UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Abandoned-Well Study in the Santa Clara Valley, California

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ABSTRACT

Ground geophysical methods, primarily magnetic surveying, were used to search for concealed abandoned water-well casings at sites in the Santa Clara Valley, California, where wells were thought to have existed in the past based on the interpretation of historical aerial photographs. Surveys over two known wells yielded positive magnetic anomalies of roughly 1,500 nT amplitude and about 20 ft half-width. Similar anomalies were detected at two other sites and probably reflect buried well-casings. Surveys at six sites revealed no anomalies that suggested the presence of well-casings. Surveys at eight other sites also revealed no characteristic well-casing anomalies, but at these sites the presence of strong, complex magnetic anomalies from man-made objects or structures may have prevented us from identifying a well-casing anomaly.

INTRODUCTION

Abandoned water wells pose a potential hazard to the quality of ground water resources in many areas. Such wells can act as conduits through which toxic wastes and other contaminants can reach deep aquifers. This problem is particularly serious in areas like the Santa Clara Valley of California which are heavily dependent on ground water for their water supplies and where spills of industrial chemicals are becoming increasingly common.

If the locations of abandoned wells are known, they can be sealed to prevent the transmission of contaminants between aquifers. Finding such wells, however, is not a straightforward task because as the areas that contain them were developed for industrial or residential use, many well casings were simply cut off a few feet below the ground surface and then buried. Finding such wells thus presents a significant challenge.

A pilot project for locating abandoned water wells in the industrial and residential areas of the Santa Clara Valley, California, was conducted in mid-July, 1985. The purpose of this project was to explore the feasibility of locating wells through the use of the historical aerial photography record followed by ground geophysical surveys to pinpoint the location of buried well casings. This report presents the results of the geophysical surveys.

Earlier work reported by Frischknecht and others (1983, 1985) evaluated the use of geophysical methods, primarily magnetic and electrical techniques, for locating steel oil-well casings, and presented the results of surveys in test areas of Colorado and Oklahoma. These studies demonstrated that magnetic methods were very effective in pinpointing the location of buried casings in the test areas and that some electrical methods provided useful auxillary information. The main difference between these earlier investigations and the present study is that the earlier tests were conducted in areas that contain wells but are relatively free of other man-made sources of geophysical anomalies, whereas the Santa Clara Valley is extensively developed and replete with man-made objects that could produce interfering anomalies. Another difference was that the earlier investigations dealt with oil-well casings, whereas water-well casings were the targets in the Santa Clara Valley. However, the geophysical signatures of the two types of wells were not found to differ significantly. Thus, the main challenge was to determine if it was possible to identify the geophysical signature of buried well casings in the presence of local disturbing influences.

GEOPHYSICAL SURVEYS

Ground magnetic surveys were made at 18 sites (Plate 1) and supplemented by ground electromagnetic surveys at a few places. The sites ranged in cultural complexity from relatively open vacant lots and a golf course to congested areas in shopping center parking lots and adjacent to steel-frame buildings. Two sites contained known wells and the other 16 were identified as possible well locations based on interpretations of historical aerial photography or on written records. A few other sites were visited, but surveys were not made because the possible well locations were found now to be under large buildings.

Most of the magnetic measurements were made with a total field proton-precession magnetometer, although at one site, where the magnetic gradients were extremely large, a portable fluxgate magnetometer was used. Electromagnetic measurements were made with a conductivity meter which uses a small transmitting and small receiving coil separated by a distance of 12 ft. This system is well suited for locating horizontally oriented electrical conductors and was used to locate utility pipes that sometimes gave magnetic anomalies similar to those over well casings.

