

GEOLOGICAL
SURVEY
OF
CANADA

DEPARTMENT OF ENERGY,
MINES AND RESOURCES

PAPER 72-42

FEASIBILITY STUDY OF GEOCHEMICAL SAMPLING
OF ARCTIC COASTAL STREAMS BY HELICOPTER
BASED ON A DEPARTMENT OF TRANSPORT
ICEBREAKER

Willy Dyck

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ICEBREAKER**

(Report and 2 figures)

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Price: \$2.00

Catalogue No. M44-72-42

Price subject to change without notice

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1973

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ABSTRACT

Using the helicopter on board the Department of Transport icebreaker, "John A. Macdonald", 69 water and sediment samples from 54 stream sites were collected from eight regions during the period July 9 to August 19, 1971. At fifteen of these sites another sample from the brackish water zone of the stream was also collected. Of the factors influencing sampling, the ship's route and weather were most decisive.

The water samples were analyzed on board ship for radon, alkalinity, Eh, pH, oxygen, calcium, total divalent cations, and chloride ions. These analyses showed that the waters were essentially saturated with oxygen at the temperature and pressure at the sample site, fluctuating around 11 ppm. Radon concentrations were generally low; however, waters from granitic regions contained easily detectable amounts of radon. Tests for alkalinity, pH, calcium, divalent ions and chloride ions gave clear evidence of the dominant rock type of the landscape through which the streams flow (e.g. limestone or granites) and also instances of intermixture with sea water.

The analytical results show that the streams sampled contain no anomalous concentrations of the trace elements, Zn, Cu, Pb, Ni, Ag, As, Sb, Mo, U, and Hg.

Cost estimates show that with appropriate modifications of the 1971 sampling program, sampling of Arctic coastal streams by the above method is economical.

RÉSUMÉ

A l'aide d'un hélicoptère attaché au brise-glace "John A. Macdonald" du ministère des Transports on a recueilli 69 échantillons d'eau et de sédiments provenant de 54 cours d'eau dans huit régions au cours de la période du 9 juillet au 19 août 1971. A 15 de ces endroits, on a également recueilli un échantillon de la zone saumâtre du cours d'eau. Parmi les facteurs qui ont influencé l'échantillonnage, la température et le trajet du bateau ont été les plus importants.

A bord du bateau on a analysé les échantillons d'eau afin d'en connaître la teneur en radon, oxygène, calcium, le total des cations bivalents et les ions chlorhydriques, et d'en déterminer l'alcalinité, l'Eh et le pH. Les analyses ont démontré que les eaux sont essentiellement saturées d'oxygène à la température et à la pression du lieu d'échantillonnage, soit environ 11 ppm. Les concentrations de radon étaient en général faibles, mais les eaux qui provenaient de régions granitiques renfermaient des quantités facilement discernables de radon. Les essais relatifs à l'alcalinité, au pH, au calcium, aux ions bivalents et aux ions chlorhydriques indiquent clairement le type dominant de roches à travers lesquelles les cours d'eau passent (e.g. calcaires ou granites), ainsi que les cas où il y a eu mélange avec l'eau de mer.

Les résultats d'analyse démontrent que les cours d'eau dans lesquels les échantillons ont été cueillis ne contiennent pas de concentrations anormales de Zn, Cu, Pb, Ni, Ag, As, Sb, Mo, U, et Hg à l'état de trace.

Selon les estimations de coûts, l'échantillonnage des cours d'eau de l'Arctique à l'aide de la méthode susmentionnée serait économique si l'on apportait quelques modifications appropriées au programme d'échantillonnage de 1971.

FEASIBILITY STUDY OF GEOCHEMICAL SAMPLING OF ARCTIC COASTAL STREAMS BY HELICOPTER BASED ON A DEPARTMENT OF TRANSPORT ICEBREAKER

INTRODUCTION

Through the efforts of Dr. H. Blandford, Canadian Hydrographic Service, we were able to secure two berths on the icebreaker, "John A. Macdonald", for the purpose of determining the feasibility of sampling Arctic coastal streams on an opportunity basis using the ship's helicopter. The ship was boarded on July 1, 1971 at Dartmouth. During the journey to Montreal and during cargo loading operations in Montreal we were able to set up and test several small portable instruments in part of the dentist office which the ship's doctor had been willing to share with us. We set sail for the North on July 9. After a month of shipping support duties in Hudson Strait and a cargo stop at Thule, the ship arrived at Resolute on August 19. Because the icebreaker was somewhat behind schedule for its annual run to Eureka, prior commitments forced us to disembark in Resolute before reaching Eureka. However, it is believed that sufficient observations were made to evaluate this year's test run, and make recommendation for further work.

