CASE REPORT

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The Search for "Yvonne": A Case Example of the Delineation of a Grave Using Near-Surface Geophysical Methods

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ABSTRACT: Shallow electromagnetic (EM) and ground-penetrating radar (GPR) surveys were conducted in an area north of Auckland, New Zealand to assist the search for human remains. The body had been buried for almost 12 years in a plantation forest that was irregularly disrupted and modified by tree harvesting and the partial removal of stumps. EM identified anomalous areas of potential interest, because a target need only be nearby to generate an EM response. GPR was then used to map subsurface layering, layering disruption, and buried objects, immediately adjacent to an EM anomaly. Because of the nature of the site, numerous geophysical anomalies were present. GPR was particularly sensitive to site disturbance resulting from the forestry operations. An isolated EM anomaly on the fringes of an expanded survey area was coincident with the location of the body. Whether for criminal investigations or for archaeological work, a combination of geophysical techniques is recommended.

KEYWORDS: forensic science, geophysical surveys, electromagnetic methods, ground-penetrating radar, human remains

Shallow geophysical surveys were carried out in a plantation forest outside of the city of Auckland, New Zealand, to aid in the location of the remains of a victim who had been buried in the forest almost 12 years ago. Because the case may still be subject to appeal, the details of the victim and the accused, as well as details about the site where the body was found, are excluded from this discussion. However, as much information will be provided about the location where the survey was conducted and where the body was subsequently found to provide the context within which the survey was conducted.

The victim will here be called "Yvonne." She had disappeared under suspicious circumstances, and her partner had been the prime suspect for most of the previous 12 years. The assailant finally came forward, for reasons that need not be outlined here, and directed police to the site. However, regular forestry operations and a change in the positions of the internal access roads hindered the investigation, and the position of the grave could not be readily determined. Geophysical surveys were thus carried out in order to identify those areas of the site that merited more detailed examination, and the results of those surveys are summarized here. The success of the surveys was not known until subsequent extensive excavations unearthed the body, but an isolated anomaly, located on the fringes of the survey, and outside the primary search area as defined by the suspect and by the police, was found to be coincident with the location of the body.

Radar has been successfully used in archaeological surveys (1–3), and with limited success in the delineation of graves (4,5). More recently, a radar survey mapped the locations of older graves placed in permafrost (6), and a combination of electromagnetic (EM), magnetic and GPR methods were successfully used to delineate graves in an indigenous burial site (7). A few studies have examined the utility of geophysical techniques in forensic work (8), but the success or failure mainly depends on the local conditions and complexity of the survey site. In addition, forensic tests have generally focussed on the detection of recent shallow graves, not older, deeper burials.

The search location will be briefly described, and the choice of the geophysical methods and the design of the surveys will be discussed. The results are presented and discussed in the context both of the ultimate success of the search for the body and the nature of the location.

Survey Design

Survey Sites

Access to the sites was from a road running east-west, with a secondary road running north from a T-junction with the main access road (Fig. 1). At the time of burial, however, the north-south road continued to the south, whereas the east-west road ended at the intersection. The "T" had thus been rotated, causing some confusion about the location of the body. Thus, two neighboring sites were surveyed (Fig. 1). The time allotted to the surveys was extremely limited, and the survey design and coverage were affected.

The topography was gently to moderately sloping to the north and, to a lesser extent, to the east, down and away from the access roads. The sites were lightly to moderately wooded with young trees. Old stumps were abundant; there were, however, areas where stumps did not exist at the time of the surveys, though there may

