HISTORICAL OCEAN DISPOSAL IN THE CANADIAN ARCTIC

SURVEY OF MATERIALS DISPOSED IN CAMBRIDGE BAY AND THE STATE OF THE MARINE ENVIRONMENT

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1. INTRODUCTION

The Canadian Arctic consists of vast areas of ocean, much of it shallow and intricately associated with land (Map 1.1). Plant and animal life in the water column and on the seabed in these coastal areas provide sustenance for many animals including Arctic charr, ringed seals, beluga, and polar bears to name a few. The dependence of Inuit and Inuvialuit on this 'country food' undoubtedly accounts for the fact that most traditional human activity occurred at or very near to the coast.

Areas of human habitation established in the last century are largely concentrated along the edge of the Arctic Ocean; these include communities, mining operations, oil and mineral exploration camps, and military installations such as radar sites. Many human activities create waste; for example: building materials; 45 gallon drums for the transport of fuel, coolant, degreasers and lubricating oils; discarded vehicles, machinery and buildings; sewage; and other domestic/industrial waste. The past disposal of waste has in some cases resulted in the release of chemical contaminants to the environment. Consequently, regulatory agencies and society in general have therefore adopted more stringent practices for waste disposal. The disposal of waste is particularly difficult in the Canadian Arctic owing to the high costs of transportation, cold temperatures, snow, and presence of permafrost which makes burial difficult.

There were two principal methods for disposing of non-combustible solid waste generated in the Arctic: disposal on land (often in an unburied state); and disposal in lakes or the ocean. **This report investigates the extent and environmental effects of the historical ocean disposal of solid waste in the Canadian Arctic, using Cambridge Bay, Northwest Territories, as a case study.**

Word-of-mouth accounts suggested that, at most radar sites, debris disposed in the ocean included primarily large vehicles and empty barrels. An underwater survey, however, in Cambridge Bay during the spring of 1993 identified objects on the seabed suspected to be electrical components. This raised the possibility that other objects in addition to environmentally benign ferrous-metal debris may have been deposited in the ocean. Environment Canada and the Department of National Defence, with assistance from Energy, Mines and Resources (now Natural Resources Canada) and Parks Canada (now Heritage Canada), conducted a detailed study of the extent and impact of historic ocean disposal in Cambridge Bay.

Cambridge Bay, NWT, is located on the southern coast of Victoria Island in the Canadian Arctic, at latitude 69° 07' N and longitude 105° 07' W. The embayment occupies an area of approximately 15 km^2 (Maps 1.1, 1.2), and receives discharge from the Greiner Lake catchment basin to the north, via Freshwater Creek (Photo. 1.1). On the northern shore of Cambridge Bay is an active radar site (CAM-M: previously a DEW Line site and presently a major component of the North Warning System; Photo. 1.2). The northern shore of the central basin of Cambridge Bay is also the site of the hamlet of Cambridge Bay, which has a population of approximately 1,100. An older, abandoned town site along with an inoperative Loran tower is situated to the south-east of the hamlet, across Freshwater Creek.

Both CAM-M and the hamlet dump contain limited quantities of soil contaminated by polychlorinated biphenyls, copper, lead and/or zinc (Photos 1.3,1.4; Reimer et al., 1993). Both areas have the potential to contribute contaminants to the marine environment via surface runoff during summer months.

Cambridge Bay was chosen for an investigation of the effects of ocean disposal, in part, because it has the largest hamlet and radar site in the central Arctic. In addition, a large amount of heavy equipment from construction and initial operation of the DEW Line can still be found in the hamlet dump and in use in the community.

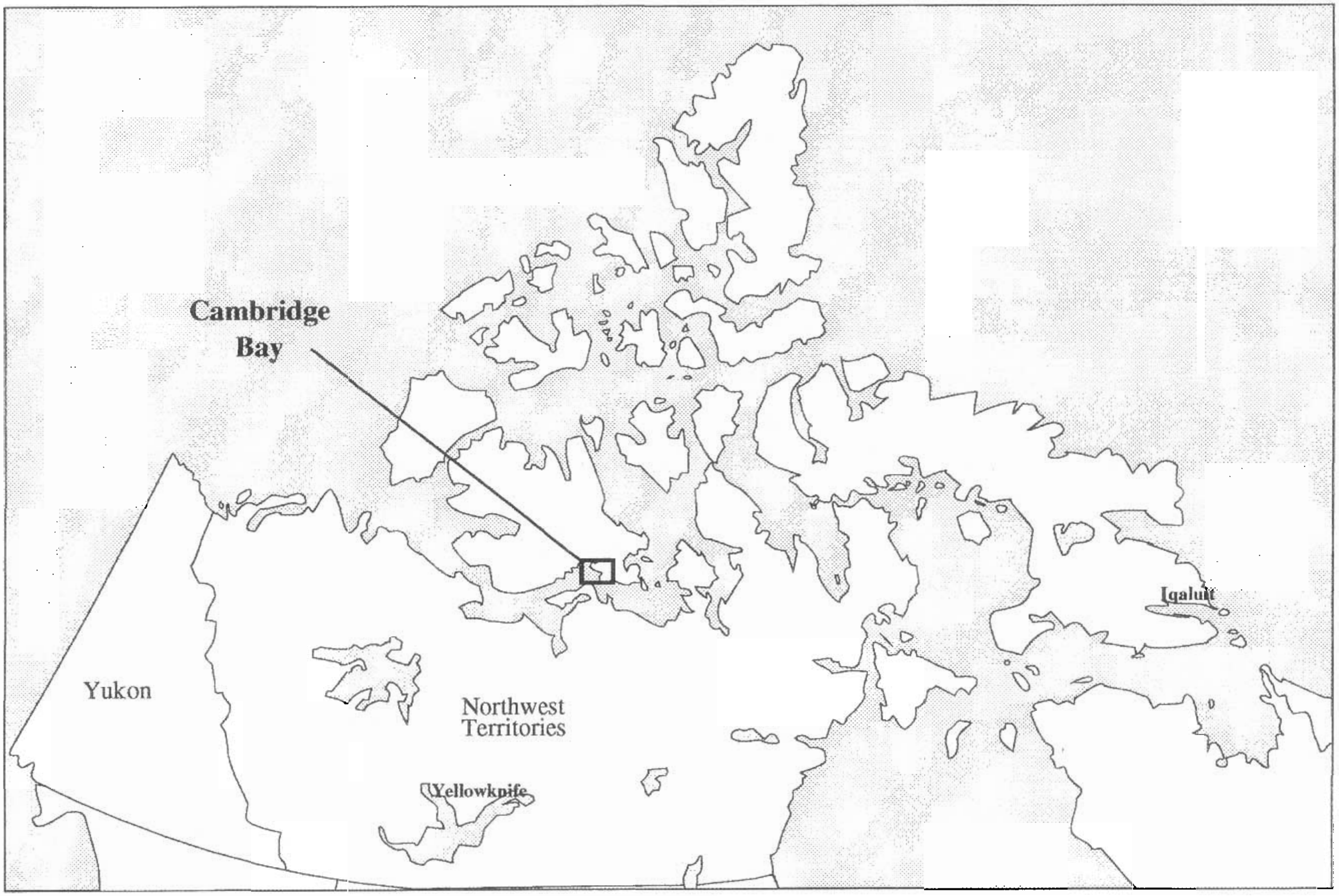
1.1. Objectives

The specific objectives of the 1993 Cambridge Bay study were to -

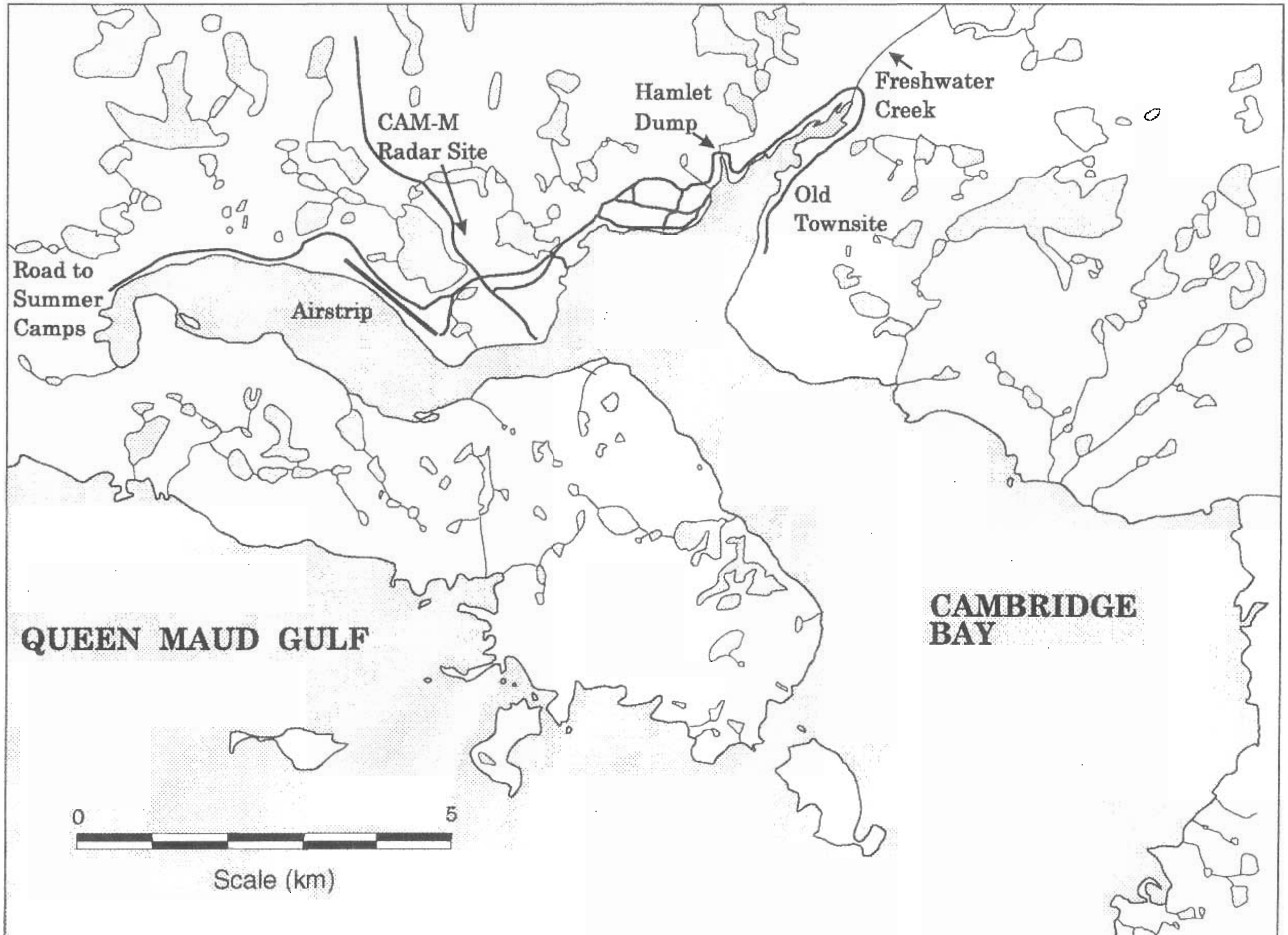
- investigate whether the previously identified electrical components contain PCBs;
- assess the extent of inputs and impact associated with any PCB-containing equipment;
- recover any equipment which would cause any immediate or future concern with respect to marine environmental quality;
- delineate the extent of historical ocean disposal in Cambridge Bay; and
- conduct scientific investigations of the relative environmental impact associated with ocean disposal versus shore-based contaminant inputs.

1.2. How to Use This Report

This report, prepared jointly by representatives from Environment Canada, the Department of National Defence, and Natural Resources Canada, summarizes the investigation of historic ocean disposal in Cambridge Bay, conducted in August-September, 1993. The report provides a summary of the major findings, and is written for both a scientific and non-scientific audience. A more comprehensive report (in preparation) will provide additional information on contaminants in Arctic marine biota, water and sediment, interpreted in the context of local inputs in Cambridge Bay, as well as food-chain mediated biomagnification of organochlorine inputs associated with long-range atmospheric transport. The second report will contain details of the quality assurance program and the complete data set obtained as part of the Cambridge Bay investigation. Additional scientific information from investigations conducted in Cambridge Bay prior to 1993 is also provided in papers by Bright et. al (in press) and in a report by Reimer et al. (1993).



Map 1.1: Location of Cambridge Bay in the Canadian Arctic.



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Photograph 1.2: North Warning Radar Site, CAM-Main.

Photograph 1.3: Large vehicles in Cambridge Bay community dump.

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Photograph 1.6: Canadian Coast Guard ship J.F. Franklin aided in the survey of Cambridge Bay in August of 1993. CAM-Main North Warning site is in the background.

2. METHODS

An investigation was carried out in Cambridge Bay from the 12th of August to the 4th of September 1993. The overall study comprised -

- the delineation of debris and geological features on the seabed;
- identification of debris 'targets' using SCUBA divers, a remote operated vehicle (ROV) equipped with video, and other techniques; and
- the scientific study of contaminant distributions in the sediment, water, and marine biota of Cambridge Bay.

Each of these is described in greater detail below.

2.1. Side-scan Sonar Investigations of the Seabed

Side-scan sonar equipment was used to provide an acoustic map of the seabed. Side-scan sonar surveys involve the transmission of sound-waves laterally from a 'towfish'; i.e., a torpedo-shaped metal transducer towed near the bottom by a surface vessel. The towfish also receives echoes of the original sound waves over a range of directions. The incoming information is processed to produce a visual image of the relief of the seabed, which allows the identification of geological features and discrete objects, including anthropogenic debris.

The side-scan sonar equipment, a *Klein* 520 Side Scan Sonar System including a 100 kHz 3/4 degree towfish, was installed on board a 21' aluminum boat which was rented locally (Photo 2.1). The towfish was towed from the stern of the vessel at a speed of three knots and maintained at a safe height above the seabed. Survey lines were run at 100 metre intervals; the trackplots are shown on Map 2.1. One line was run around the entire shoreline of Cambridge Bay. A Garmin Global Positioning System (GPS) was used for navigating; and all target positions and side-scan sonar track lines were positioned using differential GPS.

A hydrographic survey of Cambridge Bay was also conducted in order to provide accessory information on bottom topography. Launches from the Canadian Coast Guard (CCG) Ship J.F. Franklin (Photo 2.2) and Canadian Survey Ship (CSS) J.P. Tully were used to conduct hydrographic surveys of Cambridge Bay. Detailed results of these surveys will appear in a future report.

2.2. Identification of Objects on the Seabed

It was necessary to establish the identify of individual targets after the positions of objects on the bottom of Cambridge Bay were established using side-scan sonar. Temporary marker buoys were placed at the target sites. Objects were subsequently examined in greater detail using a combination of visual observations by SCUBA divers (Photo 2.3), an ROV equipped with a video camera (Photos 2.4, 2.5) and sector-scan sonar, or a drop camera (Photo 2.6) deployed from the surface. Each target was videotaped and/or accurately described in writing. All records are in archival storage at the Environment Canada office in Yellowknife.

2.3. Scientific Study of Contaminant Inputs

2.3.1. General

The overall concern with regard to disposal of debris in the ocean is whether there are adverse effects on marine life and/or human health. A detailed study of contaminant distributions in Cambridge Bay was carried out to ascertain whether the debris disposed in the sea has contributed to local inputs of potentially deleterious substances. A contaminant may be defined as a substance introduced through human activity which causes a deviation from the normal composition of the environment. A contaminant in not necessarily a pollutant, however, unless it has a net detrimental effect on the environment.

This study also included the examination of relative contributions of contaminants from debris disposed at sea, contaminants entrained in runoff from contaminated areas on land (refer to Reimer et al., 1993; Bright et al., in press), and contaminant inputs associated with atmospheric transport from distant sources, which may enter Cambridge Bay primarily via Freshwater Creek inputs.

2.3.2. Sampling Program

Samples of marine sediment, water, and bottom-dwelling invertebrates and fish were collected. The sampling locations for sediment, water and biota are provided in Map 2.2. Sediment samples were collected from 57 sites; eight of these samples were hand-collected by SCUBA divers within 0.1 - 2 m of individual pieces of debris on the bottom, while the other 49 samples were collected using a surface vessel (hydrographic launch of the CCG J.F. Franklin, small zodiac, or from the deck of the CSS J.P. Tully) and a sediment grab [stainless steel Petite Ponar, stainless steel Eckman grab (Photo 2.8), or stainless steel 0.1 m^2 Van Veen grab (Photo 2.7), respectively]. The grab-collected sediment samples were collected 'blind' relative to debris on the seabed and were therefore representative of the seabed in Cambridge Bay as a whole.

Marine fish and bottom-dwelling invertebrates were collected from Cambridge Bay in concert with the geological and sediment chemistry investigations. Biota collected included soft-shell clams, mussels, amphipods, sea urchins, seastars, and fish. (Table 2.1; Photos 2.9, 2.10) The animals also occupy an important position in coastal Arctic food webs, assimilating nutrients and potentially harmful substances as filter feeders, detritivores, or carnivores.

Table 2.1: Biota Collected in Cambridge Bay During August-September 1993.

Species	Common name	No. of sampling locations	Total no. of individual or pooled collections
Invertebrates			
Mya truncata	soft-shell clams	3	3
Mytilus edulis	common mussels	1	1
Hiatella arctica	clams	2	2
Species unident.	amphipods	2	3
Strongylocentrotus droebachiensis	sea urchins	12	19
Fish			
Myoxocephalus quadricornis	four-horn sculpins	11	71
Myoxocephalus scorpius	short-horn sculpins	11	43
Gadus ogac	Greenland cod	11	22
Salvelinus alpinus	Arctic charr	4	11
Total no. of collection sites		19 (Map 2.2)	

The geographical locations of the sampling sites and a brief description of the collection methods are provided in Table 2.2.

Table 2.2: Description of Sampling Locations in or Near Cambridge Bay.

Stn	Field I.D.	Depth	Sample Method	Latitude (N)	Longitude (W)	Comments
QM-1	GN-7	<10 m	Gill Net	69^{o} 5.45'	105^{o} 16.08'	Ref. area in Queen Maud Gulf off gravel pit/fishing camp.
W-1	GN-5	<10 m	Gill Net	69^{o} 5.83'	105^{o} 6.25'	Shoreline Area above ocean-dumped vehicles (CB04).
W-2	CB-4	38 m	SCUBA	69^{o} 5.86'	105^{o} 6.27'	Several army jeeps/trucks on seabed.
W-3	none	5-10 m	Fishing Rod	69^{o} 5.63'	105^{o} 7.58'	Sandy shoal on s. shore of w. arm; south of CB05.
W-4	GN-0	<10 m	Gill Net/Rods	69^{o} 6.08'	105^{o} 9.83'	W. arm, s. shore over and at break of large shoal.
W-5	CB1-3	20 m	SCUBA	69^{o} 6.00'	105^{o} 7.58'	Debris from Globemaster airplane wreckage and barrels disposal.
W-6	Dive #5	<10 m	SCUBA	69^{o} 5.83'	105^{o} 6.27'	
E-1	GN-6	<10 m	Gill Net	69^{o} 6.08'	105^{o} 5.22'	Near radar site beaching/POL area.
E-2	GN-2	<10 m	Gill Net	69^{o} 6.38'	105^{o} 4.92'	Shallow area on n. shore of bay, near radar site runoff.
E-3	Dive #2	<10 m	SCUBA	69^{o} 6.67'	105^{o} 4.16'	Near radar site runoff, but slightly n. of E-2.
E-4	GN-1	<10 m	Gill Net	69^{o} 6.65'	105^{o} 4.50'	Near large amounts of seabed debris off western end of hamlet.
E-5	Dive #1	<10 m	SCUBA	69^{o} 6.34'	105^{o} 4.89'	Near hamlet; east of E-4.
E-6	Gov't jetty	5 m (approx.)	SCUBA/ Fishing Rod	69^{o} 6.71'	105^{o} 3.65'	Gov't Jetty at Hamlet.
E-7	N. Store	<10 m	SCUBA	69^{o} 6.92'	105^{o} 2.30'	Off Northern Store, near hamlet dump discharge.
E-8	Freshwater Creek	<5 m	Fishing Rod	69^{o} 7.17'	105^{o} 0.50'	At mouth of Freshwater Creek, opposite to float plane base.
E-9	Dive #3a	<10 m	SCUBA	69^{o} 6.99'	105^{o} 1.17'	Around shipwreck, the "Maud", near mouth of Freshwater Creek.
E-10	Dive #3	<10 m	SCUBA	69^{o} 6.63'	105^{o} 1.64'	Near shore at old townsite/Loran tower.
E-11	Dive #4	<10 m	SCUBA	69^{o} 6.26'	105^{o} 2.13'	Near east shore, south of Loran tower, near summer fishing camp.
E-12	GN-3	<10 m	Gill Net	69^{o} 6.12'	105^{o} 2.17'	Off east shore, near entrance to upper Cambridge Bay.
E-13	GN-4	<10 m	Gill Net	69^{o} 6.05'	105^{o} 3.72'	Near south shore at entrance to west arm.

