**US Army Corps
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Waterways Experiment
Station

Beach and Underwater Occurrences of Ordnance at a Former Defense Site: Erie Army Depot, Ohio

by   Joan Pope, Richard D. Lewis, Timothy Welp

WES

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Prepared for   U.S. Army Engineer Division, Huntsville

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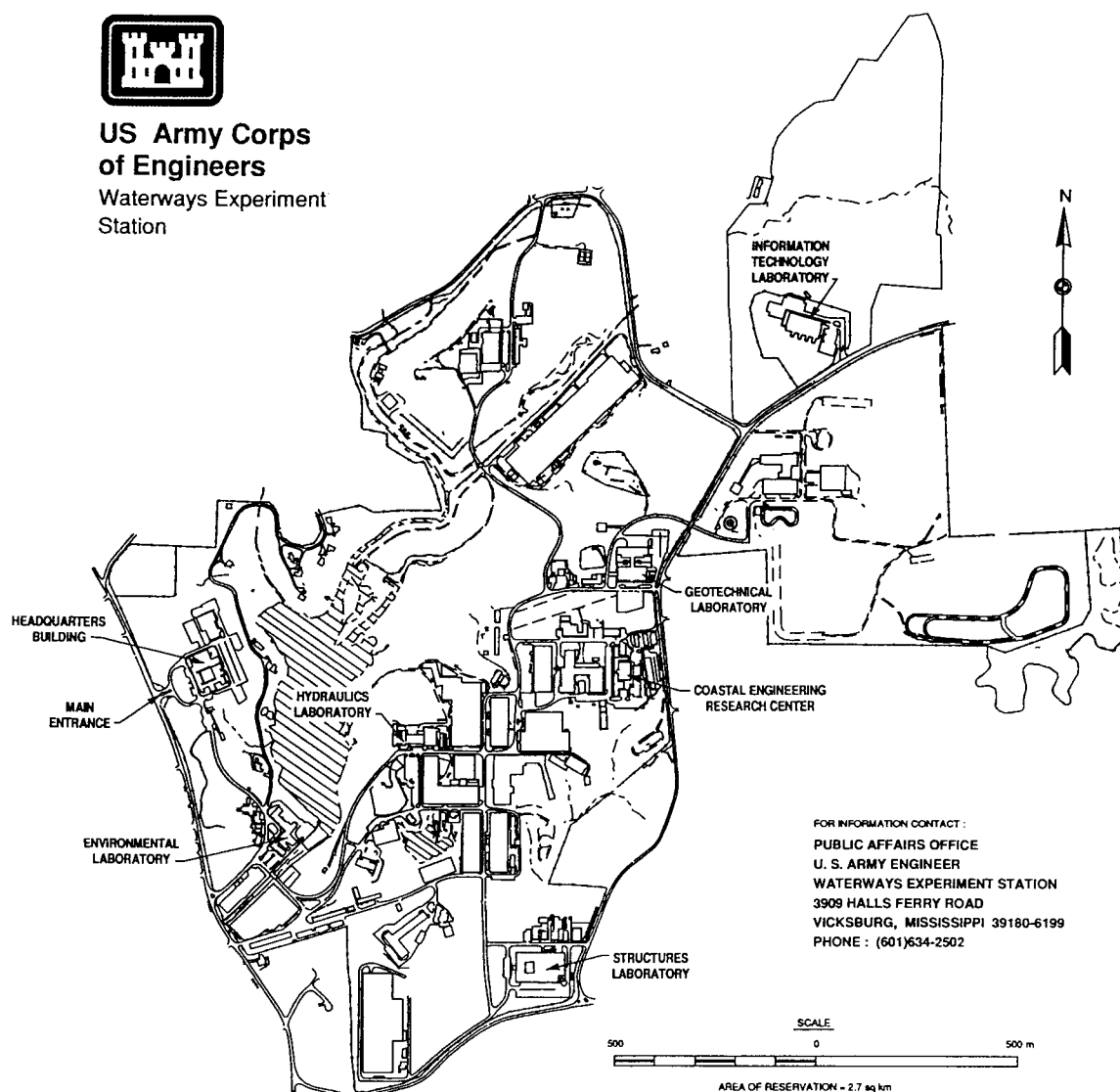3909 Halls Ferry Road
Vicksburg, MS   39180-6199

Final report

US Army Corps of Engineers
Waterways Experiment Station

Contents

List of Figures

vi

Preface

The field study and analysis described in this report were performed by the U.S. Army Engineer Waterways Experiment Station's (WES) Coastal Engineering Research Center (CERC) and Geotechnical Laboratory (GL) for the U.S. Army Engineer (USAE) Division, Huntsville. A field study was conducted at a Formerly Used Defense Site (FUDS) in western Ohio and Lake Erie called the Erie Army Depot during September 1993 to evaluate the underwater and beach occurrences of military ordnance contamination. This study and the subsequent data and coastal process analysis were conducted in support of the Department of Defense's Defense Environmental Restoration Program. The USAE District, Buffalo, is the host District for this site and is responsible for maintaining a Federal navigation channel in the subject FUDS area. USAE Division, Huntsville, provided safety oversight during the field operation and USAE District, Buffalo, provided field logistical and support assistance. CERC coordinated the overall study, coordinated the oceanographic data collection, and conducted the coastal processes interpretation of the data results. GL coordinated the geophysical data collection and data analysis. Contract personnel from David Evans & Associates provided positioning control and Golder Associates, Inc., conducted the side-scan sonar survey. Contract personnel from Western Michigan University conducted the ground-penetrating radar survey. Contract personnel from Geomar Geophysics, Ltd., conducted the electromagnetic survey. USAE Division, Huntsville, personnel responsible for project oversight include Mr. Steven Dunn, Dr. John Potter, and Ms. Alicia Allen.

WES participants in the field study were Messrs. Timothy Welp, Larry Caviness, Douglas Lee, and Troy Nelson from CERC's Prototype Measurement and Analysis Branch (PMAB); Ms. Joan Pope, Chief of CERC's Coastal Structures and Evaluation Branch; and Dr. Richard D. Lewis of GL's Engineering Geophysics Branch. USAE District, Buffalo, participants in the field study were Messrs. Dennis Rimer, Ray Pilon, and Gary Schoffstall. The USAE Division, Huntsville, participant was Mr. Wayne Galloway. Contract personnel contributing to the field effort were Mr. John Dasler (positioning control) from David Evans & Associates, Mr. Richard Sylvester from Golder Associates, Inc. (side-scan sonar), Mr. Jerzy Pawlowski (electromagnetic survey) from Geomar Geophysics, and Dr. William Shauk and Mr. Dave Seng (ground-penetrating radar survey) from Western Michigan University.

A number of individuals from the study area provided immeasurable assistance in coordinating logistical support, assisting with operational safety and security, and

providing insight into the history of the Erie Army Depot and the occurrence of ordnance contamination. In particular, the authors wish to acknowledge the assistance of the following:

Director of WES during publication of this report was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4,046.856	square meters
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
inches	2.54	centimeters
miles (U.S. statute)	1.609347	kilometers
knots	1.68781	ft/sec

1 Introduction

The former Erie Army Depot, Ottawa County, OH, is located along the western shore of Lake Erie (Figure 1). This site and the associated impact areas are classified by the United States Government as a Formerly Used Defense Site (FUDS) under the Defense Environmental Restoration Program (DERP). This property was formerly used for artillery testing, resulting in impact areas on land and in Lake Erie. Ordnance and explosive waste (OEW) and potentially live or unexploded ordnance (UXO) have been found on the lake bottom, in the Federal navigation channel at the Toussaint River, in the marshland adjacent to the firing ranges, and along beaches fronting the former Depot. The impact areas were located in, near, or offshore of the FUDS beaches adjacent to Lake Erie. Ordnance found on or near the FUDS shore of Lake Erie appears to be mobile and may have originated from offshore or nearshore impact areas. The purpose of this investigation is to determine the underwater ordnance density at specific regions and to access the potential for ordnance movement due to coastal processes within the FUDS site. This information will be provided to the U.S. Army Engineer (USAE) Division, Huntsville, to assist them in developing a site remediation strategy.

Background

The subject study area consists of the beach and area of Lake Erie fronting the former Erie Army Depot (now called Erie Industrial Park), between Camp Perry Ohio National Guard Training Center and the mouth of the Toussaint River in northwest Ohio (Figure 1). This FUDS site is located in rural Carrol Township, Ottawa County, OH, on Lake Erie, approximately 60 km (37 miles)[1] east of Toledo, Ohio, and 6 miles east of Port Clinton, Ohio. The Erie Army Depot was initially established in 1918 as the Camp Perry Proving Grounds, then redesigned as Erie Proving Grounds. For almost a half century (1918-1966) this site was used by the Department of the Army for testing and

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[1] Units of measurement in the text of this report are shown in SI (metric) units, followed by non-SI (British) units in parentheses. Units of measurement of figures are shown in British units; however, a table of factors for converting non-SI units of measurement to SI units is presented on page xii.
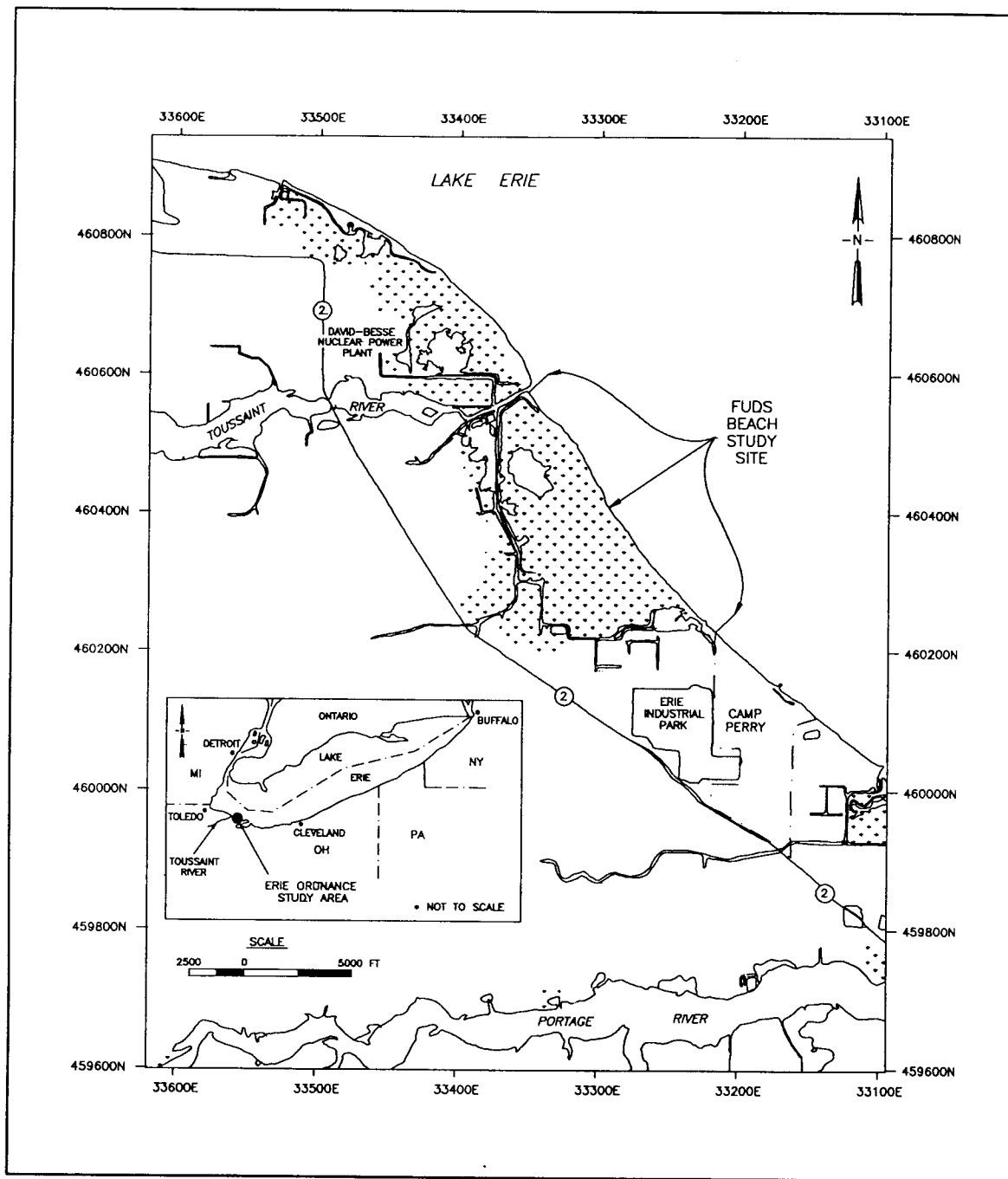
Figure 1.   Location map of FUDS beach study site

proof-firing of artillery and as an ordnance storage and issue center (USAED, Rock Island 1993).

Ordnance pattern impact areas included surfaces classified as lake (388 km² (96,000 acres)) of Lake Erie) (Figure 2), wet land (1.3 km² (329.5 acres) including the beach), and dry land. This prior Army installation and impact
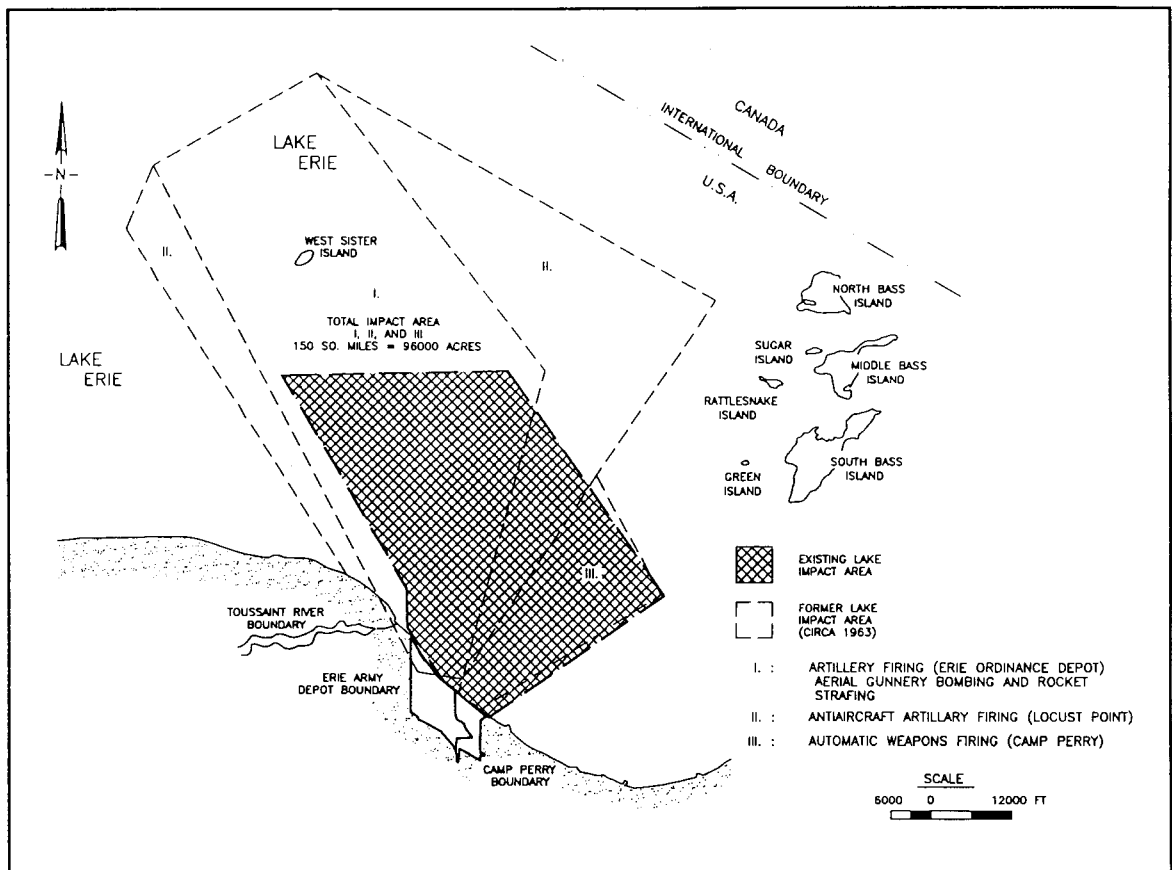
Figure 2. Erie Army Depot and Camp Perry lake impact zones

area is now classified as a FUDS, subject to Federal site cleanup action. Under DERP, this prior U.S. Army installation and impact area, or FUDS, is subject to Federal site cleanup action. OEW and UXO have been found on the study area beach and during the 1991 dredging operations for the Federal navigation channel at the Toussaint River, which were conducted by the USAE District, Buffalo.

In 1992 the Huntsville Division was assigned responsibility for conducting the immediate removal of OEW along the 4.8-km (3-mile) (an approximately 150-m-wide (500-ft wide zone)) beach frontage as part of their OEW site remediation mission. From 1 September through 9 December 1992, EOD Technology (EODT) conducted beach OEW cleanup operations under contract to the Huntsville Division. Post-cleanup site inspections revealed the presence of additional occurrences of ordnance on the beach, raising concerns that the nearshore ordnance field may be mobile and transportable to the beach by natural coastal processes. In March 1993, the Huntsville Division and the Buffalo District contacted the U.S. Army Engineer Waterways Experiment Station (WES) to request assistance in evaluating the prognosis for future ordnance deposition on the beach.

Purpose

This study has been undertaken to assess underwater and beach ordnance distribution patterns for the Lake Erie Impact Area and the implications of these patterns in terms of past and, therefore, future influences of coastal processes. The location and density of UXO in and near former artillery impact areas in Lake Erie, OH, is of concern. Potentially live ordnance has been and continues to be discovered on beaches adjacent to the former Erie Army Depot. In addition, UXO has been encountered during the initial dredging of the Federal navigation channel of the nearby Toussaint River, rendering it difficult to establish the required navigation depth and channel configuration using standard dredging procedures. This study to define and locate OEW fields in Lake Erie may be followed by other engineering investigations, at the discretion of the Huntsville Division, to determine the migration rates and patterns of OEW. Further work may include the examination of various engineered traps or barriers, to concentrate or divert ordnance migration, or to assist the Huntsville Division in developing a site management and/or remediation plan.

During a post-remedial cleanup inspection in early 1993, additional pieces of OEW were found exposed on the shore or beach surface. The new OEW occurrences along a recently cleaned beach led the Huntsville Division to question the mobility of the ordnance in the nearshore and the future potential for continuing migration of ordnance onto the beach. After consultation with WES and others, the Huntsville Division decided to sponsor an offshore and shallow- water field investigation to accomplish the following:

a. Determine the potential concentration of OEW which may be migrating toward the beach. The purpose of this portion of the study was to determine the concentration of ordnance which may be immediately offshore to a distance of about 900 m (3,000 ft) off of the shore.

b. Determine the size and location of any zone or area where a substantially high enough energy environment exists which may act to move the ordnance toward the land.

c. Provide input data for use in designing a potential ordnance trap or barrier (if needed) which will halt the movement of the OEW, (1) onto the beach area, and (2) into the Federal navigation channel.

Study Elements

During September 1993, WES (with site assistance from the Huntsville Division and the Buffalo District and several contractors) conducted a multi-instrumented geophysical and oceanographic field investigation to document site geological conditions, the influences of various coastal processes, and OEW distribution patterns. In particular, the concentrations of suspected

OEW lakeward of the FUDS beach, on the beach, and in the entrance channel of the Toussaint River was documented relative to geomorphic features, sediment type, and the geography of Erie Army Depot. All data collection was positioned using a differential global positioning system (DGPS). Data sets collected to document ordnance concentrations and site geology included land and underwater magnetometer, ground-penetrating radar (GPR), electromagnetics, side-scan sonar (SSS), a remotely operated vehicle (ROV), site narratives, historical information, and coastal process data.

Following the field investigation, these data were analyzed and mapped using an Ohio State Plane coordinate system. In addition, other site information was collected, analyzed, and evaluated. These supplemental data sets included the OEW beach concentration patterns based on the 1992 site cleanup data, a qualitative assessment of the mobility of ordnance using WES's hydrodynamic tank facilities, interviews with former Erie Army Depot employees, mapping of historical ordnance firing patterns, and a review of historical shoreline change information.

Report Structure

This report includes discussions of the field investigation, the data analysis process and results, supplemental data sets, an assessment of the OEW distribution patterns, and conclusions on the results of the data collection, as well as an evaluation of the performance of each data collection technique. The "Introduction" (Chapter 1) and "Site Background and Characterization" (Chapter 2) chapters establish the basic information regarding the study and site. Details of the "Field Investigation" are presented in Chapter 3 and also specified in Appendix A, which is a "Log of Field Activities." Chapters 4 through 7 describe the various geophysical and oceanographic technologies which were used including the data processing and data results. Additional information on the GPR and electromagnetic studies is included in unpublished contractor reports.[2,3] An analysis of the supplementary data sets is presented in Chapter 8. "Conclusions and Recommendations" are presented in Chapter 9.

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[2] Geomar Geophysical. (1993). "Ordnance investigation using an electromagnetic method, Lake Erie, Port Clinton, Ohio." Unpublished contractor report for the U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

[3] Shauk, W. (1994). "Report of Field Investigation: Lake Erie ordnance investigation using Ground Penetrating Radar." Unpublished contractor report for the U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

2 Site Background and Characterization

History

Erie Army Depot

Camp Perry was established in 1907 by the state of Ohio for the training of the state National Guard. Part of the camp was used to establish the Erie Army Depot in the spring of 1918. During the next 2 years, the site was used to proof fire (check for accuracy) thousands of pieces of artillery. Between World Wars I and II, the site was less active and was used primarily to warehouse and issue various items of ordnance. In 1941, the artillery test firing mission of the site was reactivated in support of World War II and the name of the facility was changed to the Erie Proving Ground. During the next 5 years, 70 percent of the mobile artillery used by the U.S. Army or provided to Allied armies was tested and proof-accepted at Erie Proving Ground. Between 1946 and 1951, the site reverted to a peace-time role and was renamed the Erie Army Depot. Late in 1951, the depot assumed the additional roles of anti-aircraft support testing and the overhauling of surface-to-air guided missiles (support to the Korean Conflict). Additional activities included logistical support to Regular Army and National Guard anti-aircraft units training at Camp Perry (USAE District, Rock Island 1993a, 1993b; Bovia and Wirzylo 1992).

Test firings of Vietnam-era munitions continued into the early and mid-1960's. Figure 3 illustrates 1965 period firing fans and target zones related to the present Erie Industrial Park. Discussions with previous employees of the Erie Army Depot and present officials of Camp Perry indicate that the firing source and range patterns have been similar for other periods. The Erie Army Depot was excessed by the General Services Administration in 1966 and closed in 1967. However, ARES, Inc., a company under contract to the Federal Government, has continued to manufacture and test fire artillery and other large-caliber barrels on this property as a commercially owned and operated enterprise. The majority of acreage encompassing the former Erie Army Depot site is no longer Federal property and is now classified as a FUDS. Approximately 5.7 km^2 (1,400 acres) of property at the former Erie Army
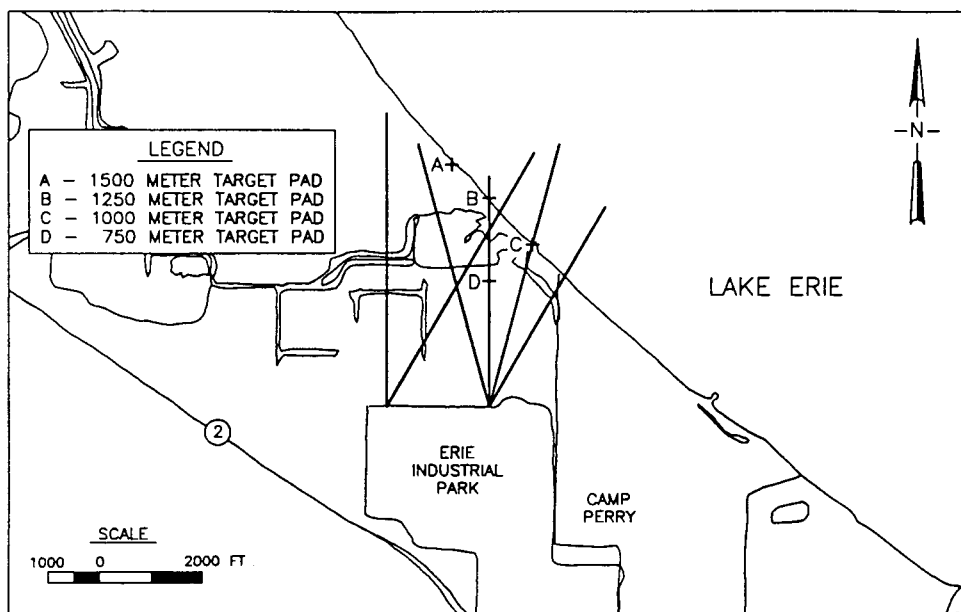
Figure 3. Firing fans and target locations for Erie Army Depot in 1965

Depot were acquired by negotiated fee and 1 km² (240 acres) was long-term leased from the State of Ohio to private land owners.

Several impact areas in Lake Erie were established by the Erie Army Depot in order to test fire artillery barrels. The boundaries of these areas are generally known for the World War II era and well known from the 1960's to present (Figure 2). The heavy caliber lake impact areas, which are currently used by Camp Perry, are significantly smaller in size than those documented as being active by Erie Army Depot in the earlier years (Figure 2). Approximately 388 km² (96,000 acres) of Lake Erie and 5.78 km² (1,427.75 acres) of land are classified as formerly used target areas. The currently maintained impact/safety zone used by Camp Perry includes 145.8 km² (36,033 acres) of the FUDS Lake impact zone (USAE District, Rock Island 1993a, 1993b). In addition to the test firing conducted by the Erie Army Depot, these impact areas were extensively used in training missions by the Navy, Air Force, National Guard, and Army Reserves. This multi-use and 75-year history of ordnance firings is reflected by the wide range in type and caliber of ordnance recovered on or near the former impact areas. OEW recovered or identified on the FUDS site beaches include a broad variety of direct fire and indirect fire munitions currently or formerly maintained in the arsenals of U.S. military forces. Shells range in size from the largest World War I 240-mm and more recent 155-mm artillery rounds to smaller World War II 45-mm

armor-piercing and 1960's 60-mm mortar projectiles and modern small-caliber rifle cartridges associated with present Camp Perry activities.

Federal Navigation Project at Toussaint River

The Toussaint River is situated immediately north of the former Erie Army Depot. This river includes several small craft and commercial fishing marinas. In 1991, a contractor operating for the Buffalo District was in the process of constructing the 76-m-wide (250-ft-wide) Federal channel by dredging the natural channel to a depth of 1.2 m (4 ft) below low water datum (LWD) through the entrance of the Toussaint River to Lake Erie (Figure 4). The equipment used was a cutterhead dredge which became jammed with a 106-mm antitank round. A U.S. Army explosives ordnance disposal (EOD) unit determined that the round was potentially live and contained a rather sensitive piezo-electric fuse. The only acceptable method of removal by the EOD was to explode the round in place, potentially destroying a significant portion of the dredge and creating a substantial uninsured loss. The contractor elected to remove the round at his own risk. Due to the occurrence of OEW material within the channel sediments, construction terminated on 25 September 1991 after 35,900 m^3 (47,000 cu yd) of the planned 42,100 m^3 (55,000 cu yd) of material had been dredged and placed in the designated disposal areas. The
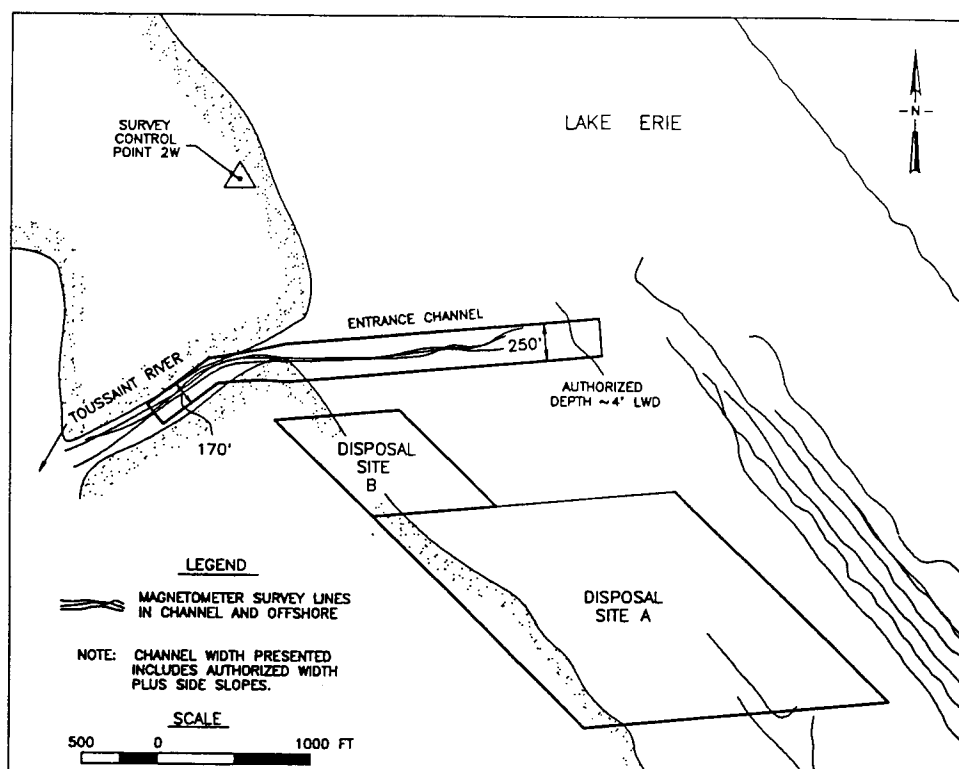
Figure 4.   Authorized Toussaint River Federal Navigation channel and disposal areas (shown relative to magnetometer lines surveyed during this study)

Buffalo District is implementing a site remediation dredging demonstration project to recover underwater OEW from the Federal Channel (scheduled to occur in 1995).

FUDS Beach

The now privately owned FUDS beach area along Lake Erie from the mouth of the Toussaint River to the Camp Perry boundary was evaluated for OEW and UXO in late 1991. The area surveyed was part of the former Erie Army Depot and was approximately 5 km (3 miles) long with a variable beach width ranging from no dry beach to approximately 150 m (500 ft). It was determined that a substantial amount of UXO may be present at the site and an OEW interim removal should be conducted under the DERP-FUDS program.

From 1 September through 9 December 1992, EODT, under contract to the Huntsville Division, removed or exploded in place all the OEW which could be visually seen on or was within 1 ft of the beach surface from the still-water surface to 500 ft inland. A total of 5,438 OEW items, ranging from small-caliber cartridges up to and including large pieces such as 165-mm projectiles were identified and removed. The largest populations of ordnance were 20 mm (24 percent), 60 mm (23 percent), 106 mm (15 percent), and 105 mm (14 percent). Approximately 20 percent of the ordnance was classified as potentially "live" rounds. During this removal and cleanup operation, EODT maintained a detailed record of ordnance finds by type, condition, and location. They installed a temporary network of rebars to demark lanes ranging from 15 to 61 m (50 to 200 ft) in width across the entire length of the FUDS beach. An analysis of the ordnance cleanup zones and density of occurrences on the beach is presented in Chapter 8.

Physical Geography

The specific zones incorporated in this study area (Figure 1) are as follows:

a. The FUDS beach from the Toussaint River to Camp Perry.

b. Offshore of this beach from the waterline to a water depth of approximately 3 to 4 m (10 to 13 ft) below low-water datum (LWD). LWD for Lake Erie is at 173.5 m relative to the International Great Lakes Datum, 1985, and will be used throughout this report as the vertical survey datum reference. At the time of the subject field study the Lake Erie water level gauge was approximately 1 m (3.2 ft) above LWD.

c. The Federal navigation channel and the mouth of the Toussaint River.

The study area is located along the south shore of the western basin of Lake Erie. The land is a low, flat, broad plain, founded on lacustrine (lake) clays deposited during interglacial periods when the predecessor of the modern Lake Erie was much larger. The eastern boundary of the study area is the Ohio National Guard Camp Perry and the western boundary is the Toussaint River. Along the northwest shore of the Toussaint River is a section of the Navarre Division of the Ottawa National Wildlife Refuge and the Davis-Besse Nuclear Power Station. The beach is a narrow, shallow-depth, sandy barrier which includes washover deposits and evidence of breaching, and in many areas the backbeach consists of a thin boundary of scrub and woodlands. The FUDS shore has a history of rapid erosion. Rubble-mound revetments have been added as shore protection at the southeastern end of the study site through the Camp Perry boundary and fronting approximately 0.8 km (0.5 mile) of the central beach.

This narrow beach is backed by a thickly vegetated marsh and an open water channel and lagoonal complex. The northwestern portion of this marsh is owned by the Toussaint Shooting Club, a private hunt club. The southwestern portion contains a portion of the former Erie Army Depot, which is now the Erie Industrial Park. Most of the buildings in Erie Industrial Park are used for light commercial and storage purposes. However, the most lakeward complex, which incorporates the original Erie Army Depot firing bunkers, is owned and operated by ARES, Inc. ARES continues the traditional role for this site as a commercial artillery and armament test facility. Both ARES and Camp Perry continue to use portions of the FUDS site (both lake and marsh) for ordnance testing purposes (Figure 2).

Coastal Processes

Water levels in the study site respond to the normal annual variability of Lake Erie (annual and seasonal trends). Figure 5 illustrates the average water level for Lake Erie for the month of September (all years of data) and shows that the water level during the September 1993 field study was approximately 1 ft higher than the long-term September average. Water depth referencing during this study is related to the water level during the September 1993 field study when the gauge recorded levels at +0.95 m (+3.1 ft) above LWD. Average annual water levels typically vary over a 0.6-m (2-ft) range, with the highest levels in the spring and the lowest levels in winter. Historical maximum and minimum recorded levels are approximately +1.5 m (+5 ft) to 0 LWD.

The western end of Lake Erie is shallow and subject to rapid water level fluctuations as storms and frontal passages can "set up" or seiche both the local and entire lake water surface. This process is an important contributor to the character of the study site.
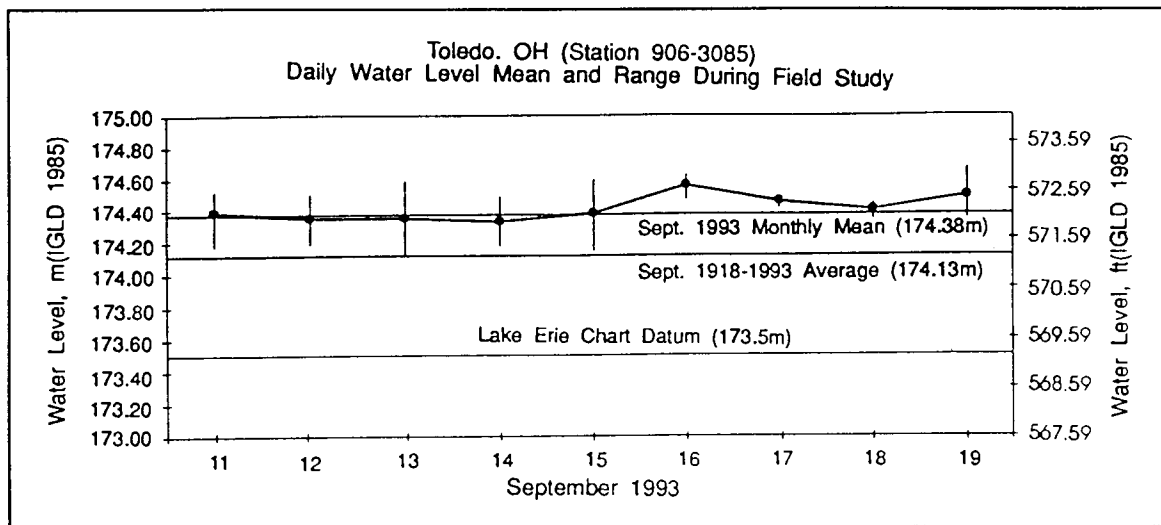
Figure 5.   Lake Erie water levels (at Toledo, OH) during field study

A wave hindcast study conducted for Lake Erie includes 32 years (1956-1987) of computed wave heights, directions, and periods for Station 2 located offshore of the study site (latitude 41.73° N, longitude 83.08° W, with a water depth of 9 m) (30 ft) (Driver, Reinhard, and Hubertz 1991). This computed wave information represents wave conditions approximately 24 km (15 miles) offshore, near the Canadian border, in a location which is not sheltered by the geometry of the land or islands. However, these data do show that the western basin of Lake Erie is not subject to very large waves, with the annual mean wave less than 2 ft (0.6 m) and peak periods of 3.6 sec. Generally, the highest waves occur during the winter months (November through April) with monthly means of 0.7 to 0.8 m (2.3 to 2.6 ft), while the summer months (June through September) experience monthly means of 0.5 m (1.6 ft). The stormiest months tend to be March and April, which is a period also characterized by the breakup of the ice cover. The largest significant wave computed for Station 2 is 2.6 m (8.5 ft) for a storm which occurred in April 1958 with winds out of the east (88 deg). The study area would have been somewhat sheltered from this event, and other big storms that tend to roll down the axis of the lake by the shoreline and island geometry.

The indented geometry to this shore and the presence of Catawba Island and the Bass Island complex to the east, shelter the FUDS beach from all wave directions except those from the north-northwest through the east-northeast (Figure 2). The most severe conditions are those where the winds and the waves are out of the northern sectors. In this case the shallow offshore and short-period "local" waves can result in a very agitated sea state with steep shoaling waves. Under these conditions, the silty, fine lake bottom sediments will be disturbed causing the water column to become turbid. These conditions occurred on the 16, 17, and 19 of September 1991 during the field study (Figure 5). However, when the winds are from the southern (particularly the southwestern) sectors, the site is becalmed. Local water level may

actually drop as the water surface is seiched toward the northern shore of Lake Erie. This condition occurred on 11-15 September during portions of each day.

Another process important to this site is the almost annual winter formation and movement of lake ice. The western basin of Lake Erie is usually the first portion of the lake to normally develop a solid ice pack cover. This ice sheet usually encases the south shore, including the study area (National Oceanic and Atmospheric Administration 1983). Lake ice can both isolate the near-shore bottom and the beach from wave forces or (particularly during ice breakup) can act as a tool, increasing the damages of the waves. Ice damages to shore developments are common in the Great Lakes. However, the effect of the moving and stacking ice sheet on bottom sediments and shore erosion is a very poorly understood phenomenon, particularly as it relates to sediment (and object) transport.

Potential and dominant littoral transport characteristics for the study site have important implications in terms of the beach condition and the migration of OEW. Longshore transport indicators suggest that the quantity of material being transported is relatively small compared to more exposed sites along Lake Erie and also that the predominate transport direction is not well-defined. The largest waves which approach the site are from the northwest through northeast directions with a fetch length of 40 km (25 miles). The predominant direction of littoral transport at the mouth of the Toussaint River through the FUDS study area to Camp Perry is from northwest toward the southeast. Based on the geometry of the shore and geomorphic indicators, the potential for transport toward the southeast should increase toward the east (less dominance at Toussaint River and more dominance at Camp Perry). The bend of the river entrance channel toward the east, the spit buildup on the northwestern side of the river, and the buildup of sand on the northwestern side of "stickout features" throughout the study area support this interpretation. A similar interpretation is presented in USAE District, Buffalo (1989) and publications of the Ohio Geological Survey.[1]

Geologic Setting

The FUDS beach is a thin (less than 2- or 3-m (6.5- or 10-ft) -thick) blanket of sand which sits on top of older lake clays. Lens of organic-rich silts and clays (including peat deposits) are intermingled within the sand body and may be exposed along the shore or in the nearshore, particularly in the troughs between bars. The peat deposits are the result of the relatively modern marsh deposits being exposed on the beach as the barrier migrates back over the marsh.

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[1] Benson, D.J. Unpublished report, "Lake Erie Shore Erosion and Flooding, Ottawa County, Ohio." Ohio, Division of Geological Survey.