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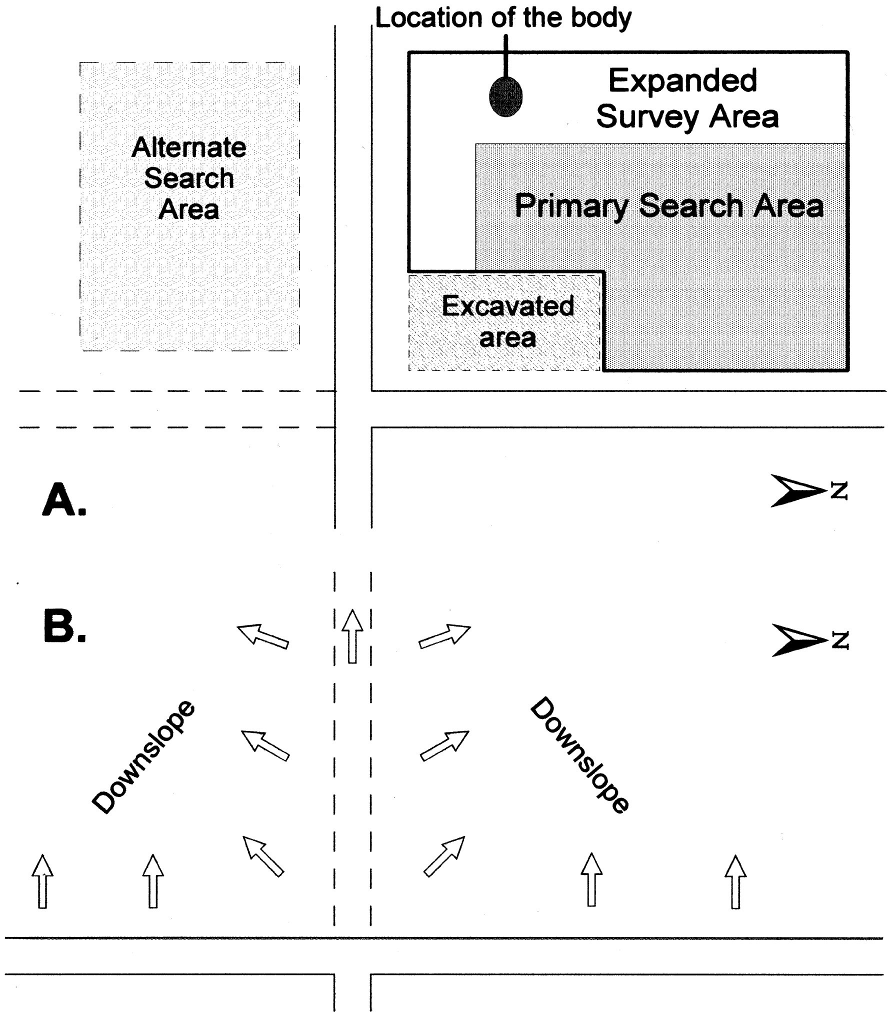

FIG. 1—*Sketch plan of the site, not to scale, showing the configuration of the access roads at the time of the investigation* (A) *and the locations of the geophysical survey area. The primary and alternate survey areas are shown shaded. The primary survey area was expanded, as shown, and the victim's remains were found approximately in the location indicated. The configuration of the access roads were different when the victim was buried* (B), *leading to some confusion about the exact location of the body.*

have been large trees in those areas at some time in the past. It was expected that the body would be located behind (to the north of) a large stump, but given that the stump may not have survived, there was some uncertainty in that expectation. From the testimony of the accused, the body was buried first in a shallow grave, and then later transferred to a deeper grave, of the order of 1.2 m deep (4 ft), adjacent to the first grave.

The soil was a well-drained, medium-grained sand, on average, with occasional pockets of silt or clay. Iron sands were common, and occurred at depths of the order of 1 m. The water content of the soil was not known, but given pore space typical of sand, the water content could range from less than 1% (very dry) to 30% (almost saturated). The conditions had been dry for a long period prior to the surveys, but during excavation, a small amount of moisture was observed to have been trapped below the near-surface dry zone.

Geophysical Methods

An anomalous geophysical response due to a buried body may be caused by a number of factors: (1) the displacement of soil by the body; (2) the clothing; and (3) the soil disturbance from the grave itself. Much of the effect will be due to changes in local moisture content, which has the greatest influence on the electrical properties. Clay and metal also affect the electrical properties (9,10), but clay is not present in significant quantities at the site, and is thus not a consideration here. Because of the speed and ease of use, an electromagnetic (EM) method was selected for the main survey. Some other methods that could potentially be useful include magnetic and electrical resistivity methods, but ground-penetrating radar was selected as a survey method to examine potential targets in more detail.

The electrical conductivity increases as the water, clay, or metal content increase, and as the concentration of dissolved ions increases in water. Clothing may keep moisture out, in which case the electrical conductivity will be lower, or trap moisture within, and thus lead to an enhancement of the electrical response. That is, the contrast between the electrical conductivity of the surrounding soil and the grave may be increased by the presence of the clothing. There may also be enough metal present in clothing and in jewelry to yield an enhanced response. The response from bones is not known. The cross-section of the body or bones may be enough to cause an anomalous radar response, by scattering the radar signal, but if a site is significantly disturbed, the target response may be masked by the background site variations. A combination of effects could cause either a larger or a smaller geophysical response, depending on the soil conditions at the time of the survey. We do not know, a priori, what response to expect.

