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GREAT LAKES FISHERY COMMISSION

Research Completion Report*

SURFICIAL SUBSTRATES AND BATHYMETRY OF FIVE HISTORICAL LAKE TROUT SPAWNING REEFS IN NEARSHORE WATERS OF THE GREAT LAKES

by

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Introduction

The reestablishment of self-sustaining stocks of lake trout in the lower four Great Lakes is substantially impeded because stocked fish are unable to produce significant numbers of progeny that live to reach the size (about 120 mm) at which hatchery reared fish are stocked and generally show satisfactory survival. The causes for this failure are unknown, but researchers attending a Great Lakes Fishery Commission-sponsored conference on lake trout rehabilitation (Eshenroder et al. 1984) examined the extended list of hypotheses and attendant strategies developed to explain and resolve the problem and concluded (1) that habitat degradation might be a significant factor in preventing natural reproduction by stocked fish in nearshore waters in many areas of the lower four Great Lakes and (2) that better descriptions of the micro-habitats available on historical spawning reefs were a prerequisite for understanding the conditions that must be met to ensure that stocked fish establish self-sustaining populations in the lower four Great Lakes.

In 1985 an ad hoc committee[1] of the Great Lakes Fishery Commission (Eshenroder 1988) formulated a field bioassay approach (Manny et al. 1989) designed to permit evaluation of the effects of cultural eutrophication on lake trout spawning habitat and on lake trout reproduction. The committee also selected one site in each of the Great Lakes where the bioassays could be performed as a coordinated, multi-agency effort (Fig. 1) and recommended that these sites be surveyed with side-scan sonar to describe their physical features and identify substrates and micro-habitats where the bioassays might best be performed. The New York Department of Environmental Conservation also assisted in selection of the study sites in Lakes Erie and Ontario.

This paper presents the results of side-scan sonar surveys that we performed on the five sites in 1986-87 and provides an evaluation of the suitability of those sites as habitat for eggs, developing embryos, and fry of shallow-water or lean-strain lake trout.

Methods

We surveyed and mapped the lakebed using an EG&G[2] side-scan sonar system, which included a Model 260 microprocessor, Model 360 digital tape, and Model 272-T 100 kHz towfish with time-varied gain. Survey and mapping methods were virtually identical to those used earlier in studies conducted on lake trout spawning grounds in northern Lake Michigan (Edsall et al. 1989) and central Lake Huron (Edsall 1990). We deployed the towfish from a cable and davit over the side of the survey vessel and adjusted the length of the cable so that the towfish ran 2-4 m beneath the surface when the vessel cruised at 7.4 km/h (4 knots). The towfish directed an acoustic signal to the lakebed, received and amplified the echo from the lakebed, and transmitted it to the microprocessor. The microprocessor converted the signal into a continuous strip chart record showing, in plan view, the physical features of the surface

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[1] Members of the committee: T. A. Edsall, R. L. Eshenroder (Chair), D. J. Jude, J. R. M. Kelso, J. A. McLean, and J. W. Peck.

[2] Mention of brand names does not imply endorsement by U.S. Government.

of a 200-m wide strip of lakebed beneath the towfish. We pulled the towfish along a series of parallel transects that covered the area to be surveyed and mapped. To facilitate navigation, these transects followed Loran C isograms. Transect spacing was about 120 m and was designed to ensure overlapping representation of the lakebed on strip chart records for adjacent transects.

To facilitate interpretation of the side-scan records we examined the lakebed at selected locations within the survey area with a Benthos, Inc. Mini-Rover MK II remotely operated submersible equipped with a color video camera. The MK II was deployed on a tether by an operator who guided its movements with joystick controls, while monitoring the video camera images transmitted to a shipboard closed circuit video monitor. An alpha-numeric display of the depth at which the MK II was operating and the compass heading it was following was superimposed on the images of the lakebed and the entire screen display was videotaped to provide a permanent record of the lakebed.

The skids on which the MK II rested when it was on bottom extended forward into the field of view of the video camera and the distance between the skids (18 cm) was used as a scale to estimate the size of rocks and other lakebed objects recorded on the videotapes. The substrate interstitial depth (the vertical distance into loose rock substrates to which lake trout eggs and fry could gravitate) was estimated from the size composition and amount of piling of the loose rock and the degree to which sand or other fine sediments appeared to have infiltrated the loose rock substrate. Occasionally a Ponar grab was used to confirm the identity of sediments identified in the field on the strip charts as sand or mud and to collect small rocks.

In the laboratory we assembled the strip charts to form 1:1000 scale, "mosaic" maps of each area that we surveyed. A regression technique (Edsall et al. 1989) was employed to ensure the strip chart records were accurately aligned in the mosaic. Substrate components were classified according to a modified Wentworth scale as sand (<2 mm), gravel (2-64 mm), rubble (65-256 mm), cobble (257-999 mm), or boulders (>999 mm). Where these components occurred in mixtures, we identified the two that covered the largest and second largest amounts of lakebed and described the mixture on the basis of those components.

We also constructed a bathymetric overlay for each mosaic map using the graphic information displayed on the margin or "profile" section of each strip chart composing the mosaic (Edsall et al. 1989). We digitized the mosaic maps and bathymetric overlays, entered them into a geographic information system, and produced computer-drawn maps at 1:4,000, 1:6,000, or 1:8,000 scale showing the distribution of major substrates and the bathymetry of each surveyed area. These maps are on file at the National Fisheries Research Center-Great Lakes and copies are available from the Great Lakes Fishery Commission.

Illustrations of the substrates described in this report were obtained in the laboratory by photographing videotape images of the lakebed that were displayed on a television monitor.

Results and Discussion

Partridge Island Reef

Partridge Island Reef lies between Granite Point and Larus Island near the south shore of Lake Superior and is separated from the mainland shore by water 20 m deep. (Fig. 2). We mapped an area of lakebed that surrounded the crest of the reef and covered about 366 ha (Fig. 3). Water depth ranged from 14 m on the crest of the reef to more than 32 m at the north end of the mapped area. At depths of 14-20 m the reef was roughly oval in shape with regular bathymetry. Substrates at the crest of the reef were smooth bedrock, broken bedrock with scattered rubble, and rubble layers with cobble piles. The rubble layers with cobble piles substrate (Fig. 4) was the border of the reef to the south and west at depths of 14-22 m. Bedrock and broken bedrock with scattered rubble were the major substrates at 14 m to about 23 m. Bedrock covered by sand patches and rubble patches on sand formed the north and east borders of the reef at depths of about 23-32 m. Sand surrounded the reef on three sides in the mapped area and occurred at depths as shallow as 20 m on the west side of the reef. Large sand ripples with crest to crest distances of 3-4 m were apparent on the mosaic map adjacent to the north end of the rubble layers with cobble piles substrate (Fig. 5).

The substrate on Partridge Island Reef that best met the criteria for good spawning and fry production habitat for shallow-water or lean-strain lake trout, as described by Wagner (1982), Nester and Poe (1984), Peck (1986), Marsden et al. (1988), and Marsden and Krueger (1990), was the rubble layers with cobble piles (Fig. 4) that covered about 42 ha on the east side of the reef. This substrate uniformly displayed interstitial depths of 30 cm or more. The absence of fine sediments on this portion of the reef and the presence of large sand ripples immediately adjacent to the reef in water 22-26 m deep indicated the rubble layers with cobble piles substrate was periodically subjected to strong scouring by littoral currents. The broken bedrock with scattered rubble substrate that covered about 42 ha on the reef also provided suitable substrate in patches where the interstitial depth exceeded 20 cm. Both the rubble layers with cobble piles substrate and the broken bedrock with scattered rubble substrate extended beyond the southeast border of the mapped area. None of the other substrates that we mapped on the reef had sufficient interstitial depth to serve as spawning or fry production habitat.

Wilmette Reef

Wilmette Reef is a small, rocky bedrock outcrop about 10 km northeast of Wilmette, Illinois in southern Lake Michigan (Fig. 6). The reef lies on the lakeward edge of a broad, gently sloping plateau. East of the reef the lakebed drops more sharply to depths of 30 m or more. We mapped an area of lakebed surrounding the reef crest and covering about 322 ha (Fig. 7). Water depth ranged from about 12 m on the reef crest to 28 m in the southeast corner of the mapped area. The reef was roughly oval in shape at depths of 12-16 m and was composed mostly of bedrock ridges. This central portion of the reef was surrounded by a relatively narrow band of rubble piles with sand patches and sand with scattered rubble, mostly at depths of 20-22 m. Rubble with sand was the major substrate on most of the rest of the mapped area at depths of about 20-28 m. Small areas of sand, sand with scattered rubble, and gravel with scattered rubble were present at depths of about 23-28 m in the southeast portion of the mapped area.

None of the substrate that we surveyed with side-scan sonar and examined with the MK II submersible on Wilmette Reef was suitable for spawning or fry production by lake trout. The bedrock ridges that were the major bathymetric feature composing the reef were free of the loose rock overburden needed to create suitable spawning and fry production habitat for lake trout. Only scattered patches of widely spaced rubble and a patchy veneer of sand were present on top of the bedrock ridges substrate and the interstitial depth on this substrate was zero. The rubble piles with sand patches substrate had interstitial depths to 5 cm in places, but extensive infilling with sand rendered this substrate unsuitable as fry production habitat. The interstitial space in the other substrates in the surveyed area was zero.

Port Austin Reef

Port Austin Reef occupies the lakeward end of a submerged, rocky point extending 3-4 km into southeast Lake Huron near the mouth of Saginaw Bay at Port Austin, Michigan (Fig. 8). We mapped an area covering about 430 ha surrounding the crest of Port Austin Reef (Fig. 9). Water depth was about 6 m at the crest of the reef and the reef at depths of 6-12 m was basically oval in shape. The reef sloped steeply into water 20 m or more deep to the north and a narrow band of water about 13 m deep separated the reef crest area from the shallower water bordering the shoreline to the south. Substrate distribution on the mapped portion of the reef was complex. The reef crest at depths of 6-12 m was composed mostly of smooth bedrock and bedrock with cobble patches. A small intrusion of cobble on bedrock was present on the southeast side of the crest and cobble evenly distributed on sand bordered the crest on the south. The smooth bedrock, cobble on bedrock, and cobble patches on sand were all extensions of substrate types that continued lakeward from the shallower water bordering the shoreline to the south. The bedrock with cobble patches substrate that surrounded the reef crest on three sides extended shoreward in a narrow finger to about the 12 m depth and also extended to the northeast to a depth greater than 20 m. Clay ridges with sand was a major substrate along the east and west borders of the mapped area at depths less than 18 m. These ridges were conspicuous features on the mosaic; they were about 5 m wide, up to 100 m long and were oriented roughly north to south (Fig. 10). The ridges appeared to be composed of stiff clay with inclusions of gravel-sized to rubble-sized rock, suggesting they were glacial till. At depths greater than 18 m the substrate was mostly sand with scattered rubble, sand with cobble patches, sand on broken bedrock, and cobble patches on sand.

On Port Austin Reef the best substrate for lake trout spawning and fry production was the bedrock with cobble patches (Fig. 11) that covered about 56 ha on the north, east, and west sides of the crest of the reef. Interstitial depth exceeded 20 cm on most of this substrate. The cobble on bedrock substrate (Fig. 12) that covered about 39 ha and extended shoreward from the south side of the crest of the reef to the boundary of the mapped area provided scattered patches of substrate several meters in diameter with interstitial depths of 20 cm or more and was also suitable spawning and fry production habitat for lake trout. The other substrates in the mapped area had interstitial depths of less than 5 cm and were unsuitable habitat.

Brocton Shoal

Brocton Shoal is a bedrock outcrop about 4-8 km offshore in eastern Lake Erie near Brocton, New York (Fig. 13). The shoal spans the 20 m depth contour and appears to be an underwater extension of Van Buren Point. Water depth between the shoal and the shoreline exceeds 15 m. The lakebed angles sharply downward north of the shoal and somewhat less sharply to the west. We mapped an area of lakebed covering about 753 ha on the shoal (Fig. 14). Three shoal crests were present in the mapped area. Water depth ranged from 16 m on the central crest and 18 m on the eastern and western crests, to 26 m in the northwest corner of the mapped area. The eastern crest, which was only partly represented in the mapped area was composed of worn bedrock at 18-22 m and was bordered on the west by sand with scattered rubble and by broken bedrock covered by sand. The central crest at depths of 16-22 m was mostly worn bedrock. Broken bedrock covered by sand and cobble ridges scattered on sand bordered the worn bedrock on the south and west at 18-20 m; sand with scattered rubble composed the border to the east and north at 18-22 m. The western crest at 18-22 m was worn bedrock, broken bedrock with scattered boulders, and broken bedrock covered by sand. This crest was surrounded by sand except on the northwest corner where broken bedrock covered by sand bordered the worn bedrock at 26 m. Broken bedrock covered by sand occupied a portion of the southwest corner of the mapped area at 18-22 m.