The shore northwest of the Toussaint River mouth is a wider and more stable sandy barrier beach than that which fronts the FUDS study site. This barrier includes several beach ridges which are crested by scrubs and trees suggesting previous beachlines and accretion cycles. The mouth of the Toussaint River is fronted by an extensive (460-m-wide by 920-m-long (1,500-ft-wide by 3,000-ft-long)) shallow sand shoal, which is asymmetrical toward the east (Figure 6). This shoal represents a trapping of littoral sands which move from the northwest toward the river mouth and are then jetted into a delta-like shoal by river discharge and returning seiche (sudden rise and fall of water levels due to atmospheric conditions) waters which build up in the river during heavy winds from the north. It is probably the presence of this shoal which is responsible for trapping sand which would otherwise have nourished the unstable and eroding beach of the FUDS study area.

Three cores were taken by Buffalo District (USAE District, Buffalo 1989) along the proposed channel line lakeward of the Toussaint River mouth in support of the proposed navigation project. Logs from these cores suggest that the shoal consists of a 2- to 3-m (6.5- to 10-ft) thickness of medium-to-fine sand, which includes some coarser sand and a gravel zone overlying lacustrine clays.

Lakeward of the FUDS study site, the shoreline is paralleled by a narrow band of fine-to-medium sandy material which extends approximately 150-300 m (500-1,000 ft) offshore to the 0.6- to 1.2-m (-2- to -4-ft) (LWD) contour (Figure 6). This underwater sand extension of the beach includes a series of well-defined two to four shore-parallel sandbars. Lakeward of this sandy zone, the shallow, flat bottom (slope less than 1:300) is covered with a soft silty-mud layer out to approximately the 3-m (-10-ft) (LWD) contour. This muddy layer pinches out toward the east and offshore, where the bottom becomes a firm blue-clay glacial till, which includes lag-deposit zones of sands and gravels.[1]

The FUDS study site beach has exhibited shoreline retreat during all recorded shore position surveys (1877 to present). In establishing its Erosion Hazard Areas, the State of Ohio, Division of Geology[2] used survey and aerial photographic data from 1877, 1973, and 1990 (Figure 7). Profiles were established at 30-m (100-ft) intervals and backbeach position was determined for each time interval. Profiles 10579 through 10759 cover the study area. These data (illustrated in Figure 7) document a shore which has experienced long-term recession rates, ranging from as little as 0.27 m/year (0.9 ft/year) (on the updrift side of the stone stick-out feature located near the Camp Perry border, profile 10625) to as much as 1.1 m/year (3.6 ft/year) (profile 10695). The average retreat rate for the study area is between 0.61 and 0.91 m/year (2 and 3 ft/year), or a total of 68.9 to 103.3 m (226 to 339 ft) since the 1877

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[1] Benson, D. J., Unpublished report, "Lake Erie Shore Erosion and Flooding, Ottawa County, Ohio." Ohio, Division of Geological Survey.

[2] Ohio Division of Geological Survey. (1993). "Lake Erie Erosion Hazard Area, Preliminary Identification," Ohio Department of Natural Resources, Frames OTT161 to OTT171.
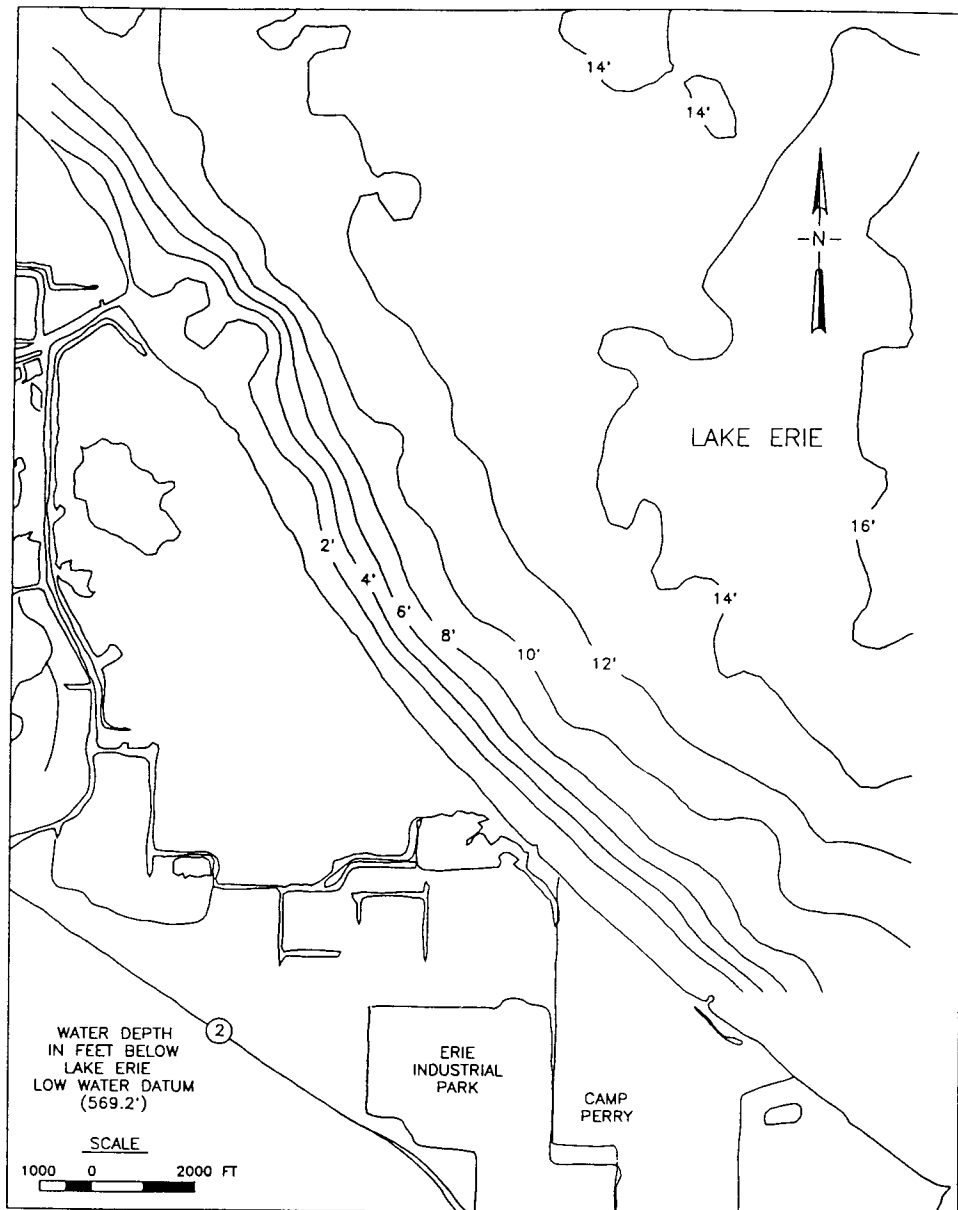
Figure 6.   Bathymetry of offshore study area

baseline survey. The Buffalo District (USAE District, Buffalo 1989) conducted a shoreline change analysis in support of the design studies for the Toussaint River Navigation Project using additional aerial photography. They found an average recession rate for the shore southwest of the Toussaint River of 0.85 m/year (2.8 ft/year).

Long-term shoreline retreat throughout the FUDS study site is exacerbated during periods of high water, when storms with winds from the north can drive the water level up the beach and over the low backbeach causing the barrier to be breached. This type of impact occurred in 1986 during record

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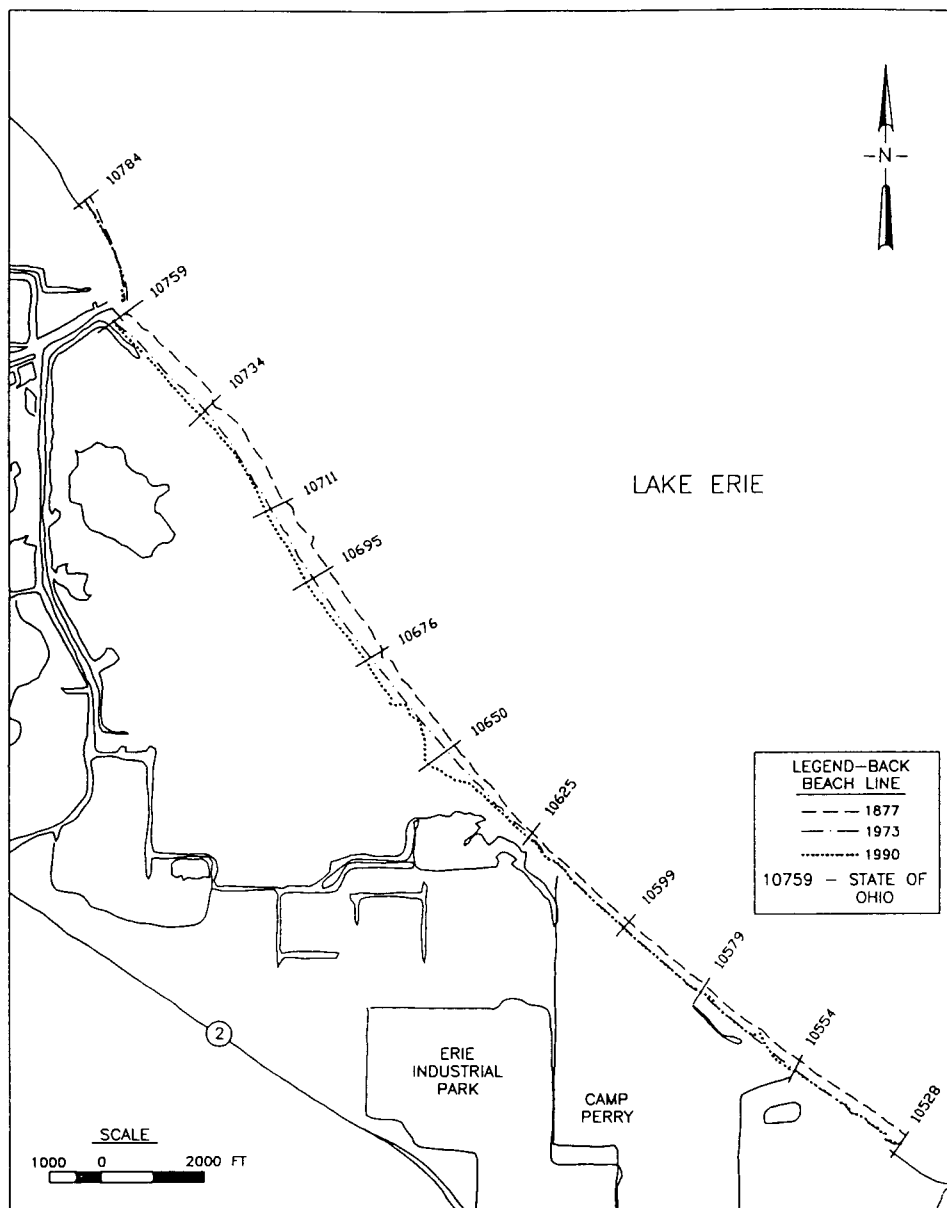
Figure 7.   Shoreline change history of FUDS study site (1877-1990)

high water levels on Lake Erie when the barrier near profile 10650 was inundated and flow between the lake and the backbeach marshes was unimpeded. This tenuous and eroding characteristic of the FUDS site beach has important implications in the evaluation of the ordnance distribution patterns. Since the Erie Army Depot was an active ordnance test facility (1918-1966) the beach has retreated 64 to 23 m (210 to 76 ft) to the present beach position. In addition, a breach occurred through the beach in 1986 which was in direct line with the dominant firing fan orientation (Figure 3). Thus, the beach which existed during the period of Erie Army Depot operation is now under

water and the present beach is being eroded from what was an area 30.5 to
61 m (100 to 200 ft) landward of the former shore.

3   Field Investigation and Methodologies

Unique Project Characteristics

Field analysis of the Erie Army Depot lake impact and FUDS beach site has three unique aspects compared to other OEW field investigations:

a. The exact location of a limited number of shells is not the goal. Most likely, tens of thousands of ordnance shells lie on the bottom of the former and present Lake Erie impact areas. Thus, the object is to determine ordnance grouping, clustering, or density in an effort to better understand where the majority of the OEW lie and their potential for movement onto the beach or into the Toussaint River navigation channel.

b. Such a high density of ordnance renders the detection and sampling problem to be considerably easier. If a marine magnetic survey is properly designed, it should discern a substantial number of the ordnance shells, resulting in a survey which has detected a representative sample of the OEW.

c. The depth of water is rather uniformly shallow, allowing towed sensors to be simply tethered on floats behind the motor vessels and at constant elevations above the lake bottom.

Field Activities

The field study was conducted during the period 7 through 20 September 1993 by WES with assistance from the Buffalo District and the Huntsville Division. The WES Coastal Engineering Research Center's research vessel (R/V) SeaQuester was used for the offshore surveys in water depths from 1.2 to 3.7 m (4 to 12 ft) and a rental scow (christened the R/V African Queen for the duration of this field study) was adapted for use as a shallow-water research vessel (loaded vessel draft of 0.23 m (0.75 ft)). This craft was an enclosed-hull rental scow, normally used by local fishermen as a towed

platform to deploy gill nets in shallow water. The scow was modified (custom-welded transom and canvas exposure cover) and motorized for conducting nearshore surveys in water depths of 0.5 to 1.2 m (1.75 to 4 ft).

Field activities occurred in the following five principal study sectors.

a. Setup and test runs of the vessels and equipment were conducted in the Toussaint River entrance channel. Data were also collected from this area during several days when conditions on Lake Erie prohibited open-lake operations and evaluated the capabilities of the various equipment to detect ferromagnetic or ordnance-like targets underwater.

b. The spit on the northwest side of the entrance to the Toussaint River was used as a mobilization and position control base. In addition, a buried inert ordnance test bed was set up on the spit to evaluate the sensitivity of land-based magnetometer, electromagnetic, and ground-pentrating radar systems.

c. A walking tour was conducted of the FUDS beach area to inspect for geomorphic indicators of coastal processes and the occurrence and orientation of OEW. Two areas on the FUDS beach were selected for a detailed electromagnetic and ground-penetrating radar survey.

d. The nearshore (0.5- to 1.5-m (1.5- to 5-ft water depths)) lakeward of the southeastern two-thirds of the FUDS study beach was surveyed from the R/V African Queen. These survey lines were generally run shore-parallel to maintain a constant water depth under the vessel and prohibit potentially dangerous groundings of towed instruments and a risk of impact with a UXO. Both the waterborne magnetometer and the electromagnetic system were used in these surveys. Some GPR surveying was also conducted in this area using either the R/V African Queen or a small outboard motor launch.

e. The offshore (1.5- to 3.7-m (5- to 12-ft water depths)) was surveyed from the R/V SeaQuester across the entire length of the FUDS study beach and extending west across the mouth of the Toussaint River. Survey lines included shore-parallel and shore-perpendicular runs. Data collection in this sector included side-scan sonar and waterborne magnetometer. In addition, an ROV was used to obtain some video images of the bottom.

Positioning for the entire study was via DGPS. Beach sites were marked with flagging and base point positions were established with the DGPS. Field study survey controls were keyed into previously established control points west of the Toussaint River. The DGPS was used to determine x-y Ohio State plane coordinates for the onshore base positions and for all survey activities.

Safety Plan. Each team member involved in the field study was responsible for complying with the Site-Specific Safety and Health Plan. Safety

review meetings were conducted at the beginning and close of each operational day and all safety aspects were first cleared by the Huntsville Division Safety Representative. All beach work areas were checked for OEW presence by the Safety Representative and safe lanes were flagged. Checks were conducted at the beginning and the end of each operational day with the Camp Perry Firing Range Control, ARES (an armament company with an active test-firing range), and Davis-Besse Nuclear Power Plant. Operational units were deployed daily from a commercial marina situated on the Toussaint River.

Site investigation. The first two days were spent collecting site condition information from local authorities, setting up equipment, mobilizing the R/V African Queen, coordinating safe beach access and offshore access logistics, establishing positioning controls and conducting a site inspection of the FUDS study beach. Appendix A is a daily log summarizing all data collection activities conducted during the field study. This appendix lists the data type collected per vessel, per day along with data line and event information. Data collection started in earnest on 11 September and continued through 19 September.

The daily operational plan was designed such that the wide array of instruments present on the site could be deployed on two waterborne platforms solely or in combination (e.g., side-scan sonar and magnetometer) to provide maximum coverage of the area. The field investigation team was usually divided into three groups, with one group on each of the vessels and a third group conducting terrestrial data collection, or ground-based support.

Survey Positioning Controls

Positioning for the entire study via DGPS provided 1-m horizontal, real-time accuracy. A DGPS receiver basically measures the distance to NAVigation Satellite Timing and Ranging (NAVSTAR) satellites by measuring the time dura-tion that a signal takes to transit between the different satellites and receiver. The intersection of these vectors determines the three-dimensional position of the receiver. In the DGPS mode, a receiver is set up over a known point, then compares its position as given by the satellites to the known position and transmits an error correction signal to a mobile station, thereby increasing the relative accuracy.

The positioning system used during this study consisted of a Trimble 4000 SSE receiver used as the reference station with two more SSE receivers used as mobile stations for the R/V SeaQuester and R/V African Queen. The Buffalo District control points established to support the Toussaint River Navigation Project provided known position controls for establishing the reference station. The differential-correction telemetry was supplied by Trimtalk radios that operated at 904 MHz and provided coverage over a 1.6- to 4.8-km (1- to 3-mile) range (due to local conditions). A computer interfaced with the mobile receiver (one for each vessel) and was configured with software that

supplied real-time data logging and navigation with helmsman guidance. This software performed real-time datum transformations from the WGS-84GPS position to NAD 27 Ohio State plane coordinates for the onshore and water survey activities. The software allowed the survey run lines to be predetermined (length and spacing) and plotted prior to each daily operation. A separate video graphic display allowed the helmsman to monitor real-time boat position as established by DGPS in relation to pre-established run lines. All position data were time-stamped in order to be coordinated with the time series of the wide variety of different types of instruments during post-processing. Fix data were logged on the computer, then down-loaded to floppies daily. Also, at the close of each day, the pre-established run lines and actual courses as performed during the survey could be plotted for data analysis and planning purposes.

The DGPS survey method was selected because it provided relatively rapid, accurate positioning for both boats and shore parties. At times the study site offered limited opportunity to set control or to occupy stations due to access limitations. This was due to nearshore and beach OEW, security drills at the Davis-Besse Nuclear Power Plant, and to live firing at Camp Perry, which frequently closed down the eastern half of the study site.

The initial study reference station was located on a Buffalo District control point (2W) west of the the FUDS Site (called the "spit"). As a result of the limited radio range of the receivers, an additional control point was established in the eastern sector close to the FUDS/Camp Perry boundary on a stone rubble stick-out structure (called the "slab"). Both stations were necessary to allow positioning coverage of the entire FUDS area. Battery power at the eastern sector positioning station allowed its unmanned operation for up to 24 hr (while the Camp Perry firing range was active). The needed reference station(s) were usually the first system established in the morning and the last to be broken down each day.

A backpack version DGPS (minus computer), with direct position output in WGS-84GPS latitude and longitude, allowed a partial baseline to be established on the FUDS shore. Positions were established for some of the survey markers used in the previous EODT beach cleanup operations. This previous interim removal action took place in the fall of 1992 and the locations of the placed survey stakes were only generally known. This activity allowed the data from this previous effort to be directly tied to the present investigation (see Chapter 8).

OEW Search Methods

Several methods were used to determine ordnance density on the bottom of Lake Erie along the coastal area of the former Erie Army Depot. These were: (a) magnetic exploration, (b) electromagnetic exploration, (c) ground-penetrating radar (GPR), and (d) side-scan sonar and remotely operated

vehicle. Each method demonstrated individual advantages for the search for underwater OEW. However, using all methods together synergistically allowed for maximum definition of the ordnance distribution patterns.

Magnetics. Waterborne magnetics has had a reasonable history of use in locating underwater wrecks, lost nautical gear, large underwater naval mines, etc. It is a passive system, in that the measured disturbance of the ferrous metal target is a result of its interaction with the earth's magnetic field. Since no signal is broadcast by the user, its application does not require complex antennas, signal conditioners, amplifiers, etc. There also is no risk of an electrical detonator or fuse undergoing a sympathetic detonation from an electromagnetic signal. The application of magnetics for the location of underwater coastal artillery ordnance has been limited; however, much effort has been placed into using the technique to locate larger underwater mines. A relatively weak magnetic field disturbance originates from a mass of ferrous material the size of more typical World War I or World War II artillery or mortar rounds. This lends most magnetic exploration methods for OEW to be limited to hand-held magnetometers with the sensor in close contact with the ground. For underwater locations of various ordnance types of the size more typically found offshore of the former Erie Army Depot (60 and 105 mm) SCUBA divers utilizing hand-held magnetometers could have been employed. For application in coastal waters and these size shells, the magnetometer's sensor should be located no closer than 2 ft (safety reasons) and no further than 1.8 to 3.0 m (6 to 10 ft) (required signal strength) from the target in order to resolve individual pieces. This tolerance is difficult to achieve in the turbid waters of this site. Thus, a towed system was used for this study.

Electromagnetics. The electromagnetic method has been infrequently applied for underwater ordnance detection and location. Typical surveys designed to detect underwater ordnance are the result of the need to locate large naval mines placed by some other nation in deeper seawater. Thus, the historical lack of use of electromagnetics for this purpose is related to the following factors:

a. Most ordnance placed in an aqueous environment has other contributing factors; for example, the object is surrounded by highly conductive seawater requiring a relatively strong electromagnetic signal which is rapidly attenuated by the saline water.

b. The explosive casing (for naval ordnance) contains a significantly large enough ferrous metal mass to render magnetic detection methods feasible.

c. The size of the device is large enough and the depth of the water is great enough (at least 3.7 to 4.6 ft (12 to 15 ft)) to allow underwater acoustic search methods to be effective.

d. Many types of naval mines may contain fuses which are activated by magnetic (and hence electromagnetic) disturbances.

e. Broadcasting and receiving antennas must be maintained (or flown) at datum elevations above the bottom. Here the tolerances are even more precisely regulated (0.6 to 0.9 m (2 to 3 feet) above bottom) than the magnetic technique.

Transient electromagnetic methods proved to be most applicable to the OEW density characterization needs at the former Erie Army Depot FUDS area. This resulted from the small ferrous target size, the relatively even profile of the fresh-water lake bottom, and the shallow water (less than 3.7 m (12 ft)) of the impact areas needing to be surveyed. The application of transient electromagnetics to locate similar types of shells in shallow underwater settings is very promising.

Ground-penetrating radar. The geophysical method of transmitting a short and focused electromagnetic pulse in the 100- to 800-MHz range down into the earth and monitoring reflected returns is termed ground-penetrating radar (GPR). This method has been actively used for the location of buried utilities, backfilled trenches, and various other applications to characterize hazardous and toxic waste sites. The depth of signal penetration and subsurface object resolution is highly dependent upon site conditions. Sandy material has physical properties with low dielectric constants, which allows these types of radars to probe several feet to a few tens of feet into the subsurface. Soils which have a substantial amount of clayey material have rather high dielectric constants which result in signal penetration depths of 0.3 m to 0.6 m (less than a foot to 1 or 2 ft). The fresh water in Lake Erie contains electrical properties which allow GPR systems with broadcast signals between 100 and 250 MHz to detect large metal items on the bottom through water columns 3.0 to 4.6 m (10 to 15 ft) in depth (Beres and Haeni 1991; Gorin and Haeni 1989; Haeni, McKegum, and Capron 1987; Mellet 1993). The metal OEW items of interest have large contrasting electrical properties which cause a large percentage of impinging electromagnetic waves to reflect or scatter off of the metal surface. Consequently, a GPR system was tested in Lake Erie for its applicability to locate ordnance items on the sandy beaches and on the lake bottom. Of particular concern was the capability of the GPR system to illuminate and detect an ordnance item in the subsurface on the beaches. Due to the physical homogeneity of the water, locating an ordnance item on the lake bottom was anticipated to be an easier task than applying the GPR to the land searches.

SSS and ROV. SSS is an active acoustic imaging system that has been used in underwater target-location and surveying applications such as wreckage/lost object searches (including mines and torpedoes), geological surveys, and pipeline tracking. These activities have taken place in lakes, rivers, and maritime regions ranging from the nearshore zone out to the deep ocean.

The digital SSS system transmits acoustic energy pulses into the water, then receives, and processes, the energy patterns returned by acoustic discontinuities encountered in the water column and lake bottom. These processed return signals produce sonographs of the lake bottom that are like low-level

oblique aerial photographs. The return signal patterns and intensities on the sonograph impart information about the physical location, shape, size, and composition of the reflector. Just as the quality (resolution and detectability) of aerial photographs is affected by equipment and environmental operational factors, the sonograph is affected by the system operating parameters (range, frequency, etc.) and physical phenomena that affect underwater sound transmission, reflection, and backscatter. For this project, a high-frequency (400-kHz), high-resolution SSS was used to generate sonar images of lake-bottom features and suspected UXO concentrations.

An ROV is an underwater thruster-propelled vehicle that is remotely guided through the water column by an operator who views the vehicle's forward motion via a real-time TV camera system. ROV's are used primarily for inspection and exploration purposes such as underwater structure inspections, salvage surveys, and diver safety monitoring. When equipped with an articulator arm, they can be used for handling and cutting applications like mine warfare and salvage operations. The ROV used in this study was deployed with a low-light, high-resolution color television camera system to visually inspect and video record lake bottom features and verify (ground truth) sonograph interpretations.

Spit Test Area

A test site, using various items of inert ordnance, was established to assess the capabilities of various geophysical methods to detect and resolve OEW. Items ranging in size from 60-mm mortars to 155-mm artillery shells were buried at known depths generally 0.3 to 0.6 m (1 to 2 ft) below the surface. This test area was established on a sand spit located on the northwestern side of the mouth of the Toussaint River where it empties into Lake Erie. Data from this site provided assessment and verification of anticipated signal responses from the ordnance items to be encountered in the conducted investigations.

Survey Coverage

Day-to-day operation and survey coverage was influenced by several factors. Wave conditions on the lake, particularly toward the later parts of each day and all day on 16-17 September (Figure 5), limited good open-water data collection. The other major limit to the survey window was on the weekends, when firing practice at Camp Perry would prohibit access to the entire southeastern half of the offshore and nearshore study sectors. Equipment and vessel downtime were a further limitation. In spite of these problems, over 80 km (50 miles) of tracklines were run and data were collected from all key study sectors. Figures 8-11 show the tracklines per survey technique and Figure 12 summarizes the entire coverage for all waterborne survey work.
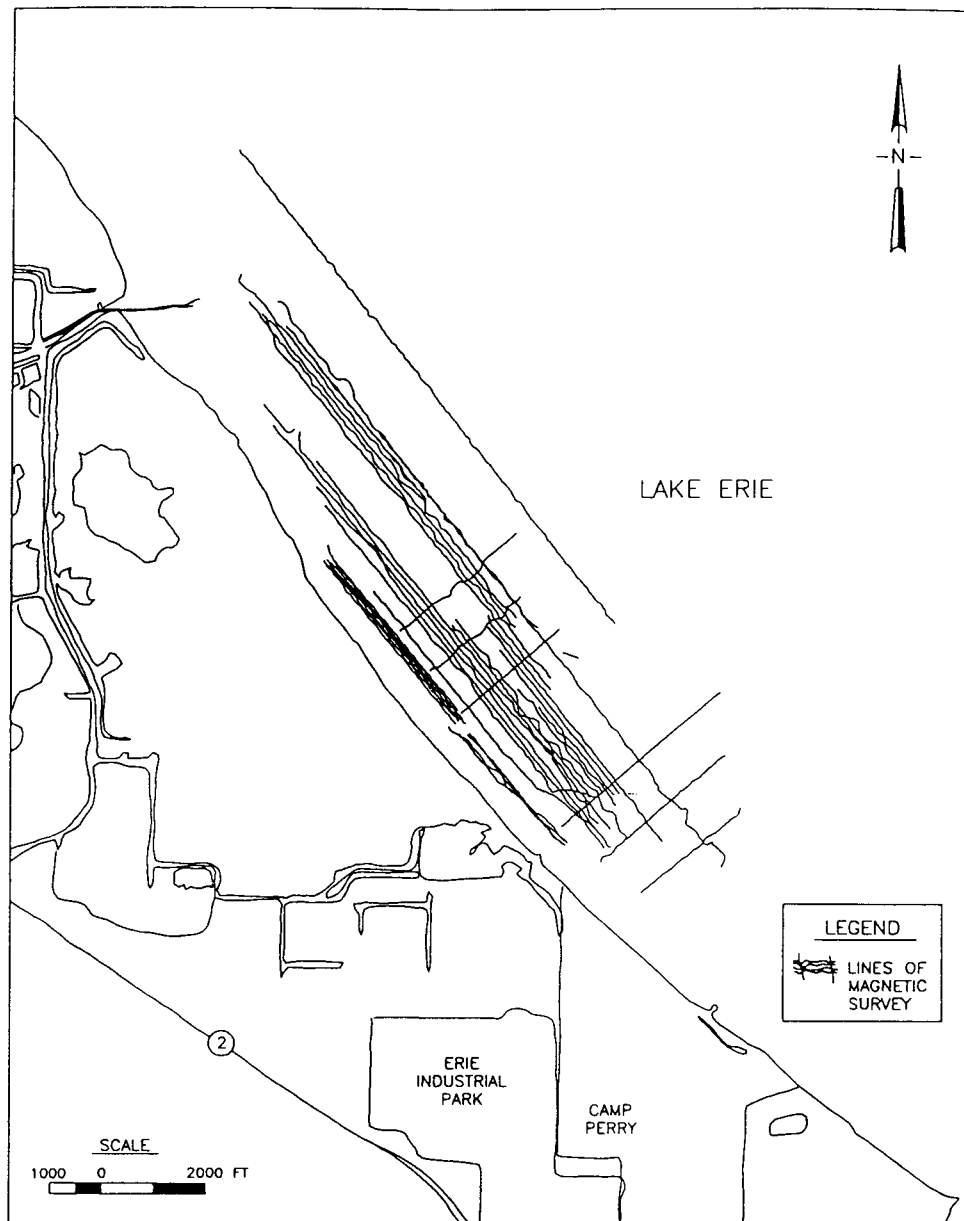
Figure 8. Base map showing all waterborne magnetometer survey lines

Figure 13 is a sketch which defines the geographic terms and local features which will be referenced throughout the rest of this report.

The most extensive underwater coverage was obtained with the waterborne magnetometer (Figure 8). Data were collected via this technique in all three underwater sectors (Toussaint River channel, offshore, and nearshore) (Figure 8). The electromagnetic system was used in four of the five study sectors (i.e., the spit, the Toussaint River entrance channel, the nearshore, and on two locations along the FUDS study beach). Electromagnetic survey coverage in the nearshore was particularly dense, with some overlapping of lines
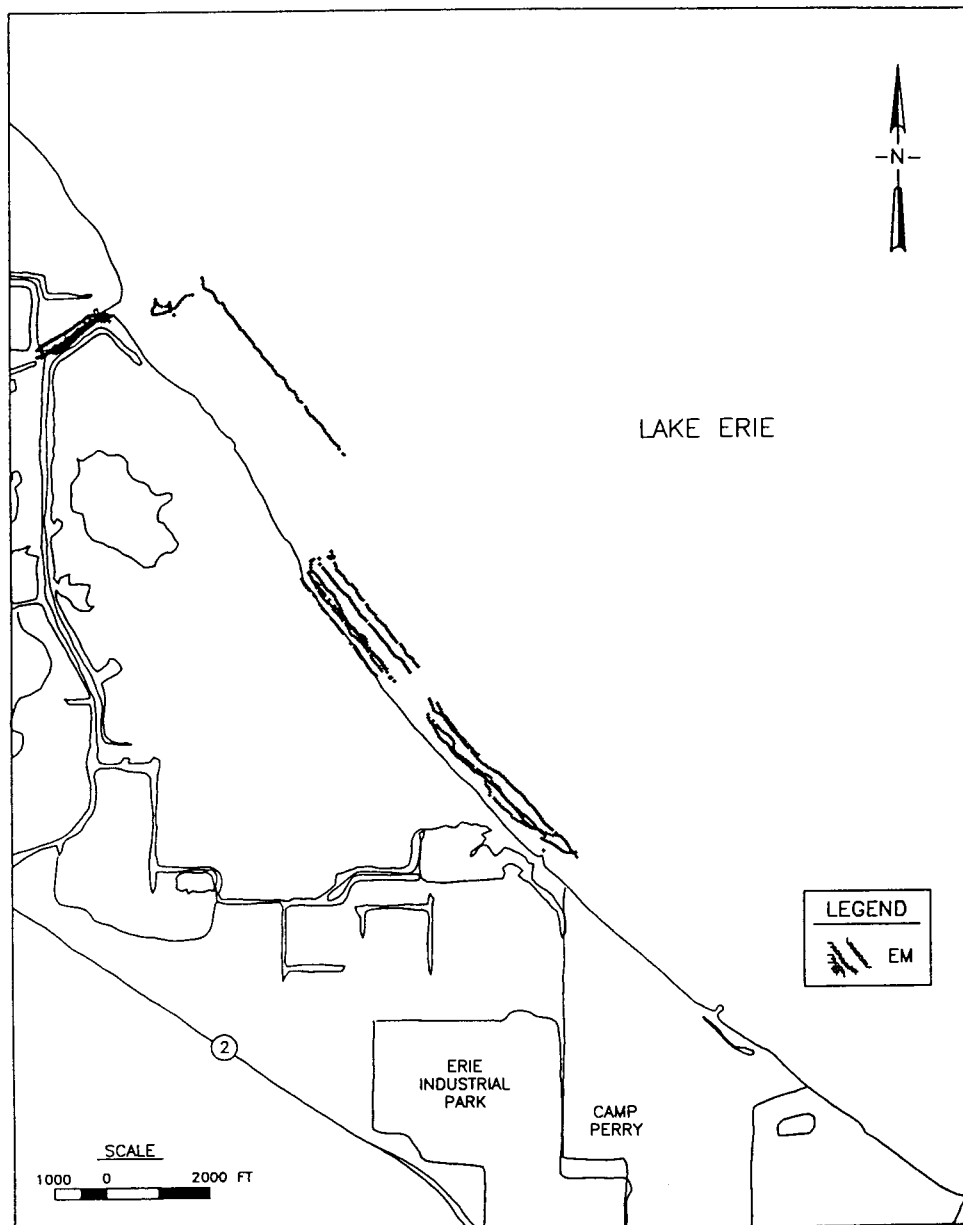
Figure 9. Base map showing all waterborne electromagnetic survey lines

