "haze") is cyclical; it increases, commencing in September, to reach a maximum in March-April. The "haze" dissipates during the spring and is not replenished in the summer months because of a poor coupling between the arctic and mid-latitude air masses (Rahn, 1981). In addition, the atmospheric scavenging rates of pollutants (rainout, washout, etc.) are higher in the summer and therefore the pollutants are not transported as far.

The effects of such contamination on northern ecosystems are presently not appreciated because of a lack of information on the chronic effects of trace levels of pesticide residues on biota. Analyses of pesticide residues in biota from the study area would be required to confirm that these residues are being incorporated into the arctic foodweb.

METALS

The snow-pack samples, taken in 1979, were analyzed for a variety of metals (Table 2a). Although Henriksen (1972) observed concentrations of copper, zinc, lead, and cadmium (30, 65, 14, and 3 $\mu g \cdot l^{-1}$, respectively) in a snow-pack profile from a "pristine" area northwest of Oslo, Norway, at Cape Herschel the only metals present in measurable concentrations were aluminum, iron, and copper ($\sim$40, 80, and 2 $\mu g \cdot l^{-1}$, respectively) which were most likely of crustal origin. A few samples contained boron and zinc and one sample contained cadmium at its detection limit. All the other metals including arsenic, lead, mercury, selenium, and vanadium were below the detection limits of the methods used. The concentrations observed at Cape Herschel are similar to yet somewhat higher than those quoted by Rahn and McCaffrey (1979b) for Barrow (Alaska) snow. Thus anthropogenic metal inputs to the region were not evident in the snow-pack samples, although this conclusion may only reflect the inadequacy of the techniques used to detect the extremely low concentrations of metal transported by atmospheric aerosols.

Aluminum, iron, copper, and zinc were usually detectable in all the surface waters at levels similar to those reported by Hobbie (1973), except for cobalt which was higher in the Alaskan lakes. Aluminum and iron were exceptionally high (350 and 440 $\mu g \cdot l^{-1}$) in the meltwater stream from Twin Glacier (site 14). Measurable concentrations of boron (40 to 60 $\mu g \cdot l^{-1}$), probably derived from Palaeozoic bedrock, were evident at sites 8 and 9. Proteus Lake (site 7) was most atypical in that the sample analyzed for metals exhibited high concentrations ($\sim$ 10 $\mu g \cdot l^{-1}$) of copper, lead, zinc, nickel, and cadmium with detectable arsenic (0.5 $\mu g \cdot l^{-1}$). Aluminum and iron were also measurable but the other metals including mercury, selenium, and vanadium were below detection. No explanation for these unusual values can be offered at this time and the site might warrant further investigation.

"ACID RAIN" SUSCEPTIBILITY

Because synthetic organic compounds have been transported into the study area through the atmosphere, the potential for regional contamination by acidic precipitation was assessed by analyzing a variety of parameters: pH levels, pH/calcium relationships, and saturation indices. The laboratory pH values of the snow-pack samples ranged from 5.2 to 7.1 with about 40% of the values less than the atmospheric equilibrium pH of 5.6. The low pH values are consistent with the observations of Johannessen and Henriksen (1977) and support the calculations of Barrie *et al.* (1981) on the suppression of winter pH values in arctic precipitation. Although none of the laboratory pH measurements on rain, snow, or surface waters was less than 5.6, almost 20% of the field pH values were below the equilibrium pH value (McNeely, 1982). Thus the field measurement of pH would appear to be essential to detect gradual changes in the acidity of atmospheric precipitation which might result from anthropogenic inputs.