Surveys over known wells

Magnetic measurements over the two known wells, identified by Santa Clara Valley Water District personnel, were made along profiles oriented along magnetic north-south and along magnetic east-west. Measurements were made out to a distance of 100 ft from the casing, where possible, and were spaced a few feet apart over the casing and up to 20 ft apart toward the ends of each profile. Both wells showed strong positive magnetic anomalies (fig. 1) of roughly 1,500 nT amplitude and about 20 ft half-width (width of the anomaly at the point where it reaches half its maximum amplitude). The anomalies are symmetrical along the east-west profiles and show a slight asymmetry along the north-south profiles (the north flanks of the anomalies are steeper than the south flanks and minor minima in field strength are present on the north sides of the anomalies). These anomalies are very similar to the well-casing anomalies found by Frischknecht and others (1983, 1985) and can be modeled by a single vertical dipole with the upper pole nearly coincident with the top of the well casing (fig 1). The similarity between the magnetic anomalies over the two known wells in the Santa Clara Valley and those over the much larger number of wells examined by Frischknecht and others in the earlier studies suggests that the anomalies shown in Figure 1 are the types of anomalies that would mark the locations of well casings at other locations in this study.

Surveys over possible locations of abandoned wells

At sites where abandoned wells were suspected on the basis of aerial photography as interpreted by K. Stout and M. Fauss of the Bionetics Corporation or from written records held by the Santa Clara Valley Water District, the geophysical search for the wells was conducted as follows: 1) the approximate location was determined by comparing the aerial photographs or the record descriptions with current 1:24,000 scale topographic maps; 2) a rough grid with a spacing of about 10 feet by 20 feet was established by pacing and magnetic measurements were made at the grid intersections; 3) any anomalous magnetic field values greater than about 100 nT that were not readily explainable by visible steel objects or structures were investigated by measurements on a more detailed grid; 4) if the results of this more detailed set of measurements yielded an anomaly with the shape and width of a typical well casing anomaly, measurements were made along profiles crossing the peak of the anomaly as had been done in the cases of the known wells; 5) in a few cases where anomalies were found that could have been caused by horizontal pipes, electromagnetic measurements were made to try to confirm the interpretation.

Results

Anomalies similar to characteristic well-casing anomalies were found at two sites, 8 and 11a. At site 8 (a parking lot at the San Antonio Shopping Center) an anomaly with the proper shape (fig 2.) was found, even though the local magnetic field was severely distorted by a magnetic low caused by a nearby steel light-post. This anomaly may reflect a buried well casing, although its amplitude (250-300 nT) is smaller than that of the anomalies over any of the known wells. At site 11a (grammar school playground,) a 650 nT anomaly (fig. 3) is probably due to a buried well casing. A second anomaly at this site, of roughly the same amplitude and located near a concrete slab stamped "WATER", probably reflects a second well but this one was not profiled.

Magnetic surveys at six other sites (2, 4, 6, 10, 14, and 15) revealed no magnetic anomalies that suggested the presence of buried well casings. Although man-made steel objects such as fences, light posts, and sprinkler system pipes, caused local anomalies at some of these sites, the magnetic fields were simple enough that we feel any well casing anomaly greater than about 500 nT in amplitude would have been detected.

Magnetic surveys at the remaining eight sites also revealed no characteristic well casing anomalies, but inaccessibility to parts of the survey area or the presence of strong, complex anomalies from man-made objects or structures may have prevented us from locating buried casings at them. The complicating factors at each site are as follows:

Site 1 - The open area of this golf course made surveying easy but a small pond may have concealed the well casing. Magnetic field values were highest at the edges of the pond.

Site 3 - The large complex anomaly caused by a steel building could have masked any casing anomaly.

Site 7 - The possible well location determined from written records was uncertain and the survey may not have covered a sufficiently large area.

Site 8a - Survey was conducted in the parking lot of a bank and no characteristic well casing anomaly was found. However, the well could have been located beneath the bank building which caused a large anomaly.

Site 10a - Large, complex anomaly from a commercial building could have masked a well casing anomaly.

Site 11 - Survey was made near an apartment complex. Local magnetic anomalies from steel reinforcing rods in a brick wall, a steel

I-beam supporting a staircase, and steel elements in the apartment sign may have masked a well casing anomaly.

Site 12 - This site was located in a clover leaf of a major highway and dense vegetation and some poison oak hampered access. The presence of steel reinforcing rods in the roadway, steel guard rails, steel beams in the overpasses, and overhead electrical transmission lines caused the proton precession magnetometer to give unreliable readings but the fluxgate magnetometer worked well.