The best substrate for spawning and fry production on Brocton Shoal was the cobble ridges on sand that occupied about 38 ha on the south and west edges of the central reef crest. These ridges, which were about 2 m high (Fig. 15) were readily apparent on the mosaic as sinuous features about 5-10 m wide, 100 m or more long (Fig. 16). The rock comprising the ridges was clean when it was photographed in July (Fig. 17) and the interstitial depth appeared to exceed 30 cm. The broken bedrock with scattered boulders substrate that covered 9 ha on the east slopes of the central and western crests was marginal spawning and fry production habitat, because interstitial depths were less than 10 cm and the spaces between the rocks were large enough to admit small fish that could prey on eggs and fry. None of the other substrates on Brocton Shoal were suitable as habitat for lake trout spawning and fry production.

Charity Shoal Complex

Charity Shoal Complex is a bedrock outcrop composed of Charity Shoal, East Charity Shoal and South Charity Shoal. This shoal complex straddles the International Border about 8 km south of Wolf Island at the head of the St. Lawrence River in eastern Lake Ontario (Fig. 18). East Charity Shoal Light occupies a small, rocky island at the north end of that shoal. Water 18 m or more deep surrounds the shoal complex. We mapped an irregularly shaped area of lakebed covering about 996 ha (Fig. 19). Within the mapped area the shoal was a ring-like structure with a tail that extended to the southwest. A pocket of deep water occupied the area within the ring of shoal water. Water depth in the mapped area, excluding the small portion of East Charity Shoal occupied by the lighthouse, ranged from about 6 m to slightly more than 22 m. The maximum depth in the deepwater area in the center of the shoal complex was 18 m.

A Ponar grab sample revealed that the substrate in the deepwater area in the center of the shoal was stiff, varved clay covered with a layer of coarse brown sand about 1-2 cm thick. A ring of broken bedrock evenly distributed on bedrock surrounded the sand, mostly at depths of 10-14 m and was surrounded, in turn, at depths of about 6-14 m, by worn bedrock ridges with patches of broken bedrock. The bedrock ridges were conspicuous features on the mosaic (Fig. 20). Rubble with broken bedrock and broken bedrock evenly distributed on bedrock bordered the worn bedrock ridges, except on the southeast edge of the shoal, where sand with scattered cobble was the bordering substrate at depths of 14-22 m. Sand with scattered cobble was also present on the northeast end of the shoal, mostly at depths greater than 14 m, and at the south end of the shoal at depths greater than 20 m.

The best spawning and fry production habitat for lake trout on the Charity Shoal Complex was the rubble with broken bedrock substrate (Fig. 21) that bordered most of the mapped area; in this substrate, piling of the loose rock created interstitial depths of 30 cm or more in patches on about the 20 m depth contour in the north east corner of the mapped area and at 14 m on the west side of the mapped area. The worn bedrock ridges with patches of broken bedrock substrate provided only marginal spawning and fry production habitat in small, widely spaced patches; little piling of loose rock occurred in this substrate, interstitial depth was usually less than 10 cm, and interstitial spaces were usually large enough to admit small fish that could prey upon eggs and fry. The other three substrates that we mapped were unsuitable habitat for lake trout spawning and fry production. The broken bedrock substrate exhibited a relatively continuous distribution of unpiled loose rock, with interstitial depths of less than 5 cm. The sand substrate and the sand with scattered cobble substrate had interstitial depths of zero.

Summary and Conclusions

Four of the five historical lake trout spawning grounds that we surveyed and mapped in the present study contained substrates that conformed to descriptions in the literature of what is believed to be good to excellent spawning and fry production habitat for the shallow-water strains of lake trout that are now being stocked into the Great Lakes. These substrates were in the 6 to 22 m depth range and were in the photic zone. They were composed largely of rounded or angular rubble and cobble that was piled sufficiently to provide narrow interstitial spaces 20 cm or more deep that would protect naturally spawned eggs and fry from predators, ice scour, and buffeting by waves and currents.

Results of the side-scan sonar surveys at Partridge Island Reef in Lake Superior and Port Austin Reef in Lake Huron have already been used by Great Lakes Fishery Commission cooperators to help plan and conduct egg survival field bioassays (Manny et al. unpublished data), which confirmed that the best substrates on both reefs have the potential to produce viable, swim-up fry from spawnings by local feral broodstocks of hatchery origin. Among the three other sites covered by the present study, it appears that Brocton Shoal in Lake Erie offers the best habitat for spawning and fry production by contemporary lake trout stocks of hatchery origin; the best substrate there is clean, deep, and reasonably contiguous. Charity Shoal Complex also contains suitable substrate, but it is distributed in relatively small, isolated, patches and exhibits a light to moderately thick covering of periphyton and silt. No suitable substrate was found on Wilmette Reef; periphyton covered most rock surfaces and the near absence of loose, piled rock coupled with infilling by sand essentially reduced the interstitial space to zero on the portion of the reef that we surveyed. If a site in southern Lake Michigan is needed for egg survival studies, Wilmette Reef should probably be rejected.

Acknowledgments

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References

Edsall, T. A. 1990. Lake trout spawning habitat in the Six Fathom Bank-Yankee Reef lake trout sanctuary, Lake Huron. Research Completion Report, Great Lakes Fishery Commission, Ann Arbor, Michigan.

Edsall, T. A., T. P. Poe, R. T. Nester, and C. L. Brown. 1989. Side-scan sonar mapping of lake trout spawning habitat in northern Lake Michigan. N. Am. J. Fish. Manag. 9:269-279.

Eshenroder, R. L. (ed.). 1988. A proposal for a bioassay procedure to assess impact of habitat conditions on lake trout reproduction in the Great Lakes. Great Lakes Fishery Commission Spec. Pub. 88-2, 12 p, Ann Arbor, Michigan.

Eshenroder, R. L., T. P. Poe, and C. H. Olver, eds. 1984. Strategies for rehabilitation of lake trout in the Great Lakes: proceedings of a conference on lake trout research, August 1983. Technical Report 40, Great Lakes Fishery Commission, Ann Arbor, Michigan.

Manny, B. A., D. J. Jude, and R. L. Eshenroder. 1989. Field test of a bioassay procedure for assessing habitat quality on fish spawning grounds. Trans. Am. Fish. Soc. 118:175-182.

Marsden, E. J., C. C. Krueger, and C. P. Schneider. 1988. Evidence of natural reproduction by stocked lake trout in Lake Ontario. J. Great Lakes Res. 14:3-8.

Marsden, T. E. and C. C. Krueger. 1990. Comparison of substrate selected by spawning lake trout, and evaluation of techniques for egg collection. Great Lakes Fishery Commission Research Completion Report, 11p. Ann Arbor, Michigan.

Nester, R. T. and T. P. Poe. 1984. First evidence of successful natural reproduction of planted lake trout in Lake Huron. North Am. J. Fish. Manag. 4:126-128.

Peck, J. W. 1986. Dynamics of reproduction by lake trout on a man-made spawning reef. J. Great Lakes Res. 12:293-303.

Wagner, W. C. 1982. Lake trout spawning habitat in the Great Lakes. Michigan Department of Natural Resources, Fisheries Research Report Number 1904, Ann Arbor, Michigan.

Figure 1. Locations (●) of side-scan sonar surveys.

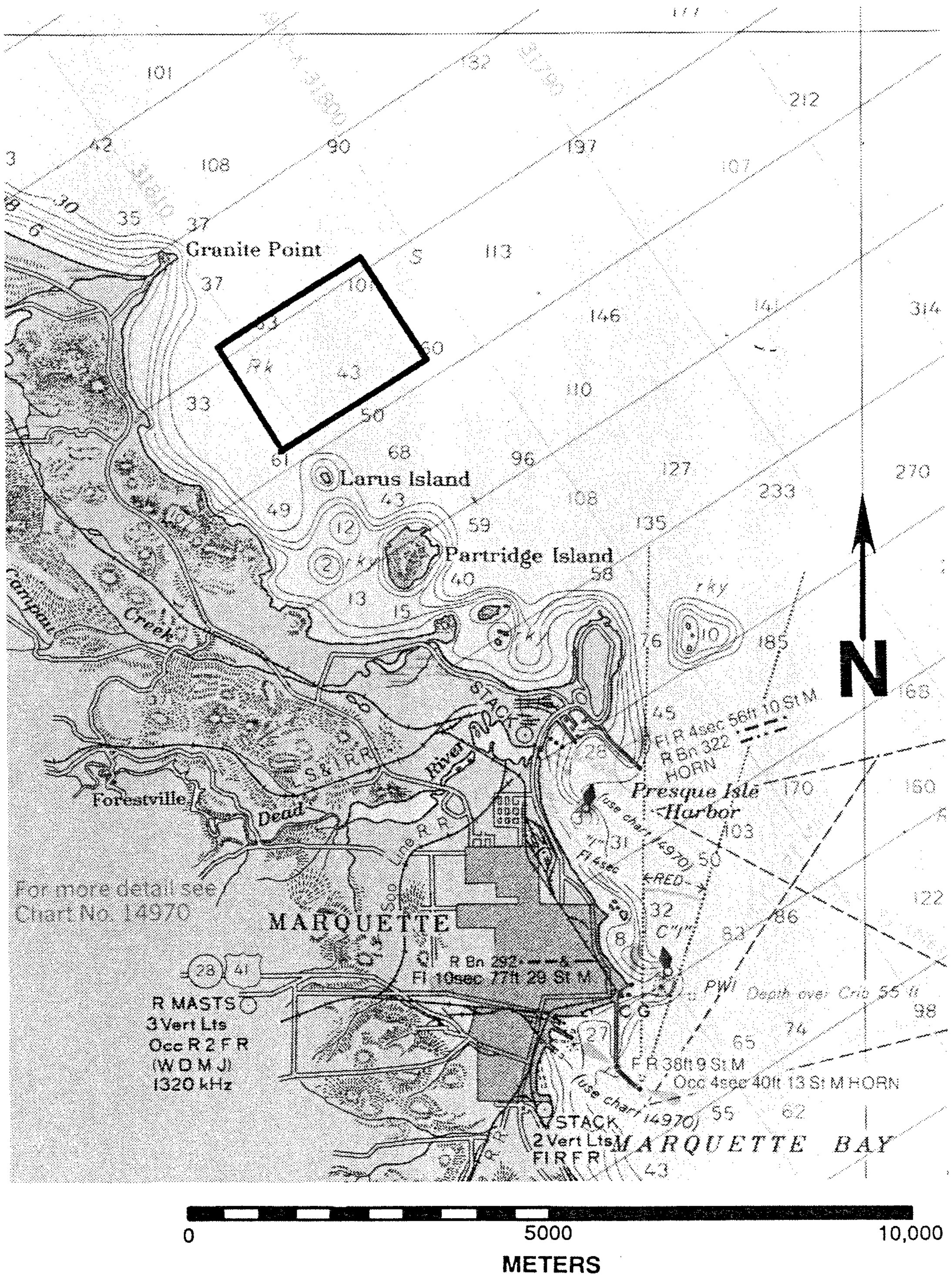

Figure 2. Location of side-scan sonar survey on Partridge Island Reef, Lake Superior. Plotted on NOAA chart 14963, Oct. 1981; depths are in feet.

