PRELIMINARY RESULTS OF INVESTIGATIONS INTO SEABED STABILITY IN THE HIBERNIA REGION OF THE GRAND BANKS DURING OPERATIONS OF HMCS CORMORANT AND SDL-1 SUBMERSIBLE

by

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ABSTRACT

In October, 1984 an 18 day scientific cruise was completed to the Hibernia area of the Grand Banks of Newfoundland on the **HMCS CORMORANT** and the **SDL-1** manned submersible in cooperation with the Canadian Forces and the Geological Survey of Canada. The surficial sediment facies reported by Barrie 'et al.' (1984) were examined and detailed observations were made of the smaller sedimentary bedforms. A deep, 10 m pit was found using sidescan sonar and 3.5 kHz profiles and subsequently examined by submersible. The feature, similar to others in the area, was formed during the impact of an iceberg followed possibly by a bearing capacity failure. An experiment site using Europium-doped tracer sand and sediment transport rods was established on the western flank of a sand ridge. Finally a regional sidescan sonar and sub-bottom profiler survey was carried out south to Carson Canyon, extending the distribution of the established sediment facies.

ACKNOWLEDGEMENTS

The success of this project to achieve all the required objectives was made possible by the full cooperation of the Department of National Defence and in particular the Commanding Officer, R. Bowers, officers and crew of the **HMCS CORMORANT** and the pilots of the **SDL-1** submersible. Use of the combined sidescan sonar and profiler as well as BRUTIV (Bottom Referencing Underwater Towed Instrumented Vehicle) were kindly made available by the Geological Survey of Canada at the Atlantic Geoscience Centre. We would like to thank C.F.M. Lewis and D.R. Parrott of the Geological Survey of Canada for their support throughout this project. We would also like to thank Bob Hooper who contributed his biological expertise to this report and Marylin Segall for her valuable assistance in cruise preparations. The work was supported by an OERD (Office of Energy Research and Development) funding contract through the Department of Energy Mines and Resources.

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INTRODUCTION

How were the large depressional pits documented in previous acoustic geophysical surveys in the Hibernia area of the northeastern Grand Banks of Newfoundland formed? What is the rate of sediment transport at the Hibernia discovery field? Such questions as these and many others are the result of an intensive investigation into the surficial geology of the northwestern Grand Banks and the modern processes affecting this shelf area (Amos and Barrie, 1980; Fader and King, 1981; Lewis and Barrie, 1981; Barrie 'et al.', 1984; Barrie 'et al.', 1985).

The northeastern Grand Banks (Fig. 1) is a dynamic shelf vulnerable to iceberg scouring and shear stress from oceanic swell (water depths range from 70 to 140 m), storm driven waves, and the intrusion of the central arm of the Labrador Current.

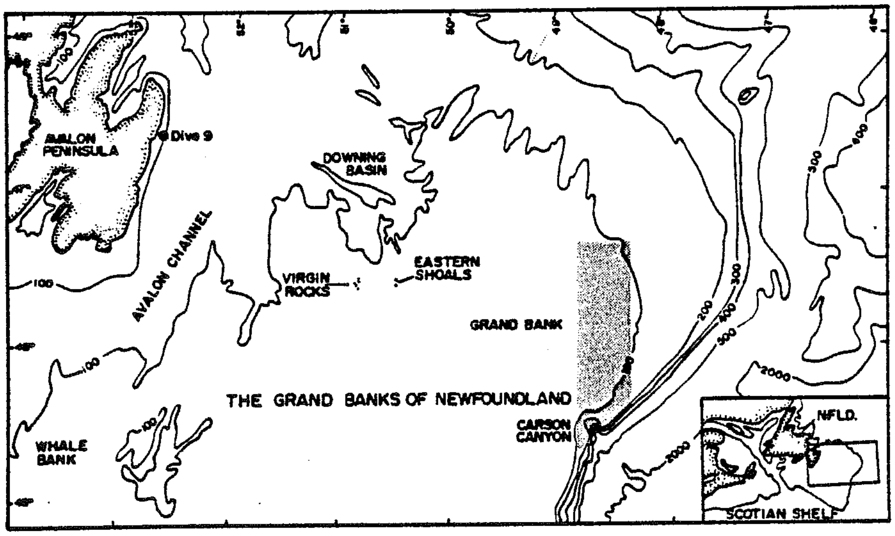

Figure 1. Map of Grand Banks with darkened block showing area of operations. Dive 9 which took place in the Avalon Channel is shown.

From qualitative analysis of sedimentary bedforms and theoretical analysis of all available oceanographic data for the Hibernia area of the Grand Banks, sediment transport predictions have been made (Barrie 'et al.', 1985). Transport direction, for example, is predicted to be south to southeast along the continental shelf at a rate of approximately 0.5 to 0.24 $m^3/m/yr$ (Barrie 'et al.', 1985).

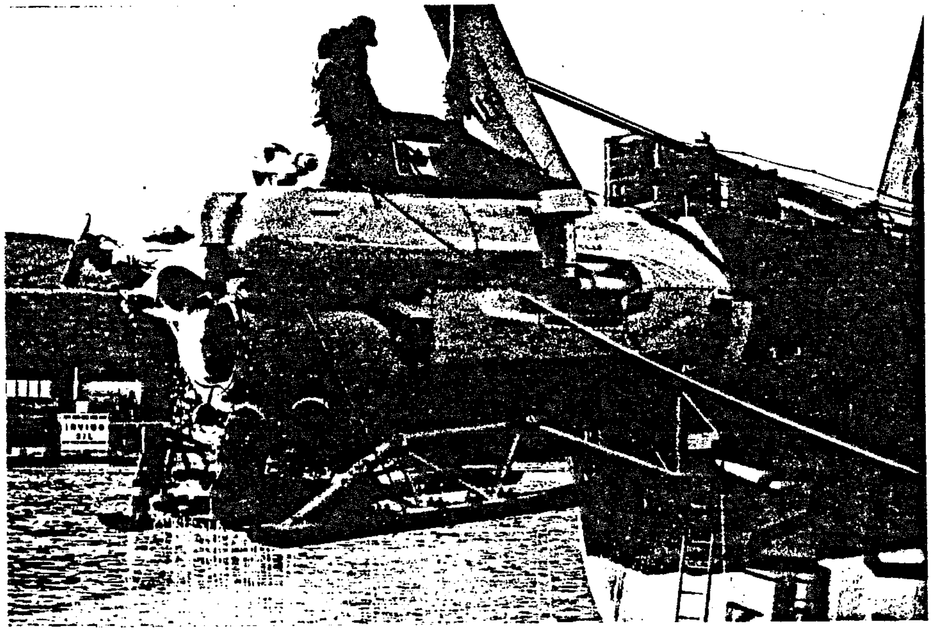

Figure 2. The **SDL-1** being launched from its support vessel the **HMCS CORMORANT**

In order to address these scientific problems directly C-CORE (Centre for Cold Ocean Resources Engineering) and the Department of National Defence undertook a joint program using the **SDL-1** (System Diver Lockout) five man submersible and its support vessel the **HMCS CORMORANT** (Fig. 2) from the 1st to the 19th of October, 1984. Scientists from C-CORE, the Geological Survey of Canada at the Atlantic Geoscience Centre and the Biology Department (Memorial University of Newfoundland) participated in these seabed investigations (Table 1).

CRUISE OBJECTIVES

To facilitate ground-truthing of the aforementioned sediment transport models, an experiment site was chosen on the western, megarippled flank of a sand ridge (Barrie 'et al.', 1984) at a distance of less than 2 km from the Hibernia P-15 discovery well. The experiment site was chosen as a representative site to measure sediment erosion, transport and deposition rates using a non-radioactive tracer sand deployed at a centre point with sediment transport rods implanted around the tracer at an average distance of 15 m.

The second main objective of this cruise was to document surficial features in the Hibernia area such as the depressional pit-like features which have frequently been observed in acoustic geophysical records. A 5.4 m pit first discovered in 1980, near the Mara wellsite, was designated the prime target as it is the largest pit in the Hibernia area. Surficial facies boundaries outlined by Barrie 'et al.' (1984) act as distinctive acoustic signatures on sidescan sonar records. The submersible is an ideal vehicle to document these boundaries and the detailed sedimentological and morphological changes recorded by the sidescan and high resolution profiling systems.

Finally, a sidescan sonar, with bottom profiling capability, was used to perform a general survey over an area south of Hibernia study area (Barrie 'et al.', 1984) to the Carson Canyon. The camera sled BRUTIV, which gives general seabed photographic reconnaissance, was used as a complement to the sidescan over the area surveyed.

CRUISE OUTLINE

At 0915 hrs on October 1, 1984 the **HMCS CORMORANT** under the command of Lieutenant Commander R. Bowers departed for the Hibernia area of the Grand Banks with the **SDL-1** manned submersible onboard.

Table 1. Scientific Personnel

	Affiliation	Responsibilities
J.V. Barrie	C-CORE	Senior Scientist
W.T. Collins	C-CORE	Diving Coordination
R. Parrott	GSC	Geophysics
R. Hooper	MUN Biology	Biological Studies
D. Haughn	St. Andrews Biological Station	BRUTIV
D. Loche (Part I)	GSC	Sidescan Sonar Technician
C.F.M. Lewis (Part II)	GSC	Iceberg Scouring

Scientific equipment included the towed camera sled BRUTIV, a 100 kHz sidescan sonar unit with an integral 3.5 kHz bottom profiler and bottom grab samplers. As submersible operations were the principal reason for this cruise, both for the scientists onboard and for the Canadian Naval Diving Unit, the cruise plan was organized around the diving conditions and the readiness of the SDL-1.

In all, nine dives were completed, all but one in the Hibernia area of the Grand Banks (Fig. 3). Dive 9 took place in the Avalon Channel (Fig. 1). (A list of dive sites and highlights are listed in Appendix 1). Approximately five days were lost due to poor sea and weather conditions (Fig. 4). Electrical problems with the **SDL-1** were encountered and on October 12th the **HMCS CORMORANT** returned to St. John's to have the problems rectified.

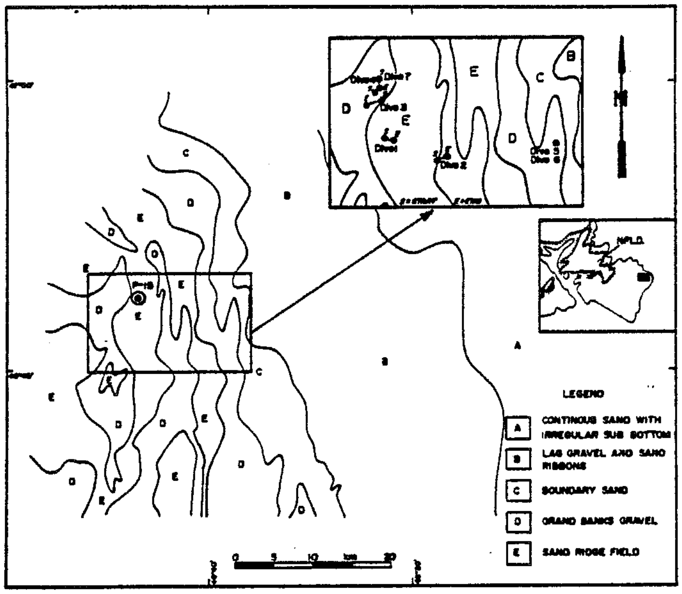

Figure 3. Location of Dives 1 to 7 in reference to the surficial sediment facies of Barrie 'et al.' (1985).