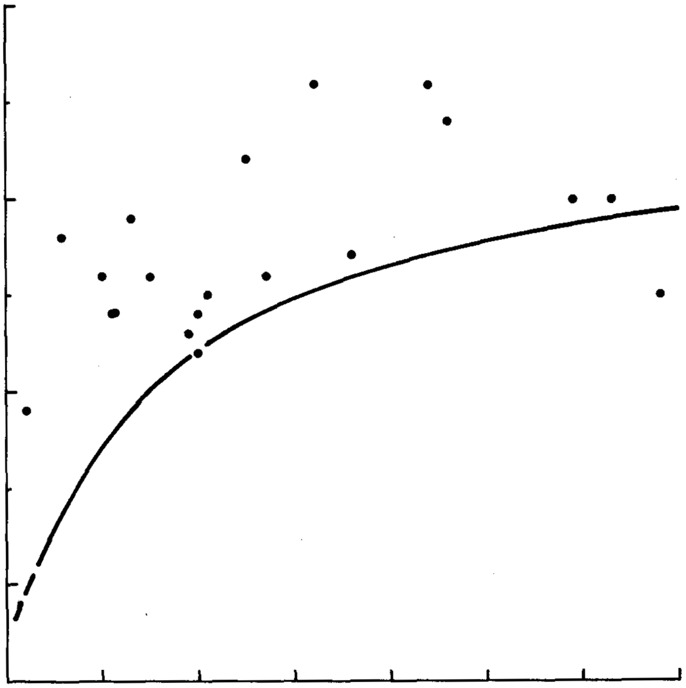

FIG. 4. A "Henriksen" plot of pH versus calcium for dilute waters ($\sim \mathrm{Ca}^{1} < 7\mathrm{mg} \cdot l^{-1}$). The zone above the curve is non-acidified; below the curve is acidified.

Henriksen (1979) differentiated between water bodies that had been acidified and those that were non-acidified by plotting calcium concentrations against pH values. Assuming that Henriksen's empirical relationship for Scandinavia applies to the Canadian Arctic, then, because most of the points (Fig. 4) plot above the curve, the waters in the study area were non-acidified. The proximity of many points to the boundary indicates that a number of sites might be susceptible to acidic inputs. The dilute water sample from a weathering pit in granitic bedrock (site 37), which lies on the boundary, is very susceptible to acidic inputs. The value for site 26 lies below the curve and is definitely acidified, not as a result of acidic precipitation but rather because of the oxidation of sulphide mineralization within the drainage basin — the pond lies in a gossan on Skraeling Island (Watts, 1981).

The Langelier saturation index is zero for waters in equilibrium with calcium carbonate (McNeely *et al.*, 1979). Approximately 25% of the water samples from the study area had saturation indices between −0.75 and +0.75 pH units and thus were stable with respect to calcium carbonate. The sites with stable indices were either on or close to calcareous (Palaeozoic) bedrock. Most (90%) of the waters analyzed were undersaturated with calcium carbonate and one-third of the sites had saturation index values of -4 or less. All of these very undersaturated waters were on Precambrian bedrock and had total solute levels of less than 25 mg·l^{-1}. Therefore, because many of the surface waters are ombrogenic and of low buffering capacity, they are potentially susceptible to changes in the acidity of the atmospheric aerosol.

MAJOR IONS

Because of the large variation in bedrock and surficial materials, and the differences in proximity to the sea of the sites sampled, a broad spectrum of water types was observed. Virtually all the surface waters had measurable concentrations of all the major ions, whereas the precipitation samples were more variable and ions such as bicarbonate, calcium, potassium, and sulphate were commonly at or below the detection limit of the analytical methods used. Surface water concentrations of total dissolved solids ranged from 2 to 400 mg·l^{-1} and slightly more than 25% of the samples had concentrations >100 mg·l^{-1}. Site 19, which is <1 m above sea level, was brackish with a concentration of 7000 mg·l^{-1}. Unlike the surface waters, most of the precipitation samples had a total dissolved solids content of <10 mg·l^{-1}. The precipitation samples exhibited a poor relationship between total dissolved solids and conductivity, with the best fit being a logarithmic function, but an excellent estimate of total dissolved solids for surface waters can be made from specific conductance measurements (Fig. 5; total dissolved solids ~ ½ specific conductance).