(Figure 9). The GPR system was used to conduct some general mapping of the nearshore geology and to ascertain its suitablity for ordnance detection (Figure 10). SSS surveying was conducted in the Toussaint River entrance channel and for a general mapping of the offshore (Figure 11). All SSS work was conducted from the R/V SeaQuester.
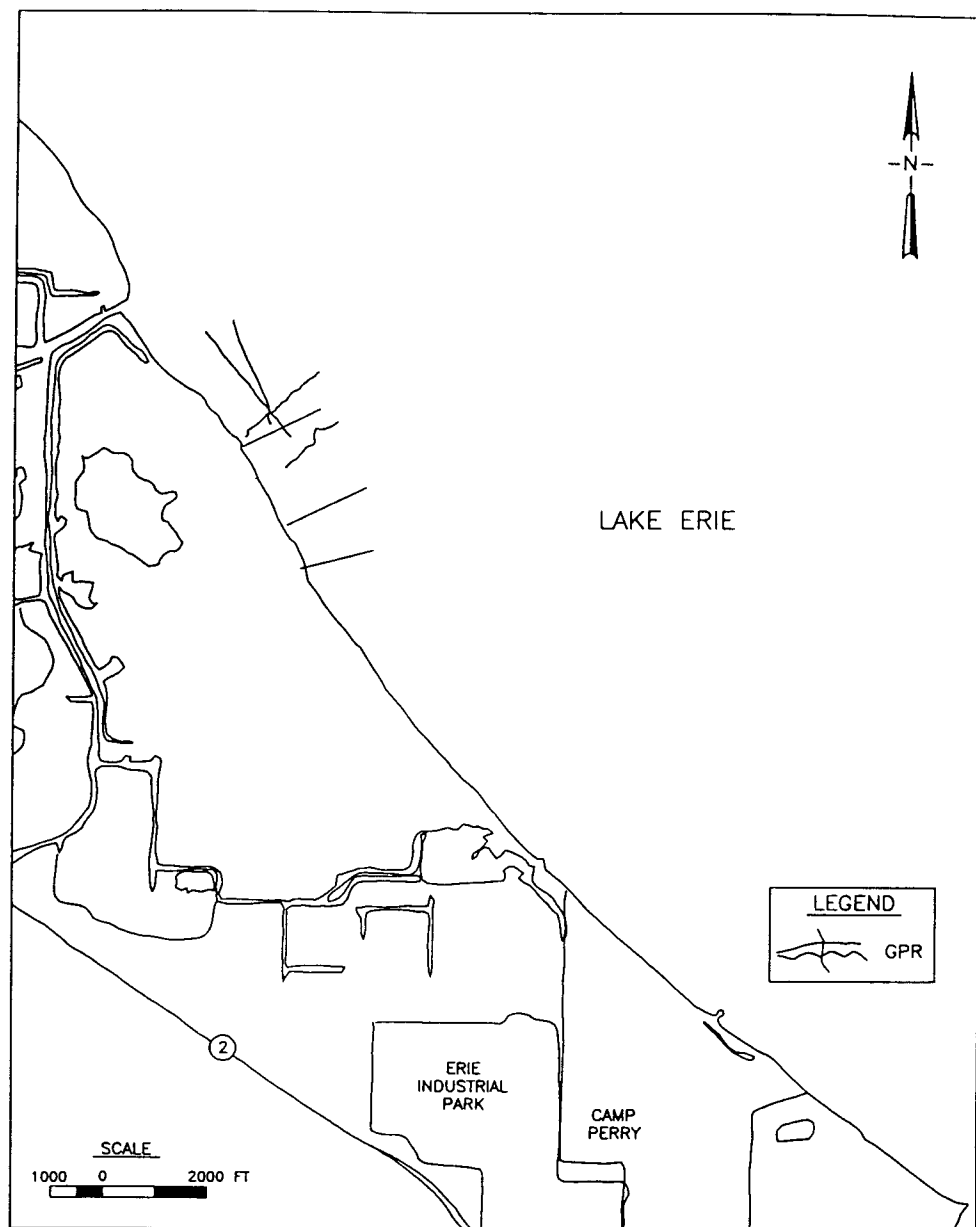
Figure 10. Base map showing all waterborne GPR survey lines
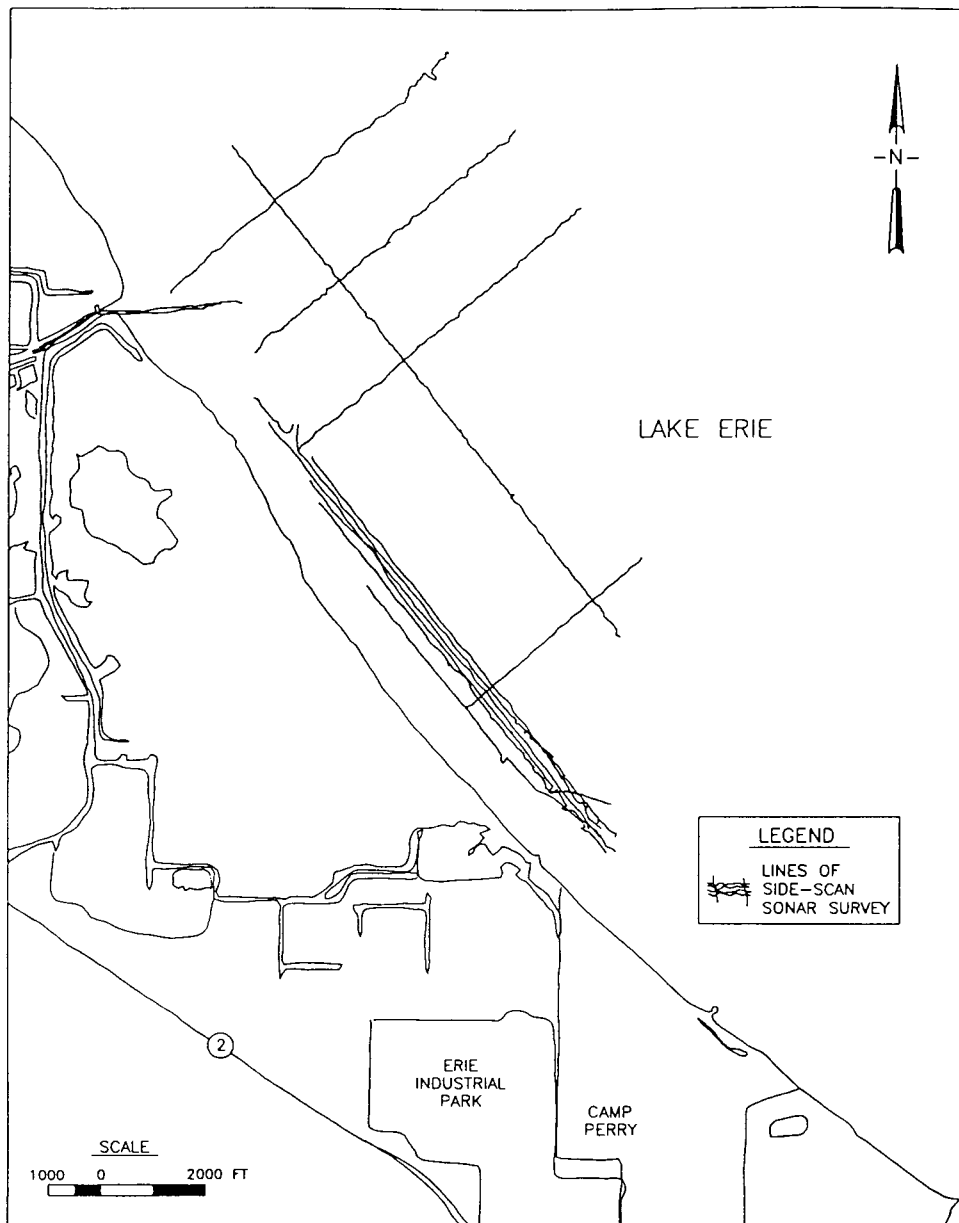
Figure 11.   Base map showing all waterborne SSS survey lines
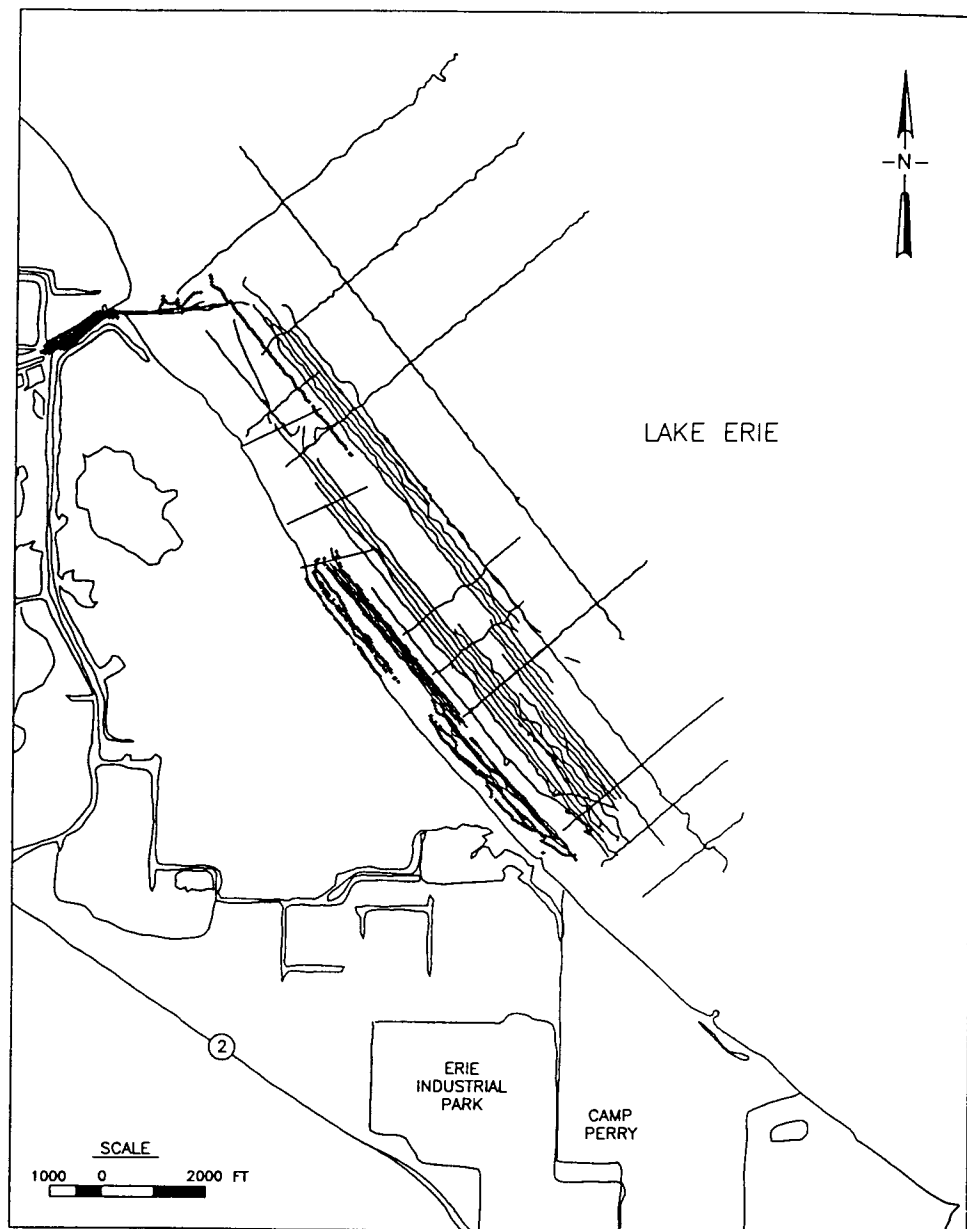
Figure 12. Base map showing all waterborne survey activities for all four survey techniques
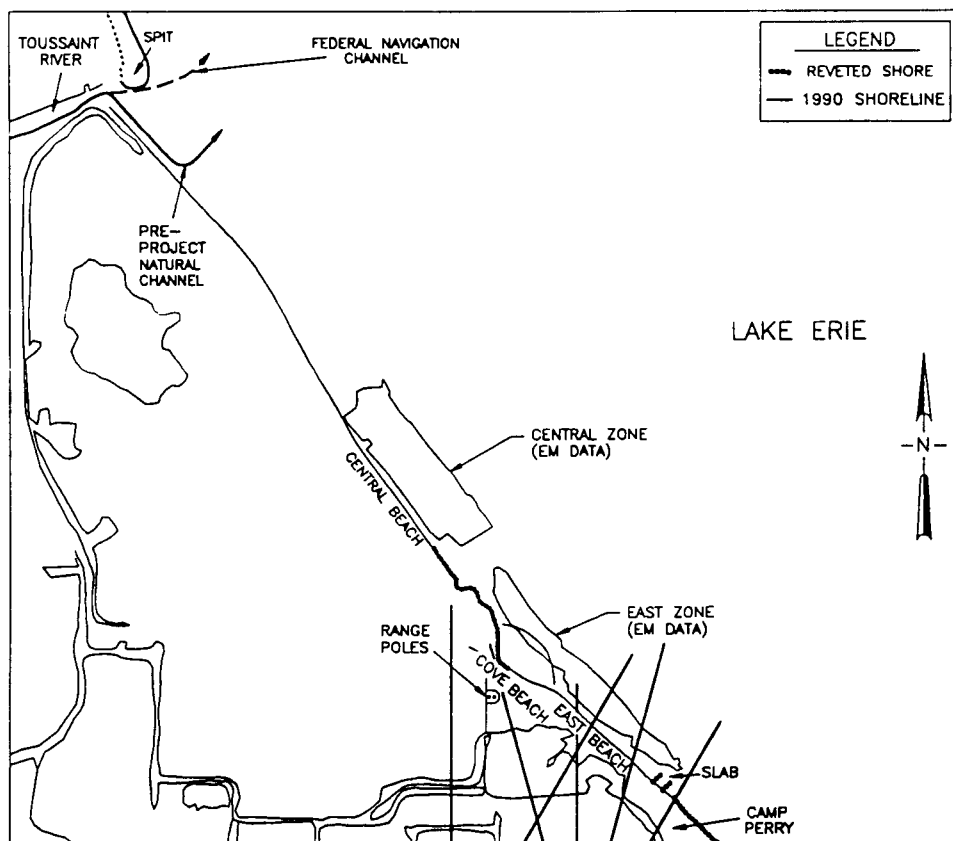
Figure 13. Sketch defining geographic feature names used in this report

4   Electromagnetic Surveys

Background

Electromagnetic methods (based upon the measurements by electromagnetic induction, without electrodes) have become widely used in North America in a wide variety of investigations ranging from buried hazardous waste and land-fill sites, to groundwater contamination studies (Glaccum, Benson, and Noel 1982; Greenhouse and Harris 1983; Valentine and Kwader 1985). The electromagnetic technique provides a fast and effective tool for mapping buried metallic objects. The results of electromagnetic ground and sediment surveys often form the basis for designing an optimum sampling or remediation program at hazardous and toxic waste sites.

The transient electromagnetic method, as applied to locating buried metallic objects, has proven to be a very efficient, fast, and cost-effective method of investigating the presence of hazardous metallic objects and mapping their spatial distribution both on land and under water. Electromagnetic measurements can be rapidly collected and used to produce maps with high spatial resolution. The virtually continuous method of data acquisition is especially important in investigations of highly anomalous areas similar to the sites researched for this project.

Transient Electromagnetic Method

The theory of the transient electromagnetic method is well described in Kaufman and Keller (1983). Wide applications of the electromagnetic method to ground investigations are discussed in McNeill (1980) and Geonics Limited (1993). In the electromagnetic method, two coils (antennas), which serve as a transmitter and a receiver, are situated on or near the earth surface or sediment-water interface. A steady voltage is applied to the transmitter coil for a sufficiently long time to allow turn-on transients in the ground to dissipate. The current supplied to the transmitter (bipolar rectangular current, (i.e. a square wave)) is sharply terminated at each cycle. A rapid reduction of the transmitter current, and thus of the associated transmitter primary magnetic field, induces an electromotive force in nearby conductors. This

electromotive force causes electrical eddy currents to flow in conductors with a decay which is a function of the conductivity, size, and shape of the conductor. The decaying currents generate a secondary magnetic field which is detected and measured by a receiver coil. The measured quantity is usually the response of the instrument to metallic objects or the apparent conductivity of the material or surrounding media.

The Geonics EM61 employed in this survey is a high-sensitivity, high-resolution time-domain instrument which is used to detect both ferrous and non-ferrous metallic objects. It consists of a transmitter with a peak power of 100 W that generates a pulsed primary magnetic field, which induces eddy currents in nearby metallic objects. By making the measurement at a relatively long time (0.45 ms) after termination of the primary pulse, the response is practically independent of the electrical conductivity of the surrounding media.

Transient electromagnetic data collection and processing

Measurements at the former Erie Army Depot were carried out within selected onshore and offshore areas using a Geonics EM61, custom adapted with only one receiver coil for this underwater electromagnetic investigation. The configuration enabled the system to act as a large, high-resolution waterborne metal detector. Due to its coil arrangement, the measured response voltage curve is a single well-defined positive peak. The depth of the target for onshore subsurface targets can often be estimated from the width of the response or from the relative response as measured by two spatially separated receiver coils. The EM61 can generally detect a single 200-liter (55-gal) drum at a depth of over 3 m (10 ft). The employed land-based instrument is equipped with an opto-counter which triggers a measurement every 7.5 in. or 19 cm. It can also be triggered in fixed time intervals with the maximum speed of three readings per second. All landborne surveys were conducted along parallel lines separated by 0.9 m (3 ft). Readings were taken using the wheel-mounted counter, which resulted in increments between stations of 0.192 m (0.63 ft). This fine line and station spacing provided excellent data. The collected logger data were then processed and stored using a portable IBM-PC-compatible computer. Contractor-written computer programs TOW and WAT61, in conjunction with the program DAT61, provided by Geonics, allowed processing and reduction of underwater and surface-collected electromagnetic data in conjunction with all navigation data. Color contour maps were constructed using the Geosoft software. Printed maps are scaled in feet in the Ohio State Plane Coordinate System. Geonics developed an algorithm to estimate the depth of the located buried metallic objects on the shore sites.

The electromagnetic underwater system consists of a Geonics EM61 metal detector with one specialized antenna, PVC pontoon, underwater towfish, two supporting fiberglass rods, an echo sounder sensor, interfacing cable, and a digital data acquisition system. The pontoon is used to allow the towing of an under-water antenna at a fixed water depth and distance behind the boat. The

DGPS antenna is mounted on the pontoon to provide a determined location for any detected ordnance. In the underwater portion of the survey, the time increment for data collection used was 0.5 sec, which corresponds to less than 0.3-m (1-ft) spacing between reading stations. A total of approximately 40 km (25 miles) of transect lines was surveyed and over 100,000 stations were measured. Data collected by the underwater system were analyzed using profile plots and only well-delineated anomalies were selected (anomalies with an amplitude higher than 15 mV and established by at least six points, three along positive and three along negative gradient of the anomaly). Locations of these anomalies are plotted as small red dots on maps. This method displayed the location of all anomalies compatible with the response of a single item of OEW along the survey traverses. Bathymetry data acquired simultaneously for navigation purposes are used to generate bathymetric maps of the study areas.

Inert ordnance test site on Toussaint River spit

Survey results collected at a test site set up on a newly formed spit west of the mouth of the Toussaint River confirmed the high precision capability of the EM61 system for detecting OEW. All detected anomalies from inert ordnance were plotted on color contour maps (Figures 14 and 15). In addition, electromagnetic survey traverses obtained along the profile lines are also presented to allow the observation of the amplitude and shape of each anomaly in more detail. Typical responses from the buried inert ordnance were:
(a) greater than 75 mV measured for the 155-mm artillery shells, 4.2-in. mortars, 120-mm tank rounds, and the 106-mm anti-tank projectiles, (b) about a 25-mV response was generally detected for the 90-mm shells, and (c) a range of 5- to 15-mV was documented for the 81- and 60-mm mortars and the 75-mm shells. Some of these data are shown in profile plots in Figure 16.

The electromagnetic survey revealed numerous high-amplitude responses originating from surface or shallow-buried metallic objects. The distribution of the EM61 response clearly exhibits the locations of all buried metallic targets at the Toussaint River spit test site. Further data analysis positively identified a number of deeper, prominent features. This information was combined to generate a summary (Figure 15) showing all anomalies deemed to be significant. These anomalies were classified into the following three groups:

a. Red circles - possible buried metallic objects.

b. Yellow circles - surface or near-surface buried metallic objects.

c. Blue circles - buried inert ordnance.

All the inert test targets shown on the maps and on profile plots are delineated with relatively high resolution, despite the fact that they are buried close
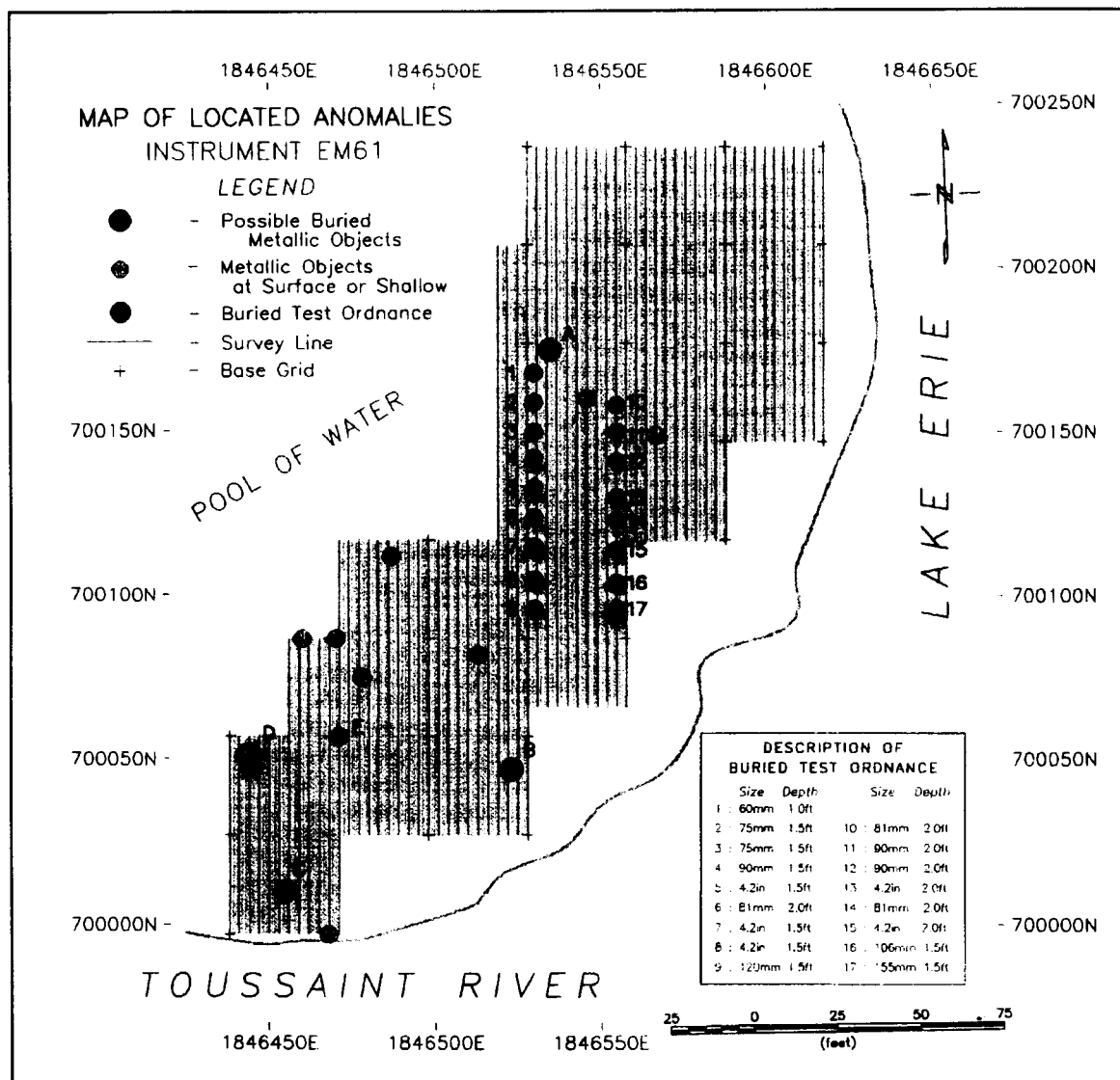
Figure 14. Inert ordnance items buried on the Toussaint River spit test site

(about 0.9 m (3 ft)) to each other. All are located at shallow depths ranging from 0.5 m to 0.6 m (1.5 to 2.0 ft).

A few other significant anomalies of unknown origin were detected during this portion of the survey in addition to the known inert ordnance. Three anomalies (labelled A, B, and C) believed to be single deeper buried metallic objects are marked as red circles. Anomalies believed to represent near-surface metallic objects (such as beverage cans) were annotated by yellow circles. A significant anomaly representing two shallow-buried objects located on a recently used fire pit is labelled D. The anomaly labelled E is associated with a surveying flag containing a small steel rod.
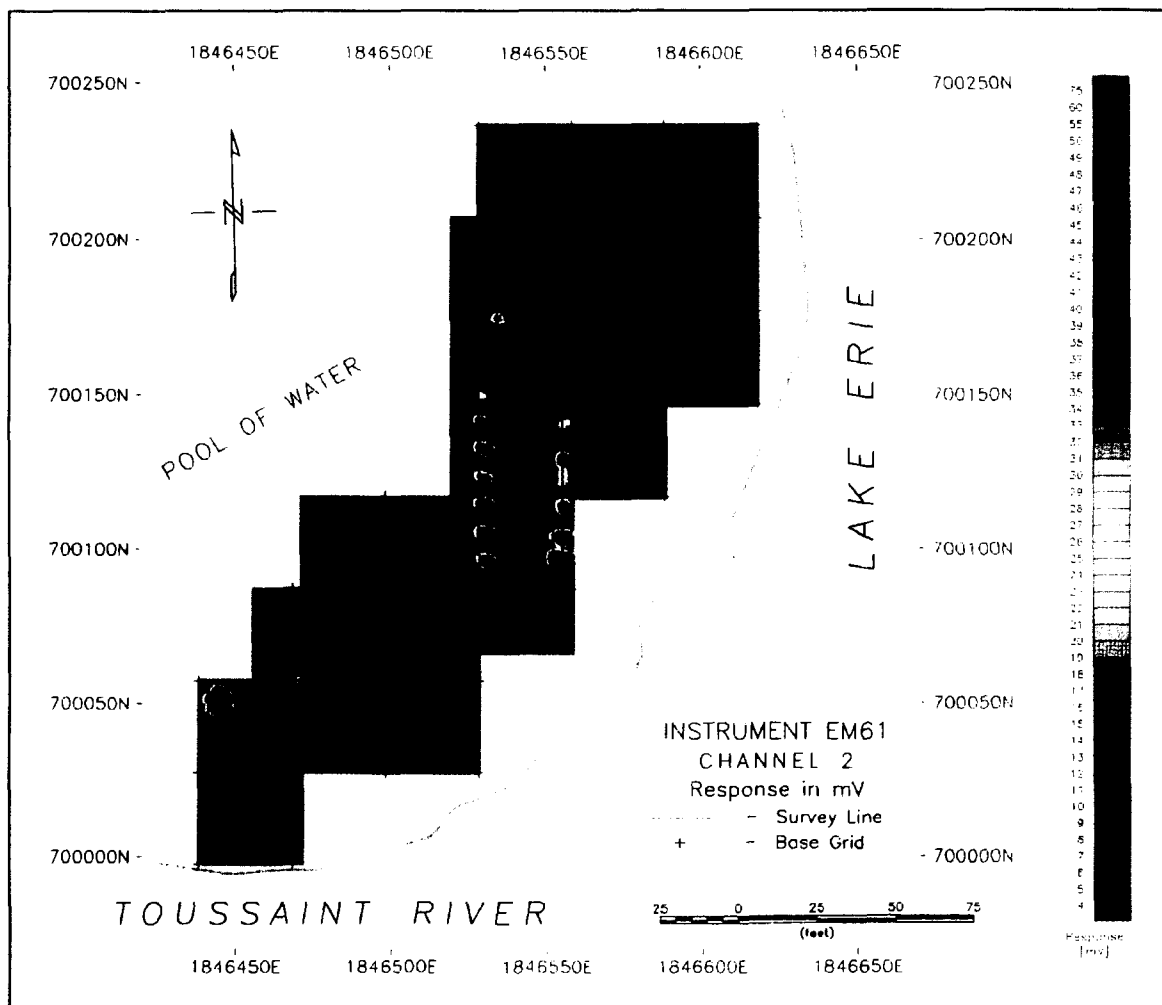
Figure 15. EM-61 response from inert ordnance items buried on the Toussaint River spit test site

Approximate depth estimation of buried targets was conducted using a newly developed Geonics software procedure, which utilizes ratio responses from two EM61 receiver antennas (upper antenna placed 40 cm (15.7 m) above the lower antenna). The results of this estimation are presented in Tables 1 and 2. Table 1 compares the known depths of buried test ordnance with the calculated depths. Table 2 presents depth calculations of located unknown anomalies A, B, C, and D.

Comparison of the given (known) and calculated depths reveals a good correspondence, indicating that the ratio calculation analysis represents a reliable method for estimating depths of unknown buried objects. An error of the calculated depth for 17 targets varies between 6 percent and 47 percent with the average value of 26 percent. However, it should be noted that the burial depths of inert ordnance were only measured to the nearest 0.15 m (0.5 ft).
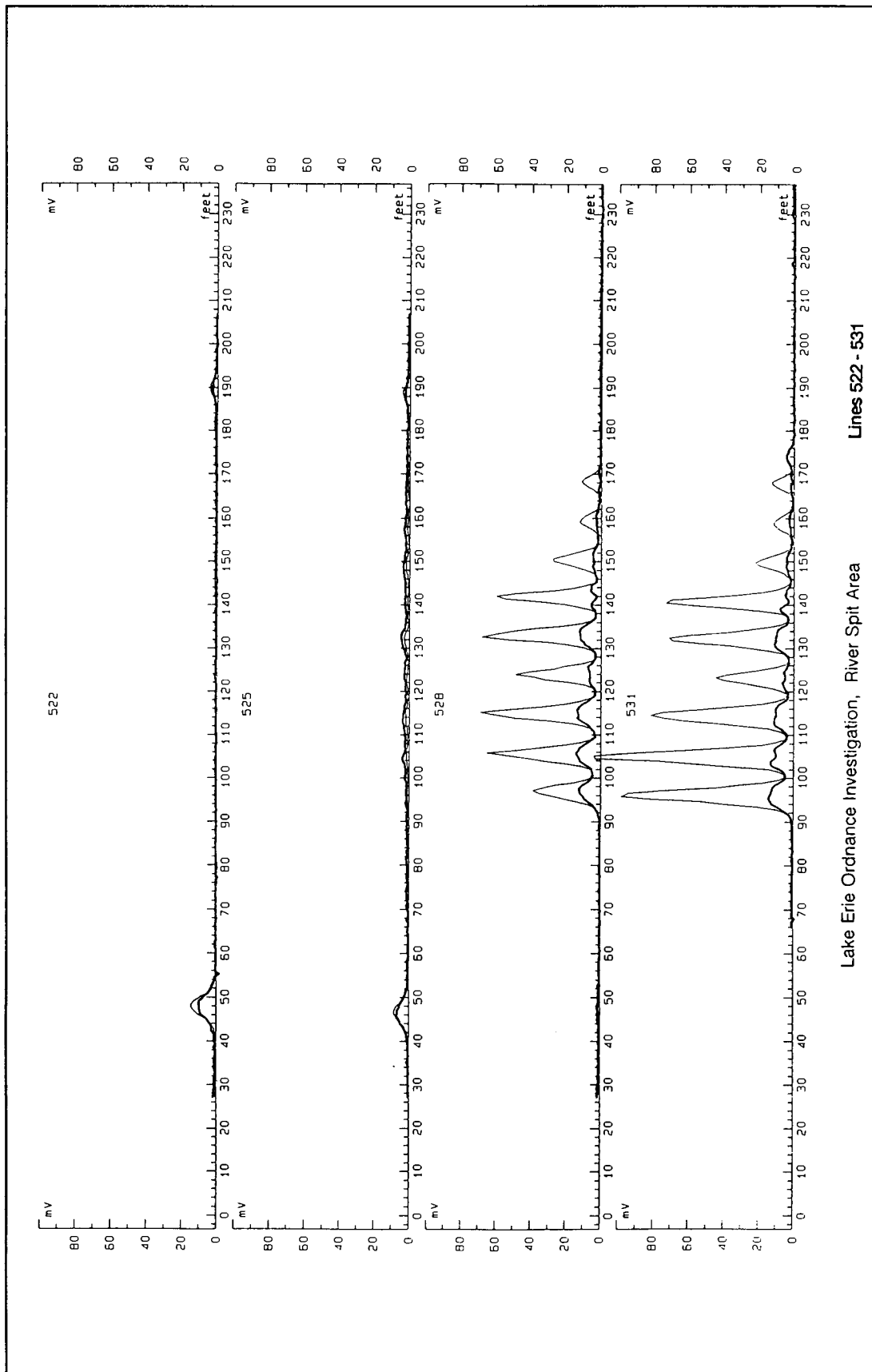
Figure 16. EM-61 response profile plots of the western row of inert ordnance items buried on the Toussaint River spit test site

Table 1
Given and Calculated Depth of Buried Test Ordnance

Description of Inert Ordnance	Given Depth		Calculated Depth		Error, (%)
	m	ft	m	ft	
60 mm	0.30	1.0	0.21	0.7	30
75 mm	0.46	1.5	0.52	1.7	21
75 mm	0.46	1.5	0.43	1.4	6
90 mm	0.46	1.5	0.24	0.8	47
4.2 in.	0.46	1.5	0.43	1.4	6
81 mm	0.61	2.0	0.37	1.2	40
4.2 in.	0.46	1.5	0.40	1.3	13
4.2 in.	0.46	1.5	0.30	1.0	33
120 mm	0.46	1.5	0.40	1.3	13
81 mm	0.61	2.0	0.52	1.7	15
90 mm	0.61	2.0	0.46	1.5	25
90 mm	0.61	2.0	0.55	1.8	10
4.2 in.	0.61	2.0	0.40	1.3	35
81 mm	0.61	2.0	0.49	1.6	20
4.2 in.	0.61	2.0	0.52	1.7	15
106 mm	0.46	1.5	0.30	1.0	33
155 mm	0.46	1.5	0.34	1.1	27

Table 2
Estimated Depth of Unknown Detected Metallic Objects

Description of Anomaly	Calculated Depth	
	m	ft
A	0.76	2.5
B	1.49	4.9
C	2.10	6.9
D	0.12	0.4

FUDS Beach, Cove Beach area

Results of a transient electromagnetic survey conducted at Cove Beach are presented in Figure 17. The surveyed sandy beach area (11.9 by 76.2 m (39 by 250 ft)) (Figure 3) is separated from the open lake by a sandbar which is located approximately 45.7 to 61.0 m (150 to 200 ft) offshore. It was suspected that onshore migration of ordnance is halted by this sandbar. The distribution of the EM61 response revealed few, very localized anomalies indicative of single buried metallic objects. Further data analysis classified all anomalies as either shallow-buried objects or surface metallic objects.

Figure 17 shows all transient electromagnetic anomalies interpreted to be significant. These anomalies are classified into two groups:

a. Yellow circles - near-surface buried metallic objects.

b. Green circle - surface metallic objects.

Four distinct (but still small) anomalies are indicated on Figure 17. Anomalies A and B, located almost at the shoreline, appear to represent very shallow-buried metallic objects. Anomalies C and D show locations of metallic debris observed on the sand during survey.

Survey results for the Cove Beach area document a sparseness of buried metallic objects (possible ordnance) in this area, giving support to the theory that the nearshore sandbar may prevent the landward migration of OEW at this location.

FUDS Beach, East Beach area

Results of the transient electromagnetic survey conducted at East Beach are presented in Figures 18 and 19. The surveyed sandy area (approximately 15.2 by 121.9 m (50 x 400 ft)) (Figure 13) was limited along its southwest boundary by relatively dense bushes and trees. A small, northern portion of the survey was conducted in very shallow water (less than 0.15 m (0.5 ft)). The East Beach is exposed to the wave activity of the open lake and does not appear to be protected by a significant sandbar system.

Data were plotted and viewed as profiles, which allows detailed observations of the amplitude and shape of each anomaly. Figure 19 shows all anomalies interpreted to be significant. These anomalies are classified into four groups:

a. Red circles - possible buried metallic objects.

b. Yellow circles - near surface buried metallic objects.

c. Red zones - either large or a group of smaller buried metallic objects.

Figure 17. EM-61 anomalies located on Cove Beach from all collected channels of data
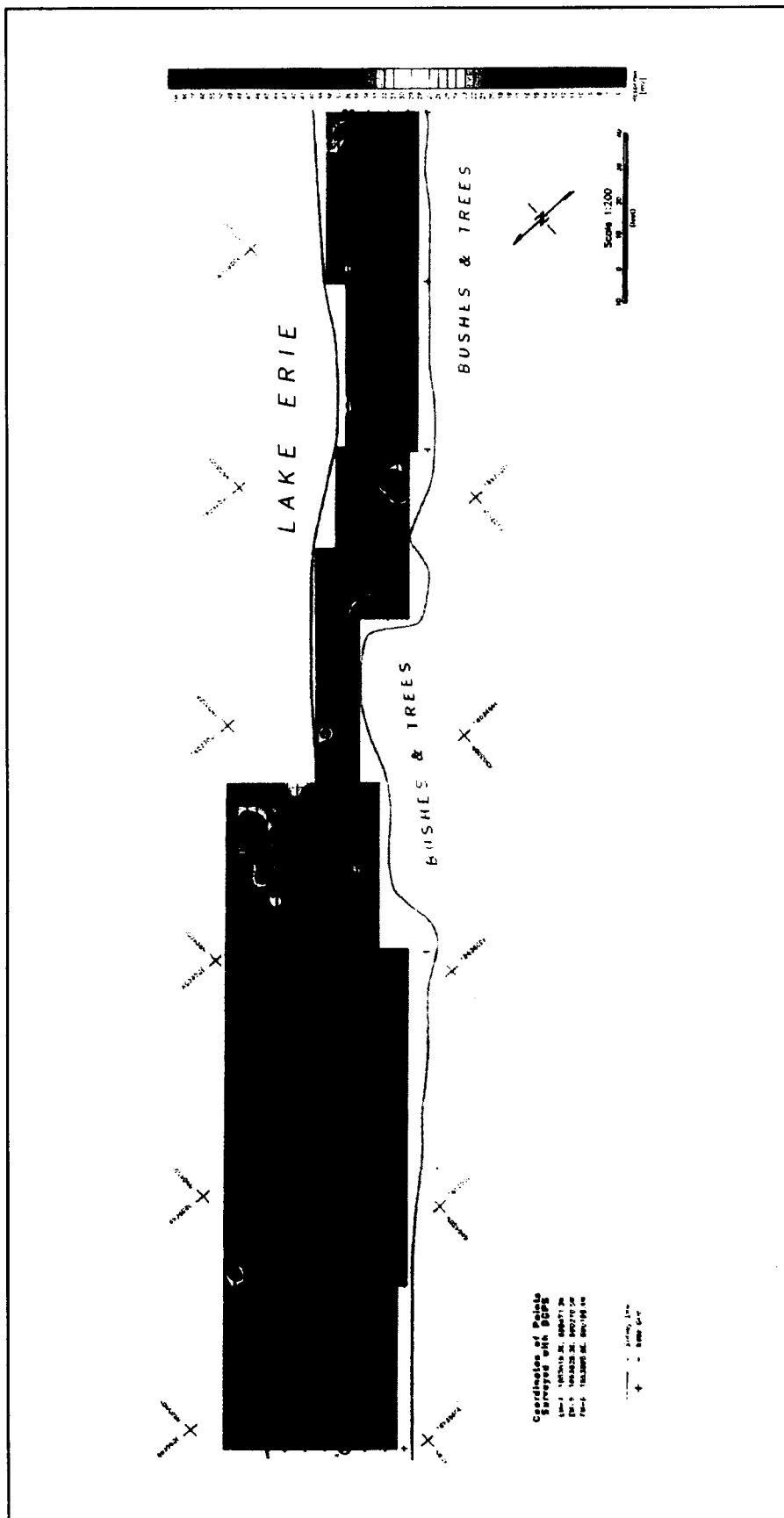
Figure 18. EM-61 response of possible ordnance items at East Beach

Figure 19. EM-61 anomalies located on East Beach from all collected channels of data

d. Pink zones - either scattered or shallowly buried metallic objects.

The EM61 response in this area was of a relatively complicated nature, indicating the presence of a large number of closely buried metallic objects. Figure 18 presents the distribution of numerous single high-amplitude anomalies as well as anomalous zones consisting of groups of buried objects. Subsequent data processing revealed a number of deeper, prominent features.

Four anomalous zones that may indicate larger buried metallic objects or groups of smaller objects are marked by red shaded zones (labelled A, B, C, and D) on Figure 19. These zones are surrounded by anomalous zones (pink shaded zones) which may represent a number of shallower scattered metallic objects. One pink zone labelled E is believed to contain only two single metallic objects. A large number of anomalies indicating single buried metallic objects can be observed within anomalous zones of both types.

Numerous localized anomalies that appear to represent single metallic objects can be observed on the color contour maps. They were classified on Figure 19 in two groups marked by red and yellow circles. Red circles indicate deeper buried objects, while yellow circles demonstrate the possible presence of shallow-buried metallic objects.

Estimates of the depth of some prominent buried objects were calculated. Results of calculations are presented in Table 3. Numbering (labelling) of the anomalies in Table 3 corresponds to the annotations given on Figure 19. The results of the survey carried out at East Beach revealed numerous deeper and shallower buried metallic objects which may represent buried ordnance. It should be noted that the largest concentration of anomalies possibly indicating OEW is located in the central portion of the surveyed area, as well as closer to the shore-line.

Offshore Transient Electromagnetic Surveys for Ordnance

The response of the transient electromagnetic method to inert ordnance was tested adjacent to the Toussaint River navigation channel, lakeward of the spit. Inert ordnance consisting of 155-mm, 105-mm, 90-mm, and 75-mm artillery shells along with 106-mm anti-tank rounds and 4.2-in. mortar shells was tied in sequence to a nylon line with hose clamps at 30-m (100-ft) spacings. The ordnance was laid in line on the bottom and tethered at each end with buoys. Several data survey traverses were made diagonally across the tethered inert ordnance with the EM61 transient electromagnetic antenna attached to the pontoon raft. Responses of greater than 30 mV at a range of 0.9 to 1.5 m (3 to 5 ft) were typically shown for the detected inert ordnance. It is estimated from these investigations that the EM61 transient electromagnetic coil in the utilized marine configuration can easily detect an ordnance shell of 90 mm or greater size within a 1.8- to 2.1-m-wide (6- to 7-ft- wide swath.

Table 3 Estimated Depth of Buried Metallic Objects at East Beach					
	Calculated Depth			Calculated Depth	
Anomaly	meters	feet	Anomaly	meters	feet
1	1.01	3.3	B	0.46	1.5
2	0.49	1.6	14	0.91	3.0
3	0.40	1.3	15	0.91	3.0
4	0.61	2.0	16	0.46	1.5
5	0.91	3.0	17	0.49	1.6
6	0.91	3.0	18	0.55	1.8
7	1.10	3.6	19	0.37	1.2
8	0.64	2.1	20	0.27	0.9
9	0.79	2.6	21	0.18	0.6
10	0.58	1.9	22	2.13	7.0
11	1.04	3.4	23	0.61	2.0
12	0.88	2.9	24	0.61	2.0
13	0.67	2.2	25	0.82	2.7

Results of the EM61 underwater survey in the East Zone and Central Zone (Figure 13) area are plotted on Figures 20, 21, 22, and 23. In the East Zone, measurements were carried out along five survey lines. Underwater transient electromagnetic data collected in the East Zone, as presented on Figures 20 and 21, show varying spatial distribution of anomalies. These responses may indicate the presence of metallic objects on or under the lake bottom. The location of these anomalies may be overlaid on the general bathymetry data. The highest concentration of anomalies is observed in the northwestern portion of the study area in the vicinity of the sandbar located near Cove Beach. The high density of metallic objects was indicated along four survey lines in this area. A second zone, smaller in aerial extent and characterized by higher concentration of anomalies, was noted in the southeastern end of the surveyed site. The zone lakeward of the East Beach appears to contain a relatively low number of detected anomalies. It appears that landward movement of ordnance is obstructed by the presence of the sandbar near Cove Beach.