SAMPLING AND ANALYTICAL PROCEDURES

The sampling procedure was as follows: When the ship was near land (i.e., within 10 miles if moving, and about 20 miles if stationary) and the weather good the pilot would, with the captain's permission, take the two-man party to shore where the streams enter the ocean. As a rule, very little difficulty was encountered in landing within about 100 feet from the selected sample site. Topographic maps with a scale of 1:250,000 were found to be adequate for identifying individual streams and landmarks. At each site a 250 ml glass bottle and a 1000 ml plastic bottle were filled with water and a cotton bag filled with 5 to 8 pounds of sediment. Where convenient, duplicate samples were taken; one from sweet water and one from estuary terrain. Where possible, gamma ray counts were obtained from boulders, rock outcrop and soil using a scintillometer. Width and depth of stream, temperature and colour of water, intensity and type of vegetation, rock type and terrain features in the vicinity of the sample site were recorded. Streams were sampled at 2- to 3-mile intervals keeping abreast of and in radio contact with the ship until the pilot indicated the need to return to the ship. Once on board, the sediments were hung to dry in the helicopter hangar, the one litre samples acidified with nitric acid, and the 250 ml samples analyzed for pH, Eh, alkalinity radon, oxygen, calcium, total divalent cations, and chloride ions.

The escape tendency of radon and oxygen and the relatively short half-life of radon ($t_{1/2}=3.8$ d) necessitate that the samples be analyzed as soon as possible. The radon content of the samples was determined by filling an evacuated zinc sulphide (silver-activated) cell with air which was bubbled through an aliquot of the sample and measuring the alpha activity of this air with an alpha particle counter. The partial pressure of oxygen was determined

Original manuscript received: September 6, 1972

Final version approved for publication: September 15, 1972

with a portable oxygen analyzer. The pH and alkalinity were determined using a pH meter and titrating the sample with standardized sulphuric acid. A specific ion meter with the appropriate electrodes was used to determine Eh, calcium, total divalent cations, and chloride ions.

The acidified water samples were analyzed for 12 elements by the Inland Waters Branch, Department of the Environment using atomic absorption for Zn, Cu, Ni, and Hg, colorimetry for As, Fe, Mn, Cl and F; titrimetry for Ca, Mg, and SO₄, and by fluorimetry for U by the Geochemistry Section of the Geological Survey of Canada. The stream sediments were sieved and the three finest fractions (-60+100 mesh, -100+200 mesh and -200 mesh), leached in dilute nitric acid containing several drops of HCl, and analyzed for 13 elements by the Geochemistry Section of the Geological Survey of Canada.

SAMPLING AND ANALYTICAL ERRORS

A number of tests were carried out in the field and in the Ottawa laboratories of the Geochemistry Section, Geological Survey of Canada to determine the extent of sampling and analytical errors. These tests include a simple screen analysis of the sediments, determination of relationship of trace element content and particle size, comparison of trace element content of water and sediment samples from estuary and sweet water zones, and a test on the accuracy of specific ion electrodes for calcium, divalent cations, and chloride. It should be borne in mind that the reported trace element contents of sediments may for some elements be somewhat lower than that actually present because the chemical pre-treatment did not dissolve the samples completely.

The simple screen analysis was carried out to determine the weight size distribution of sediments in the northern coastal streams. The average percentage distribution listed below only approximates the actual distribution in the streams because of sampling bias in favour of the finer sediments. In this particular survey all particles greater than about 2 cm were rejected at the site.

Tyler screen	+4	-4	-10	-20	-35	-60	-100	-200
mesh		+10	+20	+35	+60	+100	+200	
average	>4700	3175	1243	625	332	198	110	<75
diameter, microns								
weight per cent	25.5	14.4	10.9	16.4	14.0	7.8	6.3	4.7

The data show two maxima in the size-weight distribution, one near the 4 mesh and one near the 35 mesh size. From a comparison of normal and logtransformed data of individual size fractions it is evident that the weight distribution of the coarser fractions leans toward a normal and the finer fractions toward a lognormal distribution. From the tabled percentages one can see that in order to get about 10g of -200 mesh size one will have to collect about 200g of sediment on the average.

