HMCS **CORMORANT** and **SDL-1** operations on the inner Scotian Shelf

Cruise Report 89302

D.L. Forbes

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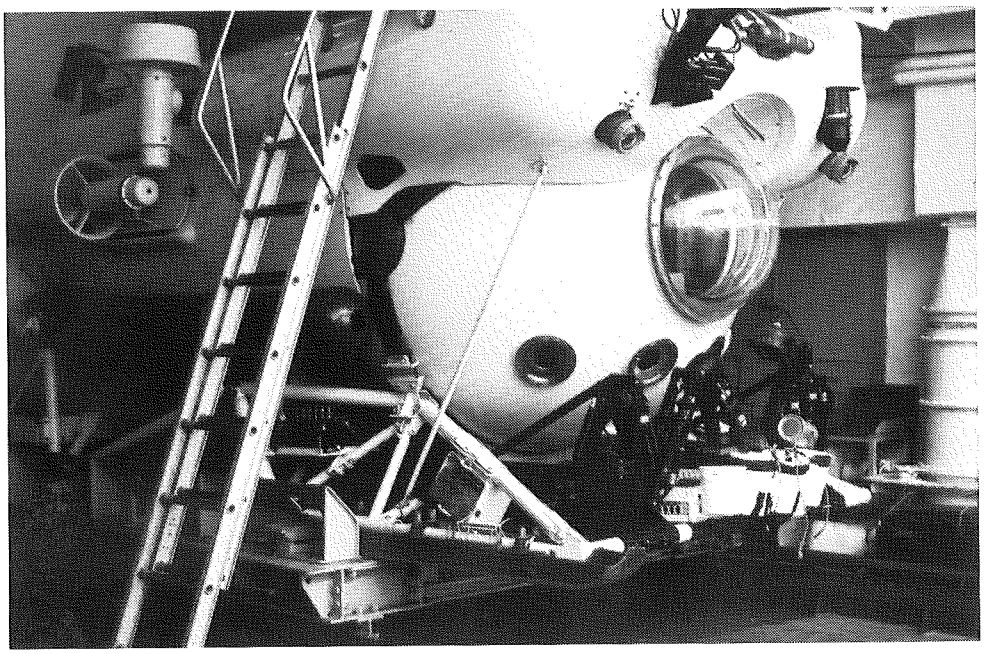

Institut océanographique de Bedford
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Cruise Report 89302

HMCS Cormorant and SDL-1 operations on the inner Scotian Shelf

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Geological Survey of Canada
Commission géologique du Canada

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1990

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GENERAL INFORMATION

Vessels:	HMCS Cormorant and SDL-1
Dates:	20-21 and 27-28 April 1989
Area of operations:	Scotian Shelf
Agencies:	Geological Survey of Canada (DEMR) Maritime Command (DND)
Master:	LCdr Malcolm Palmer
Senior Scientist:	Donald Forbes
Scientific Staff	David Frobel Darrell Beaver

OBJECTIVES

1. To ground-truth interpretations of sea-bed characteristics based on acoustic data obtained from CSS Dawson in November 1987 (Forbes et al., 1988), with dives on each of the major geological units across the inner shelf from the present shoreface to northern Emerald Basin (Appendix A).

2. To observe and sample gravel bedforms in various water depths and to establish maximum depth of present reworking. In addition, to observe and sample sandy megaripples seen locally on sidescan sonar.

3. To examine terrace features and to search for evidence of submerged shorelines on the inner shelf.

4. To determine bedrock type and to examine outcrop morphology for evidence of glacial or fluvioglacial erosion at various sites on the inner shelf.

5. To test capabilities of SDL-1, including navigation techniques, acoustic target location, sampling procedures, and general utility as an observation vehicle.

SUMMARY OF ACCOMPLISHMENTS

Six sea-floor traverses were undertaken with SDL-1 in water depths ranging from 51 to 147 m (Fig. 1). The total traverse distance was 11.4 km. Individual dives covered distances ranging from 1.1 to 2.8 km (Appendix B). Total bottom time was 12.61 hours, with individual dives totalling between 1.65 and 2.58 hours. Eight bottom sediment samples were obtained using SDL-1 (Appendix C). Video imagery was recorded on all dives except the first, the total video time being about 10.5 hours (Appendix D). The photographic record includes approximately 135 oblique views of the bottom and 4 photos of scanning sonar images.

In addition to the diving operations, sidescan sonar data were collected over a distance of approximately 2.8 km (Appendix E; Fig. 2), primarily for the purpose of identifying dive targets.

Most geological objectives of the cruise were met, although navigation data were less than ideal. In addition to general positioning problems, we were unsuccessful in attempts to home on an acoustic transponder moored at a known location. Nevertheless, the observations obtained from SDL-1 during this cruise have made a significant contribution to our understanding of sea-floor geology and sediment mobility in the study area. Direct observations and visually located samples of the sea floor are important components of surficial geological surveys. In the final analysis, the scientific value of the cruise was considerable.

NOTE:

The following conventions are adopted in subsequent sections of this report:

(1) Four-digit numbers refer to hours and minutes Universal Time (UT≈GMT=ADT+3h), where ADT [Atlantic Daylight Time] is local summer time.
(2) Sample numbers omit leading digits (e.g. sample 89302-001 is denoted simply as sample 1).
(3) Positions are given as Loran-C raw time differences with approximate geographic coordinates in parentheses.
(4) Photo numbers given in brackets [r-ff] refer to colour slides on file at the Atlantic Geoscience Centre (Coastal Group), where r is roll number and ff frame number.

SUMMARY OF OPERATIONS AND OBSERVATIONS

Thursday 20 April 1989 (day 110)

Cast off from HMC Dockyard (Halifax) at 1300 UT. Vessel proceeded out of harbour directly to site 5a (Appendix A; Fig. 1). Ran echo-sounder traverse southerly across site and back on a northerly course, obtaining result similar to record from Dawson 87042. Placed marker buoy at position 13782.0/ 30119.8 (44°23.11'N/ 63°29.76'W).

DIVE 817 (Figs 3 and 4): Launched SDL-1 at 1516. Released at position 13781.7/ 30122.1 (44°23.10'N/ 63°30.18'W) at 1524, on bottom at 1536 (depth 78 m), visibility estimated 5 m. Pebble-cobble gravel bottom with mud veneer (10-15% cover) and scattered shells. Proceeded estimated 200 m on course 060° toward site marker. Stopped to request position from Cormorant at approximately 1555. Mud bottom with scattered pebbles and shells [photos 1-01 and 1-02]. **Sample 1** [mud and fine sand with subrounded pebbles and cobbles] collected at this location at 1605 (depth 101 m). Sample secure at 1617. Moved off on course 260°. Pebble-cobble gravel bottom at 1623 (depth about 90 m) [photos 1-03 and 1-04]. Sand-pebble bottom at 1626 (depth 89 m). Cobbles and boulders at 1627 [photo 1-05]. Off boulders by 1634 (depth about 76 m). Speed 0.5-0.8 knot; up to 1 knot at 1635. Gravel bottom at 1637 (depth 65 m). Cobble-boulder bottom at 1654 (depth 53 m). Granitic bedrock with scattered large subangular to subrounded boulders at 1700 (depth about 53 m). Outcrop appeared fluted in places [photos 1-06 and 1-07]. Large joint blocks [photos 1-08 and 1-09]. SDL-1 off bottom at 1715, on surface at 1723, secure on deck at 1737. Video recorder failed on this dive.

Following SDL-1 recovery, Cormorant proceeded to site 9 in northern Emerald Basin. The intention was to run a bottom traverse from site 9 to site 8 (Appendix A).

DIVE 818 (Figs 5 and 6): Launched SDL-1 at 1947. Released at 1949 in position 13777.2/ 29975.4 (44°21.44'N/ 63°11.12'W). On bottom at 2004 (depth 138 m). Mud with few anemones. Ascended to 90 m at 2007 for adjustments to surface float. Back on bottom at 2014 [photos 1-11 and 1-12]. Moved off on course 130° at 2019 (depth 131 m). Boulder patch encountered at 2021. Scattered gravel with mud at 2023, scattered cobbles and boulders at 2026 (depth 136 m). Estimated 5-10% pebble-cobble-boulder cover at 2029. Altered course to 345°. Stopped to collect **sample 2** [muddy gravel with sand and angular to subangular pebbles and cobbles] at 2032 [photo 1-13]. Sample secure at 2045 [photos 1-14 and 1-15]. Moved off again on heading 345° at 2051 (depth 138 m). Increasing numbers of cobbles and boulders at 2100, with cobble- to boulder-sized pits in mud (depth 138 m).

Boulders more plentiful and bottom rising at 2103 (depth 135 m) [tape count 2918]. Gravel slope rising on port beam (~310°) at 2105 [photo 1-16]. Gravel and mud at 2108 (depth 136 m). Scattered cobbles and boulders at 2110 (depth 139 m). Scattered boulders in mud at 2112, with brittle stars (depth 144 m). At 2113 (depth 147 m), mud bottom (no gravel) with numerous burrows and sea pens (Pennatula sp.). Altered course to 020° at 2127. Mud bottom with burrows and tracks at 2128 (depth 145 m). Mud with fewer burrows at 2137 (depth 142 m). Muddy gravel with scattered boulders and numerous anemones at 2139. Mud with no gravel at 2140 but pebble-cobble-boulder material encountered again 3 minutes later. Mud with scattered boulders at 2145 and individual boulder at 2146. Mud bottom with depressions (0.2 m diameter and estimated ≤0.1 m deep) and sea pens at 2149 (depth 145 m at 2153). Pitted mud bottom with burrows and unidentified flatfish at 2207 (depth 142 m) [tape count 5414]. Sparsely colonized mud bottom at 2209 (depth 142 m). At 2210, bottom rising, with increasing gravel. Requested additional 5 minutes bottom time. Cobble-boulder slope with large numbers of anemones and numerous redfish (Sebastes marinus) at 2215. SDL-1 off bottom at 2223, on surface at 2242, and secure on deck by 2300.

Friday 21 April 1989 (day 111)

Cormorant approached site 1 around 0900. The plan was to run a short sidescan survey to confirm the site, to deploy a mooring with 12-kHz and 100-kHz transponders (identifiable to SDL-1 and the sidescan system respectively), to run another sidescan line past the mooring to locate it with respect to the bottom, and then to launch SDL-1. The sidescan fish was streamed at 0942 in position 13871.1/ 29875.9 (44°34.79'N/ 62°55.83'W). Two short lines were run (Fig. 2), the first on a heading of about 055° through 13873.8/ 29869.4 (44°35.18'N/ 62°54.94'W), the second on a heading of approximately 250° through 13871.6/ 29873.1 (44°34.87'N/ 62°55.47'W). The sidescan fish was recovered at 1013. At this point, it became apparent that only one dive would be undertaken this day because of an engine problem requiring Cormorant to be alongside HMC Dockyard by early afternoon local time. It was not clear from the sidescan record that the site 1 target could be easily located and we therefore chose to proceed to site 7 and dive there.

At 1138, Cormorant deployed a mooring, with 12- and 100-kHz transponders attached, in position 13835.6/ 30010.2 (44°30.08'N/ 63°14.04'W). The surface float on this mooring was observed for roughly 1.5 hours after deployment, then disappeared from view. The float was not seen again during the cruise, but was found and the mooring recovered on 27 June 1989 by CSS Dawson (cruise 89010). When recovered, there was no scope on the line and the tide was low.

