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AN INTEGRATED GEOPHYSICAL INVESTIGATION OF THE FORT FRONTENAC ARCHAEOLOGICAL SITE IN KINGSTON, ONTARIO

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ABSTRACT

An integrated geophysical investigation of the Fort Frontenac archaeological site was carried out by senior undergraduate and graduate students as part of an applied geophysics course at Queen's University. The objectives of the project were to determine the position of the shoreline of Cataraqui Bay north of the original French fort circa 1670 (now reclaimed land) and to explore for buried ferromagnetic and metallic artifacts in areas of the site not subject to archaeological investigation. Cultural noise problems encountered at the site created difficulties in carrying out the surveys and in interpreting the data.

The position of the shoreline was located by using resistivity sounding and gravity profiling techniques on a reconnaissance scale, followed by a detailed seismic refraction survey to accurately map the bedrock topography. Magnetic and electromagnetic methods were used to locate buried artifacts and, although numerous magnetic anomalies were identified, none of the artifacts recovered were of archaeological significance. The vertical magnetic gradient technique was used successfully to overcome a large horizontal gradation of the magnetic field caused by a nearby building. Electromagnetic techniques were used to delineate a shallow ground conductivity anomaly caused by the remains of a clinker railway bed.

The project demonstrated the relative merits of the geophysical techniques used, and confirmed the need for an integrated geophysical approach in archaeogeophysical investigations.

INTRODUCTION

As part of an applied geophysics course at Queen's University, an integrated geophysical investigation of the Fort Frontenac archaeological site was carried out by senior undergraduate and graduate students during the fall terms of 1983 and 1984. The location of the site is shown in Figure 1.

The project had two objectives: 1) to determine the position of the shoreline of Cataraqui Bay north of the French fort circa 1670 (now reclaimed land), and 2) to explore for buried artifacts in areas of the site not subject to archaeological investigation. The integrated geophysical approach used in both these investigations allowed evaluation of the applicability of different geophysical methods, and provided students with practical experience in the operation of a variety of techniques. Resistivity, gravity and seismic methods were used in the shoreline investigation, magnetic and electromagnetic methods in the artifact investigation. An additional objective, to locate the buried limestone foundations of the French fort, was discussed in a preliminary report of the project by Woods *et al.* (1984).

The section of the Fort Frontenac archaeological site examined in the present study is situated on reclaimed land on the southern shore of Cataraqui Bay immediately north of downtown Kingston (Fig. 1a). The region is underlain by Ordovician, sublithographic limestone bedrock. Within the present Cataraqui Bay, the bedrock drops abruptly toward the centre of the bay and is overlain by an accumulation of glacial lacustrine clays and silts. Onshore the limestone bedrock is covered by 1 to 2 m of overburden. The reclaimed land in Cataraqui Bay is built up with unconsolidated fill material: a mixture of sand, gravel, clay, organics, coal and cinders. It also includes limestone and masonry rubble, and miscellaneous construction debris such as bricks, scrap metal, and railway and dockyard material (Neilson *et al.*, 1984).

The area surrounding the site is industrialized. An iron and steel metal-working building located on the southwestern side of the site created a significant magnetic field disturbance. Other static and transient noise sources included buried pipes and cables, metal fences, power lines and nearby traffic. During the 1984 season it was necessary to coordinate the geophysical surveys

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Scientrex Ltd. is thanked for the temporary loan of its IGS MP-3 magnetometer system, which was critical for the entire project. The Geological Survey of Canada is thanked for the loan of its Geonics EM31 instrument. We are indebted to the 1984 and 1985 applied geophysics classes (in 1985 under the supervision of R.P. Young), and particularly to graduate student demonstrators Hugh Geiger and Michel Allard, for their assistance with the field work. Additional field assistance was provided by Valarie Krentz and Greg Hollyer. Members of the Cataraqui Archaeological Research Foundation, particularly W. Bruce Stewart, Nick Adams and Sue Bazely, are thanked for their patient assistance and guidance in the project. The project was financially assisted by previous contributions to the Applied Geophysics Program at Queen's University from Chevron Resources Ltd. and Mobil Oil Canada Ltd.

with concurrent archaeological activities and construction operations immediately north of the site.

History of the Site

Fort Frontenac was the first European fortification in Upper Canada (Burleigh, 1979). The original log palisade was constructed by the French military on the shore of Cataraqui Bay in 1673 (Fig. 1b), four years after the region was explored by LaSalle. During the period 1680 to 1690 the log palisade was replaced section by section with stronger limestone fortifications. Strategically placed at the junction of Lake Ontario and the St. Lawrence River, Fort Frontenac served as an active terminus for explorers and fur traders. Two years before the defeat of the French in Lower Canada in 1760, a mixed force of British regulars and colonial troops captured Fort Frontenac, destroying some of the foundations. The fort was then abandoned until 1783, when it was reoccupied by British forces in conjunction with the arrival of United Empire Loyalists from the United States. During the time from 1816 to 1820, the last structures from the French period were demolished, and some of the debris was used as landfill material in Cataraqui Bay. Concurrently, a new limestone-walled military complex was constructed by the British on the site of the original French fort.

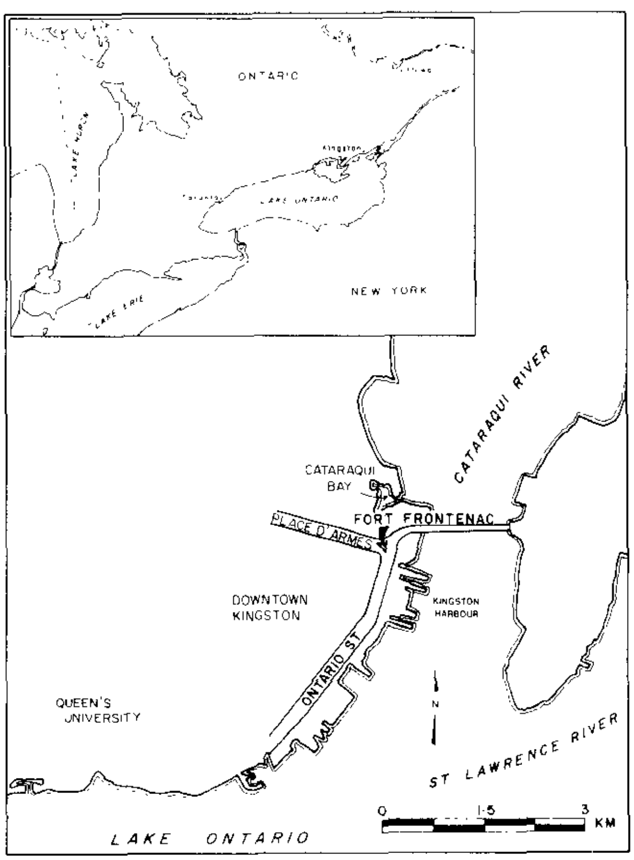

Fig. 1a. Location map of the Fort Frontenac archaeological site near Kingston, Ontario. Map courtesy of the Cataraqui Archaeological Research Foundation.