All biota samples were placed in coolers and transported back to the North Warning System (NWS) radar site at Cambridge Bay for processing, packaging and preservation. All biota were sorted into pooled or individual samples of sufficient tissue mass (generally > 5 g wet wt) to facilitate the analyses, labeled with a sequential code, wrapped in either aluminum foil or plastic, and frozen at -20^{o} C, in preparation for shipment to Queen's University Analytical Services Unit, Kingston, Ontario (for inorganic element analysis) or AXYS Analytical Services, Victoria, British Columbia (for organic contaminants). All fish were dissected, examined for internal anomalies or parasites, and the stomach contents examined. The livers were excised and separately analyzed from the rest of the whole tissue.

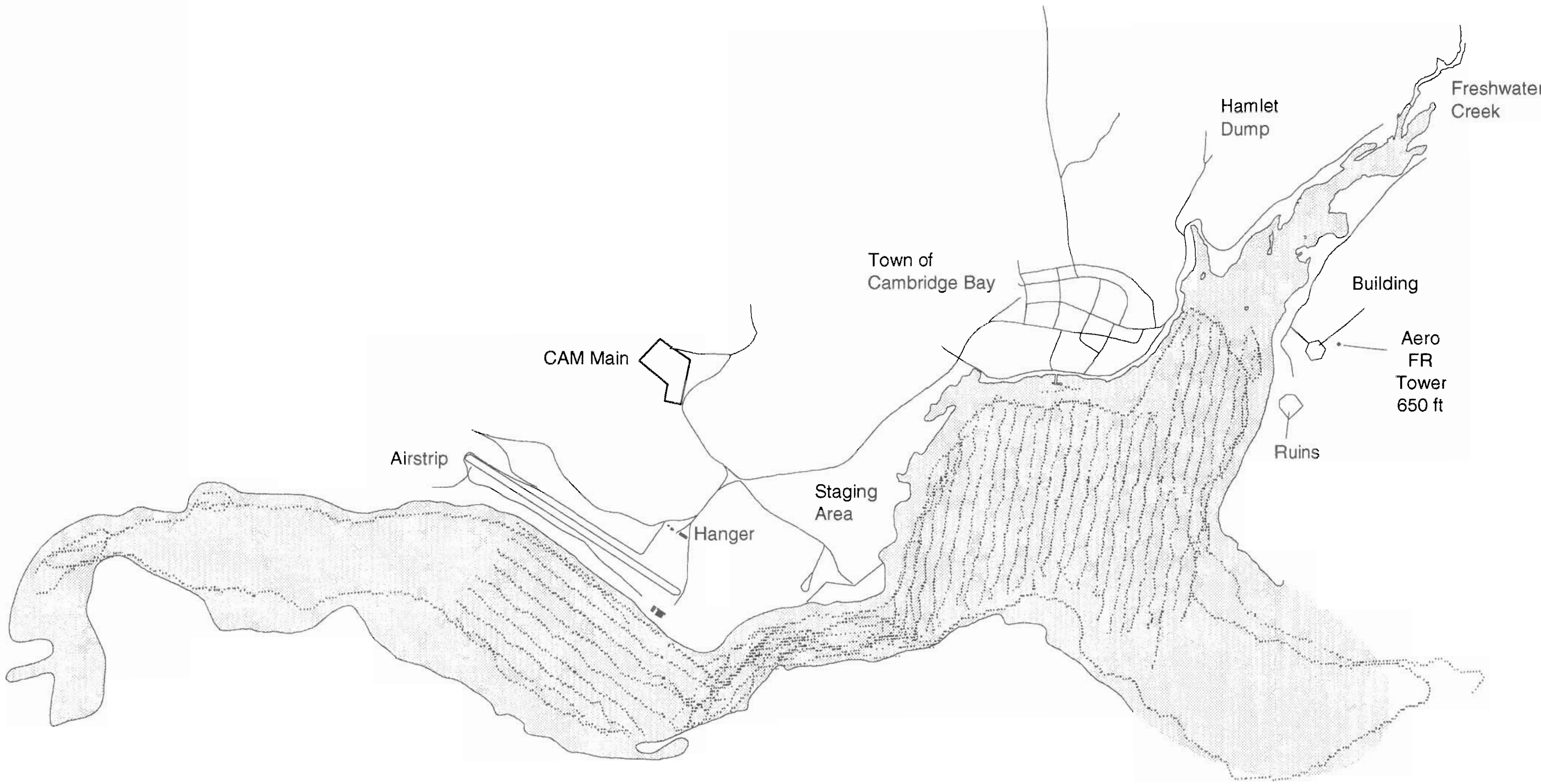
2.3.3. Analytical Program

A subset of sediment and biota samples were analyzed for a large range of possible contaminants, as shown in Table 2.3. All sediment samples were analyzed for inorganic elements by atomic absorption spectroscopy and neutron activation analysis, and all grab-collected sediment samples were analyzed for polychlorinated biphenyls (as Aroclors) by gas chromatography (GC)/high-resolution mass-spectrometry. Thirty one sediment samples were analyzed for PAHs by GC/electron capture detection (ECD) or GC/low resolution mass-spectrometry. Inorganic elements, PAHs, PCBs, chlorinated pesticides and toxaphene (or polychlorinated bornanes) were analyzed in the tissues of a subset of biota collected, using a combination of GC/ECD, GC/mass-spectrometry and GC/negative-ion mass spectrometry.

Table 2.3: Cambridge Bay Sediment Contaminant Screen.

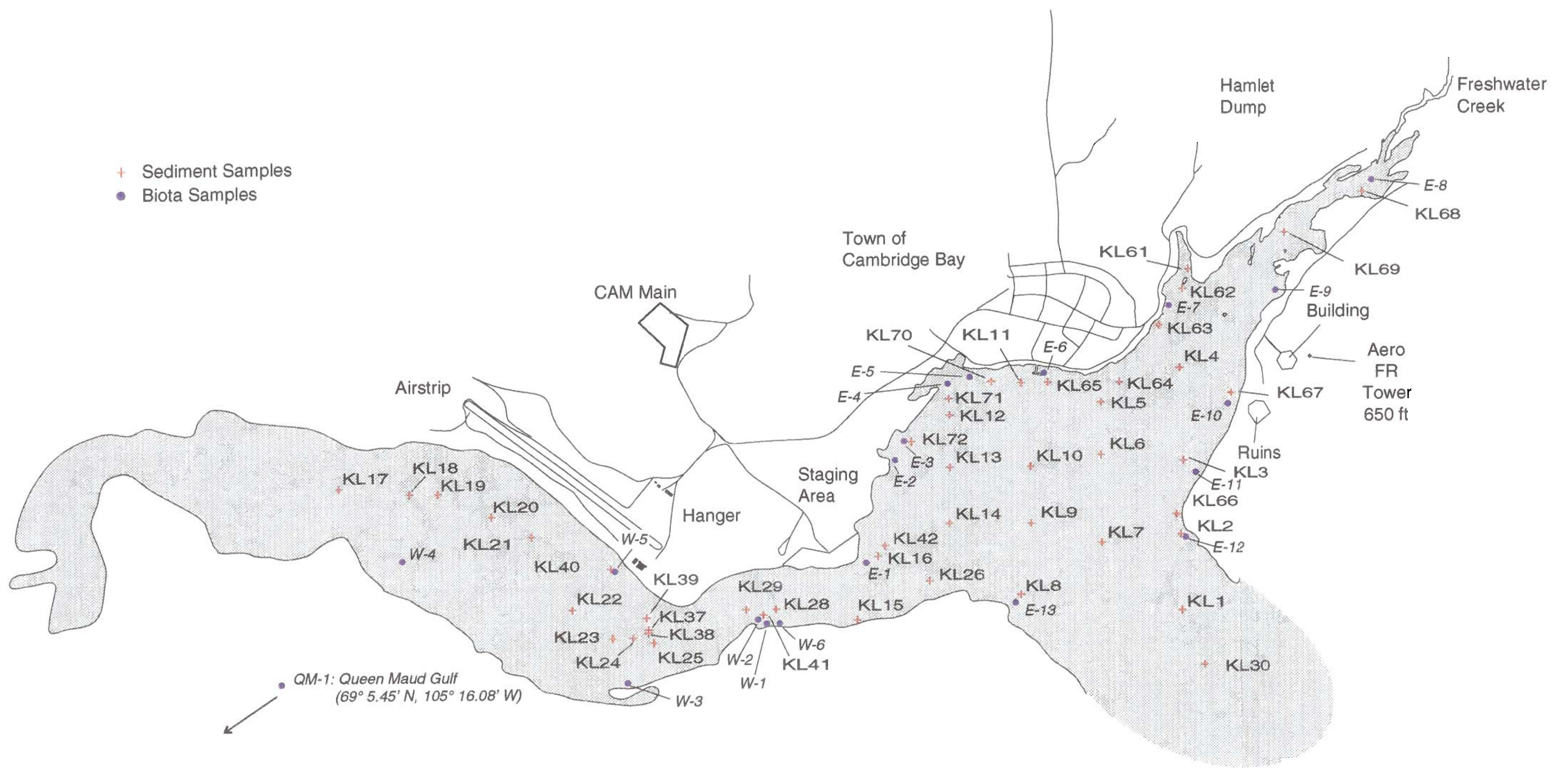
Inorganic elements	**Alkylated PAHs**	*PCB Congeners (cont'd)*	**Chlorinated Pesticides**
arsenic	C1 naphthalenes	149	Hexachlorobenzene
antimony	C2 naphthalenes	118	α-hexachlorocyclohexane
bromine	C3 naphthalenes	143	β-hexachlorocyclohexane
cadmium	C4 naphthalenes	114	γ-hexachlorocyclohexane
chromium	C1 phenanthrenes	132/153	p,p'-DDT
cobalt	C2 phenanthrenes	105	o,p'-DDE
copper	C3 phenanthrenes	141/179	p,p'-DDE
iron	C4 phenanthrenes	137	o,p'-DDD
halfnium	Dibenzothiophene	138/158	p,p'-DDD
lanthanum	C1 dibenzothiophene	129/126	Oxychlordane
lead	C2 dibenzothiophene	187/182/159	trans-Chlordane
mercury		183	cis-Chlordane
nickel	**Polychlorinated**	128	trans-Nonachlor
potassium	**Biphenyls (PCBs)**	185	cis-Nonachlor
scandium		174/181	Heptachlor
sodium	Aroclor 1242	202/171/156	Heptachlor Epoxide
tin	Aroclor 1254	173/201	alpha-Endosulphan
zinc	Aroclor 1260	180	Aldrin
		191	Dieldrin
Polycyclic Aromatic	*PCB Congeners*	170	Endrin
Hydrocarbons (PAHs)	*(IUPAC no.)*	199	Methoxychlor
	18	203/196	Mirex
Naphthalene	15/17	189	
Acenaphthylene	54	208/195	*Polychlorinated Camphenes (chlorobornanes)*
Acenaphthene	31	207	
Fluorene	28	194	Toxaphene (total)
Phenanthrene	52	205	
Anthracene	49	206	P1: 2-exo,3-endo,5-exo,6-endo,8,8,10,10-Octachlorobornane
Fluoranthene	44		P2: 2,2,5-endo,6-exo,8,9,10-Heptachlorobornane
Pyrene	40/103		P3: GC/MS: Octachloro-Derivative
Benz(a)anthracene	61/94/74		P4: 2-exo,3-endo,5-exo,6-endo,8,8,9,10,10,-
Chrysene	66/80/95		Nonachlorobornane
Benzofluoranthenes	121		P5: GC/MS: Nonachloro-Derivative
Benzo(e)pyrene	56/60		P6: 2,2,5-endo,6-exo,8,8,9,10,10-Nonachlorobornane
Benzo(a)pyrene	90/101		P7/P8: 2,2,5,5,8,8,9,10,10-Nonachlorobornane/
Perylene	86/97		2-exo,3-exo,5-endo,6-exo,8,8,9,10,10-Nonachlorobornane
Dibenz(ah)anthracene	87		P9: 2,2,3-exo,5-endo,6-exo,8,8,9,10,10-Decachlorobornane
Indeno(1,2,3-cd)pyrene	77/154/110		P10: 2,2,5,5,6-exo,8,8,9,10,10-Decachlorobornane
Benzo(ghi)perylene	151		P11: 2,2,3-exo,5,5,8,8,9,10,10-Decachlorobornane
	135/144		

Detailed descriptions of collection and analytical methods are provided elsewhere (Bright et al., in prep.) along with the quality assurance/quality control program used to ensure that the data were reliable.



Map 2.1: Side-scan Sonar Track Plots

The coastal outline was taken from a McQuest Marine Sciences Limited, Marine Environmental Survey Map done for:
Enery Mines and Resources, N.S.
Environment Canada, N.W.T.
Department of National Defence, Royal Roads, B.C.
April 1994



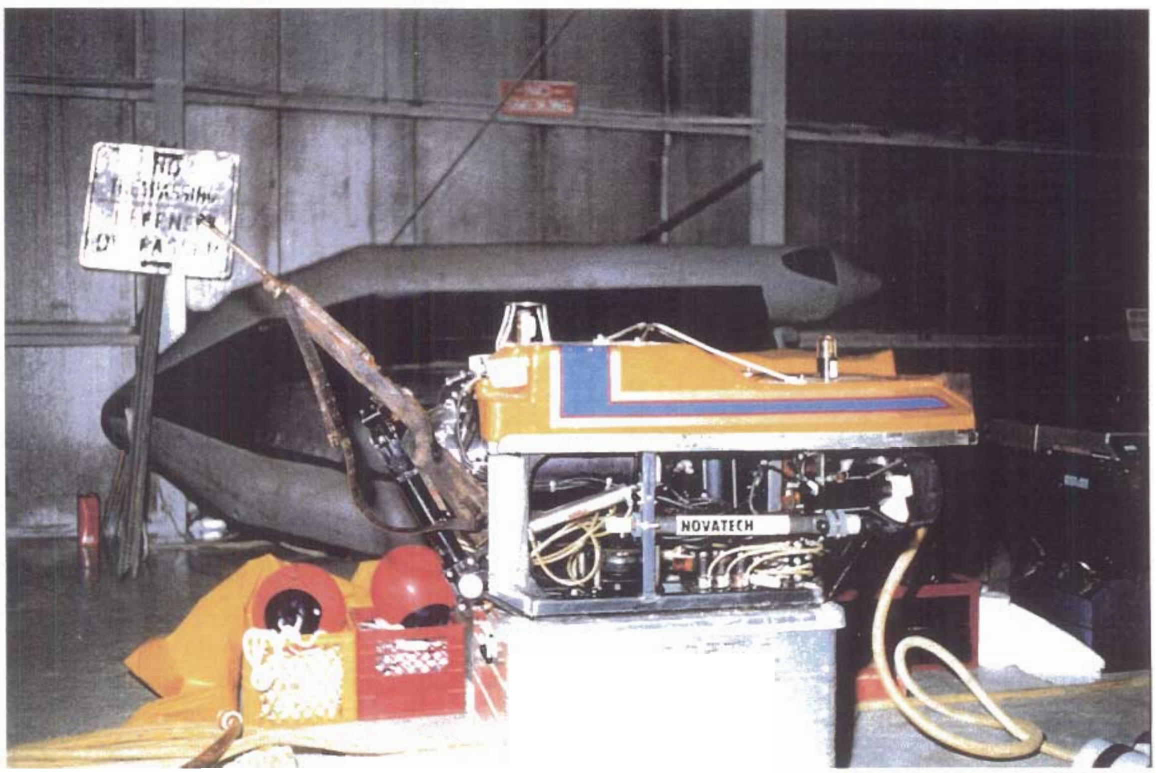
The coastal outline was taken from a McQuest Marine Sciences Limited, Marine Environmental Survey Map done for:
Enery Mines and Resources, N.S.
Environment Canada, N.W.T.
Department of National Defence, Royal Roads, B.C.
April 1994

Map 2.2: Sampling Locations for Sediment and Biota

Photograph 2.1: Side scan sonar equipment on the tow boat with Environment Canada personnel and sonar operator.

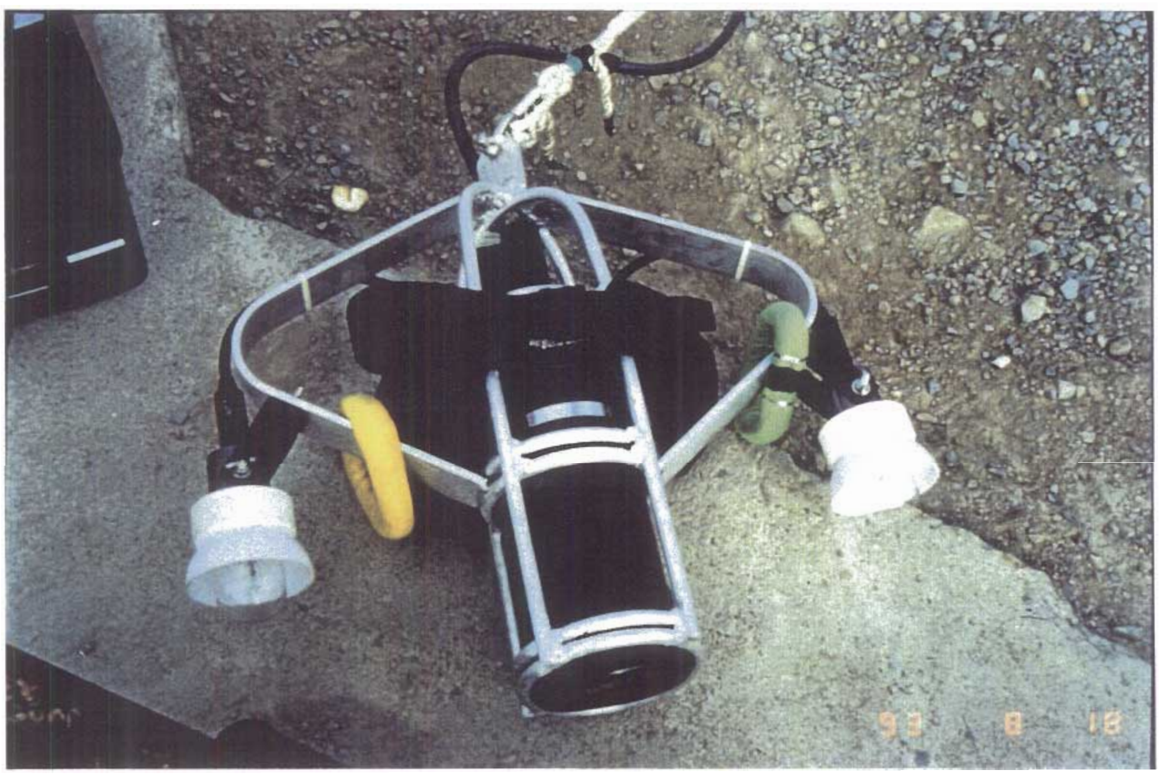
Photograph 2.2: Hydrographic launches of the C.S.S. J.P. Tully performed surveys of Cambridge Bay.