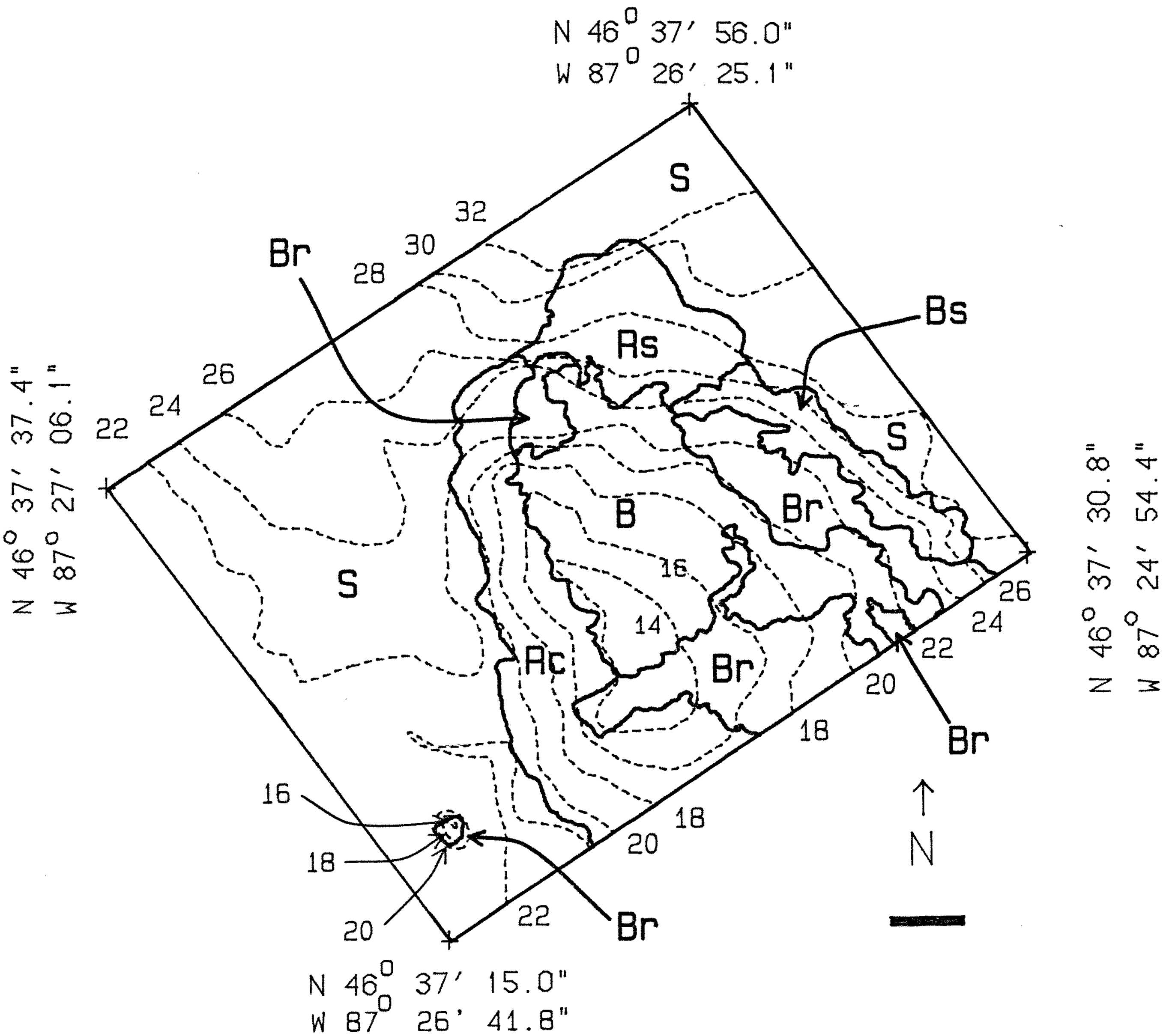

Figure 3. Partridge Island Reef substrates and bathymetry. Water depths (dashed lines) are in meters. Bar represents 0.2 km.

Substrate		Hectares
S - Sand		195.75
Rc - Rubble layers with cobble piles		41.98
Rs - Rubble patches on sand		19.87
Bs - Bedrock covered by sand patches		13.31
Br - Broken bedrock with scattered rubble		42.07
B - Smooth bedrock		52.83
	Total	365.81

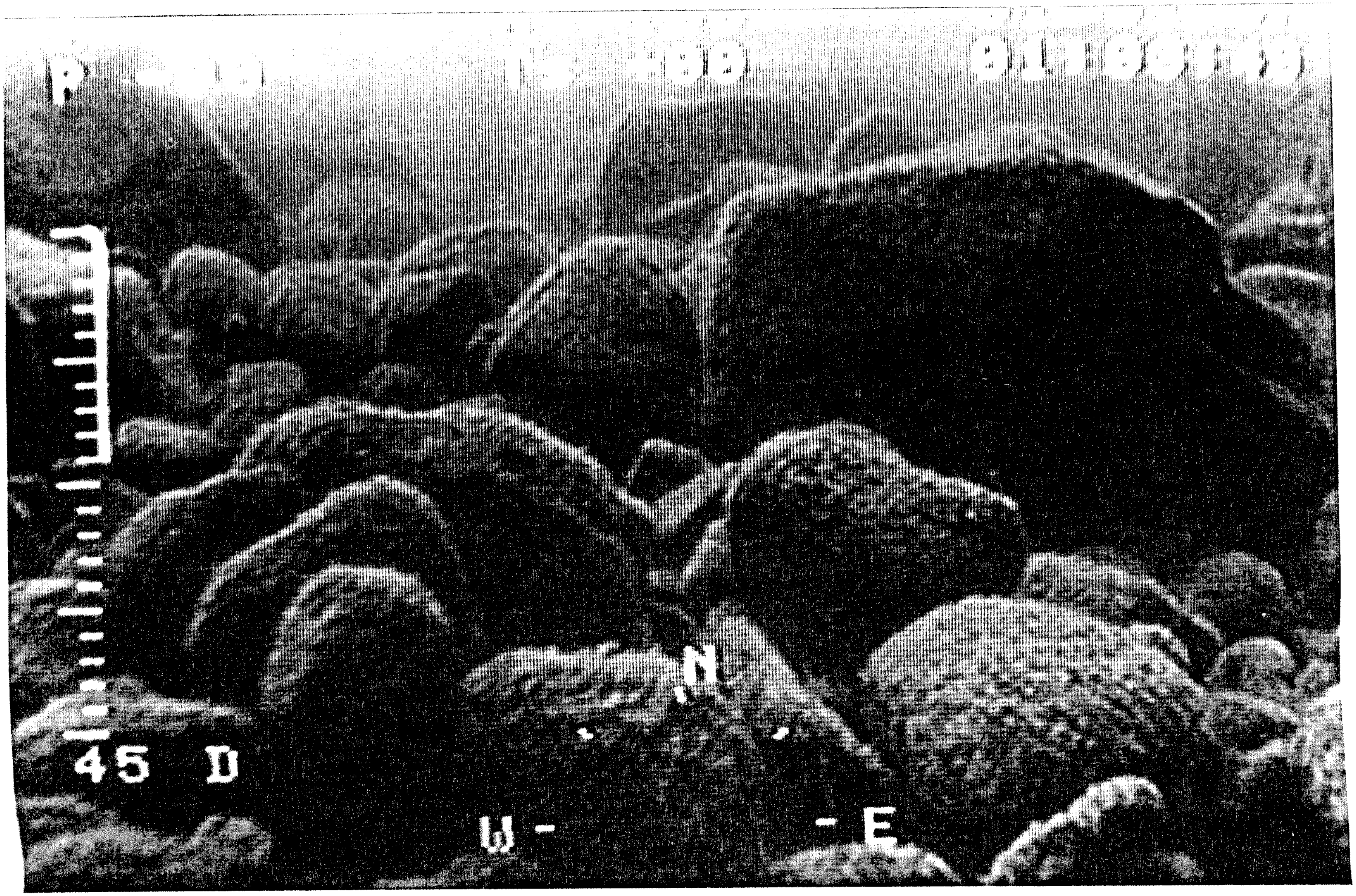

Figure 4. Rubble layers with cobble piles substrate on Partridge Island Reef.

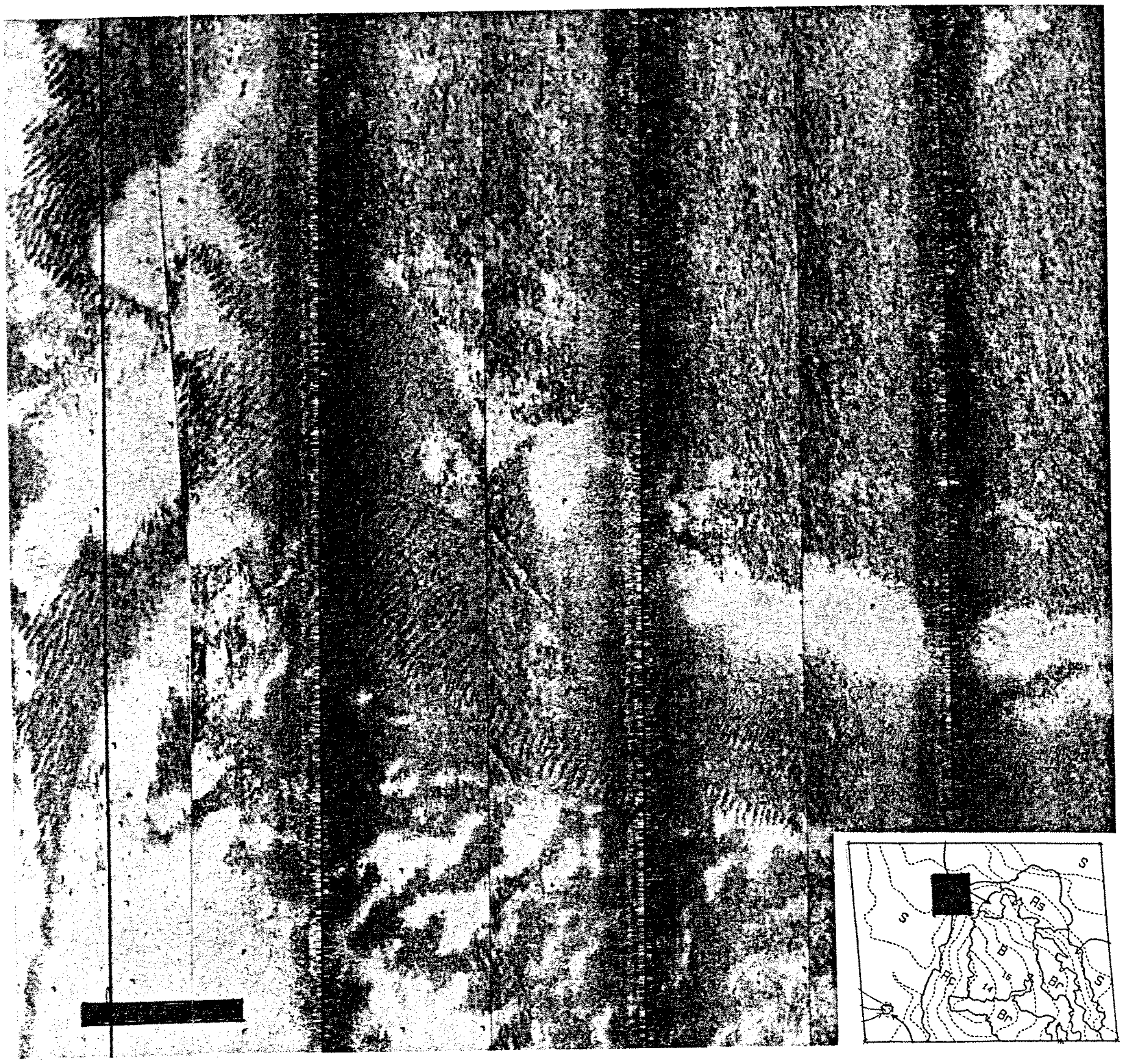

Figure 5. Large sand ripples at the north end of Partridge Island Reef. Bar represents 50 m.