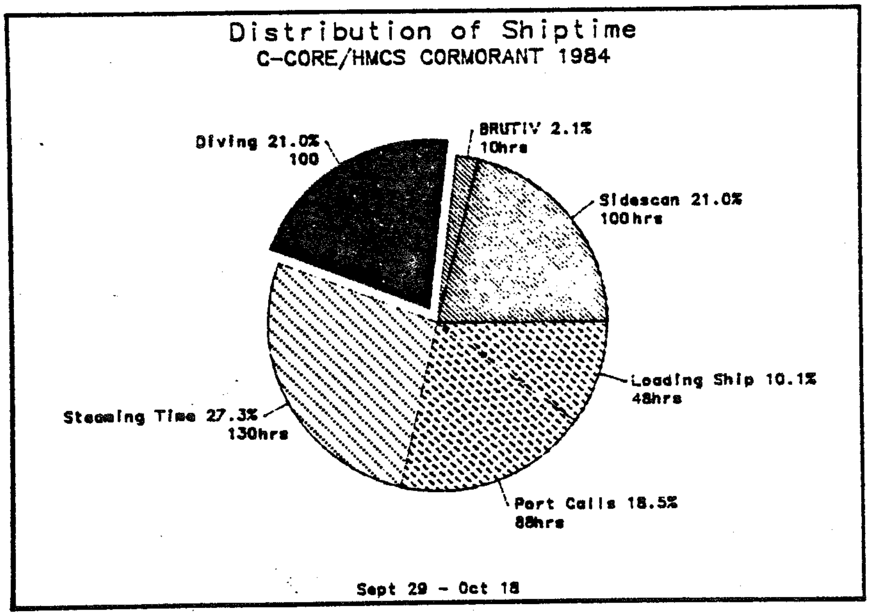

Figure 4. Distribution of Ship Time

On October 15th we began the final phase of the cruise; it was completed on October 18th when Hurricane Josephine entered our research area.

All equipment worked well throughout the cruise and over 730 km of excellent sidescan sonar and 3.5 kHz profiler coverage were obtained. After the initial electrical and flying altitude problems with BRUTIV were rectified, it operated extremely well from the stern of the **CORMORANT**.

At the beginning of the cruise Dobrocky Seatech, under contract to Mobil Oil Canada Ltd., attempted to moor a bottom sitting Aanderra current meter on the proposed sediment transport site. Due to poor weather conditions and constraints on the supply vessel, the current meter could not be deployed. Subsequently, on November 25th the current meter was placed on the seabottom at the experiment site. Over the entire period of the cruise, at six hour intervals, measurements of weather conditions, water temperature and wave parameters were made. A list of data collected is given in Table 2.

Table 2. Data Collected

Colour video with audio track		20 hours
Audio		10 hours
Colour slide photographs		450
Samples:	sediment samples	5
	rock samples	9
	water samples	5
	core sample	1
Sidescan Sonar and 3.5 Profiler Records		730 km
BRUITIV Coverage (6000 photographs)		23 km

SUBMERSIBLE TECHNIQUES

The **SDL-1** (Submersible Diver Lockout) of the Canadian Forces was well suited for the proposed scientific investigation on the Grand Banks. It can operate in conditions of up to Seastate 5 with winds up to 30 knots; this means that down time due to weather is minimized. The submersible is unteathered so its bottom time is limited by its battery life. It has a working range of about 3 km with a maximum speed of 2 knots.

The **SDL-1** consists of two spheres, a forward command sphere and an aft sphere, joined by a tunnel. The two spheres accommodate five people, generally three Canadian Forces personnel and two scientists. Piloting, observation, and still photography were carried out by looking through a 1 metre diameter acrylic 'bubble' at the front of the command sphere. A video recording was taken with a black and white 'low light' camera mounted externally and a monitor situated in the command sphere. A colour video recording was taken through the 'bubble'; a recorder and monitor were housed in the aft sphere.

There are two remote manipulator arms situated at the front of the submersible. A 7-function arm, including a rotating wrist, and a 4-function arm allowed various tasks to be performed on the seabed. A number of pieces of equipment were designed for use with the arms in order to carry out the assigned tasks.

Equipment Tray

A 1 m square tray with walls 15 cm high was fastened to the forward frame of the submersible between the two arms. It consisted of three compartments, two of which were slotted in the front to allow for extension of the corer and the sediment transport rods. The tray was used to carry equipment and samples to and from the seabed sites. A Niskin bottle, activated by the 7-function arm was attached to the front of the tray; it was used to collect water samples (Figure 5).

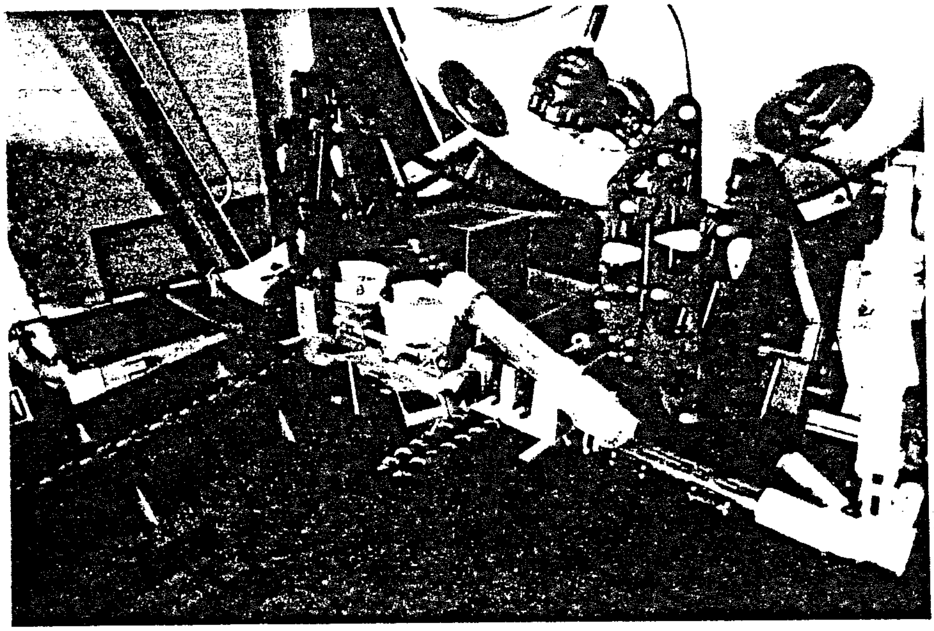

Figure 5. Equipment tray with two sediment sample buckets, two sediment transport rods and the surficial sediment corer mounted on the 7-function remote manipulator arm. A water sampler is mounted on the front of the equipment tray.

Tracer Sand

The tracer sand was an Europium-doped corderite glass prepared by Atomic Energy of Canada. The composition was approximately:

SiO_2	55%	TiO_2	9%
Al_2O_3	20%	Eu_2O_3	1%
MgO	15%		

Europium, a naturally occurring inert trace element, was selected because it is easy to detect by neutron activation analysis and it is easy to mix with the glass.

The glass was ground to a mean grain size of 0.32 mm and a shape distribution pattern typical of the sand found in this area. It has a density of 2.62; quartz, the dominant mineral in this area, has a density of 2.65. Approximately 15 kg was deployed over an area of 1.5 m^2.

The dumping arrangement consisted of a ten gallon plastic bucket with a floating lid to which a T-bar had been attached. It was picked up by the 7-function arm. This allowed for good control and minimum sediment dispersion when dumping the tracer sand.

Tracer Sand Samplers

The tracer sand samplers were designed to collect a self-contained sample of sand from the upper 5 cm of the seabed. They consisted of a 13 cm length of 4 cm square hollow tubing. The leading end has a one way rubber flap which allowed sand to enter. The other end had a 1.5 cm orifice of fine screen which allowed water to escape. The samples were manipulated by the remote arms of the submersible using a T-bar attached to the sampler.

Sediment Transport Rods

The rods were designed to measure the maximum winnowing of the seabed. They consisted of 1/2" aluminium shaft 1 m in length grooved in 10 cm increments (Fig. 6). A flat ring surrounded the

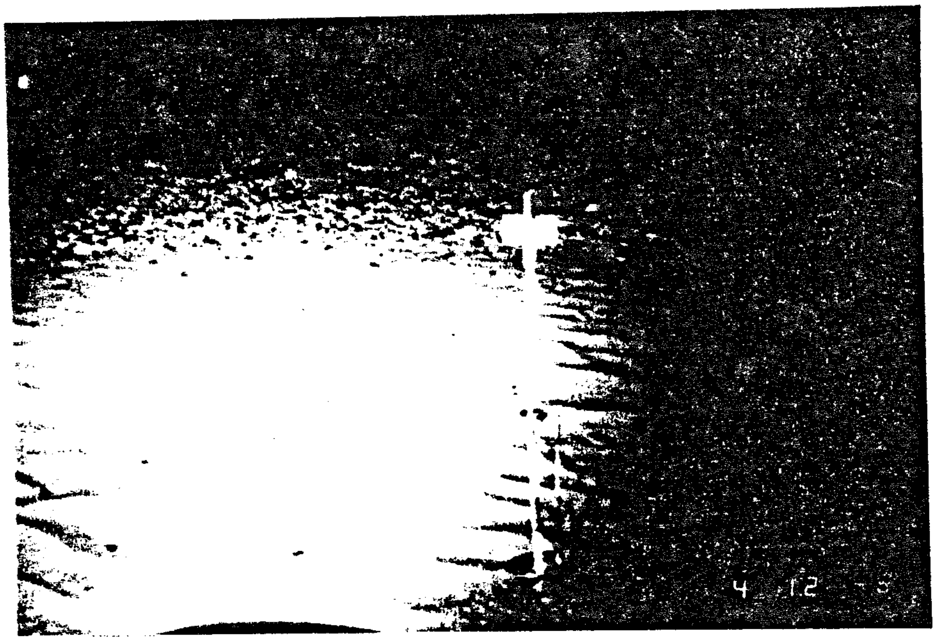

Figure 6. A sediment transport rod in position at the experiment site.

rod and rested on the seabed. As the sediment winnows, the ring drops accordingly and this distance is measured by a second smaller ring attached to the larger ring by a small shaft. The rods were designed to be augered into the seabed by a hydraulic wrench mounted to the remote manipulator arm.

Two perpendicular flights, mounted to the top of the rods, acted as both sonar reflectors and adapters for the wrench. Approximately 30 cm of auger type flights were welded to the bottom end of each rod to allow the rods to be augered into the seabed.

Surficial Sediment Corer

This corer was designed for use with the rotating wrist feature of the 7-function arm (Fig. 5). It consists of three parts: a detachable backend adapter, an auger head, and a plastic core tube. The backend adapter is a machined tube, 15 cm in length, closed at the bottom end with a T-bar at the top. It is used to attach the core barrel to the remote arm of the submersible. There are two water ports on the top to allow a one way flow of water out of the tube. The plastic tube is a standard Benthos core liner and can be cut to the desired length depending on the expected penetration. The auger head is 20 cm in length with 2 spiraled auger type flights welded to the outside. The cutting edge contains two tungsten carbide cutting inserts which undercut the core slightly. A standard steel core catcher is utilized to retain the core sample.

Datasonics Transponder

The Datasonics transponder (Model SST-320), which operates on a coded frequency of 100 kHz, was used for absolute referencing on the seabed. When the transponder is placed on the seabed and the area is resurveyed with 100 kHz sidescan sonar, a series of parabolas will appear on the sonogram. The apex of the parabolas will correspond to the exact location of the transponder on the seabed.

RESULTS - SUBMERSIBLE INVESTIGATIONS

Sediment Transport Experiment Site

To quantify rates of sediment transport in the Hibernia area, a seabed experiment site was established on the west flank of the P-15 Sand Ridge (Fig. 7). The location of the experiment site was chosen for various reasons. From the distribution of bedforms, the location of vibrocores taken in 1983, and the sediment transport results a location on the flank of a sand ridge was considered the ideal. In addition, there is intensive hydrocarbon exploration in this area and any bottom sitting facility associated with the Hibernia oil discovery probably would be situated within 1 kilometre of this site.

During the **SDL-1** Dive 4 the experiment site was set in 78 metres water depth. The site was near the Unit D-E boundary of Barrie 'et al.' (1984) and consisted of megaripples (10 - 15 m wavelength) overlying a thin pebble armour at the edge of a sand ridge. The armour was less than 10 cm thick and overlies sand.