Photograph 2.3: SCUBA divers from the Pacific Fleet Diving Unit of DND identified targets located by the side scan sonar and sampled in the areas of the targets.



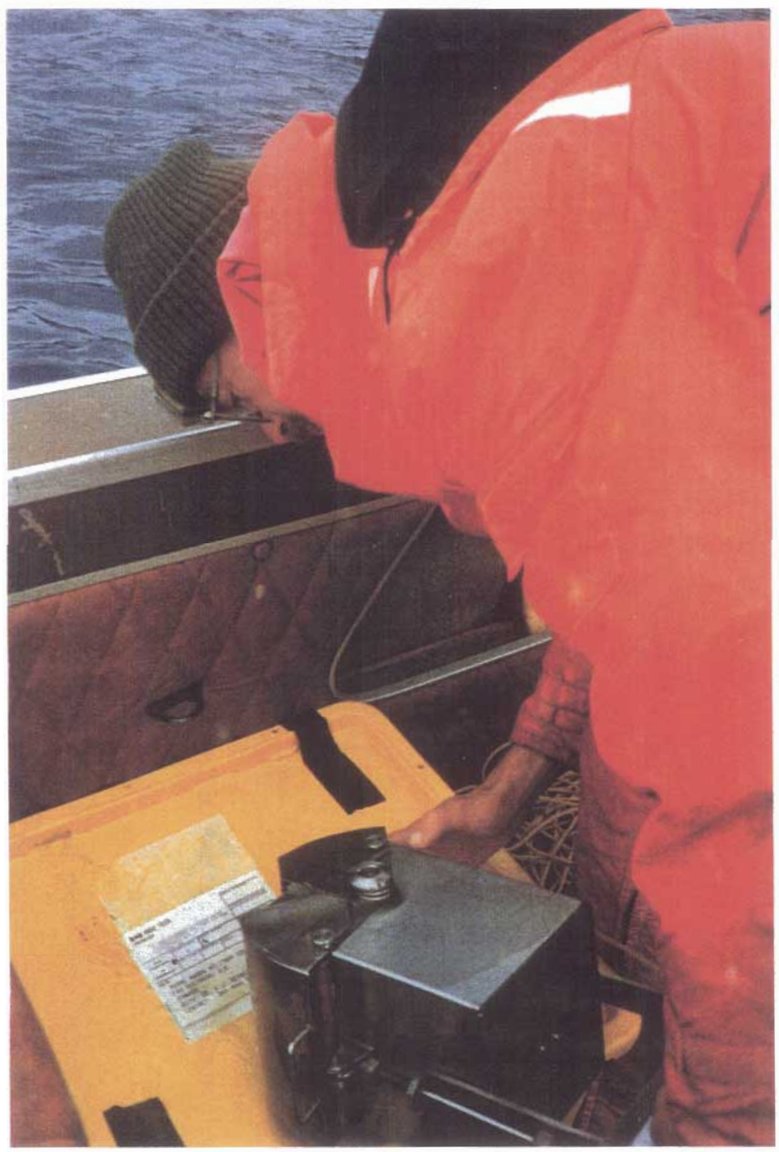
Photograph 2.4: Remote operated vehicle (ROV) equipped with video and sector-scan sonar. The object in the manipulator arm was retrieved from the bottom of Cambridge Bay.

Photograph 2.5: ROV operation in Cambridge Bay. (Photo taken from video footage)



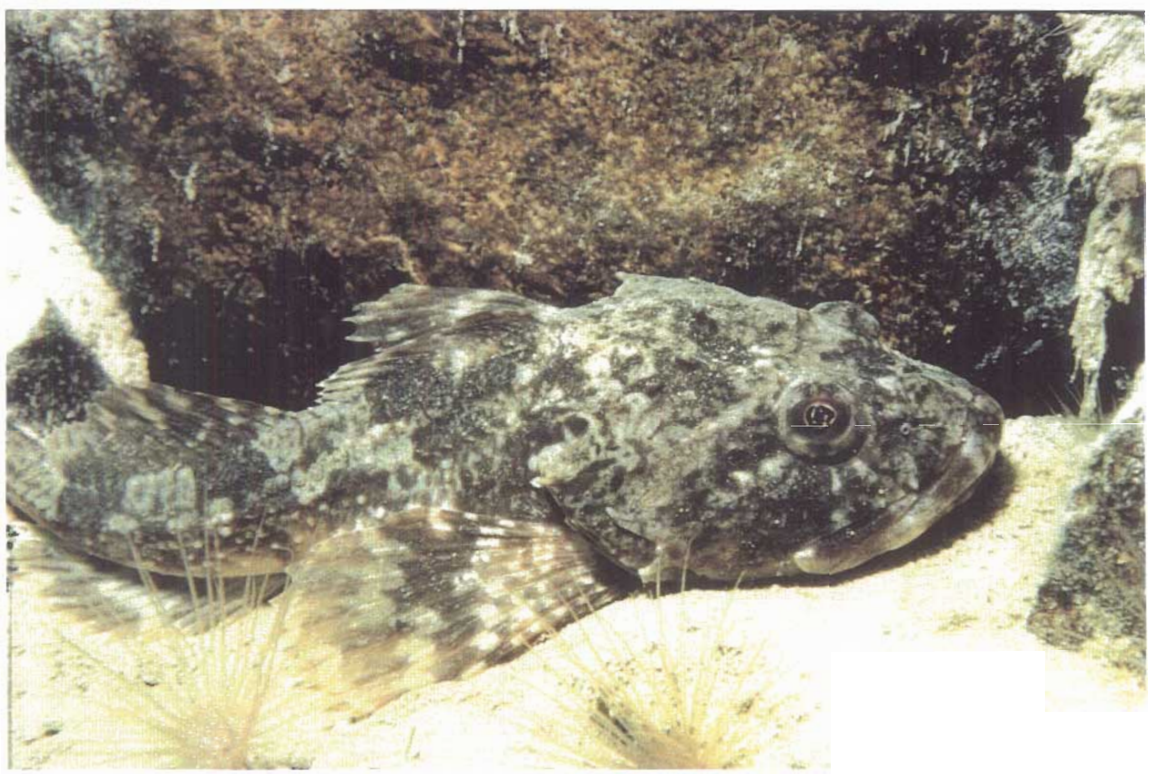
Photograph 2.6: Drop camera used to help identify targets located by side scan sonar.

Photograph 2.7: Van Veen grab used for sampling marine sediment from the deck of the J.P. Tully, August 1993.



Photograph 2.8: Eckman grab, also used for sampling marine sediments.

Photograph 2.9: Gill nets were set in shallow waters to collect bottom-dwelling fish.



Photograph 2.10: Short-horn sculpin, *Myoxocephalus scorpius.*

3. SURVEY AND IDENTIFICATION OF MATERIAL ON THE SEABED

A total of 54 objects or groups of objects on the bottom of Cambridge Bay were identified during the side-scan sonar investigation (Map 3.1). These included discrete areas suspected to contain single or multiple objects of human or geological origin. Subsequent identification of each object, or 'target' was carried out using an unmanned remote-operated vehicle (ROV), SCUBA diver observation, or a drop-camera, deployed from a small boat. A summary of results of the side-scan and identification/verification surveys is provided in Table 3.1.

Of the 54 objects, 10 were subsequently identified as rocks and boulders. (Photos 3.1, 3.2) Another 15 were identified as areas with 45 gallon drums. (Photo 3.3) In particular, the bottom of Cambridge Bay to the south of the community is littered with drums, which were too numerous to count (probably exceeding 1,000). Prior to construction of an all-weather airstrip in Cambridge Bay, an airstrip was built on the ice during the winter. Apparently, it was common practice to refuel airplanes on the ice and dispose of empty barrels through a hole in the ice after puncturing them. (Photo 3.4) Puncture marks could be clearly seen in many of the drums, as well as in drums presently found in the metal-waste dump near the community (Photo 3.5); these barrels were probably washed up by storms and ice scour, and have been collected from the shoreline and placed in the dump by local residents.

Table 3.1: List of Objects Delineated Using Side Scan Sonar

Site No.	Side-scan Sonar Survey	Identification/Verification
CB01	(5 x 13 x 3 m); 1 large target + many small targets (~1 x 0.5 m).	airplane fuselage, drums.
CB02	(1.5 x 6 x 1 m); 2 large targets + a few smaller targets (~1 x 0.5 m).	parts of wing and engine, drums.
CB03	(5 x 16 x 2-3 m); 1 very large target + numerous small targets (1 x 0.5m).	tail section of aircraft, drums.
CB04	(each 2-3 x 3-4 x 2 m); cluster of large targets.	several army vehicles; jeeps and an army truck.
CB05	(each <1m in height); 1 large target + numerous clustered targets.	electrical cabinet with ~ 8 components inside, and up to nine other loose objects (some type of electrical component).
CB06	(2 x 3 - 4 m); 2 large targets + one smaller target.	2 square metal tank-like objects, and an unknown metal object.
CB07	large target composed of cluster of smaller (<0.5m tall) targets.	large angular boulder or rock outcrop with scattered cobble.
CB08	(<1 m in height); cluster of targets.	rounded boulders.
CB09	(10 x 3 m height); 1 large target.	framework for Quonset hut, upside down.
CB10	(3 m height); 1 large target + smaller targets scattered around.	large target observed on Mesotech scan but unable to locate with DART; some boulders observed while searching for the large target.
CB11	(~0.5 m height); 1 large target.	large boulder.
CB12	(2 m height); 1 large target.	huge rock slab with smaller slabs scattered around.
CB13	(1 m in height); cluster of large targets.	large rock slabs.
CB14	(~1 m height); 1 large target.	wire spool about the size of a truck.
CB15	(<0.6 m height) cluster of large targets, within a 10-12m circle).	a metal drum attached to a sled, scrap metal, and a reel drum or spool.
CB16	(<2 m height); a cluster of targets.	an army-like pickup truck with a trailer.
CB17	(1.5 - 2 m height); 1 large target + smaller targets.	old truck with box missing, scattered drums.
CB18	numerous targets.	scattered drums.
CB19	(~1.5 m height); 1 large target + scattered smaller targets	not investigated.

Table 3.1 (cont'd)

CB20	(~1.5 m height); 1 large target + scattered smaller targets.	not investigated.
CB21	(0.8 m height); single target.	crushed navigational buoy.
CB22	numerous small targets.	old washing machine, bathtub, boat hull, tires, drums.
CB23	(~1.2 m height); 2 targets.	two large rocks.
CB24	(1.3 m height); 2 targets.	two large rocks.
CB25	(2.6 m height); a cluster of targets.	three large rocks and one drift net.
CB26	(1.7 m height); 1 large target.	not investigated.
CB27	(~0.7 m height); 1 large target.	not investigated.
CB28	(~0.6 m height); 1 large target.	airplane wreckage.
CB29	(1m height); 1 large target + smaller targets scattered around.	several drums, large target unconfirmed.
CB30	(up to 1 m height); numerous targets.	boulders and rocks.
CB31	(1.1 m height); 1 large target, very close to CB32 and CB33.	airplane wreckage.
CB32	(1.7 m height); 1 large target, very close to CB31 and CB33.	airplane wreckage, part of tail section.
CB33	(up to 2.4 m height); a cluster of targets, very near to CB31 and CB32.	airplane wreckage.
CB34	(<0.5 m height); numerous targets, debris field.	numerous drums and a box resembling a cooler.
CB35	(<0.5 m height); numerous targets, debris field.	numerous drums.
CB36	(<1.0 m height); debris field with numerous targets.	numerous drums.
CB37	(<1.0 m height); debris field with numerous targets.	numerous drums.
CB38	judged to be sunken buoy with chain/cable.	sunken buoy, chain, sinker.
CB39	(<1.0 m height); numerous targets, probably drums.	not investigated
CB40	(up to 1.6 m height); 6 or 7 large targets + some smaller targets.	truck chassis, plastic bag, drums and large rocks.

Table 3.1 (cont'd)

CB41	(approx 2 m height); 1 large prominent target.	upside-down PBY-like aircraft; twin engine with pontoons on wing tips.
CB42	(~ 1.4 m height); prominent single target.	tracked vehicle like army troop carrier.
CB43	(~ 1.8 - 2 m height); large single target + smaller targets scattered around.	numerous drums, large target unconfirmed by DART.
CB44	(0.7 m height); 2 large targets close together + smaller scattered targets.	large rocks and numerous drums.
CB45	(up to 0.6 m height); debris field, 8 or more targets.	drums.
CB46	(< 0.6m); 9 or more targets, debris field.	drums; some with open tops.
CB47	(0.9 m height); 1 linear target.	not investigated.
CB48	(~ 2.8 m height); 1 prominent target.	not investigated.
CB49	(~ 1.2 m height); 1 large target.	not investigated.
CB50	(~ 0.7 m height); 1 linear target.	not investigated.
CB51	(~ 2.4 m height); 3 large targets in close proximity to each other.	not investigated.
CB52	(~ 2.6 m height); 2 large targets in close proximity to each other.	not investigated.
CB53	(1.0 m height); 1 single target, may be a large boulder since many were seen on shore.	not investigated.
CB54	(up to 2.0 m); 1 large target, may be a rock slab.	not investigated.

Five of the target areas contained discarded vehicles, including old army vehicles (CB04, Photo 3.6), a tracked vehicle similar in appearance to a personnel carrier (CB42, Photo 3.7, 3.8), an older model pick-up truck with a trailer (CB16) and another truck chassis (CB40, Photo 3.9). Other debris included an upside-down Quonset Hut frame (Photo 3.10), sunken navigational buoys, old washing machines (Photo 3.11), a large winch (Photo 3.12), tanks and other large pieces of ferrous metal debris. Eight of the targets (CB01 - CB03, CB31 - CB33, and CB41) were wreckage from two aircraft; seven of these were parts of a Globemaster plane, found in the same general area of the West Arm (Photo 3.13). Site CB41, at 49 m depth, had an upside-down aircraft similar in appearance to a World War II vintage PBY. (Photo 3.14)

The seabed in the immediate vicinity of sites CB01 - CB03, at a depth of approximately 20 m, was littered with more than 200 45-gallon drums, as estimated by SCUBA divers; these were found predominantly along the break in the slope immediately south of the hangar. Approximately 75 of these barrels were examined by the SCUBA divers, and many more were checked using the ROV; none were found to be in a sealed condition, suggesting that they were empty prior to disposal.

The composition of the debris and objects on the bottom of Cambridge Bay is illustrated in Figure 3.1. Objects smaller than approximately 0.1 m to 0.3 m would have been overlooked by the field techniques used, and other smaller debris, including household waste, is undoubtedly found on the Cambridge Bay seabed. Several objects listed in Figure 3.1 as "no positive I.D." were suspected to be geological; i.e., large boulders deposited in association with glaciation, given the extensive presence of large boulders in the terrestrial environment near by as well as the appearance on side-scan sonar traces. These include objects at sites CB53 and 54, as well as CB26, 47 and 48 which were located in the same vicinity as other objects positively identified as boulders (sites CB07, 11, 13, 23-25). The object at one site was tentatively identified as a metal radar antenna (site CB47). Objects at site CB26 were thought to be drums based on their size and proximity to other sites containing drums. If these seven sites are subtracted from the total list of sites where a positive identification was not obtained, the number of uninvestigated sites is eight.

3.1. Detailed Investigation of Electronics Cabinet at Site CB05

The survey confirmed that the presence of electronic components in Cambridge Bay represents a departure from common historic disposal practices (see Figure 3.1).

Only one site of 54 sites total (39 with identified debris), had any electronics components. It is not difficult to understand the rationale for the past ocean disposal of vehicles and other large metalliferous objects, but the motivation for past disposal of an electronics cabinet is not clear.

Site CB05 (at 39 m depth) contained one large electronics cabinet with eight smaller individual components inside. An additional nine objects were scattered around the cabinet on the bottom (Photo 3.15). These objects had some marine growth on them. Extensive observations using the ROV, drop camera, and by divers was made of the items: all smaller items were of the same size and appearance. One of the objects was recovered by a SCUBA diver. (Photo 3.16)

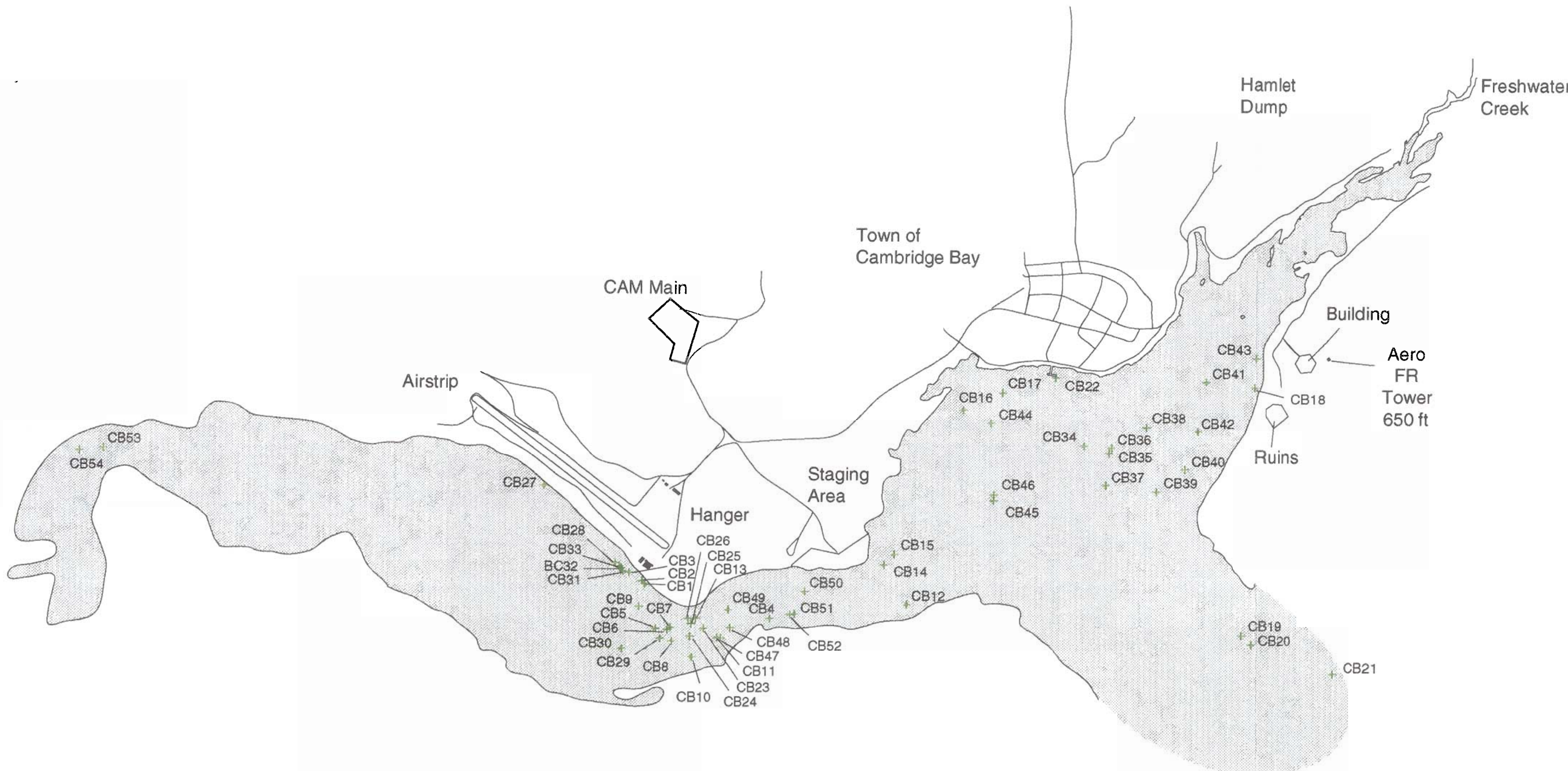
The recovered object was immediately transferred to the custody of an Environment Canada Inspector, and subsequently sent to the Environment Canada laboratory in Edmonton for identification, disassembly, and analysis for PCB content. This and the other electronic components at site CB05 were later identified as "Signal Delay Filters". Each filter, 43.5 x 12.8 x 18.5 cm in dimensions, had four circuit boards containing a total of approximately 16 to 18 each of two types of small cylindrical resistors and/or capacitors (Photo 3.17). In the bottom of the filters were four larger components which were transformers. Disassembly of these showed that the core of each contained a small (approx. 3 cm x 3 cm x 5 cm) transformer core embedded in Bakelite (Photo 3.18). The core of each transformer did not contain liquid PCBs, but rather contained an oil-impregnated paper material. Other components of the filter included three separate copper coils wrapped in cloth. The entire cavity of the filter was filled with a hard white epoxy-like plastic. All components suspected to contain PCBs were cut or hammered open and solvent-extracted in order to analyze the PCB content and composition. No free PCB liquids were found in any portion of the signal delay filter. A second filter, subsequently recovered by a local diver, was determined to be very similar in appearance and content.