Results of the electromagnetic underwater survey in the Central Zone area are plotted on Figures 22 and 23. Measurements were carried out along six survey lines relatively parallel to the shoreline. Data from the underwater survey conducted in the Central Zone area indicate a potentially higher concentration of anomalies in the southeastern end of the study area. This denser distribution of anomalies can be observed on all four survey lines located closest to the shore. The most lakeward line (1) shows very few anomalies.
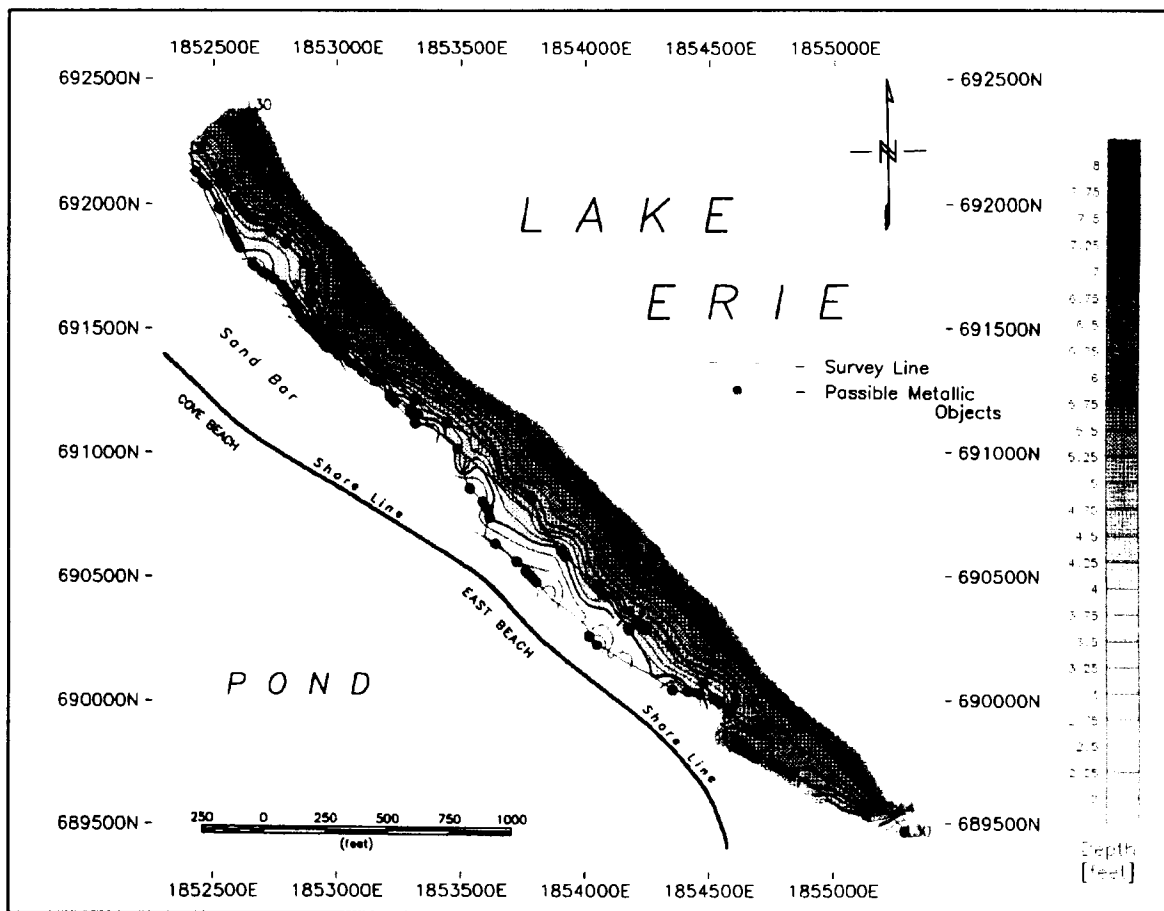
Figure 20. Location of possible ordnance items detected under water along traverses in the East Zone Area
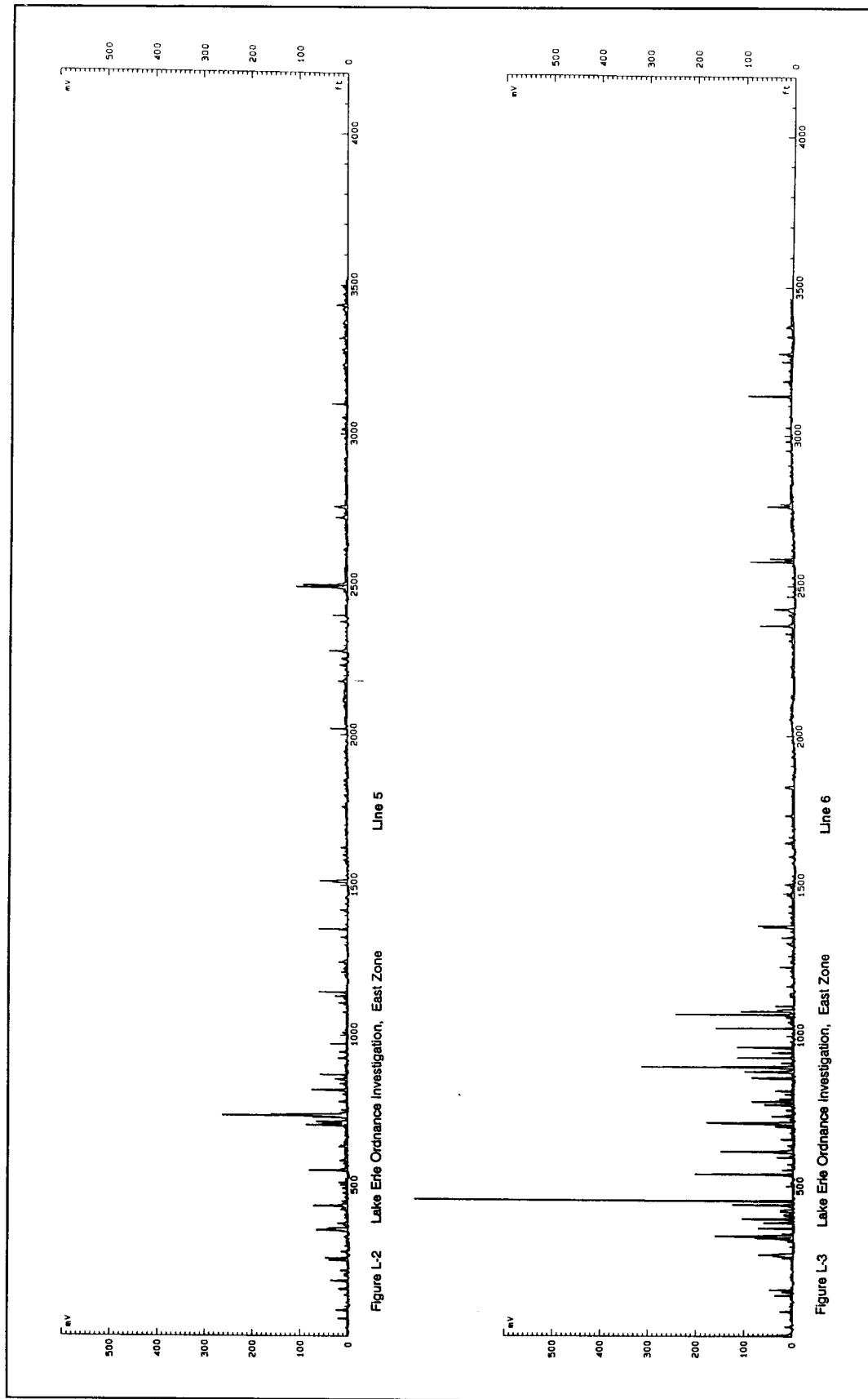
Figure 21. Profile plots of EM-61 responses of possible ordnance items detected underwater along Traverses L-2 and L-3 in the East Zone Area
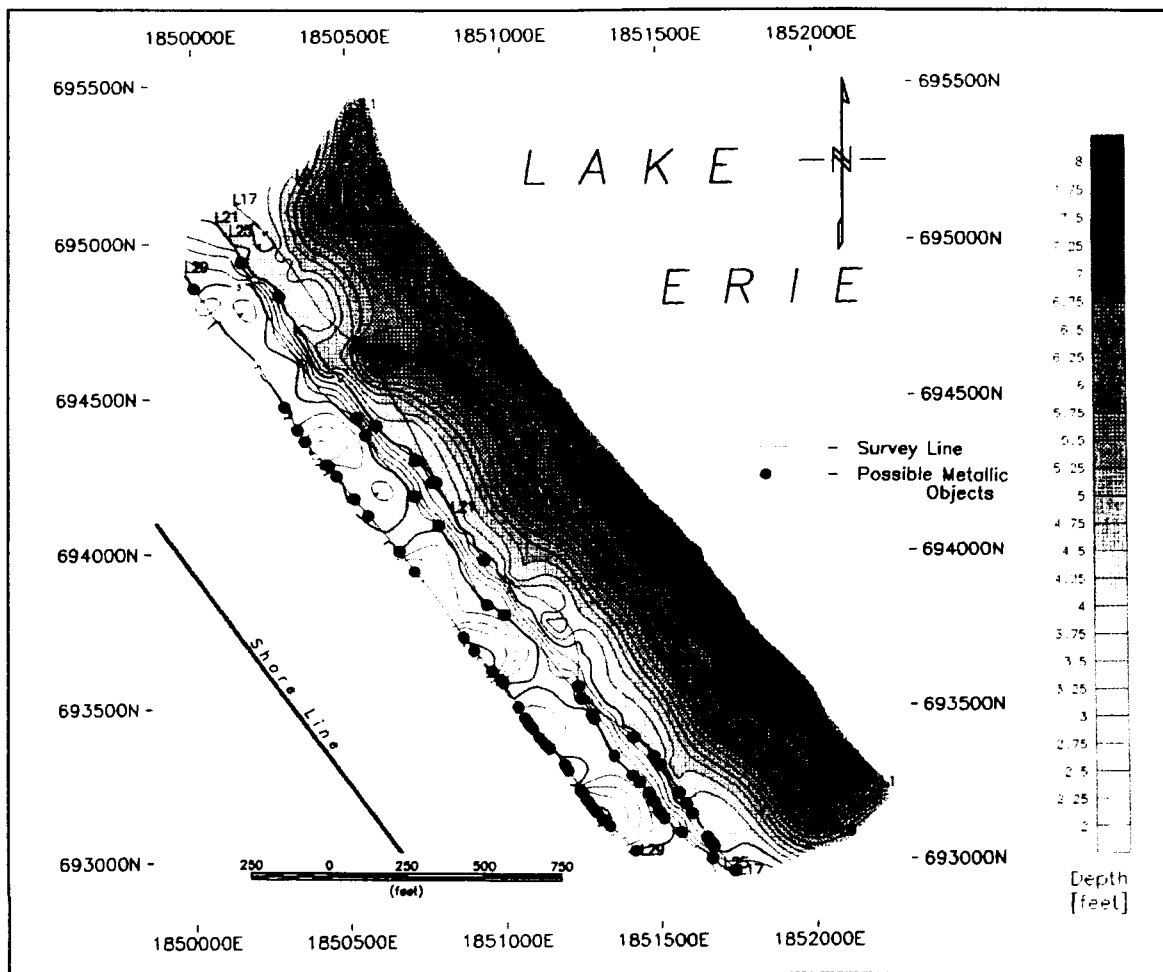
Figure 22. Location of possible ordnance items detected underwater along traverses in the Central Zone area

Figure K-5   Lake Erie Ordnance Investigation, Central Zone

Line 25

Figure K-6   Lake Erie Ordnance Investigation, Central Zone

Line 29
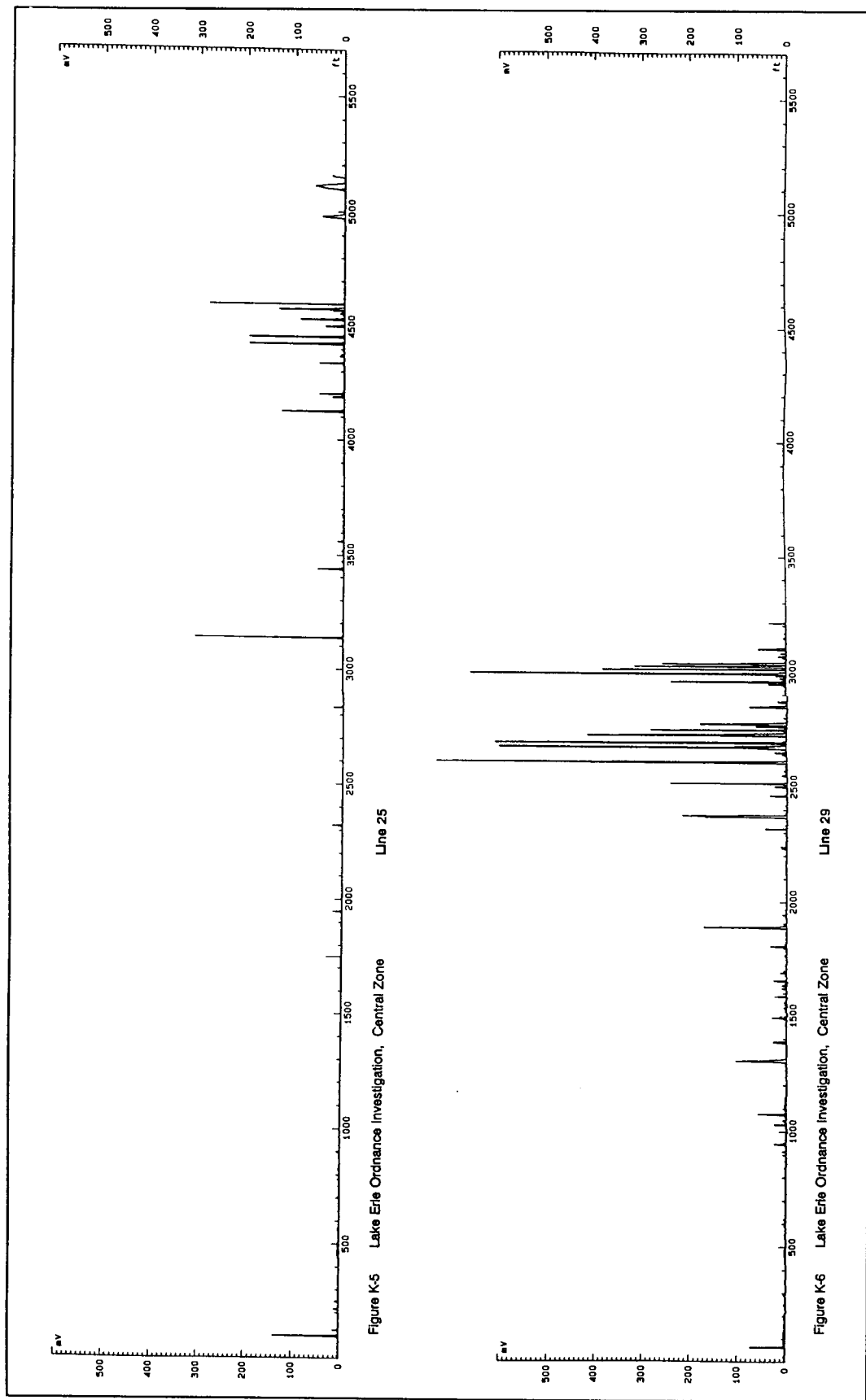
Figure 23. Profile plots of EM-61 responses of possible ordnance items detected underwater along Traverses K-5 and K-6 in the Central Zone Area

5 Magnetic Surveys

Introduction to Technology

Magnetic search techniques for ferromagnetic material are based upon two principles; magnetic induction and remanent magnetism.

Magnetic Induction

In this situation, a ferromagnetic metal object becomes magnetized by merely placing it in a magnetic field. Here the ambient field (in this case the Earth's magnetic field) is modified by the secondary field, which is generated (induced) by the ferromagnetic object. This generally results in an increase of the measured field strength when the ferromagnetic target is below the magnetic sensor and the site location is at higher earth latitudes such as northern Ohio. This effect in ferromagnetic objects can be expressed for first order principles by:

$$I_i = kH \tag{1}$$

where

I_i = induced magnetization per unit volume or weight

k = unit volume or per weight magnetic susceptibility

H = ambient magnetic field intensity or strength

For ferromagnetic iron alloys k may vary from 1 to 1,000,000. At the former Erie Army Depot, the Earth's magnetic field strength was about 0.55 gauss or 55,000 nanoTeslas. Most important for the detection of OEW by magnetic methods is the change or disturbance in the total measured magnetic field which is a result of the nearby presence of the ferromagnetic object(s). An approximation of the effect generated by small dipole objects which are not greatly elongated (such as ordnance shells) is:

$$F_a \sim (M_{fps} \times \text{lbs steel})/r^3 \tag{2}$$

where

F_a = anomalous magnetic field or change in the field due to the presence of the small dipole object in nanoTeslas.

M_{fps} = magnetic moment per pound of steel M_{fps} typically varies from 1.75×10^2 to 1.75×10^3 for soft steel

r = distance from the object to the measurement location in feet

Table 4 lists some typical expected anomalous magnetic responses for various sizes of ordnance. Typical weights for unexploded artillery shells are about:

6.8 kg (15 lb) for 75-mm artillery shell
9.1 kg (20 lb) for 4.2-in. mortar shell
9.1 kg (20 lb) for 105-mm artillery shell
40.8 kg (90 lb) for 155-mm artillery shell

Table 4
Maximum Theoretical Magnetic Response for Differing Sizes of Ordnance at Various Distances in Feet[1]

Target Object	4 ft	8 ft	12 ft	16 ft
5-lb soft steel	13 nT 60 nT 134 nT	2 nT 6 nT 16 nT	0.5 nT 2 nT 5 nT	0.2 nT 1 nT 2 nT
10-lb soft steel	27 nT 120 nT 269 nT	3 nT 15 nT 34 nT	1 nT 5 nT 10 nT	0.4 nT 2 nT 4 nT
15-lb soft steel	40 nT 180 nT 403 nT	5 nT 22 nT 50 nT	1.5 nT 6 nT 15 nT	0.6 nT 3 nT 6 nT
20-lb soft steel	54 nT 240 nT 538 nT	7 nT 30 nT 67 nT	2 nT 10 nT 20 nT	0.8 nT 4 nT 8 nT

[1] Responses are for material magnetic moments of 1.75×10^2 about 8×10^2 (best guess) and 17.5×10^2 per pound of steel.

Permanent (or Remanent) Magnetism

This is the magnetization remaining in a ferromagnetic metal object in the absence of an applied magnetic field. Most artillery shells have not been exposed to strong magnetic fields in the course of manufacture, storage, or transport, i.e., they have not been subjected to hysteresis effects. Nor have they been "degaussed" as is sometimes done on naval ordnance. No

references could be identified which classify particular types of ordnance which may contain significant remanent magnetism. However, it has been apparent from unpublished field investigations that many types contain large amounts while others contain little. The strength of this effect is most likely the result of a permanent magnetic field "frozen" into place when the Currie temperature (about 750 °C for ferrous materials) is reached during the casting of the shells. This remanent magnetism is significant in search surveys as the direction of the resultant magnetic vector is not defined by the induced magnetic field at the time of the measurement. It is defined by the direction and strength of the magnetic field at the time the shells were cast. In many cases this effect results in a strong decrease rather than an increase in the measured total magnetic field. As a result, a significant decrease rather than increase in the total magnetic field may be measured by the sensor when it is spatially over the artillery shell. The magnitude of this effect is dependent upon the orientation of the ferrous object. However, no significant negative magnetic anomalies could be identified from the inert ordnance buried on the spit.

Magnetic Field Data Collection

Magnetic surveys near the former Erie Army Depot were collected in the presence of an inducing magnetic field (the Earth's) at a strength of approximately 55,000 nanoTeslas (0.55 gauss). The field at this latitude and season varies smoothly up to 200 nanoTeslas in an 8-hr time period as part of a natural diurnal magnetic variation. The change in the total magnetic field due to the nearby presence of target ordnance may be as small as 10 nanoTeslas. As a consequence, it is necessary to regularly measure the Earth's magnetic field at a nearby reference point and to correct all measurements for this "drift." The collected field data are first corrected as if the inducing magnetic field was constant and did not vary over the time of the survey. For the land magnetic surveys, the reference station was measured every 15 min and the variation of the Earth's magnetic field was linearly interpolated between these times. For the waterborne magnetic data, the magnetic field at the reference location was measured every 20 sec and the strength of the Earth's magnetic field at a particular measurement time was also determined by linear interpolation. Examples of the variation in the magnetic field at the study base station are seen on Figure 24. An example of a traverse line of the "drift-corrected" magnetic measurements is displayed in Figure 25.

Land magnetic surveys

The test inert ordnance field on the sand spit at the mouth of the Toussaint River was magnetically surveyed to determine the response of various types of artillery and mortar shells. See Table 2 for the types and ordnance burial depths. This investigation was performed so that the results and capabilities of the transient electromagnetic survey could be directly compared to the more traditional magnetic surveys. The study was conducted with an EDA Instruments Omni IV magnetometer. This instrument contained two proton
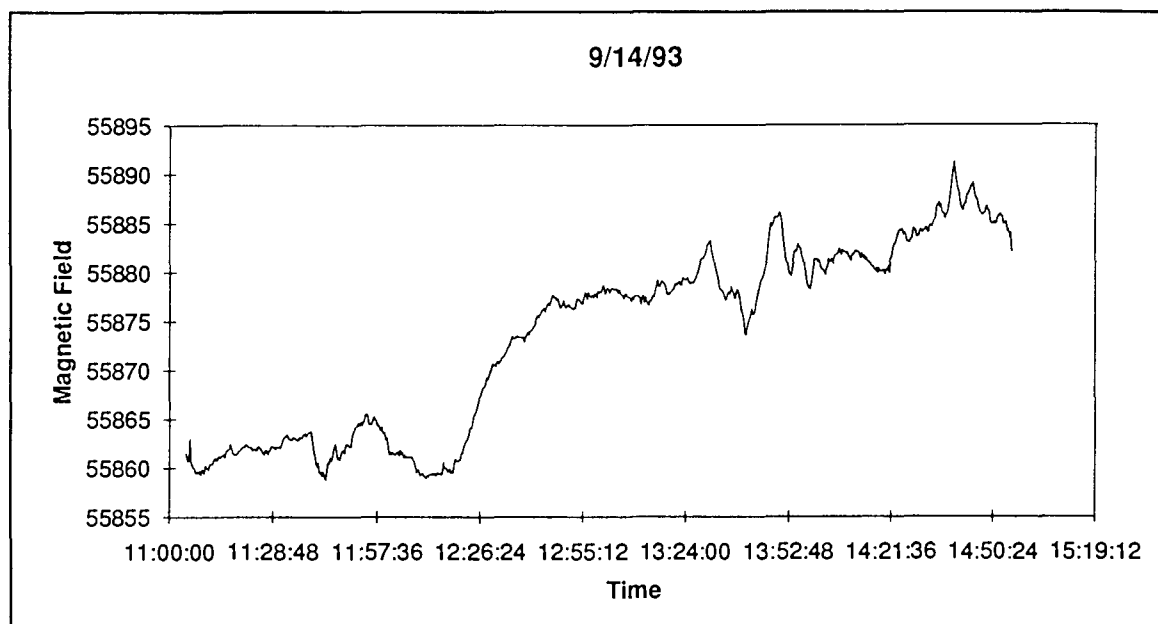
Figure 24. Variation of the Earth's magnetic field strength at the base station on the spit at the mouth of the Toussaint River

precession sensors separated by 0.5 m (1.6 ft) and it was used both as a total field magnetometer and as a vertical gradient magnetometer. The stated precision of the instrument is 0.1 nanoTesla; however it has been determined by field trials to be about 0.25 nanoTeslas. The grid over the inert ordnance magnetic survey was at 0.91-m (3-ft) spacings. Data were used to create the total field and vertical magnetic field gradient over the test spit area, as displayed on Figures 26 and 27.

The total magnetic field plot contains the response of many of the larger buried inert ordnance items and three larger and deeper buried elongated dipole ferrous objects which are not part of the investigation. These unwanted foreign objects are clearly displayed on Figure 26 by the localized areas of relative low magnetic field strengths (55,080 to 55,090 nanoTeslas) immediately adjacent to enclosed contoured areas of significantly larger magnetic anomalies (55,120 to 55,130 nanoTeslas). These most likely represent larger ferrous objects which were lost or jettisoned overboard from a marine vessel, then buried under 1.5 to 3.0 m (5 to 10 ft) of accreted sand associated with the growth of the spit across the channel entrance. They produce an interfering effect, so that some of the ordnance is not clearly resolvable. However, the inert 155-mm artillery shell has a response greater than 45 nanoTeslas. The inert 4.2-in. mortar and inert 106-mm antitank rounds display anomalous fields of about 15 nanoTeslas and the inert 81-mm mortars have a response of 10 or less nanoTeslas. All of these field strengths are for a sensor placed about 1.8 to 2.4 m (6 to 8 ft) from the target. Although inert 105-mm artillery rounds were not included in the test area, they can similarly be expected to have approximately a 20-nanoTesla response in this investigation.
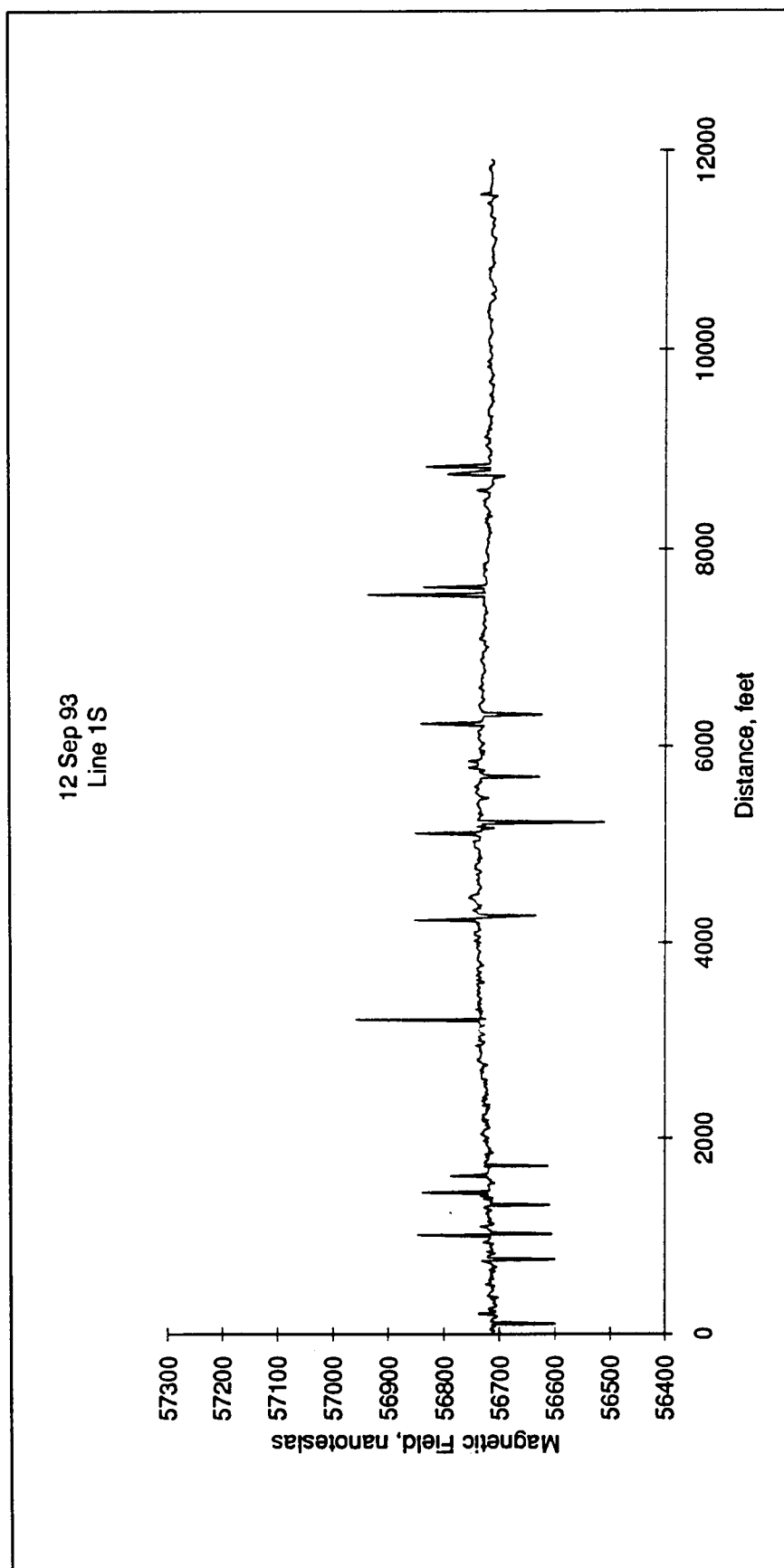
Figure 25. Magnetic-drift-corrected data for Line 1S. The low-amplitude, broad regional magnetic "high" (about 10 nanoTeslas) was centered at 1,219 m (4,000 ft). High-frequency magnetic highs and lows are from possible ordnance items
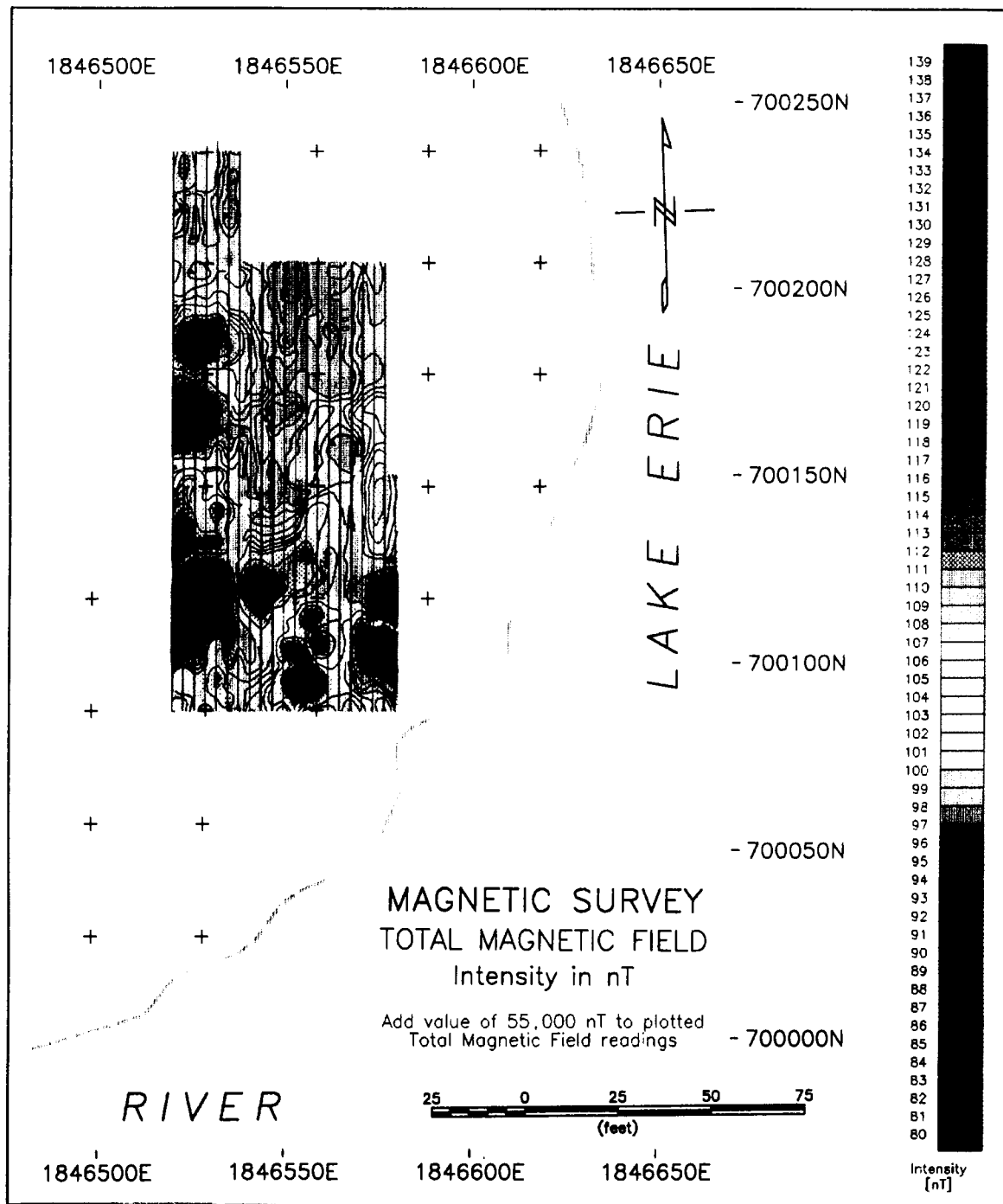
Figure 26. Total magnetic field over inert ordnance at the spit, mouth of the Toussaint River

The inert test ordnance was significantly better resolved by the vertical magnetic gradient survey (Figure 27). Almost all of the larger sized inert ordnance displayed responses greater than 30 nanoTeslas per meter. The smaller inert 81-mm mortar shells had vertical magnetic gradient anomalies of over 10 nanoTeslas per meter. This type of investigation was not attempted as a

1846500E   1846550E   1846600E   1846650E

- 700250N

- 700200N

L A K E   E R I E

- 700150N

- 700100N

- 700050N

MAGNETIC SURVEY
VERTICAL GRADIENT
OF TOTAL MAGNETIC FIELD
Intensity in nT/m   - 700000N

R I V E R   25   0   25   50   75
(feet)

1846500E   1846550E   1846600E   1846650E

49
48
47
46
45
44
43
42
41
40
39
38
37
36
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1
0
-1
-2
-3
-4
-5
-6
-7
-8

Intensity
[nT/m]

Figure 27. Vertical magnetic field gradient inert ordnance at the spit, mouth of the Toussaint River

waterborne investigation due to the significantly greater cost of operating available equipment. Most sensitive marine magnetic gradiometers are operated by the U.S. Navy and require large mobilization costs. However, this technology is becoming more commercially available at significantly less cost.

Waterborne magnetic surveys

A large total field magnetic survey was conducted from the R/V SeaQuester and R/V African Queen. The area to be surveyed extended from the mouth of the Toussaint River southward for about 3 miles along the shore of the former Erie Army Depot and then outward into Lake Erie for a distance of approximately 1.0 km (3/5 mile). The lake bottom profile was very shallow, with the water depth varying from 0.3 m (1 ft) less than a hundred feet offshore to no more than 3.7 m (12 ft) over 0.8 m (1/2 mile) from the shoreline. When the available water depth was over 1.2 m (4 ft) the R/V SeaQuester was employed for the survey, while shallower depths of 1.2 m (4 ft) to less than 0.61 m (2 ft) were traversed by the R/V African Queen. Over 113 km (70 miles) of traverses were measured at an average speed of less than 2 knots (3.4 ft /sec). A marine Proton 3 magnetometer from J. W. Fisher, Inc., was used to collect total field magnetic data for the off-shore ordnance field location investigations. This sensor employs a proton precision head with a stated accuracy of ±1 nanoTesla. The instrument was tethered to a surface pontoon to allow it to be suspended at a depth of approximately 1.2 m (4 ft) above the bottom. In water depths of less than 1.2 m (4 ft) this distance was reduced to 0.61 m (2 ft) and then in very shallow water, 0.3 m (1 ft). Data were collected approximately every 2.1 to 3.0 m (7 to 10 ft) along traverses with a 3-sec cycle time between each measurement. Adjacent line separations were about 61 m (200 ft) in the nearshore for data collected by the R/V African Queen and approximately 150 m (500 ft) for the deeper water data collection with the R/V SeaQuester. At the 3-sec data acquisition rate, a 1- to 2-nanoTesla precision was stated by the manufacturer. However, a ±2.0-nanoTesla precision was documented in the field. It is evident that some ordnance along the traverses may not have been detected with data points at 2.1- to 3.0-m (7- to 10-ft) intervals along the traverses. However, the purpose of the investigation is to determine relative ordnance density, not to resolve individual pieces of ordnance. The EM61 transient electromagnetic method is much more suited to determine absolute projectile concentrations.

The magnetic signature for both the R/V SeaQuester and the R/V African Queen were investigated with the EDA magnetometer when each vessel was beached on the spit. This was accomplished by making total field and vertical magnetic gradient measurements at 3.0-m (10-ft) intervals along traverses away from the bow of the vessels. The R/V SeaQuester (aluminum hull) had a response of 45 nanoTeslas at a distance of 3.0 m (10 ft) from the bow. The signature was less than 1 nanoTesla at a range of 18.3 m (60 ft). The R/V African Queen (steel hull) had a response of 380 nanoTeslas at a range of 6.1 m (20 ft). This response was less than 1 nanoTesla at a range of 33.5 m (110 ft). Setback distances (the distances the marine magnetometer was towed behind the vessels) were 30 m (100 ft) for the R/V SeaQuester and 42.7 m (140 ft) for the R/V African Queen. The hull length for the later vessel was 7.6 m (25 ft). Generally, five times the dipole length 38.1 m (125 ft) is usually a sufficient setback distance for a steel-hulled water craft.

The collected marine magnetic data were first position adjusted for sensor setback and then corrected for the diurnal drift of the earth's magnetic field (Figure 25). A linear trend was then removed from the data, which largely removed unwanted regional magnetic variations. All large and magnetic anomalies from ferromagnetic material on the lake bottom were then clipped and reduced to values of ±50 nanoTeslas. The ends on the data strings were then padded with zeros and a 6th order equation was fitted and removed from the data using STATGRAPHICS, a software package by STSC (Figure 28). This process deleted the effects of the much larger ferromagnetic objects on the

AFRICAN QUEEN, LINE 1, 930918
6 ORD RESD, CLIPPED AT 50 NANOTESLAS

NANOTESLAS

NORTHING
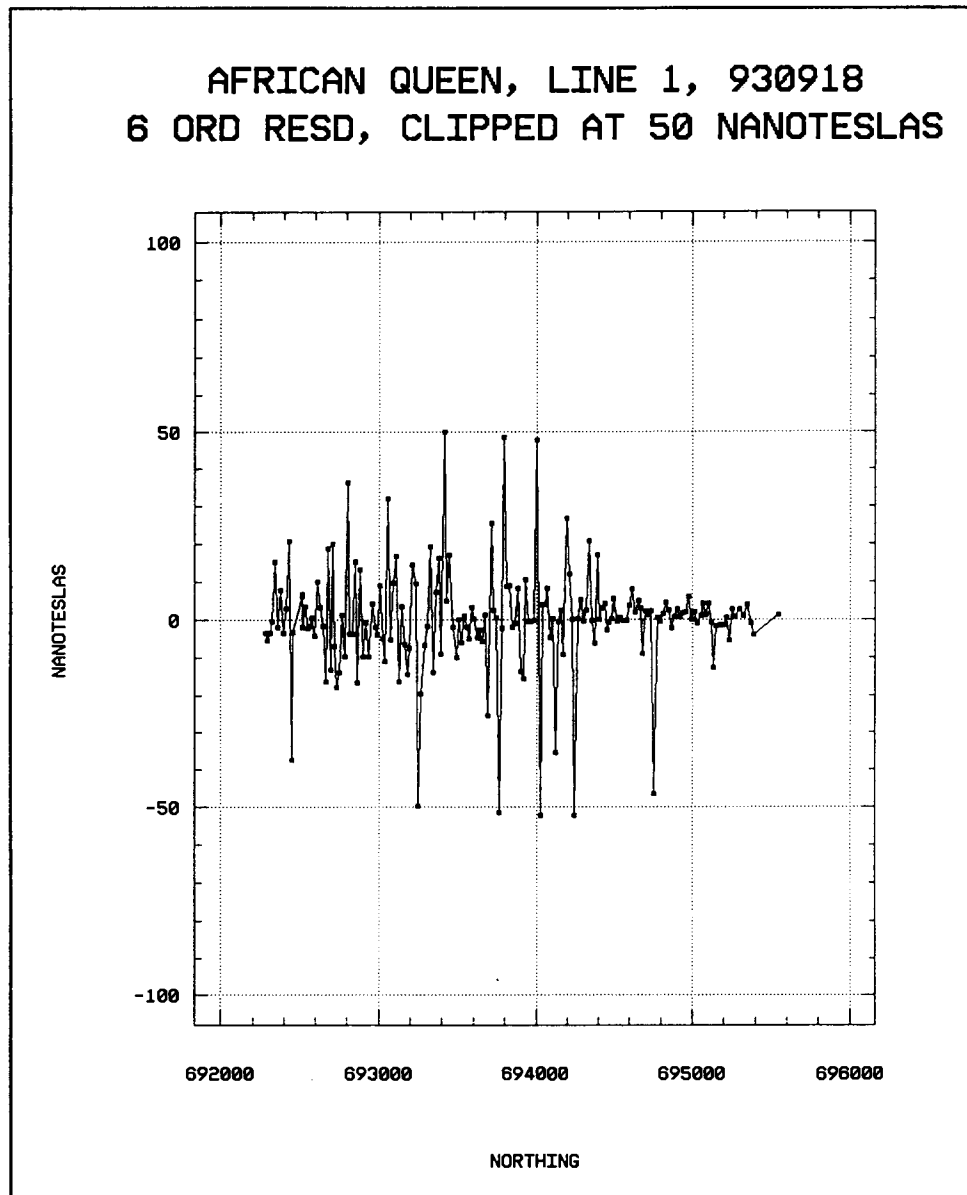
Figure 28. Total field magnetic data from the R/V African Queen Line I. Data are diurnal drift corrected, regional effects removed, and responses clipped above ±50 nanoTeslas

lake bottom such as boat hulls, crashed antiaircraft target drones, etc. Residual data largely represent the magnetic signature of the ordnance and any other smaller ferro-magnetic objects.

