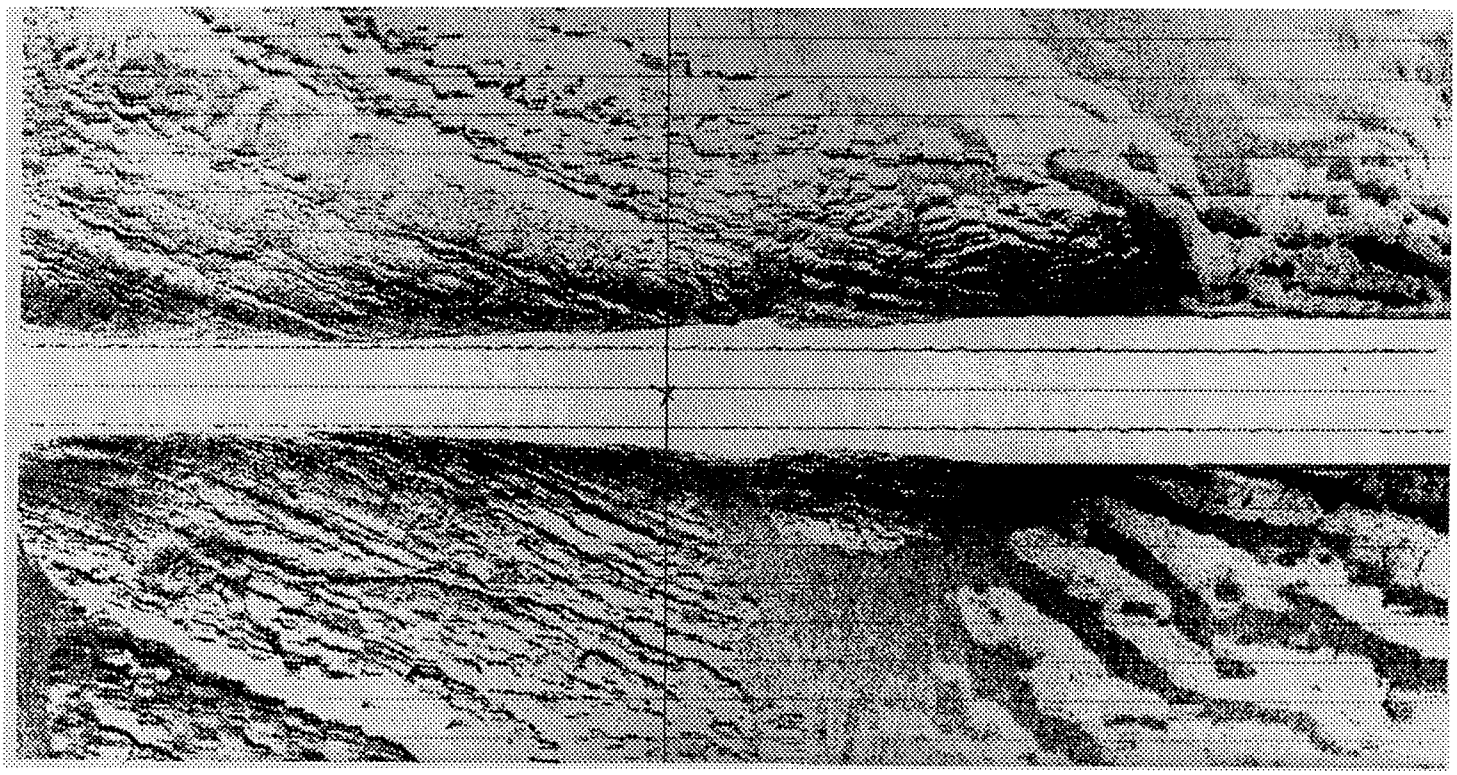
CRUISE REPORT NAVICULA 1990-010, HALIFAX HARBOUR May 22 - June 8, 1990

by

Gordon B.J. Fader and Robert O. Miller



CRUISE SUMMARY

Cruise No.:	90-010 (Halifax Harbour)
Vessel:	C.S.S. Navicula
Cruise Dates:	May 22 - June 8, 1990
Responsible Agency:	Atlantic Geoscience Centre, Geological Survey of Canada, Bedford Institute of Oceanography, Dartmouth, N.S., B2Y 4A2
Area:	Halifax Harbour and Approaches, Nova Scotia
Ship's Master:	Captain Joe Bray
Senior Scientist:	Gordon B. J. Fader
Scientific Personnel:	Robert O. Miller - Technician, AGC, Second Scientist
	Anthony S. Atkinson - Technician, AGC
	Darrell Beaver - Technician, AGC
	Shawn S. Pecore - Student, University of Waterloo
	Boris Winterhaltern - Geological Survey of Finland
	Jørn BoJensen - National Forest and Nature Agency, Denmark
	Richard Chittleburgh - Global Underwater Consultants
	Harvey LeRoy - Global Underwater Consultants
	Dale Buckley - Scientist, AGC
	Ray Cranston - Scientist, AGC
	Robert Murphy - Technician, AGC
	Gary Winters - Scientist, AGC
	Michelle Gardiner - Student, University College of Cape Breton

* The cover shows a 100 khz sidescan sonogram from the outer area of Halifax Harbour depicting bedrock on the left side of the image and a seabed of gravel overlain with megaripples in sand on the right. This is typical of the distribution of sediments and bedrock in the outer harbour.

INTRODUCTION

This cruise was the last in a series of regional studies to map the surficial geology of Halifax Harbour. It was part of a program of the Geological Survey of Canada to study the marine geology of the nearshore-coastal areas of the Atlantic Provinces. It was also intended to collect pertinent geological data to assist the Halifax Harbour Task Force in their deliberations on the choice of a sewage management system for the Halifax-Dartmouth area and surrounding communities. Part of the survey took place in the outer harbour to the south of Hartlen Point and extended farther seaward. This part of the survey was supported by the Canada-Nova Scotia Cooperation Agreement on Mineral Development and was undertaken to assess the aggregate and placer potential of the nearshore areas of Nova Scotia.

The cruise extended from May 22/90 to June 8/90. The main purpose of the cruise was to collect geological and geophysical data to fill in areas which were missed on earlier studies. These gaps came about because of navigation problems, equipment failures and the presence of ship traffic which included the presence of anchored ship dredges and oil rigs in the harbour. In addition, the availability of a Klein 500 Khz sidescan sonar system in 1990 allowed details of features and objects previously identified to be observed.

Twelve areas of the Harbour were also examined with a remotely operated vehicle (ROV) during the cruise. The sites were determined from previously collected data and covered a wide range of interpreted seabed features such as sewage banks, possible pockmarks (gas escape craters), current scour features and bedforms.

The sidescan sonar data were collected to complete the mapping of seabed sediments and surface features such as anchor marks, dredge spoils, borrow pits and shipwrecks. The high-resolution seismic

reflection data were used to define seabed morphology and subsurface stratigraphy. They were also used to locate core locations away from anthropogenic processes which have disturbed the sediments.