DIVE 819 (Figs 7 and 8): Launched SDL-1 at 1202. Released at 1205 in position 13833.0/ 30009.0 (44°29.70'N/ 63°13.96'W). SDL-1 on bottom at 1216 (depth 60 m) [photos 1-17 and 1-18]. Moved off on heading 350° at 1227 [tape count 0845]. Stable gravel surface (pebble-cobble-boulder) with small patches of sand [photo 1-19]. At 1230, encountered outcrop of Meguma Group rocks (approximate strike 080°) [photo 1-21]. Traversed an irregular bottom with bedrock outcrop [photos 1-23 to 1-26] and intervening depressions containing coarse gravel and boulders. Stopped at 1248 to locate transponder (no success). Moved off on heading 330° at 1253, over flat gravel surface [photo 1-27] with small sand patch [tape count 2532 at 1255]. Boulders and bedrock outcrop at 1259 (depth 67 m). Course roughly normal to strike of bedrock at 1304 [tape count 2981]. Sand-pebble-cobble bottom at 1309, with evidence of burrowing in sand. Rock outcrop and large boulders at 1310 (depth 60 m). At 1314, stopped again to look for transponder signal. Cormorant requested ascent to 30 m at 1319 to check float (moored float disappeared). Video off [tape count 3665]. SDL-1 back on bottom at 1329 and video on. Moved off on course 240° at 1333 over boulder field. Boulders, bedrock, and an automobile tire at 1334 [tape count 3890]. Fine gravel and bedrock at 1337, pebble-cobble gravel to bedrock at 1339. Located patch of gravel ripples at 1341 and stopped (depth 62 m). Ripple wavelength 2.2 m, height 0.2 m, orientation (crest strike) 110°, profile sinusoidal. Sand-pebble gravel with no growth on pebbles [tape count 4462 at 1349]. Sonar image of ripples [photos 1-29 and 1-33]. **Sample 3** [sandy gravel from ripple crest] collected at 1351. **Sample 4** [sandy gravel (sub-rounded pebbles and cobbles) from ripple trough] collected at 1403. SDL-1 moved off slowly at 1417 [tape count 5474]. Another gravel ripple patch encountered at 1422 [tape count 5637]. Moving on course 240° at 1426. End of gravel ripples at 1429. SDL-1 off bottom at 1435, on surface at 1438, and secure on deck by about 1500.

Cormorant proceeded to Halifax, tying up at HMC Dockyard in the early afternoon local time. Prognosis for repairs uncertain.

Sunday 23 April 1989 (day 113)

Engine repairs going well. Arrangements made for scientific staff to rejoin Cormorant on Thursday 27 April.

Thursday 27 April 1989 (day 117)

Scientific staff departed BIO in CSL Puffin to join Cormorant off George's Island in Halifax Harbour. Cormorant then proceeded to site 4, arriving at 1236. A marker buoy was deployed in position 13832.1/ 30103.0 (44°30.03'N/ 63°26.20'W).

DIVE 822 (Figs 9 and 10): SDL-1 launched, released at 1326 in position 13832.6/ 30103.2 (44°30.10'N/ 63°26.21'W), on bottom at 1335 (depth 53 m) [video on at 1340]. Pebble gravel bottom with patches of sand. Moved off at 1345 on heading 215°, encountering a few unidentified sea stars, stalked tunicates (Boltenia ovifera), and anemones. Crossed a cable at 1350 [photo 3-06]. Bottom along track varied from boulders to mixtures of silty sand and gravel. Encrusting Lithothamnion growth on all boulders. Found marker-buoy anchor at 1355 [photos 3-10 to 3-13]. Moved off on heading 270° at 1403. Bottom varied from boulders or cobbles to finer gravel and occasional sand patches. Stopped at 1417 to collect **sample 5** [sandy gravel (subangular pebbles and cobbles)]. Sample secure at 1456 (depth 51 m). SDL-1 moved off 3 minutes later on course 270° over a boulder bottom. Patches roughly 2-3 m in diameter of finer sandy gravel encountered at 1502. Scattered boulders interspersed with finer material along track to 1509. Stopped to do a 360° rotation, heading off again on course 270° at 1514 (depth 54 m). Patches of finer material, locally obscuring underlying gravel surface at 1531 [tape count 8505] [photo 3-26]. Moved into an area of more numerous boulders, becoming an extensive boulder surface by 1540. At 1543 we encountered a large boulder standing proud of the bottom, with 30 or more anemones crowding its upper surface. Shortly thereafter, crossed a boulder ridge 5-8 m wide and 1-2 m high [photos 3-31 and 3-32]. Large boulders forming ridge, heavily encrusted, with small sponges, anemones, and stalked tunicates. Changed video tape at 1548 (depth 54 m). Continued over a mixed pebble-gravel to cobble-boulder bottom, with patches of silt and sand on gravel surface locally. Came across patch of inactive gravel ripples at 1600 and stopped. Ripple wavelength approximately 2 m, orientation (crest strike) 080°, troughs infilled with mud [photo 3-34]. Sonar image [photo 3-35] less distinct than images of gravel ripples obtained earlier (dive 819). SDL-1 off bottom at 1610, on surface at 1623.

With SDL-1 secure on deck, Cormorant proceeded to site 1. A marker buoy was moored in position 13873.4/ 29871.4 (44°35.14'N/ 62°55.09'W) at 1913.

DIVE 823 (Figs 11 and 12): Launched SDL-1 at 1925. Released in position 13872.2/ 29871.3 (44°34.99'N/ 62°55.19'W) at 1926. SDL-1 on bottom at 1935 (depth 64 m). Started video tape at 1940. Moved off on course 010° over coarse boulders, including some very large blocks [photo 4-03], with occasional Meguma Group bedrock outcrop [photo 4-05]. Altered course to 330° at 1945 and to 210° at 1952. Stopped on outcrop at 1957 before moving off on heading 270° at 2002. Proceeded over extensive bedrock outcrop (prominent ridges striking roughly 045°) with patches of gravel, locally with a thin veneer of fines, and areas of boulders. Pronounced asymmetry in bedrock ridges (northwest slopes streamlined and less steep than southeast slopes), suggesting differential glacial erosion on stoss and lee sides.

Numerous anemones [photo 4-08] and occasional large sponges [photo 4-09]. Continued over blocky outcrop [photos 4-10 and 4-12]. Stopped briefly to change pilots at 2028 (depth 64 m), then moved off on same course over boulders [photos 4-13 and 4-14]. Crossed onto fine gravel at 2032 and then onto sand with large numbers of sand dollars (Echinarachnius parma), onto gravel at 2039, onto sand with sand dollars at 2040, and onto a stable gravel surface with a thin veneer of silt or sand, sand dollars, and shell hash at 2042. Gravel with scattered boulders and a thin veneer of fines at 2046. Altered course to 090° (back along track). Passed over alternating sand and gravel. Stopped at 2051 to check electrical system and collect sample (depth 65 m). **Sample 6** [fine sand] obtained at 2056 [photo 4-24]. Moved off again on heading 090° at 2104, moving onto gravel at 2106 [tape count 4628]. Altered course to 180° at 2108 in an area of gravel with shell hash. Proceeded across alternating sand and gravel, recognized as low-amplitude megaripples (dunes), with wavelengths of 10-15 m, as seen on the sidescan record (Fig. 12). The amplitude of these features was so small as to be almost indiscernible and the degree of profile asymmetry could not be determined. There was no evidence of slip-face development. Stopped to collect **sample 7** [pebble-cobble gravel (subrounded) with fine sand and mud] at 2117 (depth 68 m). Sample secured at 2128; 120 V power supply low [tape count 5303 at 2125]. SDL-1 off bottom at 2137, on surface at 2141.

Friday 28 April 1989 (day 118)

Cormorant approached site 5 and started echo-sounder run at 1105. Marker buoy was dropped at 1119 in position 13826.6/ 30093.4 (44°29.21'N/ 63°25.11'W).

DIVE 824 (Figs 13 and 14): SDL-1 in water at 1141 and manoeuvring on surface until 1154. Alongside marker buoy and vents open at 1155. On bottom at 1201 (depth 53 m). Steering 090° at 1220 [video tape started at 1226]. Altered course to 135° at 1232. Moving over bedrock, striking normal to course, with scattered boulders and encrusting growth [photos 5-04 to 5-07]. Occasional horse stars (Hippasteria phrygiana), tunicates (Boltenia ovifera), and small codfish (Gadus morhua). At 1244, passed off boulders onto flat sandy gravel surface with small patches of sand. A few scattered anemones and other organisms. Patches of boulders along track. Passed from silty sand with pebbles, burrrows, and shell hash at 1250 (depth 67 m) onto cobble-boulder pavement with fines accumulated between clasts at 1252 [photo 5-11]. Patches of boulders were locally overlain by finer gravel at 1255 and bedrock outcrop was encountered at 1257. Sandy pebble-gravel at 1259 (depth 70 m) gave way to large boulders [photo 5-13]. Continued over relatively flat bottom of sandy gravel until 1311. Stopped to collect **sample 8** [sand and gravel (angular pebbles)] (depth 62 m) [photo 5-21]. Sample

secured at 1324. Moved off on heading 135° at 1327, coming onto cobble-boulder pavement with encrusting growth and vase-shaped sponge at 1331 [photo 5-24]. Switched to light on 4-function arm, giving good illumination in the near-field and more distant dim visibility (estimated 15 m or more) with available light. Climbing to a depth of 57 m at 1335, bottom became increasingly bouldery until 1339, where various types of anemones, a sea star (probably Henricia sanguinolenta), sponges (including a large compound vase-like form), and various other organisms occurred on large sub-rounded boulders with encrusting algal growth [photo 5-30]. Continued over boulders with some finer gravel, coming onto larger boulders on a slight rise at 1048 (depth 57 m) [photo 5-34]. Crossed onto outcrop of Meguma rock, striking roughly normal to track, at 1351. Scattered boulders and finer gravel. Although encrusting growth made identification uncertain, rock surface at 1355 appeared striated (orientation estimated 150°) [photo 5-37]. SDL-1 off bottom at 1401, on surface at 1407, secure aboard Cormorant at 1418.

Cormorant returned to Halifax, arriving alongside HMC Dockyard in the early afternoon local time.

PRELIMINARY SCIENTIFIC RESULTS

From a scientific point of view, the cruise was very successful, despite a number of technical shortcomings. Although uncertainties in positioning of SDL-1 make the reconstruction of dive tracks and correlation between underwater observations and earlier acoustic data somewhat tenuous, much useful information was obtained.

A number of previous studies have elucidated various aspects of the bedrock and surficial geology of the inner Scotian Shelf and adjacent margins of Emerald Basin (e.g. King, 1970; Boyd and Penland, 1984; Hall, 1985; Piper et al., 1986; King and Fader, 1986, 1988; Forbes et al., 1988; Boyd et al., 1988; Forbes and Drapeau, 1989; among others). A limited number of direct observations using manned and unmanned submersibles and divers have provided additional information in depths less than 40 m (Judge and Forbes, 1987; Forbes and Boyd, 1987, 1989) and some additional work was carried out with the Hysub-5000 vehicle on CSS Dawson cruise 89010 (McKeown, 1989). The major contributions of the SDL-1 operations described in this report were to provide ground-truth observations of sea-bed sediments, bedforms and other morphological features, benthic ecology, and other features in the deeper parts of the inner shelf and adjacent basin where direct observations were lacking previously.

Dive 817 traversed the bottom and western flank of a deep shelf valley (Fig. 4) extending seaward from Halifax Harbour

(Fig. 1). It revealed a range of unconsolidated surficial sediment types from poorly-sorted mixtures of mud, sand, and pebbles to coarse cobble and boulder gravel. The mud and fine sand ($D < 0.2$ mm), medium-coarse sand ($0.2 \leq D < 1$ mm), and very coarse sand and gravel ($1 \leq D < 45$ mm) fractions in **sample 1** (Fig. 15) appeared to represent independent populations; the coarse fraction was poorly sorted, with a coarse-pebble mode, and accounted for approximately 50% of the sample mass. The medium-coarse sand fraction (roughly 25% of the sample) was well sorted, with a mode of 0.35 mm (1.5 ϕ). On the west side of the valley toward the end of the dive, observations demonstrated the presence of jointed granitic rocks on Sambro Ledges, a seaward extension of the granite outcrop seen onshore in the area. The submarine outcrop displayed erosion features of interpreted glacial and subglacial meltwater origin, also similar to features observed onshore.

Dive 818 was planned to traverse from a deep terrace at site 9 (Appendix A) across the floor of the northern marginal depression of Emerald Basin to the steep southern edge of the inner shelf in the vicinity of the 100 m isobath (Fig. 1). Neither the terrace at site 9 nor the bedrock outcrop characteristic of the outer part of the inner shelf was located, However, the dive provided useful observations of the muddy surficial unit forming the basin floor in the area (Fig. 6) and of the extent and character of biological reworking of this unit. A number of gravel patches were observed, often occurring on surfaces standing above the general level of the surrounding basin floor (Fig. 6). These have been interpreted as protruding exposures of an underlying glacial ice-contact unit (Forbes et al., 1988). **Sample 2** (Fig. 15) was a poorly sorted muddy sandy gravel, approximately 78% coarser than 2 mm (-1.0 ϕ), negatively skewed, with a coarse-pebble mode (45 to 64 mm [-5.5 to -6.0 ϕ]).