Data were then sorted for ordnance "detects" by the intensity of the anomalous residual magnetic response. The typical local magnetic background was found to vary by ± 3 to 4 nanoTeslas in test areas void of ordnance contamination. A threshold trigger of ± 10 nanoTeslas was established as a definite "OEW detect." Similarly a threshold of 35 nanoTeslas was ruled a "large OEW detect." These detect locations, along with the survey traverses, are shown in Figures 29 and 30. These locations can be compared with Figure 8, which displays the tracklines for the waterborne magnetic traverses.

The magnetic data present definite patterns displaying OEW density in the offshore area. The nearshore magnetic data corroborate extremely well with the transient electromagnetic investigation, where data are available for the same area in the East Zone and Central Zone.

Relative OEW densities may be visualized by assigning various colors to the traverse segments according to the number of ordnance detects found along a 152.4-m (500-ft) segment (Figures 31 and 32). Two high OEW density zones are defined from both the large-size OEW detect pattern (Figure 31) and the small-size OEW detect patterns. These lie within one more general and larger area, which contains a significant number of OEW but with a lower overall defined ordnance density. It is apparent that the ordnance density generally increases toward the shore and clusters into very dense areas toward the historical firing fan-covered portion (i.e. offshore of the range poles, Figure 13) of the study region. These high-density OEW areas, which lie just a few hundred feet offshore, should be interpreted as to their movement history and future location(s) in light of natural coastal transport processes.
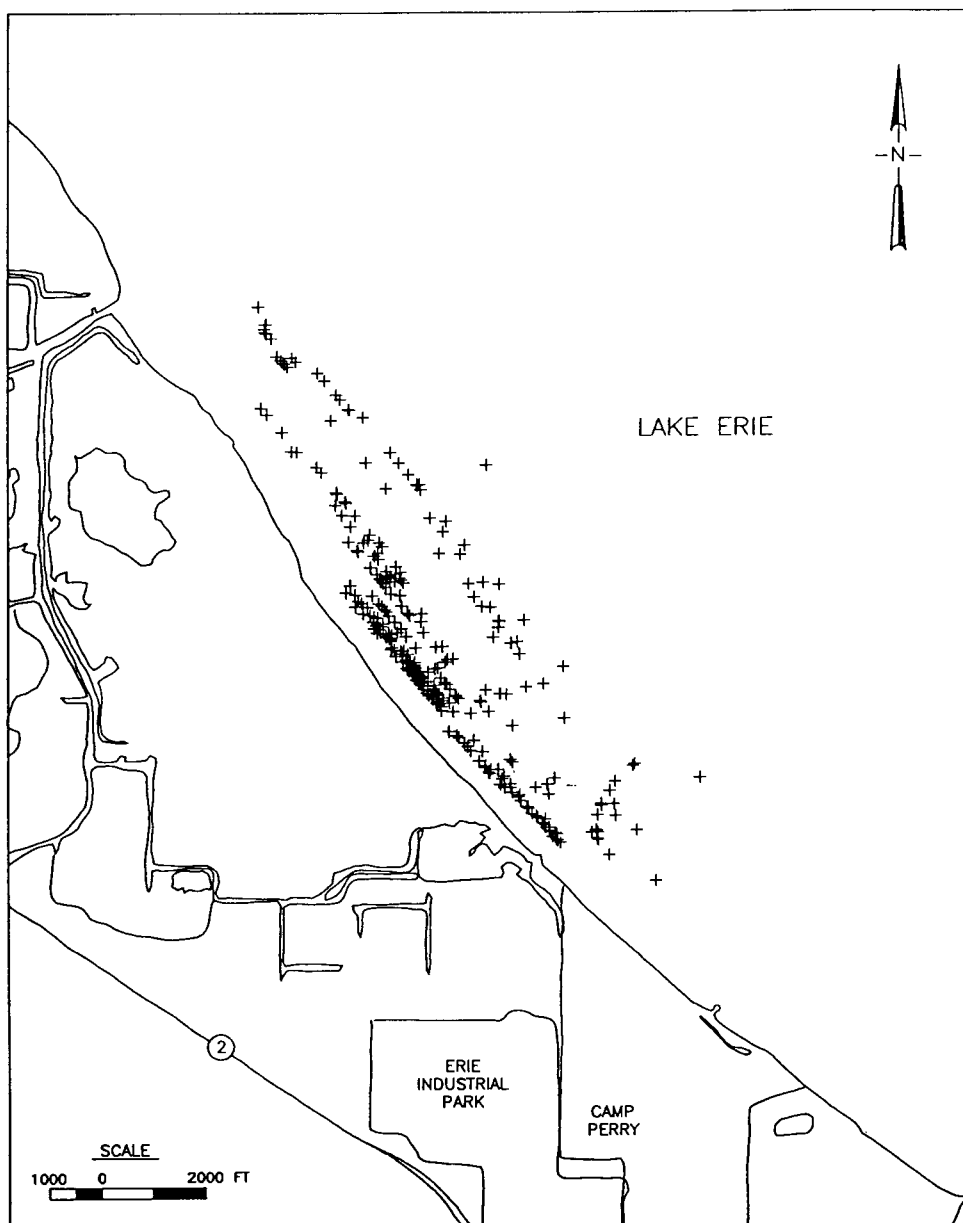
Figure 29. Location of "large" ordnance detects along total field magnetic
traverses in Lake Erie. "Large" is ±35 nanoTeslas to
±50 nanoTeslas
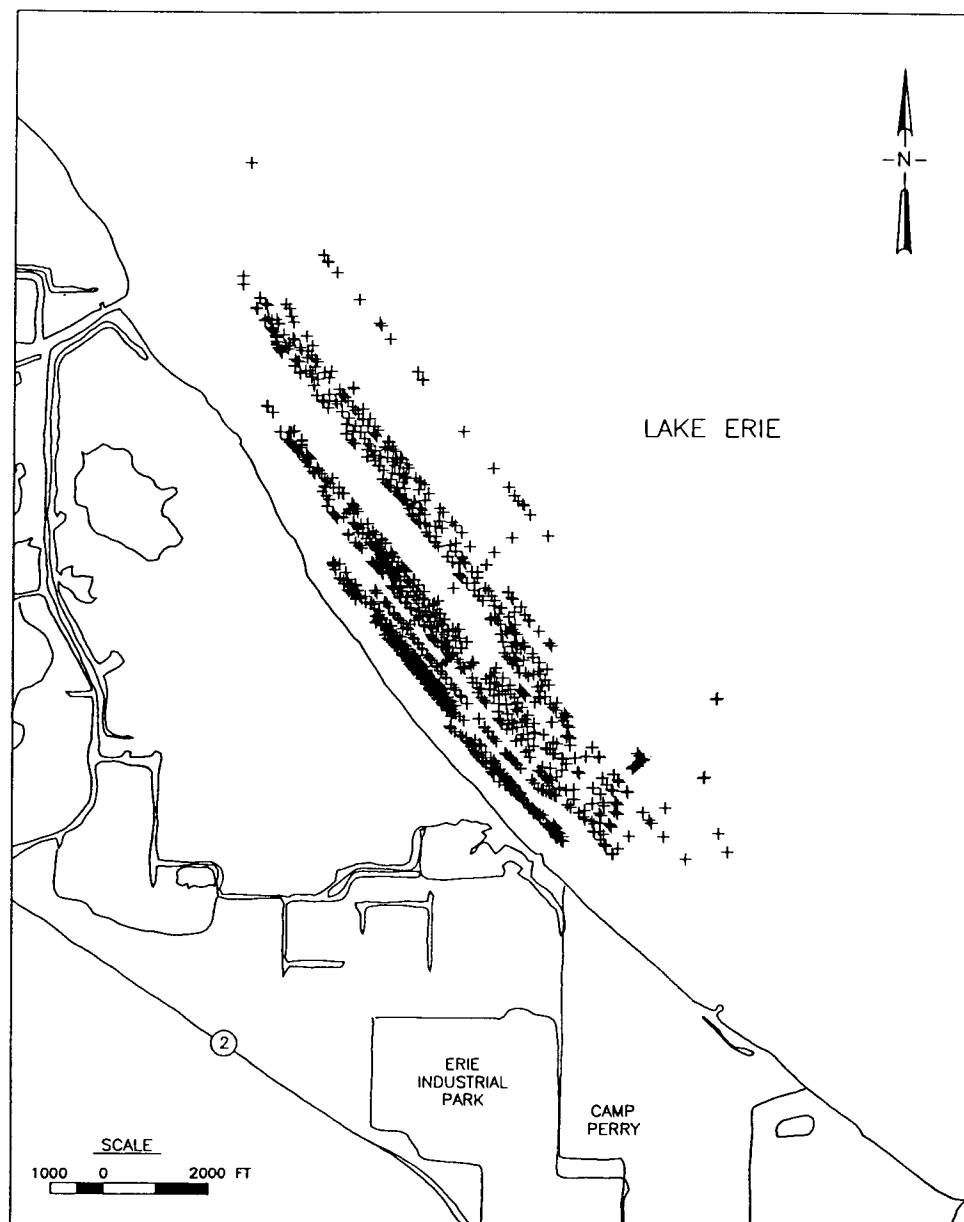
Figure 30. Location of "small" ordnance detects along total field magnetic traverses in Lake Erie. "Small" is ±10 nanoTeslas to ±35 nanoTeslas
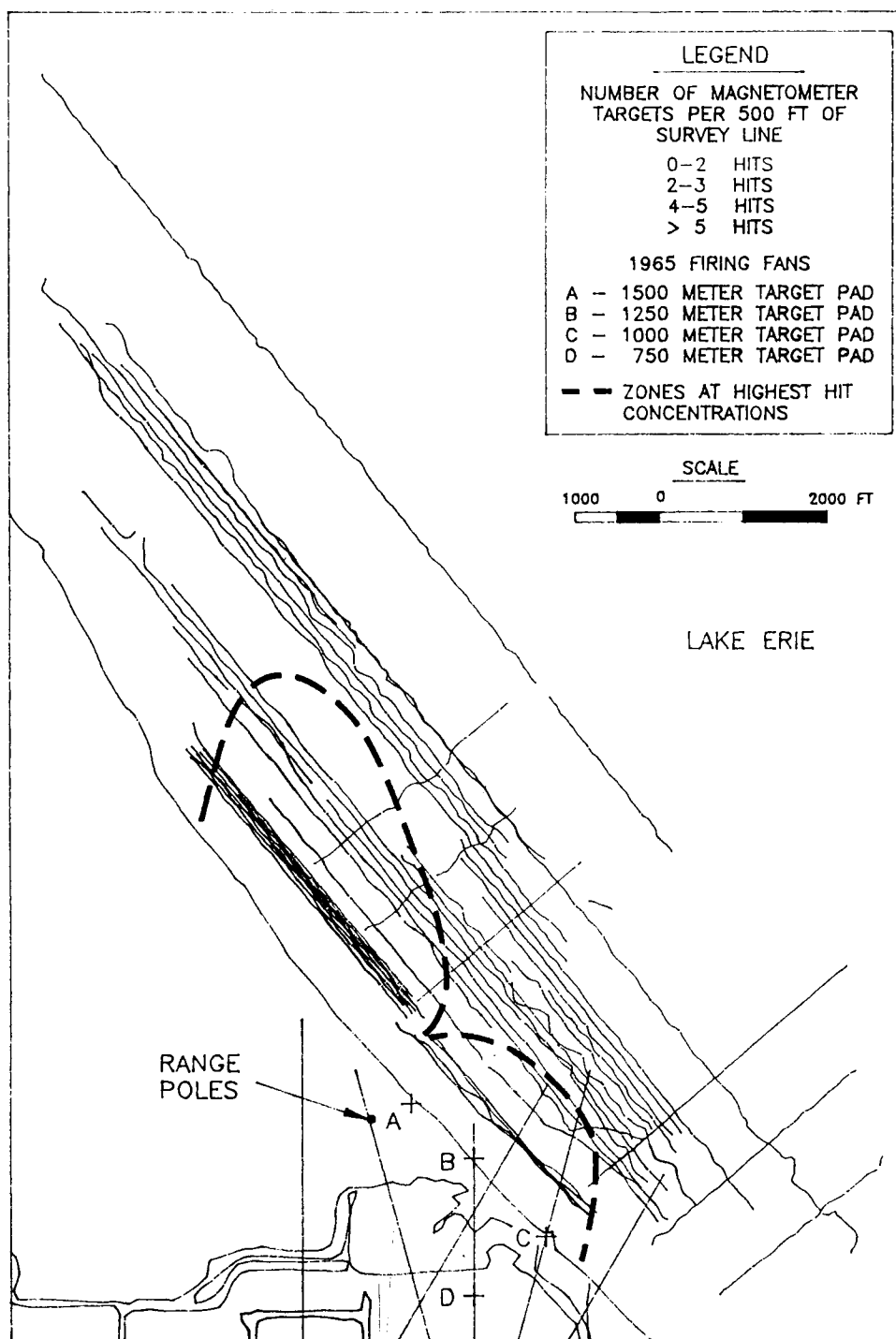
Figure 31. Ordnance densities for "large" ordnance detects. Magnetic
responses from ±35 nanoTeslas to ±50 nanoTeslas
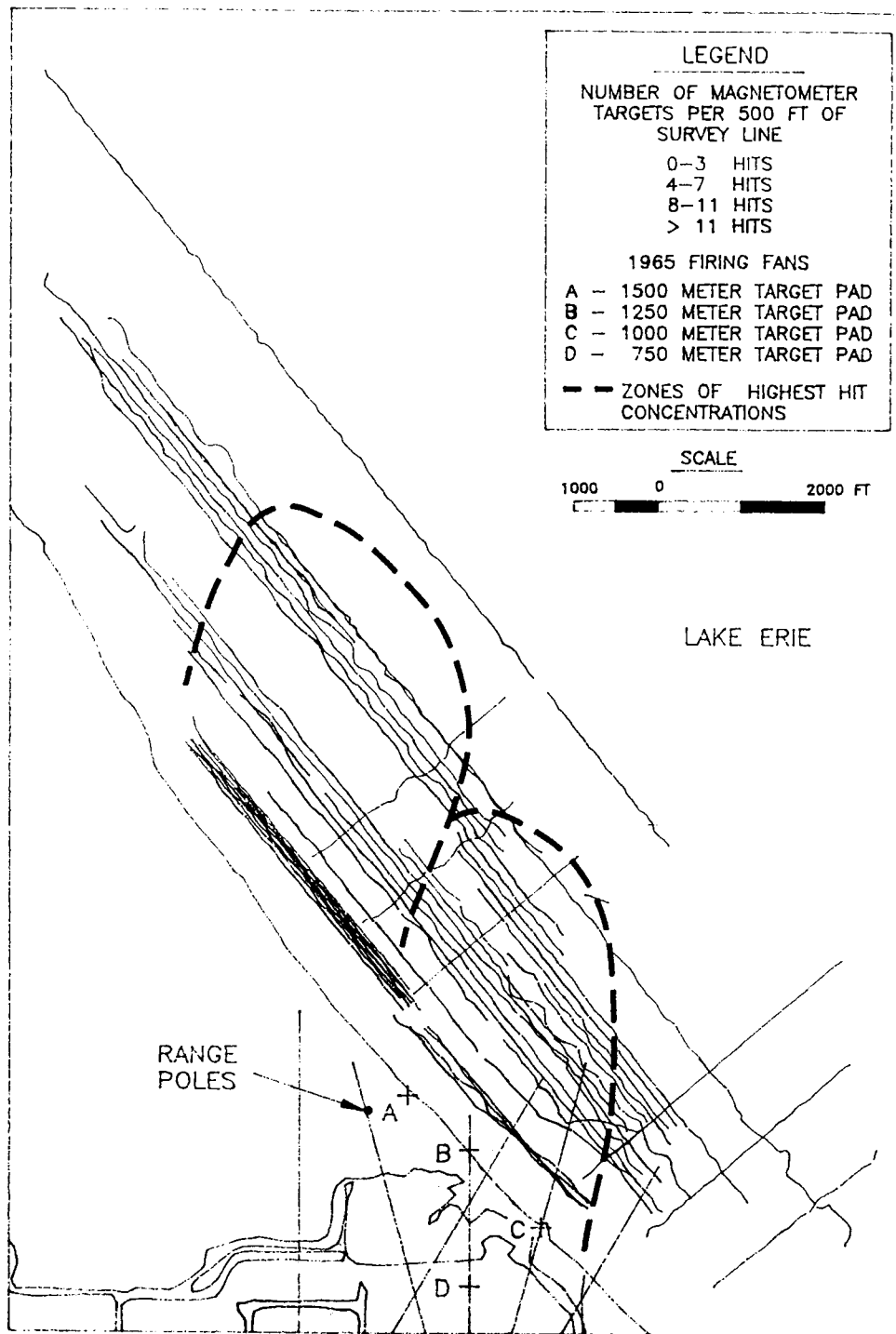
Figure 32. Ordnance densities for "small" ordnance detects. Magnetic responses from ±10 nanoTeslas to ±35 nanoTeslas

6   Ground-Penetrating Radar

A GSSI Model 10 ground-penetrating radar system was tested in various configurations to evaluate its capabilities for detection of OEW in the river, beach, and offshore environments near Camp Perry, southwestern Lake Erie. This effort should be regarded more as a feasibility evaluation than as a production survey.

Summary of GPR Surveys

Onshore calibration over inert artillery and mortar rounds buried in the sand spit at the mouth of the Toussaint River gave very unexpected results: neither the 500-MHz nor the 100-MHz antenna showed more than half of the metal objects, and those which responded gave only very weak reflections. Possible reasons could be: small target dimensions, target orientation not parallel to long axis of the antenna, conductive sand moisture, and excessive signal scattering by mussel shells and heavy mineral (i.e. magnetite and/or ilmenite) lag deposits.

Calibration attempts over underwater targets in the river and dock area were also ambiguous. In the river, difficulty was experienced in maneuvering the scow to pass directly over the targets, while in the dock area the targets probably sank into soft mud. Interference from steel walls, docks, and probable bottom debris also complicated signal clarity in the dock area.

However, investigations on Lake Erie were more successful. Every line using the floating 100-MHz antenna pair showed hyperbolic anomalies, some visible on raw records, but many more evident after careful processing. These ranged in a continuum from very strong returns to weak shadows probably representing small or off-line sources. Interestingly, many more strong returns were seen on shore-perpendicular profiles than on the shore-parallel lines. Hyperbolic returns were often clustered as well, with several returns appearing close together. The density of anomalous objects also increased toward the southeast, further from the mouth of the Toussaint River and closer to Camp Perry. One explanation for the detection of many more objects on the shore-perpendicular profiles is that there is a preferred orientation of the objects with their long axes parallel to shore, as that is the

orientation of the dipole axis (E-plane polarization) of the antenna when towed perpendicular to shore (i.e.; the antenna axis was perpendicular to the profile path).

The footprint of a floating antenna is apparently quite narrow, probably much less than three antenna widths (4.5 m). This can be deduced qualitatively from geometrical optics arguments, where the index of refraction (square root of the relative permittivity) is inversely proportional to velocity. The index of refraction or velocity contrast at the air-water interface is 1:9, so an electromagnetic ray will be severely refracted toward the normal (vertical).

Little sub-bottom information was recorded, as most of the lines were over clay bottom, with the exception of the shoreward ends of the shore-perpendicular lines. All targets appeared to be slightly buried, rather than protruding from the bottom. This is probably an artifact of the severe filtering which was applied to the high-amplitude ringing data, or it could also be due to the longer slant path to targets slightly off-line, relative to the vertical path for the bottom reflection.

GPR Theory

The GPR method as used for shallow geologic, engineering, hydrologic, and archaeological studies, is only about 15 years old. Modern commercial GPR systems commonly operate in the time domain using a 1-2 cycle transmit pulse followed by a relatively long off-time, during which echoes are received and recorded. The sharp pulse contains a multitude of frequencies, by Fourier principles, and the actual frequency propagated to the earth is an inverse function of antenna dimensions. The long dimension of the horizontal dipolar or "bowtie" antenna is usually half a wavelength (in air) of the transmitted wave. As wavelength λ = velocity/frequency, the nominal length of a 100-MHz dipole is equal to $(3 \times 10^8 \text{m/sec})/(100 \times 10^6 \text{ Hz})$ divided by 2, which is 1.5 m. Similarly, a 500-MHz dipole antenna is 30 cm long.

For normal field use, separate transmit and receive antennas are mounted parallel to each other in a rigid frame (bistatic configuration), although the same antenna can be used for both functions (monostatic configuration) if early reflection data can be sacrificed in the time required to electronically switch from transmit to receive mode.

Two main modifications occur to radio waves when they enter the earth: attenuation of amplitude or energy, and a sharp reduction in velocity. The first effect is due primarily to and is proportional to the electrical conductivity (σ) of the material—as conductivity increases, the radio energy is more readily absorbed (converted to heat), and penetration decreases. Other lesser losses can be due to geometric spreading, resonance of the water molecule (only at 20 GHz), interfacial and ionic polarization losses of clay particles, and scattering from wavelength-scale inhomogeneities. The second effect (velocity

reduction) is controlled by the relative electrical permittivity, ϵ_r, (sometimes referred to as dielectric constant—but which is not really constant) according to the relation vel $= C/\sqrt{\epsilon_r}$, where C is the velocity in air, 3×10^8 m/sec. The physical property ϵ_r varies from 1 for air to 81 for water. Thus, the radio wave is slowed in water to 1/9 of its velocity in air, and the wavelength is shortened correspondingly. Since soils are a mixture of mineral grains (with low ϵ_r), water, and air, the ϵ_r ranges from about 6 for nominally dry soils to 25-30 for saturated sands.

The GPR system records the echoes from many pulses per second as the antenna system is steadily pulled forward, and it thus provides a two-way time (down and up) measured to various reflector horizons or objects. Radar reflections in the earth occur where there is a change in one or more of the following three electromagnetic properties: electrical conductivity (σ), relative electric permittivity (ϵ_r), or relative magnetic permeability (μ_r). An intrinsic impedance is defined as

$$z = \frac{\sqrt{(\omega\mu_r)}}{\sqrt{(j\omega\epsilon_r)}}$$ (3)

where $j = \sqrt{-1}$ and the reflection coefficient at a boundary between medium 1 and medium 2 is the contrast in impedance above and below the boundary,

$$R = \frac{(z_2 - z_1)}{(z_2 + z_1)}$$

For most cases in geologic materials, μ_r is assumed to be 1, thus simplifying the expression. However, for steel targets and magnetite-rich sands, the full expression must be used. Similarly, in certain cases (ice or dry sand) σ is negligibly small and can be dropped from the expression in those cases. In summary, an abrupt change in any one or more of these three physical constants can produce an echo. The polarity of the reflected wave (sine of "R") depends upon whether the intrinsic impedance increased or decreased across the interface.

Equipment

The GPR used was a Geophysical Survey Systems, Inc. (GSSI) SIR SYS-TEM-10. Three different antenna systems were used:

a. The GSSI Model 3102 antenna (500 MHz), which is actually a bistatic pair of bowtie antennas mounted side by side in one enclosure.

b. The GSSI Model 3207 bistatic antenna pair (100 MHz, bowtie format) are in separate enclosures separated by rigid bars. They feature exchangeable plug-in modules. During this survey, a GSSI Model

7785W transmit module (high power), and a Model 766DA receiver module were used.

c. An approximately 145 MHz dipolar antenna made at Western Michigan University was used in the monostatic mode. This incorporated a GSSI Model 769DA transceiver module (to serve as both transmitter and receiver). Note that monostatic transceiver modules by necessity have approximately 25 nanoseconds of dead time to make the transition from transmit to receive operation. This antenna was used in the river to the feasibility of using a suspended antenna (below wave action), but was not used on the lake.

Simple wide-band-pass filtering of the received signals is done in the field. Tapes are normally down-loaded into a desktop computer for post-processing and printing. Hard copy output is produced on an HP PaintJet printer. Post-processing using RADAN III software can involve adding descriptive text information to the header block, stretching or compressing the distance axis to achieve a constant horizontal scale, reversing of alternate lines so that they are displayed in the same direction, and a wide variety of filtering, including deconvolution and migration. Of these options, the collected profiles have added text titles, reversed lines (where applicable), applied long horizontal high-pass filters to remove the many horizontal bar artifacts, applied short low-pass filters along the scan (vertical), and a short horizontal low-pass filter to remove high-frequency noise. Smoothing the water-bottom reflector (static correction) to remove the waves caused by the vertical and pitching movements of the antenna floating on the surface was also applied for the data from the floating antennas. With the GSSI software, this was limited to wave heights less than a wavelength of the signal. Deconvolution was also useful to compress the 5-6 cycles of ringing in water to 2-3 cycles, although this modified or even obliterated the flanks of the hyperbolas from discrete target objects. Similarly, migration was not applied, as this condenses the diffractive tails emanating from the edges of objects up to the point at which diffraction took place. For discrete small objects such as the targets of this study, migration would collapse the hyperbolic "wings" to the apex as a single bright spot. This would remove the main criterion for detectability which is a clear-cut hyperbolic image. For these small targets, the pattern recognition of the hyperbolas was used to detect the objects in the presence of numerous other strong signals and clutter.

Results at Calibration and Test Sites

The inert ordnance test site on the spit at the mouth of the Toussaint River was investigated using two GPR frequencies. N-S and E-W lines were surveyed using both the bistatic 500-MHz and bistatic 100-MHz antennas. Some lines were repeated with different scan times (ranges). Some lines were also repeated on different days as another quality assurance measure. Note that the line coordinates given on the GPR records are displaced laterally 0.91 m (3 ft)

from the N-S staked lines and 0.61 m (2 ft) from the E-W line coordinates of Figure 33. This offset was needed to avoid pulling the antennas through the flags and stakes.
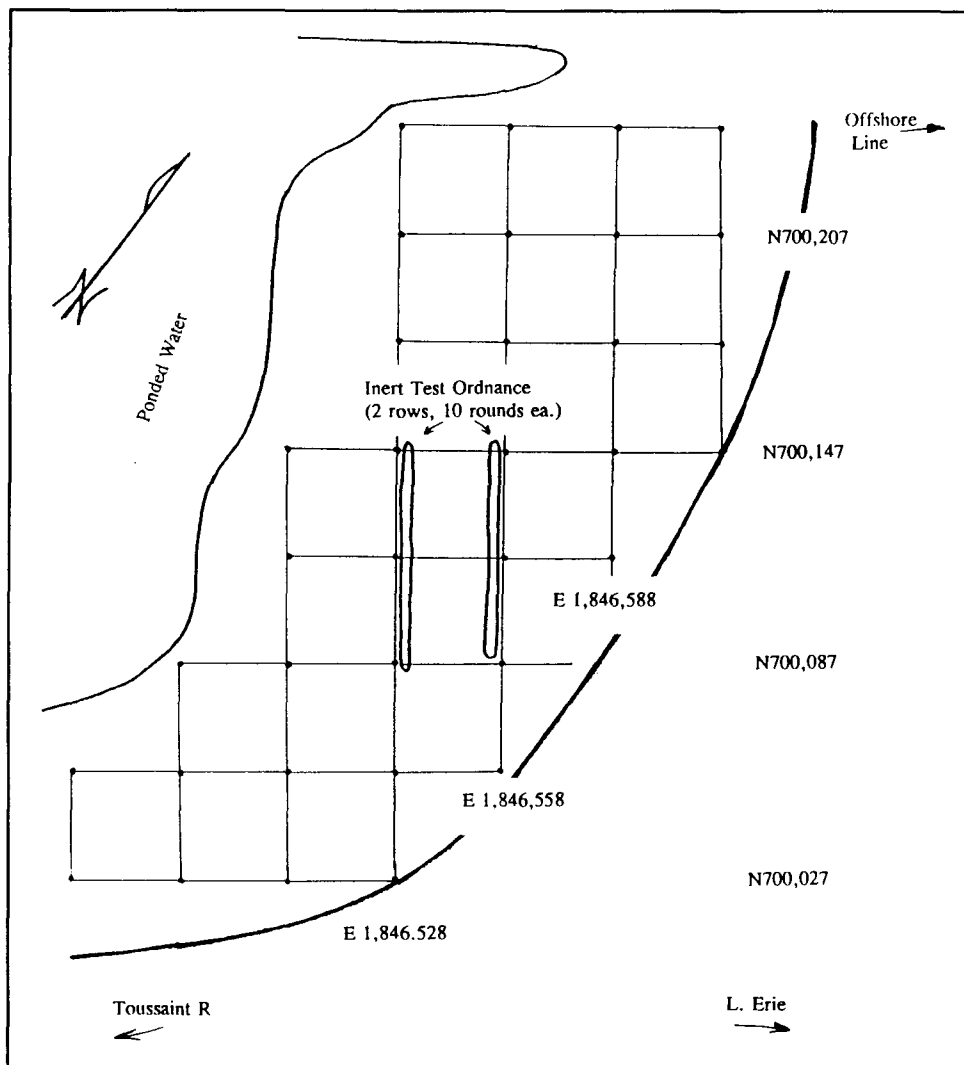
Figure 33. Sketch of sand spit test area, mouth of Toussaint River. Coordinates are Ohio State Plane in feet

A great deal of sedimentary or stratigraphic detail was observed on longitudinal profiles through the sand spit with the 500-MHz antenna. Very obvious sloping or foreset beds are observed which show the history and direction of growth of the sand spit. Two profiles are always shown on the hard copy printouts, with field data on the lower half and the processed file shown on the upper half. Profiles beginning at the water's edge show a crossing reflector dipping down and into the sand spit (Figures 34 and 35). This is really the water table, which is not shown in its true configuration of sub-horizontal because the radar profile is top justified to zero time, not to topography. This antenna penetrates very little below the water table at this site. The depth
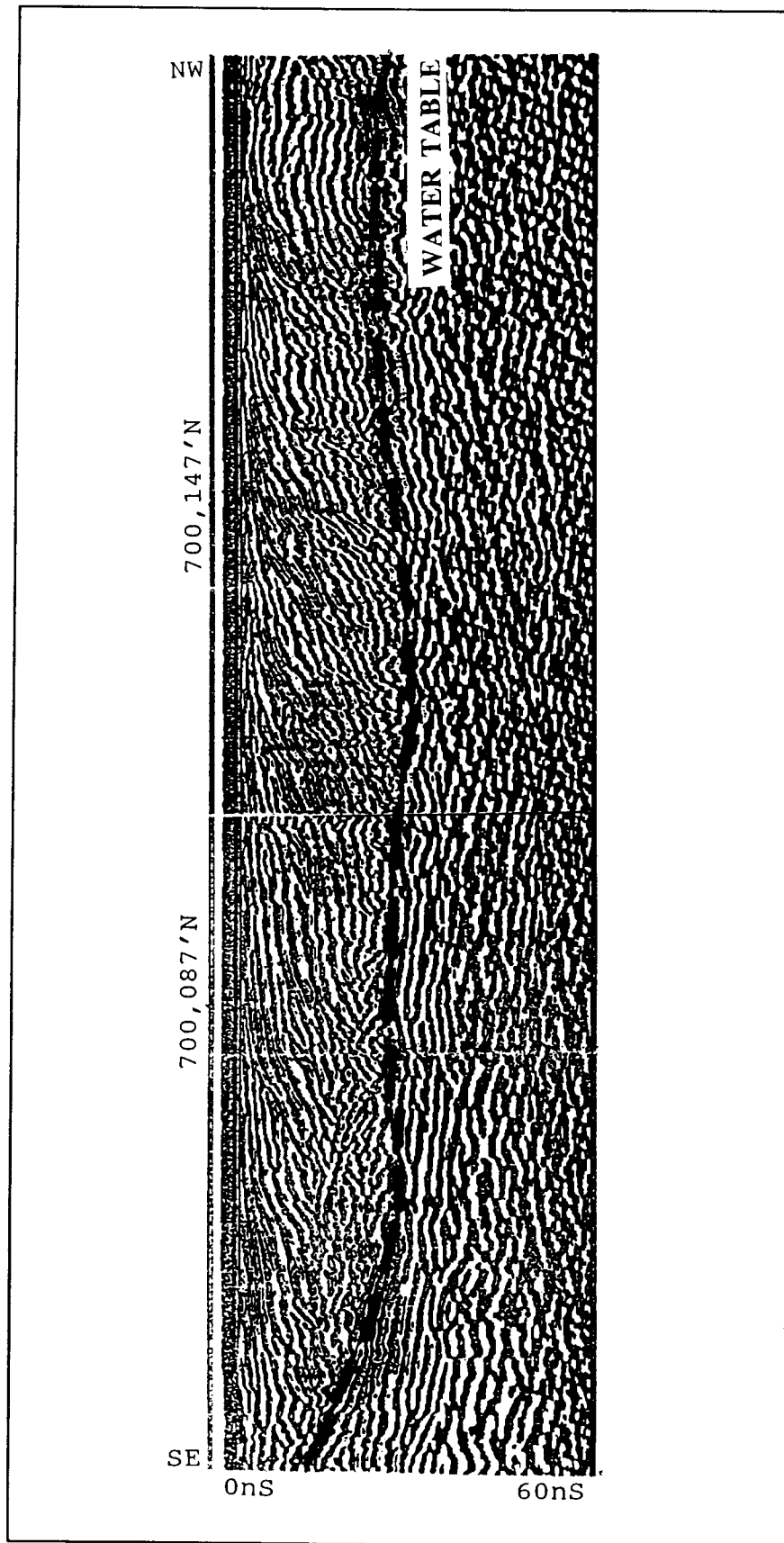
Figure 34. 500-MHz GPR profile on sand spit, shore-parallel Line 1,846,531E, directly over buried inert ordnance (10 rounds between 87'N and 147'N)
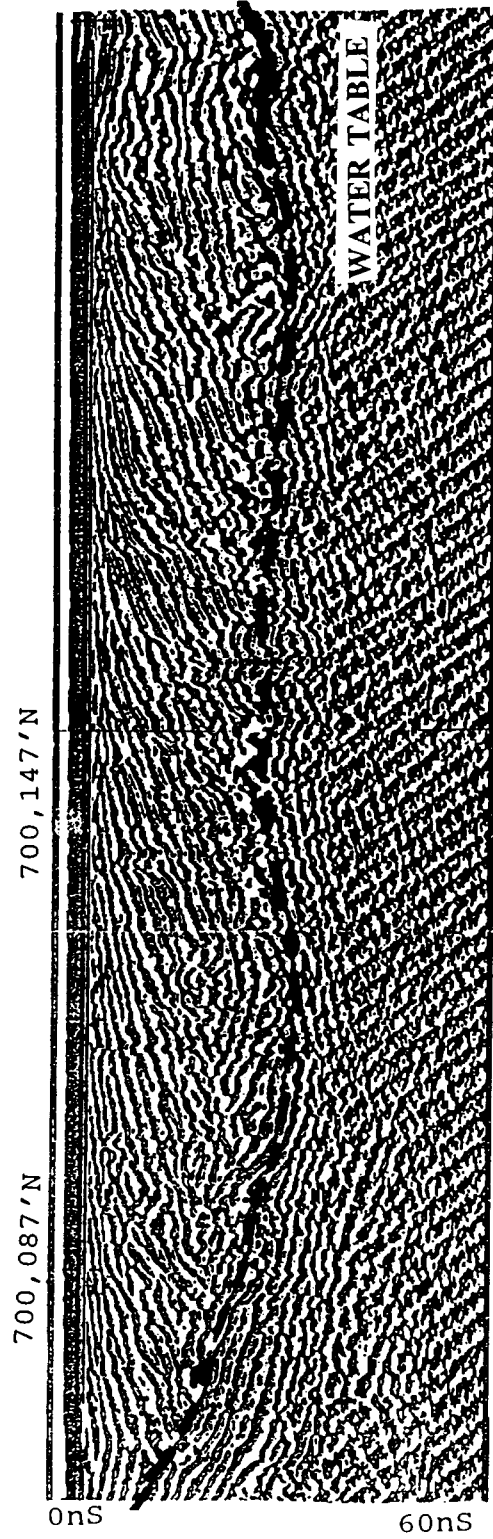
Figure 35. 500-MHz profile on sand spit, Line 1,846,555E, over 10 rounds of inert ordnance buried between 87'N and 147'N. Note stratigraphic dips toward SE, and water table reflection below

scale is an inverse function of water content, and for moist sand with assumed relative permittivity $\epsilon_r = 12$ and scan length of 60 nanoseconds, the full vertical scale is approximately 2.6 m (0.79 ft). By inspection, most of the 500-MHz records show little coherent reflection energy below mid-scale, giving a depth penetration of 1.3 m (0.40 ft) at this site. Very surprisingly, the ordnance was very poorly registered as multiple hyperbolas on the GPR records, and approximately half were not seen at all (Figures 34 and 35). Several physical reasons could have led to this result. One is that the sand was far from homogeneous and full of scatterers, and had numerous reflective layers which returned much energy and contributed to poor depth penetration. Another possible effect may have been the scattering due to the palm-sized mussel shells (in addition to heavy mineral zones) found on the sand spit. Thirdly, the sands and pore water may have been relatively more conductive than experienced in other sand environments (Lake Michigan). Finally, the objects may simply be too small to be well-resolved. The manufacturer does not specify minimum dimensions detectable with a given antenna because of the large possible range of conductivity and relative permittivity of the surrounding natural soil materials. Thus, the response of a given target object can vary greatly, depending upon the relative permittivity and conductivity of its host medium.

Roberts and Daniels (1993) used models in a sand tank which all had a minimum dimension of 0.5 m (1.6 ft), except for the case of a 5-cm (2-in.) steel pipe, which had a long dimension of 1.65 m (5.4 ft). The wavelength for the 500-MHz antenna in air is 60 cm (23.6 in.). In sand with relative permittivity $\epsilon_r = 9$, the wavelength is reduced to 20 cm (7.9 in.), while in water with $\epsilon_r = 81$, it is only 6.7 cm (2.6 in.). Thus, in air or dry sand, the ordnance targets were less than a wavelength in their maximum dimension. A long wire or metal pipe will appear very distinctly with this antenna, particularly when its long axis is parallel to the long axis (polarization direction) of the antenna. This was also noted by Roberts and Daniels (1993). Thus, there is also an orientation effect for the projectiles, such that response is maximum when the antenna axis and projectile major axis are parallel. Hence, for projectiles less than a wavelength in maximum dimension, and oriented transversely to the antenna polarization, detection would be unlikely based on these physical arguments. The two lines over the buried ordnance were repeated with the antenna rotated 90 deg from the initial orientation (Figures 36 and 37). Similar numbers of weak, narrow, ringing events can be seen on these two figures when compared with Figures 34 and 35. Figure 38 shows a typical shore-perpendicular or transverse profile through the sand spit, which also shows the stratigraphy and the water table.