Site 13 - Three areas were surveyed at this site. No characteristic well casing anomalies were found at two of them. The third contained a pile of debris which included a substantial amount of steel and a section of steel standpipe lying horizontally in a nearly north-south orientation. The positive and negative anomalies due to the standpipe were very strong but the positive anomaly was slightly offset from the end of the standpipe suggesting that a well casing could have been concealed beneath the pile of debris.

SUMMARY AND CONCLUSIONS

The results of this pilot study indicate that magnetic surveying is useful in locating abandoned wells in some of the developed areas of the Santa Clara Valley. The two known wells yielded easily recognizable anomalies and two similar anomalies at site 11a probably also reflect buried well casings. The weak anomaly at site 8 possibly indicates the location of a third buried well. The lack of characteristic anomalies at six other sites indicates either that buried well casings are not present or possibly that corrosion of the well casings has destroyed their magnetization.

At some of the remaining eight sites, where the magnetic results were ambiguous, more systematic surveys than were conducted in the pilot study would undoubtedly have reduced or eliminated the ambiguity. For example, at site 1 a survey from a wood boat could have been made over the pond and at site 12 a regular grid in the dense vegetation could have been measured by clearing some of the underbrush. At other locations, magnetic maps compiled from measurements made on a regular grid probably would have been effective in revealing well casing anomalies except in the immediate vicinity of buildings or other sources of large magnetic anomalies.

In any developed area, such as the Santa Clara Valley, there will be places where magnetic methods will fail in the search for abandoned wells. Wells located beneath structures or buildings containing substantial amounts of steel, or beneath concrete slabs or roadways reinforced with steel rods probably will not be detectable by magnetic surveying. Similarly, places that contain strong electromagnetic fields from transmission lines may be difficult to survey. Even given these restrictions, however, geophysical surveying will probably be an effective means for locating abandoned wells in much of the Santa Clara Valley.

RECOMMENDATIONS

The results of this pilot study and those of earlier studies directed toward locating buried well casing by geophysical surveying suggest procedures that should be effective in the Santa Clara Valley. These suggested procedures are based on the assumption that a typical well casing magnetic anomaly will be similar to those shown in Figures 1 and 3, i.e., will be at least a few hundred nanoteslas in amplitude, be roughly circular in map view, and have a half-width of 20-30 ft. Because magnetic anomalies from two or more sources in general will simply add to produce a composite anomaly, well casing anomalies will be more difficult to recognize in areas containing mangetic anomalies from cultural sources. Therefore, slightly different procedures are suggested depending on the nature and proximity of potential man-made sources of magnetic anomalies.

We recommend that a total field proton-precession magnetometer be the primary instrument for making magnetic measurements. Potentially useful auxillary equipment includes a conductivity meter for locating horizontal electrical conductors, a portable fluxgate magnetometer for operating in areas of strong magnetic gradients, and a magnetic gradiometer for rapidly locating shallowly buried magnetic objects.

Surveys in open areas

For searching open areas (areas more than about 100 ft from man-made structures or objects that produce magnetic anomalies) the relatively simple procedures used to survey open areas in this pilot study should suffice. We recommend producing a map based on magnetic measurements taken on a 20 by 20 foot grid established by pacing, and more detailed grids in the immediate vicinity of any deviations from background level greater than 100 nT. Both positive and negative deviations from background level should be mapped because 1) although all the magnetic anomalies over known wells in this study and in the previous studies of Frischknecht and others (1983, 1985) were positive, it is possible that a permanently magnetized well casing could be oriented in such a way as to produce an equivalent negative anomaly, and 2) a well casing will produce a single anomaly whereas a buried, horizontally oriented pipe will produce anomalies over both ends that are similar in size and shape but opposite in sign (fig. 4). Individually these end point anomalies may look similar to well casing anomalies but the combination of equivalent strength positive and nègative anomalies would suggest a horizontal pipe. Finally, we recommend magnetic measurements along profiles oriented along magnetic north-south and along magnetic east-west across the peak of any suspected well casing anomalies and that the results be compared to the shapes of the anomalies shown in Figure 1. For most open areas, all the recommended procedures and interpretations could be performed in the field.