The three finest size fractions were analyzed to obtain a measure of the change in trace element content with particle size. The results of this test are summarized in Table 1. The "t" test for significance expressed in probabilities of difference between means, shows that there are significant

TABLE 1

Comparison of geometric means of trace element contents of three screen size fractions from 53 samples

Variable	Mean of mesh size			Probability of difference between means	
	-60+100 (1)	-100+200 (2)	-200 (3)	(1) and (2)	(2) and (3)
Vol., ml	0.23	0.26	0.30	.91	.97
Zn, ppm	21.1	28.8	38.9	.99	.98
Cu, ppm	14.1	17.0	23.9	.93	.99
Pb, ppm	2.4	2.8	3.9	.92	.99
Ni, ppm	6.8	9.4	13.8	.91	.96
Fe, %	0.64	0.87	1.14	.99	.98
Mn, ppm	82.4	121.9	185.5	.99	.99
As, ppm*	2.2	2.7	3.1	.99	.86
Mo, ppm*	0.32	0.40	0.44	.89	.40
U, ppm	0.21	0.29	0.47	.99	.99
Hg, ppb	9.7	14.3	20.3	.96	.98

* Means are below detection limit of analytical method.

differences in the average leached trace element content between the three size fractions analyzed. That the differences in the means arise from differences in particle size and/or nature of sediment is evident from the variable volume, that is the volume of 250 mg of sediment. The volume of a sample, which is measured very quickly and easily in a tapered graduated glass tube, gives a measure of the combined effect of surface area and organic matter on the observed trace element content of the sediment. A third factor, namely the acid leach, carried out to bring the trace elements into solution complicates matters further. Being a partial leach, one can expect higher efficiency of element extraction from the finer particles and organic matter. It is thus clear that, in order to get a most meaningful site to site comparison it is best to analyze a very narrow size fraction of the finest size sediment and use the volume of sediment as an indicator of organic matter content. Only a few samples treated in this report contained visible amounts of organic matter so that the change in volume in the three fractions reflects chiefly a change in particle size. A better way would be actually to determine the amount of organic matter in the sample by ashing. Unfortunately, that is too time consuming for routine geochemical analyses.

To find out what effect tidal waters have on the trace element content of stream samples, twelve pairs of samples were collected, each pair coming from a different site, with one of the samples from each pair out of reach of tidal waters and the other within the tidal water zone. The geometric means and probabilities of difference in means as derived from the "t" test of variables for which the analytical method was sensitive enough are listed in Table 2. In waters a significant difference is evident for Cl and Mg only even though all the estuary water means are slightly larger. In the case of sediments the "t" tests indicate significant differences for all elements except U and Zn, with the estuary samples having the lower means (the 36 pairs were obtained by pooling 12 pairs from three screen size fractions).

TABLE 2.

Comparison of geometric means from sweet and estuary sample pairs.
(Only variables well above the detection limit of analytical methods are listed)

Variable	\bar{X}_S Sweet	\bar{X}_B Estuary	Probability of difference in means	Trend ($\bar{X}_S - \bar{X}_B$)
<u>Water samples; 11 pairs</u>				
Rn, pc/l	2.96	3.19	.09	-
pH	7.02	7.01	.05	+
Alkalinity, ppm	5.1	5.5	.13	-
O ₂ , ppm	11.2	11.3	.19	-
Eh, mv	183.	184.	.21	-
Temperature, °F	42.3	42.5	.04	-
Zn, ppb	2.3	2.5	.18	-
Cu, ppb	1.6	2.1	.76	-
Ni, ppb	4.1	4.1	.09	0
Ca, ppm	1.4	1.6	.24	-
Mg, ppm	0.7	2.2	.84	-
Cl, ppm	2.3	6.6	.89	-
Fe, ppm	0.05	0.07	.34	-
Hg, ppb	0.06	0.06	.44	0
SO ₄ , ppm	6.1	7.9	.51	-
<u>Sediment samples; 36 pairs</u>				
Volume of 250 mg, ml	0.24	0.21	.99	+
Zn, ppm	32.4	24.9	.89	+
Cu, ppm	17.7	12.6	.99	+
Ni, ppm	11.4	7.8	.97	+
Mn, ppm	194.	135.	.96	+
Fe, %	1.13	0.84	.98	+
U, ppm	0.27	0.24	.50	+
Hg, ppb	12.4	5.7	.98	+

Once again the variable volume seems to give a clue to the cause of the difference, indicating that the samples from the estuary zone were coarser and/or contained less organic matter than the samples from the sweet water zone, and hence had a lower trace element content. The mechanical action of tides is no doubt responsible for carrying the lighter and finer sediment particles away from the mouth of the stream, although one can also expect a leaching effect by the salt brines on elements such as Ag, Co, Cu, Ni which form complexes with Cl.