The 100-MHz antenna was profiled over the sand spit using a range or scan length of 200 nanoseconds, more than triple that used with the 500-MHz antenna. This was to investigate the possibility of detecting the base of the sand. However, the records are dominated by ringing and horizontal bars, and no clear-cut basal reflector could be seen. Gross structure of the sand spit can be seen (Figure 39) although the 500-MHz antenna gives far more detail. Relative to Lake Michigan beaches, this area appears to have a higher
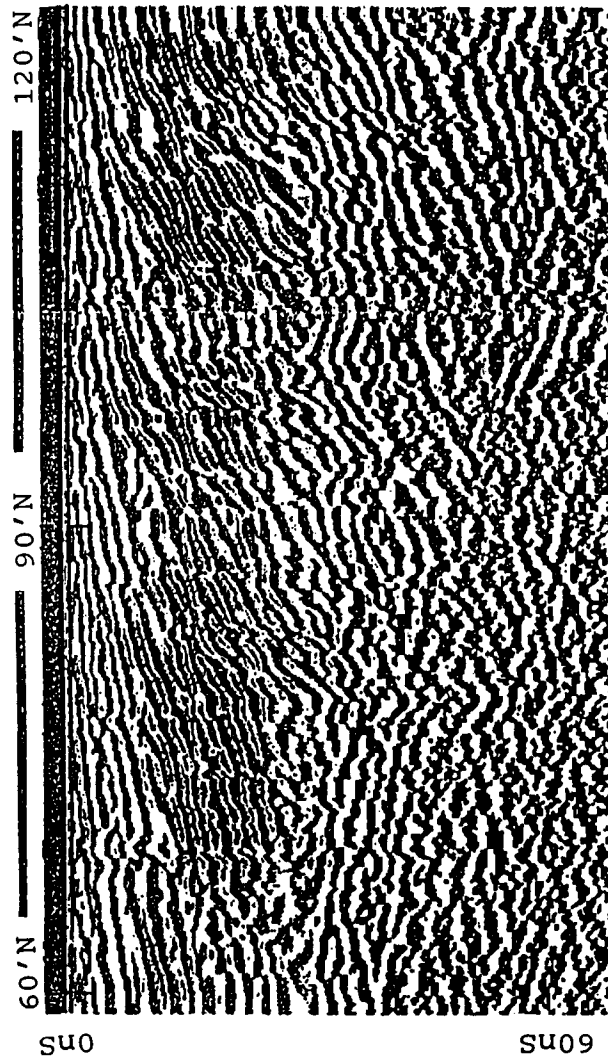
Figure 36. Central portion of Line 531E repeated with the 500-MHz antenna rotated 90 deg
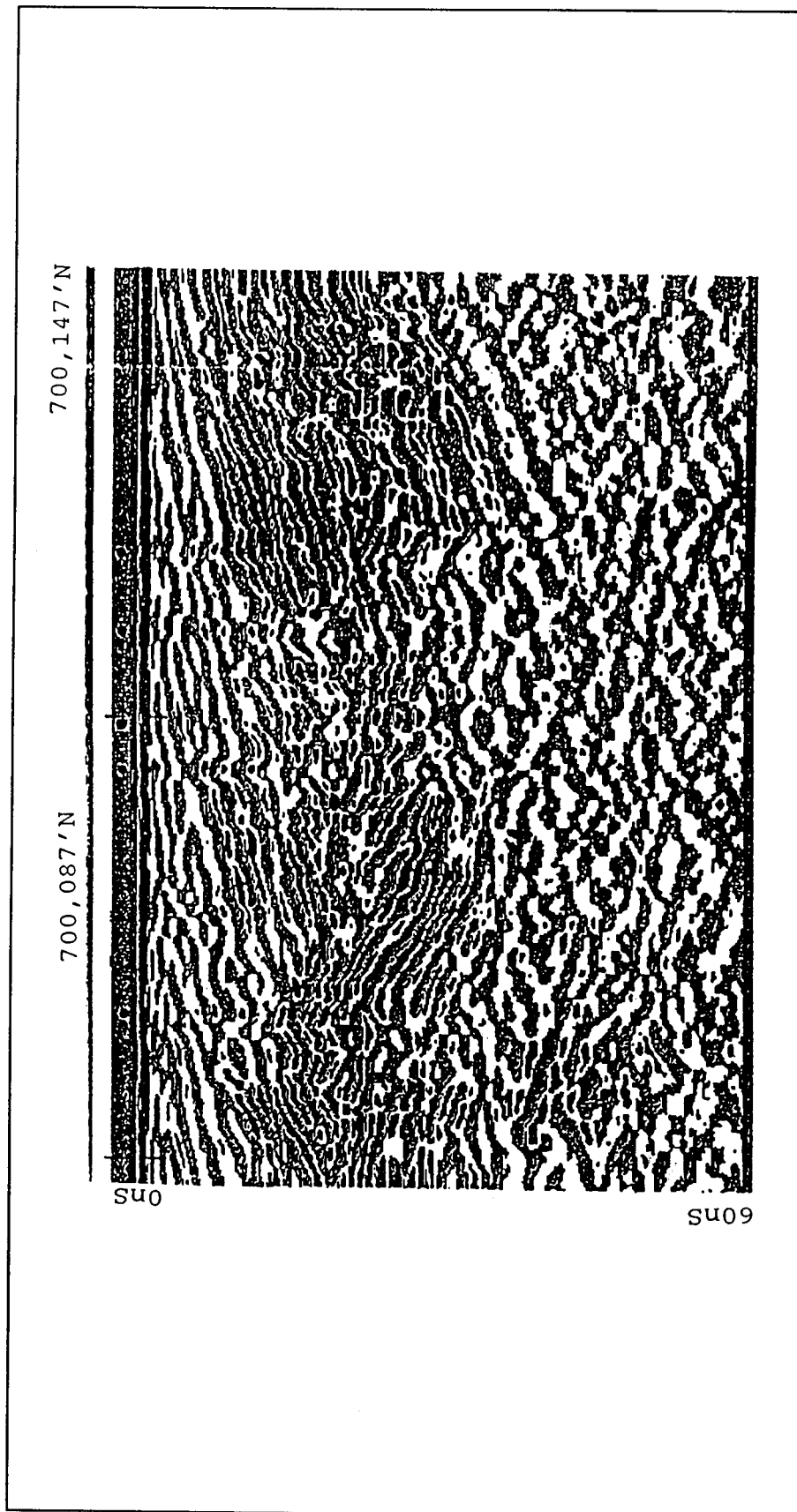
Figure 37. Central portion of Line 555E, repeated with the 500-MHz antenna rotated 90 deg
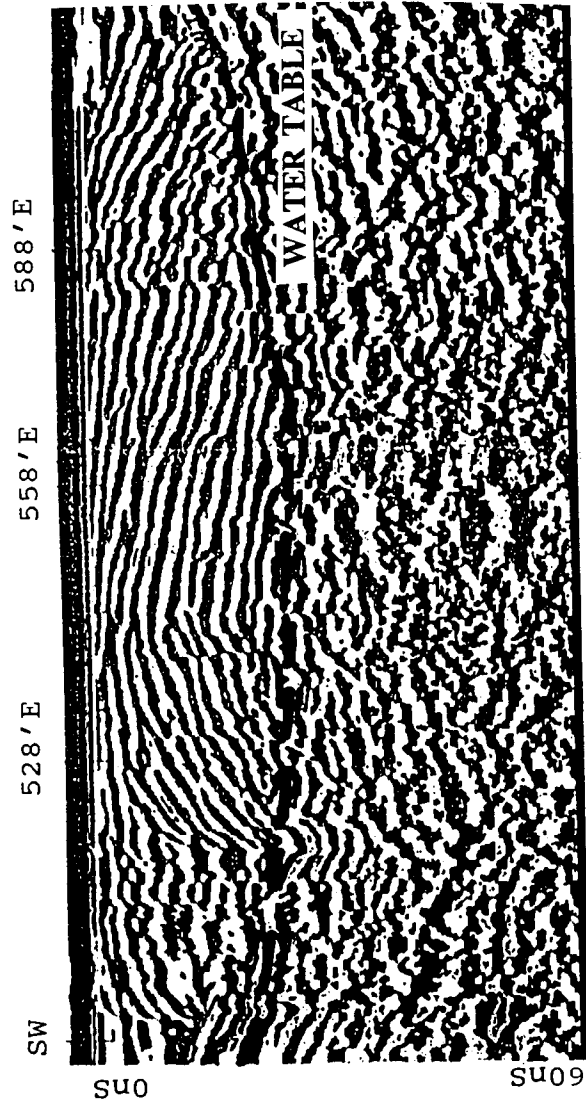
Figure 38. SW to NE 500-MHz profile across the sand spit at N coordinate 700,145N
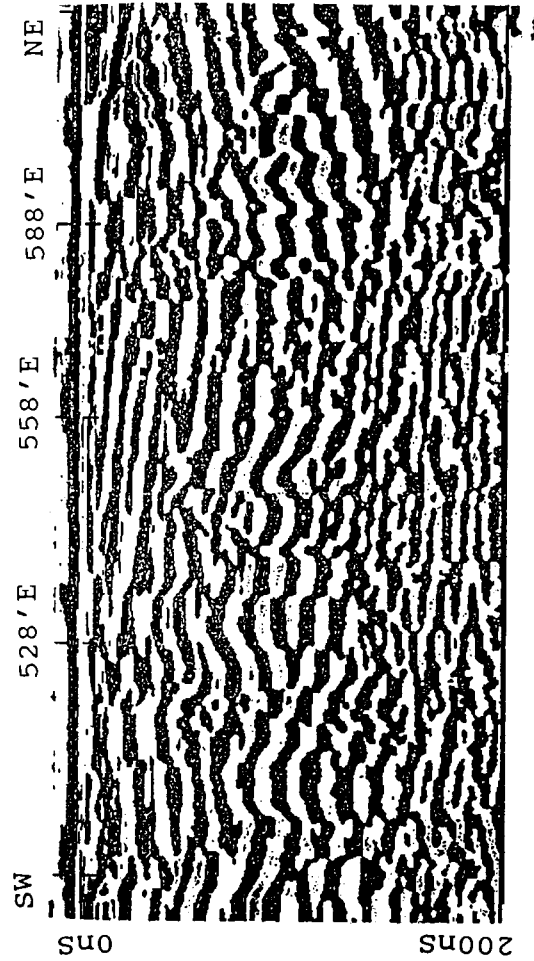
Figure 39. Transverse (shore-perpendicular) profile over sand spit with 100-MHz antennas, Line 700, 145N

conductivity (presumably of the intergranular moisture), which leads to more ringing and less penetration. If true, this also results in less electrical contrast at the hypothetical sand/clay boundary, and hence a reduced reflection coefficient. The decreased penetration could be due to layered accumulations of heavy minerals in the sands of this site. A common constituent of heavy mineral sands is magnetite, whose magnetic permeability could then become a factor. It is usually assumed to be present in negligible amounts in surface materials, and the magnetic permeability is normally dropped from the wave equation and intrinsic impedance expressions. Resolution of these questions would require electrical resistivity measurements on the site, as well as testing for the magnetite content. The lines over the buried inert ordnance (Figures 40 and 41) do reveal small disturbances over nearly half the objects. However, as in the case for the 500-MHz antenna, they are not sufficiently distinctive to discriminate them from buried logs or other similar-sized debris which can be commonly found in such beach sands.

The next stage of calibration was with the floating bistatic 100-MHz antennas. An initial test was done over a string of three inert artillery rounds tied on a rope stretched perpendicular from the shore of the Toussaint River (Figures 42-45). The floating antenna was mounted at the side of the steel scow. Three of the four passes over these targets were apparently unsuccessful in placing the antenna directly over a target. However, a number of hyperbolic reflections were seen on all four records. Profile ERI-F6P (Figure 43) shows bottom topography, possibly troughs created by past dredging. In the central area of this figure, the hyperbolic events lie beneath bathymetric troughs. This is quite clearly a focussing effect of the bottom topography, an artifact related to depth of water and radius of curvature of the bottom topography. Tucker and Yorston (1973) describe the reflection seismic interpretation "pitfall" of the apparent anticline below a syncline. At the left edge of the figure are two hyperbolas which do not appear to be related to bottom topography. The left-most is a slightly buried (or off-line) object, and immediately to the right is an object emergent from the bottom. It is possible that neither was the target ordnance, but they are the best candidates on this profile.

Figure 45 shows profile ERI-F8P. This revealed about five objects showing positive relief above an otherwise smooth bottom. Their signatures do not show the characteristic sharp ringing of metal conductors. Thus, they could be blocks of rock, logs, or other debris. This profile shows sub-bottom structure on the right half, beginning with an antiform structure which is probably too broad to be sideswiped from an off-line object, and hence may represent the actual stratigraphy. Further right, along the slope, is evidence of cross-bedding and/or bedding dipping toward the south shore.

Another river crossing profile, ERI-F28, shows at least eight sub-bottom hyperbolic responses, about half of which are sufficiently intense and ringing to be metallic (Figure 46). This line was treated with only a minimum of processing, a horizontal high-pass filter 31 scans wide. Weak hyperbolic responses from within the water column are totally invisible on the raw data
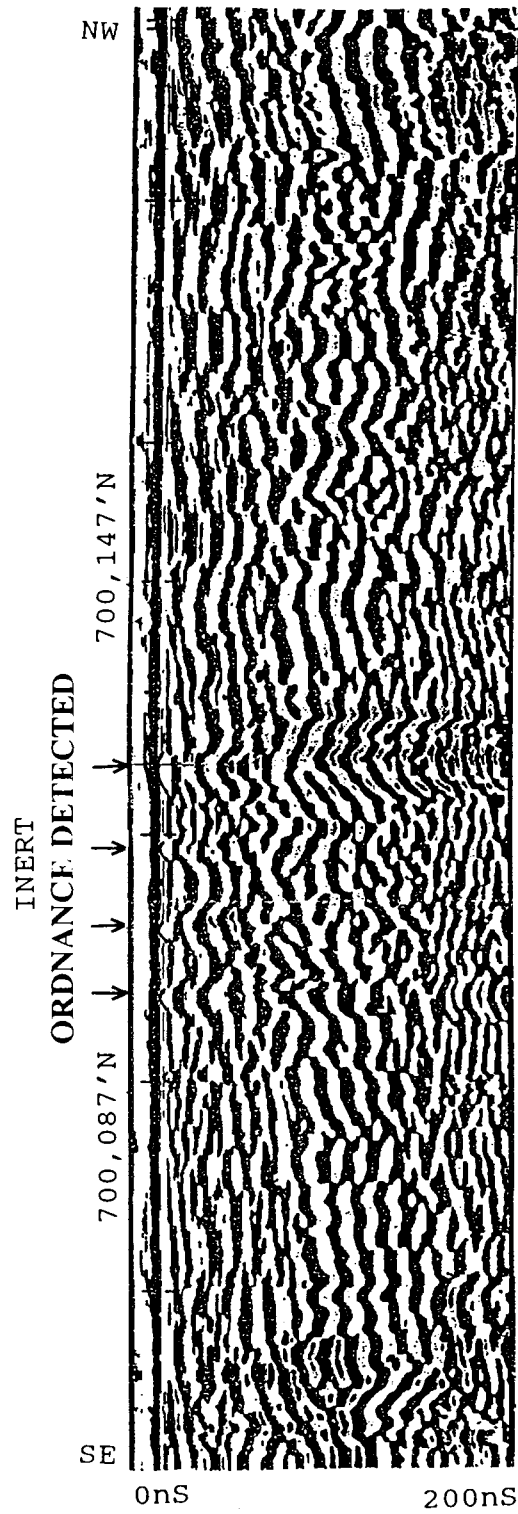
Figure 40. Longitudinal 100-MHz profile along sand spit, Line 1,846,531E, over 10 inert ordnance rounds buried between 87'N and 147'N
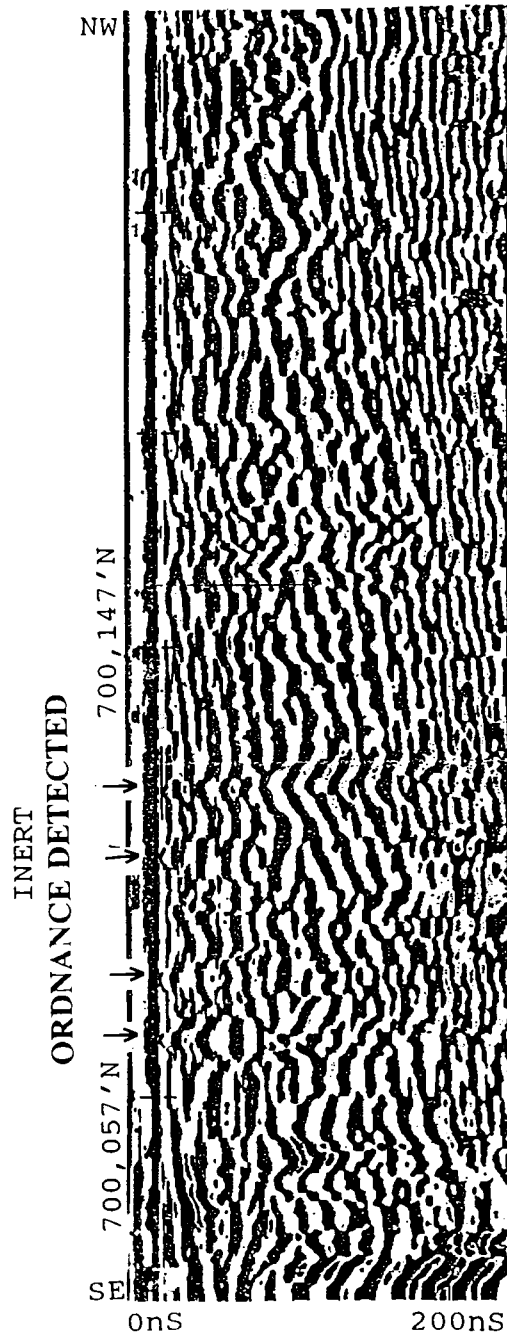
Figure 41. Longitudinal 100-MHz profile over sand spit, Line 1,846,555 , with inert ordnance buried between 87'N and 147'N
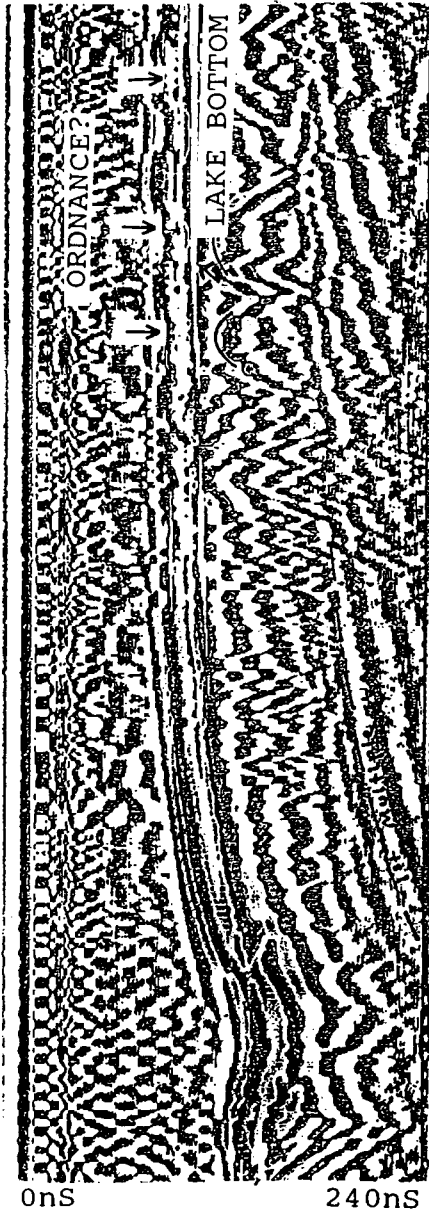
Figure 42. Toussaint River profile ERI-F5 with floating 100-MHz antennas; first attempt to pass over inert ordnance rounds on bottom
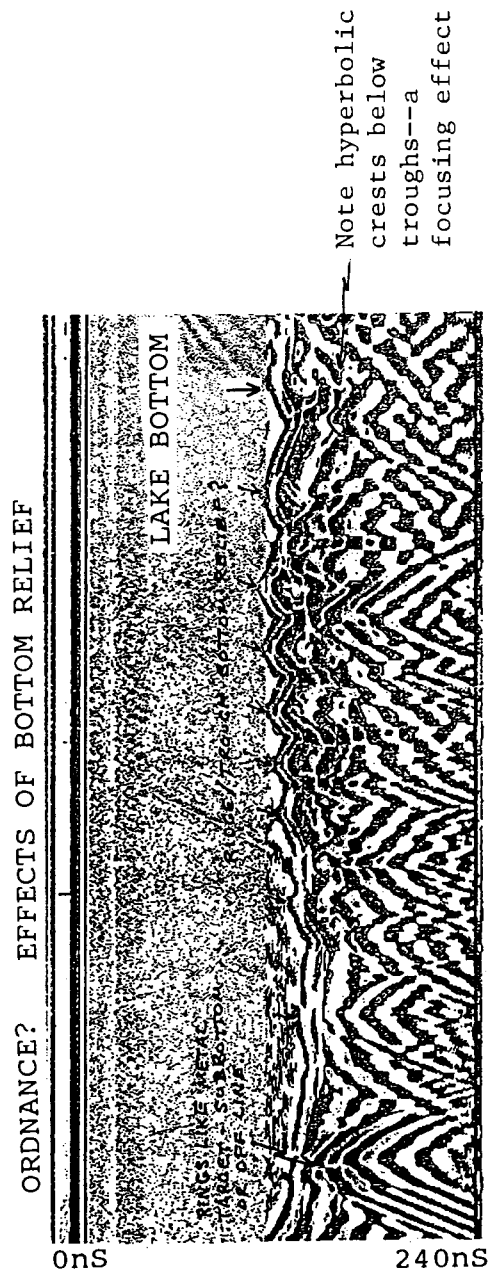
Figure 43. Toussaint River profile ERI-F6 with floating 100-MHz antennas; second pass which shows a possible metal target on the left, the remainder being topography and artifacts
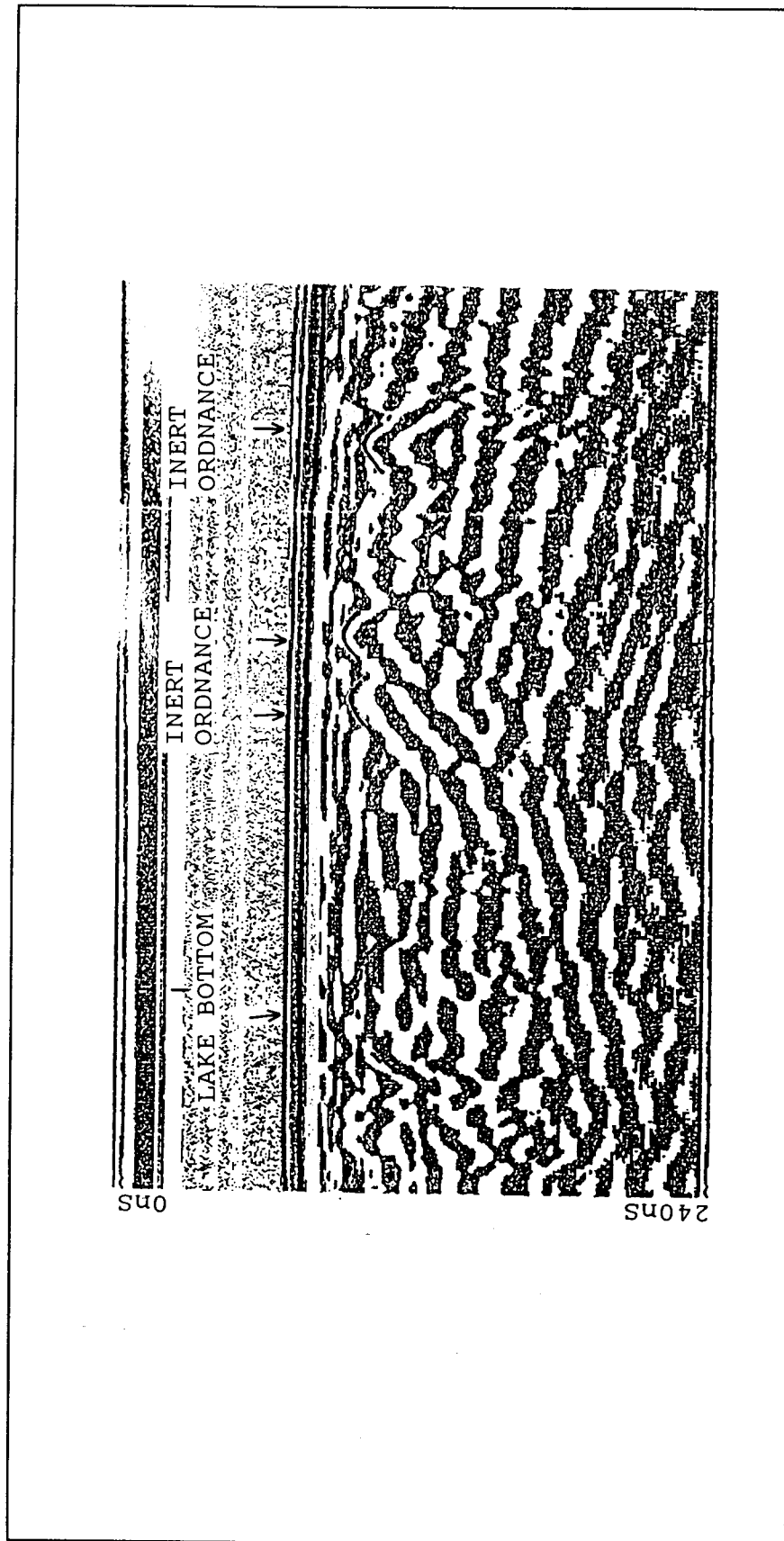
Figure 44. Toussaint River profile ERI-F7 with floating 100-MHz antennas towed over inert ordnance. This third pass apparently missed the target
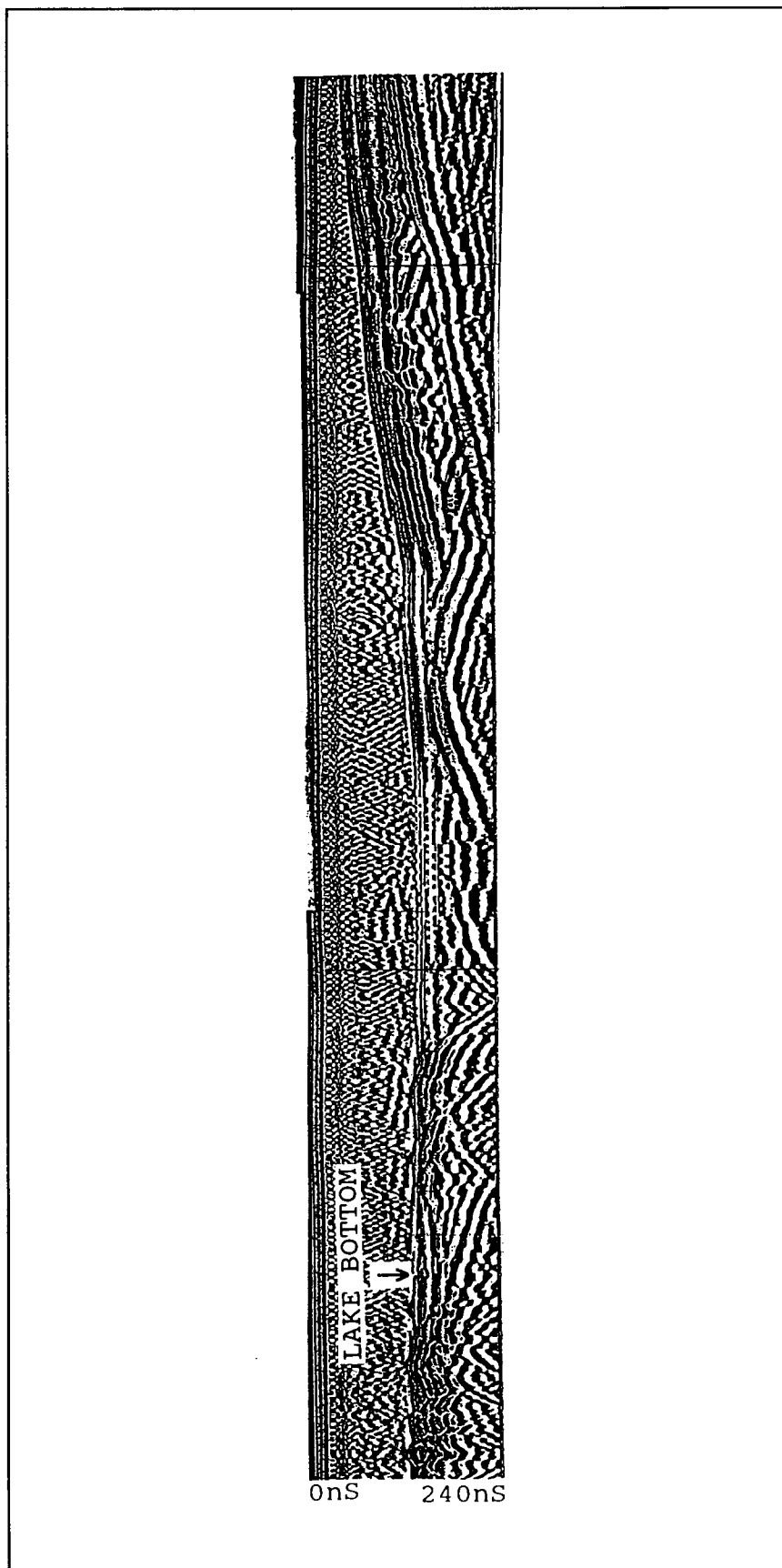
Figure 45. Toussaint River profile ERI-F8 with floating 100-MHz antennas; fourth attempt to pass over inert ordnance placed on bottom; shows topographic and stratigraphic features
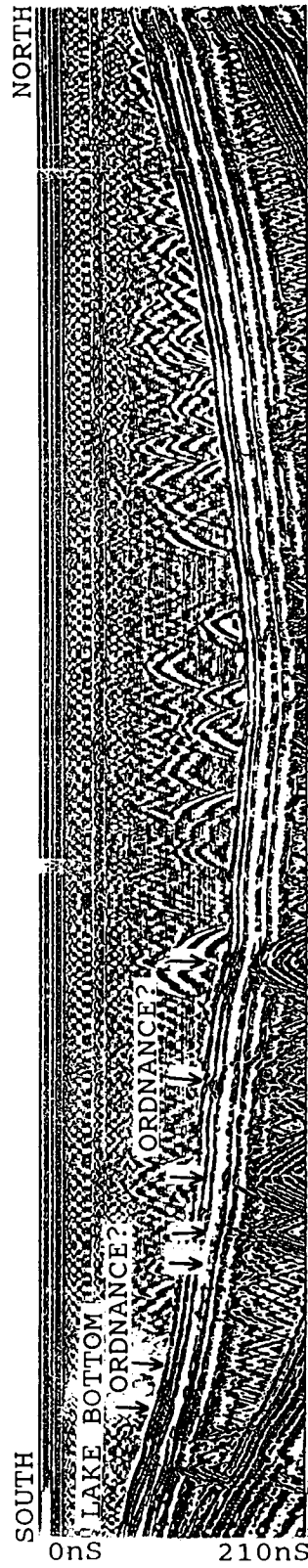
Figure 46. Toussaint River profile ERI-F28 with floating 100-MHz antennas, six objects and apparently fish in the water column

in the lower half of the figure. These are very likely large fish (i.e., possibly carp or buffalo) whose swim bladders have the maximum possible contrast in ϵ_r with the surrounding water, 1:81, and produce a detectable response within a very uniform and homogeneous background medium. These returns from within the water column are present on other profiles, but have been destroyed by more extensive post-processing where enhancement of bottom or sub-bottom objects was the goal. Submerged aquatic vegetation has never shown such response in other investigations with surface antennas.

Results with Floating Antenna on Lake Erie

Two shore-parallel and two shore-perpendicular lines using DGPS positioning control were performed within the FUDS area. Three shore-perpendicular lines with approximate positioning control using the handheld Magellan 5000 GPS receiver (see Figure 10) were also accomplished. One test was conducted outside the FUDS area with the line extending northeast off the sand spit with approximate positioning using the Magellan 5000.

Processing for the long lines on the lake was kept to a minimum. Title and header information was keyed in. Some lines were reversed such that the right end was always lakeward for shore-perpendicular lines, and always southeast for the shore-parallel lines. Initially predictive deconvolution was tried on one line to diminish the strong ringing of the bottom reflection. This could reduce the number of cycles from 5 or 6 to less than 3, but at the expense of greatly distorting or even eliminating the hyperbolic patterns from individual objects. Thus, this was not used for the remainder of the lines. A "statics correction" routine was applied to the water-bottom reflection to smooth the waves caused by the bobbing of the floating antennas. This had the effect of placing the waviness above the bottom and extending up to the start pulse. The multiple of the bottom reflection still retained a very wavy character due to its double wave amplitude. Next, a moderately narrow high-pass horizontal filter (31 scans wide) was applied to remove all the subhori-zontal elements of the (now smooth) bottom reflection and its ringing. This was very effective in removing almost all the bottom reflection energy, leaving only narrow and steeply dipping events in the window of interest—the interval between the bottom reflection and its first multiple. Returns from above that band are in the water column, while those below that band are still hidden beneath the remaining wavy high amplitude bottom multiple and its ringing. Positive identification of metallic "objects" was based on the criteria of having both limbs of a hyperbola visible, as well as ringing or stacking of hyperbolas. The metallic targets should ring with a resonance frequency crudely proportional to the inverse of their physical dimensions. (This is in fact the basis for a detection system proposed by Peters and Young (1993).) Other returns counted as "probable objects" were much weaker hyperbolas having questionable ringing, and could be small objects, off-line objects, or even non-metallic objects. Table 5 is a summary of the observations from the seven lines within the research area and the test line off the sand spit. The

Table 5
Summary of Detected and Probable Objects Using GPR Antennas

Line No./ 100 ft	File Design	Length	Number of Objects	Probable Objects	Total	Density of Targets per Line
15[1]	F1	2300'	0	3	3	0.13
17[1]	F2	2050'	2	9	11	0.54
4	F23	2000'	4	2	6	0.30
5	F24	1400'	2	5	7	0.50
1[2]	F25	1500, est	4	6	10	0.66
2[2]	F26	1500, est	18	3	21	1.40
3[2]	F27	1000, est	12	6	18	1.80
Off sandspit	F22	1000, est	7	4	11	1.10

[1] Shore-parallel lines.
[2] Ad hoc numbered GPR lines which were not DGPS position controlled.

last column is a normalized "hit" rate, or counts per 30.5 m (100 ft) of profile line.

The long lake lines done with the floating 100-MHz antennas may have crossed a communications cable which runs parallel to shore 1.8-2.4 m (6-8 ft) below LWD, or probably 2.7-3.4 m (9-11 ft) of water. The cable may have caused the very strong, isolated event readings at that depth on several of the shore-perpendicular lines.

These data, while not based on thorough coverage of the area, do appear to show several trends, as follows:

a. The objects are sometimes solitary but most are found in clusters.

b. The shore-parallel lines (numbers 15 and 17 in Table 5 show minimal numbers of detects, while shore-perpendicular lines through the same general area show higher detect rates. This could very well be a function of antenna orientation relative to the long axis of the targets. In other words, for small targets, detection is most likely if the long axis of the object is parallel to the antenna axis, and the target will probably be missed if its major axis is nearly 90 deg from the antenna axis. This implies that most objects are aligned with their major axes parallel to shore, as might be expected for those objects which are rolling on the bottom in response to wave motion. (The antenna axis was transverse to the tow direction or boat path.) Thus, the GPR can perhaps indirectly determine the dominant orientation in the horizontal plane by

the polarized response of its antennas, which are towed with their axes transverse to the profile line. Alternatively, the two shore-parallel lines may have been fortuitously selected along locations which simply did not have concentrations of OEW. This does not appear to be true as Line 4 (shore-perpendicular) crossed both Lines 15 and 17.

c. Table 5 appears to show increasing numbers of objects as the survey progressed southeast along the lake away from the Toussaint River. Lines 4, 5, 1*, 2*, and 3* are shore-perpendicular profiles located in a sequence from west northwest to east southeast and clearly show this increase. This also should be expected, as this sequence of lines goes from the west northwest limit toward the center of the target fan.

GPR Results at the FUDS Cove Beach Site

Another GPR data set was gathered at Cove Beach (Figure 13), accessed by land via a road through the marsh near the range poles. This area was flagged with six shore-parallel lines 76.2 m (250 ft) long and spaced 1.8 m (6 ft) apart going up the beach. These lines were surveyed with both the 500-MHz and 100-MHz bistatic antenna pairs.

Figure 47 is a typical shore-parallel line with about 40 nanoseconds of penetration (1.9 m, assuming moist sand with ϵ_r = 12) using the 500-MHz antenna. This profile was run in the strike direction for the beach deposit stratigraphy. These data do reveal an angular unconformity due to scalloping of the shoreline near the northwest end of the line. The cross-strike profile of Figure 48 reveals more details of shoreline accretion at this beach, with a series of accretionary on-lapping structures dipping toward the lake.

The 100-MHz data were gathered over the grid with a scan range three times longer. Some coherent reflections can be seen on Figure 49 to times of about 100 nsec. The upper reflection is probably the water table, while the lower is probably sand over peat or sand over clay. The depth scales in these two zones would be different. Assuming ϵ_r = 12 for unsaturated but moist sands, the conversion is 23 nanoseconds/m, while below the water table in 30-percent porosity sands (ϵ_r = 25) the scale is 33 nanoseconds/m.