Surveys in proximity to interfering magnetic sources

Detection of well casing anomalies in proximity to other man-made sources of magnetic anomalies is a difficult and challenging problem. Magnetic anomalies from many structures and objects are much larger than typical well casing anomalies and will tend to mask them. Furthermore, magnetic anomalies from complex structures can be complex and, in general, will not be predictable even if the shape of the structure is known. Because the interfering anomalies will not be known in advance, the recommended surveying procedures make use of the fact that anomalies from multiple sources are additive and that the anomaly from any given source will tend to decrease smoothly in amplitude as distance to the source increases, no matter how complex the anomaly may be.

For surveying in areas of known magnetic sources, we recommend measurements be taken at the intersections of a precisely defined 20 by 20 ft grid. The grid should be established by surveying or taping with one axis of the grid oriented parallel to linear features of the disturbing sources, i.e., parallel to building walls, steel fences, etc. The precise positions of any known sources of magnetic anomalies should be determined with respect to the grid for later inclusion on a map. The orientation of the grid with respect to magnetic north also should be determined. The magnetic observations should be plotted on a map along with the positions of known magnetic objects and structures. Contouring of these data at 50 or 100 nT probably will be adequate for most interpretaions.

The magnetic map can then be examined for any characteristic well casing anomalies. At this stage it must be remembered that anomalies from multiple sources are additive and that a well casing anomaly superposed on the anomaly from another source will probably appear distorted. The form that the distortion takes will depend on the size and shape of the disturbing anomaly and generally cannot be predicted in advance. However, in many cases simply knowing (1) the shape of an undistorted well casing anomaly, (2) that the interfering anomaly will decrease smoothly in amplitude with increasing distance from its source, and (3) that the anomalies are additive will be sufficient information to permit identification of a well casing anomaly.

A further aid to the identification of well casing anomalies in the presence of other anomalies would be a familiarity with the anomalies from simple objects such as spheres, rods, sheets, etc., because many complex sources can be approximated by combinations of simple shapes. Most geophysical text books give examples of anomalies due to simple objects, e.g., Nettleton (1976), Parasnis (1975), Telford and others (1976). A particularly good source of such examples is a booklet titled "Applications Manual for Portable Magnetometers" written by Sheldon Breiner and published by GeoMetrics of Sunnyvale, CA. Other examples of well-casing anomalies together with estimates of costs and time requirements of magnetic surveys may be found in Frischknecht and Raab (1985).

A remarkable aspect of this pilot study was the fact that nearly every site presented new and unique interpretational problems. The number of distinctly different magnetic objects encountered at the few sites we visited made it clear that constructing a complete catalogue of magnetic anomalies likely to be encountered in surveys of developed areas was an impossible task. The interpretations were further complicated by the fact that similar objects usually, but not always, produced similar anomalies. For example, most tall steel fences produced magnetic lows centered at the fences but one produced a similarly shaped high. Steel light-posts usually caused roughly circular magnetic lows centered at the bases of the posts but a few produced highs. Although this was confusing at first, it soon became clear that most anomalies could be understood, at least qualitatively, by approximating the sources with simple geometric shapes. Thus, the light-post anomalies could be understood by imagining the magnetic field of a thin vertical rod--a low would result if the rod was magnetized in the direction of the earth's field, whereas a high would result if it was permanently magnetized in a direction opposite to the earth's field. Similar reasoning probably applies to the magnetic anomalies associated with the fences.

Our limited experience in this study suggests that the best way to approach an interpretation of the magnetic data at any given site is for the interpreter to have a basic understanding of the principles mentioned in the preceeding paragraphs and to have at his or her disposal a knowledge of the magnetic anomalies produced by a few simple objects. As experience is gained through site investigations, it will become increasingly easy to separate out anomalies from various sources and thus facilitate the identification of well casing anomalies. The single most important tool for any interpreter will be a thorough understanding of why simple objects produce the anomalies that they do and the references mentioned in the preceeding paragraphs, especially that by Breiner, will provide the information and explanations necessary for acquiring this understanding.

