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Maps and Sidescan Sonar Images Showing Interpretation of Acoustic Backscatter Overlain on Historically Mapped Bottom Sediments of the Ohio Part of Lake Erie

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ABSTRACT

We mapped the acoustic backscatter characteristics of the lake floor of western Lake Erie based on 1300 line-km of 100 kHz sidescan-sonar data collected by the Ohio Geological Survey and the U.S. Geological Survey from 1991 to 1993. Acoustic backscatter was divided into 6 categories: low backscatter, intermediate backscatter, high backscatter, high backscatter-ripple fields, high backscatter-bedrock, and high backscatter-dumping grounds. We correlated these categories with previously published surficial sediment maps. The correlation showed the following associations: low backscatter with mud and mixed mud and sand; intermediate backscatter with sand and mixed mud and sand; high backscatter with mixed sand and gravel and mixed sand, gravel, and mud; high backscatter-ripple fields with sand; high backscatter-bedrock with shale and carbonate rock. Conflicting correlations exists, particularly those close to shore where transitions between bottom types occur most often. Some differences may be due to actual changes in bottom sediment distribution because the samples were collected 20-30 years ago, or some differences may, in part, be due to differences in navigation techniques and sediment analyses.

Areas of low backscatter are most widespread in both the western and central basins due to the extensive lacustrine deposits of mud and mixed mud and sand. Intermediate high backscatter areas are most common closer to shore, including the islands between the western and central basins. These are related to deposits of sand and gravel and exposure of bedrock in shallower water. Exceptions to this occur in the central basin between Conneaut and Ashtabula, Cleveland to Fairport harbor, and in an area between Lorain and Point Pelee. In the western basin intermediate backscatter areas are common offshore from Locust Point and to a lesser extent in the western part of the basin. These areas, except for the region between Ashtabula and Conneaut, are where Holocene deposits are thin or absent and glacial sediments are exposed at the lake floor. High backscatter associated with shale is restricted to the central basin within 5 km of the coast. In the western basin, high backscatter from carbonate bedrock is restricted to the Marblehead Peninsula and Islands to the north as well as in the area off Locust Point. Areas of high backscatter also coincide with areas where dredge spoil has been dumped. On sidescan sonar this material most often appears as distinct elliptical-shaped features.

INTRODUCTION

Purpose

This study is part of a broad, cooperative effort between the Ohio Geological Survey and the U. S. Geological Survey (USGS) began in September 1991, to evaluate the geologic framework of the Ohio part of Lake Erie including offshore, nearshore, and coastal areas. Part of this effort includes mapping the characteristics and distribution of sediments and their relationship to rates of erosion along the shoreline. This report presents the results of mapping the offshore surficial geology from interpretation of new sidescan sonar data and previously published bottom sediment distribution maps

An assessment of the amount of sand and gravel in bottom sediments is especially important because shoreline erosion rates are, in part, related to the abundance of sand and gravel on beaches and in the nearshore. Equally important is an assessment of the location and amount of these components offshore, because 1) they are needed to nourish sand-starved beaches; 2) they serve as a resource for construction, and 3) they protect underlying mud from erosion by waves and bottom currents; and 4) they provide an important component of information on which to base estimates of the sediment budget for the Lake Erie basin.

Geologic Setting

Most of Lake Erie is on the eastern flank of the Findlay Arch, thus it overlies the Upper Silurian dolomite and Devonian shale that dip to the east. A ridge of resistant carbonate rock between Point Pelee and Sandusky, Ohio forms several islands and shoals that separate the western from the central basin (Carman, 1946; Herdendorf and Braidech, 1972). The bedrock surface is composed of Silurian carbonates in the eastern basin and Devonian shale in the central basin. Most of the western basin is only 8-11 m deep and the central basin averages 19 m deep (26 m maximum).

The area was eroded and covered by at least two ice sheets, followed by a series of glacial lakes, and finally, by a series of postglacial lakes (Calkin and Feenstra, 1985). Early Lake Erie came into existence about 12.4 ka when water levels were about 30 m lower than the present lake level. Lake Erie reached present levels beginning 9-10 ka (Barnett, 1985).

Sediment overlying bedrock is mostly mud (silt and clay), sand and gravel, compact glacio-lacustrine clays, and glacial till. Verber (1957) estimated the aerial distribution of the following bottom sediments in the western basin: 3% bedrock, 3% clay, 7% gravel and coarser materials, 12% sand and mud, 17% sand, and 58% mud. Hartley (1961a) made a similar estimate for the central basin as follows: 0.9% rock, 22.5% sand and gravel, and 76.6% silt and clay (mud).