Dive 819 was in the area of site 7 (Appendix A), on the landward margin of an extensive outcrop zone characteristic of the outer part of the inner shelf (Forbes et al., 1988). The observations supported the interpretation of outcrop in this area as Goldenville Formation quartz-metawacke of the Meguma Group. In addition, the discovery of gravel ripple patches in 62 m water depth confirmed interpretations of earlier sidescan sonar imagery (Fig. 8). These are the deepest known occurrences of such bedforms on the inner Scotian Shelf (LaPierre and Boyd, 1985; Forbes and Boyd, 1987). **Samples 3** and **4** (Fig. 15) were taken from the ripple crest and trough, respectively. While both samples showed very similar distributions in the fine- to medium-pebble size range (2 to 32 mm [-2 to -5 ϕ]), with a mode of about 8 mm (-3 ϕ), the mean size of the ripple crest sample was finer. Although the sample sizes may have been inadequate for precise determination of coarse gravel proportions, the ripple trough material (sample 4) contained cobble-size material that was absent from the ripple crest (sample 3). The crest sample also

contained about 8% sand and 5% mud. Computations following Forbes and Boyd (1987) suggest that 12- to 14-s waves with a significant wave height of about 6 to 7 m would be required to move the material forming the ripple crest. Waves of this magnitude are known to occur in the area during severe winter storms and passage of tropical cyclones. The orbital diameter associated with such waves (from linear wave theory) would be about 2.5 to 3.0 m, suggesting a value of $0.7 < k < 0.9$ in the relation $\underline{l} = kd_o$, where $\underline{l} = 2.2$ m is the ripple wavelength. Although these ripples appeared to have been active recently, the 5% mud content was comparable to that found in inactive gravels at sites 4 and 5 (dives 822 and 824; see below), and mud-draped ripples were later found at 54 m water depth during dive 822.

Dive 822 traversed an area of boulder-lag and finer gravel sediments in the vicinity of site 4 (Appendix A) off the mouth of Halifax Harbour (Fig. 1). It was located in an area of poorly-defined terraces (Fig. 10) that may be related in part to relict shore features. A boulder ridge observed in approximately 54 m water depth on this dive may have formed as a nearshore boulder barricade, although other modes of origin are also possible. A sample of sandy gravel collected near the beginning of the dive (**sample 5**, Fig. 16) was negatively skewed, with a mode of 32 to 45 mm, at the extreme coarse end of the distribution, and a secondary mode of coarse sand between 0.35 and 0.50 mm (1.5 to 1.0 ϕ). Gravel ($D > 2$ mm [$-1\ \phi$]) accounted for 75% of the sample mass and mud for about 5%. Near the end of dive 822, a small patch of inactive gravel ripples with mud-filled troughs was located in a water depth of about 54 m. As noted above, this was shallower than apparently active ripples encountered on dive 819. Unfortunately, we were unable to sample the material forming these ripples and therefore cannot comment on the conditions under which they may have formed. In general, we assume that sea-floor sediments on the inner shelf were more active formerly under lower relative sea levels, down to -40 m approximately 10,000 years ago (Forbes et al., 1988; Shaw and Forbes, 1990).

Dive 823 was planned to observe a shallow, sediment-floored, north-south trending channel cutting across bedrock at site 1 (Appendix A), in about 60 m water depth off Clam Bay (Fig. 1). This had been observed on sidescan sonar, which also suggested the presence of sandy dunes (or megaripples) in the channel (Fig. 12). The dive track ran east-west across an irregular bedrock surface and eventually crossed the channel. The identification of bedforms seen on the sidescan records was confirmed and further details were observed, including the very small amplitude of the bedforms, the lack of slipface development, and the gravel-floored troughs. These suggested a sand-starved condition and restricted development or degradation. The sand was heavily occupied by sand dollars (Echinarachnius parma), which were not observed elsewhere during this program. Samples 6 and 7 were collected, respectively, from the sand and from the intervening

gravel in the 'trough' (Fig. 16). The sand (**sample 6**) was well sorted, with a mode of about 0.22 mm (2.2 ϕ), slightly negatively skewed, with a fine tail of silt and clay, and some shell fragments in the pebble size range. The gravel (**sample 7**) turned out to be a bimodal mixture of sand and gravel, less than 40% coarser than 2 mm (-1 ϕ), very poorly sorted, with a coarse-pebble mode (32 to 45 mm [-5.0 to -5.5 ϕ]). It contained about 56% sand with a size distribution and mode very similar to that of sample 6. This implied a more plentiful sand supply than had been inferred from observations of the surface morphology and sediments.

Dive 824 traversed an area dominated by lag boulder deposits in the vicinity of site 5 (Appendix A), off the mouth of Halifax Harbour in 70 to 57 m water depth (Fig. 1). Bedrock outcrop and patches of silty sand with pebbles and of sandy gravel were also encountered. A sample of muddy sandy gravel obtained on this dive (**sample 8**) yielded a grain-size distribution very similar to that of sample 5 (Fig. 16). A bedrock outcrop surface observed at the end of the dive (Fig. 14) provided the only example of possible glacial striation found during the cruise. Encrusting growth was observed on almost all bedrock, boulder, cobble, and pebble surfaces (excepting rippled gravels) at all dive sites on the inner shelf. This made the recognition of glacial striation on bedrock outcrop surfaces difficult if not impossible.

TECHNICAL SUMMARY

Navigation and bathymetry

Cormorant's position was determined on a continuous basis during survey and diving operations using Loran-C. Raw time differences and estimated geographic coordinates were logged once a minute via an RS232 link between the Loran-C receiver and a laptop PC. The receiver had to be supplied from BIO because of the absence of a serial output port on the ship's unit.

The position of SDL-1 during diving operations was determined by dead-reckoning. The sub's head was determined using a gyro set 180° to ship's head prior to each launch. Additional estimates of SDL-1 position were obtained from time to time by visual estimates of range and bearing from Cormorant to a surface float attached to the sub.

Bathymetry was determined using the ship's sounder and the pressure meter aboard SDL-1.

Sonar imaging, video and photography

Sidescan sonar data were collected from Cormorant using a

Klein towfish with port and starboard 100-kHz transducers and a wet-paper recorder. The towfish was hand-deployed from the starboard quarter and the recorder was set up in a makeshift lab in the quartermaster's station. Lack of lab space is a major shortcoming of Cormorant and an issue that would have to be addressed if she were to assume a more active scientific role (e.g. with transfer of Pisces-IV).

The tiltable sector-scanning sonar aboard SDL-1 was used in vertical mode to determine elevation above bottom during descent and in near-horizontal mode for forward scanning on traverses. It was effective for detection of major obstacles, such as bedrock ridges, and for imaging and measurement of gravel ripples. No provision was made for recording the sonar video image, but the screen was successfully photographed with a hand-held camera.

Colour video imagery was obtained from SDL-1 on all dives and recorded on 1/2-inch tape using a VHS recorder (except on dive 817, when the VCR failed). The camera was mounted externally and equipped with pan-and-tilt controls.

Still photographs were obtained on 35-mm, 400-ASA, colour-positive film using a hand-held camera with a 50-mm lens. As for the video imagery, lighting was provided by external floods, adjusted for viewing conditions without special provision for photography. In some cases, the lighting was inadequate and shutter speeds as low as 1/30 s were required. As a result, the image quality was variable (some very good and some poor).

Sampling

Sediment samples were collected using a custom-designed cylindrical scoop held in the claw of the 7-function arm aboard SDL-1. The sampler was constructed from 5-inch diameter aluminum pipe, closed at one end with a welded end-plate. A T-handle constructed of 3/8-inch aluminum rod was attached near the open end of the scoop. The handle was encased in rubber tubing. This sampler proved quite satisfactory for the acquisition of bulk samples in muds, sands, and gravels. Minor difficulty was encountered in penetrating gravelly sediments at some locations and the handle was bent quite severely by the end of the cruise.

Samples were stored in 2-gallon plastic buckets attached to the front of the wire-mesh tray on the lower forward frame of the sub. Four buckets were mounted in a row. A second bucket holding a diver weight, and with a short length of buoyant poly line attached to the wire handle, was placed in each of the sample buckets to serve as a lid. The upper bucket was removed before sampling. Each sample was dumped from the scoop into a lower bucket and the top bucket was then replaced to retain the

sample. This procedure was reasonably successful and loss of fines was minimal. The operation required considerable operator skill. One of the four buckets was found to be inaccessible and another was difficult to use. As a result, no more than two samples were collected on any one dive.

CONCLUDING REMARKS

Samples such as those obtained on dives 819 and 823, precisely located with respect to bedforms or other sea-bed features, cannot be obtained without the use of submersible vehicles. Direct stereo vision available from a manned vehicle is an asset in work of this kind. In addition, we have found the scanning sonar systems aboard both SDL-1 and the Hysub-5000 (McKeown, 1989) to be invaluable in the initial detection of large bedforms under conditions of limited visibility.

The lack of an effective positioning system for SDL-1 was a major shortcoming on this cruise. Discrepancies between dead-reckoning and Cormorant fixes on the SDL-1 surface float produce uncertainties of several hundred metres in some cases, though in others the two methods give positions that are in close agreement. An attempt to overcome these problems by running a linear traverse from a known dive position to a transponder mooring was unsuccessful.

Visual exploration of the sea bed is an invaluable adjunct to conventional marine surveys. It enables us to interpret acoustic data collected from surface vessels with much greater confidence. Despite the problems and shortcomings identified above, the program was successful and the six dives completed were very productive.

ACKNOWLEDGEMENTS

It is a pleasure to acknowledge the officers and crew of HMCS Cormorant, including especially LCdr M. Palmer (Master) and LCdr N. MacDonald (Dive Officer), for their support, seamanship, and hospitality throughout this program. The SDL-1 pilots, including LCdr MacDonald, Lt(USN) Griepenstroh, Lt(N) Reddy, C2 Larder, and P1 McEwen, are thanked for taking us safely to the bottom and back. The contributions of all other members of the dive team and scientific staff are gratefully acknowledged. Dave Heffler, Bill MacKinnon, Mark Chin-Yee, Bob DeLong, and Don Dinn provided engineering and logistical assistance. Larry Johnston assisted with preparation of dive-track plots. Brian MacLean and Steve Blasco kindly reviewed drafts of this report. I thank Cdr A.G. Sinclair (DREA) and Keith Manchester (AGC) for facilitating ship-time arrangements.

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Appendix A

DIVE SITES ORIGINALLY PROPOSED

Notes:
(1) Sites marked with asterisk are those at which dives took place on this cruise.
(2) Information in brackets [87042 day/time nnn/nnnn] refers to day/time on records collected by CSS Dawson in 1987 (Forbes et al., 1988).
(3) Geographic coordinates and depths {} are approximate.

Site 1: * 44°35.2'N 62°55.2'W {65 m} --- **DIVE 823**
[87042 day/time 310/1000]

Objective: find channel in bedrock off Clam Bay and Brig Shoal, and examine sandy bedforms developed in channel.

Site 2: 44°38.6'N 63°07.4'W {30 m}
[87042 day/time 307/1300 & 310/0640]

Objective: find and investigate sea-floor depressions in relict estuarine deposits off Martinique Beach.

Site 3: 44°34.4'N 63°23.0'W {32 m}
[87042 day/time 310/0155]

Objective: find and sample exposures of relict estuarine sediments on sea floor off Osborne Head, seen on an earlier traverse with Pisces-IV in 1985.

Site 4: * 44°30.1'N 63°25.9'W {53 m} --- **DIVE 822**
[87042 day/time 308/1150]

Objective: look for evidence of relict beach deposits on valley side terrace off mouth of Halifax Harbour.

Site 5: * 44°29.0'N 63°24.6'W {66 m} --- **DIVE 824**
[87042 day/time 308/0750]

Objective: as for site 8, in different location.

Site 5a: * 44°23.0'N 63°29.6'W {100 m} -- **DIVE 817**
[87042 day/time 308/0610]

Site 6: 44°31.4'N 63°16.7'W {55 m}
[87042 day/time 310/0345]

Objective: find, measure, and sample patch of large-scale gravel ripples close to maximum known depth of occurrence.