The differences in means shown in Tables 4 and 5 do not agree with those shown for the pairs. However, these tables include all values from all sites - including the twelve pairs and therefore are not strictly comparable. It is also probable that more than 16 estuary sites were sampled without knowing it.

As a check on the usefulness of the specific ion electrodes, the Ca, Mg, and Cl values obtained with electrodes on board ship were compared to

TABLE 3.

On-site observations of sampled areas

Location	Special Remarks
Barrier Inlet, Hudson Strait	Steeply dipping, contorted metamorphic rock, well worn hills and granite gneiss boulders. Iron staining on outcrop. Sediments difficult to collect. Fast flowing cold streams, high tides.
Churchill R., Churchill, Man.	Low lying, swampy terrain with few outcrops. Limestone and dolomite in sedimentary rocks, also large granite gneiss boulders. Evidence of glaciation, till. Organic matter in sediments. Yellow water.
George R., Ungava Bay	Hilly but glacially eroded region. Giant granite gneiss boulders in streams. Fast flowing streams. Clay sediment appeared to contain tiny flecks of pyrite, muscovite.
Buerger Pt., Frobisher Bay	Steep, mountainous terrain. Extensive weathering, talus slopes. Difficult landing close to sample site. Some iron stain, granite gneiss boulders. Clay boils. Steeply dipping, stratified sedimentary rocks. Low tundra vegetation.
Chase Is., Frobisher Bay	Low relief, rugged hills. Numerous land-locked lakes fed from meltwater. Much weathering, talus from cliff sides, granite bedrock, cracked and split. Iron banding visible from air on two small islands south of southern end of Chase Island.
York R., Frobisher Bay	Steep terrain, deep wide valley, typical delta, alluvial deposition. Large amount of sand, gravel, small boulder deposits. Fast flowing river fed by glacial meltwater. Cold, milky-coloured water in streams near ice fields.
Deception B., Hudson Strait	Well-developed river valley. Much glacial debris, boulders - granite gneiss, quartz, greenstone. Pegmatite dykes near entrance of bay. Hilly land, river meanders at mouth, flood plain and outwash at delta. Till, gravel overburden. Hills well rounded.
Hope Monument Devon Is.	Low relief, smooth surface near shore, steep mountains and ice fields farther inland. Poorly developed streams. Garnetiferous boulders, pink sand in spots, quartzlike bedrock; olivine (?) veins. Little vegetation, lichens.
Croker Bay, Devon Is.	Very low flat relief near Cape Home. Soft soggy clay with angular limestone or dolomite fragments. Smaller streams dry. Dolomite in streams more rounded towards west from Cape Home. Banded horizontal formations, some with Fe. Relatively large prominent Fe stained area (gossan?) on east side, halfway into Powell Inlet.

the values obtained by the laboratory of the Inland Waters Branch, Department of the Environment. The geometric means of results of all samples by the two methods, probabilities of difference in means as obtained from the "t" test, and correlation coefficients of elements between methods are listed below.

	Ca	Mg	Cl
Specific ion electrode means	1.2	1.3	14.8
Inland Waters Branch laboratory means	3.8	1.7	7.1
Probability of difference	0.99	0.62	0.97
Correlation coefficients	0.95	0.90	0.83

Assuming that the Inland Waters Laboratory results are more accurate, it is evident that the electrodes, although they were calibrated frequently during analysis, give poor accuracy. Oddly enough, the Mg value, which was obtained by difference using the M^{++} and the Ca^{++} electrodes, gives the best agreement. It seems a fortuitous coincidence though since Ca^{++} is so far out. The correlation coefficients indicate that there is good correspondence between the two methods, i.e., both methods give essentially the same trends in the concentrations although at somewhat different levels. Hence electrodes are acceptable where only trends in concentrations are desired, but require improvement for absolute determinations.

DISCUSSION

During the period July 9 to August 19, 69 water and sediment samples from 54 streams were collected from 5 different regions. To do this, 9 flights totaling 17 hours were made, giving a sampling rate of a little over 3 sites per hour. The approximate location of the sampled areas are marked by circles in Figure 1. Also shown in dark outline are the coastal areas which could be sampled using icebreakers as bases when they stand by for shipping support in the Arctic. More exact sample site locations are marked on Figure 2. The lower number refers to the estuary sample and the upper to the sweet water sample. On-site observations are noted in Table 3. The analytical results are summarized in Tables 4, 5 and 6. For the ecologist and the prospector they may be summarized in one sentence: the sampled streams contain normal amounts of those elements measured; no geochemical anomalies were detected.