Previous Work

The Ohio part of Lake Erie has not been systematically surveyed with sidescan-sonar before this study. Several single channel seismic surveys have been carried out (Morgan, 1964; Wall, 1968; Hobson and others, 1969; Williams and others, 1980, 1982; Fuller and others, 1995). New sidescan-sonar data from this study constitutes a significant addition to our knowledge of bottom sediment distribution.

A review of papers on Lake Erie prior to 1974 is given by Smyth (1979). Unfortunately, a comparable compilation of references since 1974 has not been done. Until this cooperative effort between the USGS and the Ohio Geological Survey, most research on the sediments and shorelines of Lake Erie was carried out in the 1950's, 60's, and 70's (see, for example, Pincus and others, 1951, Pincus, 1953, Pincus, 1962; Hartley, 1961a,b; Herdendorf, 1968, 1970, 1975; Herdendorf and Braidech, 1970; Herdendorf, 1975; Hobson and others, 1969; Lewis, 1966, 1969; Carter, 1973a,b; Kemp and others, 1977). More recent studies include Carter and Guy (1980, 1983), and Bolsenga and Herdendorf (1993).

METHODS

Field Work

The U.S. Geological Survey and the Ohio Geological Survey collected sidescan-sonar data during five cruises in 1991 (250 line-km), 1992 (689 line-km), and 1993 (57 line-km) aboard the Ohio Geological Survey's 15-m research vessel GS-l. Sidescan sonar data were collected with a 100 kHz Klein System simultaneously with the acquisition of high-resolution seismic reflection data (3.5 kHz and boomer). The sidescan data were printed on analog paper as well as in a digital format using a Triton QMIPS system. The sidescan data was most often set for a 100-m range on each channel, resulting in a 200-m swath of coverage along a trackline. An Odem ECHOTRAC digital system was used to collect bathymetric data. Boat position was determined mainly with LORAN C, although, on the 1991 cruise, a PC-based GPS (Trimble navigation unit) was also used. Vessel speed during profiling was most often 2 m/s.

Acoustic Backscatter Classification

We classified the relative amount of acoustic backscatter on the sidescan sonar records as low backscatter, intermediate backscatter, and high backscatter. Areas of high backscatter were also noted to have distinct patterns that are related to the surficial geology. We used the seismic profiles to aid in the sidescan interpretation, particularly where subbottom units crop out at the lake floor. Our interpretation is complicated by several factors: 1) most sediment sample data available were collected 20 to 30 years ago; 2) our data were collected over a period of three years and varied in quality depending mainly on weather conditions; 3) the classification of backscatter is subjective.

Correlation of Acoustic Backscatter to Bottom Sediment Maps

We correlated our interpretation of acoustic backscatter with previously published sediment distribution information (Verber, 1957; Hartley, 1961a; and Herndorf and Braidech, 1972) by measuring the percentage of sediment type associated with each category of acoustic backscatter. The sediment classifications were modified slightly by combining gravel with sediments classified as mixed sand and gravel.

RESULTS AND INTERPRETATION

Acoustic Backscatter Classification

We have mapped six categories of acoustic backscatter (figs. 1 and 2). They are: low backscatter, intermediate backscatter, high backscatter, high backscatter-ripple fields, high backscatter-bedrock, and high backscatter-dumping grounds.

Deposits of recent lacustrine fine sand and mud result in low acoustic backscatter and relatively featureless sidescan records. These are the dominant deposits in most of the offshore area of Lake Erie.

Areas with low backscatter are not always featureless. Within them are often high backscatter linear features that are several hundred meters long and tens of meters wide. They are most distinct and common in waters <20 m deep. They have been mapped in the western basin by R.C. Circe (personal communication, 1994) and attributed to ice scouring. However, beneath these features subbottom reflections disappear (fig. 3) similar to large areas in the center of western basin where the subbottom reflections also are not present. We suggest that the lack of subbottom reflections in both areas may be caused by dispersed gas within the Holocene lacustrine deposits. On the assumption that we are correct that the high-backscatter anomalies are gas-induced, and hence are not related to sediment texture, we have chosen not to include them in our sidescan backscatter maps (figs. 1 and 2). One other example of high backscatter within low backscatter areas are overlapping semicircular areas which commonly occur within charted dumping grounds (fig. 4).