Two complementary methods were used: a Geonics EM31™ soil conductivity meter (Fig. 2), with approximately 5.5 m of penetration but with a peak response in the 1 to 1.5 m depth range (9), and a Sensors & Software pulseEKKO IV™ ground-penetrating radar (GPR) system (Fig. 3). The EM31 is a shallow horizontal-loop electromagnetic (EM) instrument. A small loop at one end of a 3.66 m long boom transmits a signal at a frequency of 9.8 kHz (kilohertz, or thousands of cycles per second). The signal induces an electric current to flow in the ground; this induced current in turn generates a secondary EM field, which yields a response in the receiver loop at the other end of the boom. The secondary field is compared with the transmitted (primary) signal, and split into two parts: a quadrature response, which is sensitive to the bulk electrical conductivity of the ground, and an in-phase response, which is primarily a measure of the magnetic properties of the ground and is thus particularly sensitive to the presence of metal. The quadrature response is normally quoted in millisiemens per meter (mS/m), and the in-phase part is normally given in parts per thousand (ppt) of the primary transmitted signal. Because the EM technique generates a response from an underlying volume of material (3), then the EM31 only needs to pass near the target to elicit a response. The EM31 has been used successfully in archaeological surveys, where the type and size of the targets are similar to the target in this case (7).

A specific EM anomaly is identifiable when the target response is anomalously high or low relative to the readings around it. Thus the response from a buried object must be great enough to exceed the sensitivity of the survey instrument, and exceed the natural background variability. A large number of anomalous responses were noted, as will be discussed later, including an anomaly due to the victim's body.

The GPR transmitting antenna sends out a pulse of high-frequency EM energy, and the GPR receiving antenna measures the "echo" returned from subsurface discontinuities and boundaries (11). In order to obtain a GPR response, the target must lie beneath, or very near, the radar antennas. The GPR response depends on changes in the subsurface water content; only a few per cent change will generate a radar reflection (12). A discrete target, however, to be detected, must be larger than one-quarter of the radar wavelength (11,12), and the wavelength will vary with the moisture content of the ground and the frequency of the radar signal. If the sand at the survey sites were completely dry, then the minimum resolvable lateral dimension would be approximately 19 cm using a 200 MHz antenna; if the sand were completely saturated, which was not the situation, then the minimum resolution would be approximately 7 cm. The resolution, the size of object that can be detected, could be expected to be of the order of 15 cm. A higher frequency can be used to yield better resolution, but that can often lead to too much detail, and the target may not be readily identified (5,7). For the survey to locate Yvonne, target resolution was paramount, and the depth to the target was not expected to exceed 1.5 m. Hence the highest frequency available for the standard pulseEKKO system that was operational at the time was used, 200 MHz (megahertz). Newer systems with higher frequencies are now available, which yield much more detail; however, more detail does not necessarily equate with more information. Because of the large number of roots and spaces left by decayed roots, the detail obtained with a higher frequency GPR signal could obscure other subsurface radar echoes, including the response from the object that is being sought (7). Often a moderate frequency, e.g., 200 MHz, is preferable.

The GPR response is affected by the electrical properties. If the ground is electrically conductive, then the GPR signal will be severely attenuated, to a degree that is dependent on the GPR antenna frequency, and the radar reflections will be reduced in amplitude and may be lost completely. The logical order in which to carry out the surveys is thus to perform the volumetric reconnaissance EM31 survey first, and follow it with a detailed GPR survey. This should be standard procedure, since the EM survey can indicate potential problems and guide the choice of the GPR antenna frequency (12).