Ice conditions determined, to some degree, the area of operations and schedule of the icebreaker even though an overall route and schedule had been prepared at the beginning of the season. Its first duty, of course, was to escort merchant vessels through ice. Cargo loading was next on the list of priorities. Hydrographic work carried out on an opportunity basis followed in priority. Geochemical sampling was fitted in around these activities as the opportunity presented itself. Favourable sampling conditions depended on many things. Of most important consideration were the ship's distance from land, and the weather. When the ship was within 10 miles of land and the weather good, sampling was no problem. During very good days and with the ship on stand-by within twenty miles of land, sampling was also carried out. Heavy ice conditions slowed the icebreaker down, thus favouring sampling in some instances. Mail, cargo, and ice observation trips took only a small portion of the helicopter's time during otherwise favourable sampling conditions. In

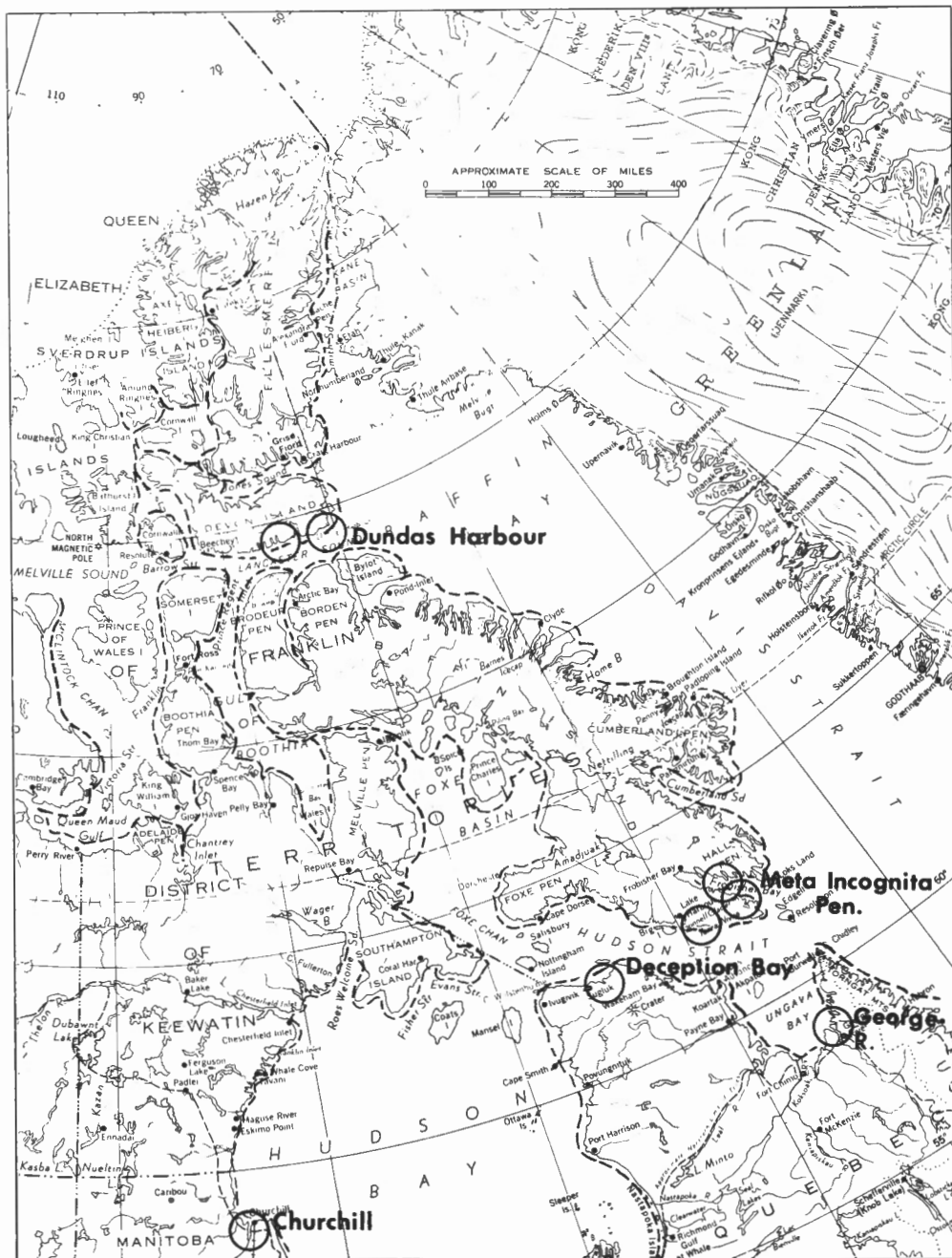


Figure 1. Areas in which streams were sampled during the 1971 season (circles) and possible coastal sampling areas (dotted line), Districts of Franklin and Keewatin.