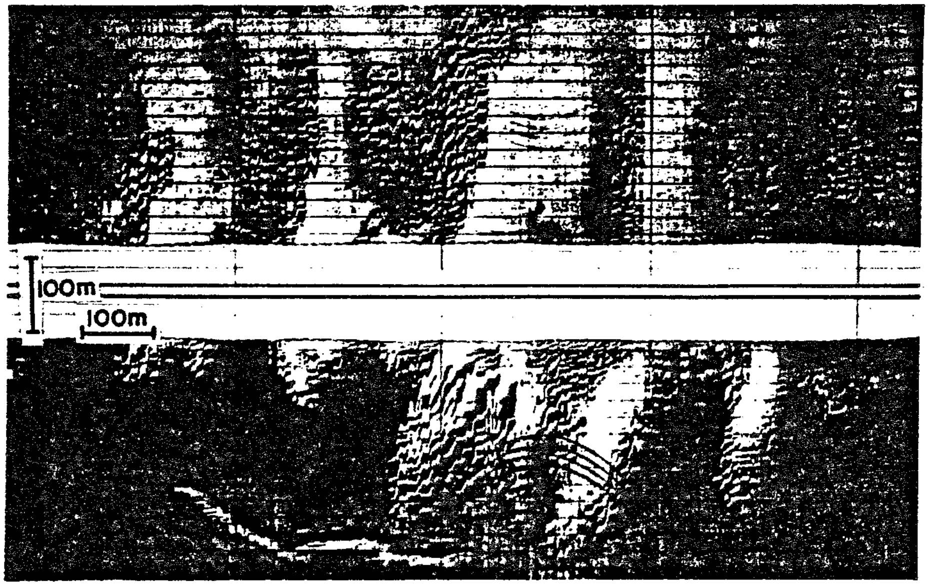

Figure 7. Sidescan sonogram of sediment transport experiment site with 4 parabolas from a 100 kHz pinger depicting exact location of tracer sand.

The megaripples were medium grained sand with shell fragments concentrating on the flanks.

Small ripples with wavelengths of 20 cm, amplitudes of 4 to 6 cm and crest direction of NW-SE were observed at the site. The wave conditions during the dive were capable of forming these ripples. The submersible itself was also responding to the oscillatory motion.

The tracer sand was deployed onto the crest of a megaripple, (Fig. 8). After deployment the main bulk of the tracer lay within a 1 m^2. There was a "plume" of finer sand surrounding the main pile which brought the total distribution to 1.5 m^2. A 100 kHz pinger was deployed adjacent to the sand.

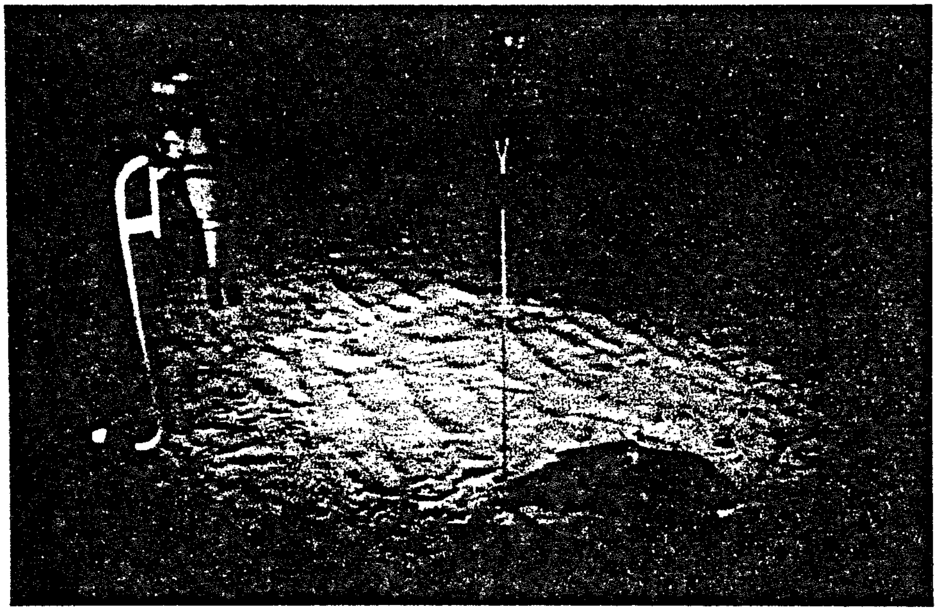

Figure 8. Tracer sand (light colored) with 100 kHz Datasonics transponder being positioned. To the left is the hydraulic wrench used to implant the sediment transport rods.

The first transport rod was implanted at a bearing due north to the tracer sand at a distance of 20 m. The rod penetrated the sand to a depth of 30 cm. Four other rods were placed at the experiment site, all within 20 m of the tracer and all 30 cm into the sand (Fig. 9).

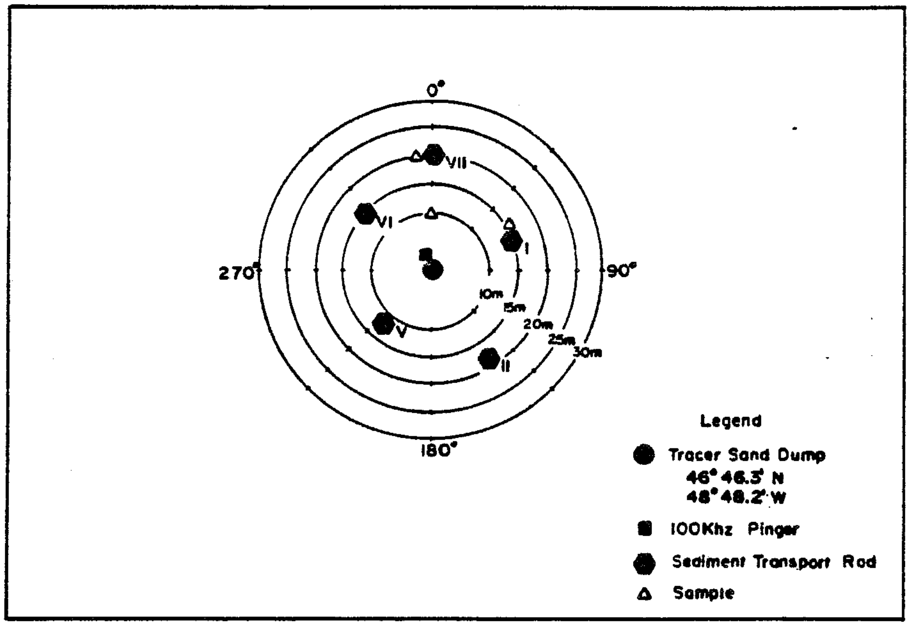

Figure 9. Diagram of the tracer sand in relation to the rods, transponder and sample stations.

The experiment site was revisited on two occasions. On Dive 7, 5 days later, the experiment site was relocated after two hours bottom time. At this time three samples were taken for tracer sand analysis. The dive was then aborted due to a low power supply. No change was observed at the rods visited but the "plume" of finer material had disappeared. The second visit to the site (Dive 8, 13 days after tracer dumping) had to be aborted due to electrical problems with the SDL-1 and the lack of visibility on the seabed. A suspended sediment sample was collected before returning to the **CORMORANT**. Despite these problems a number of significant observations were made.

During the dive there was a 3.0 m swell with 13 second period. The water column showed stratification which was recorded by the submersible echosounder bouncing off a false bottom. Also, the submersible came to a halt while under ballast configuration for a normal descent. This layer appeared at 45 m depth. From 71 m to the bottom the visibility was less than 1 m in suspended sediment (normal visibility was 30 m). Turbulence, apparently as a result of wave-induced currents, also presented a problem by preventing safe control of the submersible on the bottom. Bottom orbital velocities would have been approximately 0.32 ms^{-1} during this dive.

Iceberg Pit

Circular depressions or pits in the seabed have appeared in numerous site specific and regional survey lines on the Grand Banks below the 80 m water depth. In June of 1980 a circular depression measuring 5.4 m deep and 100 m wide was discovered (11 km) ESE of the Hibernia P-15 discovery well in 87 m water depth. In an effort to describe this feature, explain its origin and assess its potential hazard to bottom sitting facilities, two dives totalling 7 hours were completed.

In preparation for diving operations the pit was surveyed using sidescan sonar and sub-bottom profiler. The record showed an area of low acoustic reflectivity with an irregular outline (Fig. 10). The sub-bottom pit profile showed a V-shaped depression measuring 6.5 metres deep and 100 m wide with a raised berm. Two smaller features, 60 m and 30 m wide, interpreted to be features of similar origin lay 50 m to the southwest. The outline of the 60 m wide pit was similar to that of the large pit.

Based on direct submersible observations and the five sidescan lines over the pit a composit drawing was produced (Fig. 11). The feature had the planimetric shape of a square with indentations on the east and west sides. The depression occured in the southern section of the feature. From submersible observations, the maximum width was 100 m and the maximum depth of the pit was about 10 m; the depth measured by the original geophysical survey was 5.4 m. The discrepancy in the recorded depth of the feature clearly accentuates the problem of obtaining accurate depth measurements of steep sided features with high resolution profiling systems. Furthermore, it suggested that the measured depths of similar features might be in error by 30 to 50%. The side walls of the pit were steep (up to 30^{o}) on all sides except to the north where a shallow slope (10^{o}) rose between the east and west side indentations. A berm was present on all sides except to the north. The floor of the pit was relatively flat with a "comma" shaped shell stringer (scallops) near the centre.

The biological systems associated with the pit were more abundant than those of the surrounding Grand Banks Gravel facies unit (Barrie 'et al.', 1984). Each morphological component of the pit possessed its own characteristic group of animals. These reflected the unique combination of environmental factors such as sediment composition and mobility, current regime, oxygen availability, organic detritus, and age.

For the purpose of description the pit was divided into three morphological components. These are the berm, side walls,

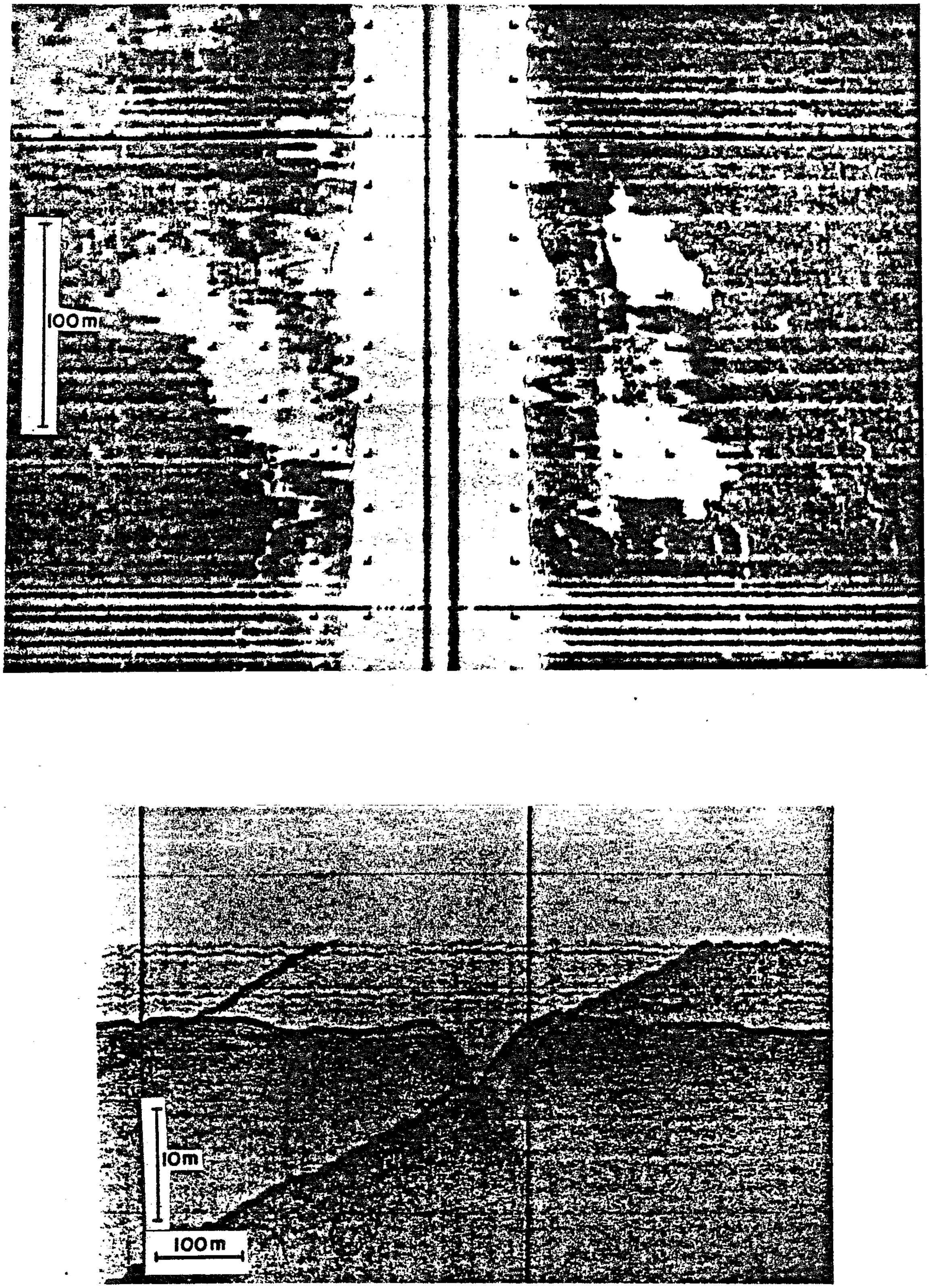

Figure 10. Klein sidescan sonar and Huntec DTS profile of the iceberg pit.