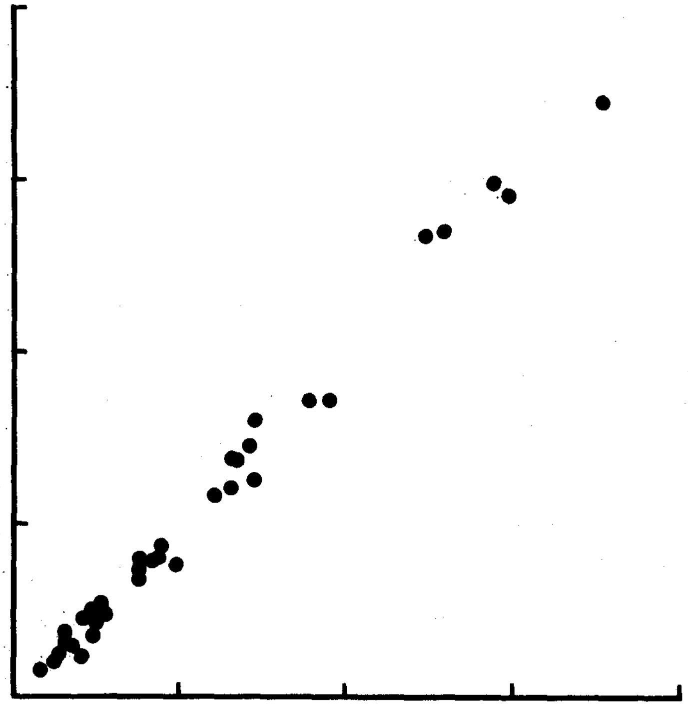

FIG. 5. Specific conductance versus total dissolved solids for surface waters (Total dissolved solids = $-1.7 + 0.5$ specific conductance).

A trilinear plot (Fig. 6) of 60 surface water and precipitation samples from the 43 sites attests to the variety of water types within the study area. The majority of the samples appear in a transverse band across the composite diamond-shaped part of the diagram, indicating that the waters ranged from strongly bicarbonate to sodium chloride-rich. The surface waters clustered in the centre-left of the cation diagram, reflecting the dolomitic component of the calcareous bedrock (Christie, 1967) and surficial materials in the region. The dominant anion in most surface waters was bicarbonate. The data appear as a cluster along the lower axis of the anion triangle because of varying amounts of chloride and very little sulphate in the waters. The brackish pond (site 19) data plot at the chloride apex. The sample from site 26 on Skraeling Island appears uppermost on the diagram because the dominant anion was sulphate (cf. Fig. 7). Samples of "mixed" anionic composition appear scattered throughout the central part of the triangle.

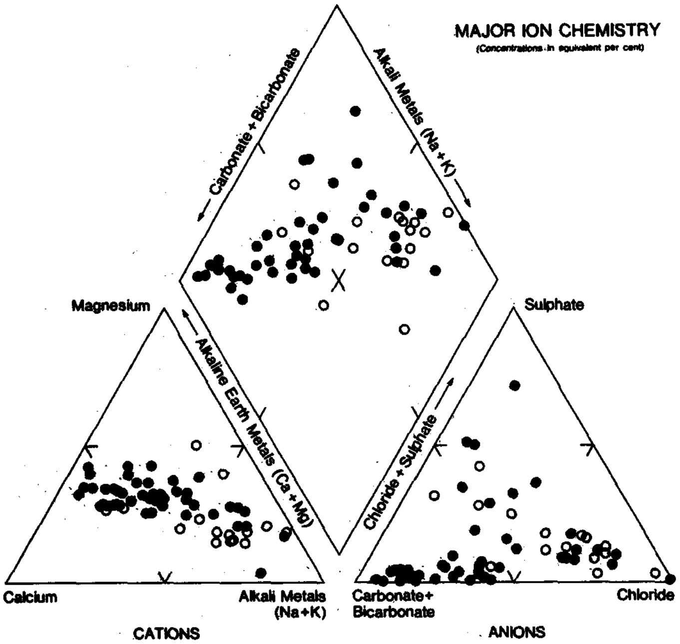

FIG. 6. Trilinear diagram: Major ion chemistry of 60 water samples (surface water ● and precipitation o).

The precipitation samples cluster in the lower right of the cation triangle indicating that sodium was the dominant cation. Most of the precipitation samples were chloride-rich although a few contained bicarbonate and sulphate as well.

Figure 7 graphically illustrates the major ion chemistry of the surface waters within the study area. The sites on Knud and Bache peninsulas reflected the presence of dolomitic bedrock within their drainage basins with water chemistry dominated by calcium-magnesium bicarbonate. Because of the higher solute content at these sites the marine influence was less discernible than at sites of lower solute content. Site 20 is an exception; it had a high solute content yet was dominated by sodium chloride. This water chemistry may have resulted from: (1) the flooding of the basin by the sea throughout much of postglacial time, or (2) the leaching of soluble salts from Palaeozoic bedrock and till in the drainage basin. Because of