TABLE 4
Geometric means of variables of water samples from 52 sweet and 15 estuary water zone sites. Concentrations in ppb unless stated

Variable	Sweet water		Estuary water	
	\bar{X}	Log S	\bar{X}	Log S
Alkalinity	13,220	.72	10,640	.63
Arsenic	3.4	.32	2.5	.21
Calcium	3,780	.70	3,740	.77
Chlorine	5,860	.68	13,500	.11
Copper	1.9	.15	1.9	.25
Eh, mv	180	.11	185	.04
Fluorine	<50	-	<50	-
Iron	80	.56	61	.57
Magnesium	1,550	.61	2,430	.95
Manganese	<10	-	<10	-
Mercury	.08	.23	.07	.26
Nickel	3.6	.25	3.9	.24
Oxygen, ppm	10.5	.11	11.5	.06
pH	7.29	.043	7.28	.036
Radon, pc/l	2.1	.51	3.0	.65
Sulphate	8,140	.38	13,100	.67
Temperature, ° F	48.5	.09	42.9	.09
Uranium	<.2	-	<.2	-
Zinc	2.4	.25	2.2	.27

fact, it was possible to sample during the mail runs if the load was not too big. The co-operation and goodwill of the captain, the pilot, and the officers was, of course, absolutely essential for the success of the sampling program.

The streams were generally cold, fast flowing, and shallow with a preponderance of large granite gneiss boulders in the beds. Near ice fields the beds were short and V-shaped with an abundance of sediment at the mouth but very little upstream, suggesting torrential floods during part of the seasonal cycle. Vegetation was sparse or nonexistent. Huge talus slopes and the abundance of sediment in the mouth of the stream on the other hand suggest that erosion is quite extensive at these latitudes. The determination of rock type at the sampling sites turned out to be more difficult than anticipated. At most sites good outcrops were not even encountered, at least, not within easy walking distance of the landing site. However, the gamma ray count and the radon count together with the other tests of the waters gave an indication of the rock type (see Table 6). Limestone and dolomite in the drainage basin gave marked increases in pH, alkalinity, Ca, Mg and Cl in the waters. Granitic terrain would generally show up in higher radon and gamma counts. All waters were found to be saturated with oxygen at the temperature and pressure prevailing at the sample site. Although the analytical results are valid and informative, the effort and skill required to obtain them on board ship more than offsets the information gleaned from them if fewer than 100 samples are involved. All but the radon values could also be obtained by shipping a small sample to headquarters for analysis when the ship stops for mail or cargo.

TABLE 5

Geometric means of variables of -200 mesh sediment samples and of site environment from sweet and estuary water zone sites

Variable	Sweet water site sediments			Estuary water site sediments		
	No. of samples	\bar{X}	Log S	No. of samples	\bar{X}	Log S
Antimony, ppm	53	<5	-	16	<5	-
Arsenic, ppm	53	3.1	.25	14	3.8	.26
Copper, ppm	53	23.8	.29	16	16.8	.26
Iron, %	53	1.14	.27	16	1.08	.24
Lead, ppm	53	3.9	.28	16	5.5	.46
Manganese, ppm	53	185	.34	16	199	.32
Mercury, ppb	53	20.3	.30	14	19.3	.17
Molybdenum, ppm	53	0.4	.39	14	.5	.42
Nickel, ppm	53	13.8	.44	16	11.1	.30
Silver, ppm	53	<0.4	-	16	<0.4	-
Tungsten, ppm	53	<2	-	16	<2	-
Uranium, ppm	53	0.4	.43	16	0.3	.33
Volume of 250 mg, ml	53	0.30	.14	15	0.23	.07
Zinc, ppm	53	23.8	.29	16	31.6	.32
Depth of stream, ft.	53	1.1	.33	16	0.9	.37
Width of stream, ft.	47	34.7	.52	16	85.5	.60
Flow rate, relative	53	moderate		16		low
Level of water, relative	52	normal		16		slow
Boulder covering of stream bed, %	52	27	.52	16	36	.33
Gamma ray activity						
- boulders, $\mu\text{R}/\text{H}$	31	7.8	.27	10	5.0	.18
- outcrop, $\mu\text{R}/\text{H}$	8	5.8	.29	1	3.0	-
- soil, $\mu\text{R}/\text{H}$	34	5.4	.19	5	5.1	.10
Relief of area, degr.	53	19	.22	16	27	.18