We include within the category of intermediate backscatter the following: 1) areas of uniform intermediate levels of backscatter; 2) areas with a mottled appearance probably resulting from thin lacustrine deposits mantling a high backscatter subsurface; or 3) areas of patchy high and low backscatter that are too complex to map at a map scale of 1:200,000.

We interpret areas of high acoustic backscatter as bedrock, glacial till, or coarse lag deposits derived from till. Bedding and fractures in the shale or carbonate bedrock surface cause distinct patterns on the sidescan-sonar records (fig. 5). The bedrock surface coincides with a rough lake-floor reflection and the cropping out of the bedrock surface reflection on 3.5 kHz and boomer seismic profiles. Glacial till or coarse lag deposits on the till cause high acoustic backscatter on the sidescan records but are relatively featureless compared to bedrock areas; however, lag deposits of coarse sand and gravel may form sediment ripples (about 1 m in wavelength) that result in ripple fields on the sidescan sonar records (fig. 6).

Correlation of Acoustic Backscatter to Bottom Sediment Maps

The correlation of acoustic backscatter to bottom sediment type is shown in Figure 7. Low backscatter is associated most often with mud and to a lesser extent where mixed mud and sand are exposed. This is consistent with the association of low backscatter to recent lacustrine deposits. Intermediate backscatter occurs most often with mixed mud and sand and less ofter with mud, sand, and mixed sand and gravel. This suggests that intermediate backscatter areas are where fine-grained material transitions to coarser-grained material or may be associated with a variety of sediment textures due to the patchy distribution of backscatter. High backscatter-featureless areas correspond to sand and gravel as well as to mixed deposits of sand, gravel, and mud. This supports our interpretation that high backscatter with no associated discernible patterns coincides with glacial till or till-related sand and gravel lag deposits. In contrast, sidescan records with high backscatter and distinct sediment wave patterns correlate almost entirely to sand. High backscatter with distinct patterns we interpret as bedding planes and joints are most often bedrock.

Although the discrepancies between our correlation of interpreted backscatter with sediment type may be due to actual movement of the bottom material, other explanations must be considered. These include navigation problems. The sidescan sonar data was mapped mostly with