Site 7: * 44°29.7'N 63°13.9'W {62 m} --- **DIVE 819**
[87042 day/time 307/0145]

Objective: as for site 6, with bedrock observations.

Site 8: * 44°22.1'N 63°11.0'W {140 m} -- **DIVE 818**
[87042 day/time 307/0315]

Objective: examine marginal-basin deposits and bedrock at outer edge of inner shelf.

Site 9: 44°20.8'N 63°10.5'W {150 m}
[87042 day/time 307/0330]

Objective: find and determine nature of surficial unit overlying unconformity on deep terrace.

Site 10: 44°33.9'N 63°18.3'W {40 m}
[87042 day/time 307/0030]

Objective: establish bottom type and observe bedforms on surficial acoustic unit identified as possible submerged shoreface deposit.

Appendix B

DIVES ACCOMPLISHED

dive number	site	time on bottom (h)	distance traversed (km)	samples collected (89302-)
817	5a	1.65	2.0	001
818	8	2.20	2.8	002
819	7	2.15	1.1	003 & 004
822	4	2.58	2.0	005
823	1	2.03	1.7	006 & 007
824	5	2.00	1.8	008

Appendix C

SAMPLE INVENTORY

sample number 89302-	dive number	day/ time (UT)	latitude longitude	water depth (m)	notes
001	817	110/1610	44°23.21'N 63°29.91'W	102	pebbles and cobbles with sand and mud
002	818	110/2040	44°21.60'N 63°10.97'W	140	angular to subangular pebbles and cobbles with sand and mud
003	819	111/1355	44°30.14'N 63°14.21'W	63	pebbles with sand and mud [ripple crest]
004	819	111/1405	44°30.14'N 63°14.21'W	63	pebbles and cobbles with sand and mud [ripple trough]
005	822	117/1405	44°30.06'N 63°26.42'W	52	coarse-pebble gravel with sand and mud
006	823	117/2100	44°35.11'N 62°55.88'W	66	fine-medium sand
007	823	117/2125	44°35.03'N 62°55.83'W	67	coarse-pebble gravel with sand and mud
008	824	118/1320	44°28.86'N 63°24.59'W	62	coarse-pebble gravel with sand and mud

Appendix D

VIDEO RECORDS

tape	dive	start day/time	stop day/time
1	818	110/2004	110/2222
2	819	111/1217	111/1433
3	822	117/1340	117/1548
4	822	117/1549	117/1608
5	823	117/1940	117/2132
6	824	118/1226	118/1400

Appendix E

SIDESCAN SONAR RECORD

roll	start day/time	stop day/time	location
1	111/0942	111/1013	vicinity of site 1

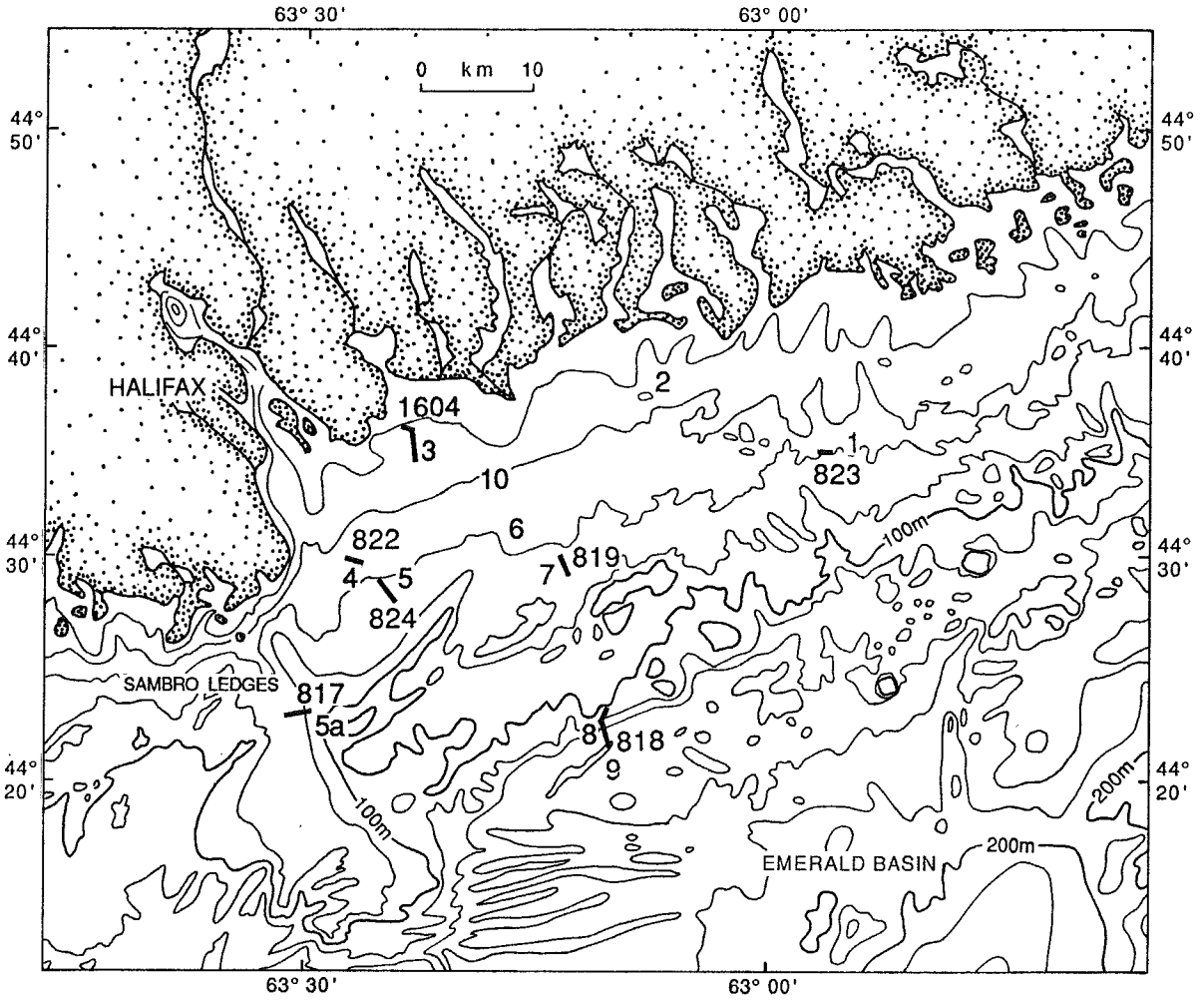

FIGURE 1

Inner Scotian Shelf and northern Emerald Basin in the study area, showing bathymetry, site numbers (1-10), and dive locations (817-819 and 822-824). Dive number 1604 refers to an earlier Pisces-IV dive (see Forbes and Boyd, 1989).

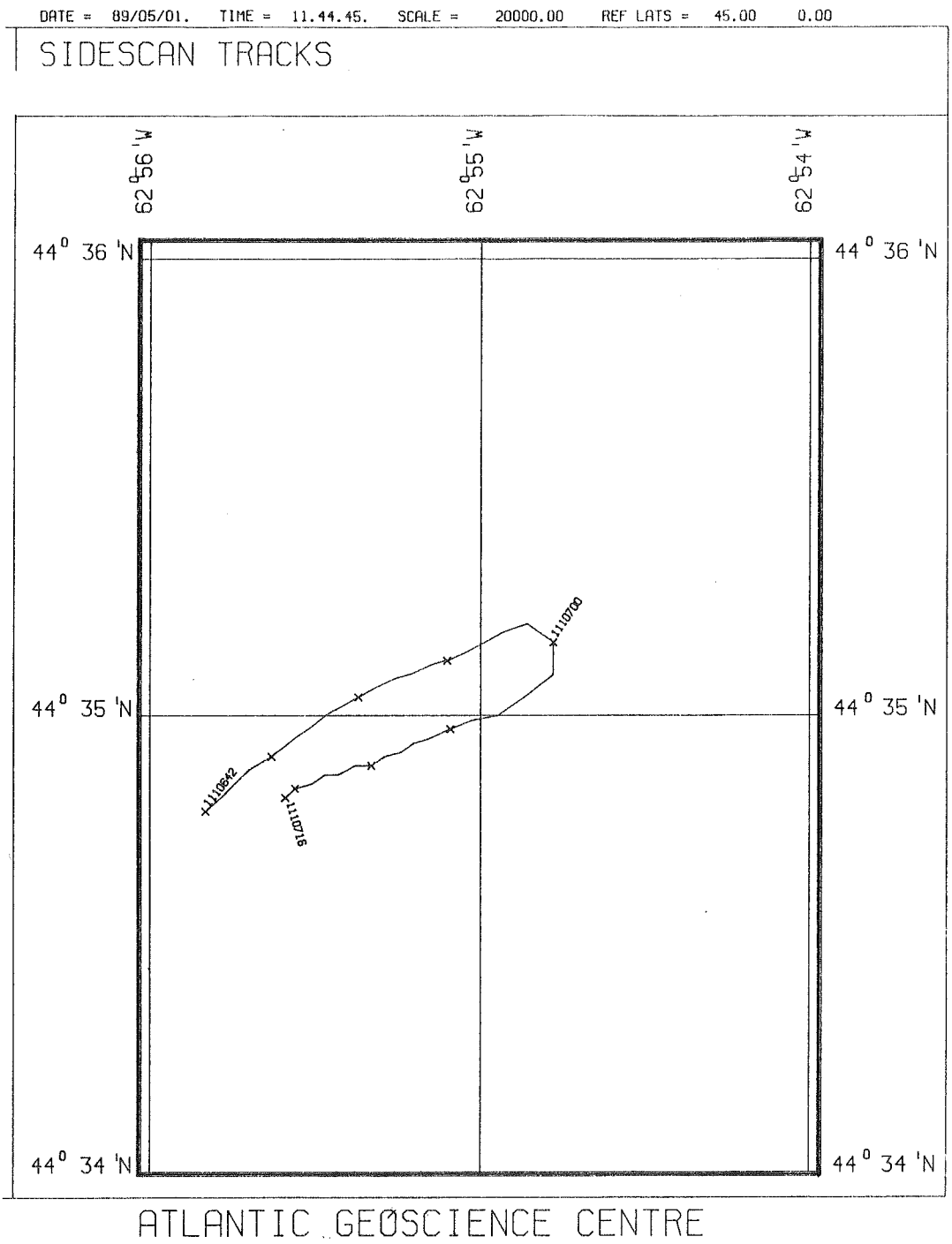

FIGURE 2

Ship's track for sidescan sonar survey (vicinity of site 1).