Correlation coefficients of log transformed data with significance at the 95 per cent probability level show in general that as the pH, alkalinity, Ca, Mg, Cl, and SO_4 contents of sweet water increases the Zn, Cu, and Ni content of water and sediment decreases, even though there is positive correlation of these elements between the two phases, i.e., equilibrium conditions are approached between water and sediment constituents. In other words, the waters and sediments from the limestone areas contain lower concentrations of these elements than from granitic areas encountered in this work. An increase in Fe and Hg in waters from limestone areas, on the other hand is accompanied by a decrease in these elements in the sediments, suggesting that the "hard" waters are able to leach these elements from the sediment.

The variable volume, which gives an indirect measure of the surface area and organic matter of the sediment gives positive correlation with Hg, U, Zn, Cu, in sediments with probabilities of significance of 1.00, .99, .99, and .89 respectively. The implication of these correlations is that these elements are more strongly adsorbed than is Ni, for instance, which shows

TABLE 6A
Geometric means of sweet water sample variables grouped by map sheet number
(concentrations in ppb unless stated)

Map Sheet Variable	24 I (2)*	25 J (8)*	25 K (3)*	25 O (5)*	35 J (8)*	48 E (7)*	48 F (1)*	54 K (3)*	54 L (15)*
Rock Type	Granite	Granite- gneiss	Granite- gneiss	Granite- gneiss	Granite- gneiss	Granite- gneiss	Limestone- dolomite	Limestone- dolomite	Limestone- dolomite
Alkalinity	4,690	3,460	5,116	1,806	6,705	9,272	75,900	93,293	74,423
Arsenic	7.7	2.5	2.0	2.0	2.0	2.0	2.0	3.2	8.8
Calcium	750	896	1,662	586	1,731	4,078	28,000	21,985	19,683
Chlorine	740	1,397	2,836	6,211	1,801	3,154	6,700	59,277	23,862
Copper	2.0	1.7	2.0	2.0	2.5	1.3	1.0	2.0	2.0
Fluorine	<50	<50	<50	<50	<50	<50	<50	<50	<50
Iron	70	68	42	19	66	50	20	140	222
Magnesium	500	311	528	521	743	1,720	7,200	9,391	6,826
Manganese	<10	<10	<10	<10	<10	<10	<10	<10	<12
Mercury	0.08	0.05	0.17	0.08	0.06	0.07	0.05	0.16	0.10
Nickel	3.0	4.9	5.4	5.0	3.3	5.8	4.0	2.0	2.4
pH	6.80	7.11	6.62	6.60	6.89	7.18	8.07	7.92	7.98
Radon, pc/l	7.4	2.4	0.6	1.3	2.7	1.9	5.7	1.2	2.4
Sulphate	4,050	5,020	10,055	4,148	6,529	18,510	28,800	11,698	9,194
Temper., °F	60	40	44	49	45	37	36	60	61
Uranium	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Zinc	3.0	2.6	3.0	2.5	1.6	2.3	1.0	3.0	2.7

* Number of samples.

TABLE 6B

Geometric means of sweet water sediment sample variables grouped by map sheet number
(concentrations in ppm unless stated)