The first week of the cruise was designed primarily to collect geophysical data on line without the collection of samples. Data gaps from previous cruises were infilled and most survey lines were run in an east-west direction to provide, with the previously collected data, a grid coverage. An attempt was made to survey in very shallow water depths to the south of McNabs Island in an area where previous surveys were unable to be conducted. With high water and careful navigation some success was achieved. The second week consisted of three days of ROV observations during which 12 dive locations were investigated followed by several days of site specific sampling of sediments and patterns interpreted from the geophysical data.

NAVICULA 90-010 - ITINERARY

Tuesday, May 22nd, Julian Day 142		* Times in G.M.T.
1030	get gear working	
1430	depart BIO	
1500	return to BIO, auto pilot not working	
1620	depart BIO after pilot repaired to survey in Bedford Basin with Seistec, Bubble Pulser, sidescan, eel	
2135	back to BIO	
Wednesday, May 23rd, Julian Day 143		
1030	get gear working	
1250	depart BIO	
1300	deploy everything but bubble pulser; work in Harbour	
1445	pilot goes down	
1505	back to BIO	
1635	depart BIO after repairs to autopilot	
1655	deploy gear to run east-west lines in Halifax Harbour	
2120	recover gear	
2135	back to BIO	

Thursday, May 24th, Julian Day 144

1030	get gear working
1130	depart BIO
1155	deploy gear for work in Halifax Harbour; east-west lines off Ives Knoll; run line up Eastern Passage
2030	recover gear off Container Pier C
2110	back to BIO

Friday, May 25th, Julian Day 145

1030	get gear working; 1145 - depart BIO
1200	deploy gear to survey gear in outer harbour
1940	recover gear
2020	back to BIO

Saturday, May 26th, Julian Day 146

1030	get gear working
1130	depart BIO
1245	deploy gear, except bubble pulser in outer harbour to Eastern Passage
2055	recover gear
2120	back to BIO

Sunday, May 27th, Julian Day 147

1030	get gear working
1215	depart BIO, and deploy gear for work in Northwest Arm to Chebucto Head
2100	recover gear
2135	back to BIO

Monday, May 28th, Julian Day 148

1030	Global Underwater Consultants prepare Phantom HD2 R.O.V.
1350	R.O.V. trials at jetty
1410	depart BIO for R.O.V. dive sites
2100	recover R.O.V. after final dive of day
2205	back at BIO

Tuesday, May 29th, Julian Day 149

1030	Global Underwater Consultants prepare Phantom HD2 R.O.V.
1140	depart BIO for R.O.V. dive sites
2110	recover R.O.V. after final dive of day
2140	back at BIO

Wednesday, May 30th, Julian Day 150

1030	Global Underwater Consultants prepare Phantom HD2 R.O.V.
1145	depart BIO for R.O.V. dive sites
2045	recover R.O.V. after final dive of day
2105	back at BIO

Thursday, May 31st, Julian Day 151

1030	get gear working
1210	depart BIO for survey in Bedford Basin
1225	deploy gear in Bedford Basin
1915	recover gear
1940	back at BIO

Friday, June 1st, Julian Day 152

1030 get gear working; Navicula taking on fuel
1400 depart BIO
1455 deploy gear off Lighthouse Bank
1815 recover gear and head for Hartlen Point
1850 deploy gear off Hartlen Point
1930 recover gear
2100 back at BIO

Saturday, June 2nd, Julian Day 153

1030 get gear working
1130 depart BIO
1245 deploy gear off Hartlen Point and run east-west lines off Chebucto Head to Herring Cove
2045 recover gear off Mars Rock
2130 back at BIO

Sunday, June 3rd, Julian Day 154

1030 get gear working
1130 depart BIO
1140 deploy gear to survey sewage outfall areas
2130 recover gear under MacKay Bridge
2140 back at BIO

Monday, June 4th, Julian Day 155

secured at BIO all day for viewing of vessel by refit bidders; take on food and supplies; strong wind and rain all day

Tuesday, June 5th, Julian Day 156

1125 Buckley and staff arrive at Navicula
1145 depart BIO for Meaghers Beach
1217 deploy sidescan and tow into McNabs Cove
1230 deploy grab and corer in McNabs Cove
1304 depart McNabs Cove for BIO
1343 back at BIO; repair Eckman grab
1620 depart BIO for survey in Bedford Basin
1710 deploy LeHigh corer and Eckman grab off Compass buoy
1850 depart Compass buoy area for BIO to drop off samples
1905 at BIO
1930 depart for McNabs Cove
2008 deploy LeHigh corer off McNabs Cove
2052 complete Eckman grab; depart for BIO
2135 back at BIO

Wednesday, June 6th, Julian Day 157

1145 depart BIO for day of grab sampling
1240 deploy gear off Herring Cove
1430 arrive east of Thrumcap Shoal; deploy sidescan and take grab samples in area
1500 depart area for Northwest Arm
1550 arrive Northwest Arm; take Van Veen grab sample off Dingle
1635 arrive off Indian Point; do bottom grabs
1850 take sample (grab) off Compass buoy
1910 back at BIO

Thursday, June 7th, Julian Day 158 at BIO to remove equipment
Friday, June 8th, Julian day 159 at BIO; complete removal of equipment

EQUIPMENT DESCRIPTION AND PERFORMANCE

Sidescan Sonar System

The sidescan sonar system deployed during the cruise consisted of a dual-frequency (100 kHz and 500 kHz) Klein 595, with a "K" wing depressor and a remote controlled Markey hydraulic winch. Sidescan signals were logged on seven inch reels of magnetic analog recording tape at a speed of three and three quarters inches per second. The eighteen hundred foot reels of Ampex type 641 tape provided one and a half hours of recording time per reel. The four channels of the Racal Store 4D tape recorder were used in the following manner: Channel one - FM port sidescan signal, Channel two - FM starboard sidescan signal, Channel three - DR sidescan reference signal, and Channel four - DR Seistec signal and voice fixes. Seismic reflection data collection was synchronized to the sidescan system providing an opportunity to record the Seistec signal on channel four and recover synchronization during playback. For the majority of the cruise, the 100 kHz sidescan data was set at a one hundred metre range and sixty lines per inch paper speed while the 500 kHz sidescan data varied from 25 m to 100 m range. This provided a resolution of ~0.5 m across track. The sidescan fish was towed at a constant height above the seabed to aid in the production of sidescan mosaics. The data are generally of high quality.

Datasonics "Bubble Pulser"

A Datasonics "Bubble Pulser" 500 Hz source and hydrophone streamer was used to define subsurface stratigraphy and delineate the bedrock surface in areas of "gas-charged" sediments. Its output was displayed on an EPC 1600 graphic recorder using a paper rate of 150 lines per inch. A sweep speed of

100 milliseconds was used with a firing rate of 400 milliseconds. The seismic profiles from this system have a resolution of ~3-5 m.