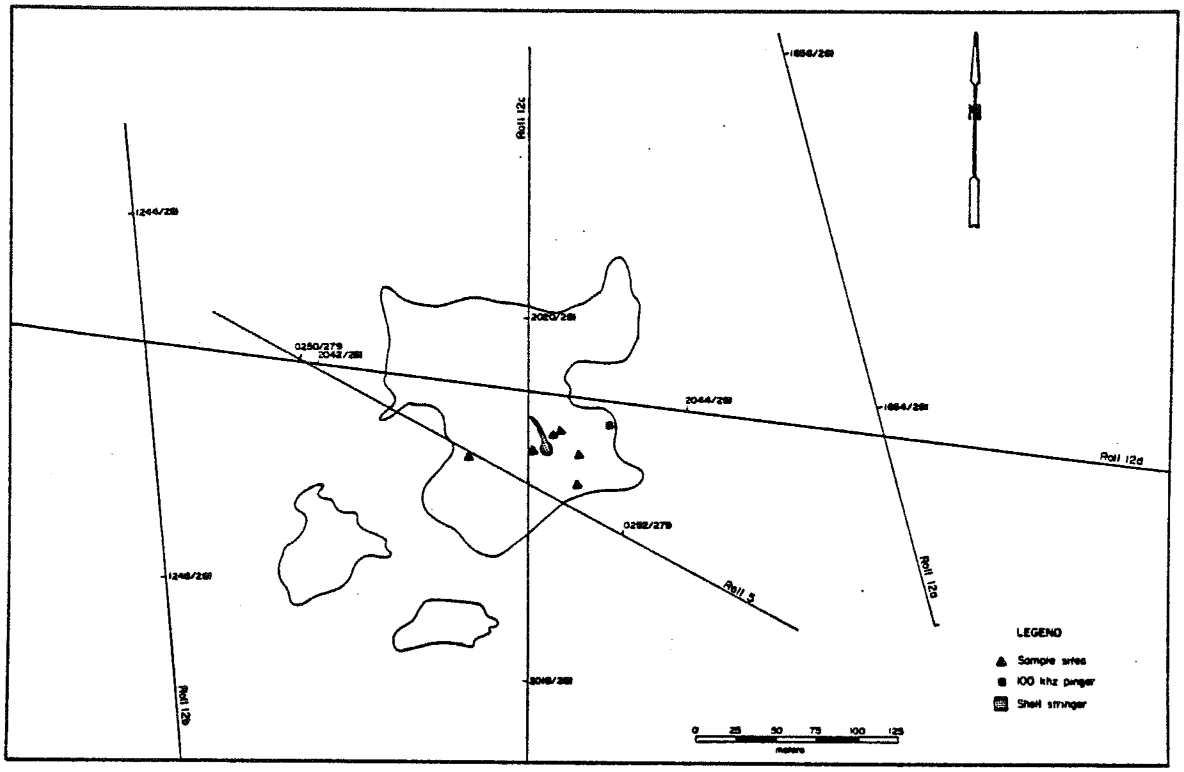

Figure 11. Composite drawing of iceberg pit recorded in Figure 10 showing sample locations and sidescan sonar lines.

and floor.

The berm consisted of boulders and cobbles. The top of the berm had been winnowed only leaving sand filling in the interstital area (Fig. 12). The largest boulders, up to 2 m in

Figure 12. The berm of the iceberg pit as seen from the SDL-1 looking from the ouside towards the centre of the feature.

diameter, were found on the leading edge of the west berm (at the point of intersection with the shallow north slope). In general, however, they averaged 0.5 in diameter. The berm was variable in height and width rising more than 2 m above the undisturbed seabed and having a maximum width of 10 m. To the north the pit graded to the normal seabed with no noticeable slope break.

The boulders were covered with a dense growth of organisms. The raised nature of this habitat held suspension feeders well out into the water column where plaktonic organisms were most abundant. This accounted for a dense growth of large soft corals, bryozons, anemones, barnacles and hydroids.

The side walls consisted of a thin layer of gravel and sand overlying consolidated clay beds. The clay beds outcropped in numerous places but were best exposed along the south slope (Fig. 13). Where exposed the clay beds dip towards the centre of the

Figure 13. Clay beds outcropping on the south wall of the iceberg pit.

pit at 10 to 15°. Bioturbation was apparent in the grey, well sorted clay beds. In general the slope of the side walls was variable. The maximum slope occurred in the south wall where it was estimated to be in excess of 30°. Actual measurements could not be accomplished since the **SDL-1** could not come to rest safely on such a steep slope. The east and west side walls had slopes of between 20° and 25°. The north slope had a dip of less than 10° and contained no exposed clay beds. It graded from the sandy floor of the pit through gravel and sand of the slope onto pebble armour at the undisturbed seabed. There were a series of troughs parallel to the slope. It was unclear whether these were related to the formation of the pit or to the prevailing hydrodynamic conditions within the pit. Numerous boulders which had rolled from the berm were found at the floor slope interface. This was evidenced by the presence of organisms on all sides of the boulders. The slope organisms were a combination of burrowing bivalve mollusks and polychaete worms which were capable of withstanding moderate changes of sediment cover.

The pit floor had an irregular outline and measured 25 to 30 m at its maximum width. It was flat lying and consisted mainly of fine to medium grained olive grey sand. Finer grained material was also present and was readily thrown into suspension by the thrusters of the submersible. Boulders which had dislodged from the berm and slope were also present on the pit floor. A "comma" shaped scallop bed was situated at the east centre portion of the floor and shelly material was scattered throughout. Wave-induced ripples were also observed. The fine sediments and shell deposits of the pit floor supported a very limited micro-infauna. The very large organisms were mobile basket stars, scallops, starfish and crabs.

A total of six samples were recovered from the berm, side walls and the floor of the pit and a sediment transport rod was installed near the centre of the feature. For bottom referencing and relocation purposes, a Datasonics 100 kHz transponder was placed on the berm to the northeast.

A series of two events are postulated for the formation of this feature. Morphologically, its overall 'amphitheater' like shape with a steep back (south) wall, two side walls, a shallow sloping north entrance and the presence of a berm suggests the formation was a result of the grounding of an iceberg. To account for the depth of the depression, which is 8 m greater than the average scour depth on the Grand Banks (Lewis and Barrie, 1981), and the dip of the clay beds towards the centre of the feature, it is postulated that the grounding event could have been followed by a bearing capacity failure of the clays.

Surficial Sediment Facies

Barrie 'et al.' (1984) have divided the Hibernia area into five depth-controlled facies units based on sediment and bedform distributions. Below 90 m the facies range from continuous fine sand, through lag gravel and sand ribbons with arcuate sand waves normal to the axis of the ribbon. Above 90 m depth alternating sand ridges up to 4 m in height and lag gravels occur.

Submersible transects were carried out over Units C (Boundary Sand), D (Grand Banks Gravel) and E (Sand Ridge Field) and extensive observations were carried out along the sand ridgetrough margins. Visual observations and shallow cores substantiated the facies model of Barrie 'et al.' (1984). Unit D (Grand Banks Gravel) is described as a seabed composed of gravelly sand or sandy gravel with the gravel fraction forming a one clast thick armour. Submersible observations confirmed this definition of the facies. Occasionally, large boulders were seen in this unit, some being up to 3 metres in width (Fig. 14). These had a random distribution and usually occurred in clusters similar to the boulder dumps described by Josenhans and Barrie (1982). The Huntec DTS profiles of the area defined the

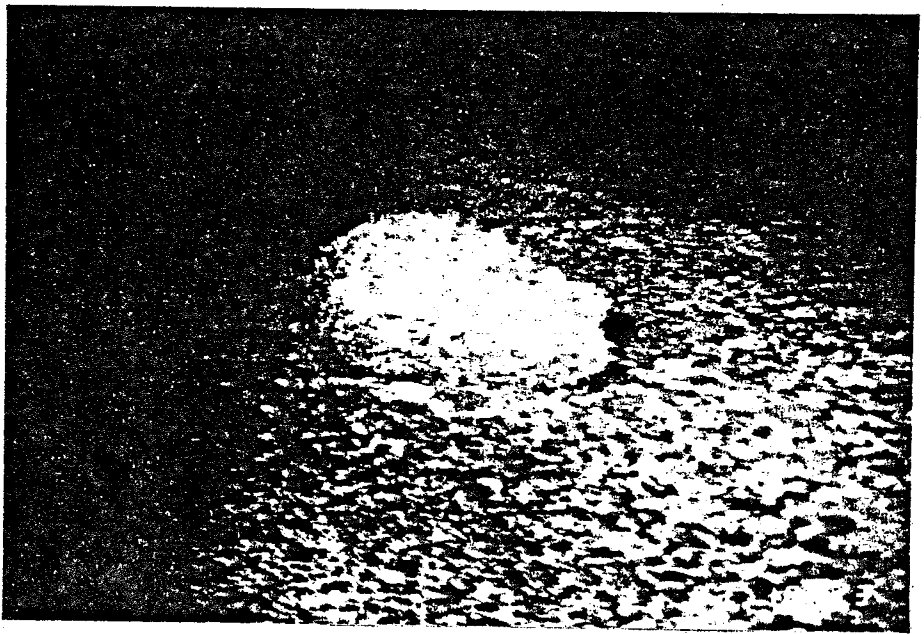

Figure 14. Large boulder seen from submersible in Unit D. Horizontal length of the boulder is approximately 3 m.

thickness of Unit D as less than 0.5 m (Barrie 'et al.', 1984). Clay beds (Tertiary-Pleistocene) exposed on the back wall of the iceberg pit were observed to within 30 cm of the surrounding surface of the floor.

The Sand Ridge Field (Unit E) as seen from a submersible was a clean well sorted sand with low amplitude ripples, megaripples and sand waves. The ability to core the sand ridge was made apparent by the ease to which the sediment transport rods penetrated the sands.

