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High Resolution Bathymetry and Lakebed Characterization in the Nearshore of Western Lake Michigan

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ABSTRACT. *The nearshore zone of western Lake Michigan is poorly characterized both in terms of its fine scale bathymetry and its lakebed characteristics. Difficulties in characterizing the lakebed of this region arise in part because of its patchiness as well as the fact that much of the lakebed is not amenable to conventional sediment sampling techniques. With this in mind, high precision bathymetry and the lakebed characteristics of ~17.5 km^2 of the nearshore of western Lake Michigan (near Oak Creek, WI) were mapped using multi-beam and single beam sonar in conjunction with lakebed characterization and surface mapping software. Lakebed features showing nearshore bluff erosion material, glacial scouring, and isolated ridges were revealed in a 1.0 × 1.5 meter resolution map of the survey area. A map of the bottom characteristics, meanwhile, showed a patchwork of four distinct bottom types (area %): mostly rock (12.8%), cobble and sand (21.0%), mostly sand (60.3%), and clay outcrops (5.9%). All predicted bottom types were shown to be accurately characterized by direct observation with an ROV.*

INDEX WORDS: *Lake Michigan, seabed classification, multi-beam sonar, glacial scouring, bottom characterization.*

INTRODUCTION

At 57,750 km^2, Lake Michigan is the sixth largest lake in the world (Beeton 1984). The lake is divided into two major basins (north and south) with the southern basin occupying approximately one third of the total lake area (18,100 km^2; Edgington and Robbins 1976.) Morphologically, the southern basin of the lake may be characterized as a relatively simple conical depression with gradual sloped bathymetry leading to a maximum depth in the center of the basin of ~170 meters. Sediment accumulation is highly skewed, with the most rapid rates of permanent deposition occurring not in the deepest portion of the lake, but on the southeastern flank, presumably in response to general circulation patterns which transport material from the western shore to the eastern side of the basin in a counterclockwise direction (Edgington and Robbins 1990). The nearshore zone of southern Lake Michigan (< 40 meters depth) exhibits little permanent net accumulation of sediment, but rather serves as a temporary repository for new inputs of suspended material that are derived from coastal erosion processes, riverine inputs, and autochthonous production.

Unlike the eastern side of the southern basin, which consists mostly of sand, the western nearshore of Lake Michigan is characterized by a

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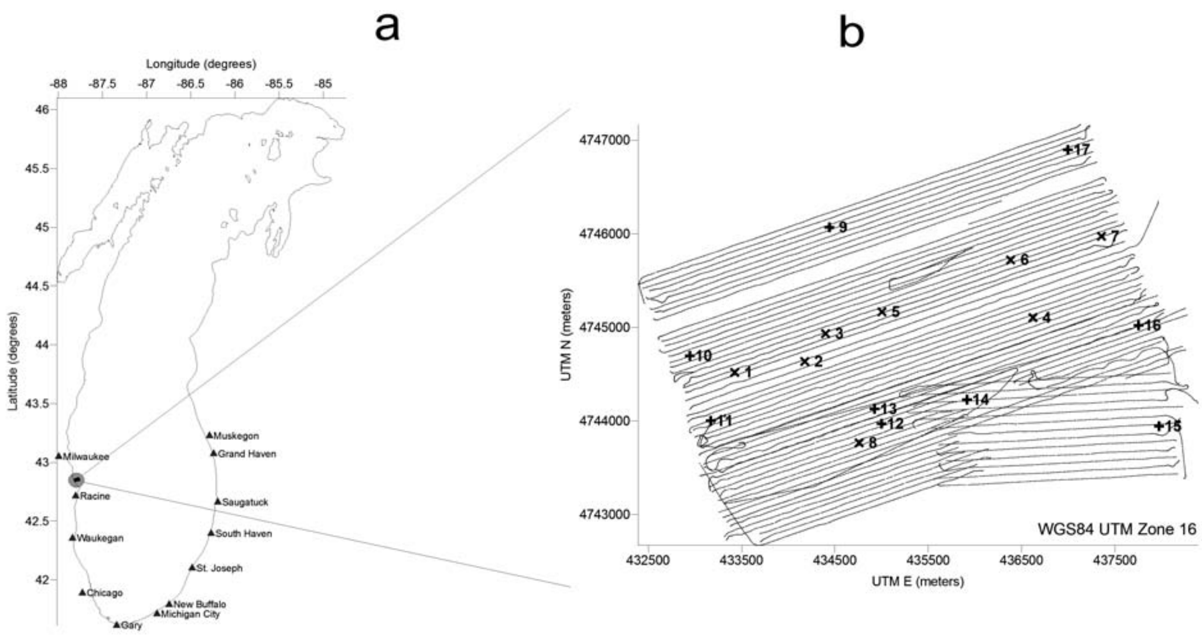


FIG. 1. Survey area in nearshore Lake Michigan: a) transect area off of Oak Creek, WI is shown in red; b) transect lines for lakebed characterization analysis (made up of individual acoustic data coordinate points from the Furuno echo sounder); symbols (× and +) identify all ROV dive sites (dives 1–8 were made on 10 October 2002; dives 9–17 were made on 5 June 2003).

diverse array of bottom types from cobble and boulder fields, to sand and gravel bottoms, to hard clay banks. These hard grounds, in turn, support a diverse fauna and provide habitat for numerous fish species (Mozley and Howmiller 1977, Janssen *et al.* 2005). The macroinvertebrate community of this region, while dominated by zebra mussels (*Dreissena polymorpha*) and quagga mussels (*D. bugensis*), also includes Porifera (*Spongilla*), Ectoprocta, *Hydra*, Ephemeroptera, Hirudinea, gammarid amphipods, pulmonate and ctenic gastropods, isopods, *Planaria*, nematodes, chironomids, caddisflies, and oligochaete naid worms. Fish species typical of rocky habitat include yellow perch (*Perca flavesceus*), sculpins (*Cottus bairdi, C. cognatus*), johnny darters (*Etheostoma nigrum*), and spawning lake trout (*Salvelinus namaycush*) (Janssen *et al.* 2005).