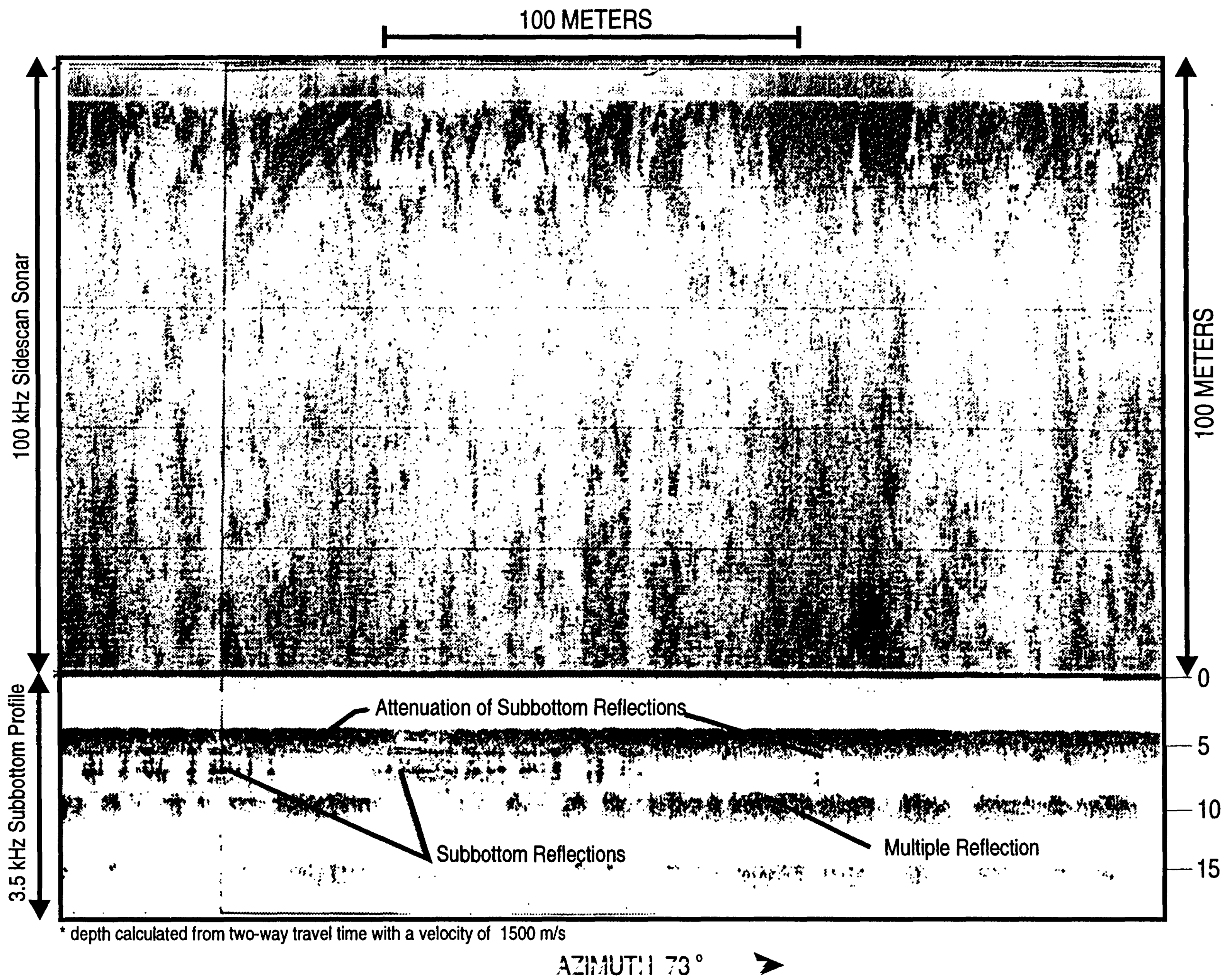

Figure 3. Sidescan sonar image from the western basin of Lake Erie (see fig. 1 for location) showing patchy high backscatter (dark areas) that coincide with acoustic attenuation of the 3.5 kHz subbottom data. Subbottom reflections occur with the lower backscatter areas (light areas) seen on the sidescan sonar image. High backscatter and poor subbottom penetration may be caused by gas within the sediment.