In 1982, members of the Cataraqui Archaeological Research Foundation began archaeological investigations at the Fort Frontenac site. Numerous cultural artifacts including regimental insignias, gun parts, ceramics, leather goods and tools have been recovered. Walls and foundations of the various fortifications have been unearthed as well as timbers from several wharfs (W.B. Stewart, *pers. comm.*). Unfortunately, archaeological investigation of the reclaimed land area of the site was terminated in late 1984 by the construction of condominiums.

Shoreline Investigation (1983)

Survey Design and Procedures

The objective of this investigation was to determine the pre-landfill position of the shoreline of Cataraqui Bay immediately north of the original French fort. Presently existing natural shorelines in the Kingston area are characterized by stepped limestone bedrock whose elevation decreases rapidly into the bay or lake basin. Isostatic rebound and water-level changes have had only a minor influence on the shoreline position over the past 300 years (Sly and Prior, 1984). Thus, the pre-landfill shoreline is defined by where the present lake level would intersect bedrock underlying the landfill.

The problem of determining bedrock topography beneath unconsolidated sediments is common in engineering and groundwater investigations. A reconnaissance survey using DC resistivity sounding and gravity methods, followed by a detailed seismic refraction survey, has been found to be an effective approach (van Overmeeren, 1981). A similar approach was adopted here because large contrasts in electrical conductivity, density and seismic wave velocity were expected between the unconsolidated landfill and the limestone bedrock.

The DC resistivity sounding technique was used to compare the overburden depth between a line located onshore near the fort site and a line located on reclaimed land. The survey consisted of two parallel Wenner arrays separated by a distance of 80 m (Fig. 2). On both lines, cultural obstacles limited the expansion of the array.

A gravity profile oriented perpendicular to these lines complemented the resistivity data. The survey was carried out with a Worden-type gravity meter. Stations were located every 4 m along the profile, and relative elevations were measured with a transit and level.

A buried shotgun source was used in the reversed seismic refraction survey with a symmetrical end, centre and end-offset geophone spread. A geophone spacing of 2 m was used for high resolution of the shallow limestone bedrock topography. Seismic signals were recorded with a 12-channel, signal enhancement, Oyo 1500 seismograph.

Results and Interpretation

The Wenner sounding data shown in Figure 3 display an over-all three-layer resistive-conductive-resistive response typical of DC resistivity soundings in the Kingston vicinity (Speirs, 1969), where resistive limestone bedrock is unconformably overlain by conductive glacial clays and tills, which are in turn overlain by more-resistive soils above the water table. Although there are discrepancies in the pattern, particularly for the north sounding data, that suggest additional layering and the effect of lateral inhomogeneities in the surficial landfill material at small electrode separation, the three-layer curve-matching technique (Elliot, 1974) has been used to interpret the data. Such a simple approach is justified in this case because of the limited data available for interpretation, and because only approximate depths are required from this reconnaissance survey.

The interpreted sections are shown in Figure 3. The south sounding gives a depth to bedrock of approximately 1 m as compared with the north sounding, where more than 10 m of overburden is interpreted. The water table at both soundings is interpreted to be about 0.5 m deep. Differences in resistivity values between the two interpreted sections, a consequence of the simple curve-matching techniques used to make the interpretations, are of less significance than the high resistivity contrast between the overburden and the limestone bedrock. The most important feature to note is the considerable increase in overburden thickness from the south sounding to the north sounding. From this it can be inferred that the pre-landfill shoreline was located between the two sounding positions.

The second component of the shoreline investigation was a gravity survey. Figure 4 shows the profile of Bouguer anomaly data relative to the base station at 0 m. The field data were reduced by applying free-air and Bouguer corrections. Terrain corrections were not applied because of the low relief at the site, and the regional gravity gradient was determined to be insignificant over the short distance surveyed (Stephens, 1970).

The northward-decreasing trend of the Bouguer data is interpreted as a corresponding increase in thickness of low-density overburden to the north. This result concurs with the findings of the resistivity survey. The isolated high at 28 m is believed to be the result of either operator or instrument error, as no buried inhomogeneity was found when the site was excavated. A shallowly buried structure of thick limestone blocks, uncovered during archaeological excavations in 1984, may be the source of the gravity peak centred at 44 m.

The final component of the investigation was the detailed seismic refraction survey. Figure 5 is a time-distance graph of the refracted first arrivals picked from