Extensive observations were made of the sedimentary bedforms on the upper terrace (above 90 metres water depth). The megaripples (predominantly 2-D) with an average wavelength of 5 m had amplitudes of 0.5 to 0.7 m and were mostly covered with a pebble armour. They contained troughs of sand and shell (Fig. 15). Within the troughs 0.7 - 1.0 m wavelength wave-induced ripples occurred normal to the axis of the megaripples. These

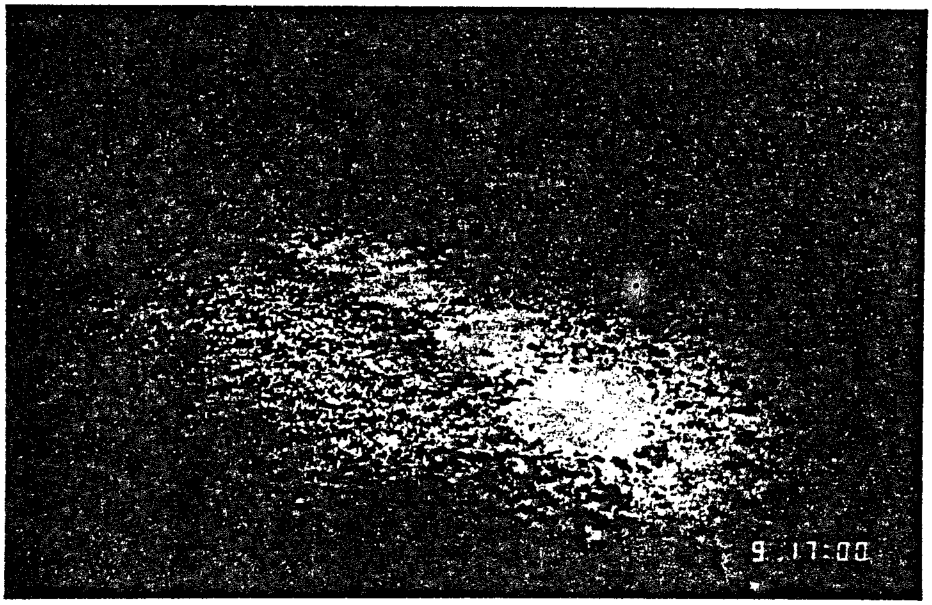

Figure 15. Megaripples (5 m wavelength) with pebble armour and traverse wave-induced ripples in the troughs in the Grand Banks Gravel (Unit D).

were also covered with a pebble armour. Normally these bedforms were best observed on the flanks of the sand ridges. The larger wavelength megaripples (average of 15 m) tended to have pebble armouring in the troughs and not on the crests or else no pebble armouring at all. Wave-induced ripples did not occur where gravel formed 70 - 100% of the seabed surface. Ripples were seen below 120 m water depth in one submersible test dive and also on the BRUTIV photographs. This alters the interpretation of Barrie 'et al.' (1984) who suggested that 110 m is the lowest water depth at which wave-induced rippling occurs. The evidence here suggests that such rippling may occur at greater depths but the depth limit is not known.

Sediment Type Versus Biota

Observations are too limited to support detailed theory but there appears to be strong correlation between biotic communities and the sedimentary environment. It is more probable that both are responding to identical physical processes than that they are interacting directly with each other. The most unstable sand patches are dominated by the propellor clam Crytodoria. The more delicate sand dollars, benthic hydroids, and sand lances, are found usually on the thicker more stable sand patches. The gravel armour belts are the harshest environment for benthic organisms supporting a low biomass of relatively mobile macroinvertebrates.

The biota of the larger cobbles and boulders seem to depend on whether the areas are particularly susceptible to sand storm scour or burial. The biggest, most diverse benthic assemblages of old animals and plants are found on the large boulders, well above the general seabed.

Dark bands observed on the slope of many of the megaripples and sand waves could be due to mobile benthic diatoms. This has been directly observed in a sand channel subject to wave action and unidirectional currents off Barbados. The presence of large numbers of sand dollars, which eat diatoms, supports the suggestion.

Avalon Channel Transect

The last dive of the cruise was a transect in the Avalon Channel off Robin Hood Bay in approximately 180 to 150 m water depth (Fig. 1). This is an area of degraded scours with a very thin surficial cover over bedrock (King 'et al.', 1985). The sediment was found to be predominantly thin silt over what is presumed to be Precambrian bedrock. Many ice/iceberg rafted cobbles and boulders were also present. Ridges observed during the transect, consisting of boulders and cobbles, are probably the remnants of relict iceberg scours.

A cable was encountered during the dive. The latter part of the dive was used to follow this cable inshore at course 270°T. In some areas the cable was buried, sometimes it was supported on large boulders, and sometimes ice rafted boulders were seen sitting on top of it.

The dive ended at 154 m where a gravel armour dusted in silt covered the seabed. A core and grab sample were collected at this point.

REGIONAL GEOLOGY - HIBERNIA TO CARSON CANYON

As mentioned one objective of this cruise was to undertake a regional survey to extend the surficial sediment map of Barrie 'et al.' (1984) south between 48° and 49°W to Carson Canyon, a potential exit point for the southeasterly sediment transport. Over 320 km of sidescan sonograms and 3.5 km profiles were collected in this survey (Fig. 16a,b).

The distribution of the facies units in the Hibernia area of the northeastern Grand Banks could be traced to the east-central portion of the Banks though the facies did change in character and near the mouth of Carson Canyon a marked zonation occurred. As the data were widely spaced (10 km line spacing on average) it would be premature to formulate a distribution map.

Unit A (Continuous Sand) was not encountered in any of the survey lines though the lines only went as far east as 40°W and to a maximum water depth of 120 m. Possibly, the lines did not go far enough east to encounter Unit A. This same unit, first defined by Fader and King (1981) as Zone 2, was shown by them to extend into the eastern portion of our survey area. Fader and King (1981) defined this area on one regional line using the BIO 70 kHz sidescan sonar. With the addition of several lines from this survey, using a higher resolution sidescan, the distributions of Unit A can be defined more accurately.

Unit B was defined by north-south sand ribbons developed on top of a lag gravel. Fader and King (1981) and Barrie 'et al.' (1984) predicted that Unit B could pinch out south of Hibernia. It appears from the new data that this unit extends south between approximately 90 to 120 m. The width of the sand ribbons was much greater to the north, ranging from 140 - 840 m in width. Arcuate-shaped sand waves were common throughout the western portion of Unit B, while to the east they become more elongate (trending N-S to NNE-SSW) with a greater distance between the sand bodies than was found in the western sector. To the south, the sand ribbons diminished markedly both in size and in quantity.

Smaller-scale bedforms such as 2 and 3-D megaripples could be seen throughout Unit B. Megaripples (2-D) trending NW-SE were most extensive in the northwestern portion of Unit B, particularly at the contacts between the sand and gravel patches, where wavelengths averaged 6-8 m. In the central and southern sectors of Unit B, 2-D megaripples with wavelengths averaging 10 m, trended NW-SE at contacts between sand and gravel. South of 46°10'N the sand ribbons disappeared altogether and the unit changes to a megarippled seabed in what appeared to be a lag surface. The 2-D megaripples are all in the 5 m wavelength range.

The southern area contained the greatest number of scours (randomly-oriented) within the region. They were generally degraded to highly-degraded and for the most part, infilled by sand which had formed megaripples within the scour tracks. These megaripples trend NNW-SSE and E-W and had wavelengths of 1-2 and 12 m, respectively.

The Boundary Sand (Unit C) could not be easily defined based on the sidescan coverage obtained on this cruise and the lack of good high resolution subbottom profiles. A sand unit, however, which divided the gravel and sand ribbons to the east and the

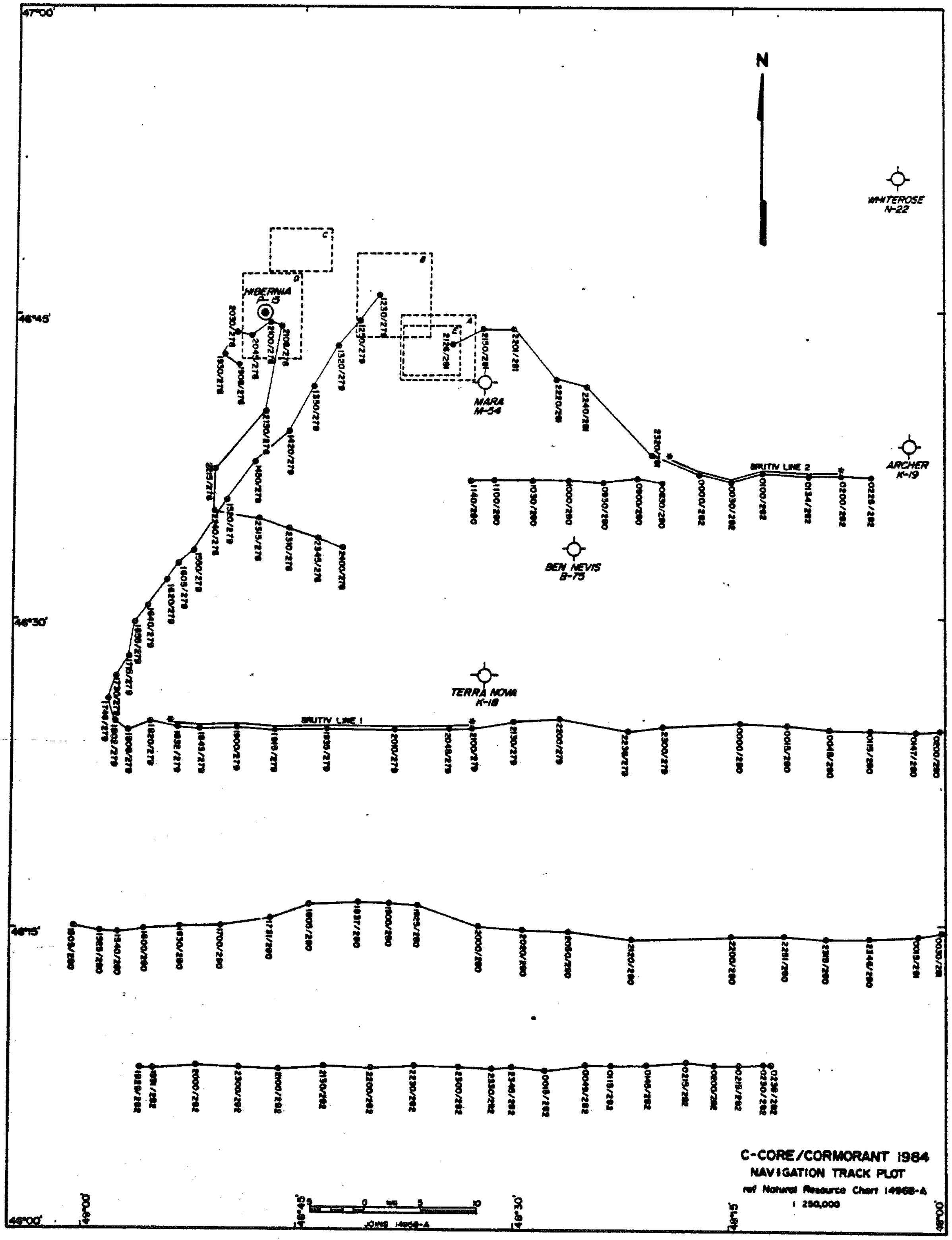

Figure 16a. Navigation track plot of sidescan sonar, 3.5 kHz seismic profiling and BRUTIV in the Hibernia area. Boxes show areas of closely spaced lines (see Appendix III).