Map Sheet Variable	24 I (2)*	25 J (8)*	25 K (3)*	25 O (5)*	35 J (8)*	48 E (7)*	48 F (2)*	54 K (3)*	54 L (15)*
Rock Type	Granite- gneiss	Granite- gneiss	Granite- gneiss	Granite- gneiss	Granite- gneiss	Granite- gneiss	Limestone- dolomite	Limestone- dolomite	Limestone- dolomite
Arsenic	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
Copper	18.4	30.8	74.3	34.2	38.0	21.0	10.0	13.7	15.8
Iron, %	0.95	2.21	1.96	1.18	1.37	1.01	0.64	0.53	0.87
Lead	6.9	5.3	6.8	2.9	2.6	4.9	3.2	2.5	3.8
Manganese	155	376	291	49.8	213	117	192	125	228
Mercury, ppb	23.0	22.4	28.7	23.1	18.0	14.4	18.6	11.1	24.2
Molybdenum	0.7	0.9	0.7	1.3	<0.5	<0.5	<0.5	<0.5	<0.5
Nickel	9.0	19.7	40.4	27.1	32.0	12.3	4.9	3.4	8.0
Uranium	2.8	0.3	1.0	1.1	0.2	0.2	0.1	0.2	0.6
Volume, ml	0.33	0.31	0.33	0.34	0.24	0.27	0.22	0.28	0.35
Zinc	27.0	69.7	62.2	82.4	41.1	29.8	12.4	26.0	29.4
Gamma ray									
- boulders, $\mu\text{R}/\text{H}$	12.6	-	-	-	5.9	4.7	4.9	12.0	12.6
- outcrop, $\mu\text{R}/\text{H}$	8.0	-	7.2	-	-	4.4	-	-	-
- soil, $\mu\text{R}/\text{H}$	7.5	-	7.4	-	4.4	4.7	-	4.9	5.8

* Number of samples.

no significant correlation with volume. It is difficult to explain the observed positive correlation between volume and Hg in water unless one assumes that Hg in streams is mainly there as a humic acid complex: humic acids result from the slow breakup of organic matter and are soluble in natural waters. They are extremely efficient ion "getters" compared to clays and other mineral surfaces in stream sediments. Only when all adsorption sites are occupied by ions do humic acids precipitate. Such saturation rarely occurs in nature, hence once liberated from the organic debris in the sediment, the humic acid could carry strongly adsorbed trace elements with it into solution. Even though the observed correlations confirm in a general way chemical principles, they are really not strong enough nor is the number of samples large enough to warrant more complex mathematical treatment of the data.

It cost \$113 to collect a water and sediment sample and carry out 9 simple analyses on the water sample on board ship. This cost includes \$95 per hour of helicopter time, and salaries, room and board, and travel and freight between Ottawa and ship for one research scientist and one student assistant. Because the ship was not diverted or delayed from its normal course, no cost allowance has been made for the operation of the ship. Naturally, the officers and helicopter crew gave of their time free of charge to make the sampling possible. It appears that with certain changes in the procedure the cost per site of the ship-based method could easily be cut in half. For example, the additional effort and cost required to obtain immediate analytical results on board ship is not warranted in view of the small number of samples that can be collected in any one season. Such analytical work could be done in the Ottawa laboratories by shipping samples during stops made by the ship to collect mail.

CONCLUSIONS AND RECOMMENDATIONS

The test showed that it is feasible to sample Arctic coastal streams on an opportunity basis using the helicopter on board an icebreaker. Although the cost per sample site of this year's test was higher than the estimated cost of conventional methods, changes in the procedure should result in considerable cost reduction, making the ship method competitive with conventional methods.

No significant mineralization was outlined by the analytical results of the samples, i.e., variations and levels of trace element contents were low, although mathematically significant differences in certain trace elements were observed depending on particle size of sediment, position of sample site, (e.g. sweet or estuary water zone) and method of analysis.

On the basis of this feasibility study, it is evident that, by omitting the laboratory and putting only one experienced student on a ship for the summer months, the method is an attractive and economical way of collecting geochemical information from the Arctic coastline - a region where normal field operations are very expensive.

The value derived from such a program, if properly planned and accepted by all parties involved, would be considerable, and well within costs of conventional sampling methods. The information obtained from these samples would not only indicate mineralization but also serve as background data for possible pollution control measures at some future date.

ACKNOWLEDGMENTS

This work would not have been possible without the assistance of Dr. H. Blandford, Canadian Hydrographic Service, and Captain J. Stewart, D.O.T., Marine Operations. Thanks also go to the officers and crew of the "John A. Macdonald" for their assistance and encouragement in this work; in particular to the master, G.S. Yarn, who more than once reiterated that he had often wondered why a sampling program such as ours had not been started years ago.

I would like to acknowledge the assistance that Mr. G.M. Thomas rendered in the collection of samples and water analyses on board ship.

Analyses of water samples were carried out by Mr. P.J. Lively and staff, Department of the Environment, Inland Waters Branch.

Analyses of sediment samples were carried out by J.J. Lynch and staff, Department of Energy, Mines and Resources, Geological Survey Branch.

Computer processing of data was carried out by Mr. J.D. Hobbs, Department of Energy, Mines and Resources, Geological Survey Branch.