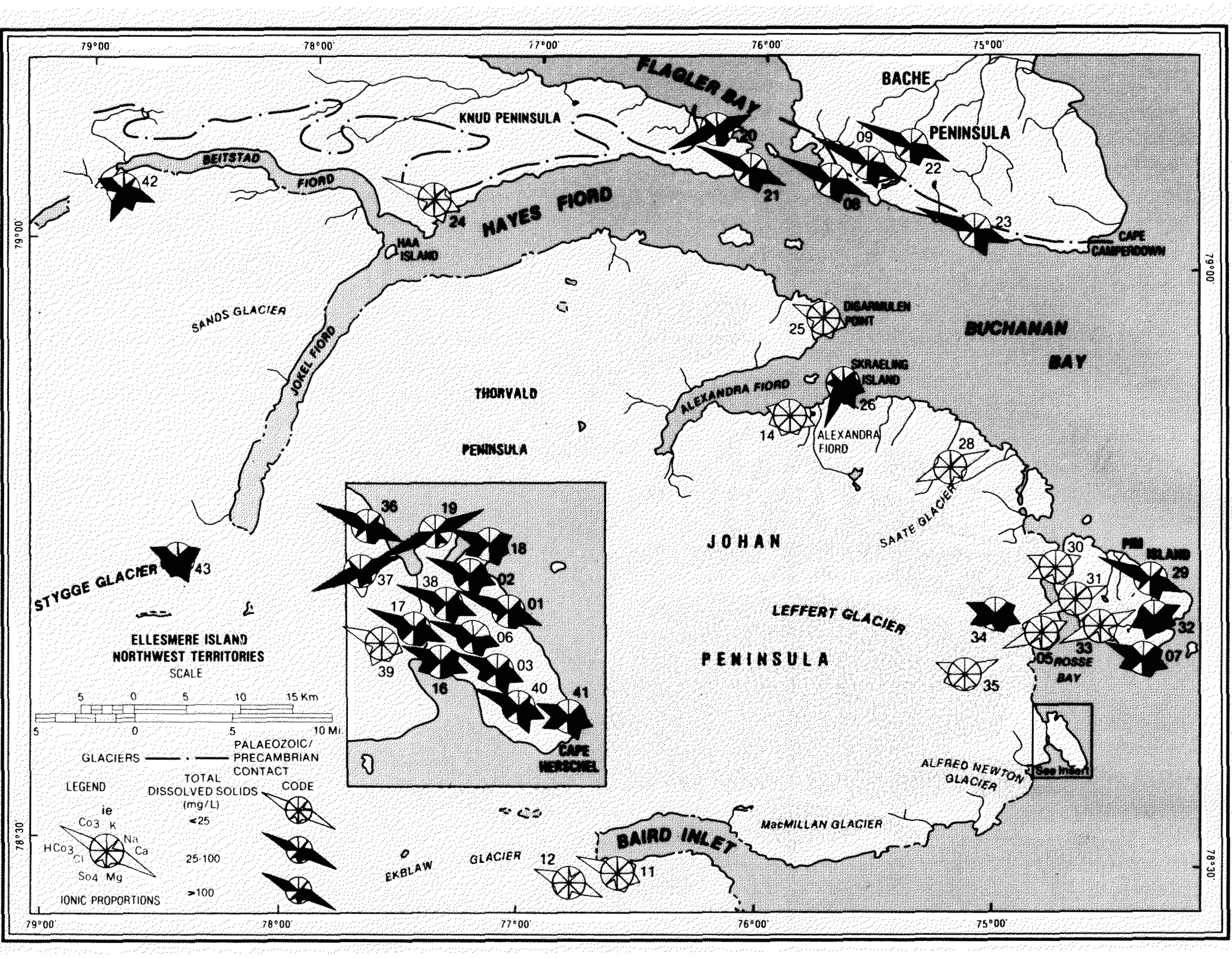

FIG. 7. Major ion proportion of surface waters.

the arid climate in the region, the dissolved solutes could have been concentrated by seasonal evaporation, leading to the observed moderately high (~ 400 mg·l^{-1}) total dissolved solids dominated by sodium chloride in the pond. Thenardite (sodium sulphate) was observed as a crust around the margin of this pond during the summers of 1979-1981 (Watts, 1981). The low solute content of a small weathering pit (site 37) southwest of Rosse Bay is a result of the Precambrian bedrock and the lack of calcareous surficial materials in the area. The dominance of sodium chloride has probably resulted from the transport of marine aerosol to the site.