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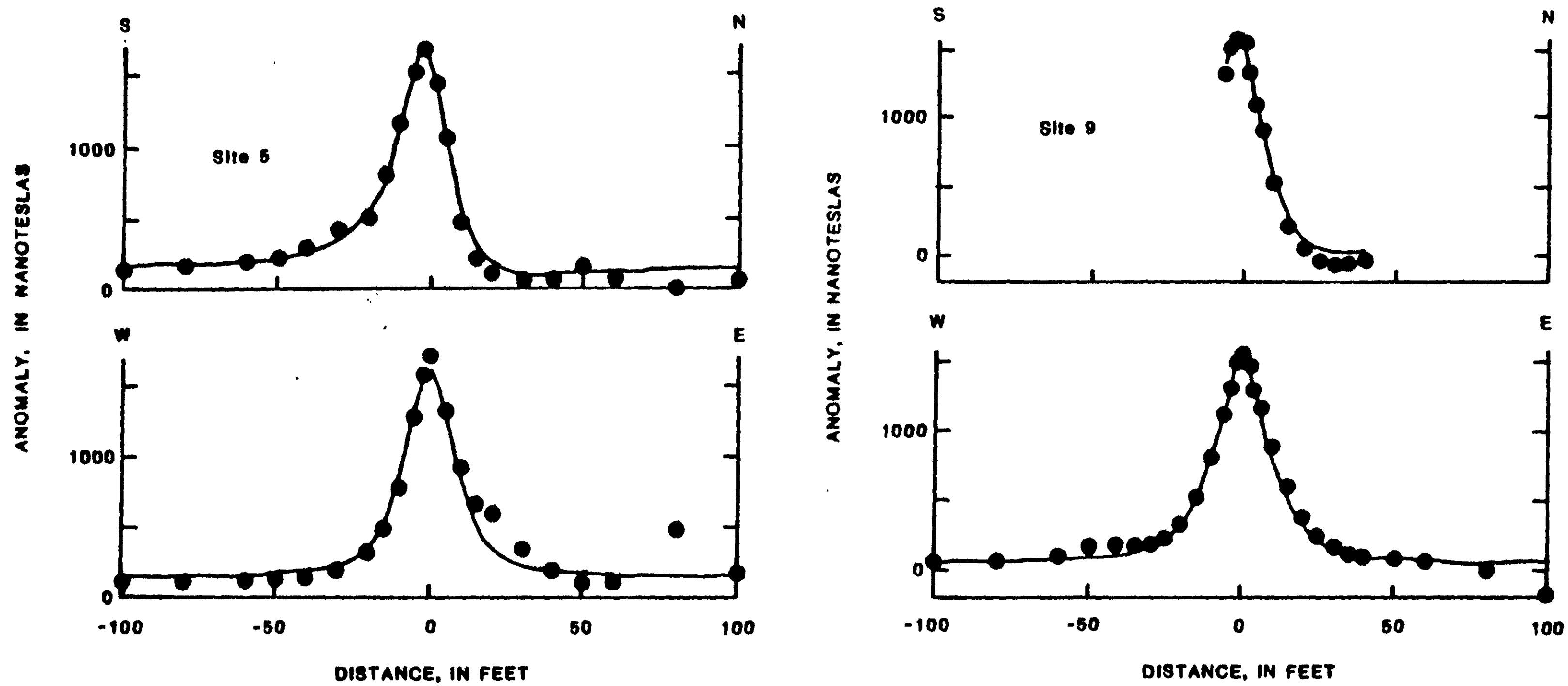

Figure 1. Magnetic profiles over known well-casings. Dots represent observed magnetic field values. Solid lines represent computed field based on the following models:

Site 5. vertical dipole model
upper pole depth = 12.0 ft
lower pole depth = 220.0 ft
pole strength = 224.7 S.I.

Site 9. vertical dipole model
upper pole depth = 14.0 ft
lower pole depth = 230.0 ft
pole strength = 295.4 S.I.