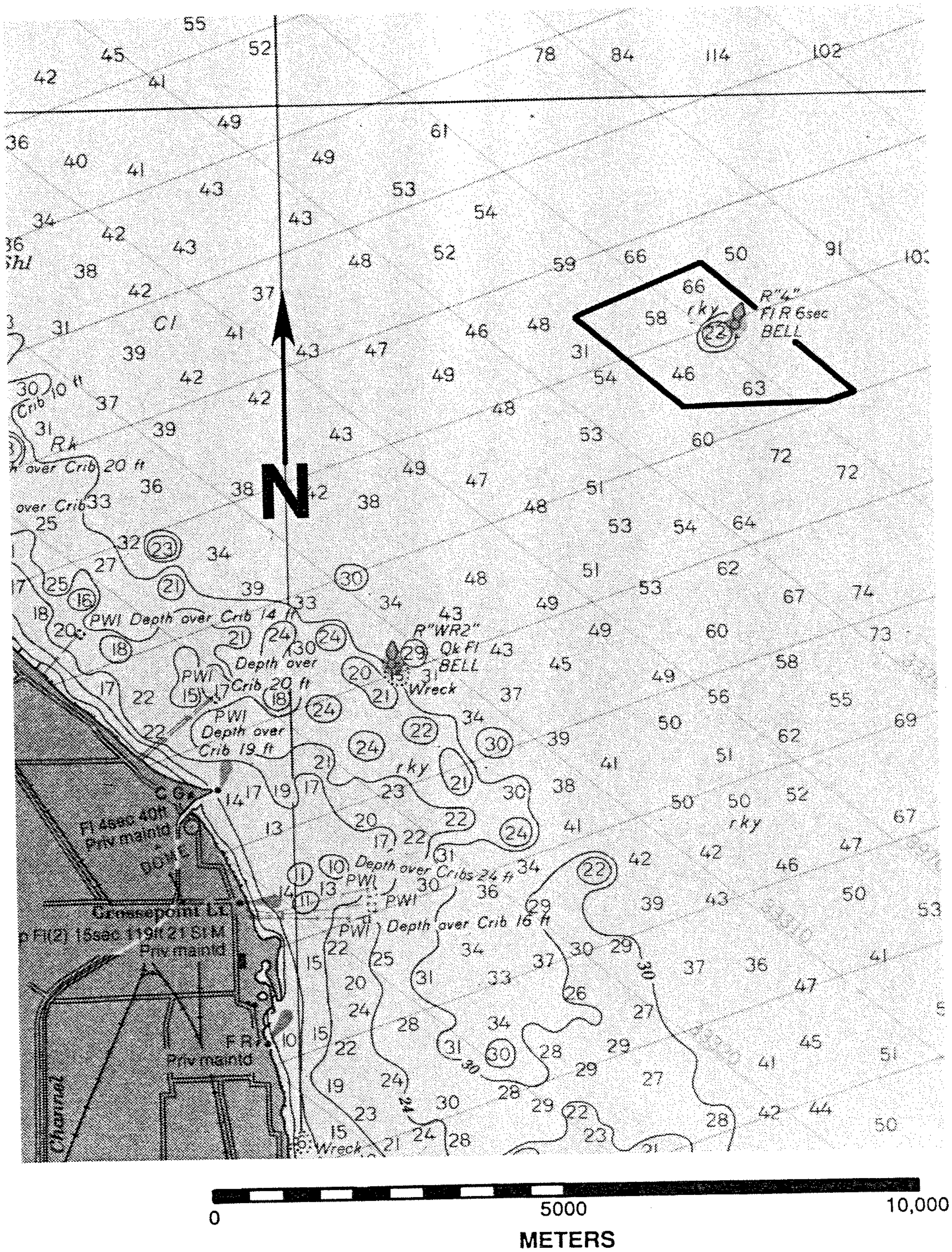

Figure 6. Location of side-scan sonar survey on Wilmette Reef, Lake Michigan. Plotted on NOAA chart 14905, Nov. 1981; depths are in feet.

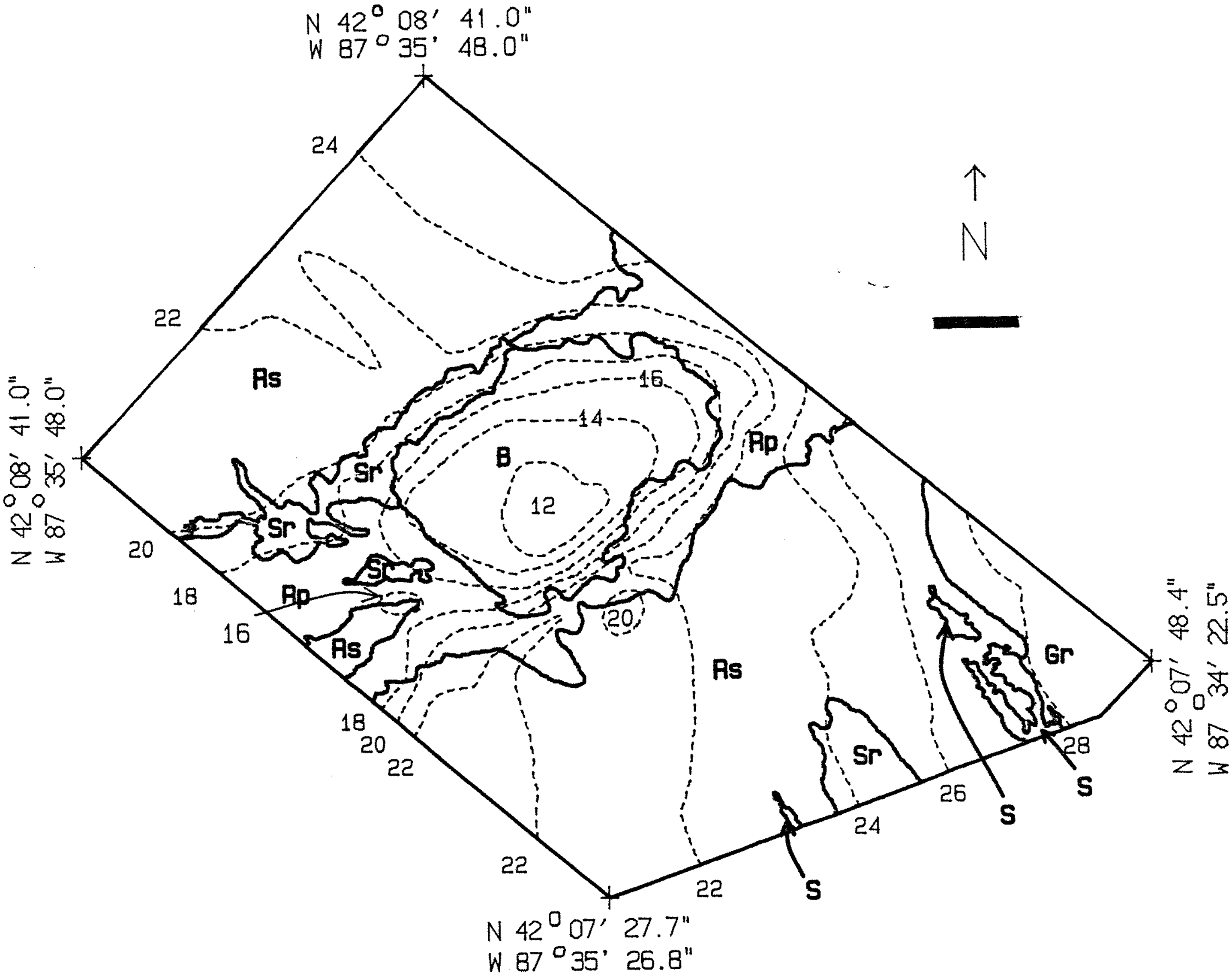

Figure 7. Wilmette Reef substrates and bathymetry. Water depths (dashed lines) are in meters. Bar represents 0.2 km.

Substrate		Hectares
S - Sand		3.29
Sr - Sand with scattered rubble		15.99
Gr - Gravel with scattered rubble		14.63
Rs - Rubble evenly distributed on sand		196.42
Rp - Rubble piles with sand patches		50.01
Br - Bedrock ridges		41.92
	Total	322.26

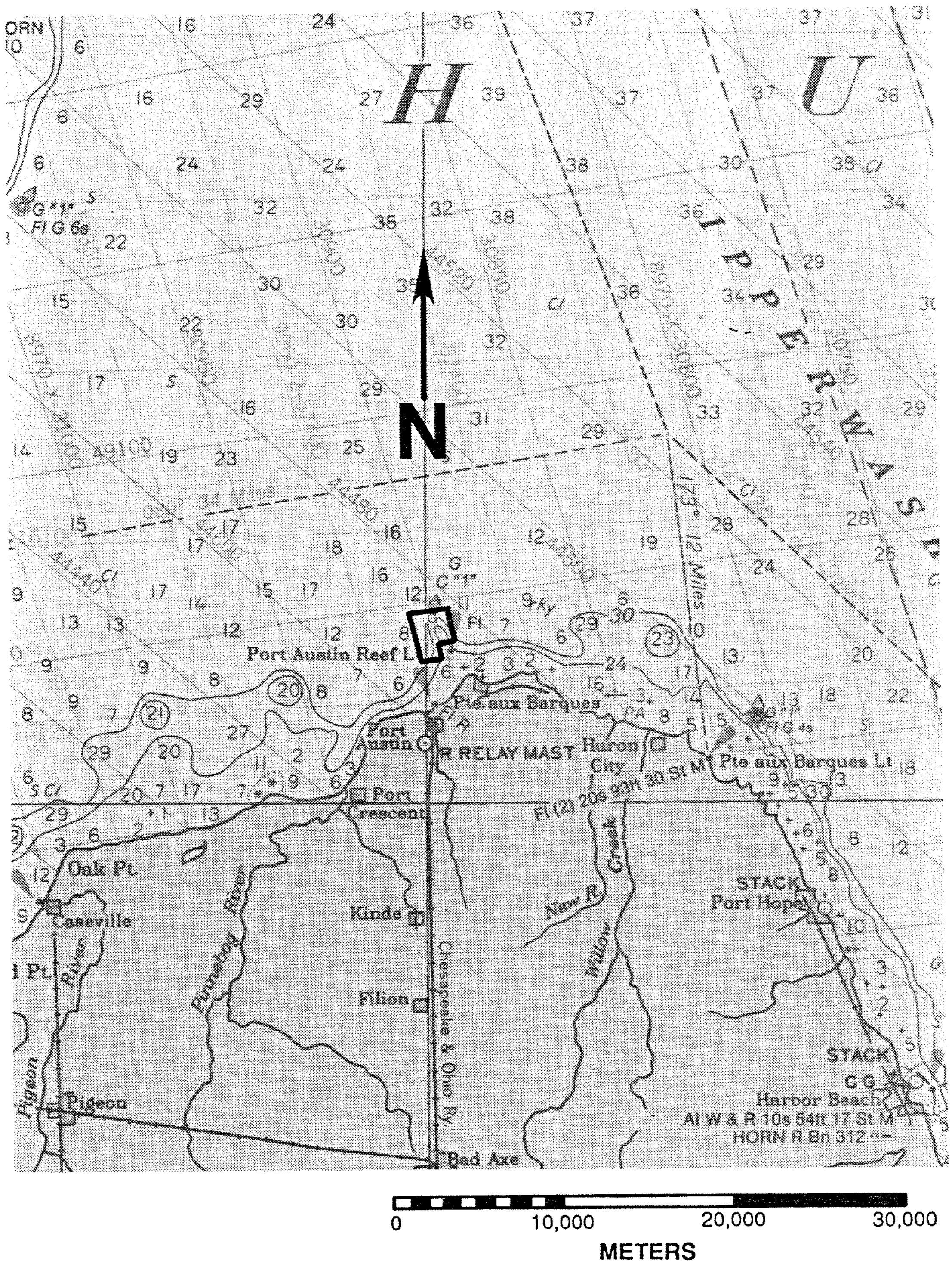

Figure 8. Location of side-scan sonar survey on Port Austin Reef, Lake Huron. Plotted on NOAA chart 14860, Oct. 1987; depths are in feet and fathoms.