Site 42, at the head of Beitstad Fiord, is predominantly a calcium-magnesium bicarbonate water, but it contained a large proportion of sulphate which may have been derived from sulphides in the drainage basin. The marked influence that sulphides can have on surface water chemistry is exemplified by the pond on Skraeling Island (site 26). About 75% of the total anions present was sulphate which is derived from sulphides; the drainage basin lies in a gossan.

Sites associated with glacial meltwater exhibited "mixed" water chemistry (cf. sites 14, 34, and 43; Fig. 7). Most of the very dilute waters (<25 mg·l^{-1}) showed evidence of marine influence with substantially higher proportions of sodium and chloride. The degree of marine influence depended on the site's proximity and exposure to the sea. This phenomenon is obvious when the sites at the Saate Glacier (28), southwestern Pim Island (05, 30, 31, and 33), and the Leffert Glacier (35) are compared to the sites in Baird Inlet (11 and 12) which are more remote and protected from the open sea. The Baird Inlet waters were dominated by calcium (magnesium) bicarbonate, whereas the other sites had waters that were dominated by sodium chloride.

The more easterly sites on Pim Island (07, 29, and 32) and all the sites on Cape Herschel Peninsula (except for sites 19 and 37, discussed above) were essentially calcium-magnesium bicarbonate waters with varying proportions of sodium chloride. The amount of sodium chloride is primarily controlled by exposure of the site to the sea. The calcium-magnesium bicarbonate dominance in these waters and their elevated dissolved solute concentration when compared to the sites on southwestern Pim Island are interpreted as indicating that calcareous (dolomitic) till is present at all elevations on Cape Herschel Peninsula, but that the calcareous till occurs only on the northern and eastern areas of Pim Island.

NUTRIENTS

Carbon

Dissolved organic carbon (DOC) levels in all the surface water samples analyzed were <3 mg $C \cdot l^{-1}$. About half the surface water samples and all the snow-pack samples had DOC concentrations below the detection limit of 1 mg $C \cdot l^{-1}$. Thus no reasonable estimate of the C:N ratio at these sites could be made.

Nitrogen

All the forms of nitrogen analyzed were measurable, but virtually all the "nitrate plus nitrite" levels were at the detection limit of 0.1 mg $N \cdot l^{-1}$ for the surface waters, whereas the snow-pack samples ranged from 2 to 14 times that level. Concentrations of total dissolved nitrogen were higher in the surface waters than in the snow-pack with median values of 160 and 80 μg $N \cdot l^{-1}$ respectively, but median particulate nitrogen levels (50 μg $N \cdot l^{-1}$) were the same in both media. The dissolved nitrogen levels ranged between two and five times the particulate concentrations.

Phosphorus

Almost half of the snow-pack samples exhibited total phosphorus concentrations below the detection limit of 3 μg $P \cdot l^{-1}$ (median value of 5 μg $P \cdot l^{-1}$), whereas the surface water concentrations were all above the detection limit but were variable. The high variability in phosphorus levels may relate to the variety of sites sampled, but more likely is due to the differences in the season when the samples were collected. In early June the water samples were taken from beneath ice which was commonly snow-covered, but by early July most of the ponds and lakes were free of ice and circulating. The surface water concentrations ranged from 3 to 120 μg $P \cdot l^{-1}$ with a median value of 13 μg $P \cdot l^{-1}$, which is comparable to the levels observed in Nora Pond near Tuktoyaktuk (Sheath *et al.*, 1975), but somewhat lower than the levels noted in some Alaskan ponds (Hobbie, 1973). Even though the total nitrogen and total phosphorus concentrations were similar to those observed by Persson *et al.* (1975) on selected subarctic Swedish lakes, the TN:TP ratios were usually higher, ranging from 9:1 to 60:1. Thus, because the N:P ratios were usually greater than 10:1, the productivity of the Cape Herschel ponds and lakes would probably respond to phosphorus additions more than nitrogen alone (Schindler *et al.*, 1974).

The water chemistry of Char Lake near Resolute, Cornwallis Island (cf. Schindler *et al.*, 1974), was similar to the lake at site 8 on Bache Peninsula (Table 5). The nutrient levels observed at site 8 were 2-10 times higher than those observed in Char Lake, but the estimated N:P ratio was only half that of Char Lake. Because no additional information is available for site 8, speculation on the nutrient differences is not warranted, although aerial photographs taken in late July or early August in 1950, 1959, and 1974, and observations made in 1979, 1981, and 1983 would indicate that the lake does not become ice-free in most years and this may influence its nutrient cycle.