FIG. 2—*The EM31 has a transmitting coil in one end, and a receiving coil in the opposite end of a 3.66 m long boom. The coils are connected through a central console, where the signal is separated into quadrature (bulk conductivity) and in-phase (metal detector) modes.*

FIG. 3—*The Sensors & Software pulseEKKO IV system, with 200 MHz transmitting and receiving antennas (far left), which are connected to the backpack console (far right), via a fiber-optic cable (center right). The radar echo record is then transferred to a laptop (center left) for storage and display. The 200 MHz antennas are 50 cm long and 11 cm wide.*

System Configuration

The EM31 is sensitive to a volume of the ground that extends approximately 2 m out to either side; using a 2 m line spacing thus allows for some overlap in the response from line to line and the continuity of an anomalous response can be confirmed. The radar lines were run in two different configurations. During the first set of surveys, lines were run only immediately adjacent to EM anomalies identified during the EM31 survey. During a second set of surveys, lines were run about 2 m apart, comparable to the EM31 line separation, but generally placed between adjacent EM31 survey lines. That is, for example, GPR line N/O was run between lines N and O, which were used as adjacent EM31 survey lines. The 200 MHz antennas are 0.1 m wide and 0.5 m long, and thus a 1 m wide strip between successive radar lines will not be covered by the radar surveys. The expected size of the target, however, indicated that some portion of the target should be covered in any one radar line. This modified survey configuration was used primarily because more area could be covered with the complementary techniques in the short time allotted to the surveys.

The surveys were extended, where possible and as time allowed, beyond the primary search area, so that a clear sense of the background response of the site could be obtained. While carrying out a separate survey to determine the background response of the site is desirable, the time constraints are such that a survey of a site separate from the main survey site may not be practical. Instead, the survey area is normally extended beyond the main area of interest in order to characterize better the background response and variability. A better knowledge of the nature and variability of the natural background response allows us to more reliably identify an anomalous location, that point where the response deviates obviously from the readings around it. An anomalous response can also, in principle, be better defined by correcting for the topography of the site, because that can influence the EM results (13). In this case, however, the site topography was not available, and there was insufficient time to correct for it. The survey results, however, indicate that any dependence on topography is relatively minor, and anomalous responses are clearly visible.

One point should be made clear: there was insufficient time to cover the expanded search area with the GPR surveys. Given the practical limitations, the surveys were concentrated in the primary search area indicated by the suspect and the police, i.e., where a significant number of old stumps were present. The area where the body was located was relatively devoid of stumps, but was surveyed using the EM31 so as to better estimate the pattern of the background response. As it turned out, the body was located near the edge of this expanded survey area. As will be discussed below, there is some question remaining whether the radar would have given an unequivocal result; the complexity of the subsurface at the site may have made a clear interpretation difficult. However, the location of the body beyond the expected search site serves to emphasize a point noted elsewhere (14): that the survey should always be extended beyond the site where a body (or other object) is expected to be located. It is nonetheless useful to discuss the GPR results, to illustrate the influence of the complexity of the site on the GPR response.

Results and Discussion

Repetition of Results

Measurements taken at a given point should be repeatable from one survey to the next, and certain survey lines and locations were duplicated to check the consistency of the results. This level of consistency can be different from the inherent measurement error for a given instrument. Comparisons between multiple readings acquired at a number of locations across the site indicated that the quadrature readings were repeatable. An individual reading had a measurement error of about 0.2 mS/m; however, over any given location the readings appear to be stable to within 0.05 mS/m, on average. The in-phase response was less accurate than the quadrature response; however, in general, where a quadrature anomaly occurred, there was often an in-phase anomaly as well. The discussion here focuses on the quadrature (bulk apparent conductivity) response. The quadrature results from all of the surveys have been merged into one data set, and contoured for final interpretation (Fig. 4).

As with the EM results, the radar results should be consistent from line to line. Dipping sand beds pervade the area, and almost every line has the same general character. The results from a typical GPR survey line are presented (Fig. 5), and are representative. The identification of anomalous features was often obscured by the radar signal that travels through the air from one antenna to the other, and by the radar wave traveling directly along the surface of the ground (Fig. 5A, top). These strongly horizontal features are easily removed by filtering (Fig. 5B, middle), but at the expense of any features that are genuinely flat-lying for any substantial distance. If the degree of filtering is too strong, then much of the structure is removed completely. It is, to a large degree, a matter of trial and error to determine how much filtering is just enough and how much is too much. The amount of time and effort required to filter and plot each and every line is substantial, and must be justified by the requirement of each individual survey.

Site Complexity and Analysis of Results

The subsurface complexity, suggestive of sands deposited either in a dune environment or in a deltaic setting, would easily mask many excavations, such as a grave. Channels or depressions are common, and are often coincident with EM anomalies. Such channels can act as small traps for moisture. Nonetheless, GPR surveys were carried out to complement the EM31 results, and to guide the excavations. When possible, and as time allowed, more than one survey method should be used, as noted earlier. However, the impatience of the investigators and the constraints of any budget are often significant factors in the choice of techniques and the coverage of any suspect sites.