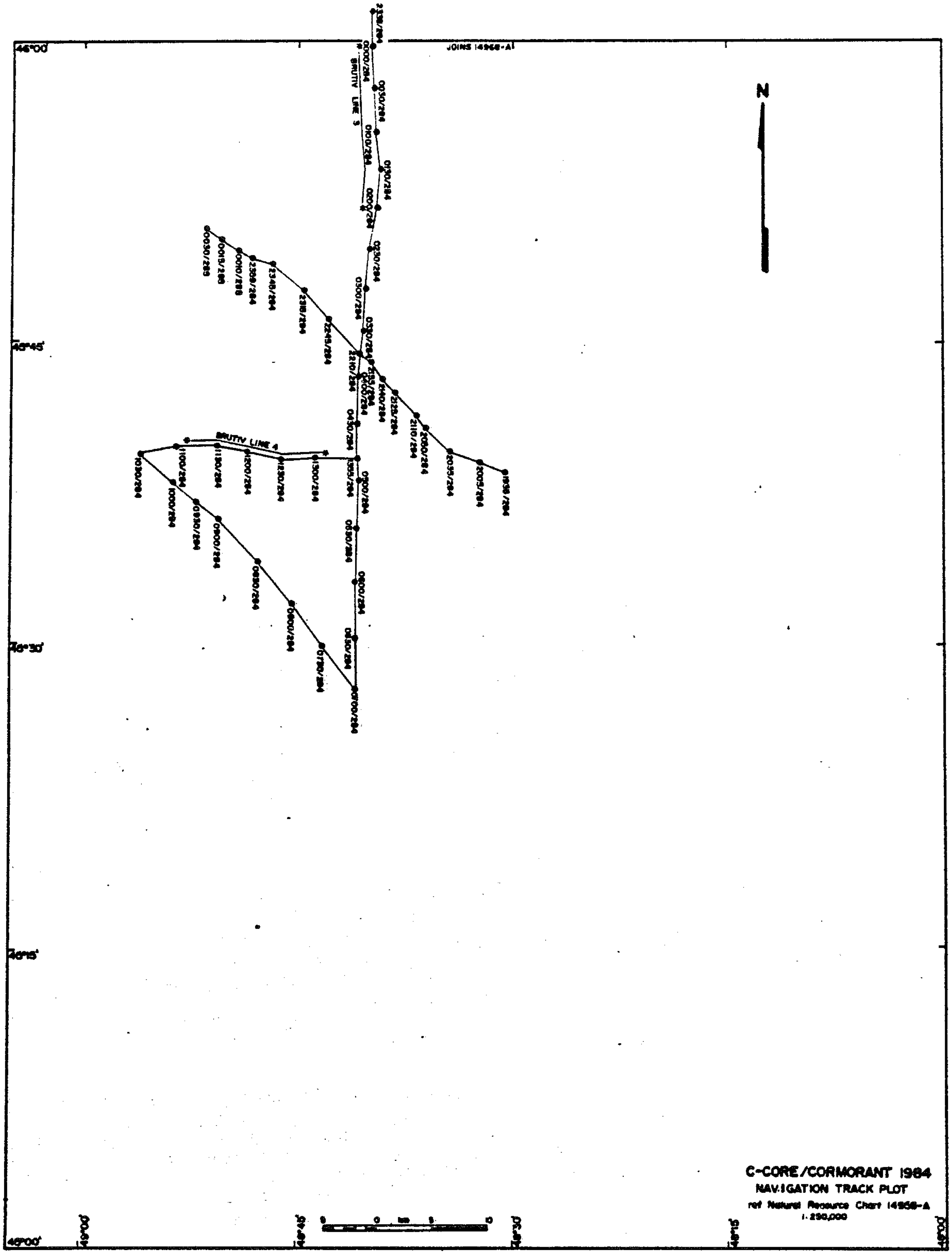

Figure 16b. Navigation track plot (Carson Canyon).

repetitive sand ridges developed on a mobile and lag gravel to the west (Units D and E) is likely Unit C.

The Grand Banks Gravel (Unit D) and Sand Ridge Field (Unit E) were mapped south as far as the survey went on the upper terrace above 80 m water depth. The sedimentary characteristics of these facies were the same as those described by Barrie 'et al.' (1984). Megaripples oriented ENE-WSW with 5 m wavelengths were common within the Grand Banks Gravel. These were the same bedforms as seen in Figure 15.

Two distinctive units were observed above 180 m (the deepest water depth at which the sidescan could obtain a record) surrounding Carson Canyon. Approximately 15 km away from the canyon head the surficial sediment thinned to a veneer of sand and gravel. Repetitive beds of what were interpreted to be Tertiary bedrock could be traced clearly, the beds had a NE-SW strike (Fig. 17). Occasional megaripples (5 m wavelength) could be seen where enough sand had accumulated. At approximately 100 m on the upper edge of Carson Canyon surficial sediment thickened and the seafloor was completely covered with 15 - 20 m wavelength 2-D megaripples oriented NW-SE. These continued into the canyon as far as good records could be obtained. Due to the limited sidescan sonar coverage, the definition of these units is only tentative.

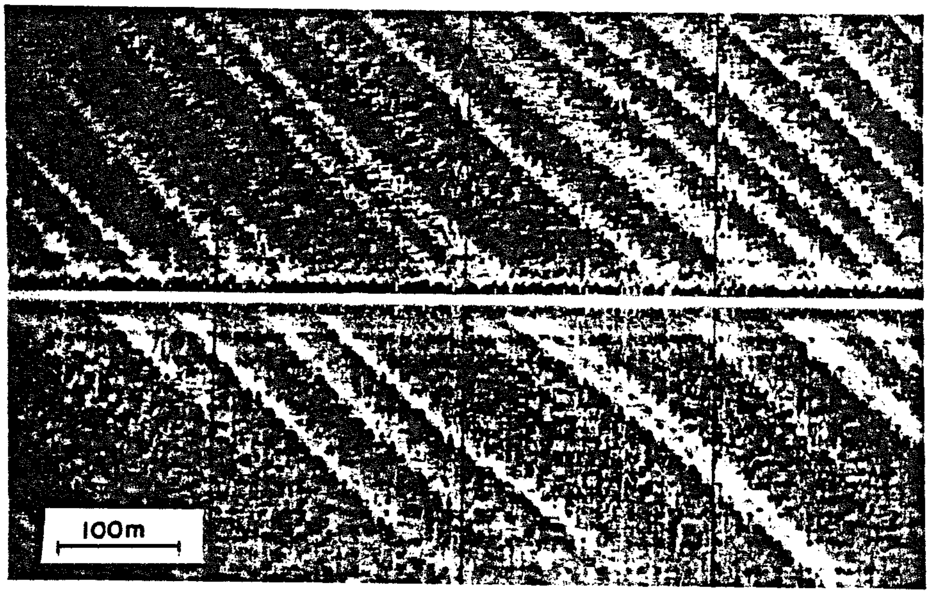

Figure 17. Repetitive bands interpreted to be Tertiary beds exposed near the surface with a very thin surficial cover as seen on this sidescan sonogram near the entrance to Carson Canyon.

SCIENTIFIC HIGHLIGHTS (SUMMARY)

1. The characteristics that made up the surficial sediment facies distribution of Barrie 'et al.' (1984) were observed visually using the submersible. The depth of surficial thickness in the Sand Ridge Field (Unit E) and the intervening Grand Banks Gravel (Unit D) were found to coincide with the depths interpreted from Huntec DTS records. The steep wall of the large pit or pockmark in the Grand Banks Gravel (Unit D) gave visual evidence of the thin surficial sand and gravel over stiff clay beds. Also, in most areas, the high reflective return on sidescan records from this unit was confirmed to be a pebble armour only one clast thick and very moveable. Large boulders and boulder dumps were seen randomly throughout the Grand Banks Gravel.

2. All the flow transverse sedimentary bedforms seen in sidescan sonograms (sand waves, megaripples and ripples) were examined in detail with the submersible. Except for the wave-induced ripples, all bedforms were low amplitude 0.25 - 0.75 m; in the Grand Banks Gravel, in many cases, they were armoured with pebbles. Wave-induced ripples were observed at water depths greater than 110 m. A high density of suspended sand under the influence of a large swell was also observed.

3. A sediment transport site was established at 78 m water depth and is presently being monitored. Initial results from subsequent dives to the site indicate continuous winnowing and occasional sediment suspension related to

waves with a long period swell. A 100 kHz transponder deployed in the Hibernia area in November, 1983 was relocated nearly one year later, approximately 0.5 km southeast of the original deployment site. This qualitative evidence supports the preliminary model of Barrie 'et al.' (1985) for sediment transport on the northeastern Grand Banks.

4. A large pit originally discovered in October 1980 east of Hibernia in the Grand Banks Gravel was relocated and two dives were carried out in the pit. Observations strongly indicated that the 10 m deep feature was formed by the impact of an iceberg with the seafloor. Subsequent bearing capacity failure is hypothesized to explain the deep, oversteepened nature of the pit. The soils directly below the thin surficial sand with pebble armour were hard clays, likely of the Tertiary to early Pleistocene age. The feature was partially infilled and was probably deeper originally. Two passes with the Huntec DTS system in 1980 and two passes with a 3.5 kHz system during this cruise indicated a total pit depth between 5 to 7 m compared to the actual depth of 10 m. This suggests that all the pits documented on the grand Banks may be underestimated by between 30 to 50% due to limitations of profiling systems over such steep walled features.

5. A regional survey with sidescan sonar and subbottom profiles south of Hibernia to Carson Canyon indicated that the surficial facies in the Hibernia area, defined by Barrie

'et al.' (1984) could be traced to the canyon. Unit B gradually changed from a sand ribbon over lag gravel unit to a highly megarippled lag surface. Two units were mapped at the entrance to Carson Canyon: 1) surrounding the canyon mouth, the surface sediment was thin over a flat lying bedrock surface; and 2) a megarippled (15 m wavelength) unit lay below 100 m into the mouth of the canyon.

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APPENDIX I

Submersible Dive Logs

DIVE NUMBER 1 DATE 02/10/84 JULIAN DAY 276

	Start	End
LOCATION	46°43.38'N 48°48.44'W	46°43.30'N 48°47.73'W

PERSONNEL	Scientists	W. Collins	Pilots	J. Larder B. Hawkly C. Edwards N. MacDonald

	ON BOTTOM	LEAVE BOTTOM
TIME	1022 hrs	1127 hrs
WATER DEPTH	78 m	78 m

DIVE NUMBER 2 DATE 02/10/84 JULIAN DAY 276

	Start	End
LOCATION	46°41.9'N 48°45.18'W	46°42.44'N 48°44.33'W

PERSONNEL	Scientists	V. Barrie W. Collins	Pilots	R. Boucher R. Hinderer B. Hawkly

	ON BOTTOM	LEAVE BOTTOM
TIME	1538 hrs	1748 hrs
WATER DEPTH	75 m	75 m

DIVE NUMBER 3 DATE 03/10/84 JULIAN DAY 277

	Start		End	
LOCATION	46°44.88'N	48°48.44'W	46°44.71'N	48°49.77'W

PERSONNEL	Scientists	V. Barrie R. Parrott	Pilots	J. Larder C. Edwards R. Hinderer

	ON BOTTOM	LEAVE BOTTOM
TIME	0826 hrs	1104 hrs
WATER DEPTH	77 M	77 m

Sample 1 Cobble
1 Sediment Sample

DIVE NUMBER 4 DATE 04/10/84 JULIAN DAY 278

	Start		End	
LOCATION	46°45.03'N	48°48.52'W	46°45.20'N	48°48.30'W

PERSONNEL	Scientists	V. Barrie W. Collins	Pilots	R. Boucher J. Larder N. MacDonald

	ON BOTTOM	LEAVE BOTTOM
TIME	0905 hrs	0115 hrs
WATER DEPTH	78 m	78 m

DIVE NUMBER 5 DATE 07/10/84 JULIAN DAY 281

	Start		End	
LOCATION	46°42.98'N	48°37.55'W	46°43.03'n	48°37.45'W

PERSONNEL	Scientists	W. Collins R. Hooper	Pilots	R. Boucher C. Edwards T. Falletta

	ON BOTTOM	LEAVE BOTTOM
TIME	1224 hrs	1615 hrs
WATER DEPTH	87 m	88 m

Samples
- 1 Water sample
- 1 Cobble
- 1 Sample from sediment retained in core barrel

DIVE NUMBER 6 DATE 09/10/84 JULIAN DAY 283

	Start		End	
LOCATION	46°43.38'N	48°37.42'W	46°43.53'N	48°38.50'W

PERSONNEL	Scientists	R. Parrott V. Barrie	Pilots	Larder Hindersen Edwards

	ON BOTTOM	LEAVE BOTTOM
TIME	0830 hrs	1140 hrs
WATER DEPTH	87 m	87 hrs

Samples
- 1 Sediment retained in core barrel
- 1 Sand sample
- 5 Cobbles
- 1 Water Sample

DIVE NUMBER 7 DATE 09/10/84 JULIAN DAY 283

	Start		End	
LOCATION	48°45.78'N	48°48.68'W	46°45.20'w	48°48.30'w

PERSONNEL Scientists W. Collins Pilots J. Larder
R. Boucher
N. MacDonald
C. Edwards