TABLE 5. A comparison of the water chemistry of a lake on Bache Peninsula (site 8) with Char Lake, Resolute, Cornwallis Island

	Depth		mg·l^{-1}						$\mu g \cdot l^{-1}$		
	(m)	pH	Na	Ca	HCO_3	Cl	Si	DOC	NO_3	TDN	TP
Site 8 (79 06 15)-	.28	8.0	6.1	44	177	15	1.2	2.0	10	180	20
Char Lake (1971)*-	25	7.9	4.0	35	140	7	0.3	0.9	1	75	2

*From Schindler *et al.*, 1974

Silica

All the snow-pack samples except one from the Cape Herschel campsite had silica (SiO_2) concentrations <0.1 mg·l^{-1} (Table 2a), whereas all the surface water samples analyzed were above the detection limit (Tables 2b and c). Virtually all the pond waters and about half the lake waters had silica values of $<$ 1 mg $SiO_2 \cdot l^{-1}$, which is comparable to the values quoted by Hobbie (1973) for selected Alaskan ponds. Silica values >2 mg·l^{-1} occurred at sites on Palaeozoic bedrock or in glacial meltwaters. A maximum value of 4.9 mg $SiO_2 \cdot l^{-1}$ was measured in a sample from site 9 on Bache Peninsula.

SUMMARY

Measurable concentrations of Lindane (γ-BHC) and its isomer α-BHC, HEOD (dieldrin), and DDT were detected at a number of sites, but no polynuclear aromatic hydrocarbons (PAHs) or chlorophenoxy acid herbicides were detected. The pesticides observed in arctic snow-pack are similar to those present in precipitation in southern Canada, although the concentrations are lower. The presence of a variety of pesticide residues in this remote area of the Arctic is presumptive evidence that the residues are globally dispersed through the atmosphere. Only copper and the lithophilic metals aluminum and iron were consistently detectable in the snow-pack and surface water samples; all other metals were at or below their detection limits. Thus anthropogenic inputs of metal contaminants such as arsenic, cadmium, lead, selenium, and vanadium via atmospheric deposition were not detected in this region. In order to confirm this presumption it is recommended that future studies be carried out using improved analytical techniques with lower detection limits and that both field and laboratory quality control be strictly adhered to.

None of the laboratory measurements of pH on spring/summer precipitation was less than 5.8, but about 40% of the melted snow-pack samples were below the atmospheric equilibrium value of 5.6. Surface water pHs ranged from 5.9 to

8.3 with 90% of the samples being undersaturated with calcium carbonate. Thus, although "acid rain" was not in evidence in the study area, the surface waters, many of which are ombrogenic, are potentially susceptible to changes in the acidity of the atmospheric aerosol of the high Arctic.

The major ion chemistry of the waters varied widely and was related to differences in bedrock and surficial materials as well as the sites' exposure to the sea. Many sites had waters with low total dissolved solids (<25 mg$\cdot l^{-1}$). These dilute waters, when in proximity to the sea, were dominated by sodium chloride, but when remote from the sea the waters were calcium (magnesium) bicarbonate-rich. Water bodies on or near the Palaeozoic bedrock, in the north of the study area, were rich in calcium-magnesium bicarbonate. "Mixed" water chemistry was associated with glacial meltwater. A high concentration of sulphate was observed in a pond in a gossan on Skraeling Island.

Nutrient concentrations in the snow-pack and precipitation samples were low, except for nitrate (maximum value = 140 μg N$\cdot l^{-1}$). Surface water nitrates were at or below the detection limit of 10 μg$\cdot l^{-1}$, but the other nutrients were higher in the surface waters: median concentrations were 13 μg P$\cdot l^{-1}$ for total phosphorus; 50 μg N$\cdot l^{-1}$ for particulate nitrogen; 160 μg N$\cdot l^{-1}$ for total dissolved nitrogen; and 1 mg $SiO_2\cdot l^{-1}$ for silica. Dissolved organic carbon concentrations were usually below the detection limit of 1 mg C$\cdot l^{-1}$ on all media. Because N:P ratios were usually greater than 10:1, phosphorus additions to surface waters will probably have a greater effect on productivity than nitrogen additions alone.

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