Surprisingly, little information on this complex habitat currently exists as both detailed information and high-resolution maps of nearshore Lake Michigan are lacking. The physical relief of this region has generally not been documented beyond that found in navigational charts, which contain only minimal bathymetric information and are insufficient for the analysis of habitat type. Moreover, the nearshore region of western Lake Michigan often does not contain bottom types amenable to conventional sediment sampling techniques. Ekman grabs, ponars, or gravity corers are incapable of operating over significant portions of these lake bottoms, where virtually no penetration by the sampler is possible. However, modern developments in acoustic and positional survey technologies can now provide an extremely accurate picture of bottom structure, relief, and habitat type on spatial scales of a meter. Accordingly, in this study, we demonstrate the utility of these techniques for mapping this largely uncharacterized and complex habitat in the Great Lakes.

METHODS

Study Site

Between 5–11 October 2002, approximately 17.5 km^2 of Lake Michigan lakebed were acoustically surveyed in an area located directly offshore of the WE Energies coal burning power plant in Oak Creek, WI (Fig. 1). The shoreline of this area is characterized by eroding bluffs and narrow sand beaches and nearshore bottoms that range from bed rock and hard clay outcrops, to cobble and boulder fields, to well sorted gravels, sands and silty sands (Janssen *et al.* 2005). Water depths over the surveyed area ranged from 5 to 20 meters. All field survey operations were conducted aboard the R/V *Neeskay*, which is maintained and operated by the UW System UW- Milwaukee Great Lakes Wisconsin Aquatic Technology and Environmental Research (WATER) Institute.

High Resolution Bathymetry

The bathymetry of the survey area was mapped using a Sea Beam 1180 multi-beam hydrographic survey sonar leased from and operated by L-3 Communication ELAC Nautik, Kiel, Germany. This sonar system employs 126 acoustic beams operating at 180 kHz and a swath width of up to 153° resulting in bottom coverage that is approximately eight times water depth. The system is fully real-time-compensated for roll, pitch, and yaw which assures that each beam hits the lake floor independent of the motion of the ship and that the surveyed area does not oscillate with the roll of the vessel. A more complete technical description of this sonar can be found at the ELAC website (www.elac-nautik.de).

Prior to the survey, a special bracket was fabricated to mount the sonar transducer on the R/V *Neeskay* to a depth just below the ship's keel. The bracket was rigid enough to hold the transducer spar absolutely still with no strumming while underway. The relative position of the sonar transducer, differential GPS (Global Positioning System) antenna, and motion sensors were then measured for motion compensation corrections while underway.

Approximately 300 km of survey lines were run over the ~ 17.5 km^2 survey area (Fig. 1b). With the survey area depth of interest ranging from ~ 10 to 20 meters, swath transect survey lines were spaced at 50–60 meters. This provided significant overlap (> 40%) in bottom coverage between adjacent transect lines over this depth range. Corrections for the speed of sound, which in shallow fresh water is largely temperature dependent, were updated twice a day, but showed virtually no variation during the course of this survey. Water temperatures were essentially uniform and the speed of sound varied between 1,457 and 1,462 m sec^{-1}. Surface waves never exceeded ~1 meter in height and sea state conditions were well within the motion compensation capabilities of the sonar system.

The raw bathymetry data (99 individual transect files containing a total of 1.68 GB of data in *xyz* format) were post-processed by ELAC Nautik in Kiel, Germany. Water depths were time corrected for lake level changes that occurred during the survey using the NOAA, National Ocean Service Center for Operational Oceanographic Products and Services (CO-OPS) sea level gauge at Milwaukee (no. 9087057, 43° 0.1′ N, 87° 53.2′ W). These data were recorded at 6-minute intervals, and lake levels during the survey ranged 18.7 cm from 176.041 to 176.228 meters (relative to International Great Lakes Datum). Digital Terrain Models (DTM) were provided to the WATER Institute at the following *xy* resolutions (file size): 5 × 5 m grid (19 MB), 2.5 × 2.5 m grid (77 MB); and a 1.5 × 1.0 m grid (205 MB). The vertical resolution of the processed data was approximately 1 cm.

Acoustic Bottom Classification and Characterization

In conjunction with the multi-beam survey, the character (e.g. sand, rock, or clay) of the lakebed was also analyzed using a Furuno echo sounder (model FCV-582L) operating at 50 kHz and a pulse width of 0.25 milliseconds. Both the single and multi-beam sonars could be operated simultaneously without interference because of their different operating frequencies (i.e., 50 kHz versus 180 kHz).