	ON BOTTOM	LEAVE BOTTOM
TIME	1600 hrs	1835 hrs
WATER DEPTH	78 m	78 m

Sample 1 Water sample
3 Tracer sand samples

DIVE NUMBER 8 DATE 17/10/84 JULIAN DAY 291

	Start		End	
LOCATION	46°45.20'N	48°48.30'W	46°45.20'N	48°48.30'W

PERSONNEL Scientists W. Collins Pilots J. Larder
R. Boucher
N. MacDonald
C. Edwards

	ON BOTTOM	LEAVE BOTTOM
TIME	1025 hrs	1045 hrs
WATER DEPTH	78 m	78 m

Sample 1 Water sample

DIVE NUMBER 9 DATE 10/10/84 JULIAN DAY 284

	Start	End
LOCATION	46°35.1'N 52°34.85'W	46°34.65'N 52°36.30'W

PERSONNEL	Scientists	V. Barrie M. Lewis	Pilots	J. Larder N. MacDonald R. Hinderer

	ON BOTTOM	LEAVE BOTTOM
TIME	1020 hrs	1410 hrs
WATER DEPTH	178 m	154 m

Samples 2 Cobbles
1 Sediment Sample
1 Core Sample

APPENDIX II

Sidescan Sonar and BRUTIV Lines

Sidescan Lines

Roll Number	Start	End	Area (Comment)
1	1908/276	2115/276	Wellsite Locations and Experiment Site
2	2120/276	2400/276	Experiment Site Location
3	1354/277	1824/277	Wreck site mosaic
4	1453/278	1648/278	Experiment site with pinger
5	1842/278	0323/279	Pit site mosaic and scour site with HU83-033 Pinger
6	0326/279	1122/279	Pit Mosaic & Scour Site with HU83-033 Pinger
7	1124/279	2120/279	Regional Line #1
8	2130/279	0300/280	Regional Line #1
9	0838/280	1140/280	Unit B-C Contact
10	1500/280	2335/280	Regional Line #2
11	2345/280	0030/281	Regional Line #2
12	1850/281	2206/281	Pit mosaic with pinger
13	2210/281	0146/282	Unit B
14	0152/282	0225/282	Unit A
15	1100/282	1239/282	P-15 & 0-35 Wellsite
16	1330/282	1509/282	P-15 & 0-35 Wellsite
17	1920/282	2249/282	Regional Line #3
18	2258/282	0238/283	Regional Line #3
19	2342/283	0548/284	Regional Line #4, Carson Canyon
20	0600/284	1355/284	Regional Lines #5 & 6, Carson Canyon

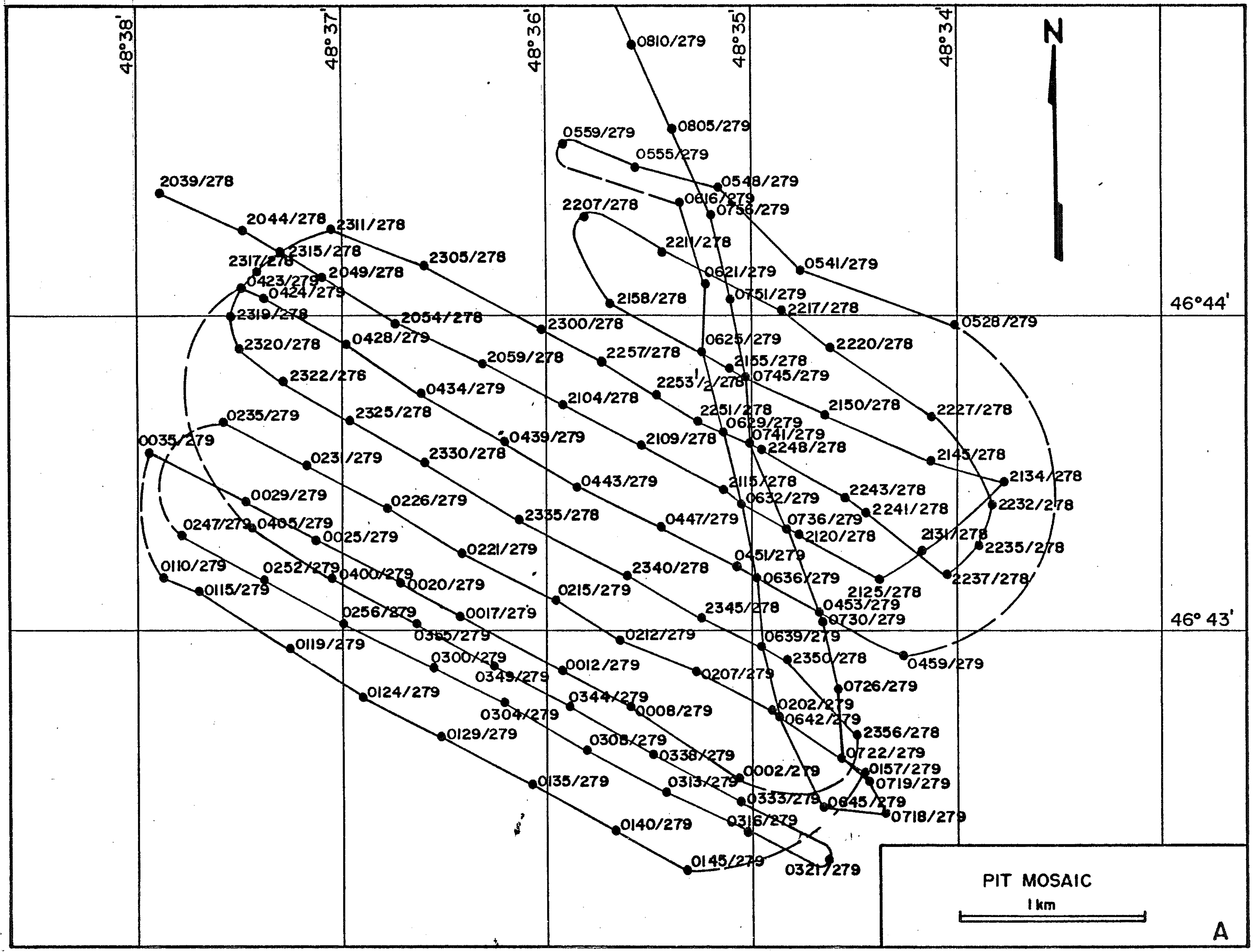
21	2000/284	0204/285	Regional Line #7
22	1750/285	0434/286	Regional Survey to St. John's
23	0438/286	0556/286	Regional Survey to St. John's
24	1710/289	1832/289	Super Furrow Search
25	1528/290	1842/290	Ben Nevis Pit Site
26	0108/291	0440/291	Bonanza Pits

BRUTIV Lines

Line Number	Start	End
1	1830/270	2100/279
2	2330/281	0200/282
3	0000/284	0200/284
4	1120/284	1320/284
5	1830/285	2030/285

APPENDIX III

Mosaic Navigation Track Plots


PIT MOSAIC
1 km
A
N
48°38'
48°37'
48°36'
48°35'
48°34'
46°44'
46°43'
0810/279
0805/279
0559/279
0555/279
0548/279
0616/279
0756/279
0541/279
2039/278
2044/278
2311/278
2315/278
2305/278
2317/278
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2158/278
2217/278
0528/279
2319/278
2054/278
2300/278
0625/279
2220/278
2320/278
0428/279
2059/278
2257/278
2155/278
0745/279
2322/278
2253½/278
0434/279
2104/278
2150/278
2227/278
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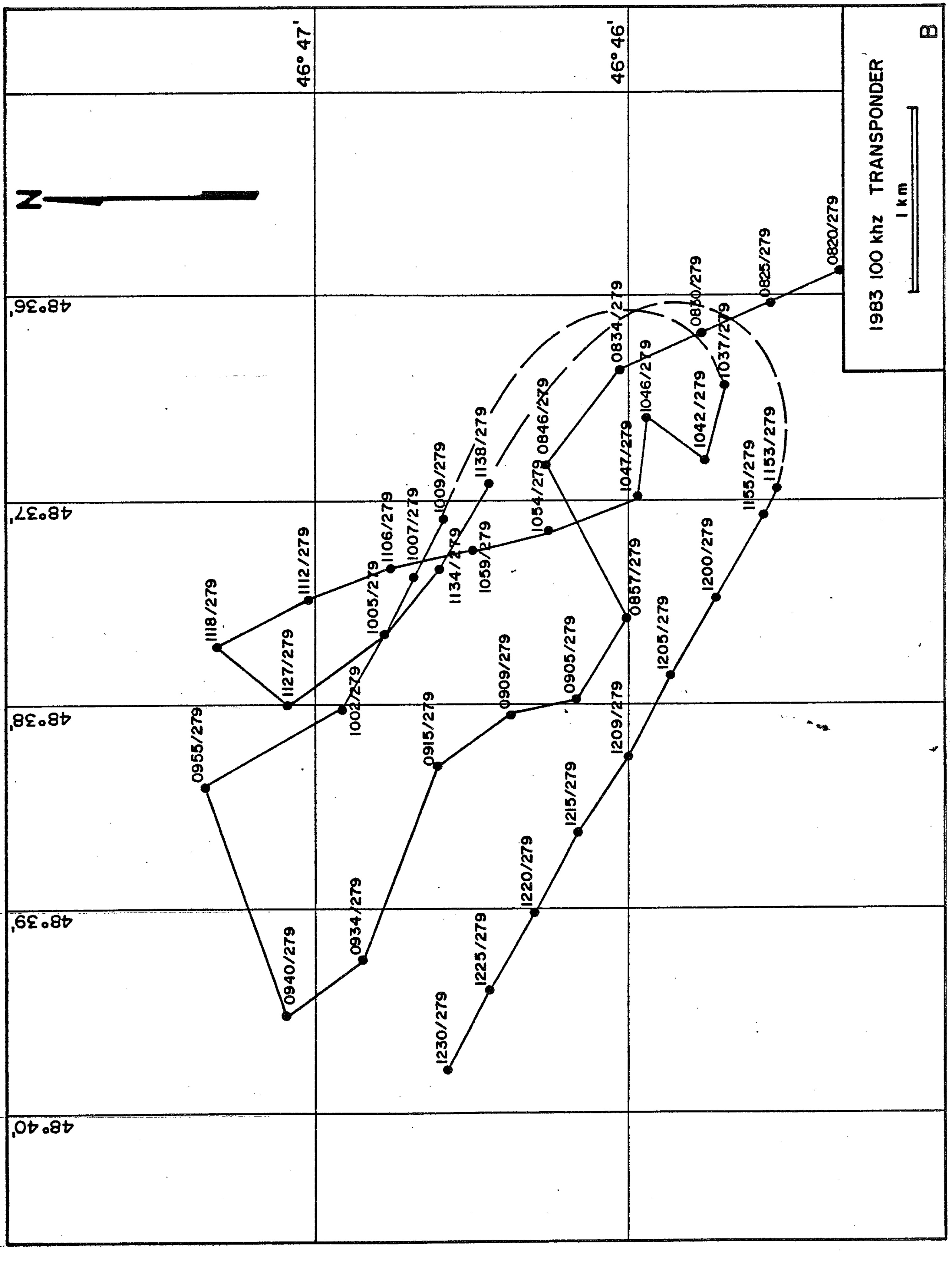
0316/279
0145/279
0321/279