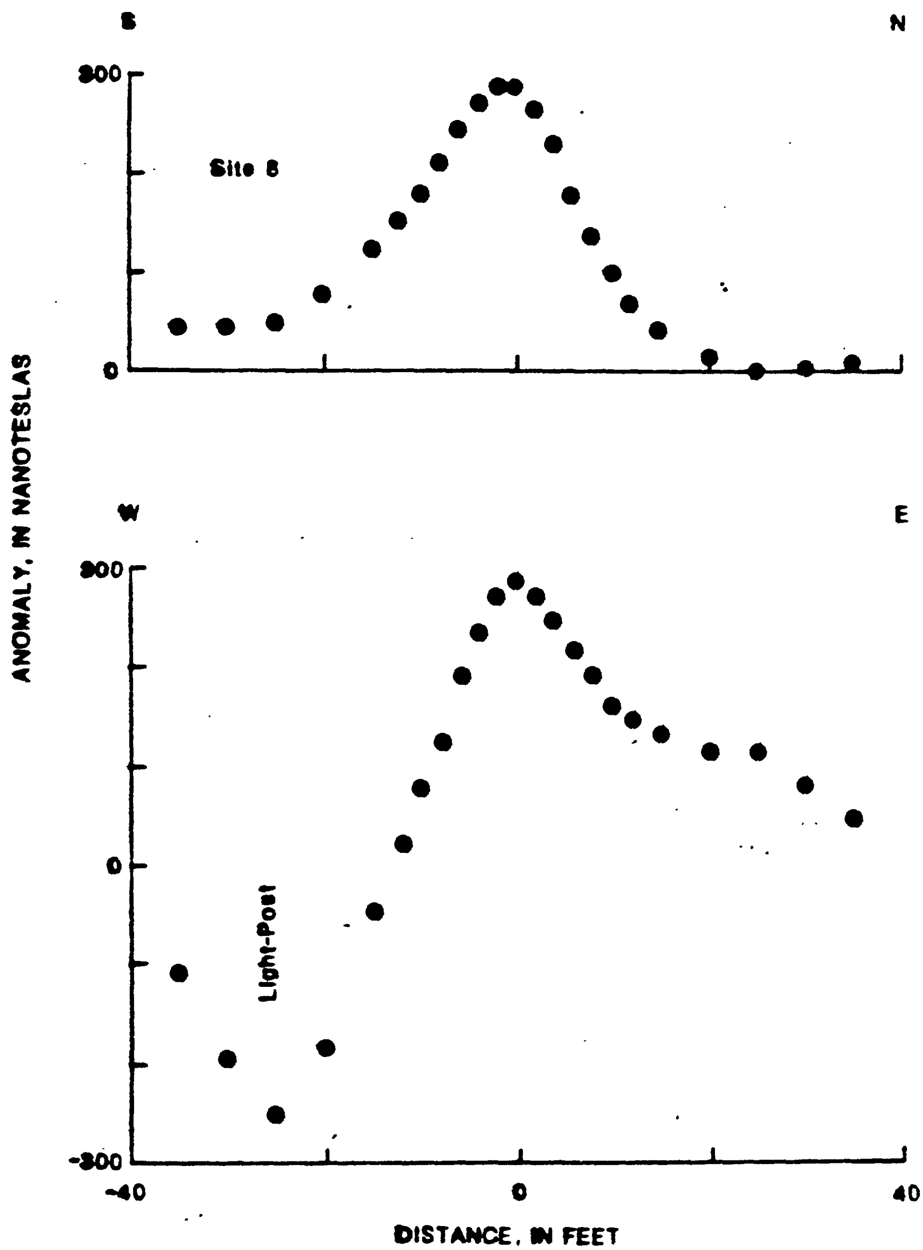

Figure 2. Magnetic profiles over a suspected buried well-casing at site 8. Note the strong negative anomaly cause by a vertical light-post.