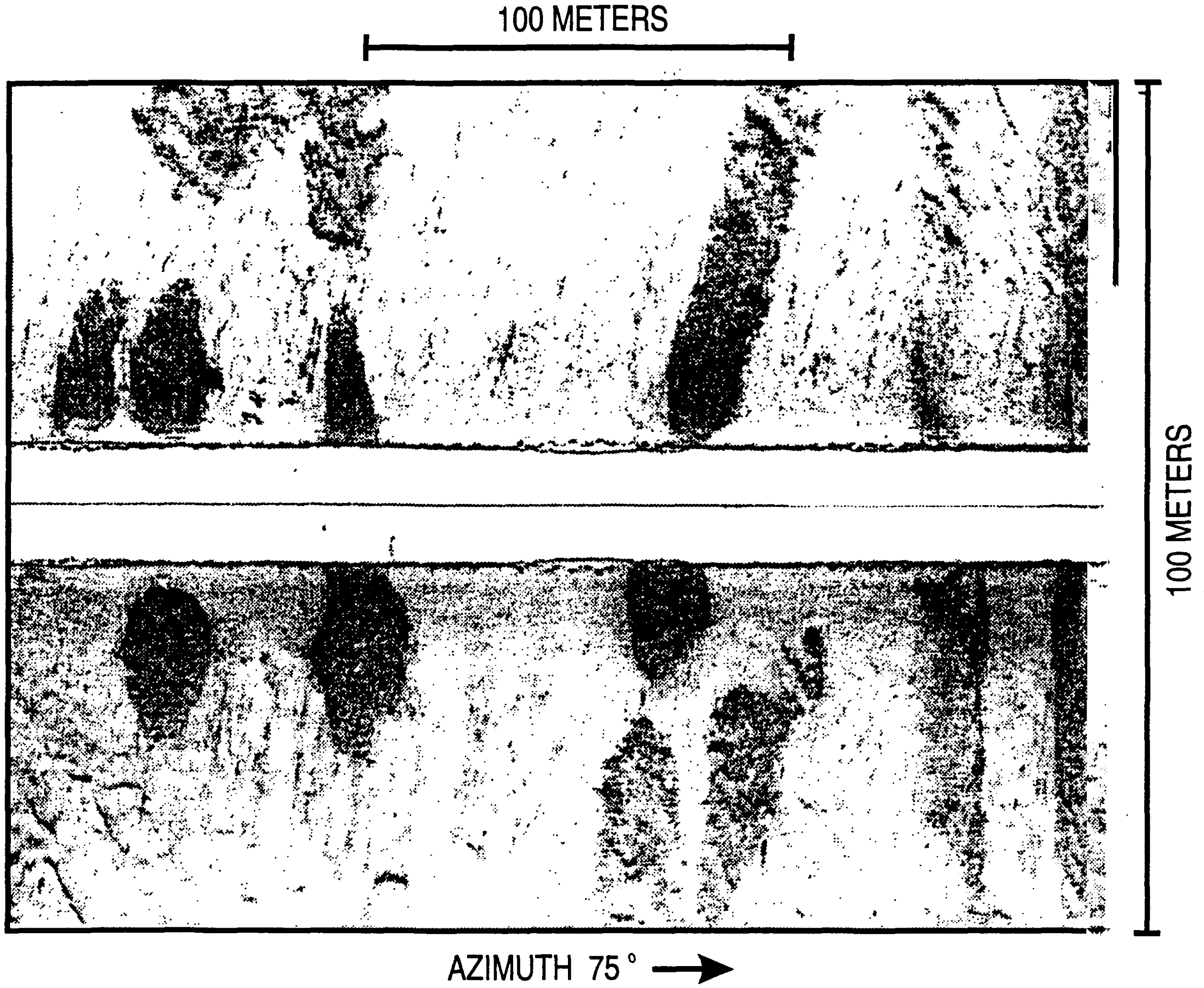

Figure 4. Sidescan sonar image from the western basin of Lake Erie (see fig. 2 for location) with low backscatter (light areas) with subcircular high backscatter (dark areas) patches. The subcircular features are interpreted to be sediment dumped by barges. These features occur most often within and near , but are not excluded to, charted dumping grounds