3.2. Biological Growth

Marine organisms were observed extensively during ROV, drop camera, and SCUBA diver surveys. This included animals in the water column such as small jellyfish and ctenophores, soft-bottom infauna, and biota growing directly on debris or boulders. Animals found on or attached to large metal objects included seastars, soft corals, sea anenomes, sea urchins and some unidentified organisms. Photographs 3.19 to 3.22 provide examples of the extent of growth and types of biota observed.

3.3. Potential Chemical Inputs Associated With the Debris Found.

The extensive disposal of drums and their residual contents near the airstrip and south of the community could potentially lead to inputs of hydrocarbons, lead, degreasing, and antifreeze agents. Polycyclic aromatic hydrocarbons (PAHs), in particular, are more persistent than other hydrocarbons and, based on the debris found, may have been introduced to the environment. Drums, vehicles, and most other debris contain a variety of inorganic elements including iron, chromium, copper lead, and zinc. These could be regarded as contaminants if present in a leachable form. The presence of electronic components at site CB05 prompted detailed investigations of PCB inputs. The distributions of PCBs, PAHs, inorganic elements and other contaminants in Cambridge Bay are detailed in Chapter 4.



Map 3.1: Location of Objects on the Bottom of Cambridge Bay, as Demarcated by Side-Scan Sonar.

The coastal outline was taken from a McQuest Marine Sciences Limited, Marine Environmental Survey Map done for:
Enery Mines and Resources, N.S.
Environment Canada, N.W.T.
Department of National Defence, Royal Roads, B.C.
April 1994

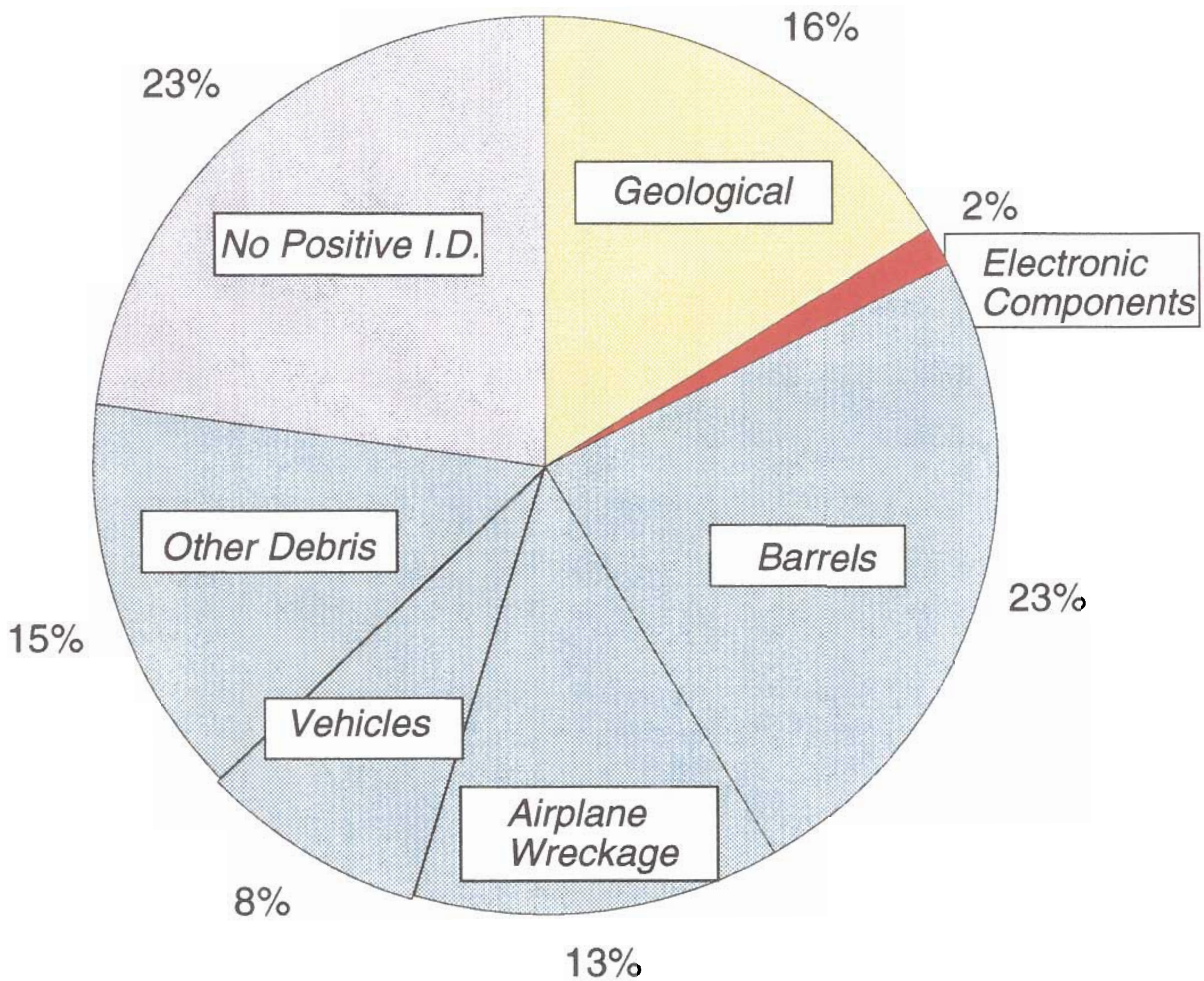


Figure 3.1: Make-up of Objects on the Bottom of Cambridge Bay.

Photograph 3.1: Ten of the 54 sites were subsequently identified as rocks and boulders on the seabed.

Photograph 3.2: F.D.U. Diver by one large rock slab targeted by the side-scan sonar.

Photograph 3.3: The number of 45 gallon drums on the bottom of Cambridge Bay probably exceeds 1000.

Photograph 3.4: It was common practice, apparently, to dispose of empty barrels from the winter airstrip through a hole in the ice after puncturing them.

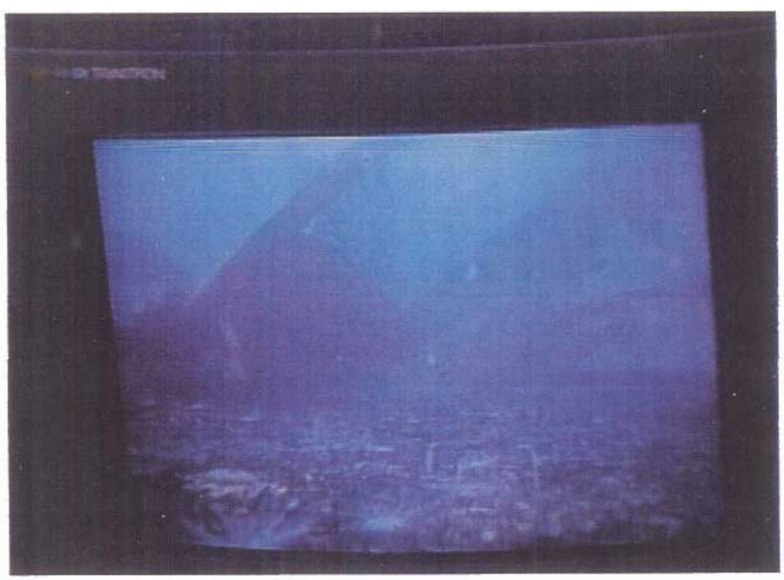
Photograph 3.5: Barrels in Cambridge Bay community dump with square puncture holes.

Photograph 3.6: Site CB04: an army truck was among several vehicles found at this location.

Photograph 3.7: Tracked vehicle found at CB42 was similar in appearance to a personnel carrier.

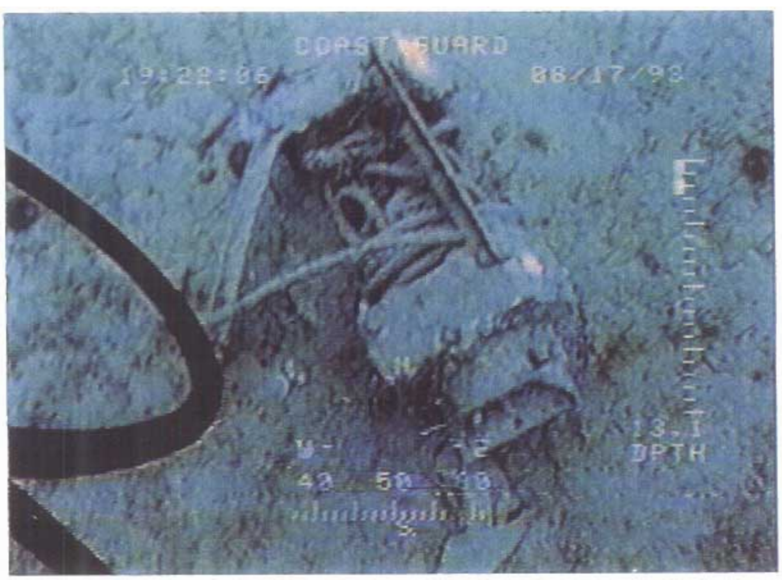
Photograph 3.8: Close view of tracks of the vehicle found at CB42.

Photograph 3.9: Truck chassis found at site CB40.



Photograph 3.10: Image of Quonset hut frame at CB09, as seen by the operator of the ROV from the surface.

Photograph 3.11: Other debris included old washing machines...



Photograph 3.12: ..... winches, and other large pieces of ferrous metal debris.

Photograph 3.13: Wreckage of a Globemaster aircraft found in the area of the West Arm of Cambridge Bay.

Photograph 3.14: Site CB41 had an intact, upside-down aircraft similar in appearance to a World War II vintage PBY.

Photograph 3.15: Large electronics cabinet with one of the nine other objects in the foreground.

Photograph 3.16: One of the nine smaller objects was retrieved by a SCUBA diver and later identified as a "Signal Delay Filter".

Photograph 3.17: Inside of a signal delay filter showing corrosion; two of four rectangular transformers and three copper coils.

Photograph 3.18: Cylindrical electronic components from circuit boards, following solvent extraction for PCB analysis.

Photograph 3.19: Extensive growth on the propellor of the PBY aircraft found at CB41.

Photograph 3.20: Anemones on the seabed of Cambridge Bay.

Photograph 3.21: Anemone by 45 gallon drum on the bottom of Cambridge Bay.

4. ASSOCIATED CONTAMINANT INVESTIGATIONS

Samples of sediment, water and marine biota were obtained in order to identify the types and concentrations of potentially deleterious substances introduced into Cambridge Bay in association with historic ocean disposal. It was also necessary to distinguish between inputs from ocean disposal and contaminants (especially polychlorinated biphenyls (PCBs)) introduced from either shoreline runoff into Cambridge Bay (Bright et al., in press) or via atmospheric transport from more distant areas (Ballschmiter, 1992; Barrie et al., 1992). Contaminant concentrations/distributions in sediment (Section 4.1) were examined to identify anthropogenic inputs, since sediments tend to be the major repository of both inorganic elements and organic contaminants. Contaminant concentrations in biota from Cambridge Bay (Section 4.2) were examined in order to identify areas of the bay where potentially-deleterious substances have entered the marine food chain, and where impacts might be expected. The concentration of PCBs in the water column (Section 4.3) was measured only at one site; at a location within 2 m of the seabed and in the proximity of site CB05, where electrical components were found on the bottom.

4.1. Contaminants in Sediment

The concentration of an inorganic element in sediment has two components: the natural level in the minerals present, plus both natural and anthropogenic inputs to the seabed from the overlying water column. Inorganic elements are added as sedimented particulates and through precipitation and adsorption from dissolved forms. The important point is that inorganic elements such as copper, lead, iron, mercury or zinc do occur naturally, but can become contaminants if found at levels exceeding natural or background concentrations.

Conversely, most organic contaminants such as PCBs and chlorinated pesticides (DDT, toxaphene) do not occur naturally. It is necessary, however, to distinguish between locally-elevated levels and background concentrations, since most chlorinated organic contaminants are persistent in the environment and have been globally re-distributed from major areas of anthropogenic input. The following sections examine the concentrations of inorganic elements (4.1.1) and organic contaminants (4.1.2) in Cambridge Bay sediment and comparisons are made with background concentrations.

4.1.1. Inorganic Elements

The sediment sampling sites along with the locations of objects delineated using side-scan sonar are shown on Map 4.1. Table 4.1 provides the ranges and average levels of inorganic elements in Cambridge Bay sediment samples.

The Cambridge Bay sediment levels can be compared with limited data for inorganic elements in marine sediment from other areas of the Canadian Arctic. (Table 4.2) Sweeney and Naidu (1989) determined 'natural abundances' of some inorganic elements in the coastal region of the Beaufort Sea, Alaska. Campbell and Loring (1980) similarly investigated the background sediment concentrations of some inorganic elements along the coastal periphery and central region of Baffin Bay in areas removed from anthropogenic inputs. Estimates of crustal abundance are also provided, adapted from Seiler and Sigel, 1988. All inorganic elements were also examined in detail with regard to their known geochemical cycling and ecotoxicology.

Table 4.1: Range and Average Concentrations of Inorganic Elements in Cambridge Bay Sediment (n = 57)

		Concentration (ppm, unless otherwise indicated)			
Inorganic Element	Method[1]	Average	St. Dev.	Min.	Max.
antimony	NAA	**0.6**	0.8	0.1	6.1
arsenic	AAS	**12.9**	12.9	1.8	69.8
arsenic	NAA	**14.7**	13.2	2.5	76.0
bromine	NAA	**114.4**	48.6	29.0	290.0
cadmium	AAS	**<1.0**	-	-	<1.0
chromium	AAS	**53.6**	53.7	14.0	438.5
cobalt	AAS	**3.9**	1.8	2.5	7.3
copper	AAS	**15.2**	8.0	3.5	1937.5
halfnium	NAA	**6.8**	2.3	2.0	13.2
iron (%)	NAA	**2.5**	2.6	0.9	16.8
lanthanum	NAA	**33.8**	8.5	6.0	46.0
lead	AAS	**23.3**	112.2	9.7	853.6
mercury	AAS	**<0.2**	-	-	<0.2
nickel	AAS	**11.0**	3.5	2.5	17.7
potassium (%)	NAA	**3.5**	0.7	1.5	5.0
scandium	NAA	**8.4**	2.1	3.2	11.5
sodium (%)	NAA	**1.5**	0.4	0.4	2.1
tin	NAA	**4.6**	0.9	2.3	7.1
zinc	AAS	**52.4**	125.0	7.4	801.3

1: AAS - Atomic Absorption Spectroscopy; NAA - Neutron Activation Analysis (see Appendix B).

Table 4.2: Documented Background Concentrations of Inorganic Elements in Canadian Arctic Marine Sediments (in parts per million, ppm)

	Baffin Bay, Eastern Arctic[1]				Beaufort Sea[2]	Crustal Abundance[3]
	Coastal Areas (N=29)		Basin (N=13)			
Element	Average	Range	Average	Range	Range	Mean or Range
antimony						0.2-1
arsenic						1.5-3[4]
bromine						
cadmium						< 1
chromium	57	16-139	84	56-109	15-125	~ 100
cobalt	10	6-14	16	11-42	3.3-18	~ 10
copper	20	4-42	47	12-81	6.3-83	10-300
halfnium (%)						10->300
iron (%)						~ 5%
lanthanum						10- >300
lead	18	11-33	23	12-32		10-30 in soil
manganese	310	120-660	3580	260-9450		~ 1000
mercury	0.05	0.02-0.08	0.07	0.04-0.11		~ 0.5
nickel	19	5-71	51	19-94		
potassium (%)						2.6%
scandium						~ 5
sodium (%)						
tin						
zinc	45	17-83	77	34-106	28-170	~ 70

1: Campbell and Loring, 1980; 2: Sweeney and Naidu, 1989; 3: adapted from Seiler and Sigel, 1988; 4: Cullen and Reimer, 1989.

An initial examination of the sediment data lead to the following conclusions:

Inorganic which were not of concern with regard to possible impact in Cambridge Bay included -

- <u>cadmium, mercury:</u> There is no impact from cadmium or mercury as all samples were below the analytical detection limits.

- <u>nickel, cobalt:</u> There was no evidence of contamination by nickel or cobalt as their concentrations were uniformly within the range of background levels in Arctic marine sediment.

- <u>bromine, potassium, sodium, halfnium, lanthanum and scandium:</u> These are not examined in more detail below, since it is exceedingly unlikely that these were either introduced to Cambridge Bay in significant quantities in association with human activities. In addition, no ecotoxicity would be expected based on the physicochemical properties of these elements.

- <u>tin</u>: It was not possible to find previously documented background tin concentrations in Arctic sediments; however, the levels in Cambridge Bay were all similar to the reference sample collected in Queen Maud Gulf, and exhibited a very narrow range of concentration overall.

Inorganic elements which merited additional scrutiny included -

- <u>iron</u> : The levels and distribution of iron required further examination (see below), since iron is a major constituent of much of the debris found on the seabed of Cambridge Bay (Chapter 3), and the maximum iron concentration (16.8%) far exceeded the crustal abundance of this element.