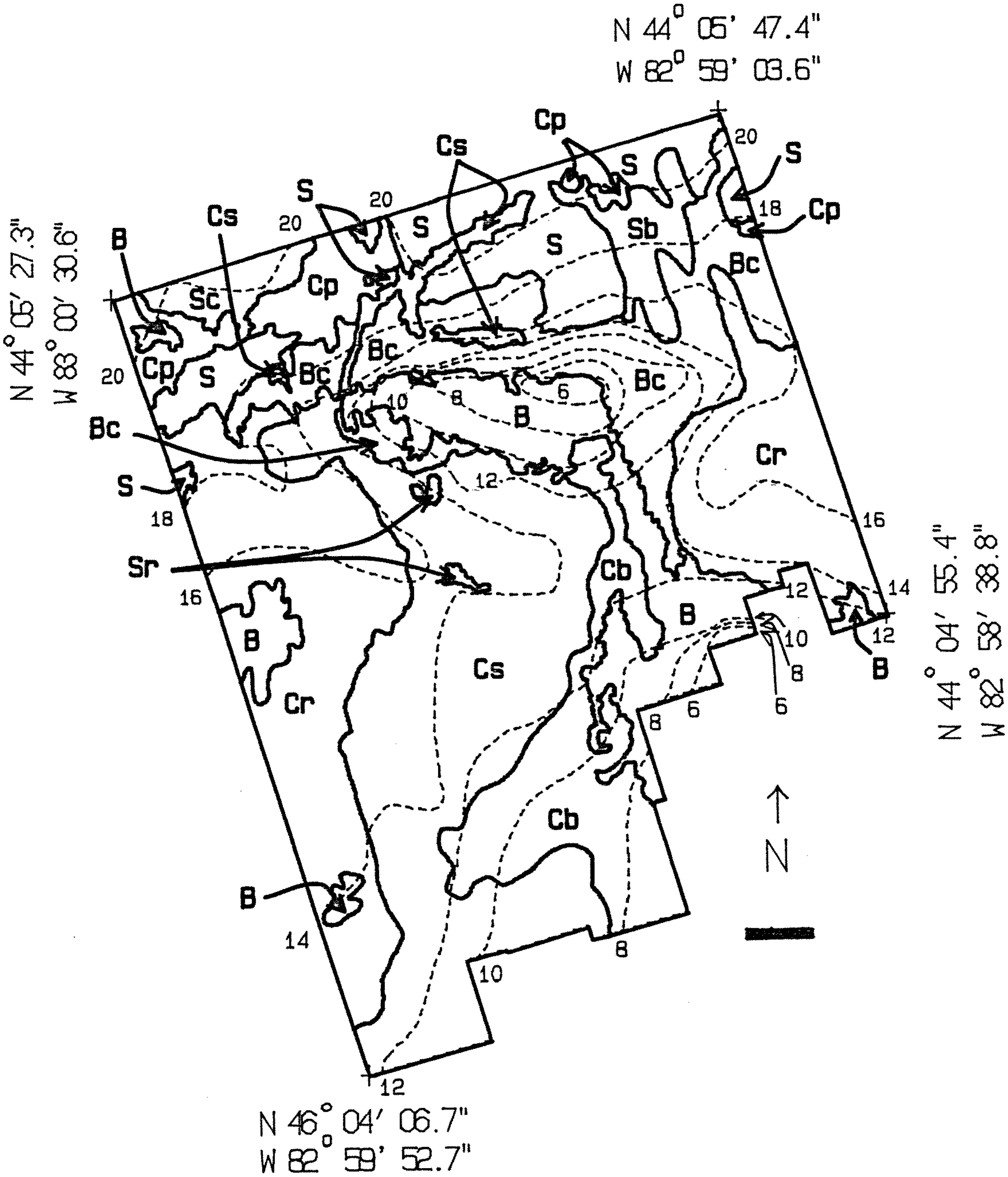

Figure 9. Port Austin Reef substrates and bathymetry. Water depths (dashed lines) are in meters. Bar represents 0.2 km.

Substrate	Hectares
S - Sand	37.74
Sr - Sand with scattered rubble	1.09
Sc - Sand with cobble patches	7.36
Sb - Sand on broken bedrock	10.48
Cb - Cobble on bedrock	39.12
Cs - Cobble evenly distributed on sand	113.54
Cp - Cobble patches on sand	17.32
Cr - Clay ridges with sand	99.62
Bc - Bedrock with cobble patches	55.54
B - Smooth bedrock	48.26
Total	430.07

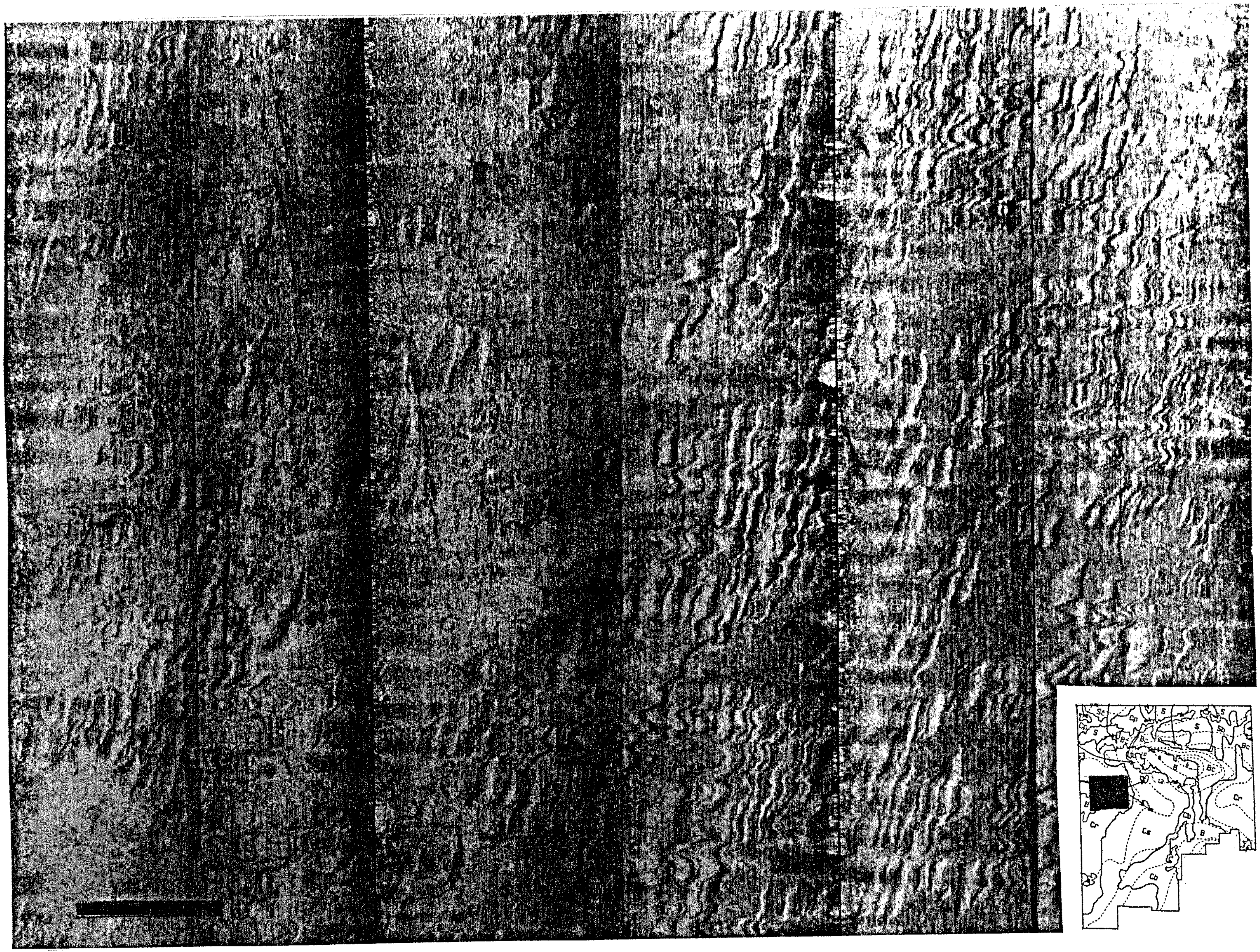

Figure 10. Port Austin Reef mosaic showing clay ridges on sand substrate.
Bar represents 50 m.

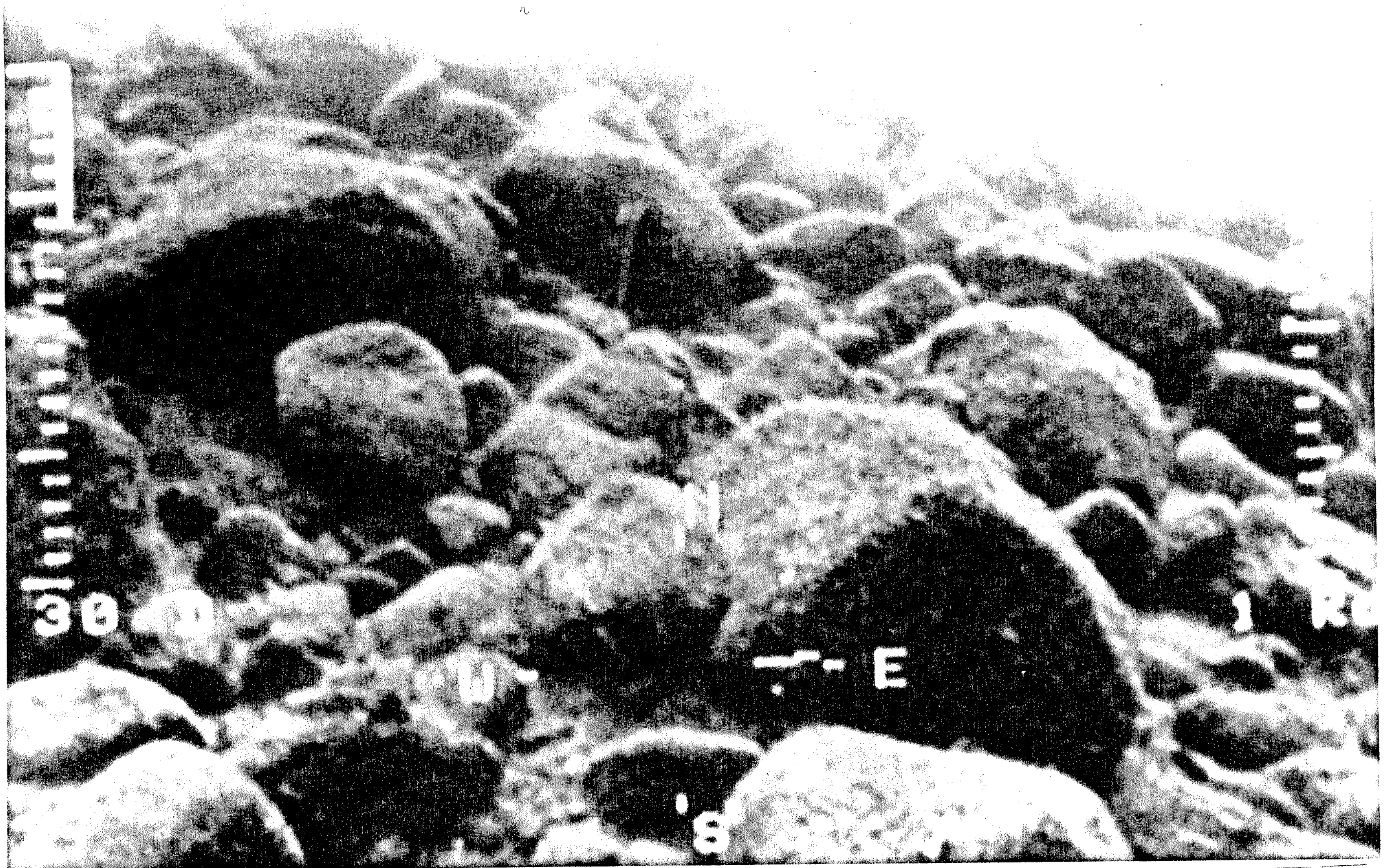

Figure 11. Bedrock with cobble patches substrate on Port Austin Reef.

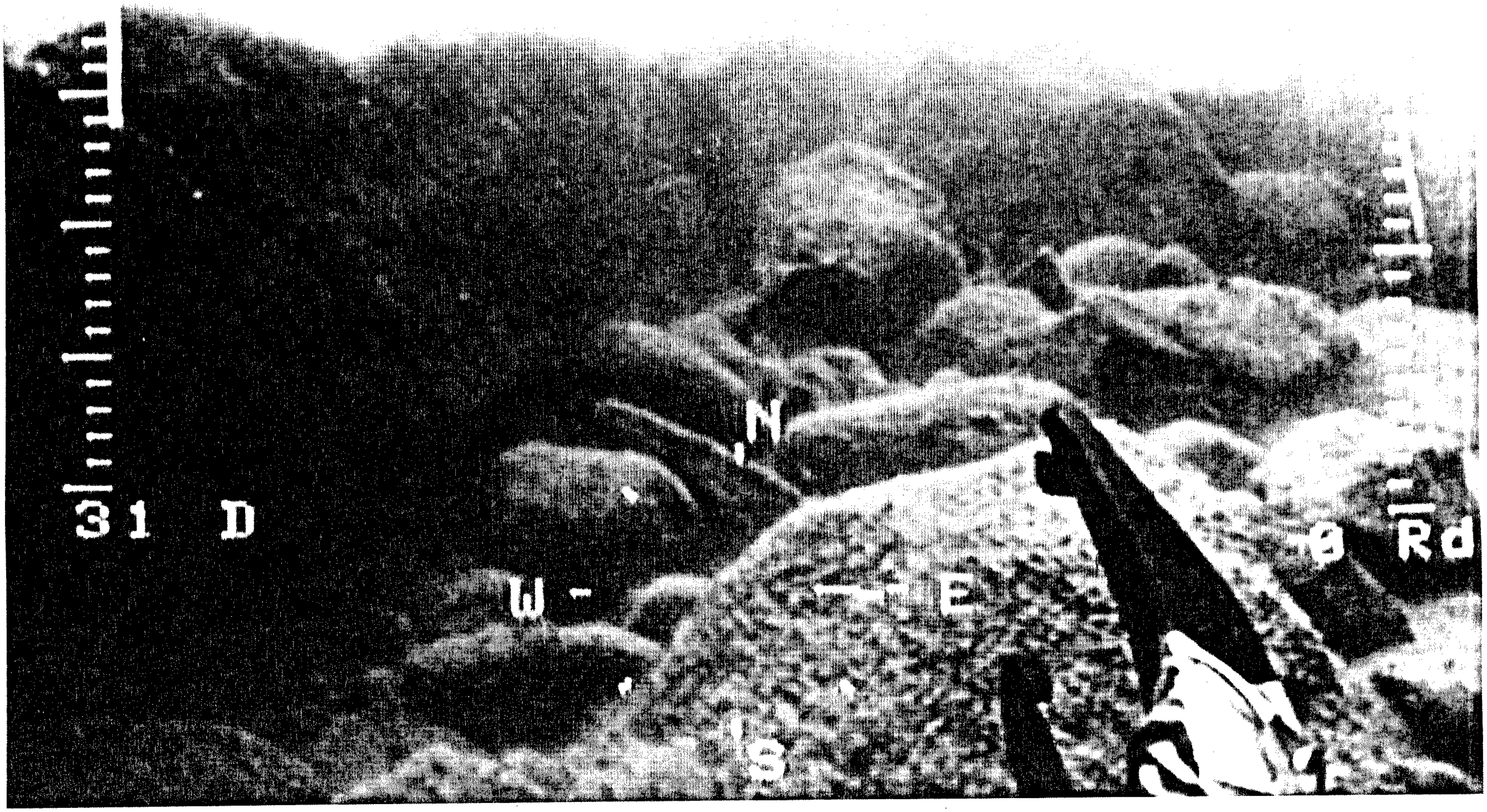

Figure 12. Cobble on bedrock substrate on Port Austin Reef.