IKB Seistec System

High resolution seismic reflection data were gathered using an ORE Geopulse power supply firing a Huntec Model 4425 boomer at 105 Joules, an ORE 5210A seismic receiver, an EPC graphic recorder, and an IKB Seistec surface towed line-in-cone array. The Seistec data were displayed on an EPC 1600 recorder using a 60 millisecond sweep speed and a paper rate of 150 lines per inch. Water column time delays were included as required and noted on the graphic records. A firing rate of 400 milliseconds was used for the Seistec system. The resolution of this system was ~0.5 m.

Few equipment problems were experienced. A trigger pulse was sourced from the sidescan recorder and this was used to fire the Seistec and Datasonics systems. Synchronizing the systems removed the boomer transient pulse from the sidescan records. Using 100 metre range on the Klein sidescan, a trigger pulse was produced every 130 milliseconds. It was necessary to divide this time by three to produce a seismic trigger every 400 milliseconds. Since the low cut frequency of the Seistec was 100 Hz and the Bubble Pulser system had a centre frequency of 500 Hz, there was little overlapping between the two systems and they could be triggered at exactly the same time. All records were simultaneously annotated using the TSS annotator.

Navigation

Navigation was provided by radar fixes supplemented by Loran C, with accuracy being erratic in Halifax Harbour, but improving towards the outer harbour. Geographic referencing of sidescan sonar data with data collected during Navicula 89-009 cruise also helped with the navigational accuracy.

ROV OBSERVATIONS

One of the primary objectives of the survey was to fill in data gaps from previous studies of the marine geology of Halifax Harbour. This was largely accomplished. In addition, the new 500 Khz sidescan sonar system provided details of previously identified harbour features. The use of an ROV to obtain visual observations of sediment texture, morphology and anthropogenic features provided an important data base to assist in the interpration of the remotely sensed data. The following is a summary of the new findings from the cruise and observations from the ROV dives of the targets investigated.

ROV Dive Site # 1 and 2

These ROV dive locations were at the entrance to the Northwest Arm in approximately 15 m water depth. The dives were intended to investigate the occurrence, characteristics and origin of many pockmark-like depressions floored with zones of high acoustic backscatter. Two of the features were visited with the ROV and were found to be up to 2 m deep. One was floored by large boulders and debris. The other was completely covered with kelp so that the bottom substrate could not be seen. It is possible that some of these depressions have been formed by gravel inadvertently dropped from barges. The Holocene mud would have been displaced by the gravel forming an impact feature. A large gravel pit is located in adjacent Purcells Cove and material was frequently transported to the dock areas of Halifax. It is also possible that some of the barges lost their loads during the journey and this is what we found at the seabed. The Holocene mud is the dominant sediment across the area and it is thick and gas-charged. Some of the depressions have rims and appear volcano-like on the sidescan sonar data. It is also possible that some of the features are true pockmarks formed by the venting of biogenic methane.

ROV Dive Location #3

This dive examined linear groupings of unusual circular patches of high acoustic backscatter at the seabed in the outer harbour near Bear Cove Shoal. An early interpretation suggested that the features may be dredge spoils, but the ROV showed that they consisted of flat circular, well -rounded, cobble gravel patches 15 m in diameter surrounded by a flat seabed of medium-sized clean sand. They occur adjacent to a steep bedrock high which forms the eastern flank of the main channel of the western outer harbour. Most of the patches appear to be connected by linear narrow zones of high reflectivity, similar to the interior of the circular patches. Many have small 2-3 m diameter patches of sand in their centres. One possible explanation for the unusual distribution and shape of the circular patches is that they may have formed through erosion by a wall of vortices shed from the adjacent steep bedrock cliff. Strong currents generated during storms may have produced the vortices. The consistent parallel alignment of the circular patches, the small deposit of sand in the centre of each patch and their composition of rounded gravel suggest that they are not randomly dropped dredge spoils.

ROV Dive Location #4

This dive location in the deep channel of the outer harbour was intended to investigate the presence of megaripples interpreted from the sidescan sonar data. The seabed consisted of fine to medium -grained sand with whole and broken shells. Wave ripples were present on the sand as well as large megaripples. Several old lobster traps with attached rope were found across the seabed. Several old electrical and communication cables were also located at the seabed.

ROV Dive Location #5

This dive location was undertaken at the entrance to Herring Cove near the navigational buoy to the north of Lichfield Shoal. It was intended to investigate the presence of sandy sediment interpreted from the acoustic data, a lack of bedforms which results from topographic sheltering by Lichfield Shoal and a large sonar target thought to be the wreck of the vessel Deliverance which sank in 1917. The seabed was composed of rippled sand. The water column was charged with much particulate material which appeared more concentrated in bottom water. It likely eminates from the raw sewage outfall at the adjacent shoreline in Watley's Cove which drains much of Halifax mainland south. No megaripples were present and the fine particles from the sewage effulent did not appear to accumulate at the seabed. The particulates appeared to be moving to the north and northeast. The wreck of the Deliverance is clearly visible and consists of a wooden hulled vessel with a large metal boiler protruding as the uppermost object. Much of the vessel appears to have caved in to the central area of the wreck and cables and rope are widespread. Debris is also strewn around the wreck at the seabed.

ROV Dive Location #6

This dive location was undertaken in the central area of the Northwest Arm in an area we now refer to as the "Bottle Collector Hole". It is a large unusual depression adjacent to the Dingle Tower in Flemming Park. Here the currents of the Northwest Arm appear to increase in velocity because of the narrowing constriction of the Arm in this area, and prevent the deposition of fine grained Holocene mud. The ROV confirmed that much of the sediment in the depression consisted of gravel with boulders. Both to the north and south of the site the mud thickens considerably and is gas-charged. In the depression were found a large number of new and old bottles. The older ones were completely covered with lithothamnion, a coralline, pink concretionary growth.

ROV Dive Location # 7

This dive site was directly in the plume of the major sewage outfall at the mouth of the Northwest Arm extending from western Point Pleasant Park. Sonar images indicated the presence of a small 20 m diameter sewage bank at the seabed. The ROV showed that the seabed directly in front of the outfall pipe consisted of a loosely compacted patch of organic debris with raw sewage. Huge kelp beds were present near the outfall attached to the pipe itself and large boulders were common. Farther away from the outfall, the seabed consisted of mud and was generally flat and featureless. Flatfish were common across the seabed.