- <u>lead</u> : Previous studies (Reimer et al., 1993) have The data indicated that lead concentrations were elevated in the sediment near the Northern Store and sewage discharge relative to natural concentrations found elsewhere in the Arctic Ocean.

- <u>chromium, copper, zinc:</u> The maximum levels of chromium, copper, and zinc were either elevated above documented background concentrations, or there was insufficient information in the literature to determine whether they were elevated. These inorganic elements (along with arsenic and lead) are known to exert considerable toxicity to marine plants and animals if present in the more toxic chemical form(s), and if found at substantially elevated concentrations.

- <u>arsenic and antimony</u> - Preliminary interpretation of the data suggested that arsenic levels in sediment are elevated over most of the West Arm of Cambridge Bay relative to typical marine sediment values in other regions of the world.

The concentrations of arsenic, chromium, copper, iron, lead, tin and zinc in individual sediment samples from Cambridge Bay are illustrated in Figure 4.1 to 4.7. The data shown in red are from samples collected by grab, which are reflective of the general distribution patterns in Cambridge Bay. Samples shown in blue were hand-collected by SCUBA divers within 0.5 to 2 m of individual debris objects, and reflect worst-case contamination of the seabed.

Arsenic (Figure 4.1) levels were very high in Cambridge Bay's West Arm compared with the sediment sample from Queen Maud Gulf (Fig 4.1: green bar) as well as general crustal abundances. The areas of elevated concentration, however, do not coincide with the presence of debris (see Map 4.1), and the high arsenic values probably reflect local minerals with high arsenic concentrations. The sample-to-sample variation in concentration was similar for antimony (not shown). Antimony is often found in association with arsenic in both natural minerals and anthropogenic inputs.

Chromium (Figure 4.2), copper (Figure 4.3), iron (Figure 4.4), and zinc (Figure 4.7) were similar in their distribution patterns: None of the samples collected using a sediment grab contained levels that exceeded maximum background concentrations or crustal abundances, and all 48 samples from within Cambridge Bay exhibited a narrow range of concentration, overall. One or more of the eight samples collected by SCUBA diver in proximity to the objects exhibited extremely high concentrations, indicating local inputs.

Lead (Figure 4.5) was elevated in most of the SCUBA-collected samples relative to the grab-collected sediment samples in Cambridge and Queen Maud Gulf, and was also found at a high concentration in the grab sample collected near the Northern Store.

Overall, the results for inorganic elements in sediment samples from Cambridge Bay indicate that chromium, copper, iron, lead and/or zinc have been introduced to the sediment at abnormally high concentrations in association with some debris; however, the scale of inorganic element input was very limited, and was probably confined to an area encompassing a few meters around debris objects. The elevated iron (Figure 4.4) in samples KL50 and KL51, in particular, was undoubtedly attributable to the presence in the sample of rust found on the sediment under corroding barrels. The rust would not be expected to dissolve under oxic conditions. Any redistribution, therefore, of the iron from the site of ferrous metal debris would occur only through the bulk transport of sediment.

4.1.2. Organic Contaminants

The average and ranges of organic contaminants found in the sediment of Cambridge are provided in Table 4.3. The concentration of PCBs in all sediment samples from Cambridge Bay was higher than at the reference site in Queen Maud Gulf. Concentrations of organic contaminants in the Queen Maud Gulf sediment sample are assumed to be representative of cumulative inputs associated with long-range atmospheric transport from distant sources.

The range of concentration of PAHs was 4.8 to 510 ppb for total PAH, including alkylated forms [or 2.9 to 150 ppb for 'parent' (non-alkylated) PAHs]. This can be compared with an average concentration of 650 ppb 'parent' PAH in Mackenzie River shelf sediments of the Beaufort Sea (Yunker et al., 1993): The maximum PAH concentration in Cambridge Bay was extremely low relative to PAH concentrations found in sediments in the coastal Beaufort Sea, as well as concentrations found in most harbours farther south. Toxaphene was not found in Cambridge Bay sediment at levels exceeding the analytical detection limit. Therefore PAHs and toxaphene were not considered to be contaminants of concern in association with local inputs in Cambridge Bay.

PCBs were analyzed in all 49 sediment samples collected using a grab from a surface vessel. PCB levels are illustrated in Figure 4.8 and the spatial distribution of PCBs in the surface sediment is illustrated in Map 4.2. The highest observed PCB levels were found near the discharge from the hamlet dump (Map 4.2); elevated PCBs in this area of Cambridge Bay have been previously documented (Reimer et al., 1993; Bright et al., in press). Other areas where PCB levels were locally elevated included a shallow area near the shoreline and south of the old Loran tower (KL02; Map 4.1) and in an area to the southwest of the hamlet, where past ocean disposal took place (KL12). The source of PCB inputs to sediment at these sites has not be determined. PCBs were not elevated in the sediment near where electronic components (site CB05) were found - in comparison with other areas in Cambridge Bay.

Table 4.3: Concentrations of PCBs and PAHs in Cambridge Bay Sediment (in ppb, or ng/g).

Substance	No. of samples	Concentration Mean	Min.	Max	Background Conc. (KL31 - Queen Maud Gulf)
PCBs (total)	48	3.8	0.22	32.4	0.066
PAHs					
Naphthalene	36	5.6	1.3	16	
Acenaphthylene	"	1.3	<0.1	7.9	
Acenaphthene	"	1.1	<0.3	2.1	
Fluorene	"	1.4	0.5	3.9	
Phenanthrene	"	4.1	0.8	16	
Anthracene	"	1.9	<0.4	10	
Fluoranthene	"	3.2	0.3	18	
Pyrene	"	2.5	0.4	13	
Benz(a)anthracene	"	2.1	0.1	14	
Chrysene	"	2.3	0.3	21	
Benzofluoranthenes	"	3.9	<0.2	25	
Benzo(e)pyrene	"	1.7	0.1	7.7	
Benzo(a)pyrene	"	2.0	<0.1	9.9	
Perylene	"	1.0	<0.1	2.8	
Dibenz(ah)anthracene	"	0.6	<0.1	1.9	
Indeno(1,2,3-cd) pyrene	"	1.3	<0.2	5.1	
Benzo(ghi)perylene	"	1.5	<0.5	4.7	
C1 naphthalenes	"	6.6	<0.9	28	
C2 naphthalenes	"	11.4	<0.2	13	
C3 naphthalenes	"	7.5	<0.3	23	
C4 naphthalenes	"		<0.1	<0.1	
C1 phenanthrenes	"	50.1	1.8	300	
C2 phenanthrenes	"	32.0	<0.1	97	
C3 phenanthrenes	"	27.1	<0.9	140	
C4 phenanthrenes	"	10.4	<0.1	18	
Dibenzothiophene	"	0.8	0.2	2	
C1 dibenzothiophene	"	2.2	<0.1	6.6	
C2 dibenzothiophene	"	2.5	<0.1	11	
Total PAH	"	121	4.8	510	
Parent PAH	"	27	2.9	150	
Alkylated PAH	"	94		410	
Toxaphene	8		<0.1	<0.7	<0.1

4.2. Contaminants in Biota

A large number of marine biota from Cambridge Bay were analyzed for inorganic and chlorinated organic compounds (Table 2.3), which are often assessed in association with long range atmospheric transport. Chlorinated pesticide levels (including toxaphene) in fish collected from Cambridge Bay and the Queen Maud Gulf did not show evidence of input from marine debris or local runoff. Similarly, the levels of PAHs in fish were not obviously higher in specific areas of Cambridge Bay. A discussion of PAH and organochlorine bioaccumulation in bottom-dwelling animals in Cambridge Bay is provided elsewhere (Bright et al., in prep.). PAHs levels in all biota were very low (the maximum concentration of parent PAH, in short-horn sculpin liver tissue, was 125 ppb on a wet weight basis). Most of the PAH body burden in all biota was attributable to the more water soluble, lower molecular weight naphthalenes (40 % of total PAHs on average) and C1-naphthalenes (16 % of total PAHs on average). The concentrations of toxaphene (max. concentration, in Greenland cod liver, was 550 ppb) and other chlorinated pesticide residues such as DDT (max. concentration of DDT plus it's breakdown products DDEs and DDDs, in Greenland cod liver or pooled four-horn sculpin livers, was 260 - 280 ppb) were considered to be typical of Arctic background concentrations; this and previous data (Bright et al., in press), however, demonstrate that riverine input from terrestrial areas receiving *atmospheric* inputs are reflected in nearshore organisms. **Only inorganic elements and PCBs were examined in detail here, since there was evidence of local inputs in sediment samples.**

4.2.1. Inorganic Elements.

Inorganic elements were analyzed in sea urchins, soft-shell clams, *Hiatella* clams, four-horn sculpins, short-horn sculpins, Greenland cod and Arctic charr. The average and range of concentrations in samples from all sites are provided in Tables 4.4 and 4.5.

Table 4.4: Concentration of Inorganic Elements in Invertebrates From Cambridge Bay (in ppm, unless otherwise indicated).

	sea urchins (n=17 pooled) *S. droebachiensis*			soft-shell clams (n=3 pooled) *Mya truncata*			clams (n=2 pooled) *Hiatella arctica*		
	mean	min	max	mean	min	max	mean	min	max
antimony	0.26	<0.2	0.30		<0.2	<0.2	0.25	0.20	0.30
arsenic	13.2	7.5	26.2	10.4	9.8	10.9	14.0	13.6	14.5
cadmium	1.9	0.7	6.6	2.5	1.9	3.5	2.1	1.6	2.6
chromium		<10	<10		<10	<10		<10	<10
cobalt	2.9	<2.0	3.4		<2.0	<2.0	3.1	<2.0	3.1
copper	10.9	6.8	21.1	18.3	13.1	22.7	24.4	12.4	36.4
iron (%)	0.81	0.3	2.9	0.75	<0.3	0.80	0.60	0.50	0.70
lead	12.6	<10	14.1		<10	<10		<10	<10
nickel	3.8	1.8	5.5	2.3	1.9	3.0	6.4	3.9	8.9
zinc	73.5	39.9	123	144	115	189	97	94	99

Table 4.5: Concentration of Inorganic Elements in Fish From Cambridge Bay (in ppm, unless otherwise indicated).

	four-horn sculpins (n=9 pooled) *M. quadricornis*				short-horn sculpins (n=7 pooled) *M. scorpius*			
	mean	min	max	QM-1	mean	min	max	QM-1
antimony	0.30	<0.20	0.35	<0.20	0.27	<0.20	0.27	<0.20
arsenic	18.0	11.2	23.0	6.3	21.6	13.2	27.0	8.9
cadmium		<0.5	<0.5	0.5	0.67	<0.50	0.83	0.87
chromium		<10	<10	<10		<10	<10	<10
cobalt		<2.0	<2.0	<2.0		<2.0	<2.0	<2.0
copper	11.5	3.6	19.9	4.9	7.6	5.4	10.8	5.6
iron (%)		<0.2	<0.2	<0.2		<0.20	<0.20	<0.20
lead		<10	<10	<10		<10	<10	<10
nickel	4.2	2.8	8.8	<2.0	3.6	<2.0	4.8	2.0
zinc	103	89	133	109	71.2	54	85	71

cont'd

	Cod (n=9) *Gadus ogac*				Arctic charr (n=2) *Salvelinus alpinus*			
	mean	min	max	QM-1	mean	min	max	QM-1
antimony	0.45	<0.20	0.72	<0.20		<0.20	<0.20	<0.20
arsenic	46	20	75	24	1.7	1.5	1.8	9.1
cadmium		<0.5	<0.5	0.8	0.9	0.70	1.1	0.83
chromium		<10	<10	<10		<10	<10	<10
cobalt		<2.0	<2.0	<2.0		<2.0	<2.0	<2.0
copper	5.1	3.3	12.4	6.6	3.5	3.4	3.7	3.5
iron (%)		<0.20	<0.20	<0.20		<0.20	<0.20	<0.20
lead		<10	<10	<10		<10	<10	<10
nickel		<2.0	<2.0	<2.0		<2.0	<2.0	<2.0
zinc	61	29	80	75	43.8	29	58	44

Mercury was also analyzed in fifteen tissue samples but all samples had mercury levels which were lower than the analytical detection limit (<0.20 ppm).

Clams

Clams, *Hiatella arctica* and *Mya truncata*, were only collected from three and two sites respectively. The small number of sites prohibits any interpretation of contaminant uptake by these animals.

Sea Urchins

The site-to-site variation in the concentrations of arsenic, copper, cadmium, iron, and lead in sea urchins is illustrated in Figure 4.9. Sea urchins were not collected from the Queen Maud Gulf reference site. The arsenic concentration in sea urchin soft tissue was slightly higher at site E-7 (near the Northern Store) and site E-9 relative to the other sites. The higher tissue arsenic levels near the hamlet did not parallel the arsenic distribution in sediment; sediment arsenic levels were highest in portions of the West Arm. The small variation in copper levels in sea urchins from different sites is probably attributable to factors other than contaminant inputs. Sea urchins contained lead at concentrations above the detection limit in pooled samples from only four of nine sites: W-5, E-7, E-9, and E-10. The maximum lead concentration was 14 ppm, which only slightly exceeded the detection limit.

Cadmium, iron, lead, and zinc concentrations were highest in sea urchin soft tissue from site W-5, in the vicinity of the Globemaster airplane wreckage and barrel debris in the West Arm. In addition, cadmium and zinc levels were also higher in sea urchins from site E-9 than at most other locations. Sea urchins at this site were collected near the "Maud".

Fish

Inorganic elements were also analyzed in whole tissue homogenates, excluding livers, from pooled sculpins or individual cod and Arctic charr from Queen Maud Gulf (QM-1) and sites in Cambridge Bay (Table 4.5). Lead, chromium and cobalt in all fish were below the detection limit (<10 ppm) in all samples. In sculpin and cod tissue, cadmium, iron, nickel and zinc were either below the detection limit, or the maximum levels in samples from Cambridge Bay were similar to Queen Maud Gulf samples. Figure 4.10 illustrates the between-site variation in the levels of arsenic and copper in four-horn sculpins; similar results were found for arsenic and copper in short-horn sculpins, as well as for arsenic in cod tissue. Arsenic and copper levels in the Cambridge Bay samples were higher than those in Queen Maud Gulf. This is probably attributable to differences in the environmental concentration and bioavailability associated with factors other than local inputs from debris or shoreline runoff. Copper levels in Greenland Cod from Cambridge Bay (range of 3.3 to 4.9 ppm) were uniformly lower than in the two fish collected from Queen Maud Gulf (5.1 and 6.6 ppm), except for in one of two samples from site W-3 which contained 12.4 ppm copper.

The pattern of antimony distribution in fish from different sites was not as clearly defined, since more than 50% of all tissues did not contain antimony at a concentration above the detection limit (<0.20 ppm). Antimony occurred at a detectable concentration in four-horn sculpins from site E-2 (0.30 ppm) and E-7 (<0.20 - 0.35 ppm). Antimony occurred at a detectable concentration in short-horn sculpins only at site E-12 (0.27 ppm). In addition, the maximum antimony concentration found in Greenland cod tissue was 0.72 ppm at site E-1, which can be compared with <0.20 to 0.21 ppm in Queen Maud Gulf specimens. The antimony level in cod tissue may have also been slightly elevated in the West Arm (0.47 to 0.64 ppm at site W-3) in comparison with most other areas; however, the data set is too small to allow any conclusions.

Arctic charr from Cambridge Bay do not have elevated concentrations of any inorganic element relative to charr collected from Queen Maud Gulf.

4.2.2. PCBs

The concentration of PCBs (as Aroclors) was analyzed in pooled sea urchin, four-horn sculpin, short horn sculpin tissue and in homogenates of individual (Greenland) cod and Arctic charr. Reference samples were obtained from Queen Maud Gulf for all species except sea urchins. There was substantial between-site variation in the PCB concentrations in Cambridge Bay samples for most species analyzed, as illustrated in Figure 4.11. The range of concentrations between sites for PCBs was much greater than for any inorganic element (compare Figure 4.11 with Figures 4.9 and 4.10).

Very high PCB concentrations were found in sea urchin soft tissue from site W-5 (near the Globemaster airplane debris and barrel dump south of the airstrip) and site E-10 (south of the old townsite/Loran tower off the eastern shore). The PCB levels were generally elevated in the nearshore areas to the east of the Cambridge Bay community relative to nearshore areas farther west.

Four-horn sculpins, short-horn sculpins and, to a lesser extent, Greenland cod collected in Cambridge Bay, contained substantially higher concentrations of PCBs in liver or whole tissue than samples of the same species collected in Queen Maud Gulf. The two species of sculpins are bottom-dwellers/feeders which probably exhibit limited migration and the concentrations would reflect those in the sediments nearby. Greenland cod are more pelagic and migrate over a broader area. The elevated PCB concentration in cod from Cambridge Bay was probably related to their diet: most of the samples caught contained juvenile four-horn or short-horn sculpins in their stomachs.

The concentrations of PCBs in Arctic charr from upper Cambridge Bay (sites E-2 and E-12 were lower or the same as in charr from Queen Maud Gulf. The maximum PCB concentration in Arctic charr samples (from a fish collected in Queen Maud Gulf) was 6 ppb in whole tissue and 12 ppb in liver.

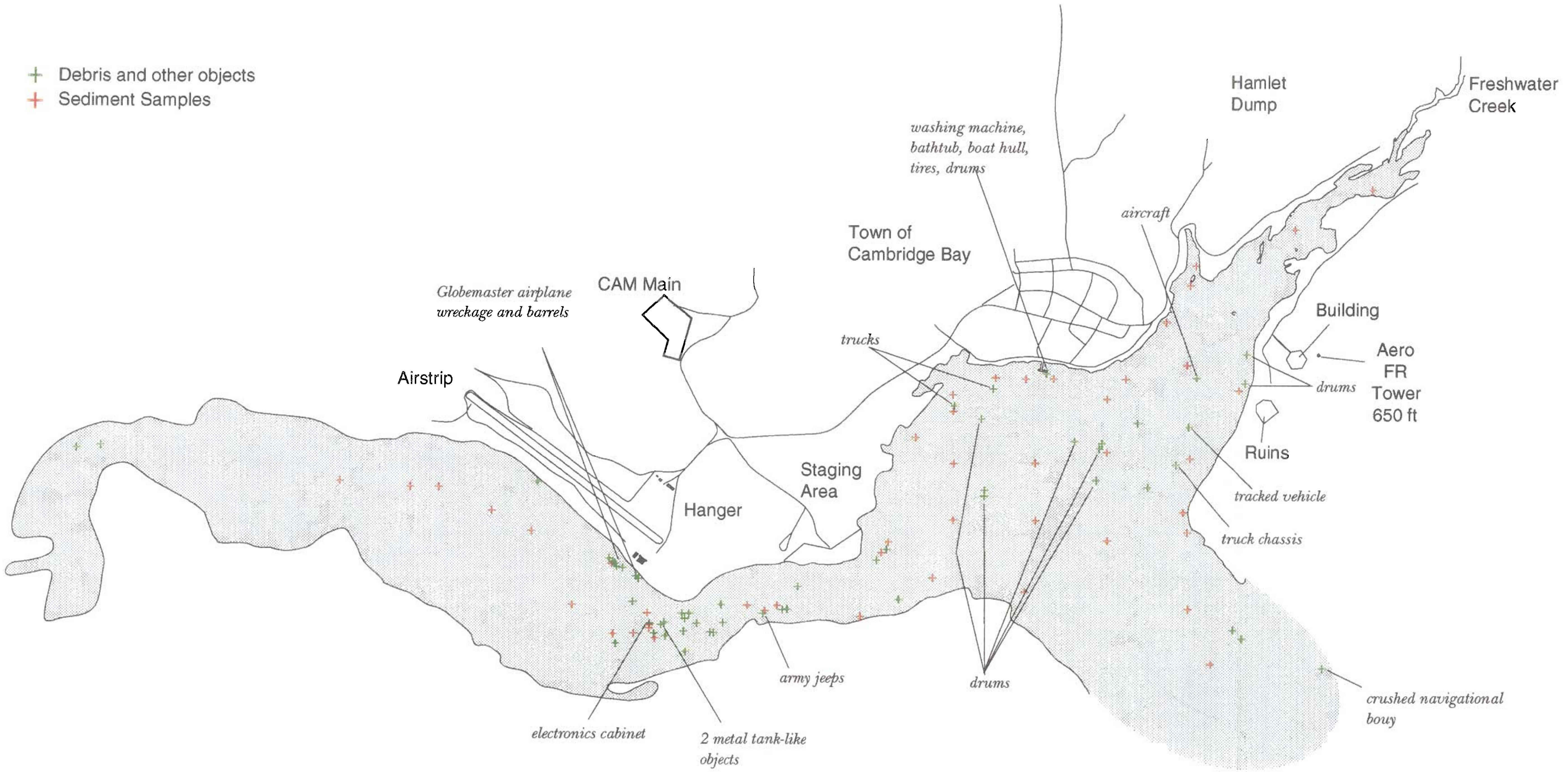
4.3. PCBs in Water

PCBs were measured in the water column over site CB05, using specialized *in situ* water samplers (INFILTREX II^{TM}) fitted with amberlite (XAD-II) resin extraction columns. The samplers are designed to extract PCBs and other organic contaminants having low water solubility from large volumes of water (approx. 30 to 400 L). This facilitates the analysis of contaminants typically found in seawater a concentrations in the parts-per-quadrillion range.