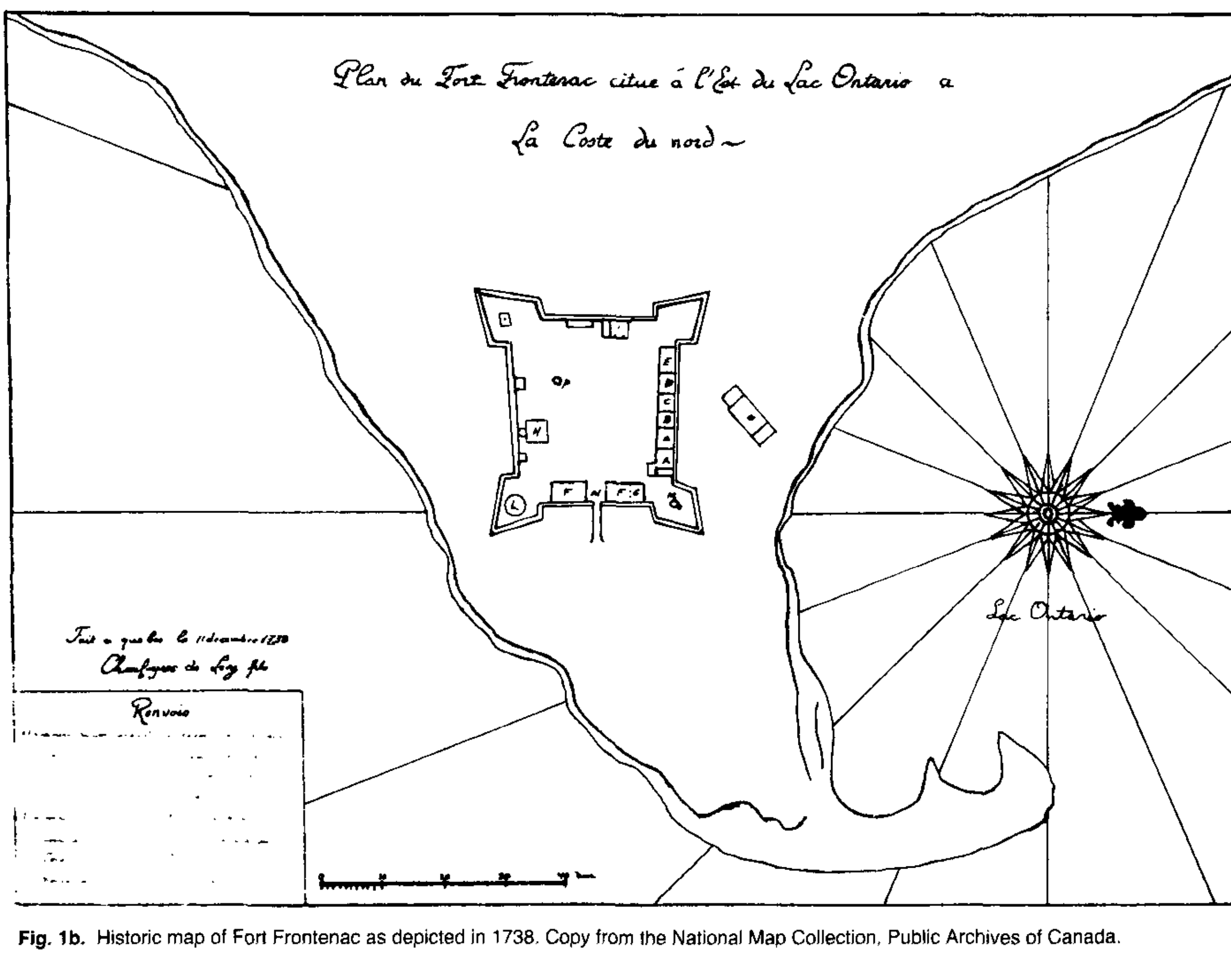

Fig. 1b. Historic map of Fort Frontenac as depicted in 1738. Copy from the National Map Collection, Public Archives of Canada.

the seismograph field records. Intercept-time, delay-time, and the plus-minus methods of interpretation (Hagedoorn, 1959; Redpath, 1973) were used to construct the seismic velocity section illustrated beneath the graph.

Within the upper layer of heterogeneous landfill material, seismic waves propagated at a velocity of 400 to 450 m/s. No distinction is noted between material above and below the water table. At the southern end of the profile, the overburden lies directly on limestone bedrock, which has an average seismic velocity of 5200 m/s. This relatively high velocity is typical of the sublithographic limestone of the Kingston region (McConnell, 1984). The bedrock decreases in elevation stepwise northward into Cataraqui Bay. A layer of intermediate velocity (1800 m/s) was found between the landfill and bedrock within the basin. Excavation in 1984 revealed that this layer is composed of glacial clays and silts. The nature of the material within the three layers can be seen in Figure 6.

The pre-landfill shoreline is interpreted to lie between 16 m and 20 m along the seismic line at the position of the first major elevation decrease in the bedrock topography. This corresponds to a location about 30 m along the gravity line (Fig. 2). Archaeological activity, which was concentrated in this area in 1984, confirmed our depth to bedrock estimates and our interpretation of the shoreline position. As can be seen in Figure 7, heavy timbers and posts, interpreted as remnants of a wharf structure dating to the late French or early British period (W.B. Stewart, *pers. comm.*), were recovered.

ARTIFACT INVESTIGATION (1984)

SURVEY DESIGN AND PROCEDURES

The objective of this investigation was to locate buried artifacts in areas of the site that were not examined by archaeological methods. Numerous artifacts, which had presumably been discarded in the bay or perhaps lost during shipping activities, were recovered during excavation of the shoreline area. Ferromagnetic and other metallic objects were representative of the targets sought in the geophysical investigation. In addition, the archaeologists were interested in determining if there was any geophysical evidence of buried cannons purported to have been dumped into the bay by the French to prevent their being captured by British forces.

As a result of the geophysical shoreline investigation in 1983, and subsequent archaeological excavations, the nature of the exploration environment was well established. While geophysical anomalies were expected to result from recently buried objects within the upper two metres of landfill, artifacts of greater historical interest were expected to be at the base of the landfill resting on the hard clay layer at depths of 2 to 3 m.

A detailed magnetic survey, which consisted of total field strength and total field vertical gradient measure-