ROV Dive Location # 8

This dive site was intended to investigate a peculiar set of large parallel mud berms flanking a central trough in the Holocene mud of the inner Harbour to the north of Georges Island. The ROV showed much debris at the seabed across two mud berms up to 3 m in height. One berm was smaller. Anchor furrow marks cover the seabed in the area and some cut the berms. In the depression and adjacent to it were large rolls and bales of paper. The rolls were approximately 0.75 m in diameter and 5 m in length. Many pairs of leather boots were also found. Through historical archives we now know that this depression was formed by the scuttling of the Trongate in 1942. It was a munitions ship which caught fire in the Harbour. Despite efforts to extinguish the fire, and fearing another Halifax Explosion, the Navy sank the vessel with dummy bullets. The ship fell to the seabed and formed the large depression in the mud which we now refer to as the "Trongate Depression". The vessel was subsequently salvaged by cutting it into pieces and removed. The material we found at the seabed may have been part of the cargo of the Trongate. It is surprising to note that the paper rolls were only covered with a light dusting of sediment after sitting at the seabed for almost 50 years. This provides another qualitative assessment of sedimentation rate for this area of the harbour.

ROV Dive Location #9

This ROV dive location was intended to investigate a transition between gravel to Holocene mud in the inner Harbour off Pleasant Shoal. The transect to deeper water also examined a large target, a possible shipwreck. The seabed on the flank of Pleasant Shoal consisted of gravel with boulders, partly covered with a diverse attached fauna. Toward the east in the deeper channel, the seabed consisted of thin Holocene mud with large boulders protruding through the mud from a buried gravel substrate. A large shipwreck was investigated at this location as well. It was a wooden vessel, likely a schooner, over 30 m in length, partly lying on its side at the seabed. A large mast of the vessel lies across the seabed and the binnacle of the vessel hangs from its side. Rope and cable is abundant. The vessel is completely covered with sponges and sea anenomies so that details of the hull could not be determined. Archival data suggest that it may be the Alexander R., a schooner which was in a collision in the Harbour with the Afranmore and sank in 1906. The vessel has since been visited by local scuba divers and found to contain ammunition as well as many large kegs.

ROV Dive Location # 10 and 10.1

These dive locations surveyed the seabed of the inner harbour that was dredged with a clamshell bucket within the past year. The seabed consisted of a very hummocky topography and the sediment looked to be till- a mixture of clay, silt, sand and gravel. No growth or other organic material occurred on the bottom. This dive provided a calibration for the images collected with sidescan sonar across this seabed.

ROV Dive Location #11

This dive location was in The Narrows and was intended to observe the sediment texture at the seabed and to explore the old bridge footings of the first two original bridges which spanned Halifax Harbour in the

late 1800's. The seabed consisted of flat cobbles with boulders. Very large old mussel shells were widespread. At the bridge footing locations, large rock filled cribworks are abundant on the harbour floor. The cribs are filled with boulders. Other material in the area consisted of carved granite blocks, wooden pilings, and twisted railway track, much of which is covered with marine growth.

ROV Dive Location #12

This dive location was intended to investigate the presence and characteristics of boulder berms which ring the entire perimeter of Bedford Basin at a present depth of 23 m. They are interpreted to have formed approximately 6000 years ago when Bedford Basin was a lake, before the marine invasion, as sea level rose in post glacial time. The boulder berms consist of very large boulders some as large as 5 m in diameter. The berm ridges are separated by approximately 10-15 m and are up to 3 m in height. Some of the boulders have localized deposits of fine grained Holocene mud on ledges and flat surfaces. Biogenic growth is virtually absent on the boulders.

DISCUSSION

The high-resolution sidescan sonar data collected during this cruise provided details of features identified during the 1989 Navicula cruise. The reader is referred to Miller et al., 1990 and Fader et al., 1991 for a comprehensive discussion of the entire data base and interpreted maps of sediments and features based on the 1989 and 90 Navicula cruises.

The 23 m depth old boulder berms (shorelines) identified in Bedford Basin are widespread around the entire shoreline of the Basin and paleogeographic maps can be constructed on this basis. For example, Jonquiere Bank was an island prior to 6 thousand years ago. Other shorelines at shallower depths occur throughout the northern part of The Narrows and in an area around Georges Island. On the northwestern

area of Ives Knoll features interpreted as buried barrier beaches are found. In The Narrows, a shallow area once considered a hazard to navigation appears to have been removed through blasting. The feature could not be observed on the 1989 data because a dredging barge was temporarily moored over the area. The feature now clearly shows to be a bedrock exposure at the seabed of The Narrows.

Details of anchor furrow marks and pits can clearly be seen on the sidescan imagery. Individual chain link features often occur along the main furrow marks and likely result from the swaying of the anchor chain across the seabed in response to changes in tides and currents. The largest anchor furrow marks in the harbour are 5 m in width.

In the area off Hartlen Point and extending seaward for 3 km, a detailed survey was conducted to investigate the presence of gravel and sand as a potential aggregate source. The survey indicated that the seabed was composed of gravel, mostly of boulder sized clasts with bedrock outcrop in a few local areas. This material would not likely be suitable as aggregate in contrast to the area off Sambro on the western side of the outer harbour where considerable deposits of fine-grained gravel have been identified (Miller and Fader, 1989). This part of the survey was supported by the Canada-Nova Scotia Cooperation Agreement on Mineral Development.

In the 25-30 m deep water channel between Fergusons Cove and Sandwich Point, a series of linear depressions in the Holocene mud was identified. These features are commonly referred to as sedimentary furrows and are thought to form in muddy sediments as a result of strong currents greater than 50 cm/sec. They generally form as a result of erosion by recurring, directionally stable and episodically strong currents (Flood, 1983). They often have "tuning fork" junctions which can be used to determine the direction of the forming strong current. They open into the flow direction. The furrows off Sandwich Point are an important sediment transport indicator and suggest flow up the harbour to the north on the bottom. This direction is

similar to the direction of flow in the outer harbour south of Lichfield Shoal interpreted from the orientation of megaripples in sand.

The depressions at the entrance to the Northwest Arm which resemble pockmarks (gas-escape craters) can be clearly seen to be of several varieties. Some are depressions filled with a large number of single targets. These were investigated with the ROV and found to contain boulders and debris. They are interpreted to represent depressions formed by material dumped by barges-similar to dredge spoils. The presence of large quarries in adjacent Purcells Cove and a transportation route directly over the depression areas to the docks of Halifax where the material could have been used as fill, suggests that barge material may have inadvertently been dropped to the seabed. Of particular concern with these deposits is that they created depressions at the seabed as the coarse material compressed or displaced the fine-grained Holocene mud. This allowed the venting of local methane gas as the depressions occur in gas-charged sediments. Another class of depression in which single point reflections are not seen also occurs in this area. Some of these appear to be filled with kelp so that their base could not be observed. A third group appeared volcano-like with raised rims. These were not investigated with the ROV. So the question remains as to what formed these depressions at the entrance to the Northwest Arm and what role if any, did gas venting play in their formation.

During the cruise sidescan sonar tracks were run as close to the shoreline as was safely possible in order to fill in areas not previously surveyed. In the outer Harbour the data show a consistent pattern of bedrock exposure closest to shore, followed by a gravel apron often with ripples in the gravel and farther seaward a sand deposit with megaripples. Although many large ships have run aground along the shoreline of the outer harbour extending from Herring Cove to Chebucto Head, there was little evidence of these wrecks on the sidescan sonar data. Large boulders are common across the bedrock area as well, but this is a high energy coastline and it is likely that most of the large vessels have been broken into small pieces and redistributed over large areas and as such are not easily recognizable.