In situ samplers were deployed in duplicate, but sampled disparate volumes of water. One sampler extracted organochlorines from 208 L of seawater; the PCB concentration was 0.15 ng/L as total Aroclors. The second sampler pumped only 46 L of seawater prior to shutdown due to battery failure or diminished pumping rates; the PCB concentration was 0.36 ng/L as total Aroclors. The higher of these two values is probably the more accurate. Our previous experience has shown that higher pumping volumes invariably lead to lower per volume recoveries, possibly due to washout or association of organic contaminants with large amounts of particulates retained on pre-filters.

The water-borne PCB concentrations over site CB05 can be compared with seawater concentration data collected during other sampling programs (see Figure 4.12). They were similar to levels previously observed in other areas of Cambridge Bay, such as the CAM-M Beaching/POL area and the nearshore area which receives runoff from the CAM-M sewage discharge area. The PCB levels were lower than in the water column in 1992 near the hamlet dump discharge and these values, in turn, are lower than seawater PCB concentrations measured near Victoria, B.C. (Figure 4.12; light blue bars).

In conclusion, the seawater PCB concentration over site CB05 is typical of most of upper Cambridge Bay. The water-borne PCB concentrations here probably reflect inputs from the hamlet dump as well as remobilization from sediments, which are contaminated in all of upper Cambridge Bay.



The coastal outline was taken from a McQuest Marine Sciences Limited, Marine Environmental Survey Map done for:
Enery Mines and Resources, N.S.
Environment Canada, N.W.T.
Department of National Defence, Royal Roads, B.C.
April 1994

Map 4.1: Sediment Sampling Locations Relative to Debris on the Bottom of Cambridge Bay

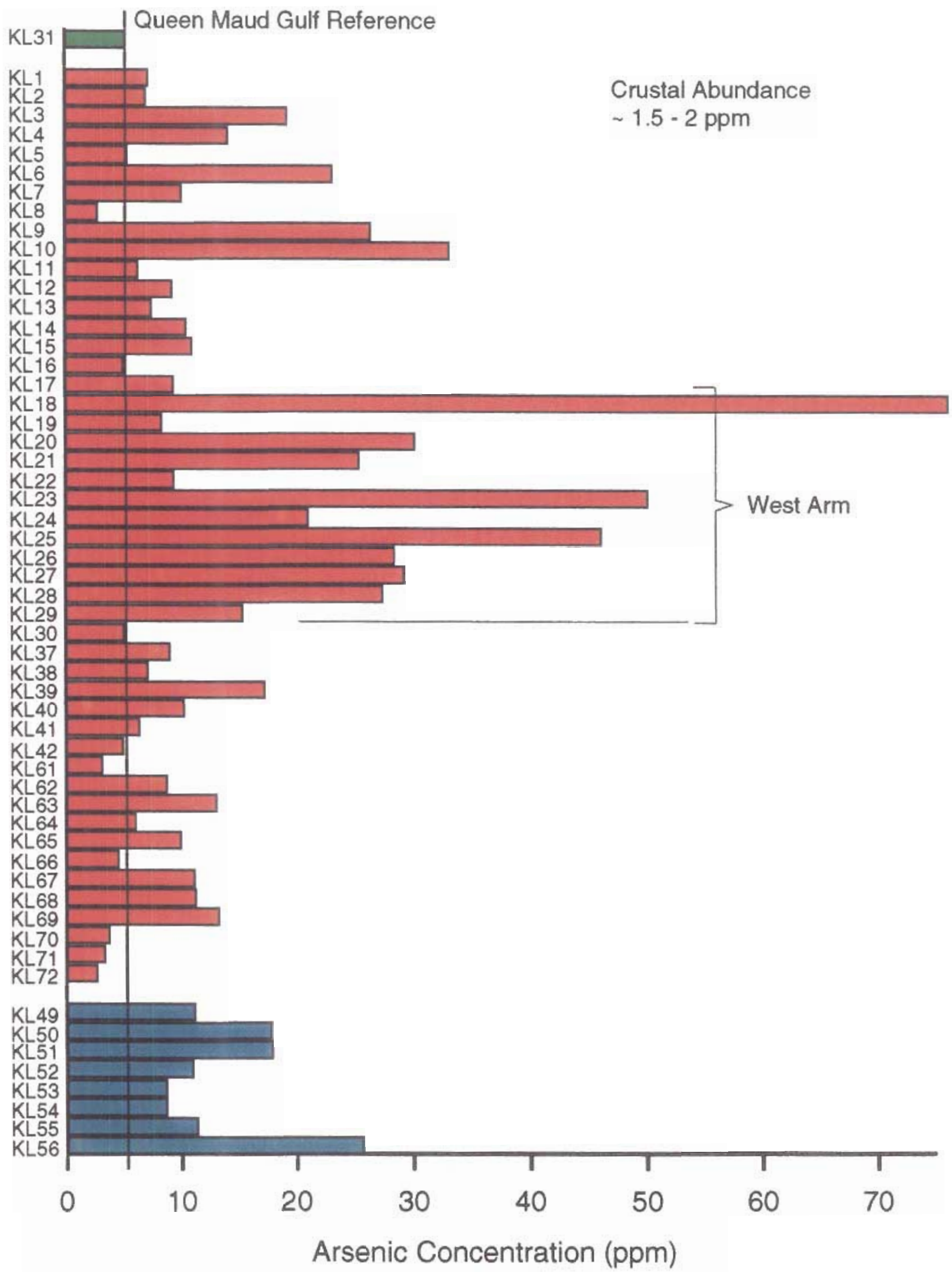


Figure 4.1: Arsenic Concentration (ppm) in Individual Sediment Samples from Cambridge Bay

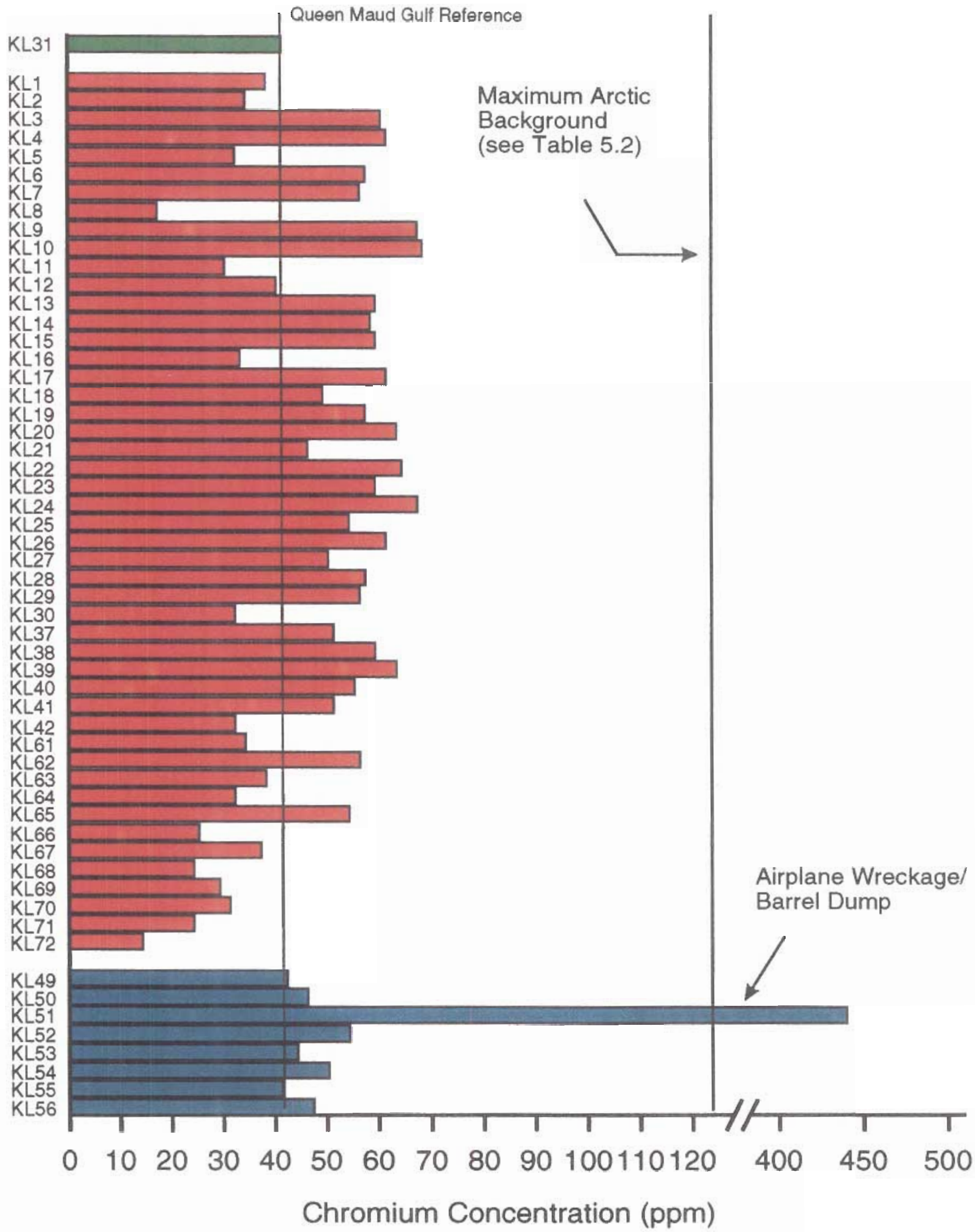


Figure 4.2. Chromium Concentration (ppm) in Individual Sediment Samples from Cambridge Bay.

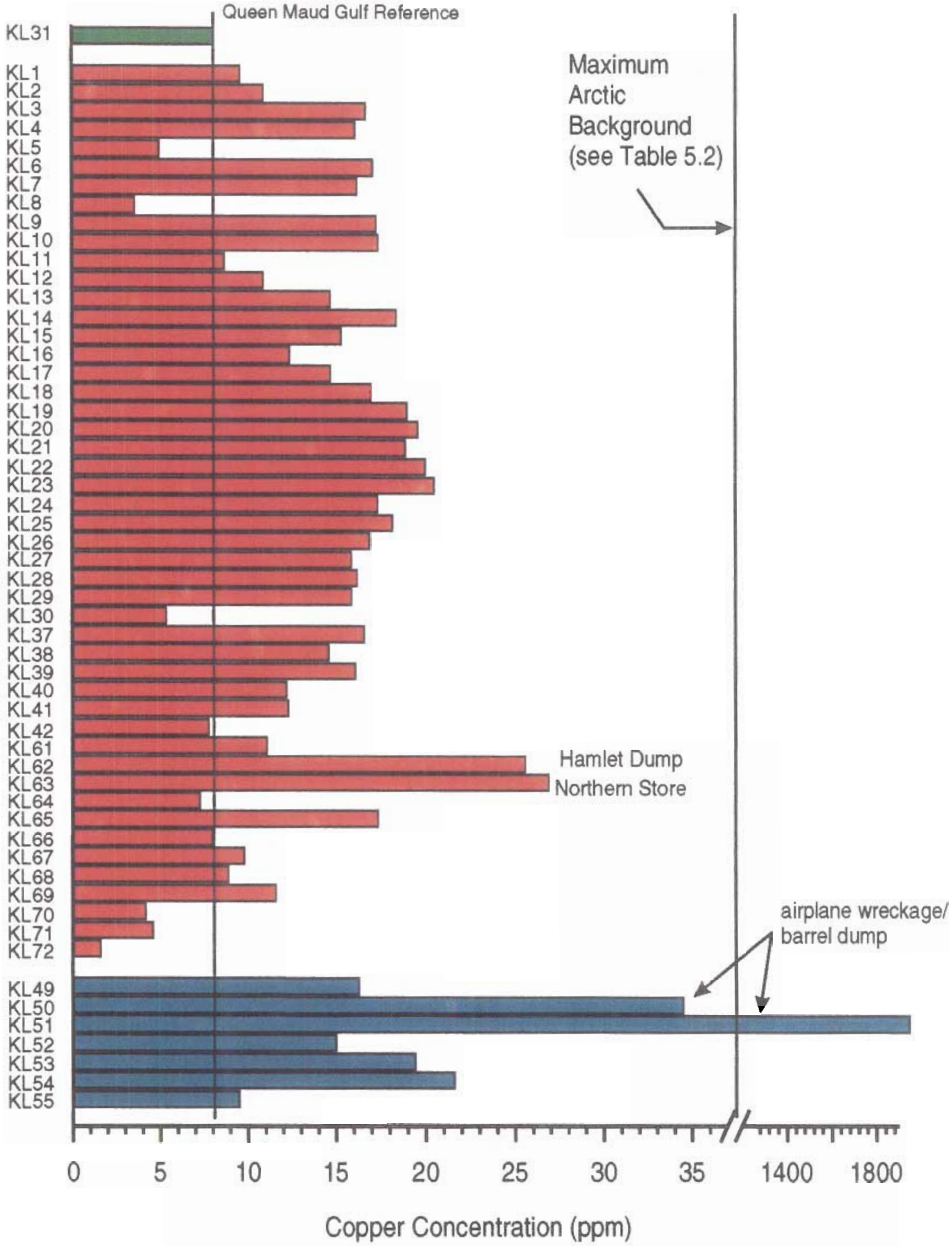


Figure 4.3: Copper Concentration (ppm) in Individual Sediment Samples from Cambridge Bay.

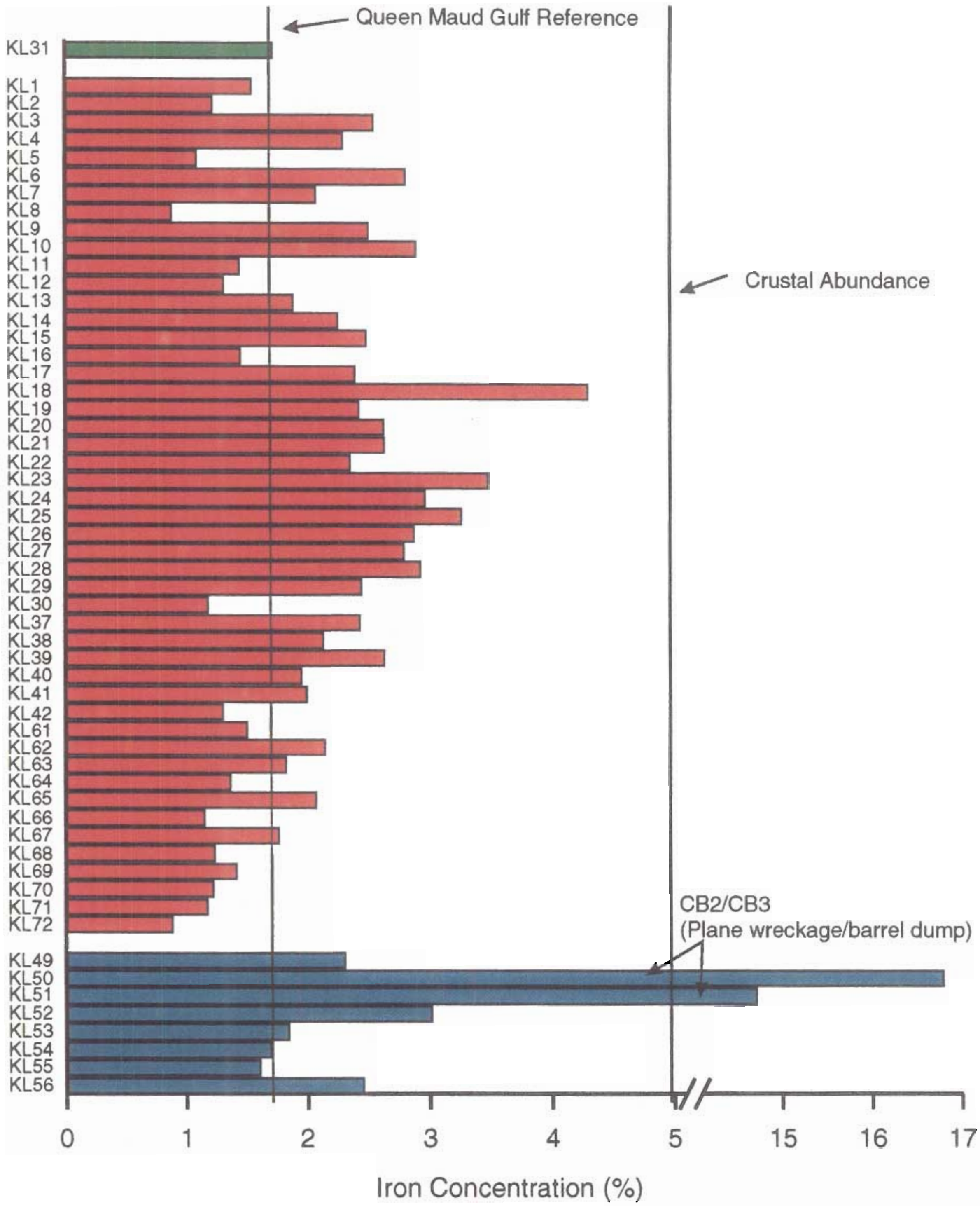


Figure 4.4: Iron Concentration (%) in Individual Sediment Samples from Cambridge Bay.