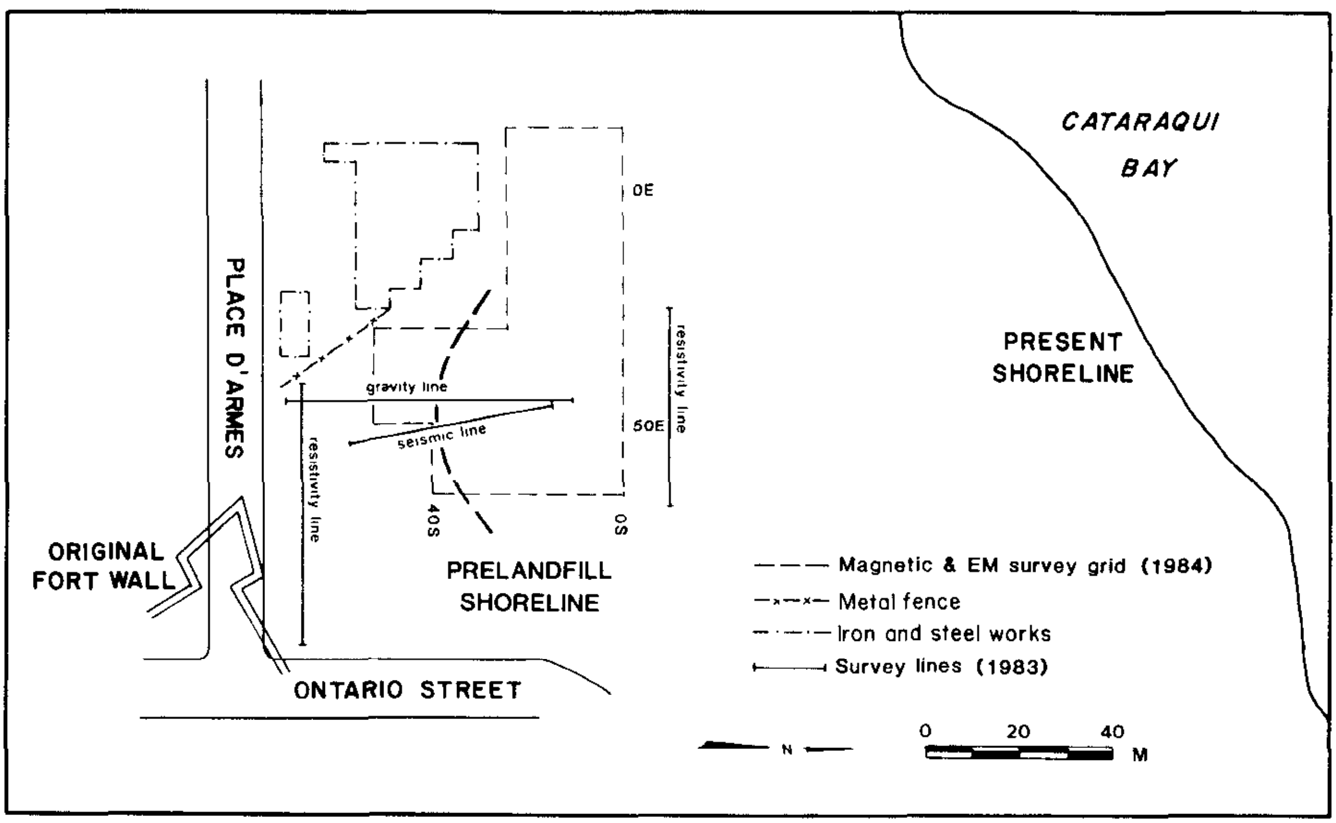

Fig. 2. Location map showing the positions of the resistivity, gravity and seismic surveys carried out in 1983, and the magnetic and electromagnetic survey grid used in 1984.

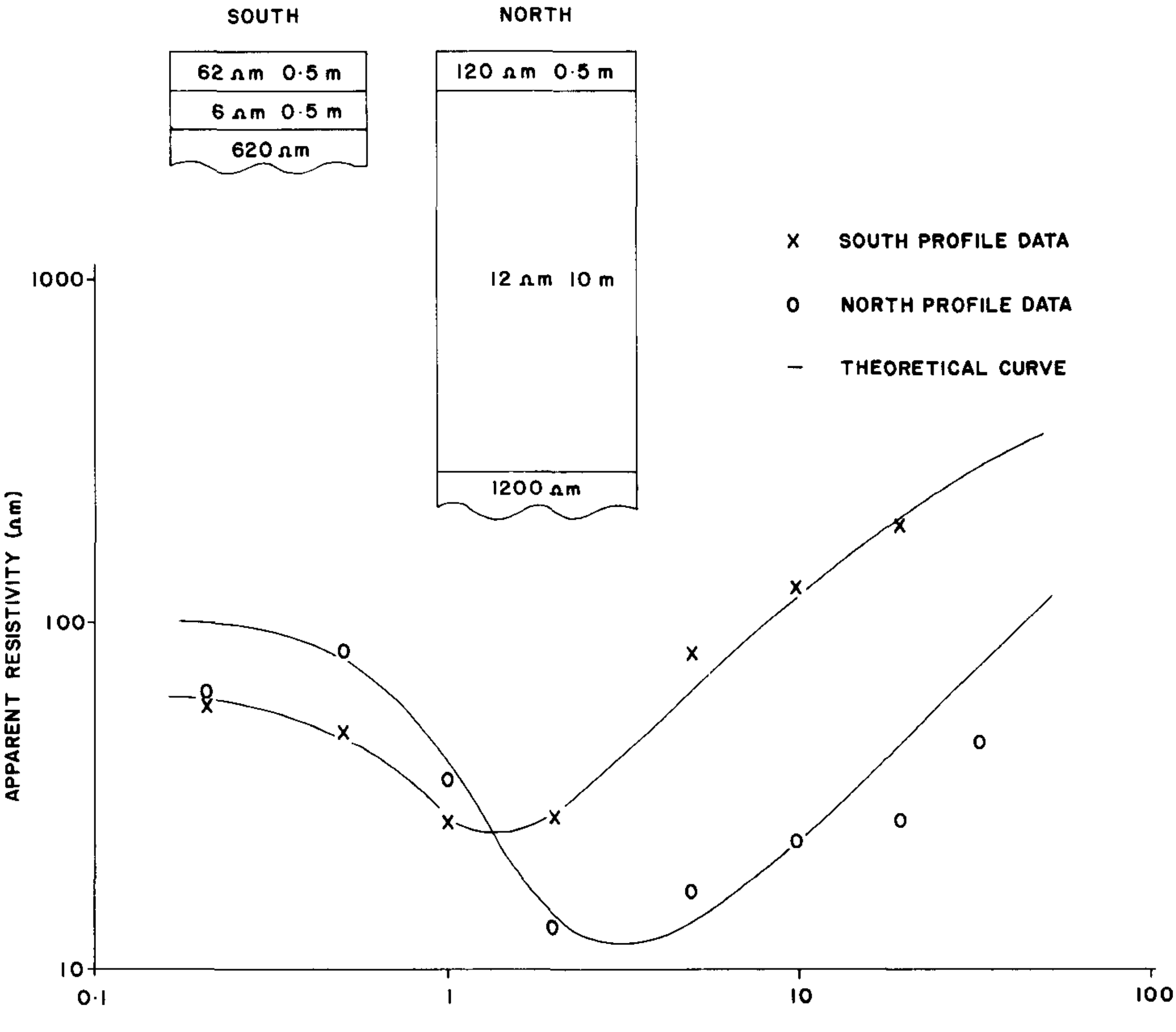

Fig. 3. DC resistivity sounding data and interpreted sections using three-layer curve-matching techniques from Elliot (1974).

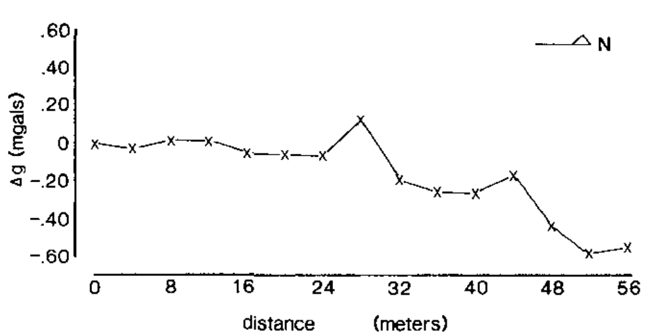

Fig. 4. Bouguer-corrected gravity anomaly data reduced to relative gravity with respect to station 0.

ments taken on a one-metre grid, was carried out over most of the archaeological site (Fig. 2). A Scintrex MP-3 proton precession magnetometer connected to an IGS-2 digital recorder was used in the survey. The system has a resolution capability of 0.1 nT. Sensors were mounted on a staff at heights of 2 and 3 m in order to reduce the influence of near-surface noise sources. The lower sensor was used for total field strength measurements. A base station on-site provided diurnal drift corrections.

Two electromagnetic surveys were carried out at 4-m intervals over a portion of the site to explore for nonmagnetic, metallic artifacts (Fig. 2). A hand-held rigid boom device, the Apex Double-Dipole, was used for shallow investigation. The Double-Dipole instrument measures the in-phase and quadrature response at a frequency of 8,000 Hz. A horizontal-loop electromagnetic (HLEM) survey with a 25-m coil separation was carried out with an Apex Max-Min II instrument. The Max-Min II system was operated at 3555 Hz and 444 Hz. The HLEM technique is generally not suitable for archaeological investigations because of its lower resolution but was included here for teaching purposes.