Seismic reflection data collected close to the shoreline indicate that many of the docks along the shoreline have been constructed on pre-existing highs-positive features of bedrock and/or till. Such is the case for the large waterfront development in Bedford around the existing sewage treatment plant where most of the infilled area has extended seaward across boulder-strewn till.

The nearshore surveys confirmed an earlier interpretation that propeller scour is an important process of sediment erosion in the harbour. Many of the docks have adjacent areas of the seabed that appear as scallop-shaped erosional depressions.

These data together with those collected during the 1989 Navicula cruise form a comprehensive base for interpretation of the marine geology of Halifax Harbour. From an engineering perspective the data can be usefull for design of a sewage treatment plant for the regional area where deep and long tunnels are required and areas of the harbour may be infilled. It can also be usefull in the selection of future sample locations for monitoring the environmental health of the harbour and the operation of the regional sewage treatment facility.

ACKNOWLEDGEMENTS

We wish to thank the Captain and Crew of the CSS Navicula for their support and assistance during the field project. Operations in a harbour such as Halifax are difficult for many reasons and we appreciate their dedication and professionalism. The Program Support technicians of AGC are particularily thanked for their assistance to the project. Long days and a small crew are characteristics of small boat operations and require constant monitoring of incoming data. We thank Tony Atkinson, Darrell Beaver in this regard. We also thank Richard Chittleburg of Global Marine for operation of the ROV and his assistant divers. Finally, we thank the Halifax Harbour Task Force for their support. Their deliberations on the design of a sewage

system for Halifax Harbour were underway during this survey and much of this data was used in their analyses. This report was critically reviewed by Brian MacLean and John Shaw.

REFERENCES

Fader et al., 1991. The Marine Geology of Halifax Harbour and Adjacent Areas (Volume 1 and 2, 25 maps). GSC Open File #2384.

Flood, 1983.

Miller and Fader, 1989. Cruise Report 88-018(A) Phase 1, F.R.V. Navicula, Halifax-Sambro, Nova Scotia, May 26 - June 2, 1988. 22 pages, 1 map. GSC Open File # 2093.

Miller et al., 1990. Cruise Report 89-009, Phase A, Halifax Inlet, F.R.V. Navicula, May 29 - June 18, 1989. 66 pages. GSC Open File #2242.

Table 1. Total Sample Inventory

Sample #	Sample Type	Day/ Time (GMT)	Latitude	Longitude	Depth (m)	Geographic Location	Comment
001	ROV	1481537	44 36.68N	63 33.64W	15.0	Halifax Harbour (entrance N.W. Arm)	pockmarks, dredge spoils, unusual pits
002	ROV	1481655	44 36.75N	63 33.82W	55.0	Halifax Harbour (entrance N.W. Arm)	kelp in pit (pockmarks?)
003	ROV	1481845	44 32.62N	63 31.87W	38.1	Halifax Harbour (outer harbour)	gravel circles off Bear Cove
004	ROV	1481947	44 31.53N	63 30.90W		Halifax Harbour (outer harbour)	megaripples, deep water
005	ROV	1491310	44 33.93N	63 32.86W	32.0	Halifax Harbour (off Herring Cove)	Deliverance wreck site, sand & wreck
006	ROV	1491725	44 37.82N	63 35.68W	13.0	Halifax Harbour (central N.W. Arm)	off Dingle, "bottle collector hole"
007	ROV	1491819	44 37.14N	63 34.35W	11.0	Halifax Harbour (entrance N.W. Arm)	sewage outfall (N.W. Arm)
008	ROV	1492013	44 38.97N	63 33.54W	19.0	Halifax Harbour (north Georges Island)	Trongate depression site
009	ROV	1501320	44 37.23N	63 33.09W	27.0	Halifax Harbour (off Pleasant Shoal)	shipwrecked schooner - Alexander R.?
010	ROV	1501520	44 39.43N	63 34.35W	18.0	Halifax Harbour (inner harbour)	dredge bottom, fresh till
010.1	ROV	1501600	44 39.29N	63 34.24W	16.0	Halifax Harbour (inner harbour)	dredge bottom, fresh till
011	ROV	1501710	44 40.56N	63 36.38W	20.0	Halifax Harbour (The Narrows)	old bridge footings
012	ROV	1501930	44 40.34N	63 38.28W	19.0	Bedford Basin	boulder berms
013	Grab	1561227	44 36.50N	63 31.96W	17.0	Halifax Harbour	
014	Core	1561253	44 36.50N	63 31.96W	18.0	Halifax Harbour	
015	Grab	1561718	44 41.52N	63 38.55W	70.0	Bedford Basin	
016	Core	1561757	44 41.52N	63 38.55W	70.0	Bedford Basin	
017	Grab	1561826	44 41.65N	63 38.05W	67.0	Bedford Basin	
018	Core	1561841	44 41.69N	63 38.06W	67.0	Bedford Basin	
019	Grab	1562030	44 36.57N	63 32.02W	18.0	Halifax Harbour	
020	Grab	1562045	44 36.57N	63 32.04W	18.0	Halifax Harbour	
021	Grab	1571326	44 31.46N	63 31.68W	41.0	Halifax Harbour	
022	Grab	1571357	44 32.10N	63 30.66W	37.0	Halifax Harbour	
023	Grab	1571443	44 35.14N	63 28.76W	15.0	Halifax Harbour	
024	Grab	1571454	44 34.48N	63 28.97W	18.0	Halifax Harbour	No sample
025	Grab	1571553	44 37.85N	63 35.75W	19.0	Halifax Harbour	
026	Grab	1571639	44 37.79N	63 32.01W	23.0	Halifax Harbour	
027	Grab	1571706	44 38.99N	63 33.62W	22.0	Halifax Harbour	
028	Grab	1571748	44 40.59N	63 36.36W	22.0	Halifax Harbour	
029	Grab	1571824	44 43.09N	63 39.95W	15.0	Bedford Bay	
030	Grab	1571846	44 41.91N	63 38.77W	69.0	Bedford Basin	