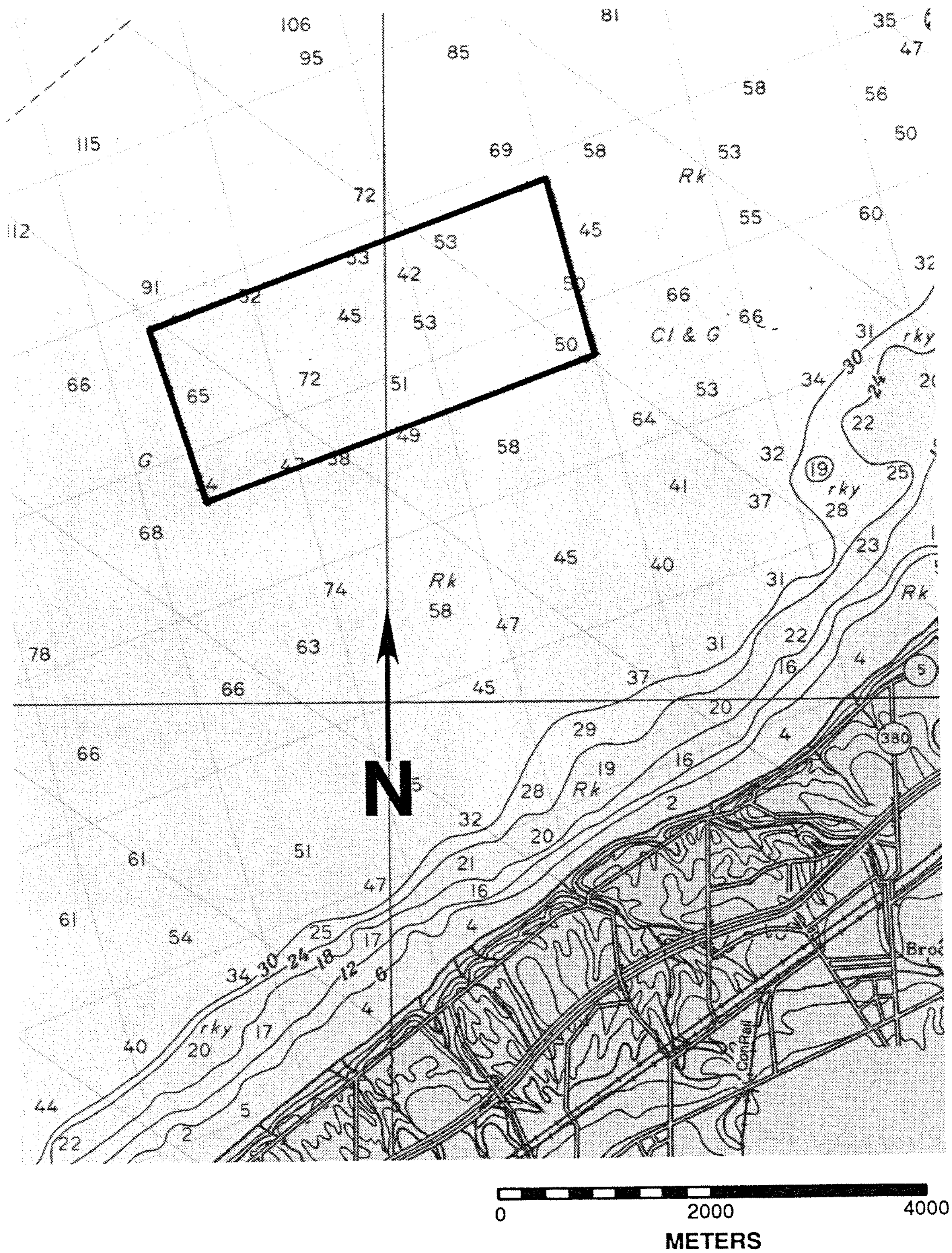

Figure 13. Location of side-scan sonar survey on Brocton Shoal, Lake Erie. Plotted on NOAA chart 14823, Sept. 1987; depths are in feet.

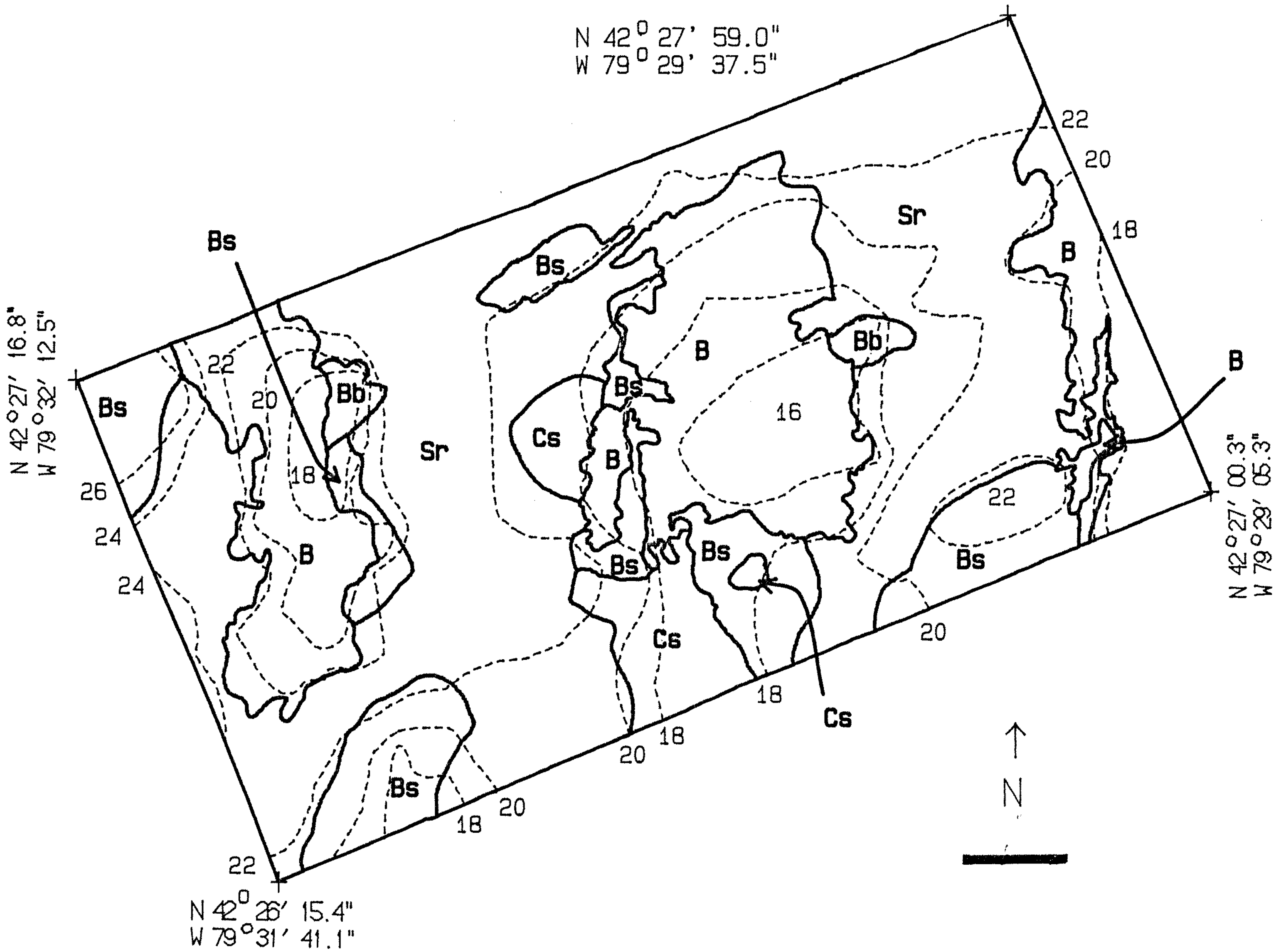

Figure 14. Brocton Shoal substrates and bathymetry. Water depths (dashed lines) are in meters. Bar represents 0.4 km.

Substrate	Hectares
Sr - Sand with scattered rubble	392.19
Cs - Cobble ridges on sand	37.51
B - Worn bedrock	204.74
Bb - Broken bedrock with scattered boulders	9.01
Bs - Broken bedrock covered by sand	109.49
Total	752.94

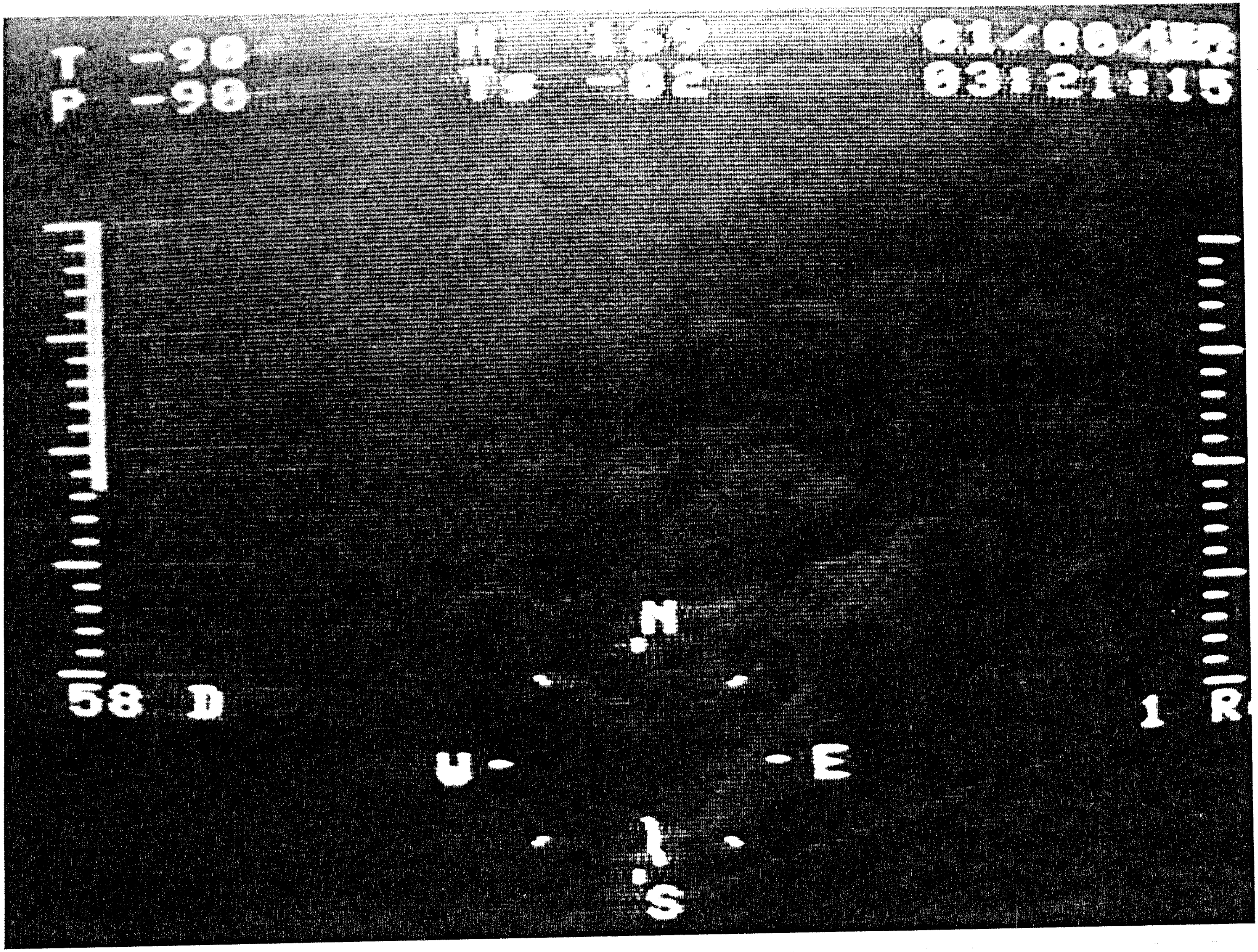

Figure 15. Cobble ridges scattered on sand substrate on Brocton Shoal.