Backscatter from the single beam sonar was digitized and recorded to a Pentium PC using acoustic echo classification hardware and software from the Quester Tangent Corporation (QTC). Lakebed classification via acoustic echo analysis is based upon the principle that the shape of the reflected sonar signal is affected by lakebed characteristics, including sediment grain size, bottom roughness, bedforms and outcrops, as well as organisms living on or in the lakebed. Each acoustic echo was translated into a digital string of 166 shape descriptors using QTC VIEW CAPS (v3.25) software and stamped with a geographic coordinate relating to the position of the survey vessel (R/V *Neeskay*) over the survey site. The position of the ship was measured using a Raytheon GPS unit (model RN300) operating in the high resolution (undithered) mode with an accuracy of approximately 1 meter. Geographic coordinates for the lakebed classification data were saved as decimal degrees of longitude and latitude in the WGS84 datum. These coordinates were then converted to a UTM Zone 16 (Universal Transverse Mercator) map projection to obtain coordinates in units of meters (East and North). The coordinate projections were translated using Arc/Info v.4.

Based on an initial survey of the variety of lakebed bottom types within the survey area (see below), the digitized sonar backscatter points were sorted by principal component analysis (QTC IMPACT v3.20) into four clusters, each of which was assumed to represent a different lakebed type. The individual points in each cluster were then mapped geographically. Direct observation with a remotely operated vehicle (ROV) determined what specific lakebed bottom type each cluster represented.

A more detailed discussion of the statistical analysis of acoustic backscatter data can be found in Legendre *et al.* (2002), Preston and Kirlin (2003), and Legendre (2003).

Mapping

The DTM and QTC lakebed classification data (*xyz* format) were translated to a grid matrix using Surfer v8.0 (Golden Software, Inc.). The DTM files were gridded using triangulation with linear interpolation—an exact interpolation gridding technique that is optimal for regularly spaced data. The QTC lakebed classification matrix was created using a kriging gridding method.

Direct Lakebed Observation

On 10 October 2002, eight dives were made along a transect of stations running from shallow to deep water (Fig. 1b, dives 1–8) using an ROV system leased from and operated by Eastern Oceanics Inc. Video of each dive was recorded in Hi-8 format. Photographs were also obtained using an underwater Benthos 35 mm camera and strobe system that was mounted to the ROV.

On 5 June 2003, nine additional dives on the lakebed survey site were made using a VideoRay Pro II ROV (Fig. 1b, dives 9–17). An attempt to video record each dive, however, failed.

All dives were approximately 10 to 30 minutes in length. An attempt was made during each dive to physically disturb the lakebed surface with either the ROV's manipulator arm (Eastern Oceanics Inc. ROV) or grasping tool (VideoRay Pro II ROV), in order to better assess the nature or composition of the lakebed material.

Whereas the first eight dives were made primarily to determine the variety of lakebed bottom types over the survey area and the latter nine dive sites were specifically chosen to explore interesting features and areas that appeared on our preliminary bathymetry and lakebed character maps, all 17 dives were eventually used to corroborate the four lakebed character types identified via the methods described above using acoustic backscatter data.

RESULTS AND DISCUSSION

High Resolution Bathymetry

The high resolution DTMs were used to produce three types of bathymetric maps: 1) a contour map (Fig. 2a); 2) a 3-dimensional surface map (Fig. 2b); and 3) a shaded relief map (Fig. 3). The contour map was based upon the 5.0×5.0 m resolution DTM and a Surfer generated grid matrix consisting of 915 rows × 1,176 columns. The surface and shaded relief maps, meanwhile, were based upon the 1.5×1.0 m resolution DTM and a Surfer generated grid matrix consisting of 3,045 rows × 5,874 columns. Areas outside of the survey track line were blanked.

All maps show a gradual offshore gradient with a mean slope of less than 0.3%. In the nearshore (western) portion of the survey area, the isobaths trend predominately shore parallel, probably reflecting relatively recent wave-induced shoreline erosion and alongshore transport processes. Further offshore (> ~8 meters), isolated ridges and outcrops are visible. Even more interesting, however, are the SSW- NNE trending topographic features that are reminiscent of glacial scouring and scraping. These lakebed features are in exact alignment with the orientation of drumlins in southeastern Wisconsin, which indicate ice flow directions of the Lake Michigan lobe of the Laurentide Ice Sheet (Dott and Attig 2004, Larson and Schaetzl 2001).

Bottom Classification

On 10 October 2002, four types of bottom habitat were visually observed with the ROV: 1) a predominantly rock bottom, consisting of cobble and boulder fields, generally populated by a dense community of *Dreissenid* mussels (i.e., *D. polymorpha, D. bugensis*) and associated biota (e.g., amphipods); 2) mixed cobble, gravel, and sand bottoms; 3) predominately sand and silty sand bottoms; and 4) hard clay outcrops (Fig. 4). From these observations, two bottom characterization maps were developed using the classified (i.e., sorted) sonar data from QTC IMPACT and Surfer: 1) a 2-dimensional lakebed classification map showing the eight initial ROV dives and the ~ 300 km of