Table 2. Grab Samples

Samp. #	Sampler Type	Day/ Time (GMT)	Latitude Longitude	Depth (m)	# Attempts	Geographic Location	Grab Sample Notes
013	Eckman	1561227	44 36.50N 63 31.96W	17.0	9	Halifax Harbour	McNabs Cove. Silty clay - clayey silt, some grit, numerous attempts, kelp and other organic debris preventing closure, no sample saved.
015	Eckman	1561718	44 41.52N 63 38.55W	70.0	3	Bedford Basin	Thin oxidized layer on seabed, black sediment, worm tubes, few grits, silty clay to clayey silt.
017	Eckman	1561826	44 41.65N 63 38.05W	67.0	2	Bedford Basin	Small sample, oxidized brown surface layer (very thin), black silty clay - clayey silt.
019	Eckman	1562030	44 36.57N 63 32.02W	18.0	8	Halifax Harbour	McNabs Cove. Silty clay - clayey silt, some grit, numerous attempts, kelp and other organic debris preventing closure.
020	Eckman	1562045	44 36.57N 63 32.04W	18.0	10	Halifax Harbour	McNabs Cove. Silty clay - clayey silt, some grit, numerous attempts, kelp and other organic debris preventing closure.
021	Van Veen	1571326	44 31.46N 63 31.68W	41.0	1	Halifax Harbour	Outer harbour, off Portugese Cove, coarse sand, fine gravel, shells - 20% broken, sea urchin spines. In area of gravel ripples. See sidescan record.
022	Van Veen	1571357	44 32.10N 63 30.66W	37.0	3	Halifax Harbour	Outer harbour. Medium grained sand, broken shells, 1st attempt - some gravel and shells - broken with lithothamnion coating, no silt or clay, well sorted sand. Area of megaripples.
023	Van Veen	1571443	44 35.14N 63 28.76W	15.0	1	Halifax Harbour	Outer harbour, east of Thrumcap Shoal. Medium-fine, well sorted grey-green sand, few shell fragments. See sidescan record.
025	Van Veen	1571553	44 37.85N 63 35.75W	19.0	1	Halifax Harbour	N.W. Arm (Dingle). Layered sample - 10 cm mud, base gravelly sediment, peculiar broken fragments of Halifax slate, hornfels facies.
026	Van Veen	1571639	44 37.79N 63 32.01W	23.0	1	Halifax Harbour	North of McNabs Island. Two layered sample. Fine grained mud on surface and more gravelly sediment subsurface. Note in pit area, no apparent sand, thin oxidized layer of brown mud.
027	Van Veen	1571706	44 38.99N 63 33.62W	22.0	1	Halifax Harbour	Trongate. Stiff mud, two layered, mostly silty clay, brown oxidized thin layer, klinkers abundant, some gravel, one piece of coal.
028	Van Veen	1571748	44 40.59N 63 36.36W	22.0	4	Halifax Harbour	Narrows. 4 attempts, last one 1 large mussel, eroded shell; broken shells, few pebbles, sea urchins, very hard seabed, gravel, no sediment.
029	Van Veen	1571824	44 43.09N 63 39.95W	15.0	1	Bedford Bay	Mud-silt, clay; numerous worm tubes, thin oxidized layer brown mud, remainder black, few ice rafted pebbles.
030	Van Veen	1571846	44 41.91N 63 38.77W	69.0	1	Bedford Basin	Special sample - thin brown oxidized layer, mostly black mud with worm tubes, but layer of clean sand 3 cm thick. Sand layer subsampled.

Table 3. Core Samples

Samp. #	Samp. Type	Day/ Time (GMT)	Latitude Longitude	Depth (m)	Corer Length (cm)	App. Penn. (cm)	Core Length (cm)	# Sect.	Geogr. Loc.	Notes
014	LeHigh	1561253	44 36.50N 63 31.96W	18.0	150		68	1	Halifax Harbour	McNabs Cove. Silty clay, thin brown layer at seabed, remainder of core black.
016	LeHigh	1561757	44 41.52N 63 38.55W	70.0	150	200	134	1	Bedford Basin	Good core, very thin brown surface layer, black sediment, methane gas measured.
018	LeHigh	1561841	44 41.69N 63 38.06W	67.0	150	200	110	1	Bedford Basin	Black silty clay - clayey silt.

Table 4. ROV Surveys

Sample #	Dive #	Latitude Longitude	Start Time/ End Time	Max Depth	Video Tape #	Type of Vehicle	Geographic Location	Notes
001	1	44 36.68N 63 33.64W	1481537 1481643	15	1	Phantom HD2	Halifax Harbour (N.W. Arm)	Entrance to N.W. Arm. Large boulder type objects with debris. Areas of crushed stone, suspect dump site. Pockmarks (depressions)
002	2	44 36.75N 63 33.82W	1481655 1481745	55.0	2	Phantom HD2	Halifax Harbour (N.W. Arm)	Entrance to N.W. Arm. Small kelp bed in pockmarks. See sidescan record.
003	3	44 32.62N 63 31.87W	1481845 1481915	38.1	3	Phantom HD2	Halifax Harbour (outer harbour)	Bedrock, gravel, sand. Unique gravel circles near bedrock outcrop.
004	4	44 31.53N 63 30.90W	1481945 1482040		4	Phantom HD2	Halifax Harbour (outer harbour)	Sand bedforms off Bear Cove, sand and shells, sand bedforms - megarippled area.
005	5	44 33.93N 63 32.86W	1491310 1491625	32.0	5	Phantom HD2	Halifax Harbour (off Herring Cove)	Entrance to Herring Cove, sand bottom, some kelp and weed. Wood wreckage (wreck 5.1) with boiler. Sand ripples. No fine grain silt and clay sediment. Deliverance shipwreck.
006	6	44 37.82N 63 35.68W	1491725 1491800	13.0	6	Phantom HD2	Halifax Harbour (N.W. Arm)	N.W. Arm (Dingle). Hard bottom, scattered rocks and boulders, light film of mud, many bottles at seabed.
007	7	44 37.14N 63 34.35W	1491820 1491925	11.0	7	Phantom HD2	Halifax Harbour (N.W. Arm)	Point Pleasant sewer outfall. Kelp, fine grained sediment, plume.
008	8	44 38.97N 63 33.54W	1492010 1492110	19.0	8	Phantom HD2	Halifax Harbour (north Georges Island)	Trongate wreck site. Wood found with rolled paper on a silt bottom, also numerous anchor scours. Silt and sand. Boots and paper bales.
009	9	44 37.23N 63 33.09W	1501312 1501430	27.0	9	Phantom HD2	Halifax Harbour (off Pleasant Shoal)	Pleasant Shoal. Wreckage found in 107 ft. of water, unable to identify, maybe wooden mast and railings? 120' old schooner. Alexander R.?
010	10	44 39.43N 63 34.35W	1501515 1501625	18.0	10	Phantom HD2	Halifax Harbour (Inner Harbour)	Purdy's Wharf, mainly dredge marks and anchor scours, no life, fresh till, dredged in 1989.
010.1	10	44 39.29N 63 34.24W	1501515 1501625	16.0	10	Phantom HD2	Halifax Harbour (Inner Harbour)	Purdy's Wharf. Mainly dredge marks and anchor scours. No life, fresh till. Tape mark 10.1.
011	11	44 40.56N 63 36.38W	1501710 1501850	20.0	11	Phantom HD2	Halifax Harbour (The Narrows)	Narrows (old bridge footings). Large boulders, hard gravel floor, wood and steel, shells, woodpiles, steel rails, copper pot, beer cans.
012	12	44 40.34N 63 38.28W	1501930 1502045	19.0	12	Phantom HD2	Bedford Basin	Fairview Cove. Possible wreck/boulder berms. Sand and silt bottom (heavy silt). Sandy bottom at 85 ft. Large boulders at 75-80 ft. Large block 4 x 3 m.