The first EM31 surveys were run using only the quadrature mode (soil electrical conductivity) for three reasons: (1) the in-phase response tends to be noisier; (2) the in-phase and quadrature responses could not be simultaneously monitored during the survey; and (3) the data processing and interpretation would proceed more quickly than if both the quadrature and in-phase components were measured. The radar surveys were carried out along short lines that crossed the larger EM31 anomalies which were noted during the course of the EM survey.

At least two notable features were subsequently excavated, but revealed objects not relevant to the investigation: a very large tree root at shallow depth located at the primary site, and some reddish ceramic (?), a piece of which was removed, measuring about 12–15 cm in diameter located at the alternate site. The ceramic, if such it is, had a sandy core and may have resulted from a hearth or similar feature that had been constructed on the iron-rich sands that comprise the soils of the area. Unfortunately, no further ex-

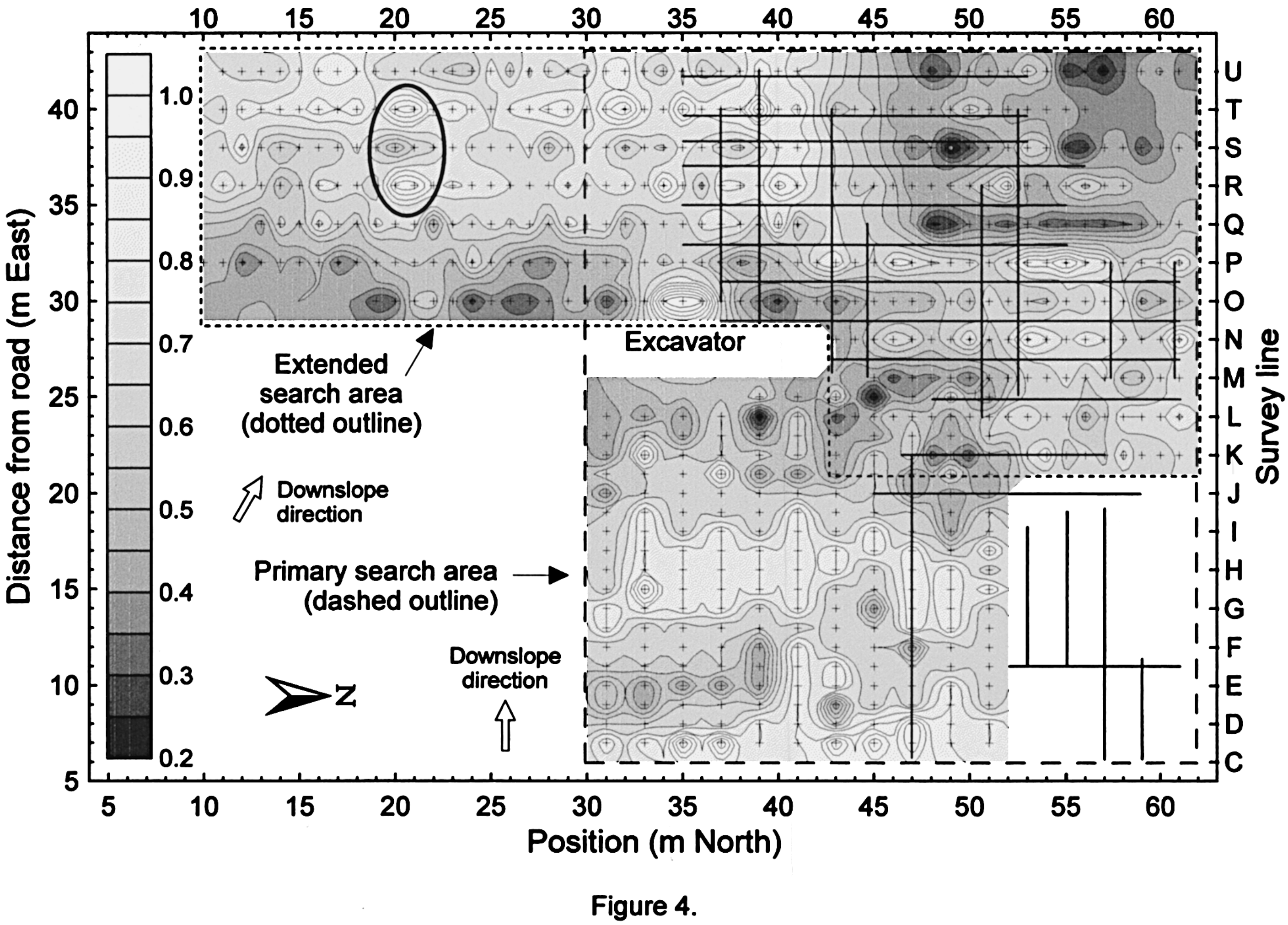

FIG. 4—*The EM31 quadrature response, combined from both the primary and extended surveys, is presented using a 0.05 mS/m contour interval. GPR survey lines are indicated by the solid lines. The primary search area is delineated by a dashed outline; the extended search area is shown with a dotted outline. Downslope directions are indicated by the arrows. The excavator (indicated) caused a major anomaly. The bold oval (top) shows where the body was ultimately found during subsequent excavations. The blank area in the northeast corner (lower right) is due to a loss of data during downloading. The field notes were incorporated into the final interpretations.*

amination was made of the ceramic because it was not relevant to the investigation.