Results and Interpretation

Contoured total magnetic field strength data are shown in Figure 8. The most prominent feature in these data is the rapid decrease in field strength toward the metalworking factory southwest of the grid (Fig. 2.) The overwhelming influence of the magnetic field disturbance from this structure is demonstrated by the concentric orientation of the contour lines around the southwest quadrant of the grid. Weak anomalies from small buried sources would be either masked or distorted by this large "regional" field gradation. The influence of this disturbance was effectively minimized by using the vertical gradient technique as shown in Figure 9. A further advantage of the gradiometer technique is its inherent ability to resolve composite or complex anomalies into their individual constituents, such as those in the northeast quadrant of the grid.

The isolated section of grid bounded approximately by lines 46E, 59E, 25S and 37S is the location of an archaeological pit approximately 2 m deep. The low-amplitude, elliptical anomaly near the centre of the pit

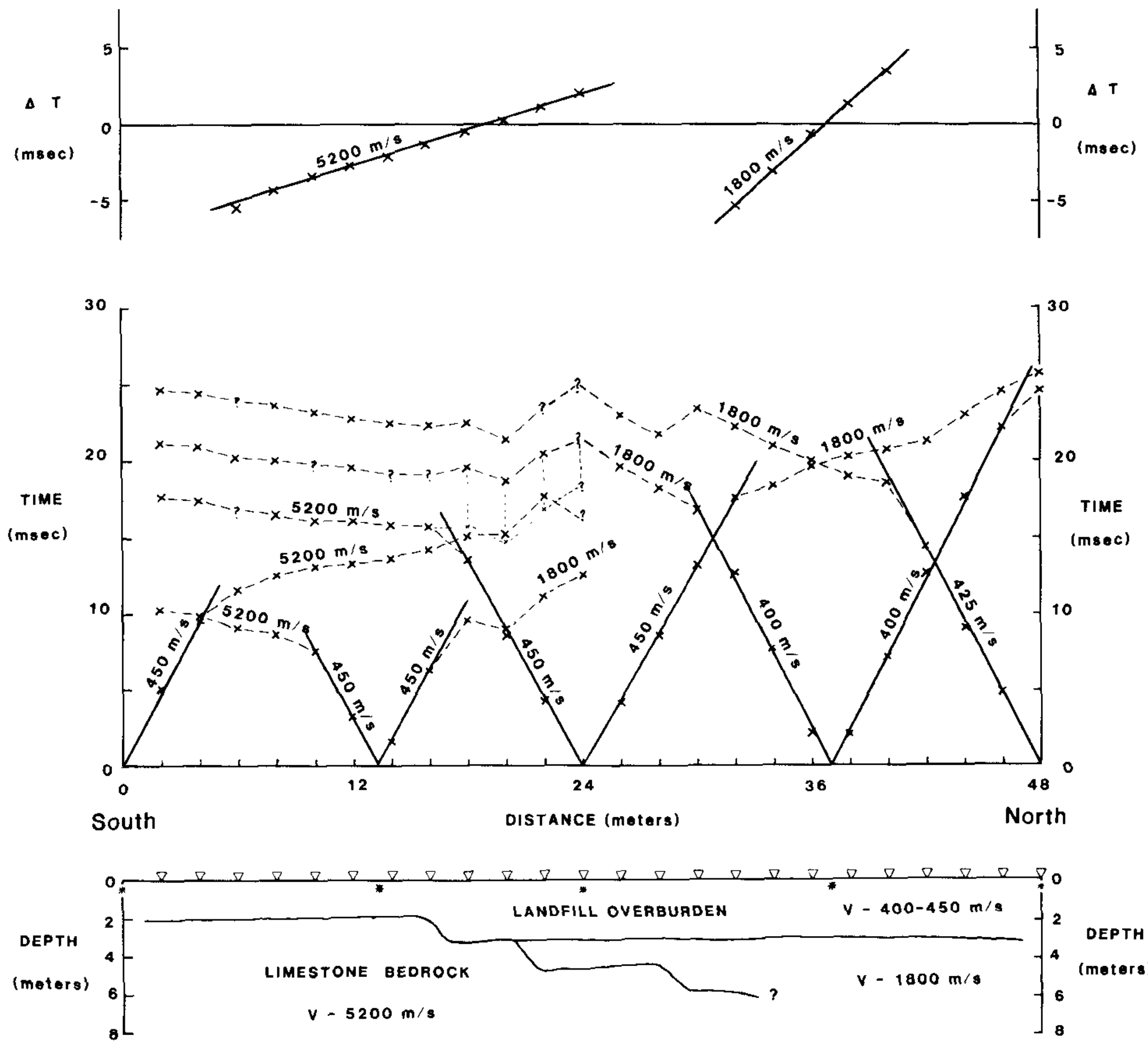

Fig. 5. Seismic refraction data and interpretation using intercept-time, delay-time and plus-minus techniques.

Fig. 6. Stratigraphic section near the original shoreline. Limestone bedrock, visible at the bottom right, is dipping to the north (right to left). The clay layer is visible between the limestone and the heterogeneous landfill material in the demarcated pit. The well-defined layering in the landfill records the stages of the land reclamation process.

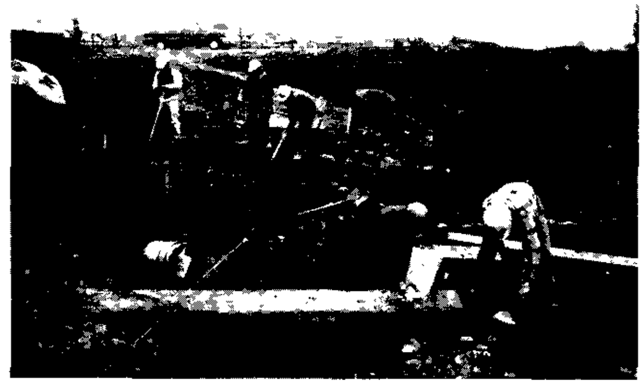

Fig. 7. Excavation of the shoreline area (looking north). The interpreted shoreline would pass left-right through this photo. The heavy timber and wooden post in the foreground are believed to be remnants of a 19th century wharf structure. Photo courtesy of the Cataraqui Archaeological Research Foundation.