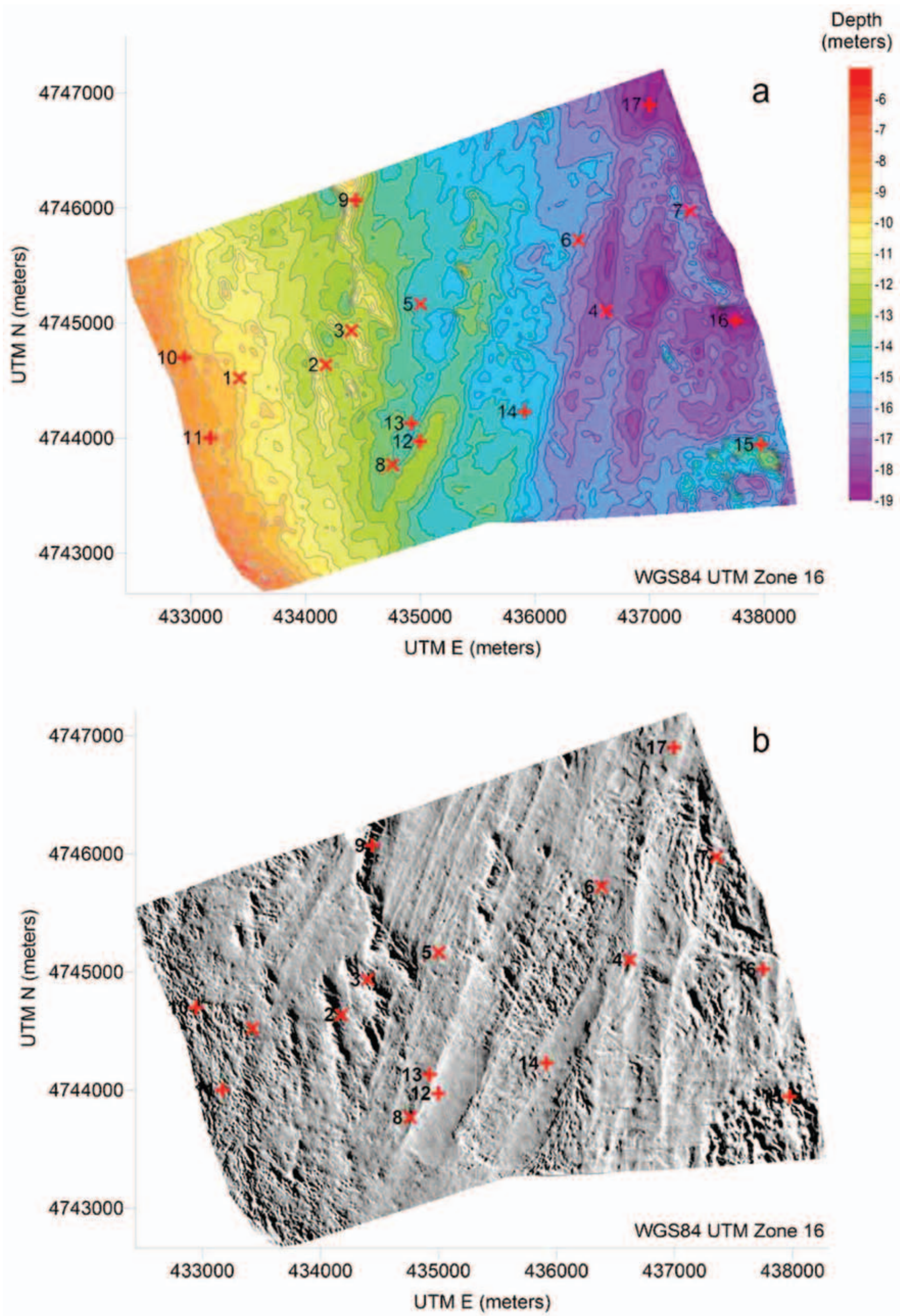


FIG. 2. Bathymetry of survey area: a) color contour map showing 0.5 meter isopleths based on 5.0 × 5.0 meter resolution DTM; b) shaded relief map based on 1.0 × 1.5 meter resolution DTM. Red symbols identify all ROV dive sites.