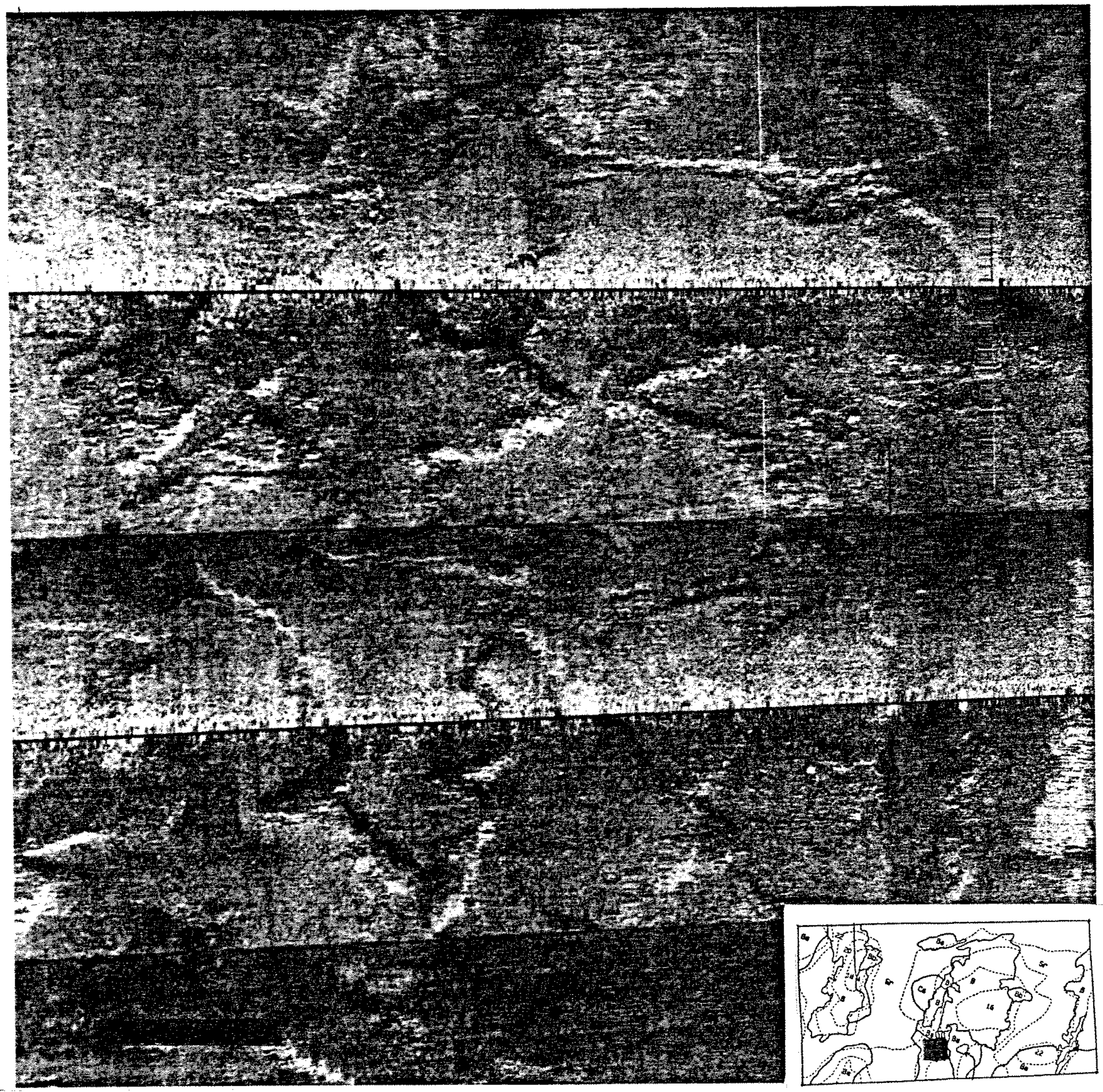

Figure 16. Brocton Shoal mosaic showing cobble ridges scattered on sand.

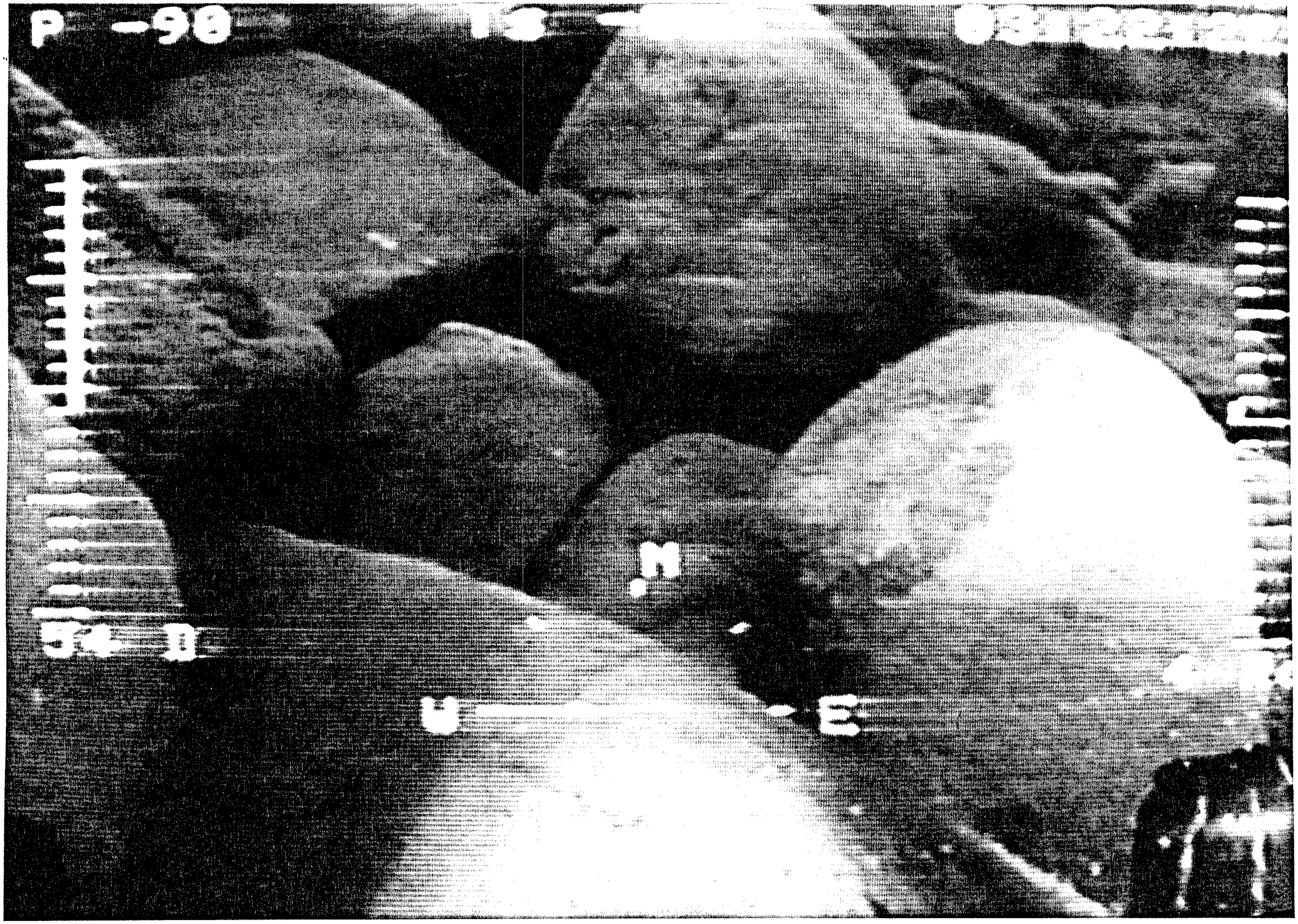

Figure 17. Close-up of cobble shown in Figure 15. Note clean surface of rocks.

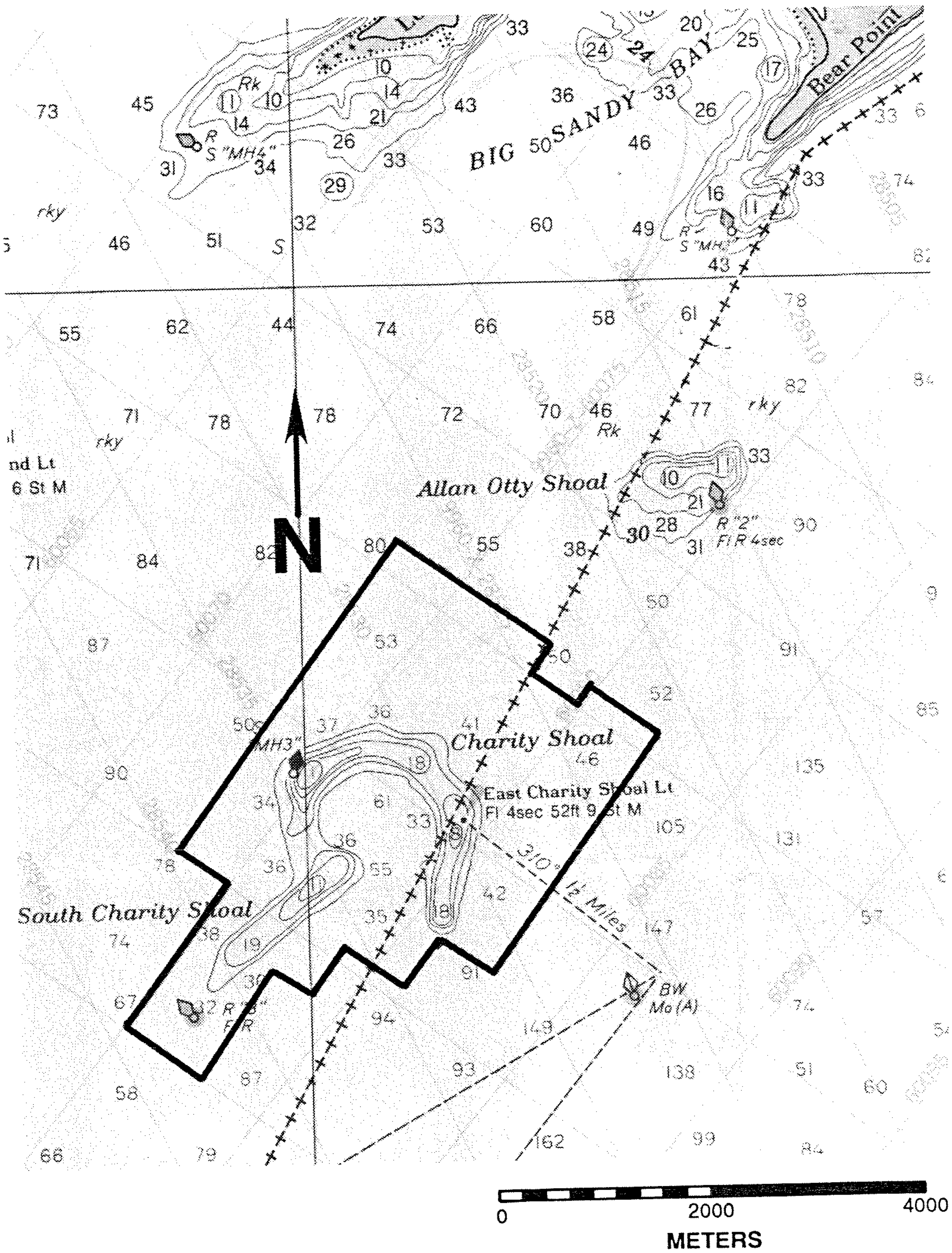

Figure 18. Location of side-scan sonar survey on Charity Shoal Complex, Lake Ontario. Plotted on NOAA chart 14802, Mar. 1981; depths are in feet.