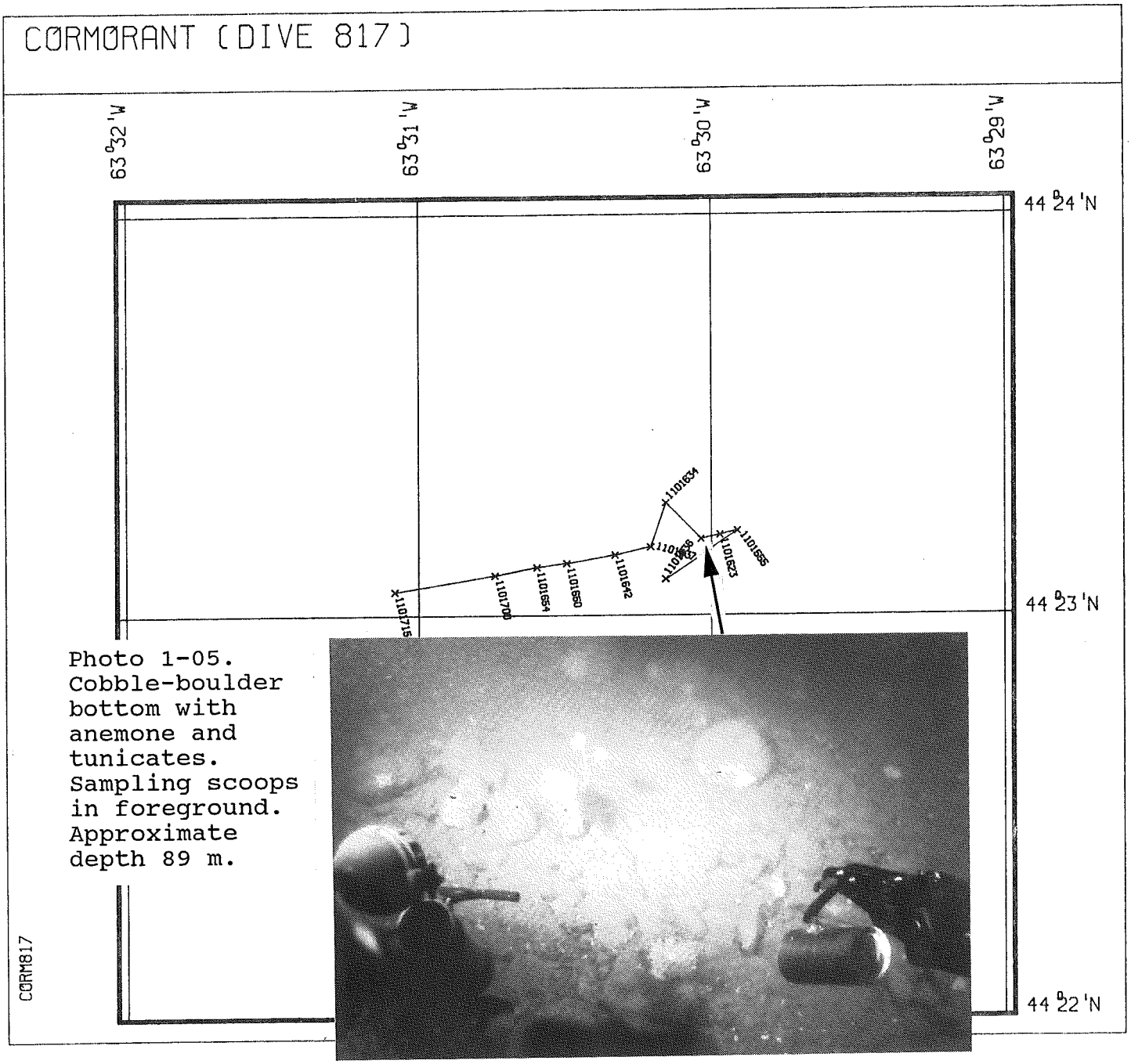

Photo 1-05. Cobble-boulder bottom with anemone and tunicates. Sampling scoops in foreground. Approximate depth 89 m.

FIGURE 3

SDL-1 track, dive 817.

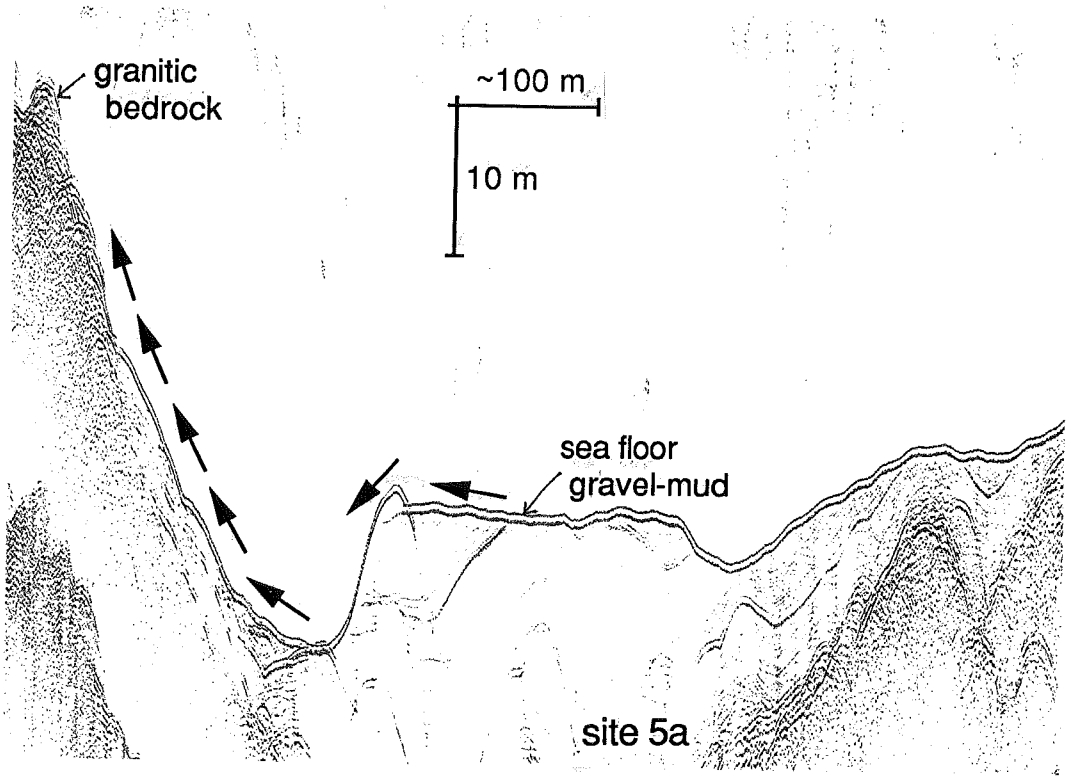

FIGURE 4

Deep-tow sparker shallow seismic record, site 5a, vicinity of dive 817 (from CSS Dawson cruise 87042). Arrows denote dive track (schematic).

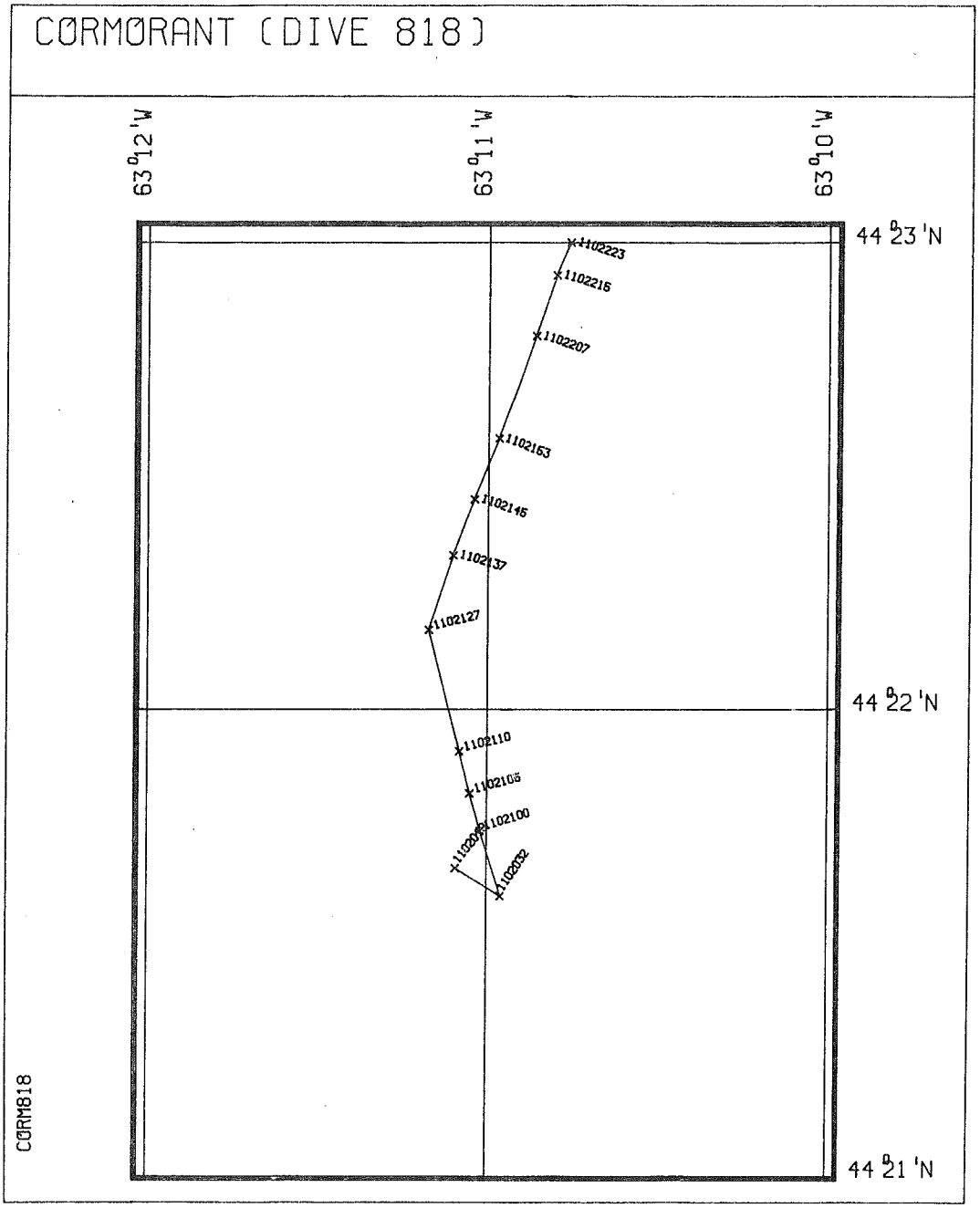

FIGURE 5

SDL-1 track, dive 818.

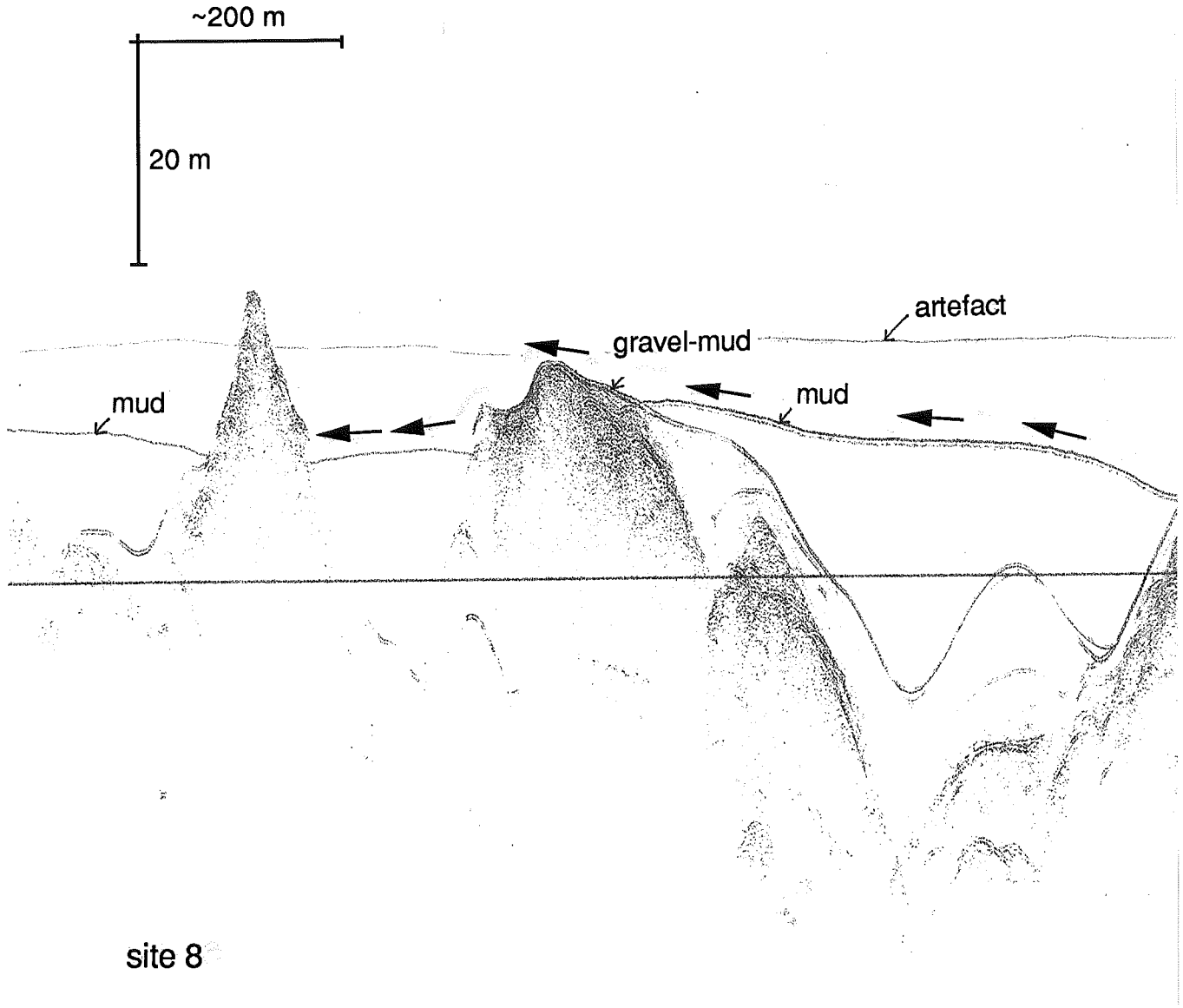

FIGURE 6

Deep-tow sparker shallow seismic record, vicinity of site 8 and dive 818 (from CSS Dawson cruise 87042). Heavy arrows denote approximate dive track.