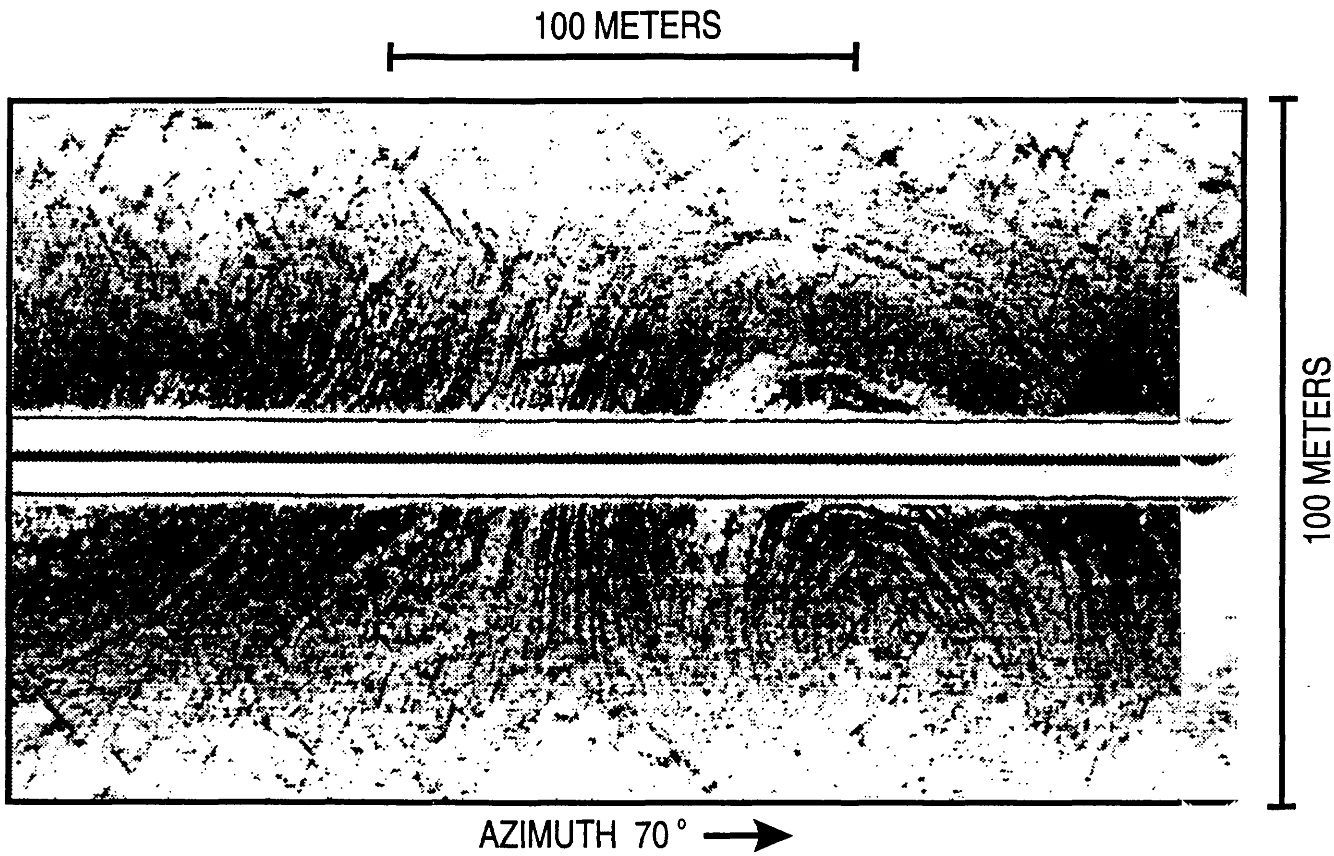

Figure 5. Sidescan sonar image from the central basin of Lake Erie (see fig. 1 for location) showing a typical pattern of shale bedding planes cropping out at the lake floor. The circular pattern of the bedding is likely due to the low dip of the bedding and uneven lake floor.