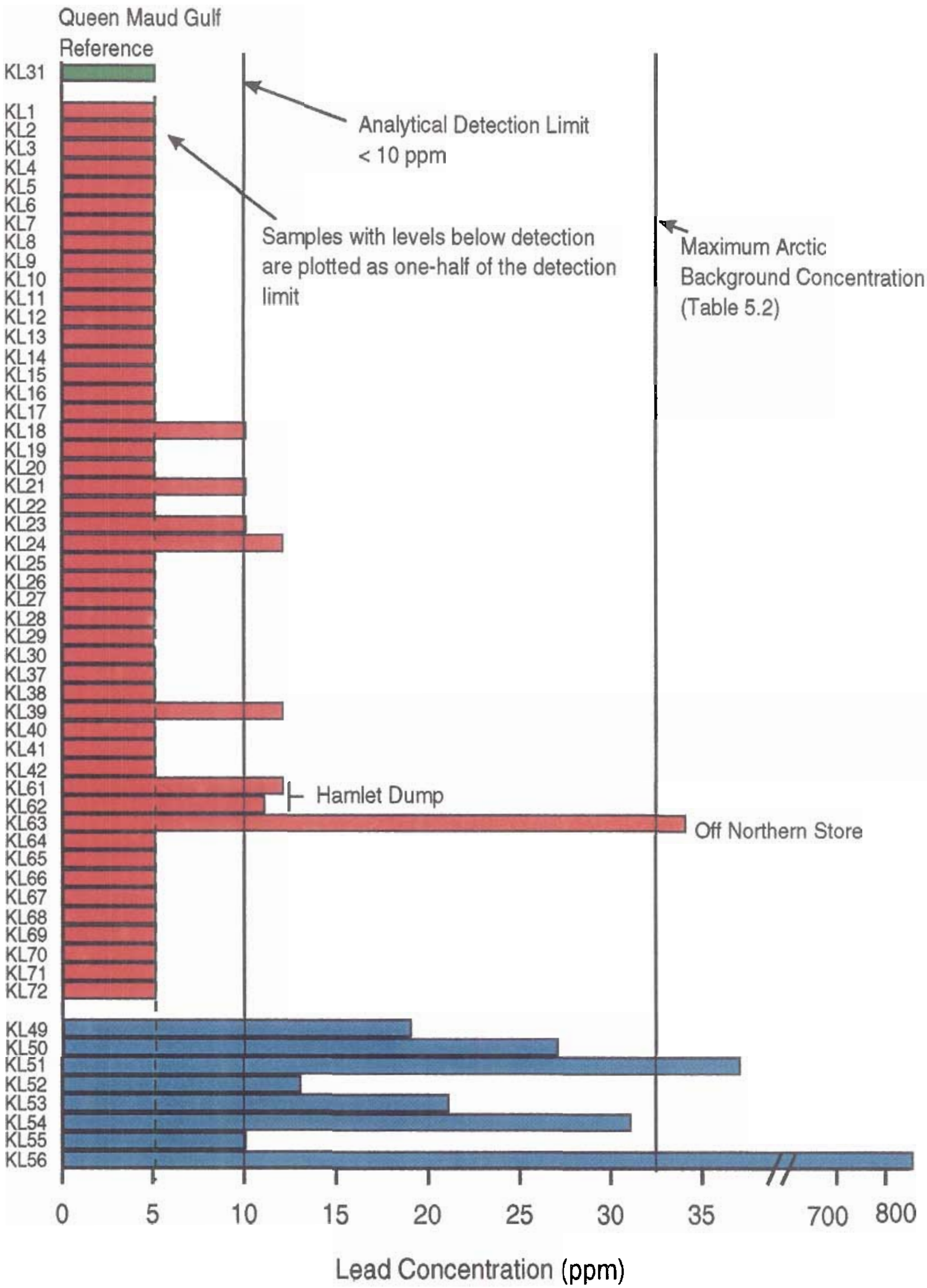


Figure 4.5: Lead Concentration (ppm) in Individual Sediment Samples from Cambridge Bay.

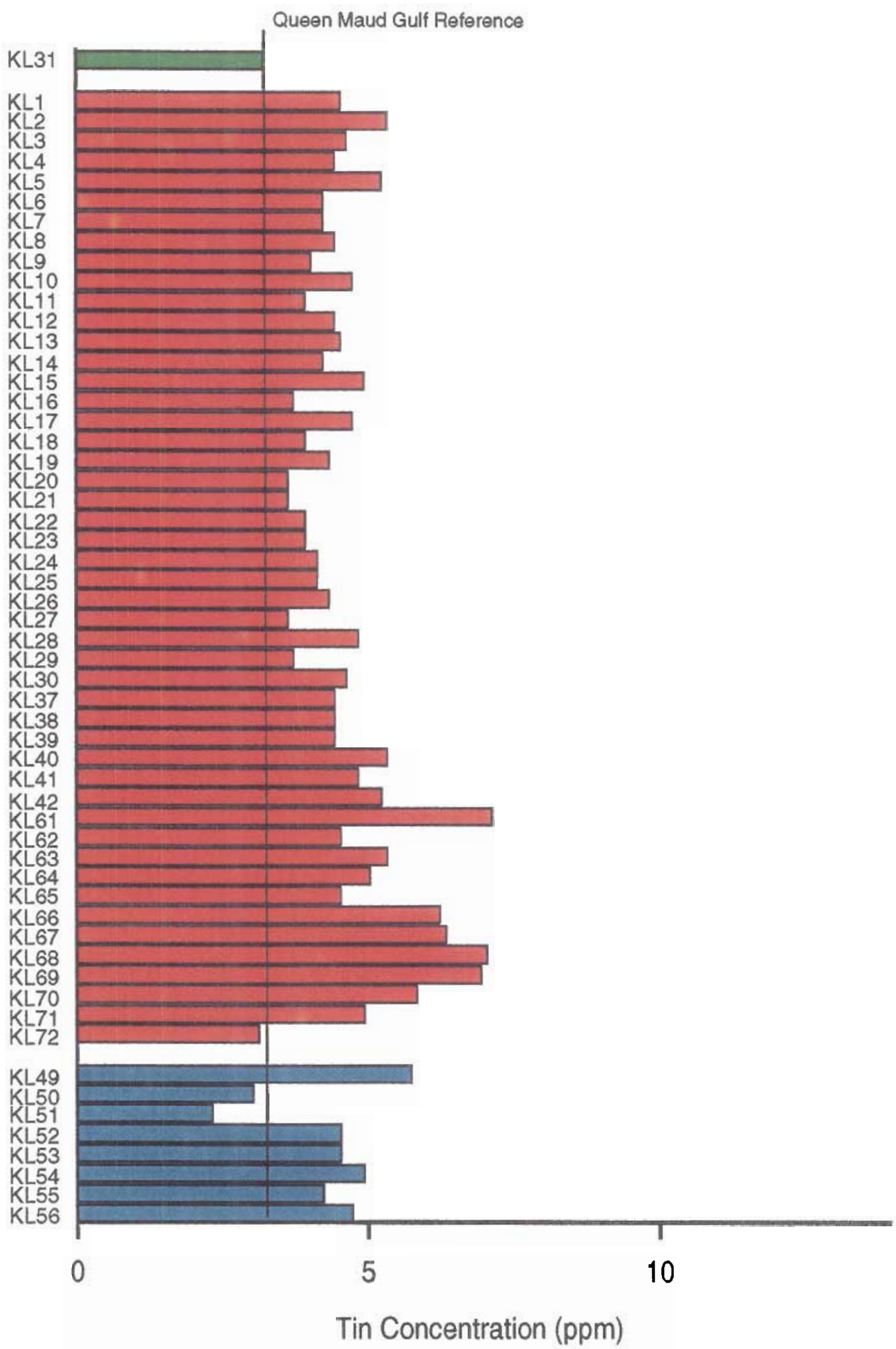


Figure 4.6: Tin Concentration (ppm) in Individual Sediment Samples from Cambridge Bay

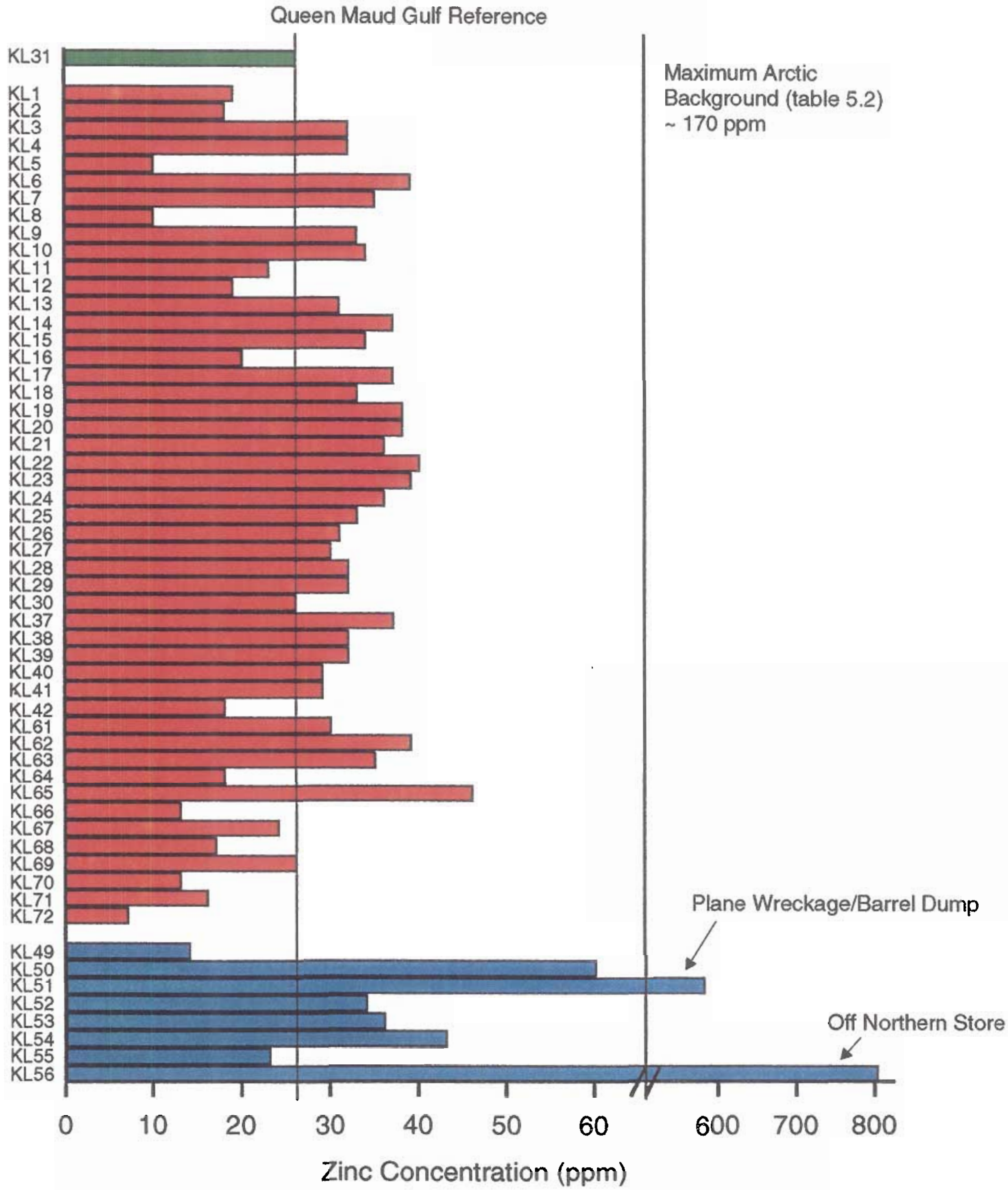


Figure 4.7: Zinc Concentration (ppm) in Individual Sediment Samples from Cambridge Bay

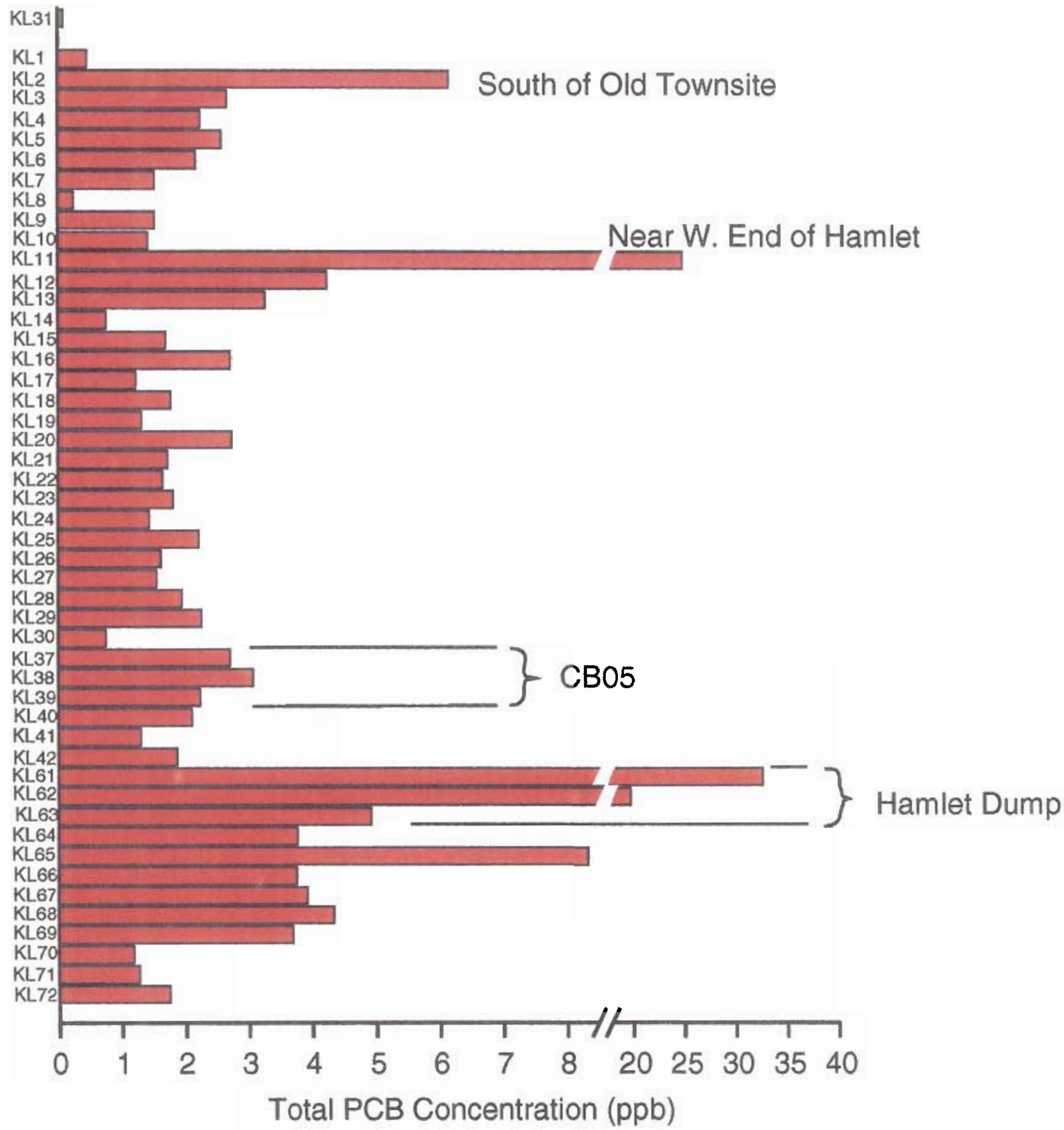
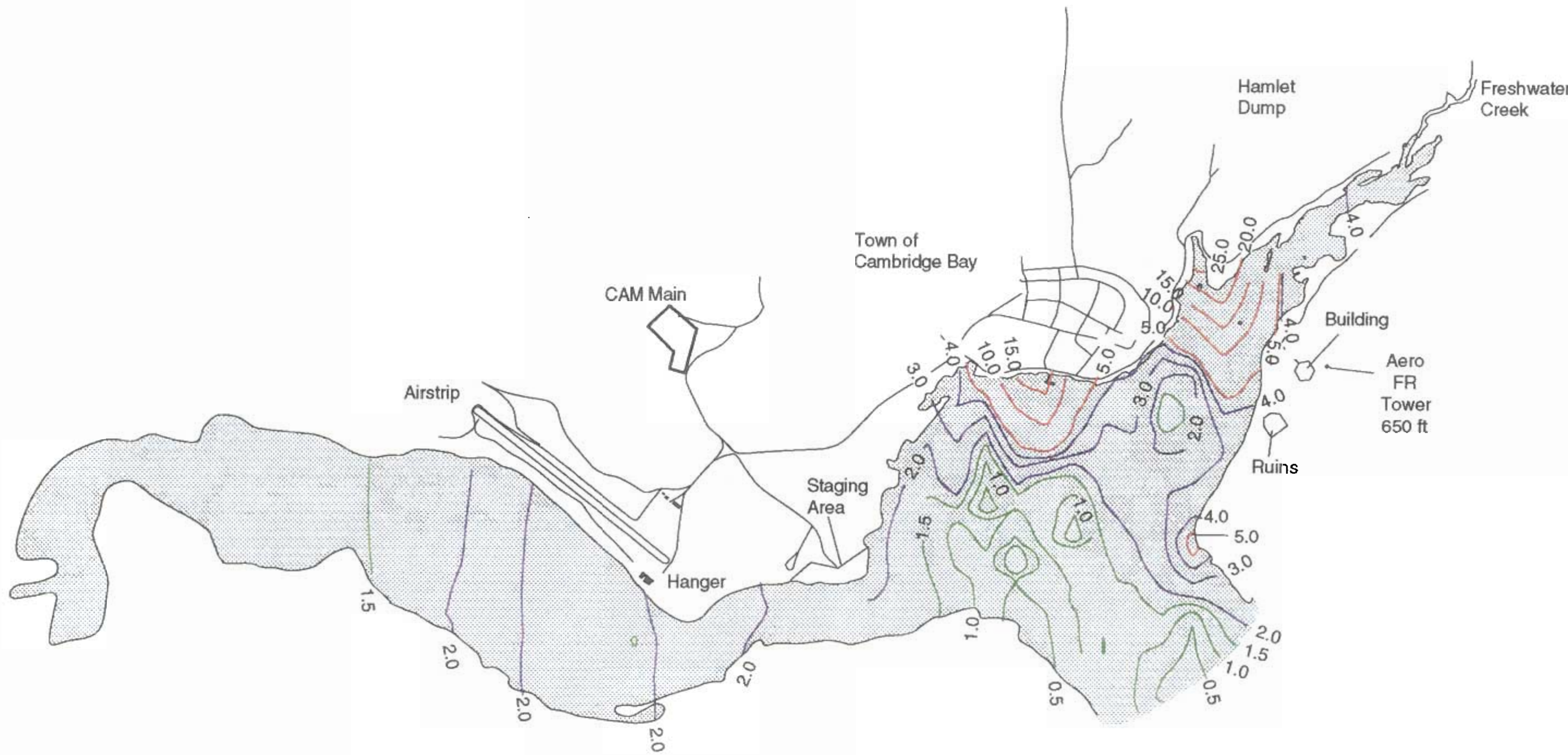


Figure 4.8: PCB Concentration (ppb) in Individual Sediment Samples from Cambridge Bay

Map 4.2: PCB Distribution in Cambridge Bay Surface Sediment
(concentration contours, in ppb)