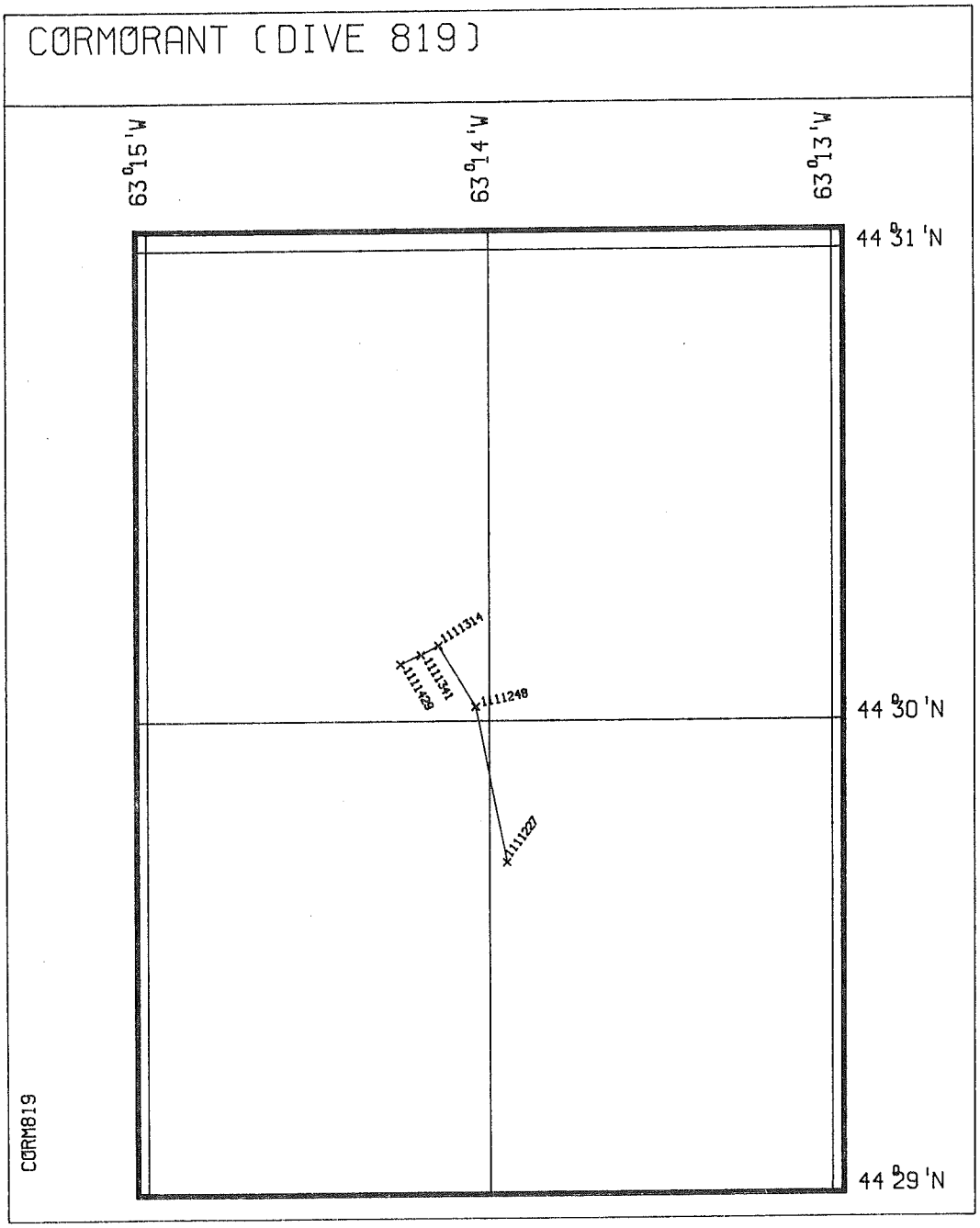

FIGURE 7

SDL-1 track, dive 819.

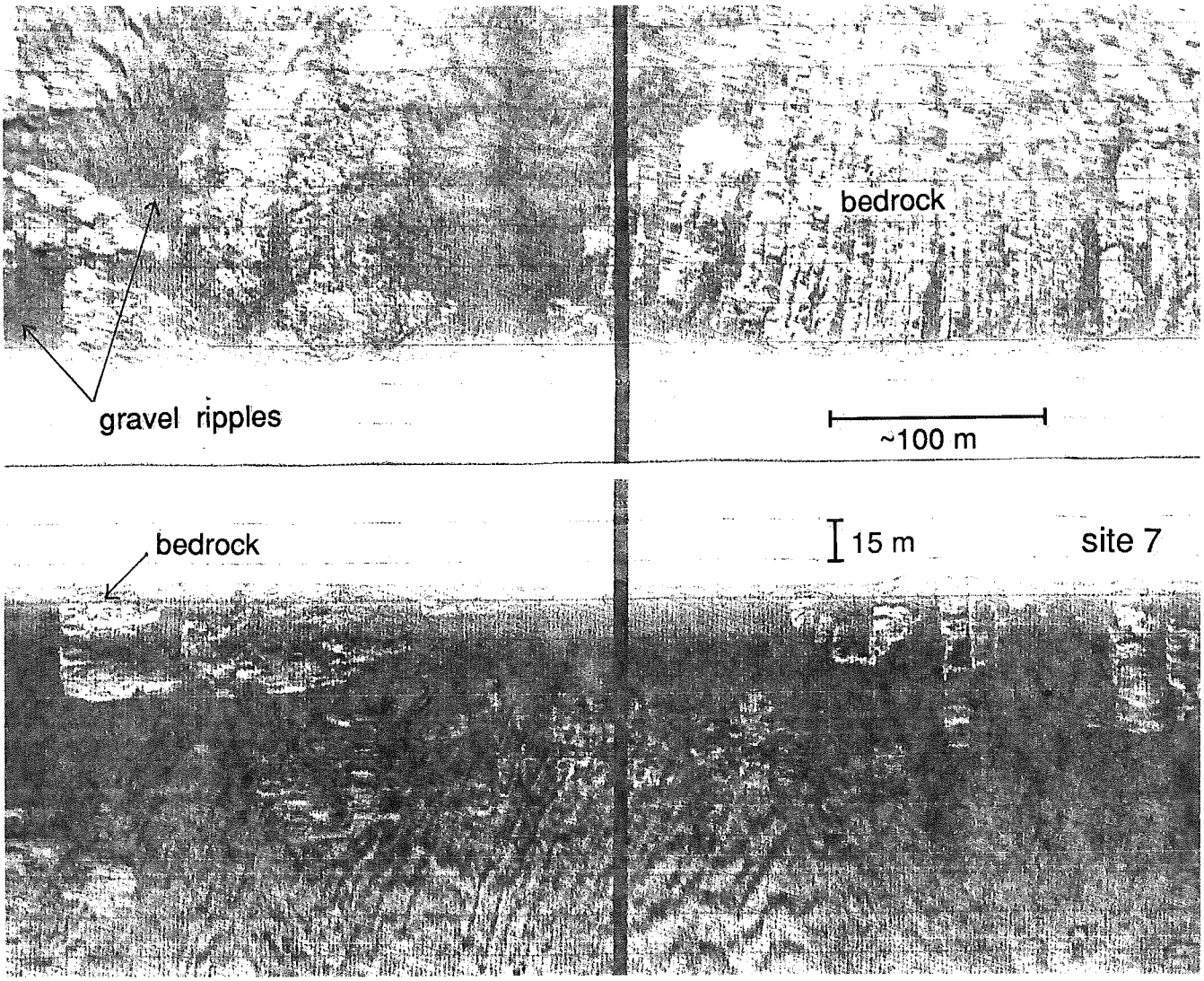

FIGURE 8

Sidescan sonar record, site 7, area of dive 819 (from CSS Dawson cruise 87042).

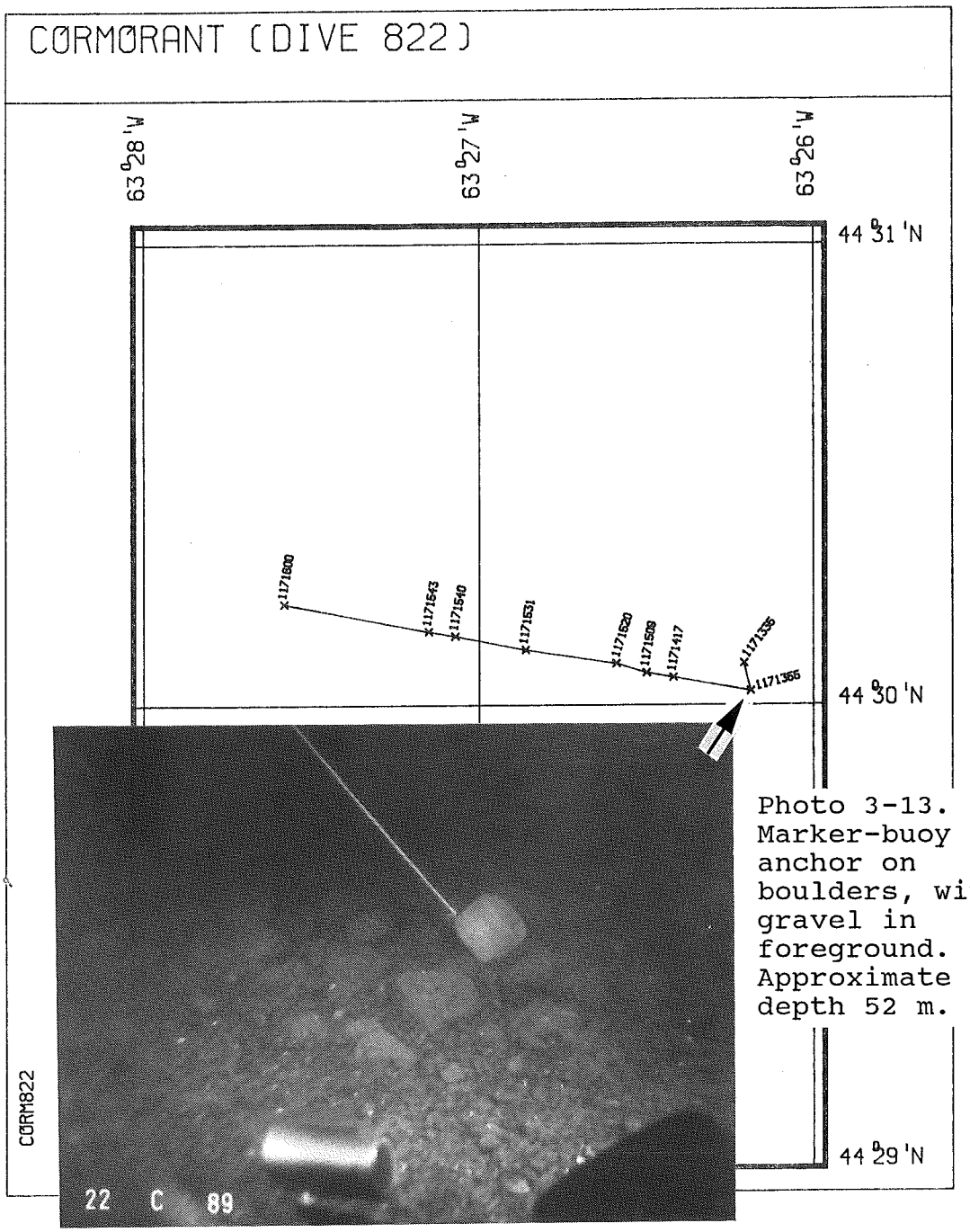

Photo 3-13. Marker-buoy anchor on boulders, with gravel in foreground. Approximate depth 52 m.