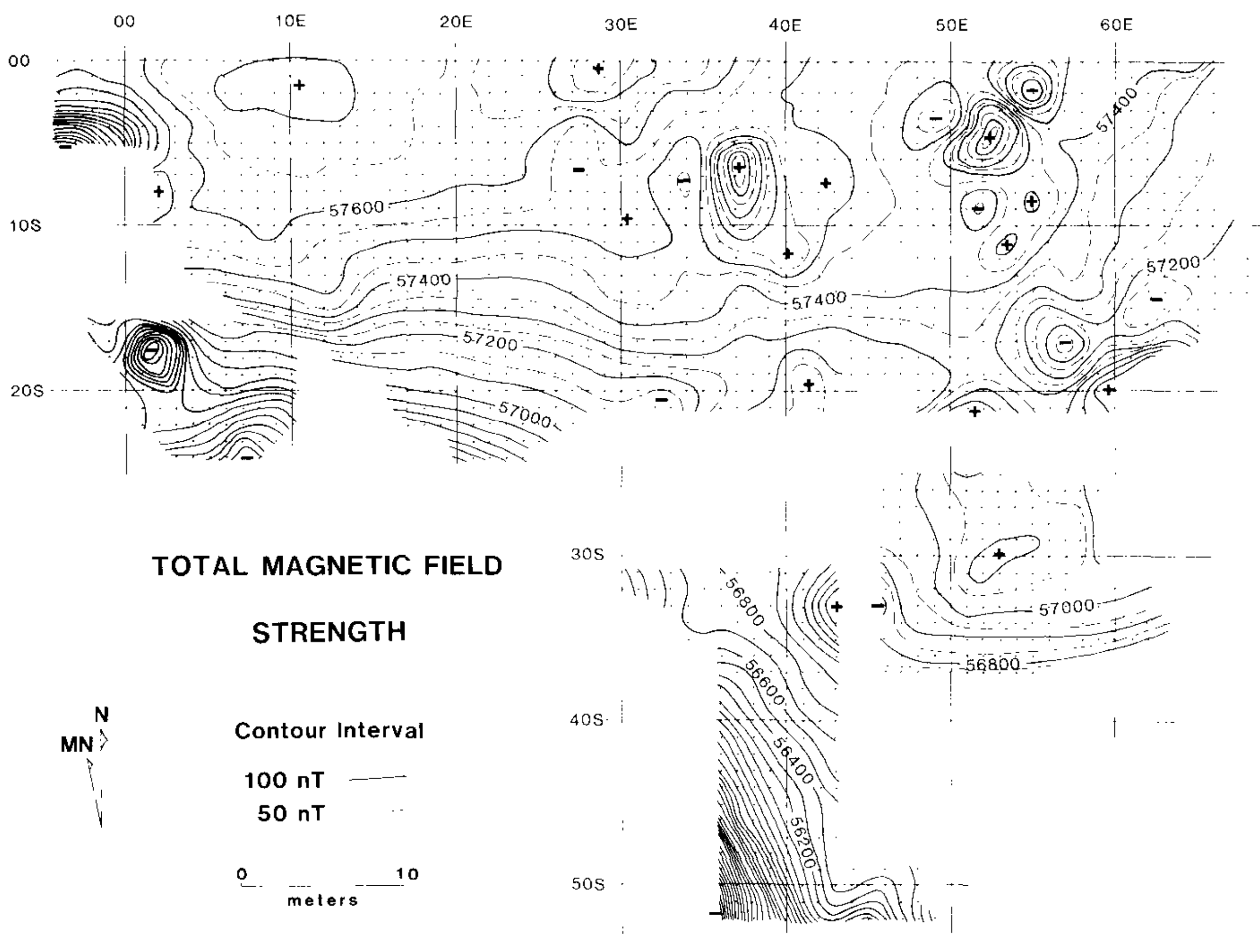

Fig. 8. Contoured total magnetic field strength data over the archaeological site. Each dot represents a measurement location.

is caused by a piece of sheet metal buried a few centimetres beneath the pit floor. On the southwest edge of the pit is a partially defined negative anomaly next to a similarly defined positive anomaly 3 m immediately to the west. This unusual geometry is a result of the 2-m difference in sensor elevation between the east and west locations. A collection of shallowly buried iron artifacts from twentieth-century railway activity is the source of this anomaly.

A negative vertical gradient is prominent adjacent to the pit walls. The amplitude of this gradient is inversely proportional to distance from the wall, being essentially negligible at distances exceeding 1 m. This implies that the landfill material has a substantial magnetic susceptibility. It is, therefore, reasonable to expect the total magnetic field strength to increase northward into the basin of Cataraqui Bay in response to the thickening wedge of landfill above the lacustrine clays and limestone bedrock. Such a trend is particularly noticeable in the northeastern quadrant of the grid, where the total field strength contour lines parallel the inferred shoreline position.

Several of the anomalies in other parts of the site are associated with above-ground objects. Metal fences and a steel I-beam account for the large, negative amplitude anomalies at 4W/5S and at 36E/52S. The apparently monopolar negative anomaly centred at about 2E/18S is associated with a large metal garbage bin located a few metres to the west. An iron stake and a partially buried cable are the sources of the positive anomalies near 34E/34S and 43E/51S respectively. Iron debris contained within a pile of excavated landfill is believed to be the cause of the anomaly near 4E/24S. The combined effects of shallowly buried telephone cables and surface iron debris produced the disordered pattern of magnetic highs and lows in the vicinity of 60E/20S.

Two prominent anomalies are located at 37E/7S and 53E/4S and will be referred to as anomalies "W" and "E" respectively. Anomaly W is the simpler of the two with a dipolar geometry, an amplitude on the order of 350 nT above the ambient field, and a wavelength of approximately 5 m. The west-southwest trend of the dipole is approximately at right angles to the ambient