Table 5. Seismic Records

Roll #	Start Day/Time	Stop Day/Time	Hydrophone	Record Type	Geographic Location	Recorder	System/Sound Source
001	1421705	1422100	Internal	Single	Halifax Harbour	EPC 8700	Seistec Boomer
001	1421659	1422100	External	Single	Halifax Harbour	EPC 1600	Datasonics Bubble Pulser
002	1431307	1432110	Internal	Single	Halifax Harbour	EPC 1600	Seistec Boomer
002	1431306	1432108	External	Single	Halifax Harbour	EPC 1600	Datasonics Bubble Pulser
003	1441201	1442028	Internal	Single	Halifax Harbour	EPC 1600	Seistec Boomer
003	1441433	1442027	External	Single	Halifax Harbour	EPC 1600	Datasonics Bubble Pulser
004	1451159	1451650	Internal	Single	Halifax Harbour	EPC 1600	Seistec Boomer
004	1451206	1451430	External	Single	Halifax Harbour	EPC 1600	Datasonics Bubble Pulser
005	1451653	1451941	Internal	Single	Halifax Harbour	EPC 1600	Seistec Boomer
005	1451159	1451941	External	Single	Halifax Harbour	EPC 1600	Datasonics Bubble Pulser
006	1451440	1451941	Internal	Single	Halifax Harbour	EPC 8700	Seistec Boomer
006	1461316	1462051	External	Single	Halifax Harbour	EPC 1600	Datasonics Bubble Pulser
007	1461221	1462051	Internal	Single	Halifax Harbour	EPC 1600	Seistec Boomer
007	1471256	1472059	External	Single	Halifax Harbour	EPC 1600	Datasonics Bubble Pulser
008	1461221	1462051	Internal	Single	Halifax Harbour	EPC 8700	Seistec Boomer
008	1511253	1511858	External	Single	Halifax Harbour	EPC 1600	Datasonics Bubble Pulser
009	1471255	1472058	Internal	Single	Halifax Harbour	EPC 1600	Seistec Boomer
009	1521500	1521922	External	Single	Halifax Harbour	EPC 1600	Datasonics Bubble Pulser
010	1471255	1472059	Internal	Single	Halifax Harbour	EPC 8700	Seistec Boomer
010	1531245	1532036	External	Single	Halifax Harbour	EPC 1600	Datasonics Bubble Pulser
011	1511231	1511858	Internal	Single	Halifax Harbour	EPC 1600	Seistec Boomer
011	1541142	1542124	External	Single	Halifax Harbour	EPC 1600	Datasonics Bubble Pulser
012	1511233	1511858	Internal	Single	Halifax Harbour	EPC 8700	Seistec Boomer
013	1521500	1521922	Internal	Single	Halifax Harbour	EPC 1600	Seistec Boomer
014	1521549	1521922	Internal	Single	Halifax Harbour	EPC 8700	Seistec Boomer
015	1531248	1532036	Internal	Single	Halifax Harbour	EPC 1600	Seistec Boomer
016	1531248	1532036	Internal	Single	Halifax Harbour	EPC 8700	Seistec Boomer
017	1541142	1542124	Internal	Single	Halifax Harbour	EPC 1600	Seistec Boomer
018	1541755	1542124	Internal	Single	Halifax Harbour	EPC 8700	Seistec Boomer
019	1541141	1541750	Internal	Single	Halifax Harbour	EPC 8700	Seistec Boomer

Table 6. Sidescan Records

Roll #	Start Day/Time	Stop Day/Time	Record Type	Geographic Location	Recorder	Sidescan System
001	1421632	1422102	Combined	Halifax Harbour	Klein 595	595 (100/500 kHz)
002	1431300	1431815	Combined	Halifax Harbour	Klein 595	595 (100/500 kHz)
003	1431820	1432115	Combined	Halifax Harbour	Klein 595	595 (100/500 kHz)
004	1441201	1441851	Combined	Halifax Harbour	Klein 595	595 (100/500 kHz)
005	1441855	1442031	Combined	Halifax Harbour	Klein 595	595 (100/500 kHz)
006	1451152	1451942	Combined	Halifax Harbour	Klein 595	595 (100/500 kHz)
007	1461221	1462051	Combined	Halifax Harbour	Klein 595	595 (100/500 kHz)
008	1471215	1472102	Combined	Halifax Harbour	Klein 595	595 (100/500 kHz)
009	1511231	1511857	Combined	Halifax Harbour	Klein 595	595 (100/500 kHz)
010	1521456	1521811	Combined	Halifax Harbour	Klein 595	595 (100/500 kHz)
011	1521846	1521922	Combined	Halifax Harbour	Klein 595	595 (100/500 kHz)
012	1531248	1532038	Combined	Halifax Harbour	Klein 595	595 (100/500 kHz)
013	1541142	1541253	Combined	Halifax Harbour	Klein 595	595 (100/500 kHz)
014	1541256	1542007	Combined	Halifax Harbour	Klein 595	595 (100/500 kHz)
015	1542011	1542117	Combined	Halifax Harbour	Klein 595	595 (100/500 kHz)
016	1542121	1542126	Combined	Halifax Harbour	Klein 595	595 (100/500 kHz)

Table 7. Bathymetry Records

Roll #	Start Day/Time	Stop Day/Time	Frequency	Parameter	Geographic Location	Recorder
001	1421640	1422100	30 kHz	30 kHz	Halifax Harbour	ELAC
002	1431258	1471747	30 kHz	30 kHz	Halifax Harbour	ELAC
003	1471750	1511900	30 kHz	30 kHz	Halifax Harbour	ELAC
004	1521455	1562045	30 kHz	30 kHz	Halifax Harbour	ELAC
005	1571240	1571846	30 kHz	30 kHz	Halifax Harbour	ELAC