A second set of surveys was carried out across the expanded search area. Both EM31 quadrature and in-phase components were recorded to allow for identification or clarification of potential targets during later data examination and processing. The primary search area, with numerous large stumps, was surveyed using both EM and GPR methods; a wider area, almost devoid of stumps, was surveyed using the EM31 only, both to get a more complete sense of the background response and in case the primary search area did not yield any remains. Time constraints prevented covering the wider survey area using GPR as noted earlier. Numerous EM anomalies are present in the primary search area (Fig. 4); the GPR results, however, indicate that the structure of the subsurface is complex (e.g., Fig. 5), and is further complicated by the presence of numerous tree roots.

Human remains were subsequently uncovered near the edge of the expanded search area, near the intersection of lines 21 and S (Fig. 4), downslope from a zone previously excavated during the search. There is a clear and isolated EM anomaly at the location where the remains were discovered. While GPR surveying was not extended for wider survey coverage, the results from the primary search area suggest that clear identification of the burial site may have been difficult, given the complexity of the subsurface structure in the area. Such speculation must, however, remain inconclusive.

Identification of Anomalies

Although the remains have been located, it is useful to examine the results as if we were still looking for potential targets. There are numerous features that appear to be anomalous, and if all but one are due to natural causes, then more work may need to be done to find techniques (physical or numerical) that may be used in future searches to more clearly characterize the response from human remains. The body of the victim was located between lines 19 and 21, and extending across lines R, S and T, and was associated with an isolated anomaly (Fig. 4). In that sense, it is different from the other anomalies identified in the survey. On the other hand, there are many other anomalous features present in what was the primary search