1983 100 khz TRANSPONDER
1 km
B
N
46° 47'
46° 46'
48°36'
48°37'
48°38'
48°39'
48°40'
0820/279
0825/279
0830/279
0834/279
0846/279
0857/279
0905/279
0909/279
0915/279
0934/279
0940/279
0955/279
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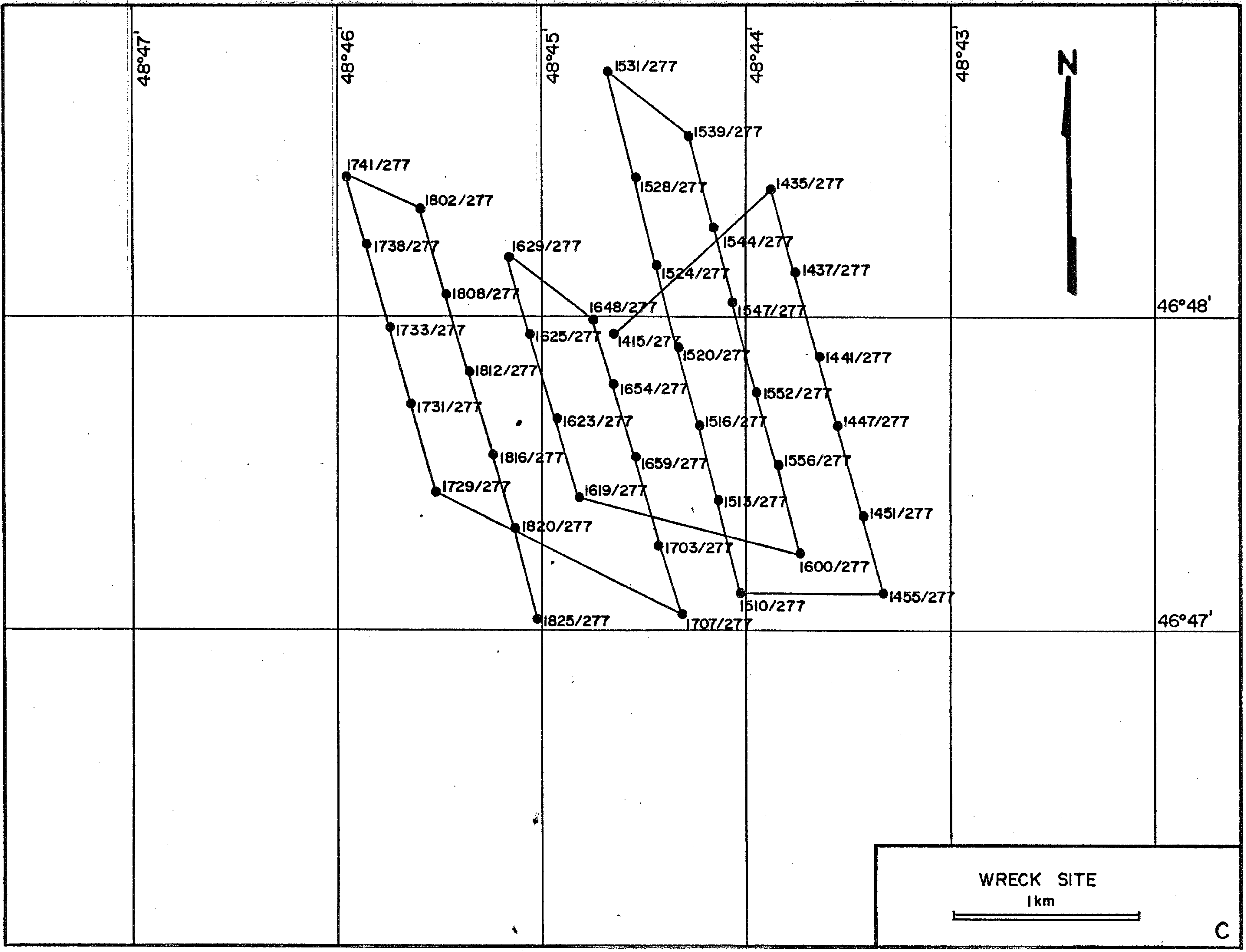
1230/279


48°47'
48°46'
48°45'
48°44'
48°43'
46°48'
46°47'
N
1531/277
1539/277
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1528/277
1435/277
1802/277
1544/277
1738/277
1629/277
1524/277
1437/277
1808/277
1547/277
1648/277
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1731/277
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1516/277
1447/277
1816/277
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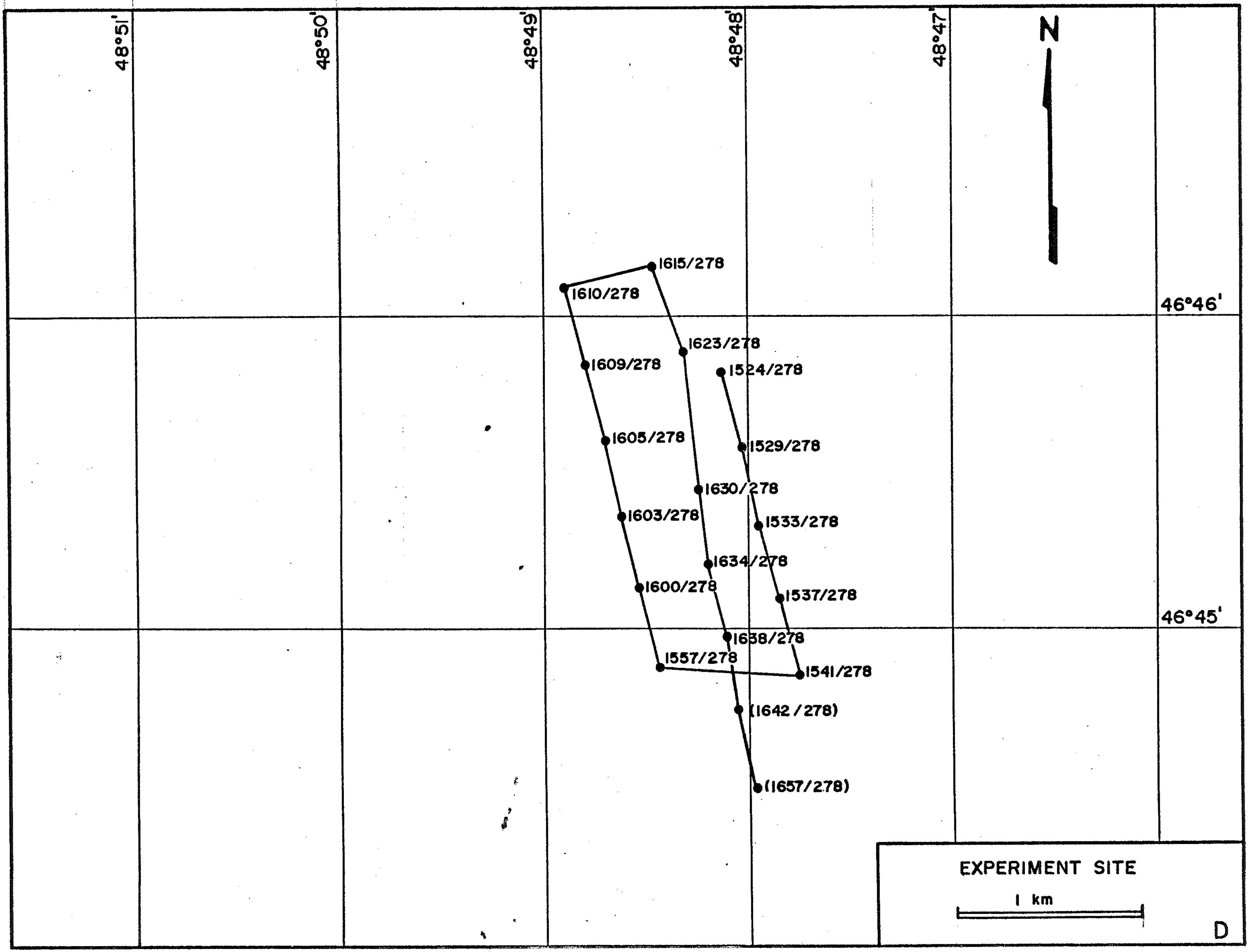
1729/277
1619/277
1513/277
1451/277
1820/277
1703/277
1600/277
1510/277
1455/277
1825/277
1707/277
WRECK SITE
1km
C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48°49'
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48°47'
N
46°46'
46°45'
1615/278
1610/278
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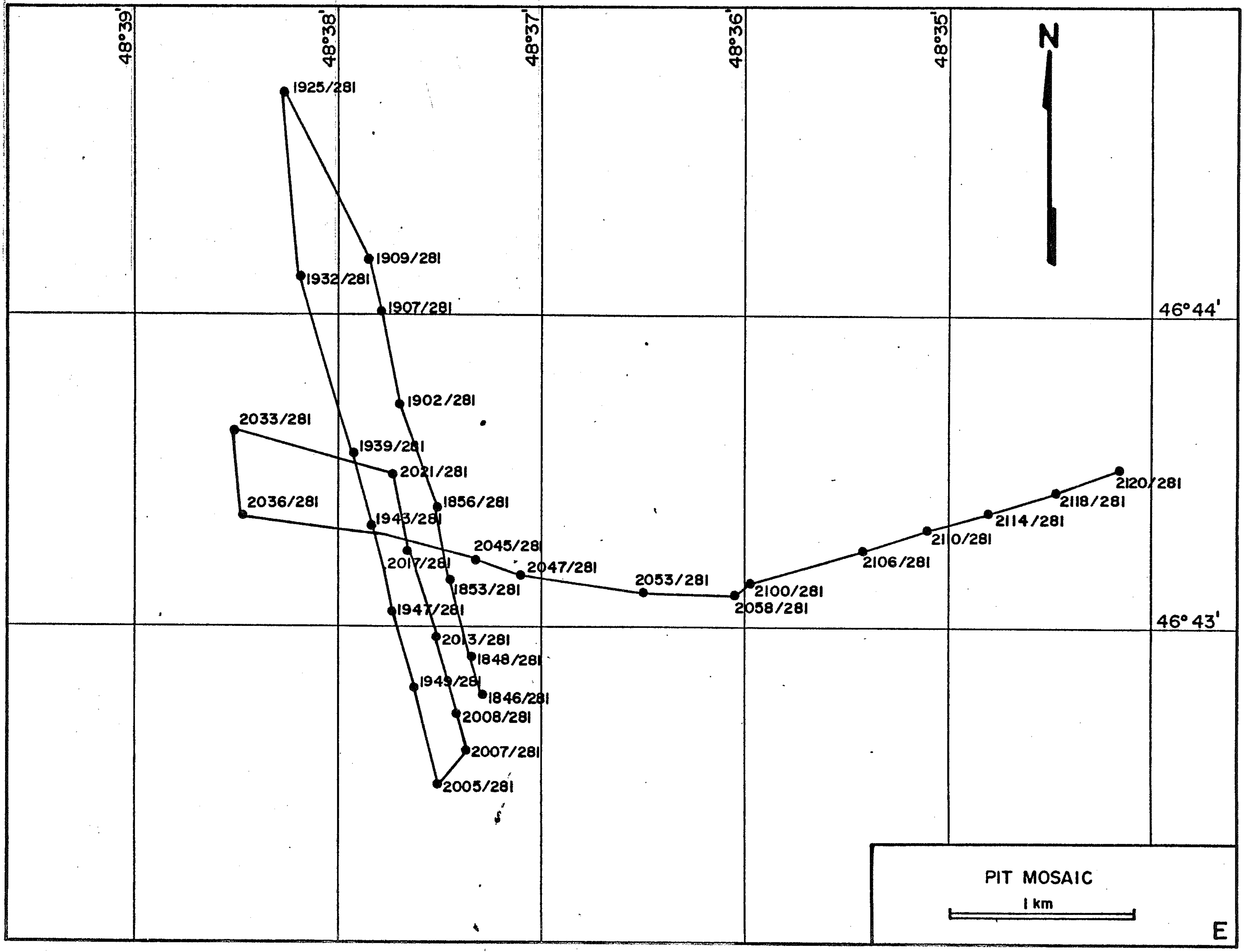
1524/278
1609/278
1605/278
1529/278
1630/278
1603/278
1533/278
1634/278
1600/278
1537/278
1638/278
1557/278
1541/278
(1642/278)
(1657/278)
EXPERIMENT SITE
1 km
D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48°38'
48°37'
48°36'
48°35'
N
46°44'
46°43'
1925/281
1909/281
1932/281
1907/281
1902/281
2033/281
1939/281
2021/281
2036/281
1856/281
1943/281
2045/281
2017/281
2047/281
1853/281
2053/281
2100/281
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1949/281
1846/281
2008/281
2007/281
2005/281
2106/281
2110/281
2114/281
2118/281
2120/281
PIT MOSAIC
1 km
E