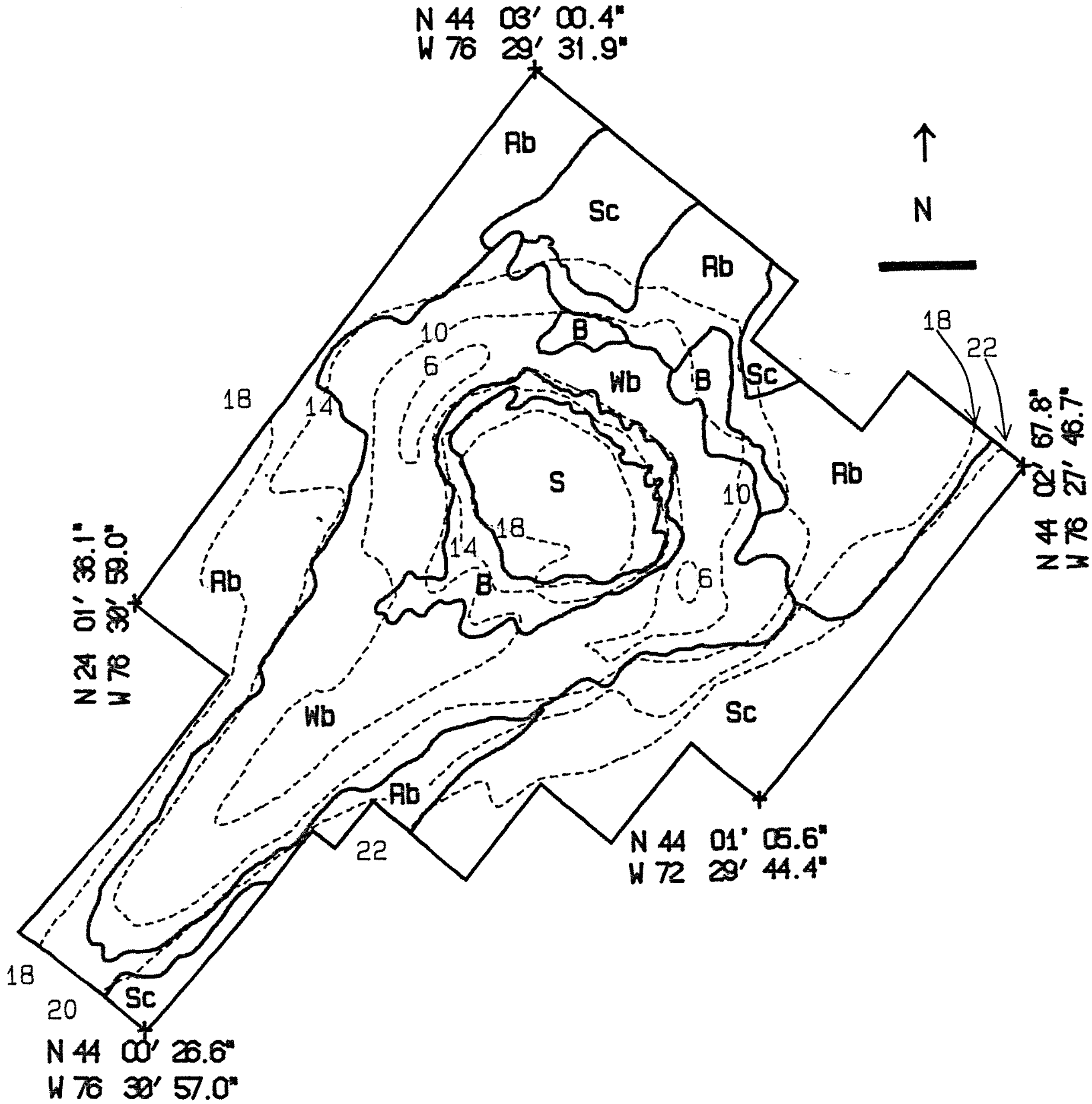

Figure 19. Charity Shoal Complex substrates and bathymetry. Water depths (dashed lines) are in meters. Bar represents 0.4 km.

Substrate	Hectares
S - Sand	66.22
Sc - Sand with scattered cobble	199.98
Rb - Rubble with broken bedrock	319.18
Wb - Worn bedrock ridges with broken bedrock patches	341.14
B - Broken bedrock evenly distributed on bedrock	69.17
Total	995.69

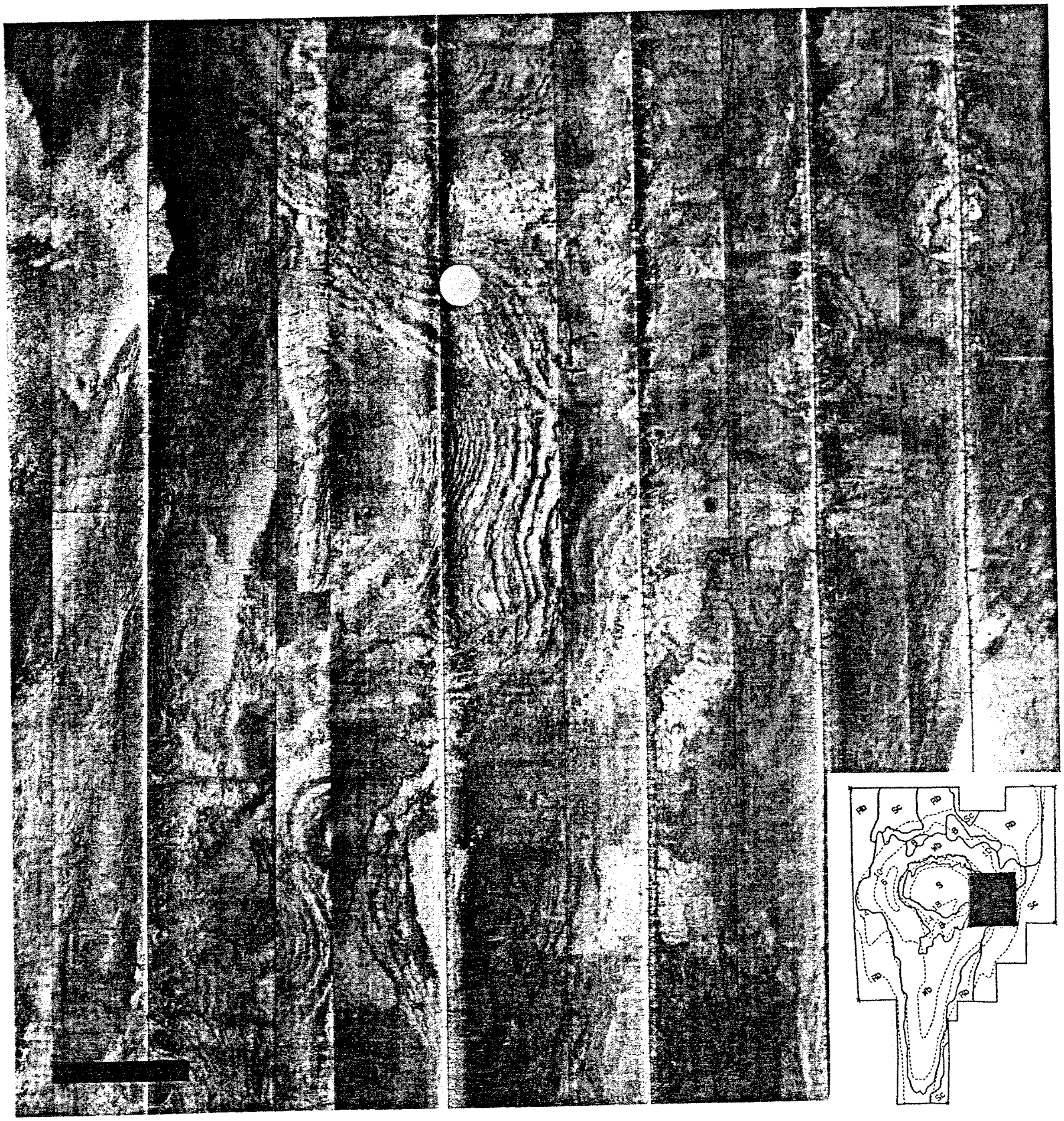

Figure 20. Charity Shoal mosaic showing worn bedrock ridges. Dot shows the approximate location of East Charity Shoal Light.

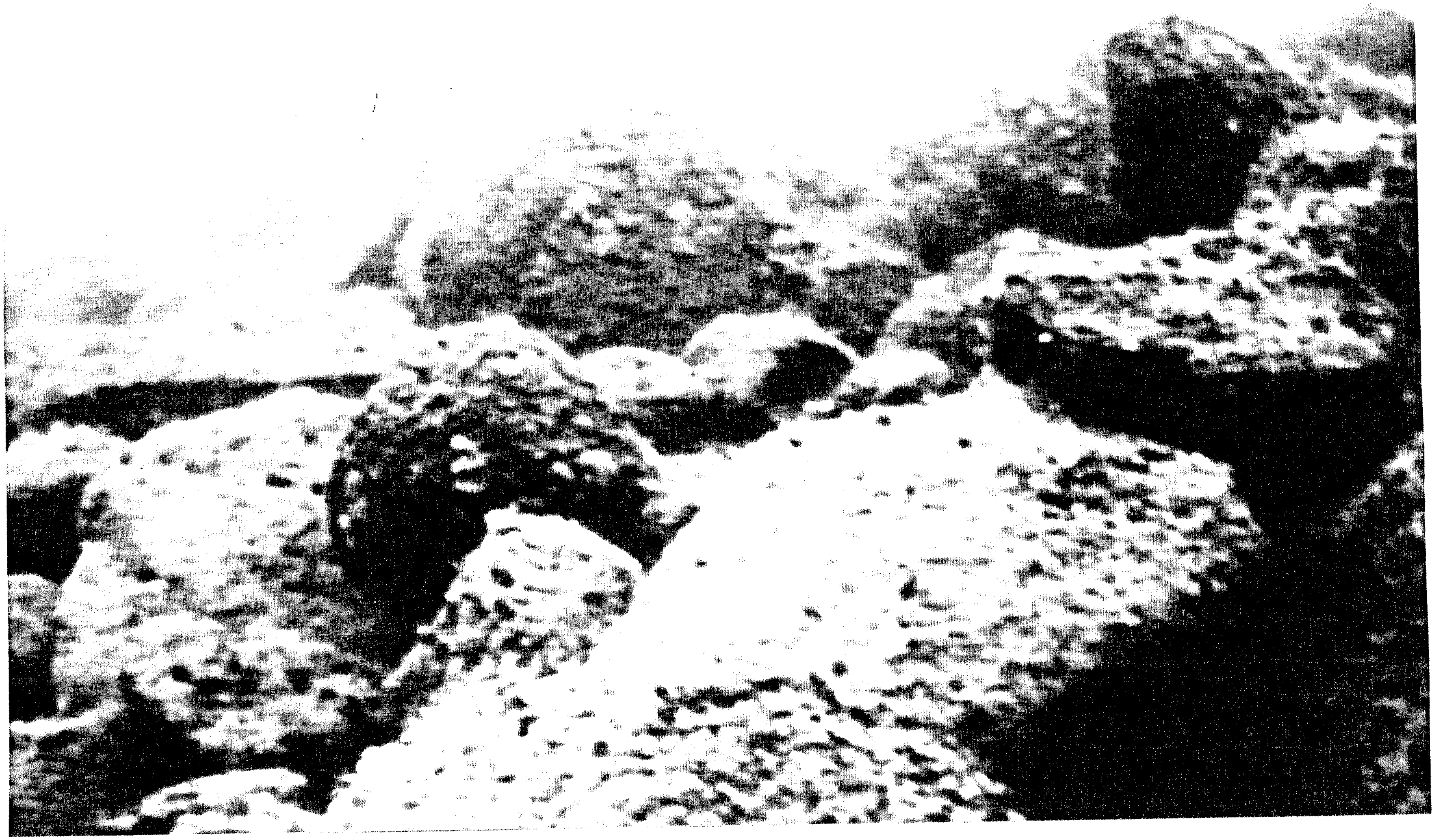

Figure 21. Rubble with broken bedrock substrate on Charity Shoal Complex.