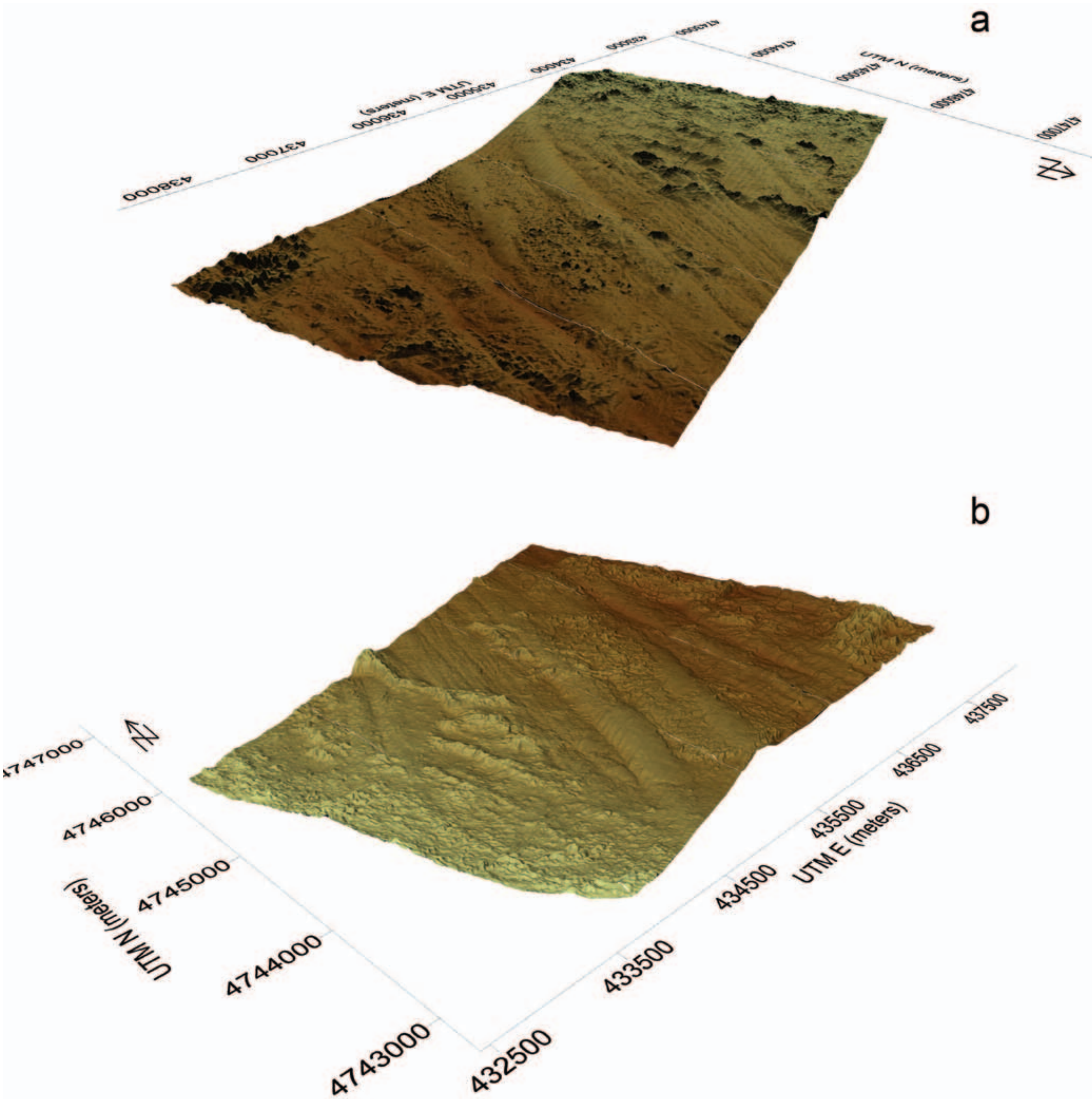


FIG. 3. Surface maps of survey area based on 1.0 × 1.5 meter resolution DTM: a) perspective projection from NE corner of survey area; b) perspective projection from SW corner of survey area. Z-axis scaling exaggerated by a factor of ~30. The light source for both images was positioned at ~WSW on the horizontal plane and 50° on the vertical plane.