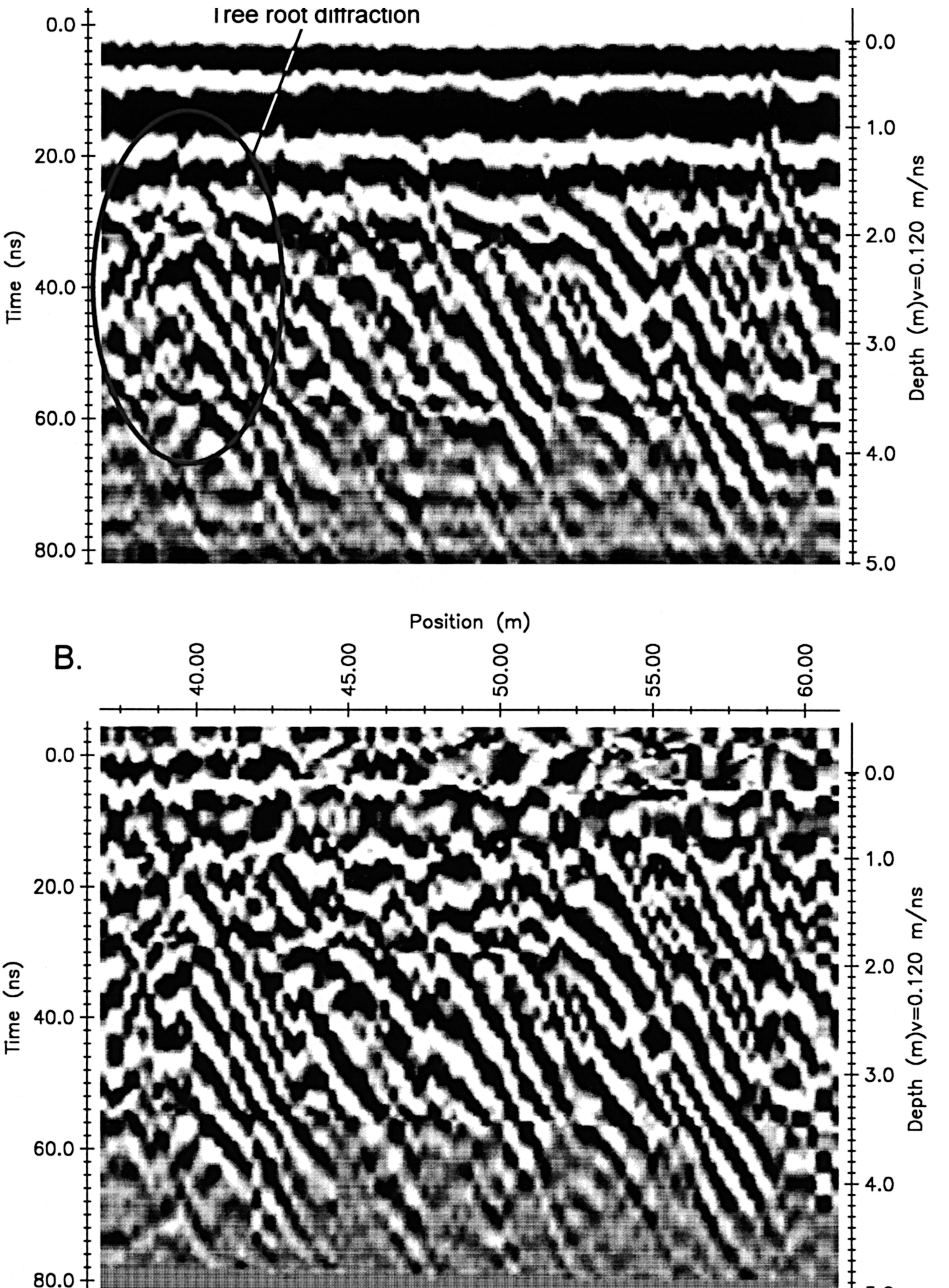

FIG. 5—*GPR profile located between lines O and P, 31 m from the NS access road.* (A) *The raw data are strongly overprinted with the air wave (first shaded arrival) and the direct ground wave (second shaded arrival). Positive radar echoes are shaded dark, negative echoes are white. There appears to be a large diffraction near position 40 (as indicated), and was due to a large tree root. The top of the diffraction corresponds to the location of the tree root, and the energy is scattered in both directions from the tree root.* (B) *Filtering removes the air and ground wave, enhancing the dipping and undulating layering of the subsurface.*

area, and there was one clear distinct anomaly identified at the alternate search area, the reddish ceramic-like material discussed previously.

Most features near the access road (located along lines D to F, Fig. 4) are associated with discarded saw blades and parts of saw blades. Numerous anomalies are located between 35 and 50 m North and lines J and M (between 20 and 26 m East from the main access road) and in the northwest corner of the survey site. The majority of these anomalies are due to stumps or to tree roots, often large, that were left in the ground after timber harvesting; while on the surface there is usually a stump associated with large tree roots at depth, sometimes no stump remains. The long stretch of anomalous features along line O, adjacent to the previously excavated area, are likely due to the excavation itself.

Concluding Remarks

Could the location of the body have been better defined? Given the current state of our knowledge, probably not. We were not carrying out a survey in a farm paddock or in a suburban backyard. The natural complexity of the layering of the subsurface sands, combined with the disturbance caused by the reworking of the forest plantation site, served to create numerous anomalous features, both in the EM and the GPR results. It must be noted, however, that the number of clear and significant anomalies was still small, only eight primary targets and approximately 30 more smaller anomalies in all, and included the location where the body was ultimately found. Had the geophysical survey been allowed to be completed, and the results analyzed, before excavations began, then there could have been a substantial saving in time, effort and, doubtless, emotion, since a limited number of sites would have required excavation. Lastly, a combination of techniques is always better than relying on only one method. Not only can one compare and contrast the anomalies, but some techniques are better suited to wide coverage in a short period of time, and others are better suited to detailed subsurface mapping.

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