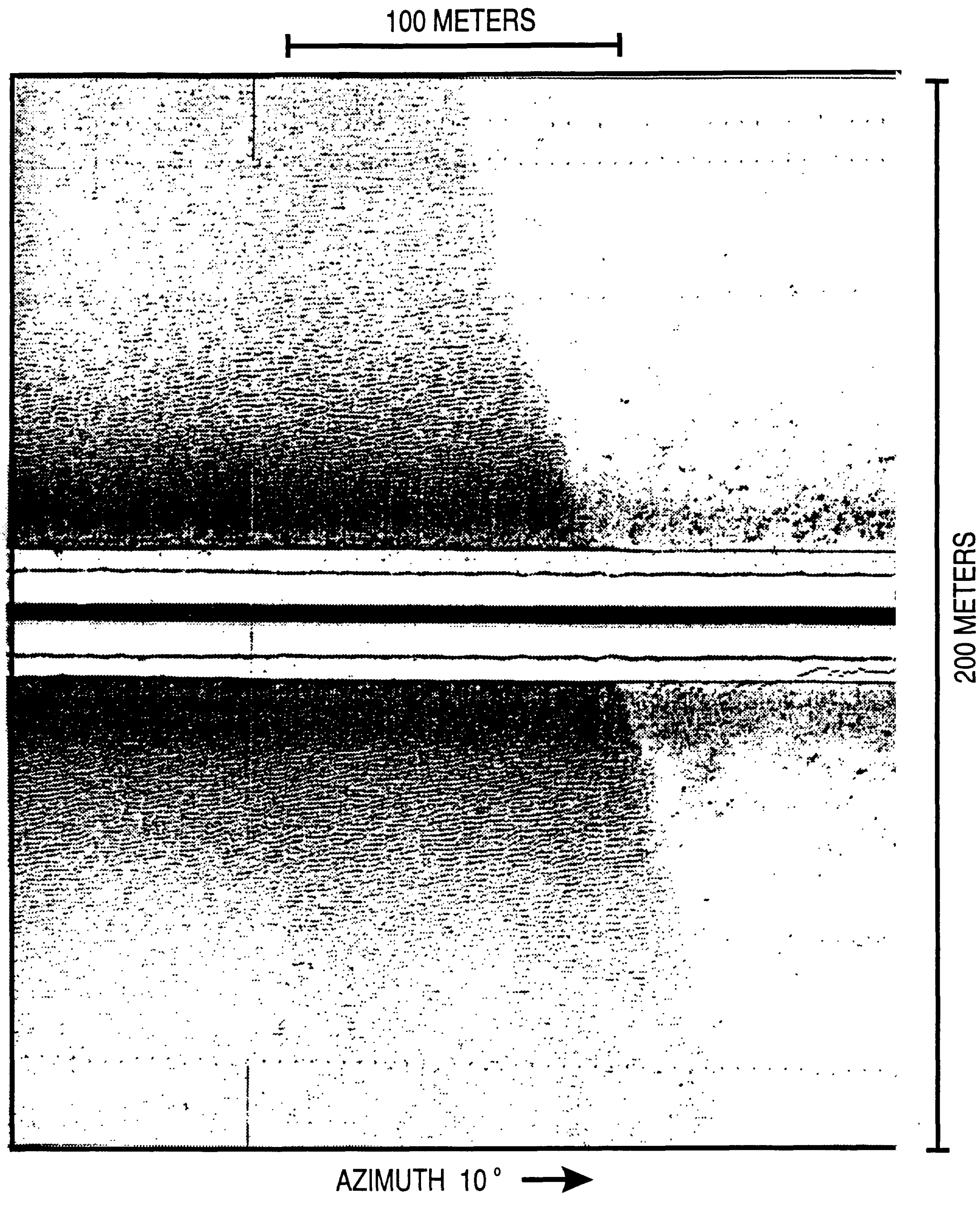

Figure 6. Sidescan sonar image from the central basin of Lake Erie (see fig. 2 for location) showing high backscatter, ripple fields (left side) and low backscatter (right side).