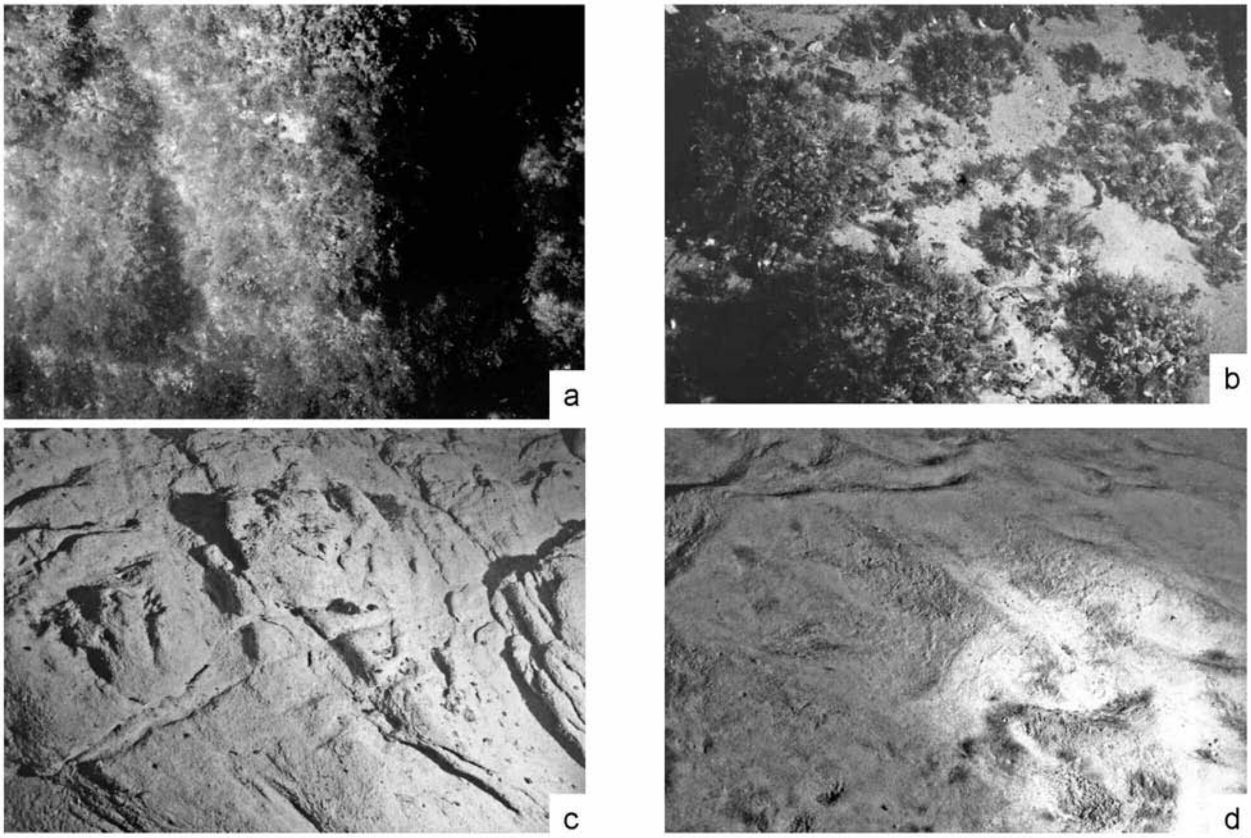


FIG. 4. ROV obtained photographs of the lakebed in the survey area of nearshore Lake Michigan: a) a predominantly cobble bottom at dive site no. 1; b) a cobble and sand bottom observed at dive site no. 7; c) a clay outcrop observed at dive site no. 4; d) a well sorted sand bottom observed at dive site no. 8. All photographs show an area approximately 1 to 2 meters in width.

acoustic survey transect lines (Fig. 5a); and 2) the same lakebed classification map overlaid with the contour line bathymetry from the multi-beam survey and all nine post-survey ROV dive sites (Fig. 5b). The four lakebed classification types are characterized as: 1) *mostly rock*; 2) *cobble and sand*; 3) *mostly sand*; and 4) *clay outcrops.*

The predicted bottom types based on acoustic characterization are consistent with observed bottom types at at least 16 of the 17 ROV dive sites. Close-ups of the bottom characterization map (Fig. 5b) at all 17 ROV dive sites and the associated recorded commentary based on visual observations for each dive are given in Table 1. Each survey map close-up is 150 meters to a side. Without dynamic positioning, it was not possible to hold the R/V *Neeskay* at a particular geographic location. Nor was it possible to determine exactly where the ROV was located relative to the ship without acoustic tracking. Nevertheless, 150 meters was chosen as a conservative estimate of the range of the ROV during the length of its deployment based on the extent of ROV tether deployed and whether the R/V *Neeskay* was anchored during ROV deployment (dives no. 1-8) or not (dives no. 9–17). During the eight initial dives, the ROV surveyed an area of approximately 50 meters in diameter over the lakebed bottom. Surveys with the smaller ROV (dives 9–17) generally covered much less ground and averaged not more than 20 meters in diameter. Specific lakebed characteristics within this area, as predicted by the acoustic survey, should have been visible to us via the ROV camera, and, indeed, this proved to be the case in most instances. Clay outcrops were clearly identified during the ROV dives at sites 4, 16, and 17 and sand completely covered the lakebed bottom at sites 6, 8, 12, 13, and 14. Acoustically characterized areas of sand and cobble

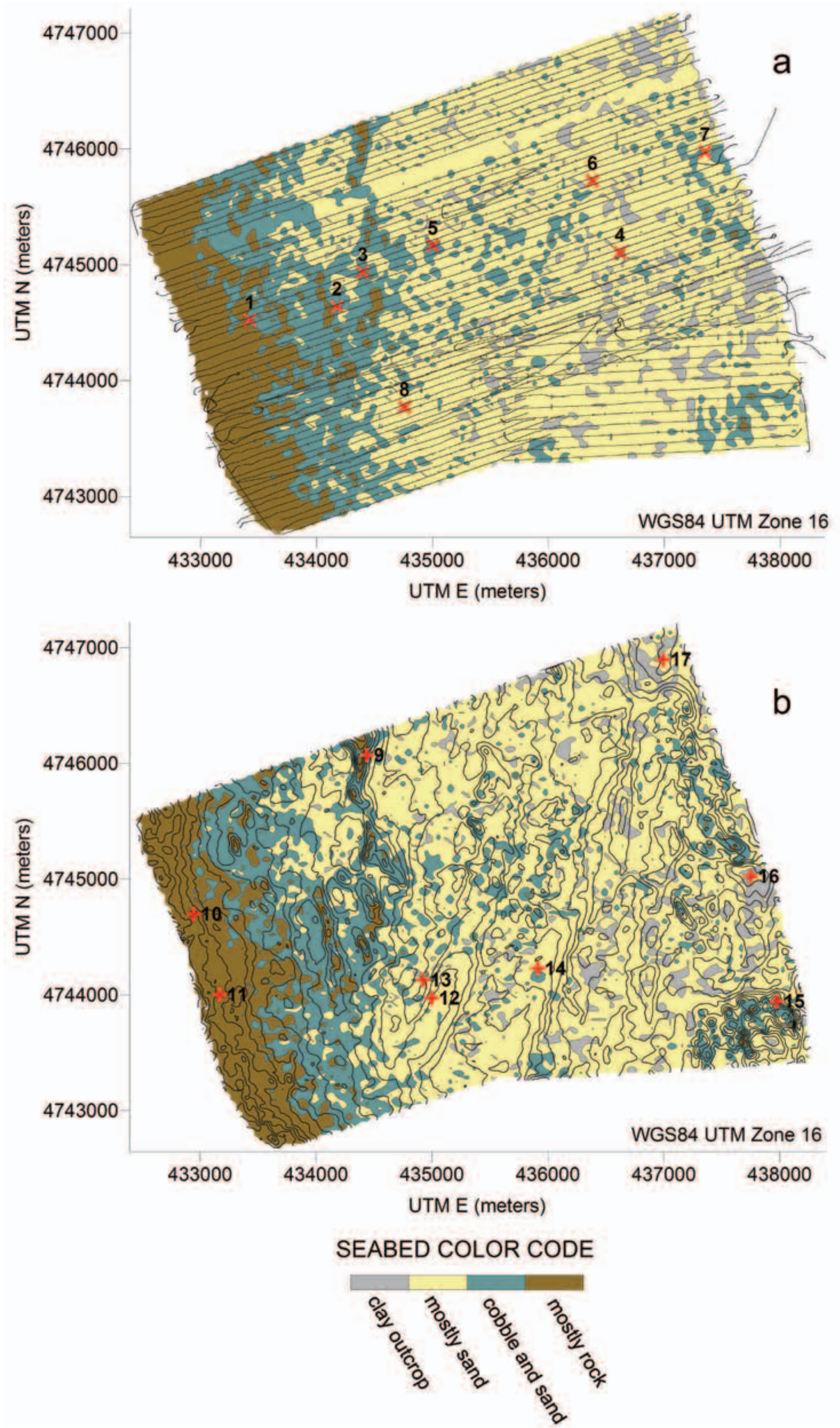
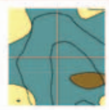
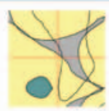
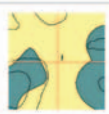
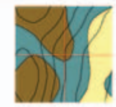
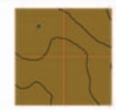
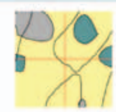
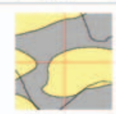