FIGURE 9

SDL-1 track, dive 822.

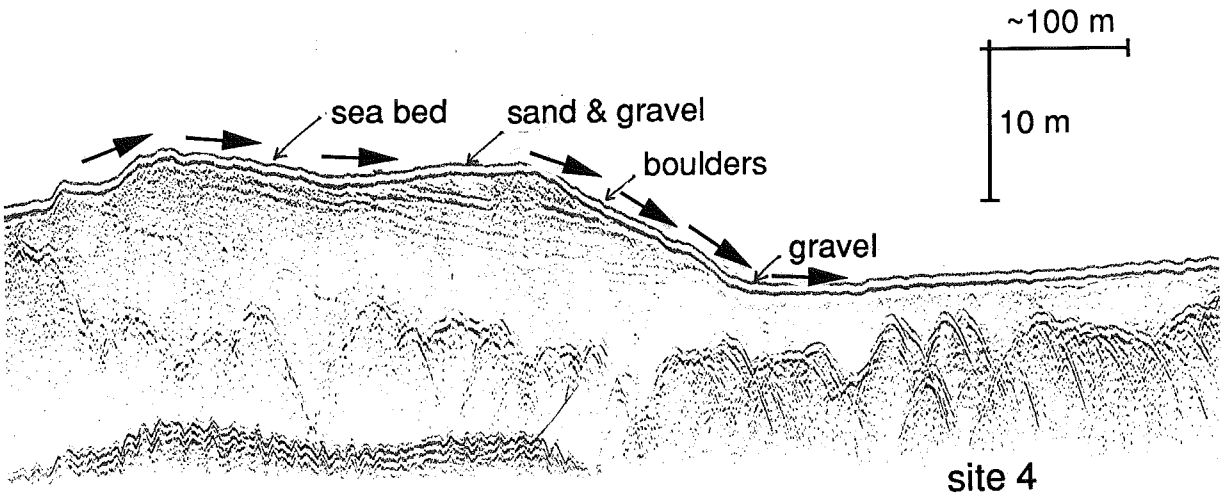

FIGURE 10

Deep-tow sparker shallow seismic record, site 4, area of dive 822 (from CSS Dawson cruise 87042). Heavy arrows denote approximate dive track.

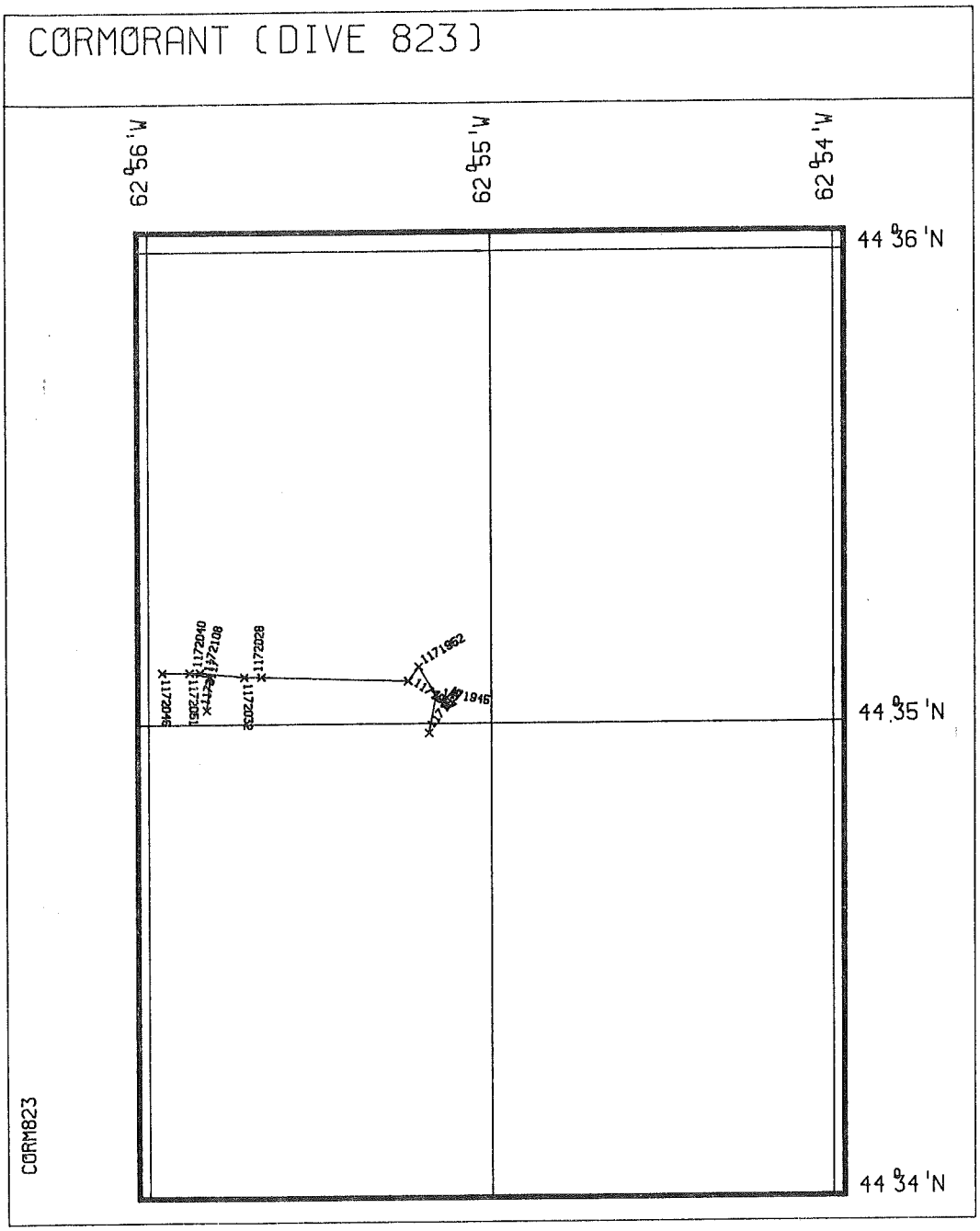

FIGURE 11

SDL-1 track, dive 823.

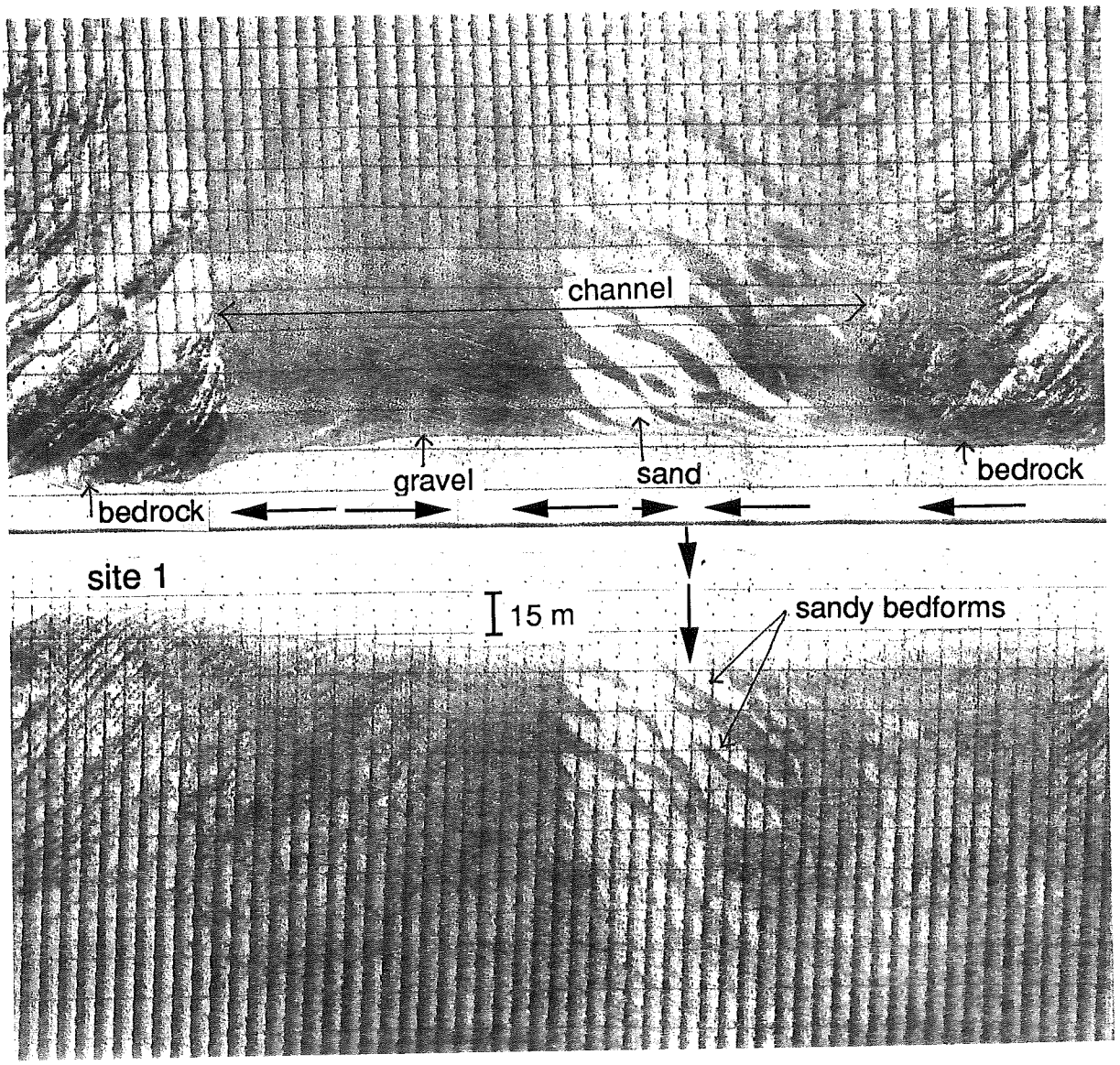

FIGURE 12

Sidescan sonar record, site 1, area of dive 823 (from CSS Dawson cruise 87042). Heavy arrows denote partial approximate dive track.

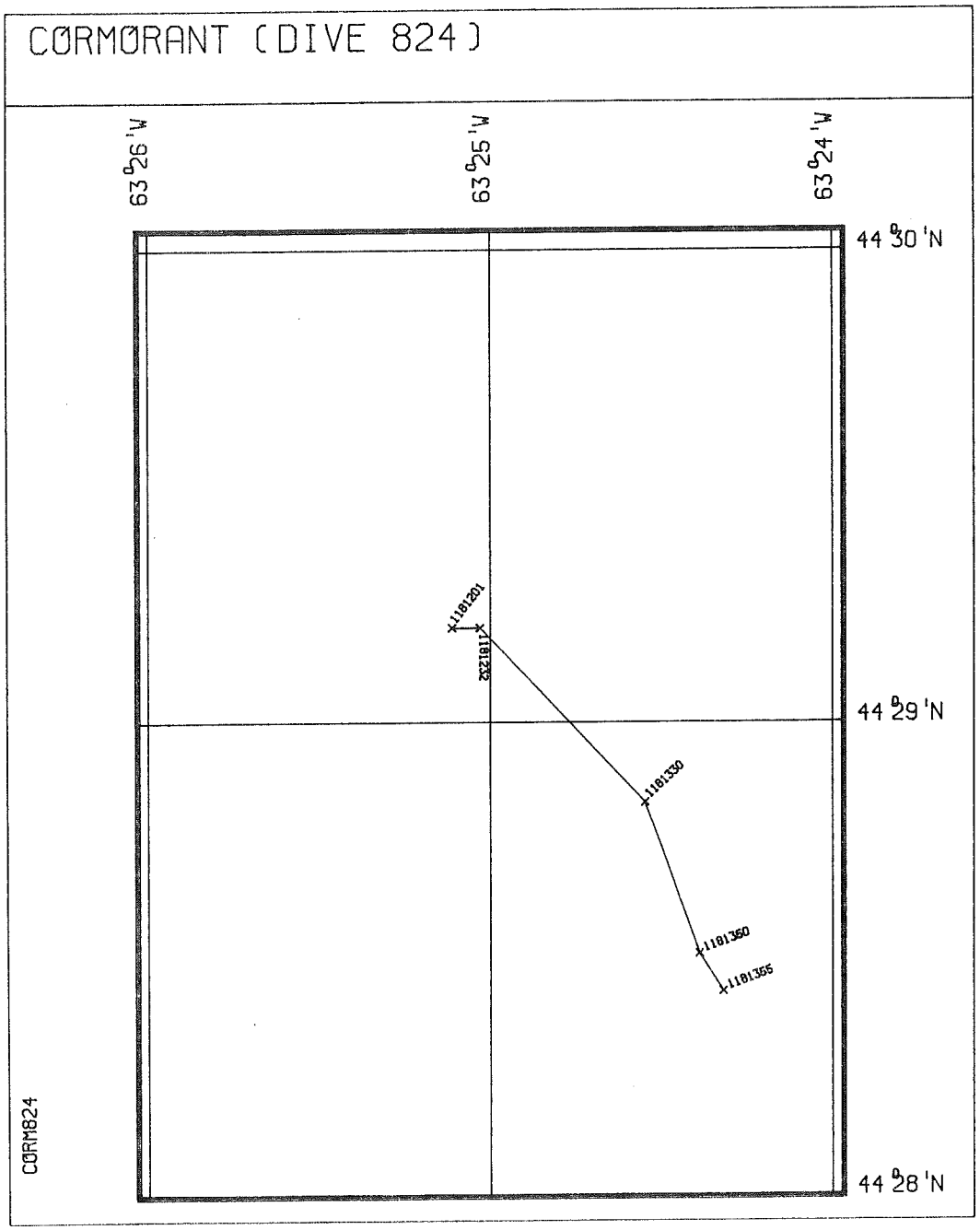

FIGURE 13

SDL-1 track, dive 824.