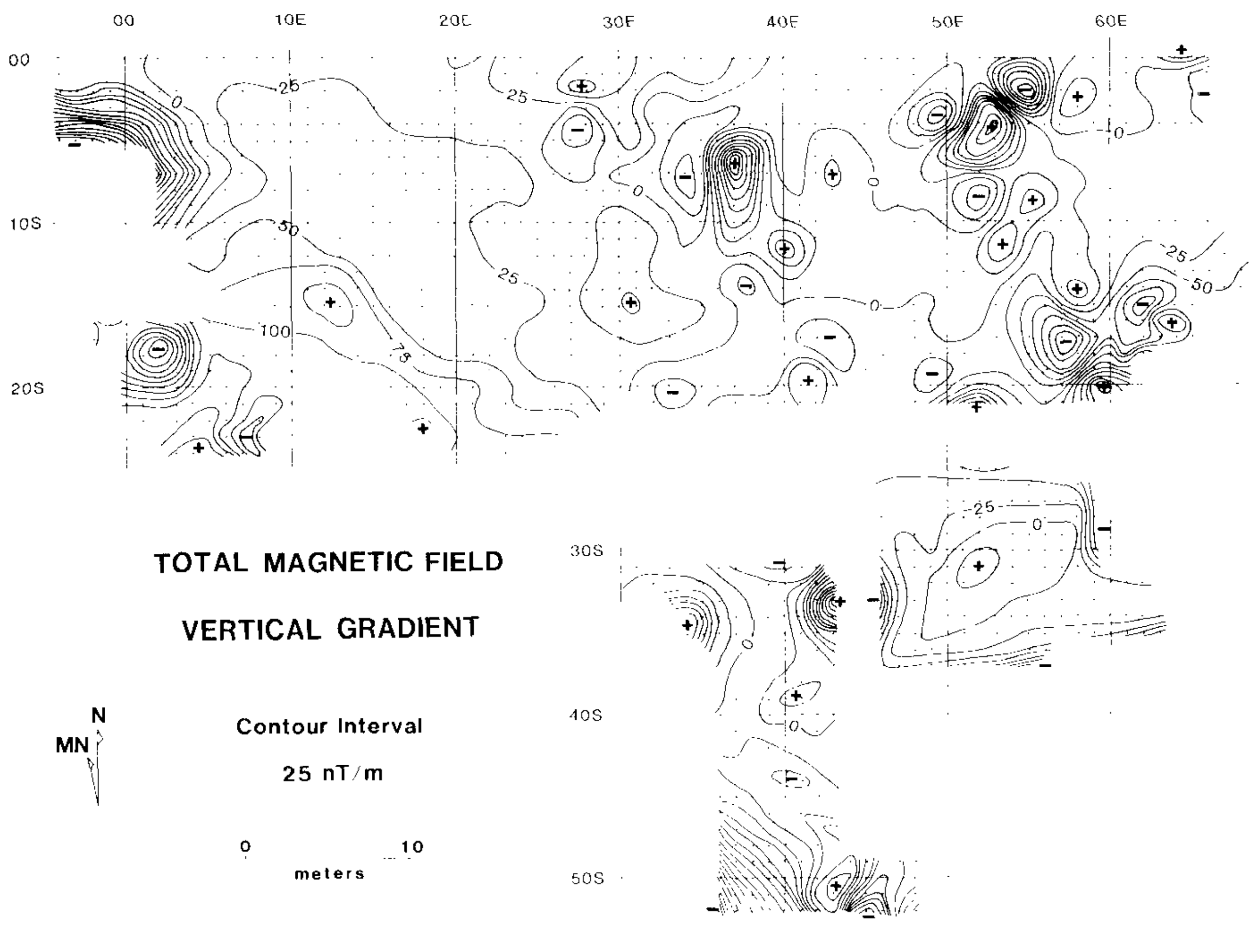

Fig. 9. Contoured total magnetic field: vertical gradient data over the archaeological site as in Figure 8.

field declination of 11° W, indicating a significant component of remanent magnetization. These features suggest a shallowly buried iron object, or concentration of objects, as the probable source. The shallow nature of the source is supported by empirical depth calculations (*e.g.* depth equals 0.65 times the half-width of the anomaly, or 2.0 times the ratio of maximum gradient anomaly to maximum total field anomaly for a point source), which give a maximum depth of 2.5 m.

Anomaly E appears to consist of a pair of dipoles at right angles to each other. There are two well-defined negative peaks situated to the northeast and northwest of an elongated positive peak. The negative peak to the northeast has an unusually large amplitude (250 nT below the ambient field) relative to the positive peak, resulting in a maximum peak-to-peak difference of approximately 600 nT. A strong component of remanent magnetization is again indicated by the nonalignment of both dipole trends with the ambient magnetic field declination. The large amplitude and sharply defined wavelength of this complex anomaly qualitatively indicate a shallowly buried iron source.

Other smaller-amplitude and greater-wavelength anomalies can be seen in the vertical gradient data in Figure 9, suggestive of more deeply buried or weakly magnetized objects. Most of these anomalies were found to be due to various iron or steel objects in the landfill

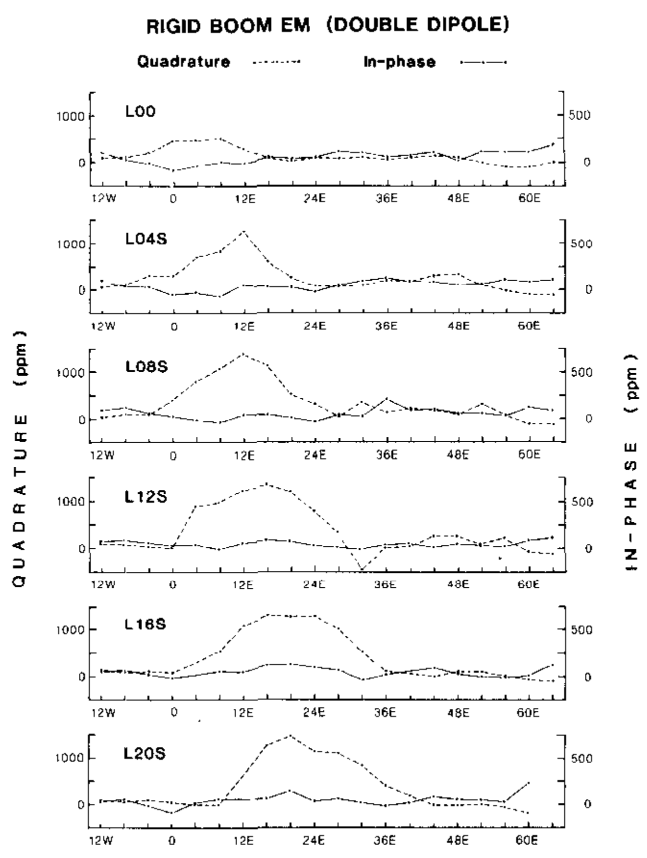

Fig. 10. Rigid-boom (Double-Dipole) electromagnetic profiles showing in-phase and quadrature responses. Note difference in scale between in-phase and quadrature plots.

material when the site was prepared for condominium construction.

The rigid-boom electromagnetic data shown in Figure 10 provide further information on the nature of magnetic anomalies W and E. At 36E/8S, approximately 1 m south of anomaly W, the EM profile is characterized by a positive in-phase response, 140 ppm above background, and a nonanomalous quadrature response. In view of the high operating frequency (8 kHz), and hence the large response parameter of the Double-Dipole system, this indicates a metallic target of moderate conductivity. There is no anomalous electromagnetic response associated with anomaly E, suggesting that the source either is very small or has low electrical conductivity.

During preparation of the site for condominium construction, the top 1.7 m of landfill was removed from portions of the survey area. Unfortunately, this resulted in the removal of the source objects of both anomalies W and E without establishing their identity. However, their removal, which was confirmed by a walk-over magnetic survey of the immediate area a few days later, proved that they were shallowly buried.