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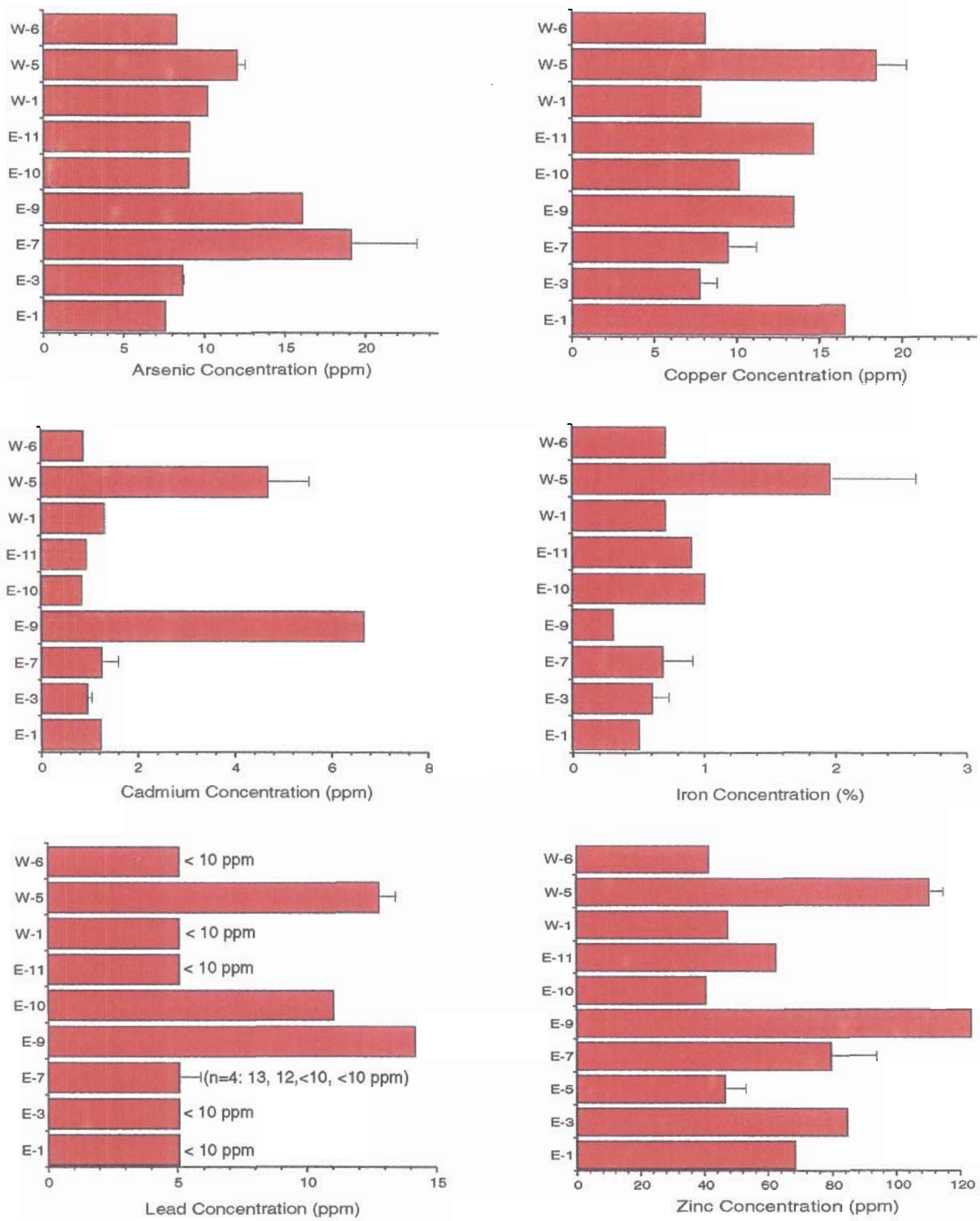

Figure 4.9: Inorganic Element Concentrations in Sea Urchin Soft Tissue

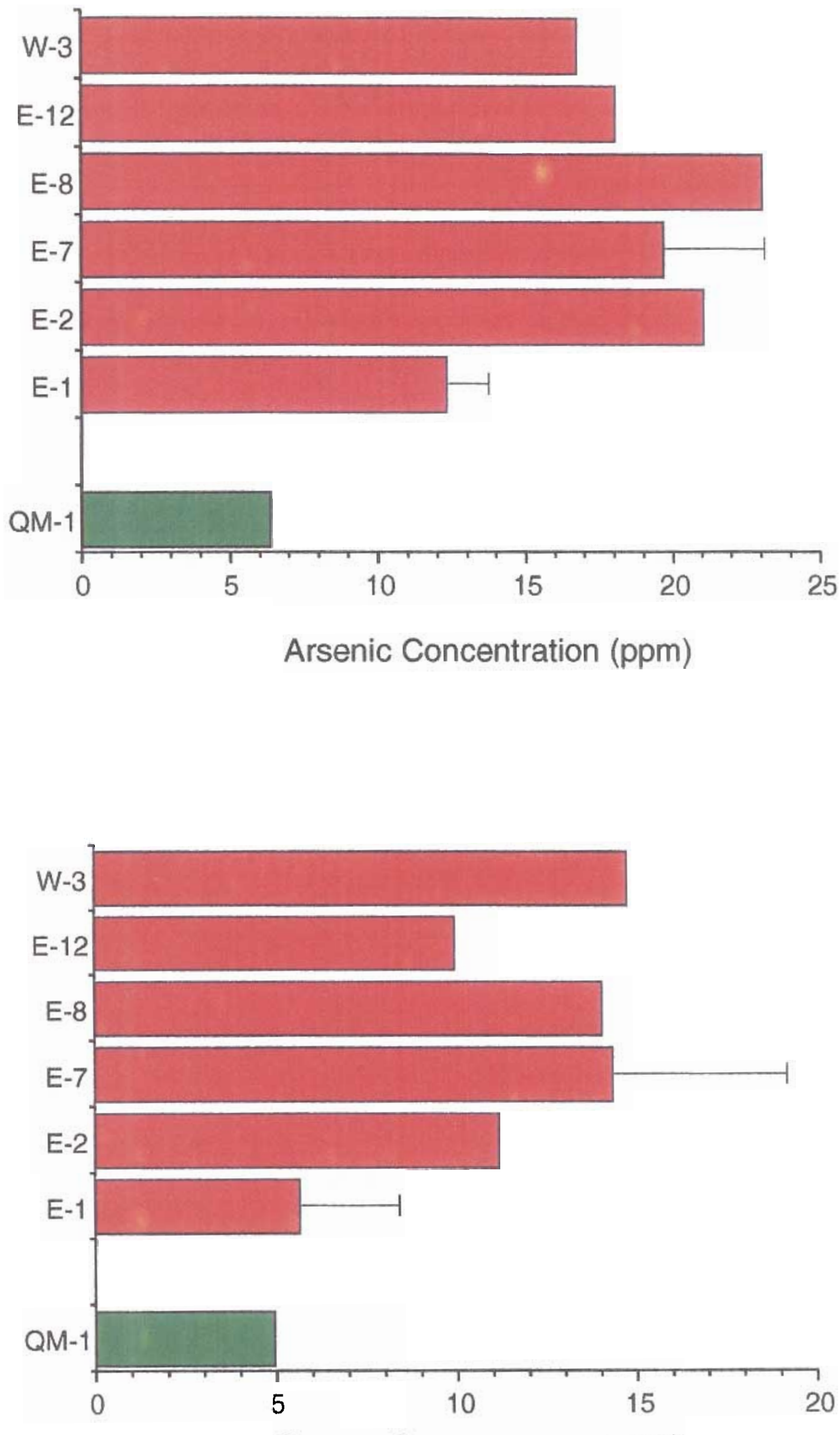

Figure 4.10: Concentration of Arsenic and Copper in Four-horn Sculpin Tissue Collected From Cambridge Bay.

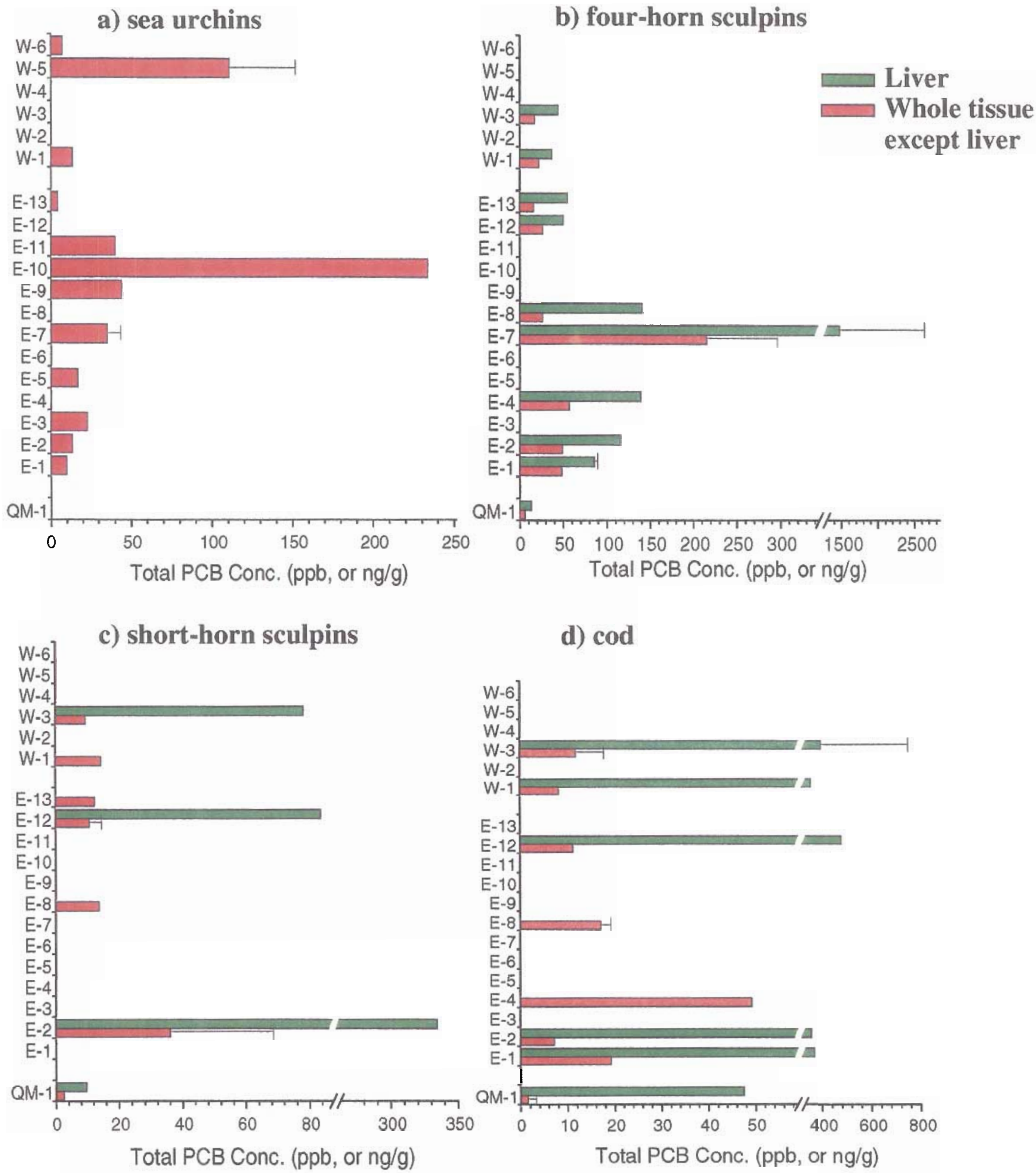

Figure 4.11: Distribution of PCBs in Cambridge Bay Biota

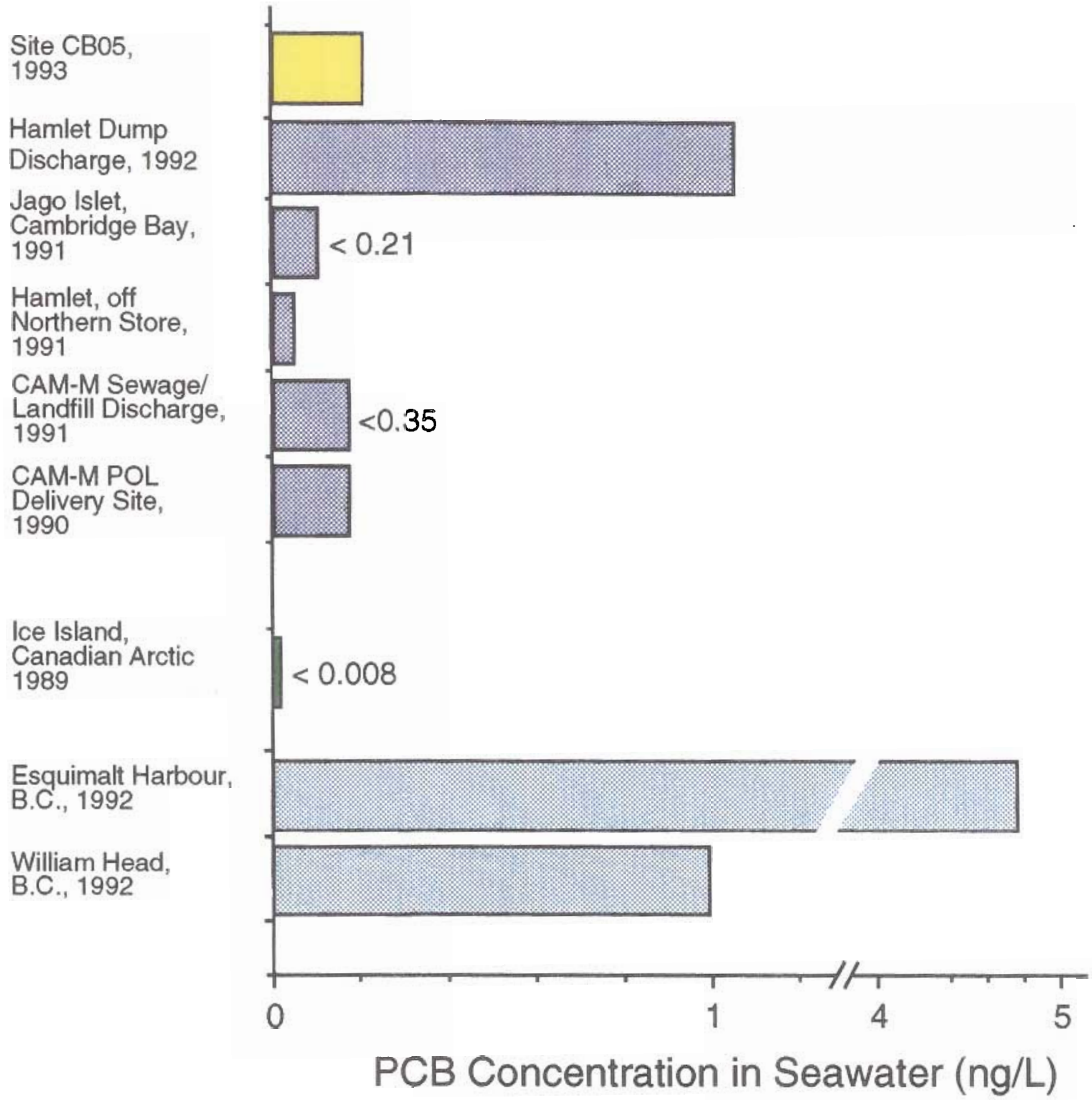

Figure 4.12: Concentration of PCBs in Seawater at Site CB05 and Elsewhere.

5. CONCLUSIONS

The survey of Cambridge Bay, conducted during August-September, 1993 confirmed that a large variety and amount of debris has been discarded on the sea floor. A total of 39 sites with one or more items of human origin were identified. Debris includes wreckage from two airplanes, large numbers of barrels, old vehicles, and other objects. Several of the vehicles and the two airplanes were undoubtedly disposed at sea in association with the building and operation of the CAM-Main DEW Line site. A considerable quantity of ferrous-metal debris (barrels, household objects) was also observed off the foreshore of the hamlet.

An electronics cabinet containing Signal Delay Filters, which was discovered in the West Arm (site CB05), was an anomaly relative to both the types of items found and most word-of-mouth accounts of past ocean disposal. Recovery of one of the 17 signal delay filters and subsequent analysis of the PCB content showed no PCB-containing free liquids within the filters. An estimate of the total PCB mass in all of the signal delay filters was 87 mg which is approximately equivalent to the weight of a paper clip. The inside of the signal delay filter showed signs of corrosion associated with seawater infiltration, suggesting that some of the PCBs contained in the filter should already have been released to the surrounding environment.

Extensive scientific investigations were made of inorganic elements, polycyclic aromatic hydrocarbons, PCBs, and other chlorinated organic compounds in surface sediment samples and marine biota, including sea urchins, four-horn and short-horn sculpins (often referred to as "bullheads"), Greenland cod and Arctic charr.

The inorganic element arsenic occurs at high concentrations in the West Arm of Cambridge Bay relative to a reference sample from Queen Maud Gulf, or typical concentrations elsewhere in pristine sediment. The distribution of high arsenic levels, however, did not parallel the distribution of debris, and is probably derived from a natural mineral source in the area. Arsenic concentrations in marine animal tissue were not elevated in the West Arm.

Sediment samples collected within 0.5 to 2 m of some individual debris objects provided evidence that these objects had resulted in the input of four inorganic elements (chromium, copper, iron, zinc) to the sediment. The elevated concentrations near the objects may be attributable to the presence of rust underneath corroding objects; this material has very limited solubility and, hence, bioavailability. The spatial redistribution from debris appears very limited, and the same inorganic elements were not found at concentrations higher than maximum Arctic background levels in any of the 49 "background" samples. (collected using a sediment grab deployed from a surface vessel)

Lead contamination of sediments near the Northern Store and near the Globemaster airplane wreckage/barrel dump south of the airstrip may be slightly more widespread. However, lead concentrations in the sediment in Cambridge Bay are within the range documented for pristine Arctic marine sediments.

Iron, zinc, and lead levels in sea urchins collected near the Globemaster airplane wreckage/barrel dump, and near the "Maud" shipwreck were higher than elsewhere. This also suggests localized contaminant inputs from debris on the seabed. Increased local bioaccumulation of these elements, however, was not observed in fish (sculpins, Greenland cod, or Arctic charr).

Given the large number of barrels on the Cambridge Bay seabed which may have contained residual liquids, there was initially some concern over the possible input of organic contaminants such as polycyclic aromatic hydrocarbons (PAHs). The PAH concentration in all 31 sediment samples analyzed was very low, and was less than the average concentration in sediment from the Mackenzie River shelf of the Beaufort Sea.

The concentration of PCBs in all 48 sediment samples from Cambridge Bay were from one to three orders of magnitude higher than in a reference sample from Queen Maud Gulf. Local hotspots of PCB contamination included the seabed near the hamlet dump drainage, the western end of the hamlet, and in a shallow area on the eastern shore and south of the old townsite. There was no evidence for PCB inputs near site CB05, where the electronic components were discovered.

The PCB concentration in sea urchins, four-horn sculpins, short-horn sculpins and Greenland cod was very high in all Cambridge Bay samples relative to Queen Maud Gulf. Between-site variations in the tissue content of PCBs generally paralleled the distribution of PCBs in the surface sediment. The maximum PCB concentration in whole tissues, excluding livers, of four-horn sculpins, short-horn sculpins, Greenland cod and Arctic charr from Cambridge Bay was 290 ppb, 59 ppb, 52 ppb and 3 ppb respectively (expressed on a wet-weight basis). The maximum PCB concentration in liver tissue of the four species was 2,500 ppb, 330 ppb, 650 ppb and 4 ppb respectively.

The main source of PCB input to Cambridge Bay, in light of the documented sediment, water and animal tissue concentrations was undoubtedly runoff from the Hamlet dump, as well as inputs near sediment sites KL02 (eastern shore, south of the Loran tower) and KL12 (near the west end of community). Previous research (Reimer et al., 1993) has also shown that the discharge path from the CAM-Main radar site is a potential source of PCBs to Cambridge Bay.

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