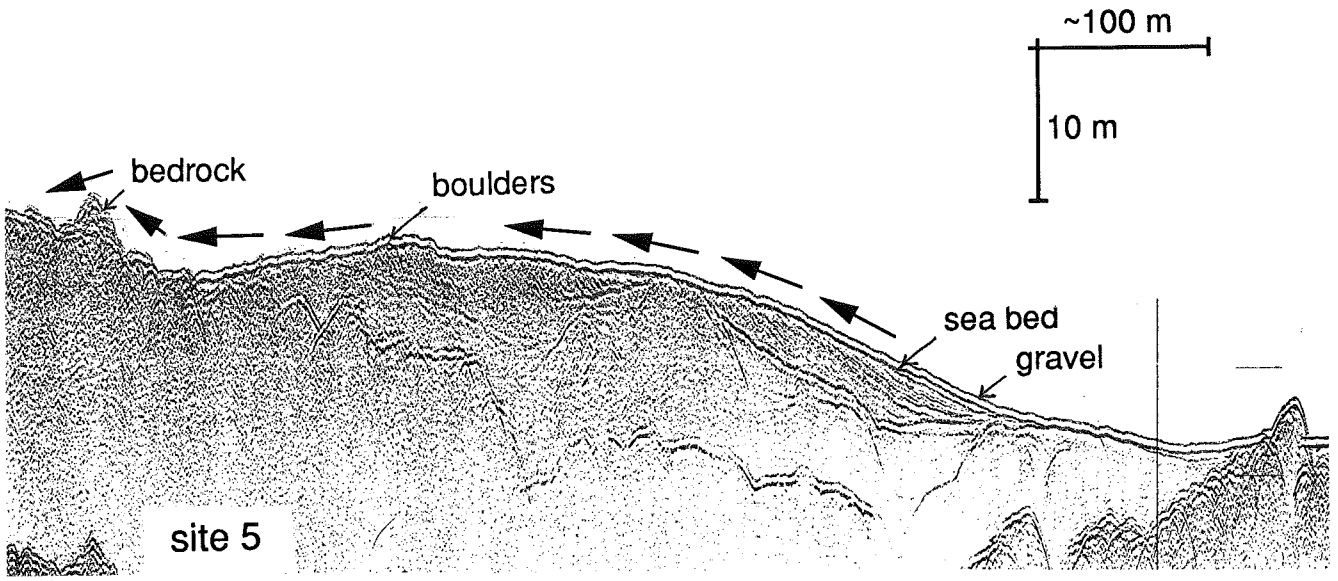

FIGURE 14

Deep-tow sparker shallow seismic record, site 5, area of dive 824 (from CSS Dawson cruise 87042). Heavy arrows denote approximate dive track.

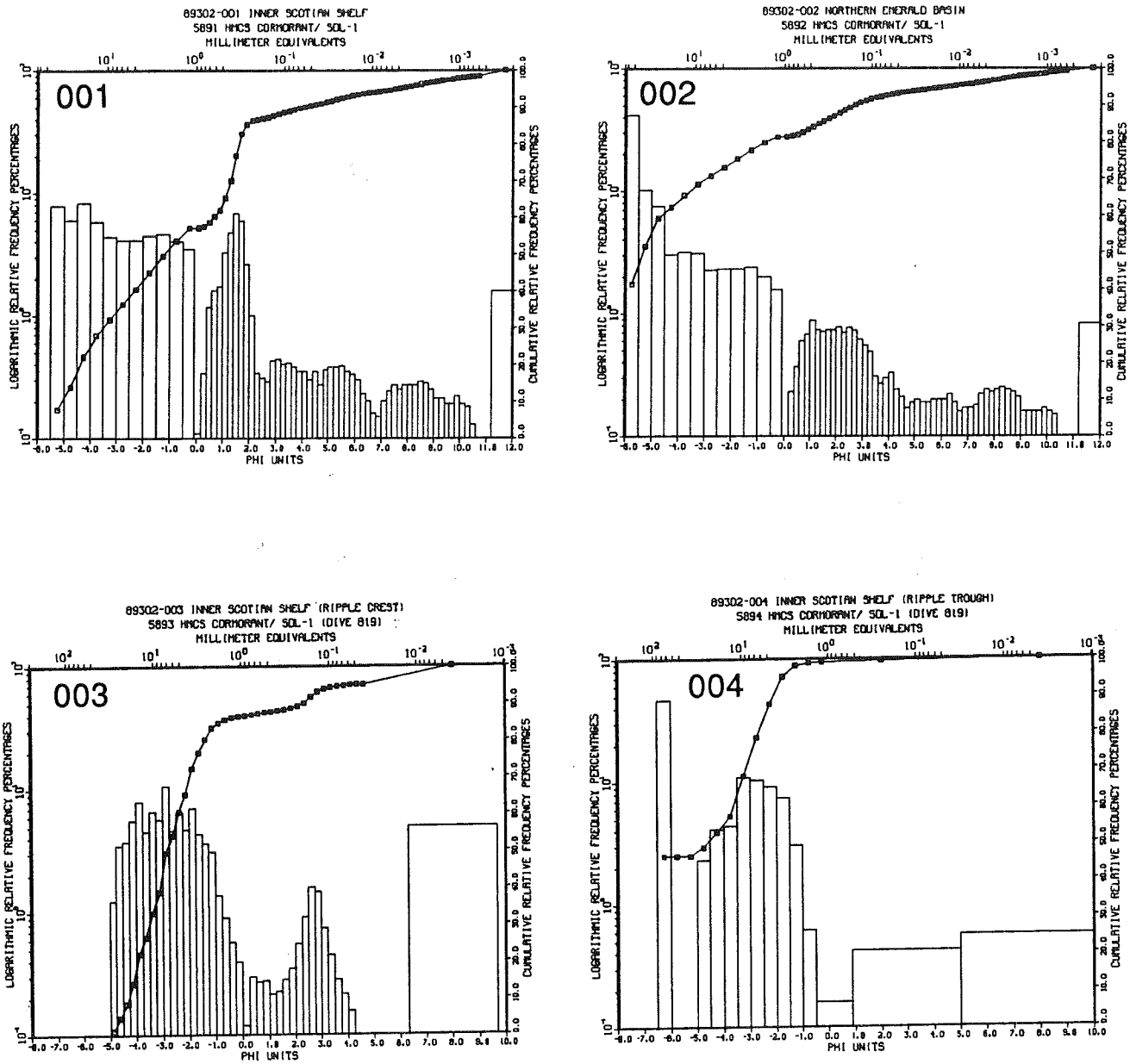

FIGURE 15

Grain size distributions displayed as histograms (logarithmic scale, 0.1-100%, on left axes) and cumulative curves (linear scale, 0-100%, on right axes) for samples 1 to 4 (dives 817 to 819).

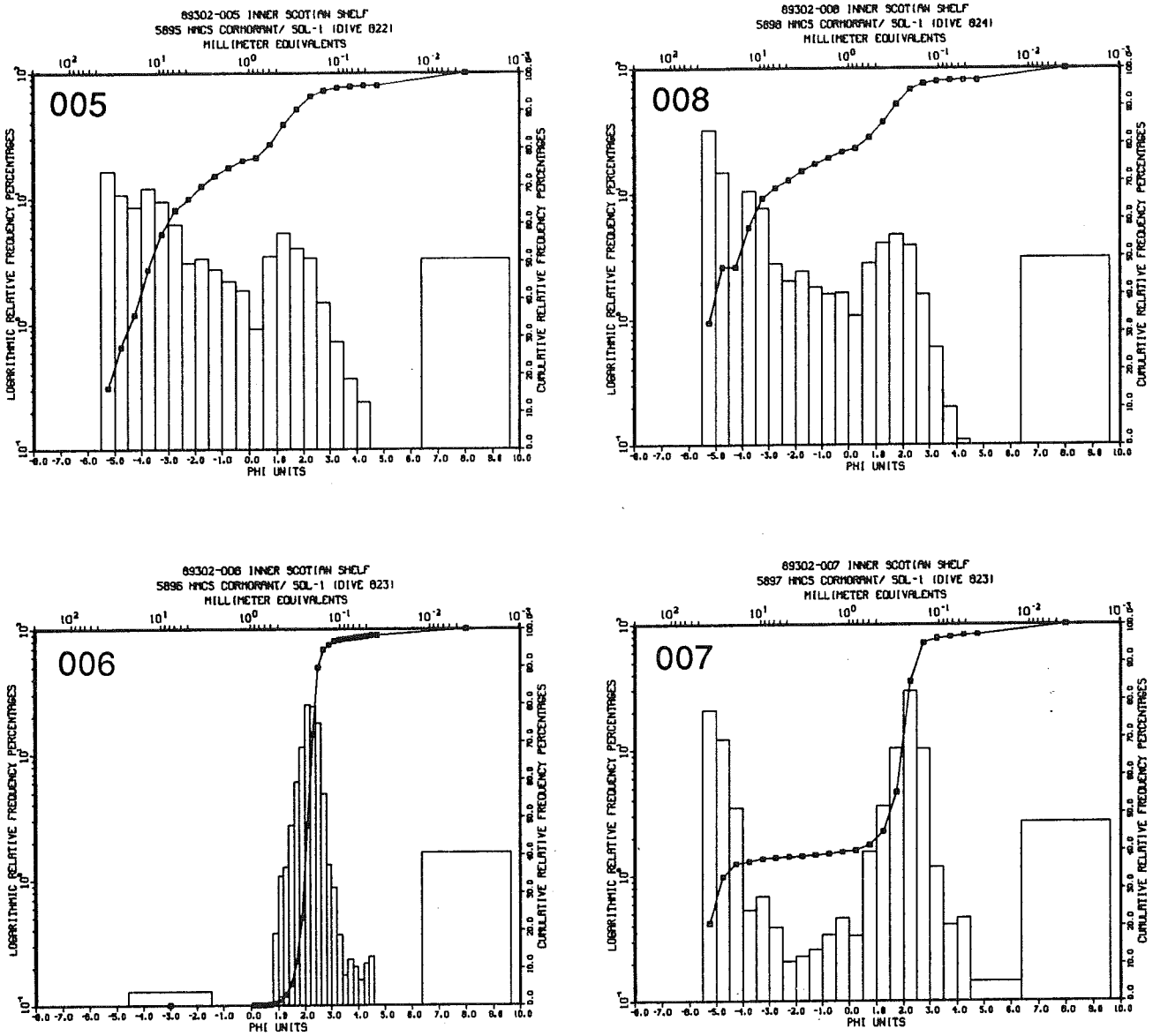

FIGURE 16

Grain size distributions displayed as histograms (logarithmic scale, 0.1-100%, on left axes) and cumulative curves (linear scale, 0-100%, on right axes) for samples 5 to 8 (dives 822 to 824).