FIG. 5. ***Lakebed characterization of survey area: a) lakebed characterization based upon acoustic and visual data obtained at ROV dive sites (1–8). The ~ 300 km of acoustic survey transect lines are shown as dotted lines with each dot representing an acoustic data point that was used in this classification process; b) lakebed characterization with lakebed bathymetry based on multi-beam survey and post survey ROV dive sites (9–17).***

TABLE 1. Visual and acoustic lakebed character comparison.

DIVE	VISUAL CHARACTER	ACOUSTIC CHARACTER
1	*Cobble (rock), sand and pebbles, Zebra mussels and Cladophora*	
2	*Sandy bottom w/ rock*	
3	*Gravel and sand, w/ rocks*	
4	*Clay outcrops, sandy w/ fewer rocks*	
5	*Mostly sand w/ cobble*	
6	*Sand, well sorted w/ no rocks*	
7	*Cobble and sand: 40/60*	
8	*100% medium fine sand w/ ripples, well sorted*	
9	*Cobble w/ sand, some larger boulders, largely cobble (rock)*	
10	*Rock (cobble) well covered, with sand between, zebra mussels abound, infrequent boulders*	
11	*Sand and gravel, drifting into area with greater rock coverage, significant gravel coverage, many alewives*	
12	*Sand, sand, sand, with ripples*	
13	*Sand, with Cladophera clumps in depressions of sand ridges*	
14	*Sand, smaller ripples than at dive site 13, some Cladophera in small depressions*	
15	*Rock, clay, reef like area, rubble piles, many fish*	
16	*Mainly clay, some sand, small ridges of small gravel interspersed in clay*	
17	*Clay, with rocks scattered throughout, a few larger boulders, algae coverage of rocks*	

Lakebed color code: gray = clay outcrop (c), yellow = sand (s), bluegreen = cobble and sand (r+s), brown = mostly rock (r). ROV dives 1–8 were made on 10 October 2002, ROV dives 9–17 were made on 05 June 2003. Visual character based on notes taken at time of ROV deployment. Acoustic character maps are all 150 meter sided squares. Black lines denote bathymetric isopleths. Red crosses show location of *Neeskay* when ROV was deployed.

as well as mostly rock were also corroborated by direct observation. Only at site 15 was clay observed without any corresponding feature on the map. However, because the *Neeskay* was adrift at the time, the ROV may have been located at a point further south than indicated on the map. The observed clay outcrop might also have been too small to be differentiated on the map. As shown in Figure 5a, lakebed classification zones that extend over at least several track lines increase the confidence of the bottom type identification.

The acoustically derived lakebed classification was also corroborated to some extent by the multibeam sonar survey. An overlay of the lakebed classification map and the bathymetry map in Figure 5b shows good correlation between distinct classification zones and the physical relief features of the lakebed. Of particular interest are the rocky areas on top of ridges and the clay outcrops in depressed areas. Although we did not inventory the fauna of the habitats, it is interesting that we observed adult alewives (Alosa psuedoharengus) only at the four rocky sites when testing our bottom character predictions in May, 2003. They were not seen at the five non-rocky habitats and the preference for rocky habitat was statistically significant ($P < 0.02$, Fisher Exact Test). These fish were near bottom and feeding. There was an emergence of midges and caddisflies during this time, which may have been what attracted the alewives to the area. Janssen and Luebke (2004) made similar observations for young-of-the-year alewives.