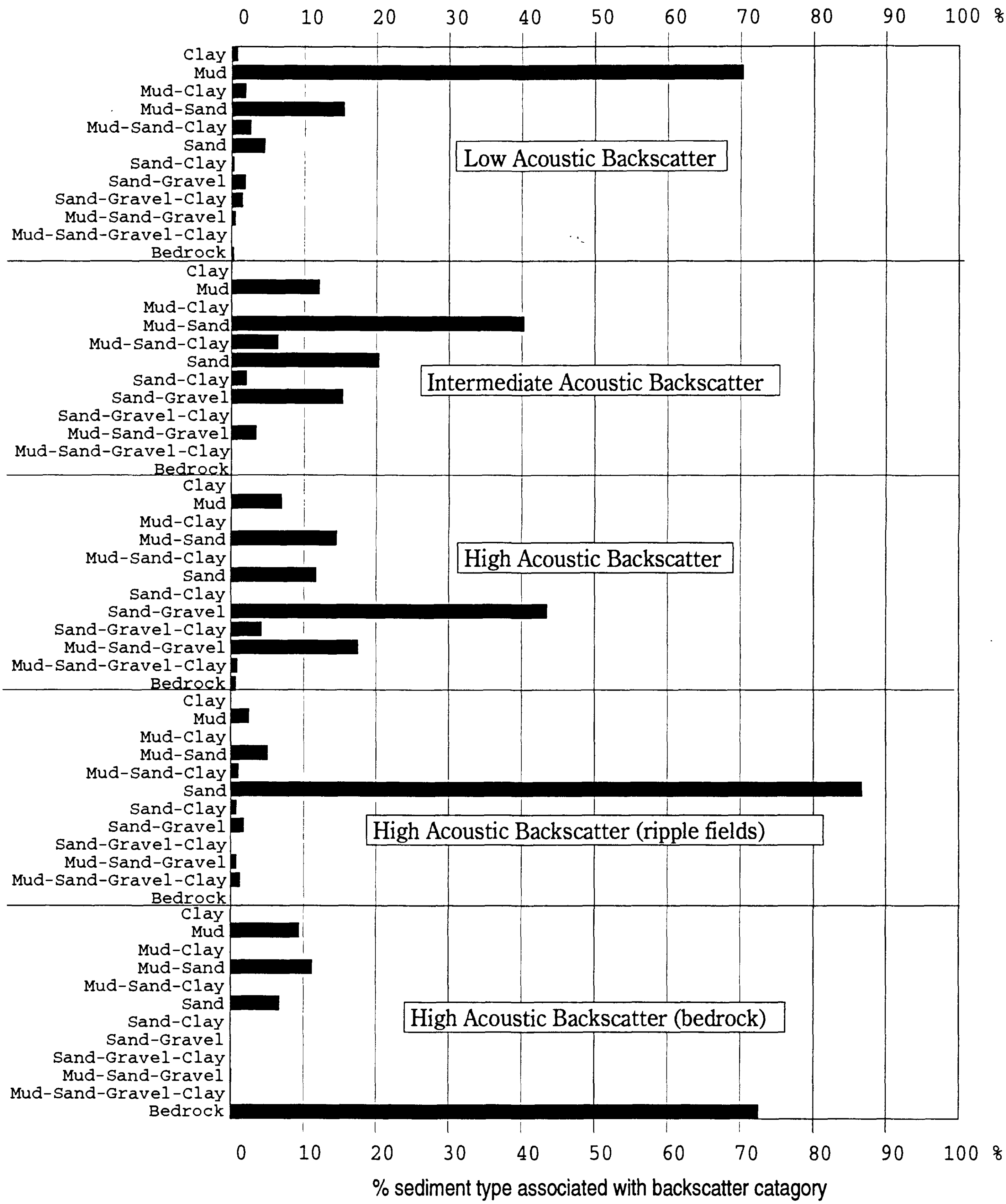

Figure 7. Graph showing the correlattion between cattagories of acoustic backscatter and sediment type.

Loran-C positioning. Distortions occur in areas particularly nearshore. The sediment maps were mainly derived from bottom samples located by measuring horizontal angles between landmarks with a sextant or, when landmarks were out of sight, by dead reckoning. We consider the positioning of sample locations with a sextant to be quite accurate and dead reckoned location to be much less accurate. These samples often were collected 1-2 km apart and thus provide a point source of data. The sidescan records are continuous and thus provide a more accurate position for sediment-type boundaries along the vessels track. The sediment classification system may also be a source of error. For example, if the size of the sand was not specified, the associated backscatter could range from low (fine sand) to high (coarse sand).

If the lack of correlation between backscatter and bottom sediment type can be explained by a real change in sediment distribution we would expect greatest changes to be nearshore. For example, an obvious difference is present between Fairport Harbor and Conneaut where we map shale farther offshore than the sediment maps indicate (fig. 2). This may be the result of lakebed erosion exposing more shale.

Distribution of Acoustic Backscatter and Bottom Type

In both the eastern and central basins, areas of low backscatter are widespread due to the extensive deposits of lacustrine mud and mixed mud and sand. The low backscatter mud coincide with postglacial mud mapped by Fuller and others (1995).

Intermediate to high backscatter areas are more common close to shore, including the islands between the two basins. These are related to deposits of sand and gravel and exposure of bedrock in shallow water. Exceptions to this occur in deeper water of the central basin between Conneaut and Ashtabula, between Cleveland and Fairport Harbor and in an area between Lorain and Point Pelee. In the western basin areas of intermediate backscatter are common off Locust point. These areas, except for the region between Ashtabula and Conneaut, are where Holocene deposits are thin or absent and glacial sediments are exposed at the lake floor (Fuller and others, 1995). The coarser sediment and higher backscatter between Lorain and Point Pelee coincide with the exposure of the Lorain-Point Pelee moraine. Coarser sediment and higher levels of backscatter offshore between Ashtabula and Conneaut may result from glacial sediments transported from the nearby Norfolk moraine that is located to the east.

High backscatter associated with shale is restricted to the central basin within 5 km of the shore. In the western basin, high backscatter from carbonate rock is restricted to the Marblehead Peninsula and Islands to the north as well as in local areas off Locust Point.

CONCLUSIONS

We have interpreted new sidescan sonar data for the Ohio part of Lake Erie and have overlain the interpretation on previously published surficial sediment maps.

Our interpretation of the sidescan-sonar yields the following conclusions: 1) sidescan-sonar records can be qualitatively divided into categories of backscatter strength; 2) backscatter categories can be correlated reasonably well with sediment maps constructed from analyses of samples collected from the bottom; 3) an assessment of real changes in bottom sediment distribution must be evaluated in view of discrepancies in navigation and variations in methods of qualitative and quantitative sediment sample analyses or descriptions; 4) high backscatter linear features and anomalous high backscatter areas may be caused by gas in bottom sediments which complicates the interpretation of the records.

Mapping of the distribution of bedrock, till, and lacustrine deposits provides an important framework for evaluating the sediment budget, sediment transport, and coastal erosion. The sidescan-sonar data that we have interpreted along widely-spaced tracks in the two basins updates the sediment distribution maps based on samples collected 20 to 30 years ago. The similarity of the results in most areas provides confidence that further, more detailed sidescan-sonar surveys will provide essential new information critical to assessing the sediment character near the eroding bluffs. In a follow-on study, the Ohio Geological Survey has now collected a new series of shore parallel lines in 1994 and is in the process of mapping, with sidescan-sonar, the nearshore sediment distribution (Fuller and others, 1995).

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