The most prominent feature in the rigid-boom EM data is the large-amplitude quadrature phase anomaly, which can be correlated across all six survey lines. This broad, positive quadrature response with little appreciable in-phase response is characteristic of a zone of enhanced ground conductivity. Excavation revealed that the source was a very shallow (<0.5 m) bed of "clinker" (coal furnace slag material) which served as a foundation base for a nineteenth-century railway spur. The variable thickness of this bed, ranging from a few centimetres to about one metre, accounts for the variations in the rigid-boom profile shapes.

Horizontal-loop EM data are shown in Figure 11. At both frequencies the in-phase data are essentially featureless with random 5% deviations, which are considered to be within the background noise level. At 3555 Hz there are small, negative in-phase responses at 20E to 24E and 40E to 44E, particularly on lines 4S and 8S. These anomalies are supported by much stronger coincident responses in the quadrature phase and are probably due to ground conductivity variations. In particular, the clinker bed produces a large, negative response at or near the west end of the profiles. The absence of an anomalous response at the lower frequency is indicative of the thin, relatively poorly conductive nature of the clinker bed.

Discussion

The case study presented here represents an application of geophysical methods to two very different problems within the context of an archaeological investigation. Both projects demonstrated the usefulness of an integrated geophysical approach.

In the shoreline investigation, an efficient approach was found to include either resistivity sounding or gravity profiling on a reconnaissance scale, followed by detailed seismic refraction surveys in areas of interest. Resistivity sounding may be preferable to gravity profiling because of the ease of field operations and data analysis. The choice ultimately depends on the expected physical property contrasts of the subsurface media, the depth of investigation and the lateral homogeneity of the surficial material.

The results of the artifact investigation support the magnetic method's reputation as the primary geophysical tool for archaeological purposes. Although all the techniques were (to varying degrees) adversely influenced by the problem of cultural noise, only the total magnetic field strength data were seriously affected. The success of the vertical gradient technique in overcoming the large regional field gradation underscores the desirability of using a combination of geophysical techniques.

Electromagnetic techniques have not been used extensively in North American archaeological applications, possibly reflecting the fact that prehistoric sites are commonly devoid of metallic artifacts (Weymouth, 1984). In Europe, electromagnetic techniques have received more attention and have been used successfully, for example, in locating Bronze Age hoards (Tabbagh, 1984). In this study the electromagnetic techniques did not locate any additional artifacts, although the rigid-boom data were a useful adjunct to the magnetic data. The resolution of the HLEM technique was, as expected, inadequate for detection of shallowly buried archaeological artifacts.

The usefulness of geophysical methods in providing a preliminary assessment of a site's archaeological potential has been established. An often overlooked extension of this work, however, is the information that can be derived concerning site parameters. For the archaeologist, *a priori* knowledge of the subsurface conditions (*e.g.* water table depth), particularly at poorly documented sites, can be of invaluable assistance in designing a suitable archaeological investigation.

Finally, our experience in this project has emphasized the important role that good communication between archaeologists and geophysicists plays in contributing to a successful project. Despite considerable differences between the two disciplines, steady interaction can result in a geophysical survey that is well matched to the archaeological environment and will be most beneficial to the project. In the long term, good communications will lead to a better mutual understanding of the unique and interesting features of archaeogeophysics.

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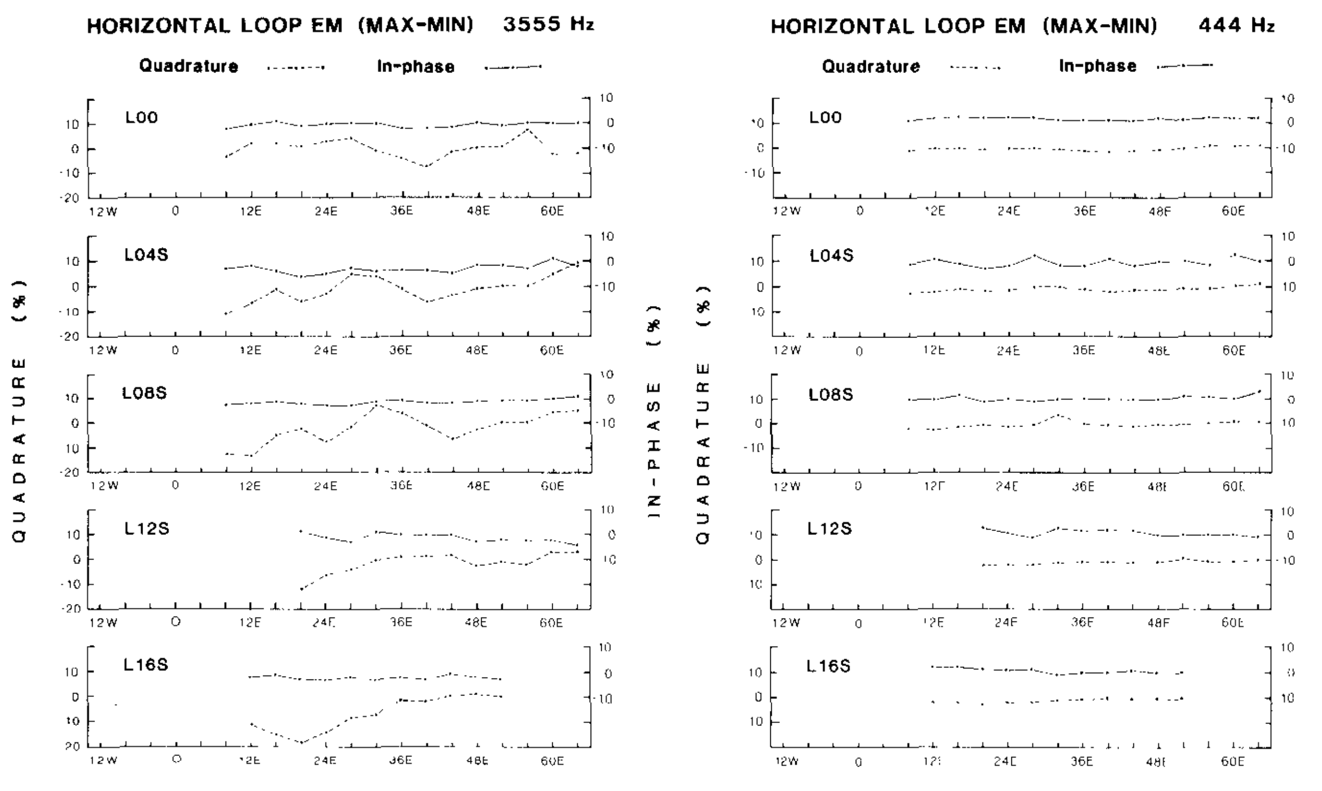

Fig. 11. Horizontal-loop (Max-Min II) electromagnetic profiles showing in-phase and quadrature responses at a frequency of 3555 Hz and 444 Hz.

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