Percentages of each lakebed character type over the entire 17.5 km^2 survey area were: 60.3% *mostly sand*, 21.0% *cobble and sand*, 12.8% *mostly rock*, and 5.9% *clay outcrops*. Cobble (rock) was most frequently found near shore. Increasing areas of sand were found away from the lakeshore. In deeper areas of the survey site, clay outcrops were more prominent. The sparse literature available to us generally supports our characterization of the lakebed bottom. Mozley and Howmiller (1977) concluded that much of the western Lake Michigan littoral zone is rocky. The area is underlain by Paleozoic bedrock, probably entirely Silurian at the study site (Foster and Folger 1994). The strata are tilted slightly with the western parts of strata slightly elevated relative to eastern parts. This tilt may be responsible for the general bottom shape. Bedrock is exposed at some locations along the western shore. The closest example is at Wind Point just north of Racine (Fig. 1a). There may be some bedrock exposures in the mapped area of Figure 5b, most likely at the ridge cutting through the northern edge of the map and in the southeast corner. However, these could also be deposits of cobble and boulder (which was what was observed at dive site 9 and 15, Table 1). Overlying the bedrock are layers of glacial till that include clays and cobble (Lineback *et al.* 1971, Lineback *et al.* 1974, Wickham *et al.* 1978). Sand often overlies the till and the sand in the mapped area must drift to some extent (based on studies in Illinois, Shabica and Pranschke 1994), but determining exactly how much drift occurs would require repeated mapping. It is likely that there is cobble beneath the sand that may be exposed if the sand drifts significantly. Areas with mixed sand and cobble showed sand in ridges, frequently with either gravel or what appears to be clay in the troughs.

The value of an increased understanding of lakebed characteristics, even on a basic level such as this, is obvious. Many fauna have specific benthic substrate preferences or requirements (Janssen *et al.* 2005), and accurate knowledge of bottom types can be used to construct fairly accurate estimates of community structure, exotic species invasion potential, sensitive hatchery protection zones, and so on. Moreover, repeated mapping of a particular nearshore habitat might very clearly identify the impact of coastal urban and industrial development. Based on these early bottom classification results, further mapping along the western shore of Lake Michigan appears warranted.

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REFERENCES

Beeton, A.M. 1984. The World's Great Lakes. *J. Great Lakes Res.* 10:106–113.

Dott, R.H., and Attig, J.W. 2004. *Roadside Geology of Wisconsin.* Missoula, Montana: Montana Press Publishing Company.

Edgington, D.N., and Robbins, J.A. 1976. Records of lead deposition in Lake Michigan sediments since 1800. *Environ. Sci. Technol.* 10:266–274.

———, and Robbins, J.A. 1990. Time scales of sediment focusing in large lakes as revealed by measurements of fallout ^{137}Cs. In *Large Lakes: Ecological Structure and Function*, M. M. Tilzer and C. Serruya (eds.), pp. 210–223. New York: Springer-Verlag.

Foster, D.S., and Folger, D.W. 1994. The geologic framework of southern Lake Michigan. *J. Great Lakes Res.* 20:44–60.

Janssen, J., and Luebke, M. 2004. Preference for rocky habitat by age-0 yellow perch and alewives. *J. Great Lakes Res.* 30:93–99.

_____, Berg, M., and Lozano, S. 2005. Submerged terra incognita: the abundant but unknown rocky zones. In *The Lake Michigan Ecosystem: Ecology, Health and Management,* pp. 113–139, T. Edsall and M. Munawar (eds), Amsterdam: Academic Publishing.

Larson, G., and Schaetzl, R. 2001. Origin and evolution of the Great Lakes. *J. Great Lakes Res.* 27:518–546.

Legendre, P. 2003. Reply to the comment by Preston and Kirlin on "Acoustic seabed classification: improved statistical method". *Can. J. Fish. Aquat. Sci.* 60: 1301–1305.

_____, Ellingsen, K.E., Bjornbom, E., and Casgrain, P. 2002. Acoustic seabed classification: improved statistical method. *Can. J. Fish. Aquat. Sci.* 59:1085–1089.

Lineback, J.A., Gross, D.L., Meyer, R.P., and Unger, W.L. 1971. *High resolution seismic profiles and gravity cores of sediments in southern Lake Michigan.* Environmental Geology Notes Number 47. Illinois State Geological Survey.

_____, Gross, D.L., and Meyer, R.P. 1974. *Glacial tills under Lake Michigan.* Environmental Geology Notes Number 69. Illinois State Geological Survey.

Mozley, S.C., and Howmiller, R.P. 1977. Environmental status of the Lake Michigan Region. Vol. 6. *Zoobenthos of Lake Michigan.* Argonne National Laboratory, Argonne, IL.

Preston, J.M., and Kirlin, R.L. 2003. Comment on "Acoustic seabed classification: improved statistical method." *Can. J. Fish. Aquat. Sci.* 60:1299–1300.

Shabica, C., and Pranschke, F. 1994. Survey of littoral sand deposits along the Illinois and Indiana shores of Lake Michigan. *J. Great Lakes Res.* 20:61–72.

Wickham, J.T., Gross, D.I., Lineback, J.A., and Thomas, R.L. 1978. *Late Quarternary sediments of Lake Michigan.* Illinois Geological Survey Environmental Geology Notes 13.

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