Figure 50 is a shore-perpendicular profile which crossed over a sizable, almost completely buried, tree trunk. This caused the hyperbolic disturbance which began at the top of the record, and extended with ringing to the bottom of the record. A reflector at about 48 nanoseconds could be the water table, approximately 2.1 m (5.4 ft) deep if the relative permittivity is 12.
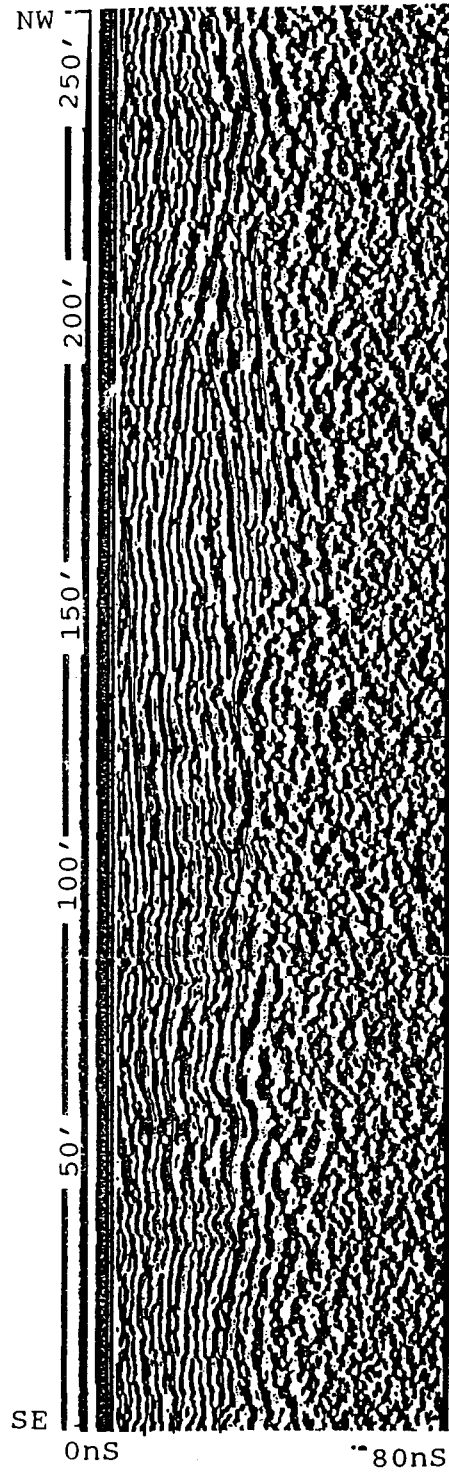
Figure 47. Shore-parallel 500-MHz GPR profile at the Cove Beach site, Lake Erie; this was the highest line on the beach grid, about 11 m (36 ft) landward from water's edge
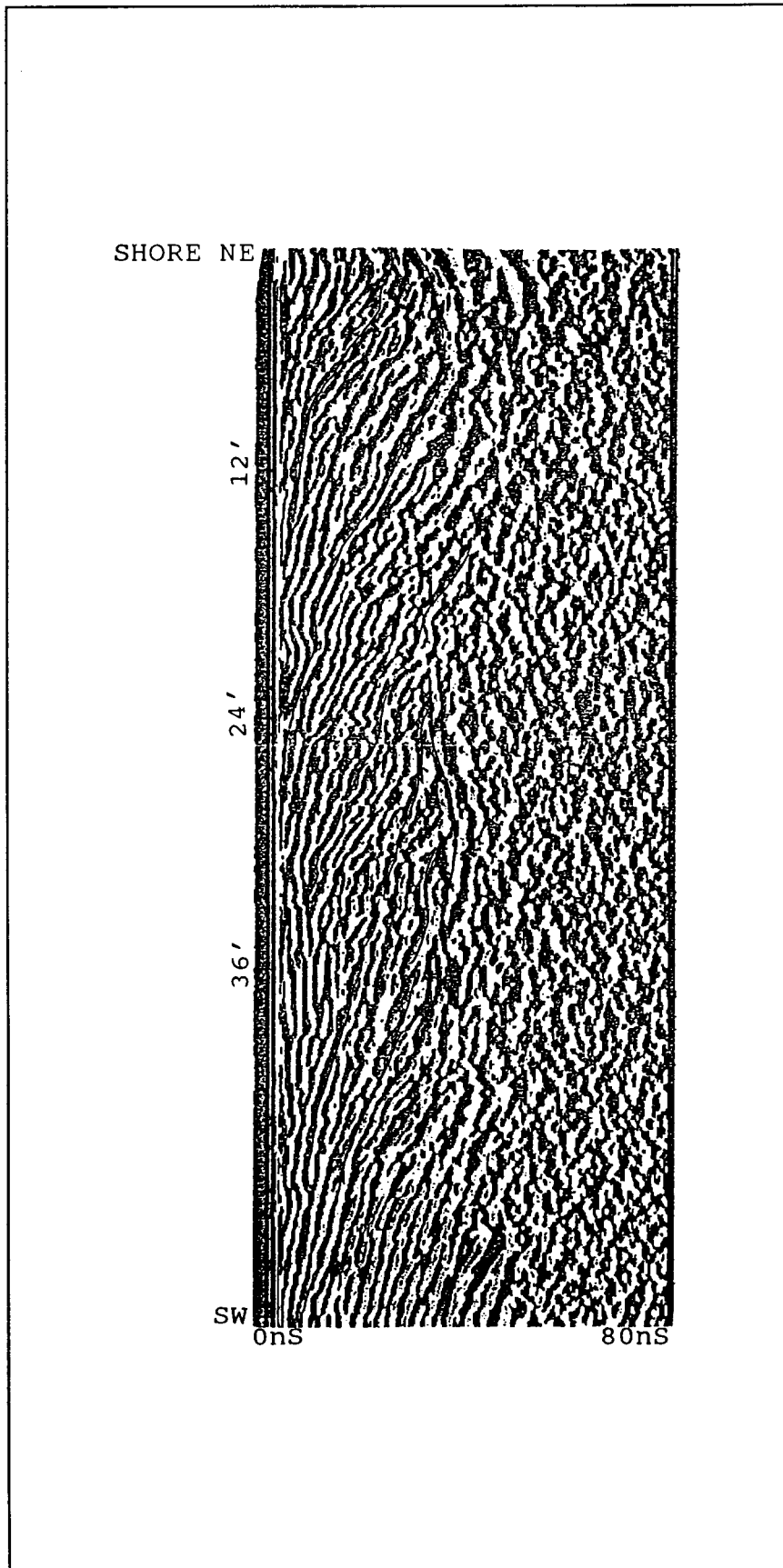
Figure 48. Shore-perpendicular 500-MHz profile at Cove Beach, Lake Erie; this extends from the access path to the water at about the 21-m (70-ft) NW coordinate
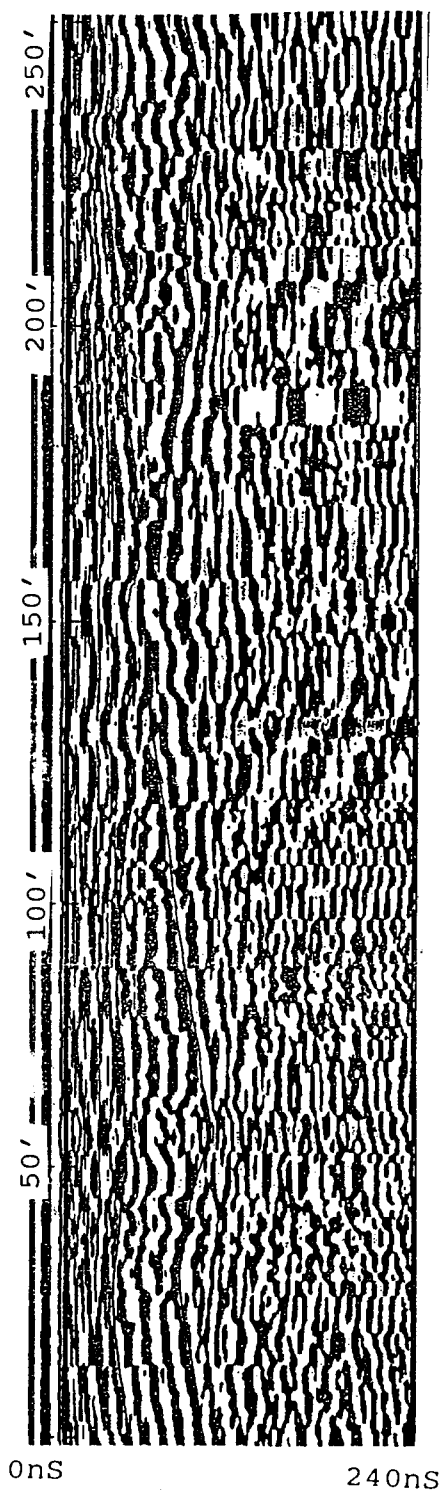
Figure 49. Shore-parallel GPR profile with bistatic 100-MHz antennas at Cove Beach grid

Chapter 6   Ground-Penetrating Radar
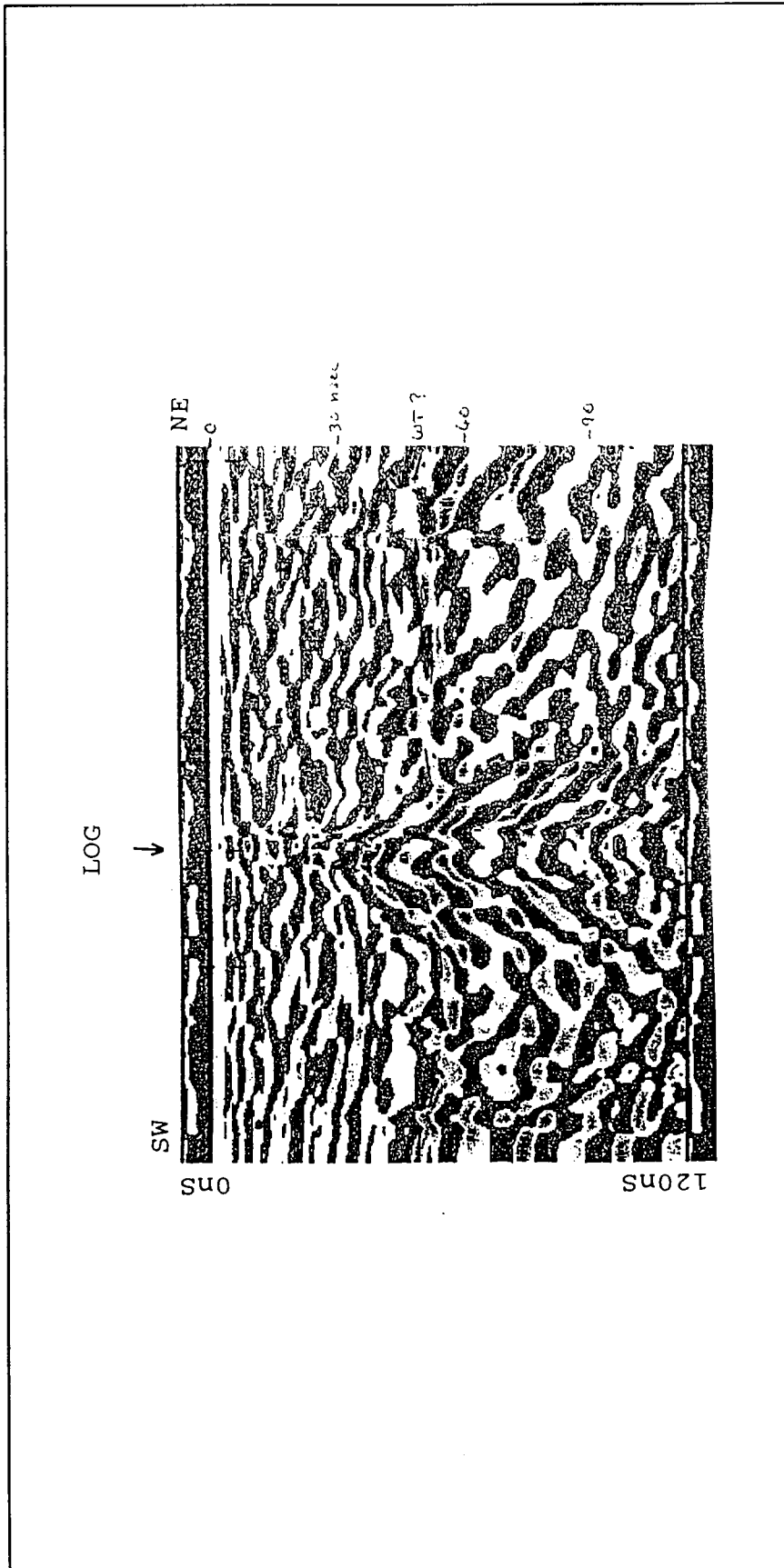
Figure 50. Shore-perpendicular 100-MHz profile at the 21-m (70-ft) NW coordinate of the Cove Beach grid. Center feature is a log whose top was at the surface

GPR Application Observations to Detect OEW

OEW was more difficult to detect when buried beneath unsaturated beach sands than when lying on hard bottom in the river or lake. GPR (500 MHz) did show internal stratigraphic structure in the upper 1.5-2 m (4.9-6.6 ft) of sand at the two beach sites. Some of the smaller OEW is clearly at the lower detection limit for the system in this environment. No size:response relationship has been established. This is made difficult by the weaker response of slightly off-line targets, and by the dependence of signal strength on the target orientation of the host medium. Return signal strength is very much dependent upon small target orientation, with maximum return when the major axis of the target is horizontal and parallel to the E-plane of the antenna. OEW with its major axis vertical or perpendicular to the long axis of the antenna would not be detected.

A detection system using a transverse receiver antenna (crossed dipoles) has been suggested by Walton (1993) and by Peters and Young (1993) and is the basis of an antenna constructed at Ohio State University. This approach should remove most of the strong flat bottom reflection and its ringing and multiple, while relatively enhancing the hyperbolic returns from discrete objects, particularly metallic objects at random orientations for which part of the return signal is rotated out of the E-plane of the transmit dipole. The data required much post-processing to minimize the strong, ringing bottom reflection. Of course, a crossed-dipole receiver would not detect much stratigraphic information. Hence two receiver dipoles would be appropriate, one perpendicular and one parallel to the transmit dipole, recorded on separate data channels. The GSSI System 10 can easily handle multiple antennas with its option of 2 or 4 transducer interface modules. This application of using crossed dipole antennas for UXO detection merits further investigation.

A floating antenna must be stabilized to minimize vertical motion and pitching with waves and swell. If not, the bottom reflection faithfully records the wave action and can often obscure or mask the hyperbolic patterns expected from the OEW. A very tedious "static correction" is needed to smooth the bottom reflection prior to other processing. A submerged dipole antenna held at a fixed depth is an alternative for days too rough for floating antennas. It would have to be used along shore-parallel lines, as it is operationally too difficult to adjust the antenna depth while under way.

The hyperbolic pattern is the preferred diagnostic (or pattern recognition) for identifying the OEW, as it covers a much larger area on the record section than would a corrected "image" of the ordnance. Thus, processing is done to enhance the hyperbolic patterns. Migration and deconvolution processing destroy this pattern and are to be avoided. The GPR method, as applied from a floating or near-surface antenna system, can detect discrete metallic objects lying on lake bottom in water depths to at least 3.0 m (10 ft). An additional bonus is that water depth is shown directly on the same record, and if crossed receiver dipoles are used, generalizations about preferred orientation of the

major axes of the objects can be made. With a boat and system adapted specifically to this site and problem, production survey coverage at a high data rate during calm to light wind conditions is plausible.

7 Side-Scan Sonar and Remotely Operated Vehicle (ROV)

Side-Scan Sonar

The modern-day SSS evolved from the first active sonars developed during World War I to provide accurate echo location of submarines. During World War II these sonar systems were further refined for submarine warfare applications (Laskey 1975) and it was during this development phase that the correlation between high frequency sound reflection intensity and seabottom lithology was first identified (Fleming, Klien, and Denbigh 1982). A series of experiments in the late 1950's and 1960's, coupled with major engineering advances of equipment in the 1970's and 1980's, have produced contemporary SSS systems capable of producing extraordinary underwater images (Fish and Carr 1990).

To optimize data collection for the various applications and environments in which SSS has been used, numerous systems have evolved using different combinations of range and frequency. These systems are used in commercial applications such as wreckage/lost object searches (ships, aircraft, mines, torpedoes, etc.), seabed geological surveys, pipeline tracking, and biological surveying.

An EG&G Model 260-TH image-correcting side-scan sonar, with a 380 digital tape unit, and Model 272-TD Towfish, was used to collect information about lake-bottom features, and suspected ordnance density characteristics. The system consisted of a towfish, cable, processor/graphic recorder, and digital tape recorder. The towfish is streamlined (torpedo-shaped) with acoustical transducers mounted on the port and starboard sides. As the towfish moves through the water, it periodically transmits and receives acoustic pulses in a direction transverse to the towfish track. The beam pattern in the 400-kHz operating frequency mode used almost exclusively during the study, is relatively narrow (0.5 deg) in the horizontal plane compared to its wide-angled vertical component (50 deg). After this short-duration (0.01-millisecond) acoustic pulse is transmitted, the towfish "listens" for the

90

potential return of signals (from that same pulse) reflected by targets, or backscattered by the lake bottom. These reflected signals are received by the towfish as they return, then amplified for transmission up through the cable to the processor/graphic recorder. There the signals are again amplified, processed, and printed on a hard-copy sonograph. The processor/graphic recorder contains the control electronics for operating parameters such as frequency, range, and gain. By tuning these parameters an operator can optimize the data quality in response to mission requirements and acoustical environment. The digital tape recorder provides unprocessed sonar data storage for later playback or electronic enhancement.

ROV

A Benthos Mini-ROVER MKII ROV equipped with an underwater television camera was deployed to collect visual observations of the lake bottom features and aid in sonograph interpretations. The image from the forward-looking video camera was transmitted via umbilical cord to a monitor and recorder aboard the support vessel. The operator guided the ROV through the water column using the images on the monitor and the vehicle's thrusters; two fore-and-aft, one vertical, and one lateral. The video system consisted of a low-light, high-resolution color TV camera, video recorder, and two quartz halogen lamps for illumination. The 80-deg field-of-view lens system possessed tilt and pan capabilities. Vehicle heading and operating depth were graphically displayed on the video monitor.

Field Data Collection

During the SSS survey, the towfish track information (position and time) from the DGPS was entered on the sonograph as event numbers. Rough wave conditions, turbidity, and shallow water degraded the quality of the sonographs. Four days were scheduled for SSS surveying, but only one day produced sonographs of sufficient quality for interpretation purposes.

Waves affect the quality of a sonograph in two ways, towfish instability and entrained air in the water column. Because the towfish was deployed from the R/V SeaQuester at very shallow depths and an average speed of 2 knots (3.4 ft/sec), the towfish hung close to the boat on a short cable. Much of wave-induced pitch and heave of the vessel was translated to the towfish by this short length of cable. The sonographs are blurred in proportion to the amount of such motion. In rough wave conditions it is preferable to deploy the towfish as deep as possible to allow the catenary in the cable to act as a shock absorber, but in this shallow water the cable had to be kept short to keep the towfish at a sufficient elevation above the lakebed.

The fish was deployed from the R/V SeaQuester in various positions and orientations (stern, near midships, bow) to experiment with optimizing the

quality of sonographs. Trackline headings (relative to wave direction) were also varied to minimize unwanted movement. However, the amount of good coverage was limited by the distortions caused by the towfish instability, coupled with clutter formed on the record by acoustic reflections from the undersides of waves and air bubbles entrained by white caps.

For one full operational day the wave heights diminished to a level where usable sonographs could be produced. The majority of shore-parallel transects in Figure 51 were collected that day. On the closest transect to shore the tow
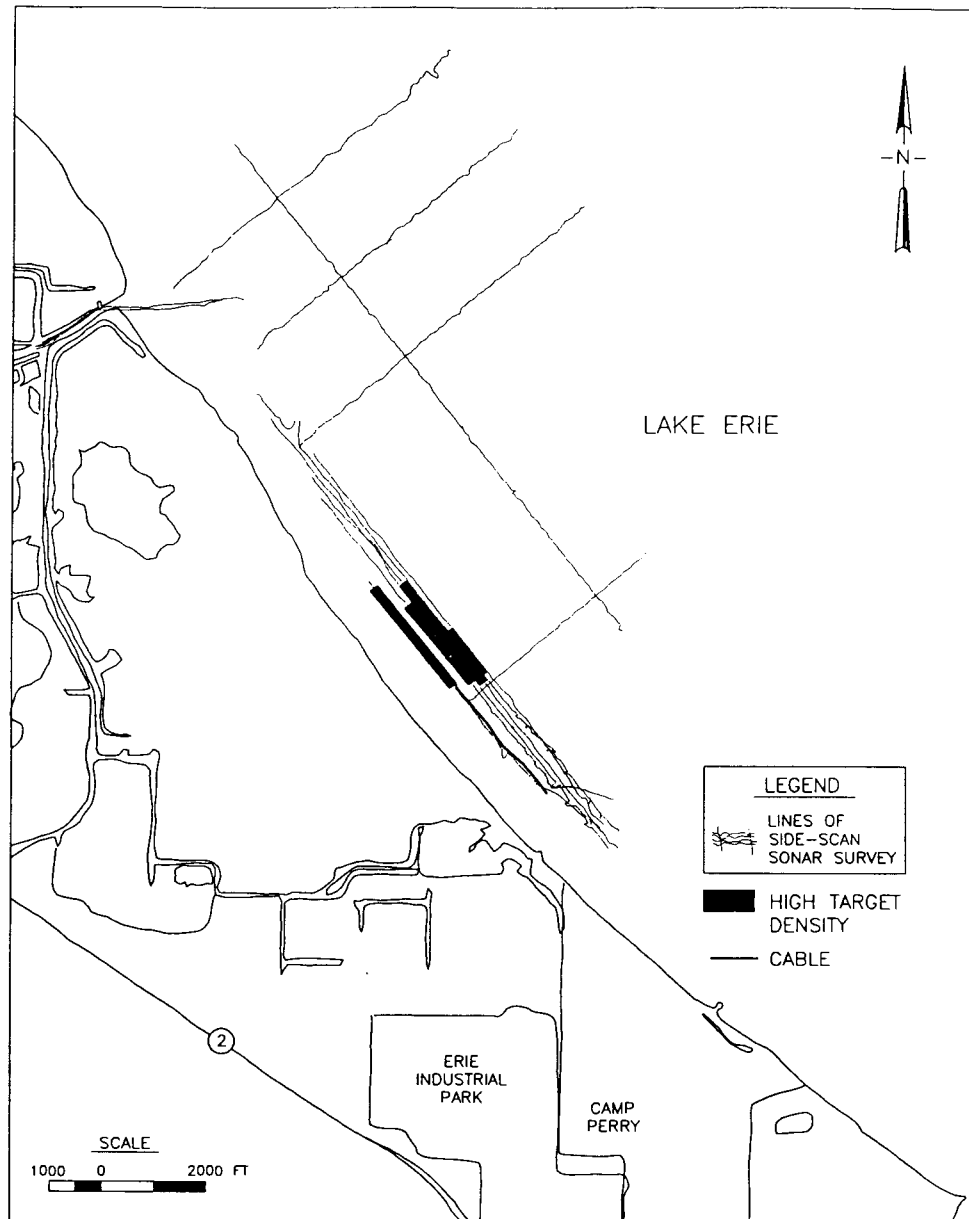
Figure 51. SSS survey tracklines in Lake Erie showing lines with high density of hard target returns

fish was too close to the lake bottom for assured safe operation, so subsequent transects were conducted farther out in deeper water.

The first objective of the surveying plan was to optimize sonar imaging of possible OEW densities. The second was to derive information on the lake bottom itself. The towfish operates at frequencies of either 100 kHz (standard) or 400 kHz (high resolution). Sonographs at the two frequencies were compared to decide whether wave conditions had diminished enough to achieve the higher resolution possible at 400 kHz. The 400-kHz option was selected due to the slightly better imaging quality produced by its higher frequency, shorter pulse length, and narrower horizontal beam width.

The SSS range is the horizontal distance (measured perpendicular to the trackline) from the trackline to the furthest lakebed point represented on the sonograph. The Model 260-TH has nine possible range settings (25 m (82 ft) up to 600 m (1,969 ft)). The smallest of these, 25 m (82 ft), was used to optimize resolution and detectability by providing the highest possible pulse repetition rate. This range provided a total sonar swath, or footprint, of 50 m (164 ft) (25 m (82 ft) on each side of the towfish). An average survey towing speed of 2 knots (3.4 ft/sec) (minimum speed of the R/V SeaQuester with sea anchor deployed) was maintained to maximize the number of acoustic pulses per unit length of trackline.

Results of the SSS and ROV

Sonographs produced under these operating parameters should be interpreted as plane-view perspectives similar to those of low-level oblique aerial photographs (Figure 52). The center line (A) represents the towfish's path, or trackline. The areas on either side of the trackline correspond to return signals received by the port and starboard transducers (in this record the "top" area was collected by the port transducer and "bottom" area by the starboard transducer). Line (B), running parallel to the towfish trackline, represents the first signals backscattered to the port transducer by the lake-bottom. The contiguous lighter contrasted zone bounded by lines (A) and (B) is the port side water column.

The relative intensity of the acoustic energy that returns to the transducers is indicated by the darkness of the sonograph image. The stronger the reflected (or backscattered) energy, the darker the corresponding image. The intensity of this reflected signal is affected by the reflecting surface's composition, size, and orientation to the incident signal. The air/water interface is a very strong reflector of sound. The "slash" pattern in the port water column (area between lines A and B) was caused by reflections from the undersides of waves and wave-entrained air bubbles. The darker areas on Figure 52 indicate a different type of lake bed material from the lighter-contrasted linear

5 METERS
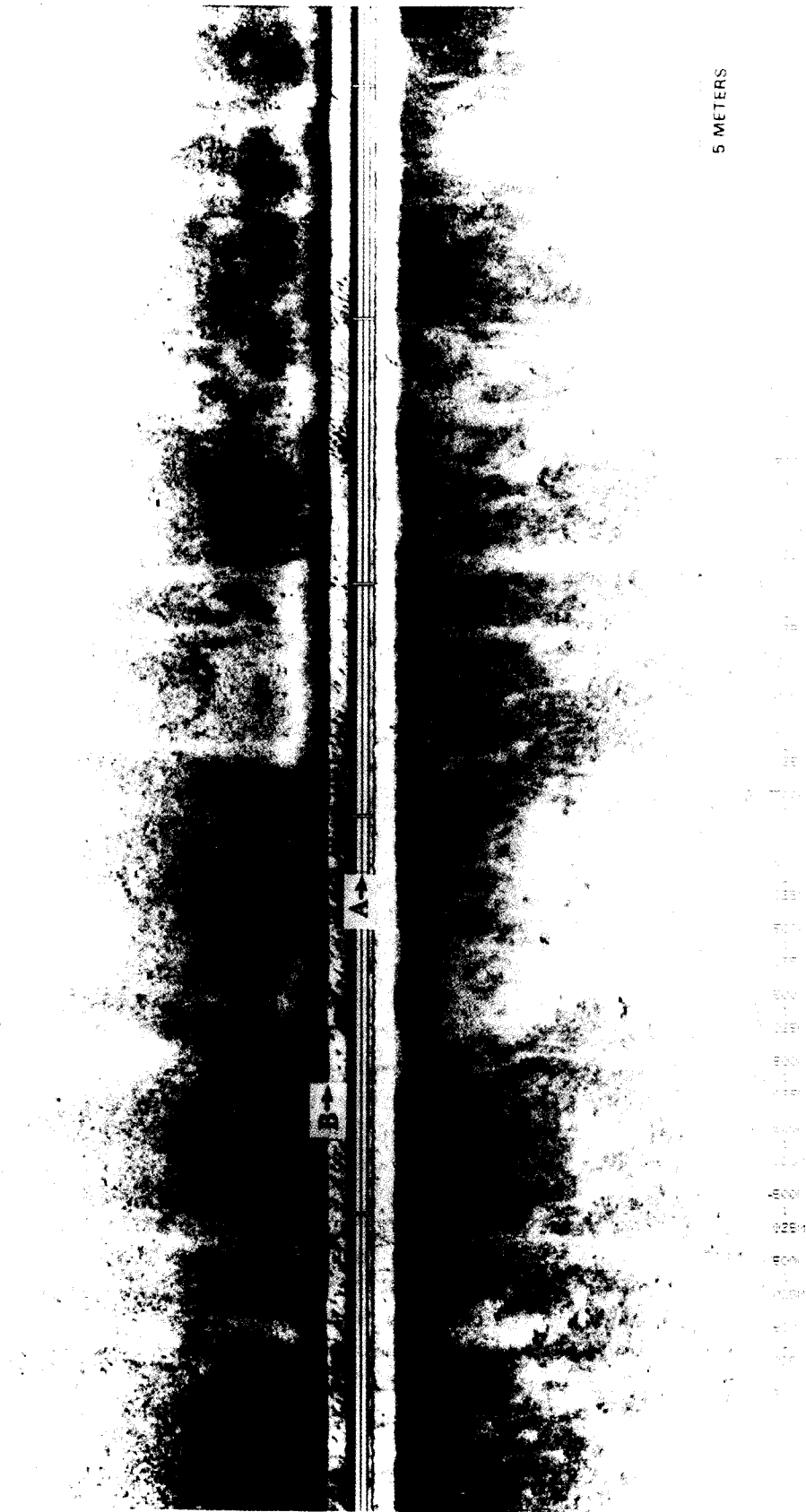
Figure 52. Sonograph generated by EG&S Model 260 SSS at 490 kHz (25-m (82 ft) range)

features (running approximately perpendicular to the towfish trackline) and angular areas.

In order to groundtruth the SSS observations, the ROV was deployed for additional qualitative (visual) data collection. Unfortunately the wave conditions that affected the SSS survey also impacted the ROV data. In shallow water, the waves stirred up the lake bed and caused the water to be quite turbid. Even with the low-light, high-resolution color TV camera, the ROV's visibility was reduced by the turbid water. Whenever the ROV was close enough to start to "see" (and record) bottom features, a course correction by one of the thrusters would stir up fine bottom material and shroud the features from sight.

In deeper water (4.3-m) (14-ft depth) visibility was improved and the ROV could discern bottom features more clearly. Here the bottom was seen to be flat and featureless, with little relief except for scattered algae mats. These algae mats rose up slightly from the lake bottom. The bottom was coated with a film of shell hash, and any significant objects were covered with zebra mussels. The difference in the amount of acoustic energy backscattered by the algae mat zones, compared to the flat lake bottom, was significant enough to produce the sonograph contrasts. It is not known if the algae mats produced this increased backscatter, or possibly the substrate beneath it. Algae require a competent foundation to grow upon, so it is possible that the increased backscatter on the sonograph is due to outcroppings of harder material (that the algae are anchored upon) surrounded by less competent lake-bottom material. The lighter-contrasted linear features running perpendicular to the towfish trackline in Figure 52 were probably formed by ice scour and drag marks left by gill netters who trawl their nets through the area.

The spacing between adjacent parallel tracklines was selected to allow overlap of the sonographs. Adjacent sonographs were aligned and joined to create mosaics, which are continuous, two-dimensional images of the lake bottom. The portion of mosaic shown in Figure 53 was created in this manner. Two adjacent tracklines (with the water columns removed for ease of interpretation) were aligned by correlating event marks and overlaying common bottom features. The two "wavey" patterns (one from each trackline) on the sonograph were caused by the wave-induced instability of the towfish. The "pencil-shaped"" image in the upper left corner, possibly a log, protrudes up from the lake bottom as is indicated by its acoustic shadow. When a significant target like this protrudes up from the bottom, it creates a strong dark image because its surface is more normal to the incident acoustic pulse (more energy is reflected). By reflecting and absorbing the incoming pulse, it produces an acoustic shadow (immediately behind the reflector) on the side away from the trackline. This acoustic shadow zone shows up as a white area. The general absence of acoustic shadows on all the sonographs collected in the FUDS site indicates that the area surveyed is basically flat, with no significant relief.

Figure 53. Portion of mosaic created by aligning adjacent SSS tracklines

5 METERS

Chapter 7   Side-Scan Sonar and Remotely Operated Vehicle (ROV)
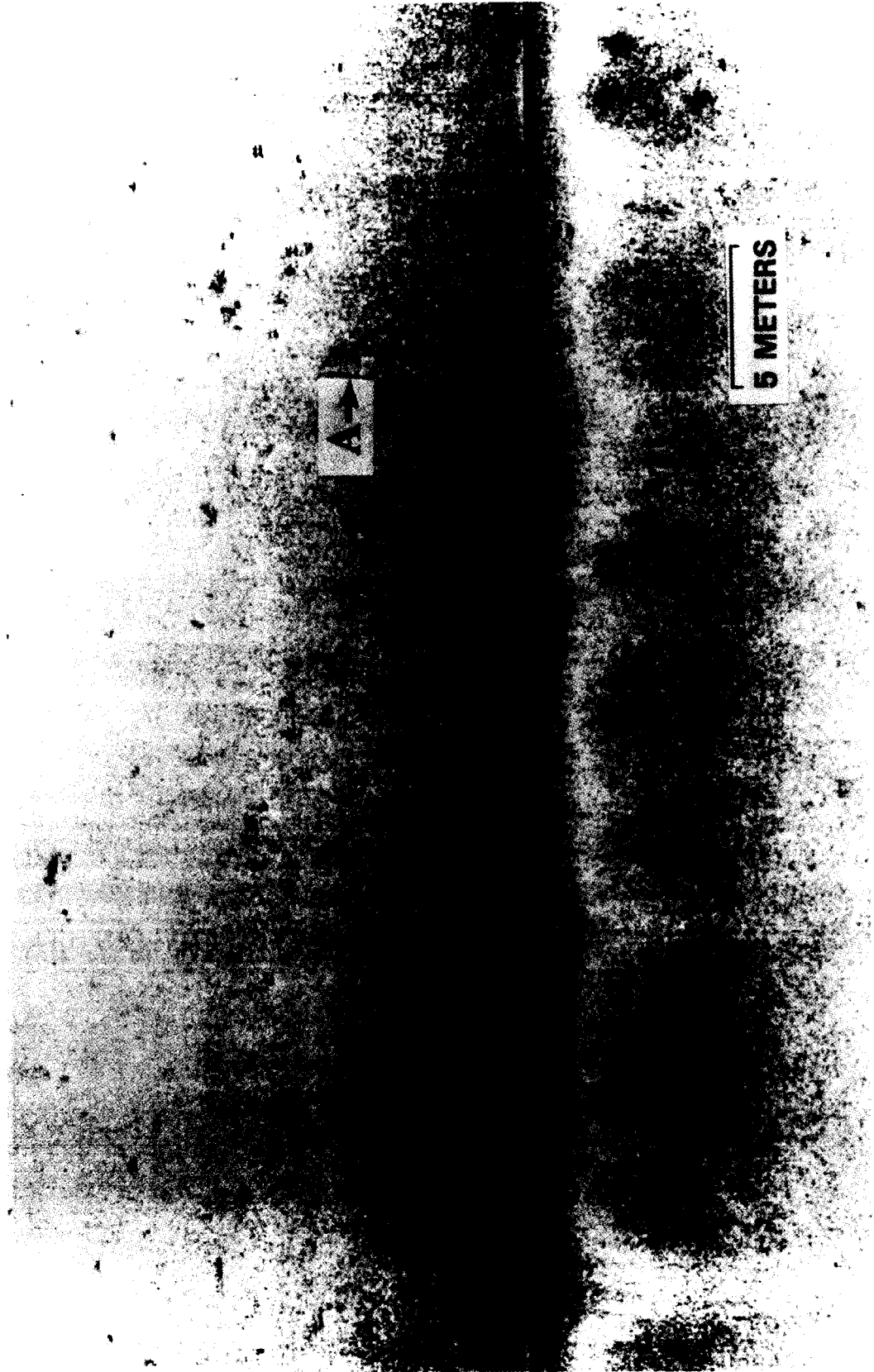
Figure 54. Enlargement of a zone of concentrated targets

Figure 55. Further enlargement of the zone of concentrated targets in Figure 54

Chapter 7   Side-Scan Sonar and Remotely Operated Vehicle (ROV)

The small, elongated, dark images in this sonograph indicate small, relatively "hard" targets. Figure 54 is an enlargement of a zone of concentrated targets (A). This zone is further enlarged in Figure 55.

A material's acoustic reflectivity is a function of its acoustic impedance (material density times the speed of sound through the material). Consequently, steel has a higher reflectivity than stone or concrete, which, in turn, have a higher reflectivity than wood. The SSS system gain was set relatively low during the FUDS site survey. This tuned the sonograph such that the backscatter of the lake bottom was relatively light, and presented a greater contrast to hard target returns. The linearity of the targets suggests that they are man-made. These targets do not significantly protrude up from the lake bottom, as is evidenced by the absence of acoustic shadows. The small, dark, elongated images on Figures 53 through 55 have the characteristics expected for ordnance.

As described before, the turbidity in shallow water severely limited visibility from the ROV. When the ROV was deployed to look at these small targets, the result was limited numbers of unclear glimpses of elongated objects covered in zebra mussels. Conversations with gill netters active in this area revealed that the ordnance retrieved from nets was usually "covered with zebra mussels."

To test the SSS's ability to detect ordnance of the type found in the FUDS site, test trials were conducted in the Toussaint River with selected rounds (90 mm up to 155 mm) from the Toussaint River spit experiments. These river tests were conducted when wave action precluded surveying the FUDS site. Several test runs were conducted using different SSS settings and operational practices; however, individual rounds could not be readily detected on the riverbed. Reflections from the riverbed, bathymetry, and debris produced considerable backround "noise" that may have obscured echoes from the ordnance. In general, the noise level was greater in the river than the FUDS area.

The published resolution of the EG&G 260 Series SSS in the 25-m range is 0.06 m. Given this resolution, the SSS operating parameters (400-kHz, 25-m range, 2-knot tow speed, etc.), metal composition of ordnance, the size and linear features of targets on the sonograph, and the flat bathymetry of the lake, it is highly probable that the hard targets are ordnance. Figure 51 shows the areas where the target populations appeared most dense.

The sonograph (water column removed) presented in Figure 56 contains images of a cable (A) that appears to be partially covered by bottom material in the middle of the sonograph, and emerges on the far right side of the record. The portions of exposed cable that were detected on the mosaic are illustrated in Figure 51.

5 METERS

Figure 56. Sonograph showing portions of a cable detected on the SSS mosaic

Chapter 7   Side-Scan Sonar and Remotely Operated Vehicle (ROV)

8 Analysis of Data Results and Interpretation of OEW Distribution Patterns

General

Data used for analyzing the coastal processes of the study site and interpreting the ordnance distribution patterns were collected during the September 1993 field study and also gathered from several supplementary sources. Supplementary data include observations made of the beach geomorphology, interviews with knowledgeable resources, analysis of ordnance finds data from the 1992 beach cleanup, and additional information on Erie Army Depot firing practices. These non-field study data sets proved very valuable in providing additional insight and helped in interpreting the results of the field investigations.

Beach Observations

Observations made during several site visits to the FUDS beach revealed evidence that the ordnance is quite mobile through the surf zone. The beach is a narrow, thin sand sheet which lies over a clay and peat marsh-deposit base. This is a highly eroding shore which has retreated over the former back-beach marshes. Peaty clays are exposed in the troughs between the sandbars and clay flats appear along the beach, particularly in the eastern third of the study area. A multiple bar field fronts much of the study area. However, in front of the more eroded eastern third, the bars are closer to the shore and in some cases appear as a discontinuous nearshore shoal.

Ordnance was observed on the beach in numerous places along the eastern half of the FUDS beach. No ordnance was seen along the wider beaches of the western half. Ordnance occurrences emulated those typically seen as a coarse-grained lag deposit on eroding beaches. For example, ordnance was seen usually adjacent to stick-out features such as fallen trees, tree trunks, or stone revetment headlands. Although occasional pieces would be spotted partially buried in sandy sections, ordnance was much more common in the clay

flats. This suggests that the ordnance rolls along the surf zone until it runs into a feature which it will pile against or a rough, more frictional clay base. Ordnance along the waterline tended to be lined up with its long axis parallel to the shore suggesting that the ordnance rolls up and down the beach face with the waves. A final, critical observation was that ordnance on the beach tended to be clustered in some locations and absent from others. No ordnance was seen in beach areas which were fronted by broad offshore sand shoals (for example, in Cove Beach). Yet ordnance was common in areas where the nearshore bar field was locally discontinuous or very close to shore (i.e., East Beach).

The overall implication of these observations is that ordnance rolls as a bedload onto the beach and along the beach as a coarse-grained littoral sediment. Ordnance finds on the beach are strongly controlled by nearshore terrain (areas where it can transit the bar field) and longshore littoral transport (rolls as bedload until it hits a feature or clay zone).

Results of Interviews

Several individuals were contacted and interviewed because of their unique insight into the physical processes of the FUDS study site, the history of ordnance occurrences, or operational practices of the Erie Army Depot. The firsthand knowledge they were able to provide helped to explain and/or reinforce the data and reference material collected during this study. The key information obtained from each interviewee is summarized here in paragraphs which paraphrase their comments.

Mr. Mike Short of EOD Technologies, Inc. (EODT) participated in the 1992 beach cleanup. He was asked about the orientation and locations of ordnance on the beach. Mr. Short confirmed that all ordnance had been cleaned out to a depth of about 46 cm (18 in.). On a couple of days when the water had really gone out, the magnetometer "squealed" during searches across the exposed bars. The troughs of the offshore bars are full of ordnance. In the Cove Area about 400 rounds were cleaned up. When the same area was checked 1 month later approximately 500 more rounds were retrieved. Most was light-cased 106-mm-rounds with fins. The area around rock revetment, west of Cove Beach, was heavy with 106-mm-rounds. Toward the west, ordnance concentration decreased. Closer to the Toussaint River, the numbers of finds increased. When asked about orientation of the rounds, Short said they were somewhat aligned parallel with the troughs. One day about 20-25 rounds were pulled up to the vegetation line (because of the big waves). The crew returned the next day to detonate the rounds, but they had disappeared, and the crew assumed the waves had taken them out. However, when a magnetometer was run over the same ground, it detected hits, and the rounds were found buried below the sand surface.

Mr. Clifford Biggert worked as a base security guard at Erie Army Depot in the 1950's and has fished in the local area extensively, including seine fishing off the FUDS beach during the late 1960's and early 1970's. He observed that in some places 30-61 m (100-200 ft) of beach width has gone. On the east end of the range, machine guns and mortars were fired, in the "center" the larger rounds were fired, and to the west, the recoilless rounds were shot. A "fair" majority were fired for speed and accuracy (level trajectory "treetop" level). Over the years, Biggert has always seen shells on the beach and landward in the marsh. In the winter, he has seen shells impact on the ice and just lie there. The study areas were popular seine fishing areas in the 1960's and 1970's. Biggert and other seine fishermen would drag their nets onshore from about a 3-m (10-ft) water depth up onto the beach. They would drag a lot of ordnance towards the shore and usually get a few pieces hung up in their nets. Biggert feels that that this seine fishing probably contributed toward moving significant quantities of ordnance toward the shore.