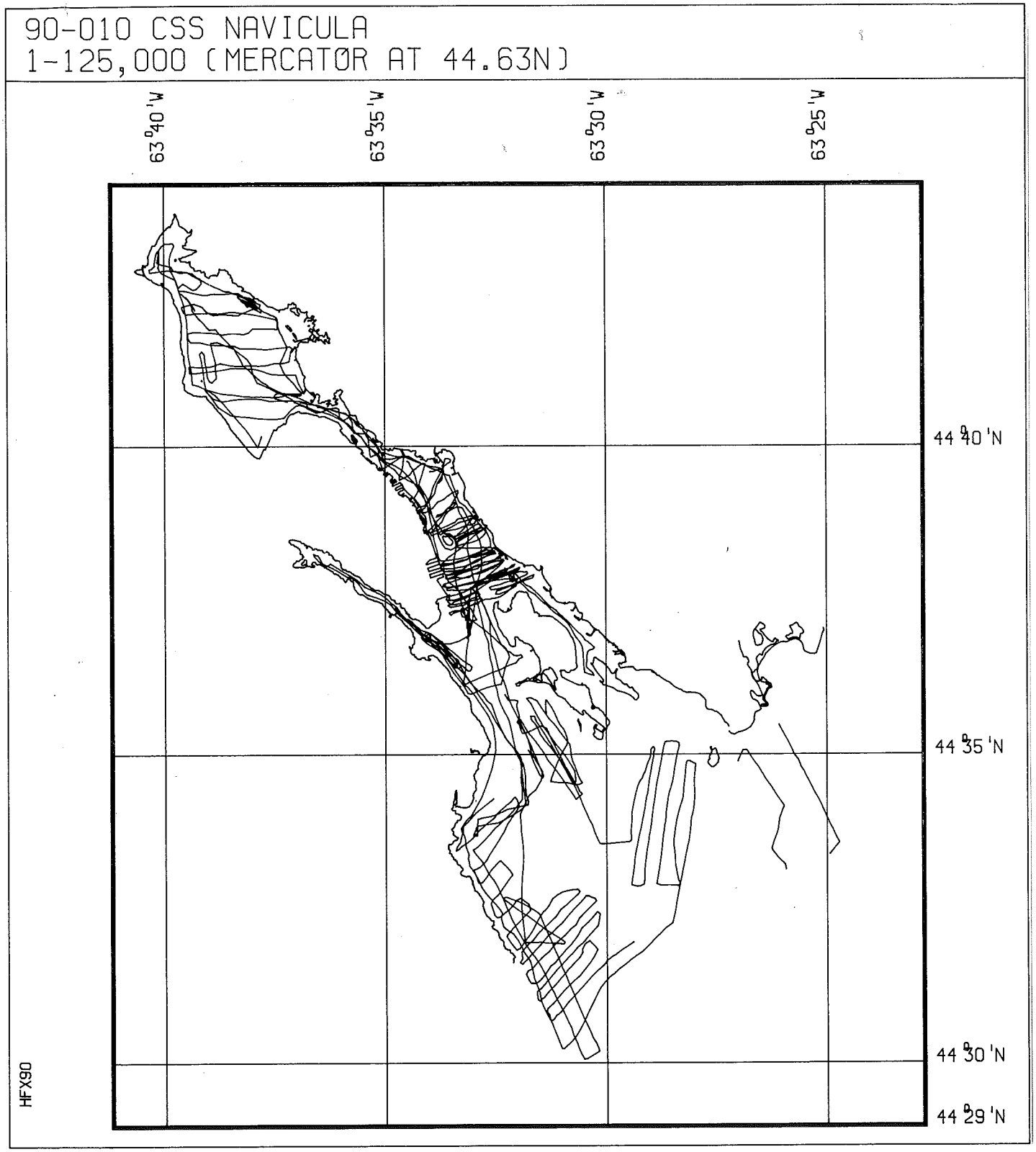


Figure 1: Ship's tracks, Navicula 90-010.

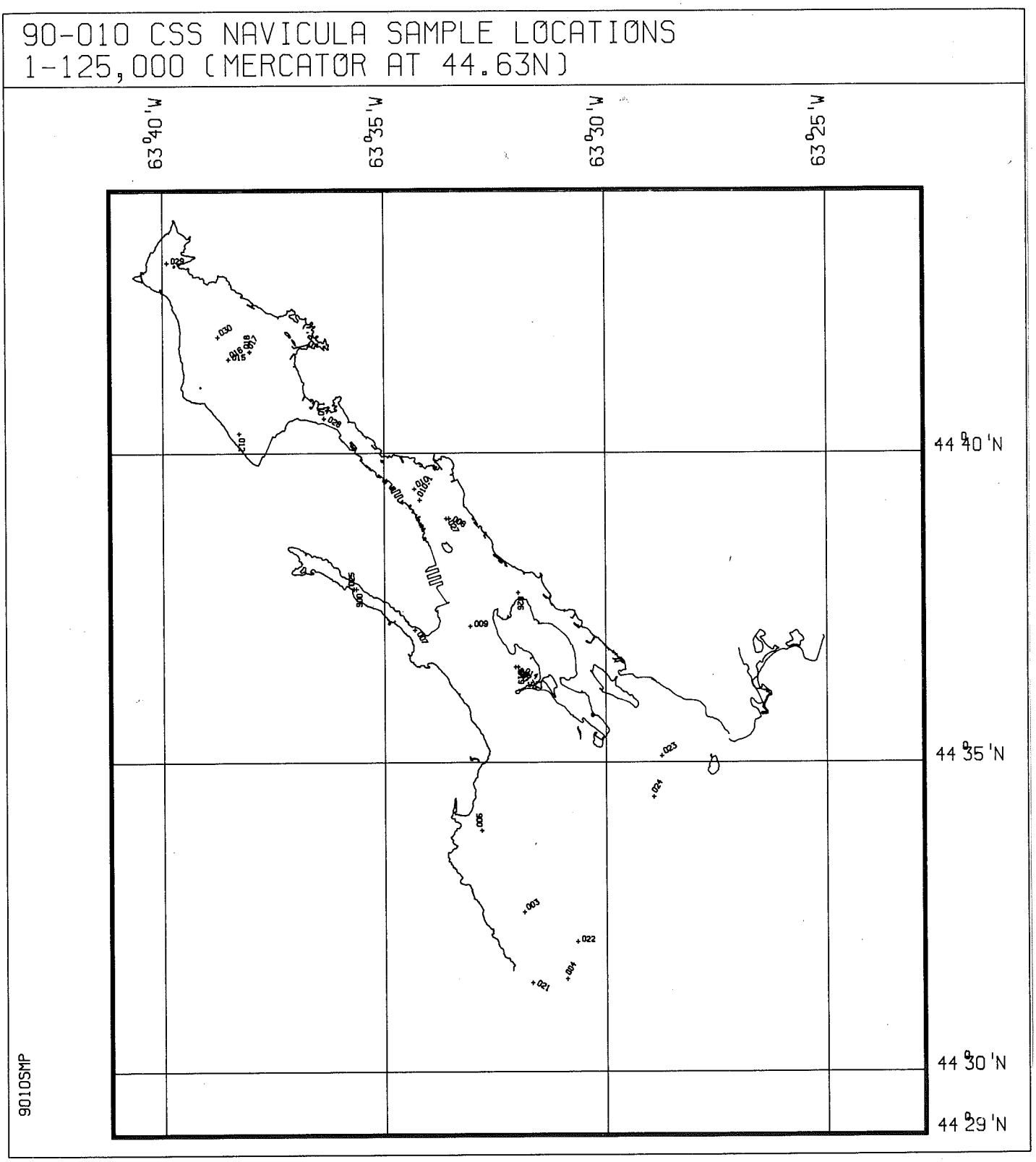


Figure 2: Sample and ROV stations, Navicula 90-010.