Mr. Keith Floro is a local marina operator who worked in the Erie Army Depot shop repairing guns. During his service in the Army he became very familiar with the range of weaponry tested at Erie Army Depot. Mr. Floro said the big shells were fired both for accuracy and elevation (accuracy implies low trajectory, shorter ranges because of shooting at targets at treetop elevations). When workers were installing a pump inland on the David Besse northwest side of Toussaint River (supposedly well out of the firing fan) a number of shells were encountered. Short-range rounds, such as the 4.2-in., 60-mm, and 81-mm-mortars, were fired during his period of experience in the range fans documented for 1965 (Figure 3). Fifty-caliber, 2-1/2-in. rockets, twin 40's and 90-mm antiaircraft rounds were fired from the David Besse side (north). Personnel from the Erie Army Depot would occasionally go out into the firing fans to clear surface rounds. Mr. Floro states,

> Basically they shot all over and the ground is saturated with ordnance. Movement and appearance of ordnance changes every year. Some years the winter storms move the shells. Other years there might be a good ice cover and a "south-wester" will blow the ice out. When the ice is driven back on shore it will stack on the bars. Out on the reefs anchor ice forms on the bottom then radiates upward.

Mr. Floro gave the David Besse outfall (located 0.8 m (1/2 mile) out) as an example where they have problems with ice. In the shallower water, ice will freeze down and attach to the ordnance, then transport the ordnance with the ice flow once it breaks loose.

Analysis of EODT Beach Finds

Records maintained by EODT during the 1992 cleanup of the FUDS beach included ordnance removal types and counts per numbered lane. Lane widths were 7.6 m (25 ft) and the length (going offshore from the baseline) varied from 10.7 to 61 m (35 to 200 ft). Each lane was marked by steel

rebars driven into the sand at the back of the beach. Distances and angles between rebars were recorded, which allowed a charting of ordnance concentrations relative to a baseline. Unfortunately, although the EODT records were quite detailed, none of the rebars were tied into a recognized and reproducible coordinate system and the baseline could not be readily positioned in space. However, this problem was rectified during the investigation by the WES study team.

Horizontal datum control was required in order to compare the ordnance concentration field on the beach to the ordnance concentration fields identified in the offshore survey. During the field investigation a total of 14 rebars remaining from the 1992 EODT cleanup were located and their horizontal position determined using DGPS. The located rebars were not individually nomenclatured with easily identified tags. However, the rebars which were located on the beach were positioned on a control map and the EODT baseline was adjusted to a best-fit location (Figures 57 and 58). Figures 57 and 58 illustrate the two primary lane groups where ordnance was cleared from the beach (Lanes 1B-154B and Lanes 1-162) relative to the 1965 firing fans (see Figure 3). These two lane groups cover the eastern half of the FUDS beach (a total of 2,581 m (8,467 ft)). EODT records did list 65 lanes extending southeast from the mouth of the Toussaint River (a total shoreline length of 458 m (1,503 ft)). However, only two pieces of ordnance were found over this entire section of shore. No ordnance was reported for the 1,146-m (3,760-ft) section of shore between Lane 154B and the Toussaint River lanes.

Ordnance counts per lane were divided into "large ordnance" and "small ordnance," with the demarkation occurring with the 60-mm size. Large ordnance ranged from 75 to 165 mm including a few larger rockets and warheads, while small ordnance included anything 60 mm and smaller. Figures 59 and 60 illustrate the large and small ordnance finds for Lanes 1B-154B, while Figures 61 and 62 exhibit the same data for Lanes 1-162. Lanes 1B-154B include a sand beach over the northwestern portion and are fronted by a rock revetment over the south-eastern third. Figures 59 and 60 reveal that this section of beach was dominated by large ordnance, with most of the finds located in the southeastern portion. Only a dozen pieces were discovered across the northwestern 305 m (1,000 ft) of this section. Concentrations increase toward the southeast. Conversely, Lanes 1-162 were dominated by finds of small ordnance, with as many as 383 shells found in a single 7.6-m-wide (25-ft-wide) lane (Lane 150) near the northwestern boundary of this lane group. This lane is located along the southeastern flank of the revetment and along the flank of a large sand shoal. This same sand shoal fronts across the Cove Beach and blocks ordnance from reaching the beach along a 213-m-wide (700-ft-wide) section to the southeast. The irregular pattern of ordnance finds throughout the rest of this section of beach are due to the periodic exposure of clay flats which locally concentrate the ordnance.
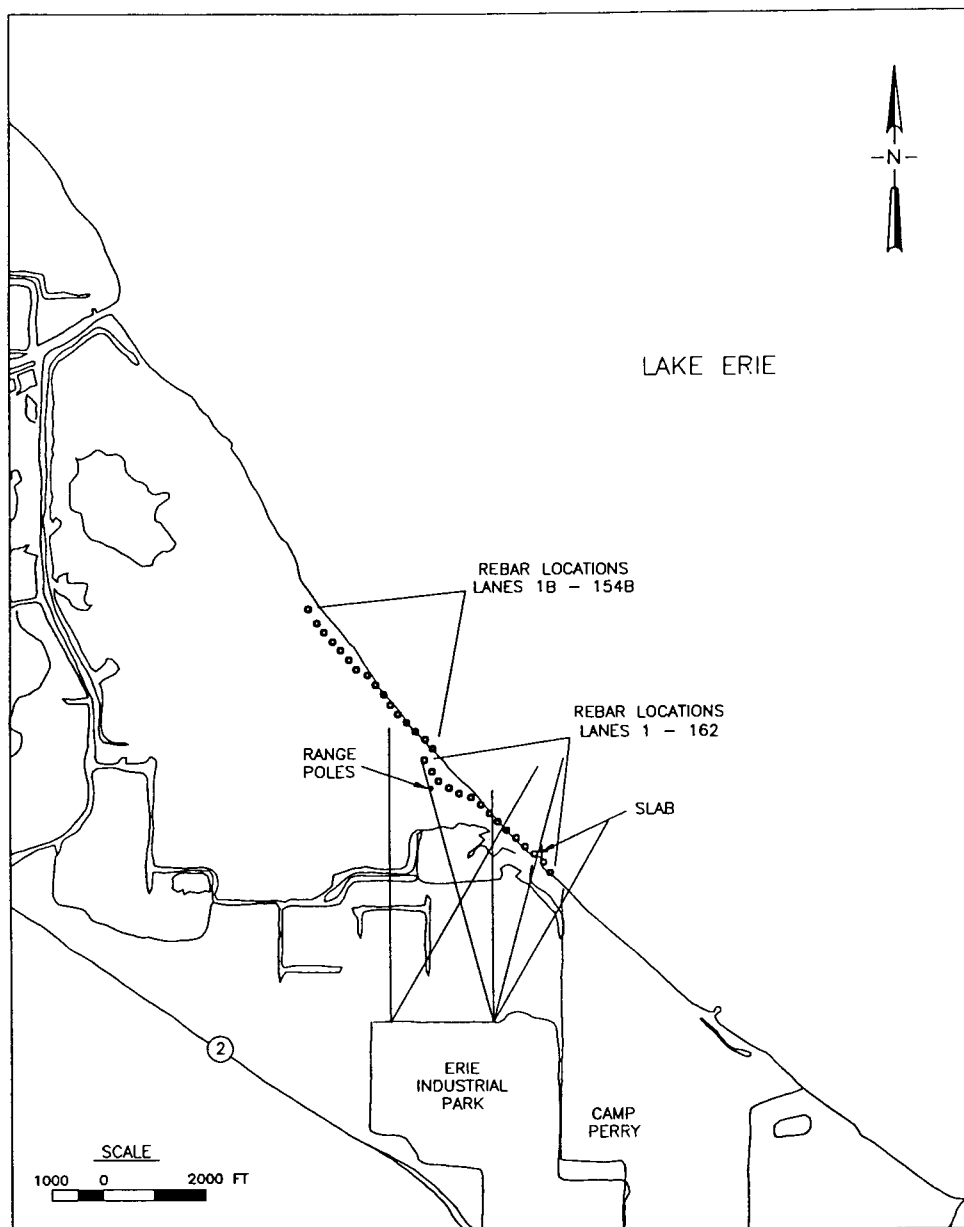
Figure 57. 1992 EODT rebar locations showing beach cleanup zones

These data quantitatively support the observations made during the field investigation and reported in the section entitled "Beach Observations." Several key statements can be made based on these data:

    a. Ordnance concentrations on the beach line up with the firing fans with larger pieces toward the west, which is also where the larger rounds were reported to be targeted (per Mr. Biggert) and the longer shot target pads were located (Figure 3).
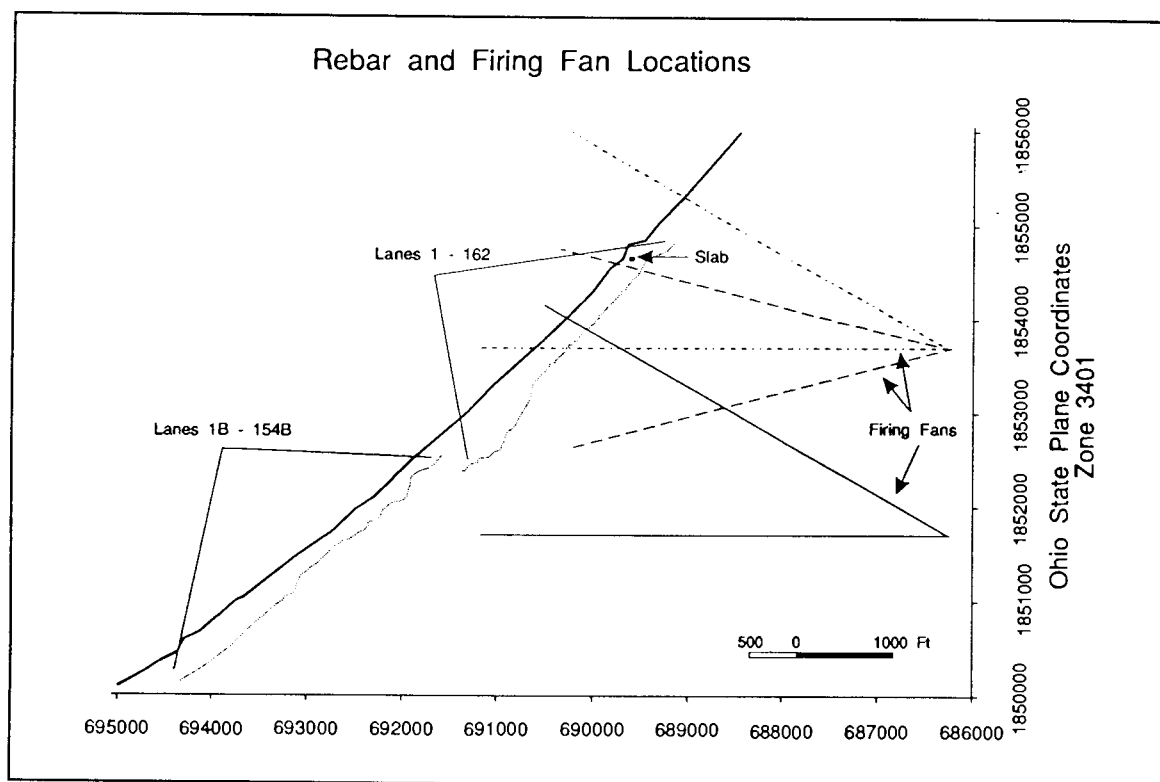
Figure 58. Detail of 1992 EODT cleanup zones shown relative to coordinate controls

b. The pattern of ordnance finds on the beach reveals higher concentrations where the sandbars are closer to shore (in front of the revetment and toward i.e. East Beach) where clay flats trap the ordnance. Ordnance is also concentrated where beach features (headlands and stickout features) interfere with the longshore movement of the pieces.

c. Ordnance finds on the beach become almost non-existent (due possibly to a better developed sandbar system and less concentrations in the offshore considering the firing fans).

d. Ordnance is blocked from reaching the beach in a broad area, called Cove Beach, by a large offshore sand shoal.

e. The northwestern 1.9 km (1.2 miles) of the FUDS beach were almost devoid of ordnance contamination, while over 5,000 pieces were recovered from the southeastern 2.3 km (1.4 miles).

Interpretation of Ordnance Distribution Patterns

The geophysical data on ordnance concentrations presented in Chapters 4-7, EODT beach finds data, bottom type information, and an
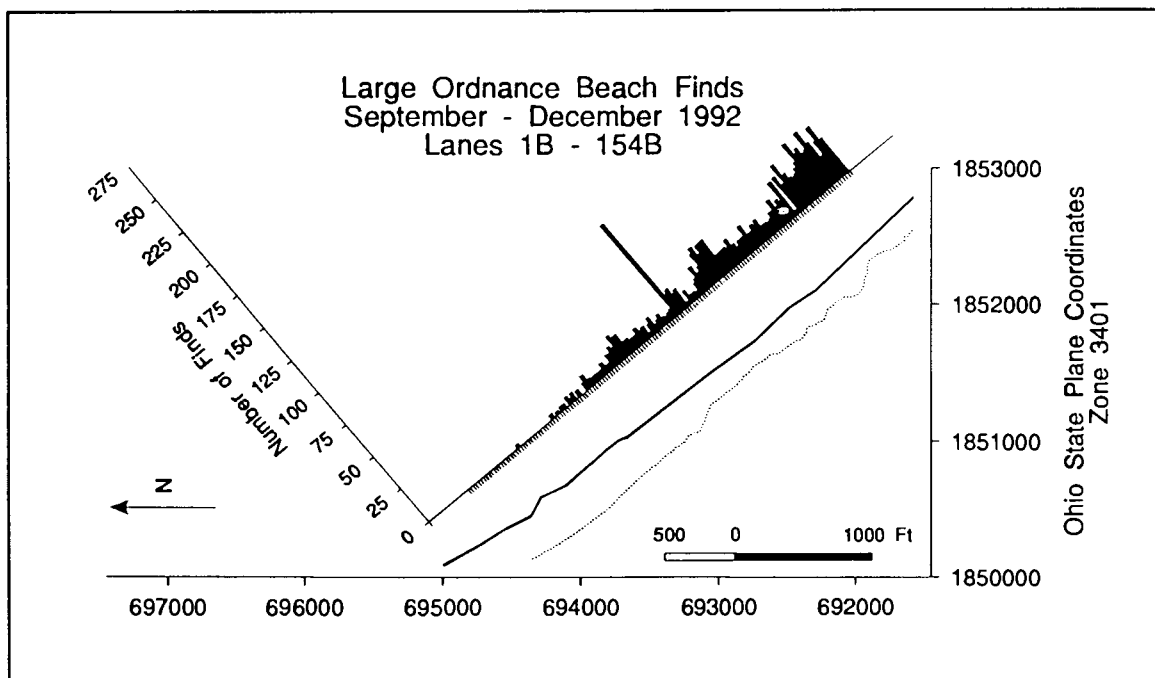
Figure 59. EODT large ordnance beach finds, September-December 1992 data for Lanes 1B-154B
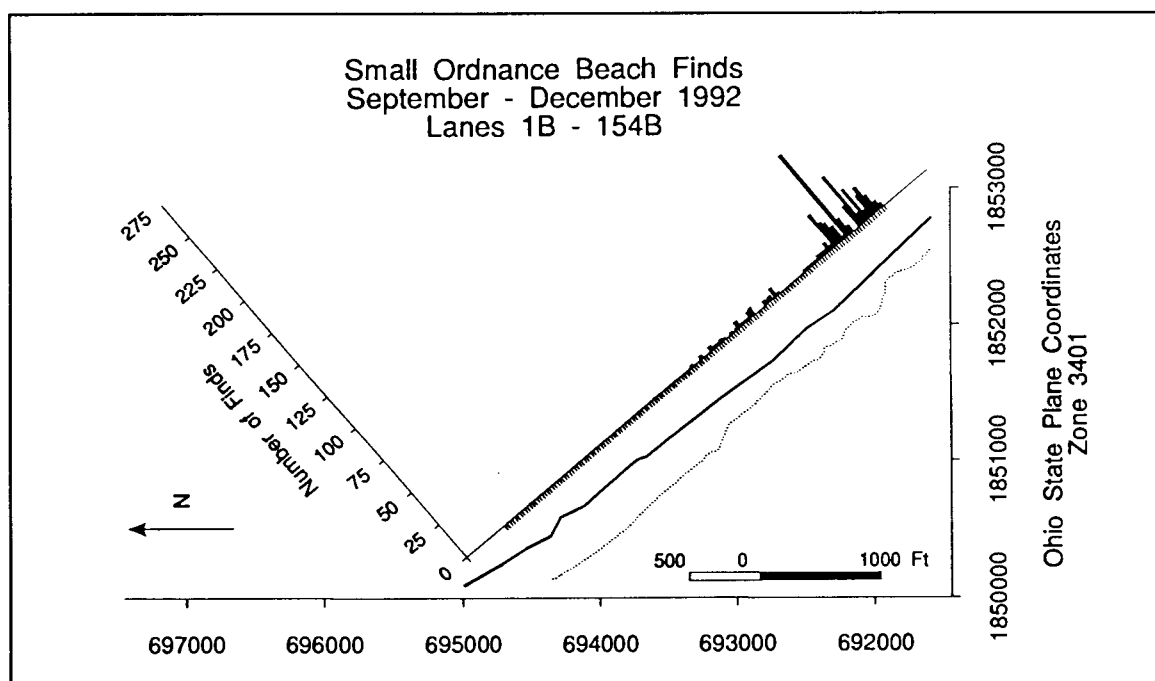
Figure 60. EODT small ordnance beach finds, September-December 1992 data for Lanes 1B-154B
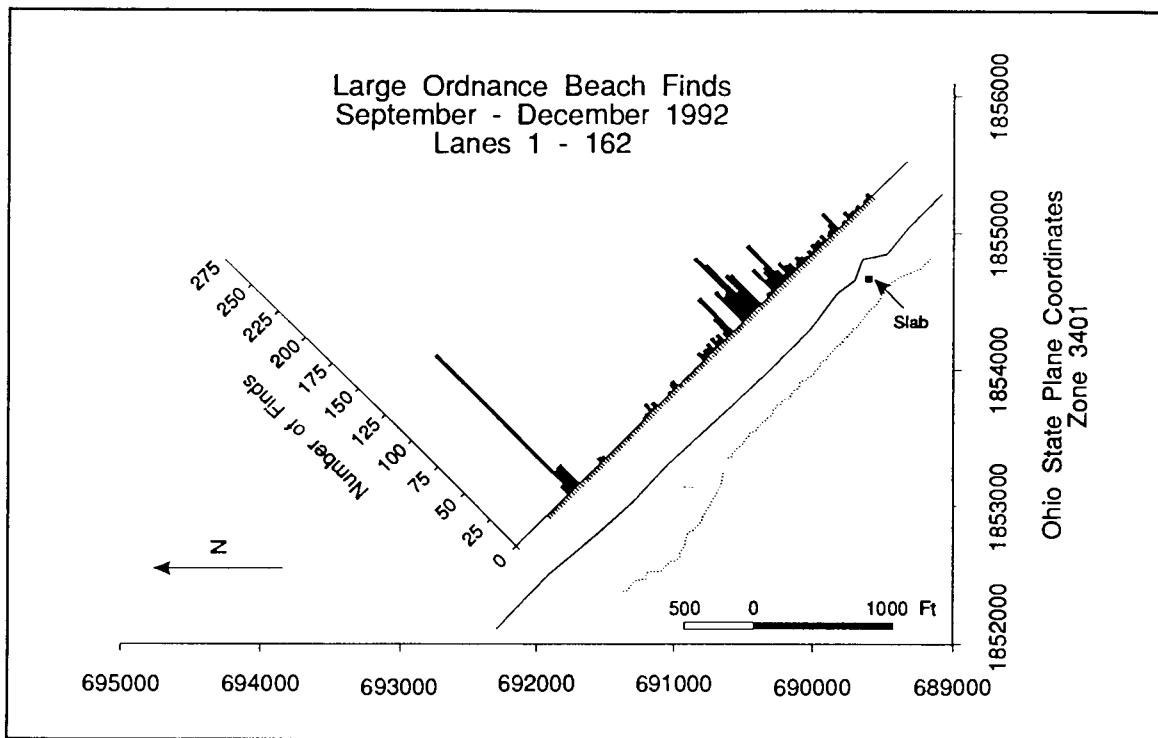
Figure 61. EODT large ordnance beach finds, September-December 1992 data for Lanes 1-162
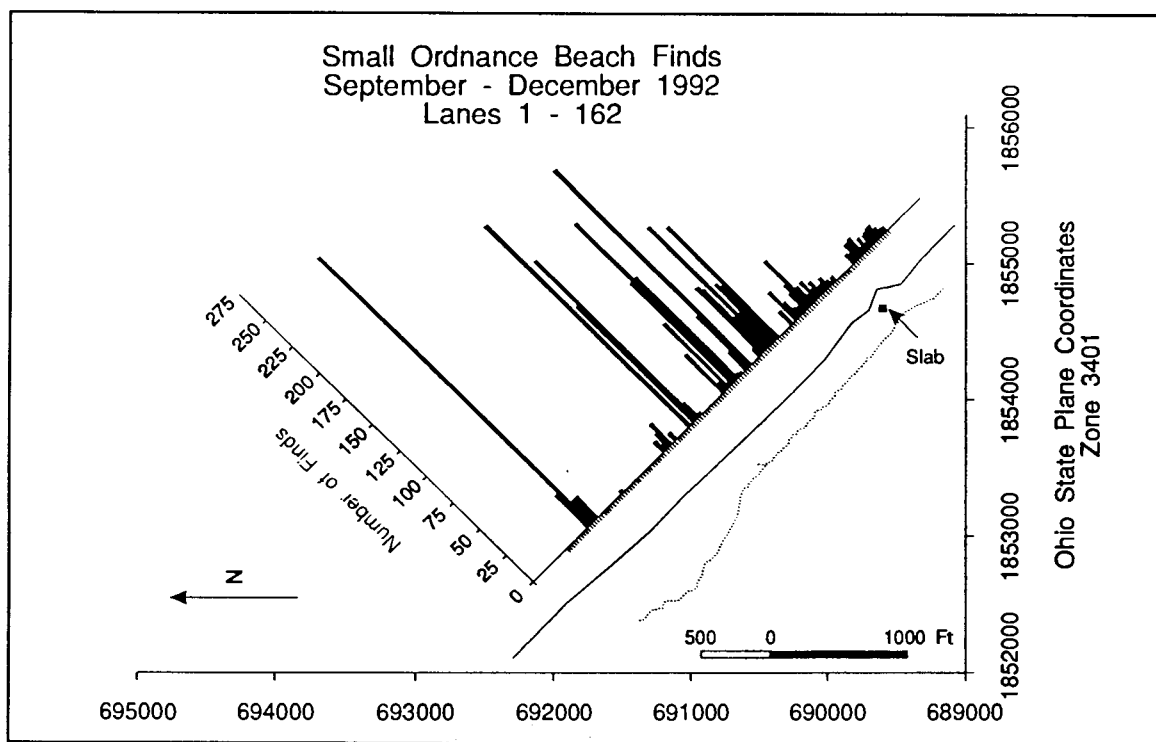
Figure 62. EODT small ordnance beach finds, September-December 1992 data for Lanes 1-162

interpretation of the local coastal processes lead to several observations regarding this study site. Figure 63 is a schematized sketch which presents a summary from the many divergent data sources. Figure 63 illustrates the bottom type zones, beach features, and the nearshore zones of ordnance concentration.
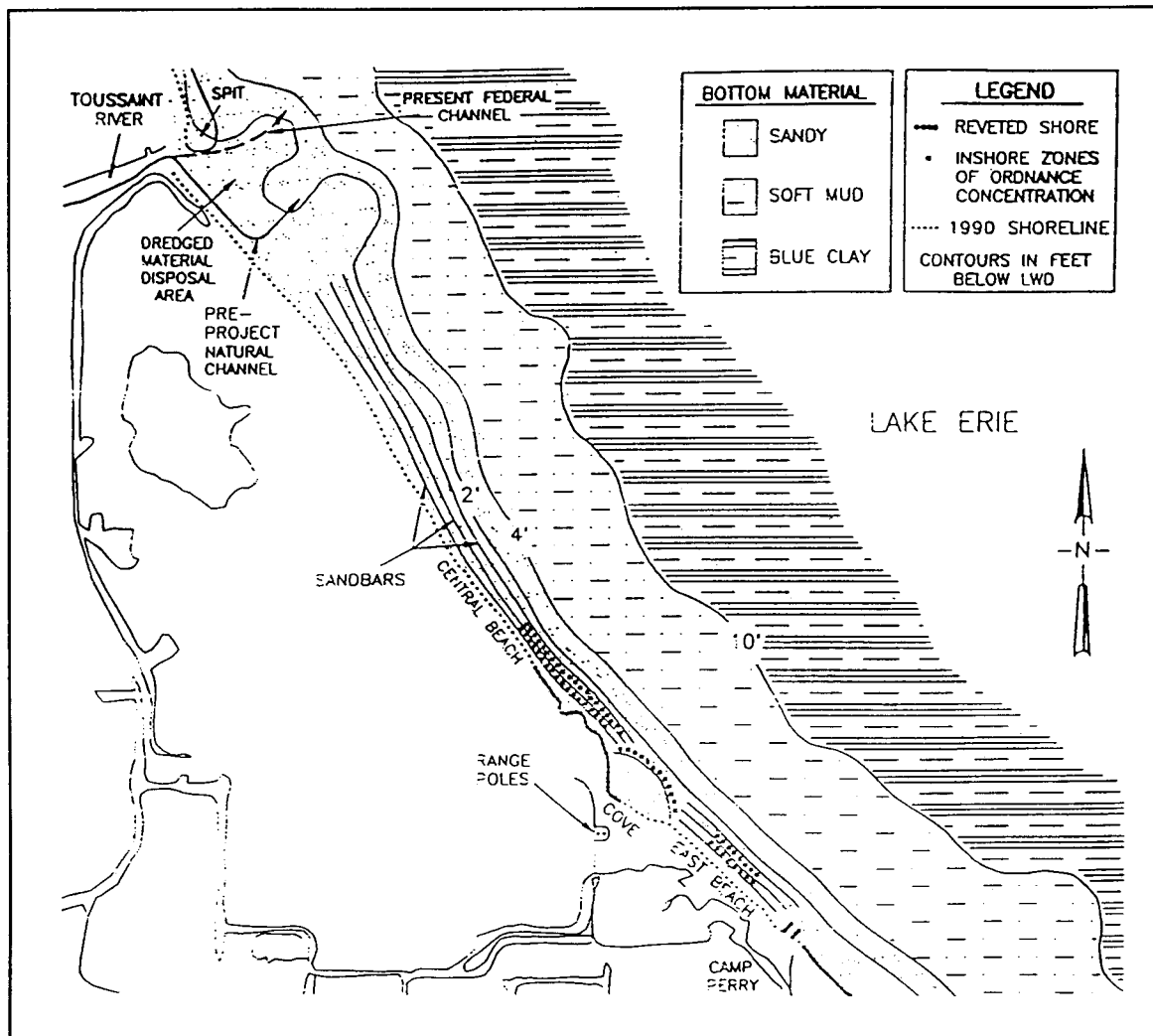
Figure 63. Sketch of FUDS study site illustrating features, bottom type zones, and nearshore ordnance concentration fields

The bottom, in deeper water (say 3.0-4.3 f (10-14 ft) LWD), is a hard blue clay which exhibits shell fragments and a silty veneer. Ordnance in this zone appears to be scattered and covered with zebra mussels. The zone from 3.0-1.8 m (10-6 ft) LWD is a very soft muck bottom with little surface evidence of ordnance from the SSS record (ordnance probably sinks below the surface in this zone) and though magnetic data indicate ferromagnetic targets are common in this zone, the bottom becomes sandy from 1.2 m (4 ft) LWD to the shallower sequence of sandbars and shoals with clay or peat outcrops between bars. Ordnance appears to be more concentrated in the troughs and

on the bottom side of steeper inclines in this area. Ordnance in the bar field is concentrated in the southeastern half of the FUDS beach and at the lake side of the shoals or in the troughs between the sandbars (Figure 63). Nearshore concentrations were greatest on the lakeward slope of the shoal off of Cove Beach and the Range Poles. The modern Range Poles are located close to the center of the 1965 Firing Fan net (Figure 63). Thus, the highest concentration of nearshore ordnance targets are (considering 30 years of shoreline retreat) at or just lakeward of "ground zero."

The occurrence of ordnance on the beach is concentrated in the southeastern half of the FUDS beach from the Central Beach through the East Beach, with concentrations peaking on either side of Cove Beach. Beach ordnance appears to be littorally (longshore) concentrated, piling up against stick-out features, such as the revetments or the stone dock (i.e. the slab) close to the Camp Perry border. This pattern is typical of a rolling bed-load sediment. The shallow, below still water, clay flats also contain higher concentrations of ordnance, characterized by a tendency to lineup linearly to the wave crests. Ordnance probably reaches the beach by rolling through gaps in the sandbar field or where the bars weld onto the shore due to shoreline retreat.

Very little ordnance was found on the beach or the nearshore of the northwestern half of the FUDS beach. This is probably due to several factors, including being located outside of the primary firing fans and the presence of a broad shallow sand shoal/river discharge delta which would block the onshore migration of ordnance in this area.

9 Conclusions and Recommendations

General

The subject study was designed and conducted in a manner that would address several issues, as follows: equipment performance, site coastal processes and ordnance distribution patterns, and future site management strategies. The primary purpose of the field study was to obtain sufficient information to interpret ordnance concentration and migration patterns. The results of this analysis would lead to certain implications relative to future site management and clean-up procedures. However, the field study also involved a unique assembly and testing of various types of geophysical and oceanographic equipment. The systems used were each commercially available, with a reasonable service record for other types of applications, and inexpensive to operate and support. The field study explored the applicability of these systems for ordnance detection and mapping.

Conclusions - Equipment Performance

The deductibility and resolvability of the various ordnance items at the spit test area by the applied techniques was in order of best performance: (a) transient electromagnetics, (b) vertical gradient magnetic, (c) total field magnetics, and (d) ground-penetrating radar. Direct comparison of the electromagnetic time domain data with the magnetic survey for this study and site characteristics resulted in a finding that the electromagnetic method is superior to the magnetic technique in that it delineates more clearly and precisely the presence of buried ordnance.

Electromagnetics. The electromagnetic study at the Toussaint River spit test site of buried inert ordnance documented the capabilities of the EM61 system in detecting and locating buried ordnance both on land and under water. Further-more, the calculated depths of buried inert ordnance placed in the Toussaint River spit area was in general agreement with the placed depths. With a controlled survey grid, the EM61 has the potential to be used to map approximate depth of burial and the gross size of ferromagnetic objects.

However, the EM61 antenna and electronics need further ruggidization and a more automated deployment procedure to improve waterborne survey coverage and efficiency. In particular, a deployment technique which allowed for running offshore perpendicular lines would allow better correlation of the bathymetry with ordnance concentration.

Waterborne measurements using the EM61 system confirmed suitability of the electromagnetic method for underwater studies and its suitability in the detection and delineation of OEW concentrations. Waterborne electromagnetic survey carried out in the East Zone area defined two very localized areas of higher concentrations of OEW presence on the lake bottom. This type of information was necessary to understand the physical processes which are moving and concentrating the ordnance.

Magnetics. Waterborne total field magnetics proved satisfactory for gross mapping of ordnance concentration zones over a broad area. The marine total field magnetic investigation defined the zone of ordnance density in Lake Erie off of the shoreline of the former Erie Army Depot and defined the general boundaries of this ordnance field. Within this region, two higher density ordnance fields which lie close to the beach were resolved. The results of the transient electromagnetic survey conducted in the Central Zone and East Zone corroborated well with the nearshore portions of the waterborne total field magnetic data. In some areas ferromagnetic target density exceeded detection frequency of the magnetometer, limiting the applicability of this system for pinpoint mapping and classification of complex ferromagnetic target fields. Further improvements in survey quality would be realized by developing a swath-like deployment technique.

GPR. GPR shows promise in locating bottom OEW in fresh water. Data collected during this study suggest that GPR might be used to detect the orientation of a target, particularly if the antenna polarization was deployed perpendicular rather than parallel. This should provide much more favorable results. Further improvement in the GPR deployment procedure to allow stable towing above the bottom is needed due to safety concerns in ordnance-contaminated areas.

Side-scan sonar and remotely-operated vehicle

Shallow-water towing of SSS requires a relatively calm sea state to optimize sonograph quality. During this study SSS did detect suspected ordnance concentration field and various bottom texture patterns. Larger features including stone fields, cables, linear drag-marks, and containers were readily detectable. However, the real value of the SSS was in providing an image of the bottom sediment reflectivity which, with proper ground truthing (obtained via sampling and ROV imagery), can provide information suitable for mapping bottom type.

Underwater video is extremely helpful in defining bottom types and for inspecting underwater target objects. However, the murky waters and silty bottom at this site limited the visibility and effectiveness of an ROV. Results would have improved with a low light camera and/or less turbidity. Even with this limitation, the ROV and underwater video did provide information on bottom type and the stability of objects in deeper water.

Conclusions - Ordnance Distribution Patterns

Ordnance distribution patterns were accessed as a result of the patterns documented through the geophysical surveys, but also in terms of the interpreted coastal processes of the study area. Four different zones were defined within the study area; (a) the Toussaint River, (b) the offshore, with water depths greater than 1.8 m (6 ft) during the study period (i.e., greater than approximately 0.9 m (3 ft) LWD), (c) the nearshore from the inshore bar field (approximate water depth of 0.6-0.9 m (2-3 ft) during the survey) through to the 1.8-m (6-ft) water depth, and (d) the beach, including the subaerial beach through the nearshore bar field to a water depth of 0 ft LWD.

Toussaint River. The Toussaint River channel contains large quantities of ferro-magnetic objects both in the channel and along the adjacent river bottom. The highest concentration of these objects is just landward of the spit. The location and size of many of the targets suggests that numerous marine-activity related debris (for example gas cans, motors, bait buckets, 55-gallon drums, cables, etc.) should be suspected. Improved electromagnetic surveys along controlled grids would be needed to pinpoint suspected OEW as opposed to larger and irregular-shaped marine debris.

Offshore lake bottom. The deepest zone surveyed extended offshore to water depths of 3.7-4.3 m (12-14 ft) during the survey. Based on the SSS and underwater video coverage, the bottom in the deeper portions of this zone is a firm, mottled, clay surface which is coated with a thin film of algae-matting and fine silt. Zebra mussels cover all hard objects and occur as nodules. Closer to shore (from 1.8- to 3.0-m (6- to 10-ft water depths) the bottom is a very soft mud with little evidence of targets or other surface features (ordnance in this area would probably sink below the surface). Ferromagnetic targets were distributed throughout the area surveyed, although concentrations increased lakeward of the southeastern half of the FUDS beach, mirroring the firing fan pattern. Concentrated target fields and bottom features are largely preserved. The evidence collected during this study suggests that ordnance in this area is not very mobile and does not exhibit any evidence of a net transport trend.

Nearshore lake bottom. The nearshore zone includes the transition from the soft clay bottom through the sand bottom and exposed peat surface in water depths ranging from approximately 0.6 to 1.8 m (2 to 6 ft). This is the area which was surveyed with both the electromagnetic and the magnetometer systems and includes the lakeward slopes of the inshore bar field. The

general ferromagnetic target concentration patterns does mirror the firing fan drop zones with highest concentrations lakeward of the eastern half of the FUDS beach. There is also some littoral smearing of the target pattern with the greatest concentrations found on the lakeward side of the bar slope and in the bar troughs. Zones of ordnance concentration appear to be influenced by the nearshore bathymetry. Concentrations increase both in an onshore direction and toward the Range Poles.

Beach. This zone includes the subaerial beach from the dune/vegetation line to water's edge and the inshore bar field out to approximately the 0.6-m (2-ft) water depth (say LWD). This is the area which can be readily exposed as dry beach when southerly winds set down the water surface and includes the zone over which the shoreline has retreated since this site was originally used for military support purposes. The greatest concentrations of OEW finds during the 1992 EODT beach cleanup occur in the same alongshore sectors as the highest concentrations in the nearshore. That is, ordnance on the beach is primarily found in the eastern half of the FUDS beach with the highest concentrations in line with the firing fan pattern (Cove Beach and the Range Poles). The ordnance distribution pattern on the beach is littorally (longshore) concentrated as ordnance is trapped by "stick-out" features and rolls onto and sticks on irregular clay surfaces. New ordnance contamination on the beach appears to be facilitated in areas where the nearshore bar is missing or welding onto the shore. This effect is particularly characteristic of the East Beach.

Conclusions - Site Remediation Issues

Approaches to site remediation could include additional access restrictions, developing of a cleanup schedule and strategy, or even the construction of engineering works. Engineering approaches could be designed to trap ordnance to divert it from reaching the subaerial beach or to facilitate cleanup operations. Evaluation of these various approaches requires a review of some significant findings from this study.

a. There are tremendous quantities of ordnance just lakeward of the beach and the nearshore sandbars. Ordnance in the nearshore bar field is subject to onshore migration and exhibits a tendency for limited alongshore transport.

b. Ordnance concentrations and onshore migration pathways are focused in the southeastern half of the FUDS beach, peaking on the lakeward side of the Cove Beach shoal.

c. Ordnance concentration patterns in the beach and nearshore are consistent with the behavior of bedload transported coarse-grained material in a coastal environment.

d. Ferromagnetic targets in the offshore exhibit little evidence of a net transport dominance, retaining the scatter characteristics associated with a targeted shot pattern.

e. The need for future OEW cleanup operations across the southeastern portion of the FUDS beach is likely.

f. The appearance of ordnance on the beaches in the northwestern half of the FUDS beach is expected to be rare due to a lack of nearshore ordnance concentrations and the wide, shallow, sand shoal complex.

Recommendations - Site Remediation Strategies

The transport and deposition patterns of the ordnance are conducive to the employment of an engineering approach to concentrate or intercept the ordnance. Possible engineering options for controlling OEW contamination on the FUDS beach include:

a. Blocking the OEW from reaching the beach by placing sufficient quantities of sandy material to rebuild the eroding bar field.

b. Removal of the OEW from the naturally concentrated zone lakeward of the bar field, reducing the quantities available to migrate on shore.

c. Installing structural traps, such as groins, along the shore which could concentrate the longshore moving OEW.

d. Excavating depressions in the nearshore (particularly along the OEW transport pathways) to intercept the ordnance prior to reaching the beach.

e. Artificially anchoring the bar field via breakwaters.

f. Building a sill-like structure off the toe of the beach to block future onshore transport.

There are many safety, economic, engineering, and policy issues which must be considered in selecting and designing an engineered approach. Each of the aforementioned alternatives has numerous pluses and minuses which need to be evaluated. Although each approach is feasible from an engineering standpoint, their performance efficiencies cannot be predicted with current data. A criteria would need to be selected for evaluating various engineering alternatives which considers construction and OEW removal costs. These engineered approaches should be weighed against other options, such as an effective restricted access program and the costs on a continuing beach cleanup operation.

The selection of an appropriate engineered alternative would be facilitated by a better understanding of the sediment transport pathways which the ordnance follows to reach the beach. In addition, the actual design for an engineered work would need beach and nearshore survey data for use in positioning any ordnance traps and computing the required material quantities. The pathways and nearshore surface are not always as observed during this field investigation. Beach erosion and storms will change the bar field pattern and continue to drive ordnance onto the beach. Any engineering approach would need to consider the natural variability in the beach and nearshore and the fact that this is a rapidly eroding shore. A trap which blocks ordnance from reaching the beach should be signed so that it does not also block sand from the beach, aggravating the erosion problem. Positioning of any permanent device should consider beach evolution trends or it could become ineffective as the pathways, beach, bar field, and ordnance migrate to different locations.

There are still a number of significant unknowns regarding mobility and pathways for ordnance contamination. The actual offshore extent of the ordnance field which is mobile and could potentially contribute to beach contamination is unknown. The mechanisms of ordnance transport appear to be the result of several factors (i.e., waves, ice, and human (dragging of fish nets toward the shore). The contribution of each factor to the concentration patterns documented during this field study is unknown. Additional geophysical investigations of the ordnance distribution field are needed to fill in some of the data gaps. The conduct of a tagged ordnance (drogue) study in combination with mapping of the inshore bathymetry would help to define the zones of ordnance mobility and transport pathways. Finally, continued mapping of the ordnance finds on the beach (i.e., recording of ordnance finds and removal of data with survey position controls) will facilitate a better understanding of ordnance mobility and contribute toward the development of future site remediation strategies.

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