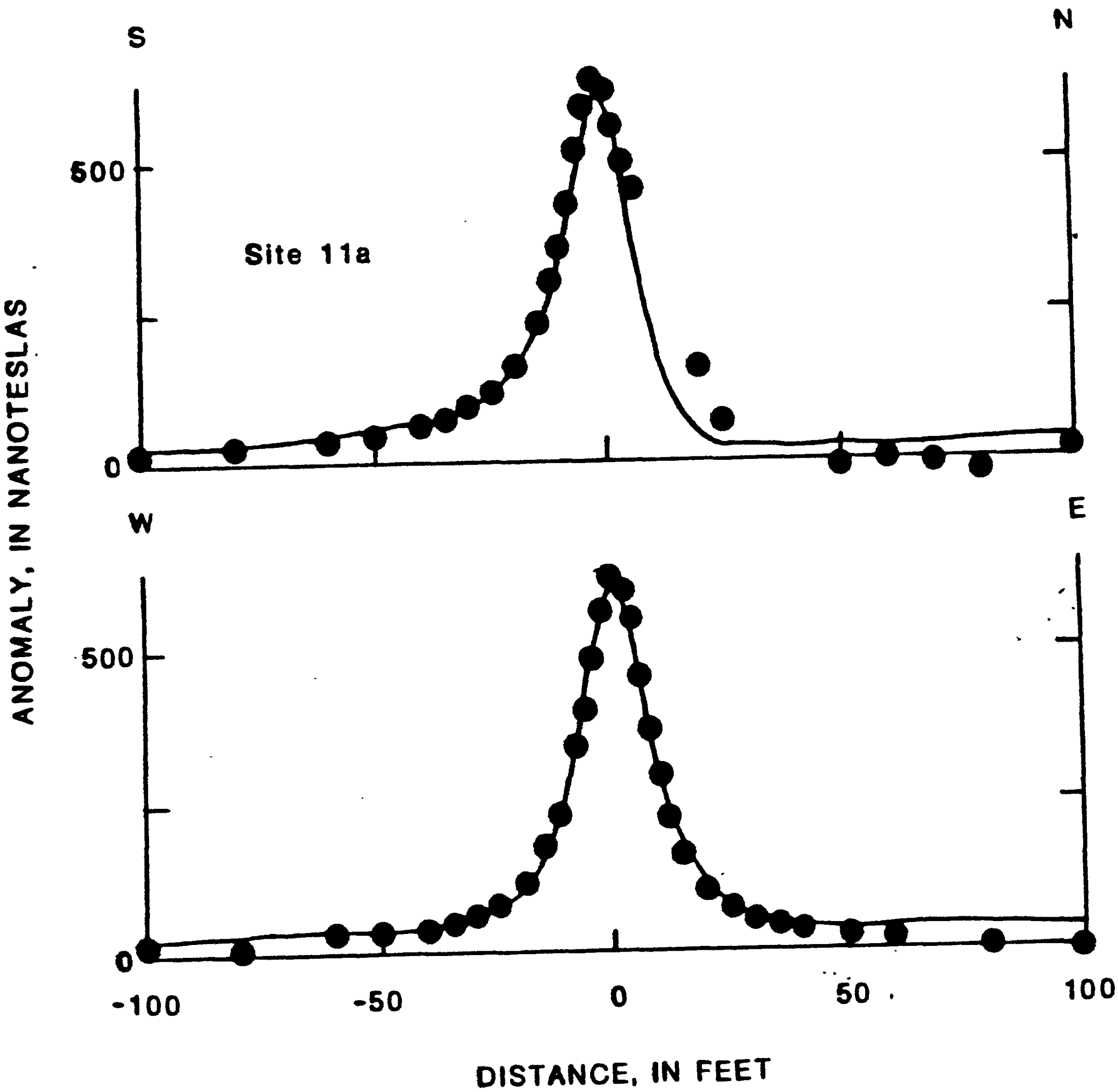

Figure 3. Magnetic profiles over a suspected buried well-casing at site 11a. Dots are observed data and solid line is computed field based on vertical dipole model with:

upper pole depth = 11.9 ft
lower pole depth = 275.0 ft
pole strength = 85.6 S.I.

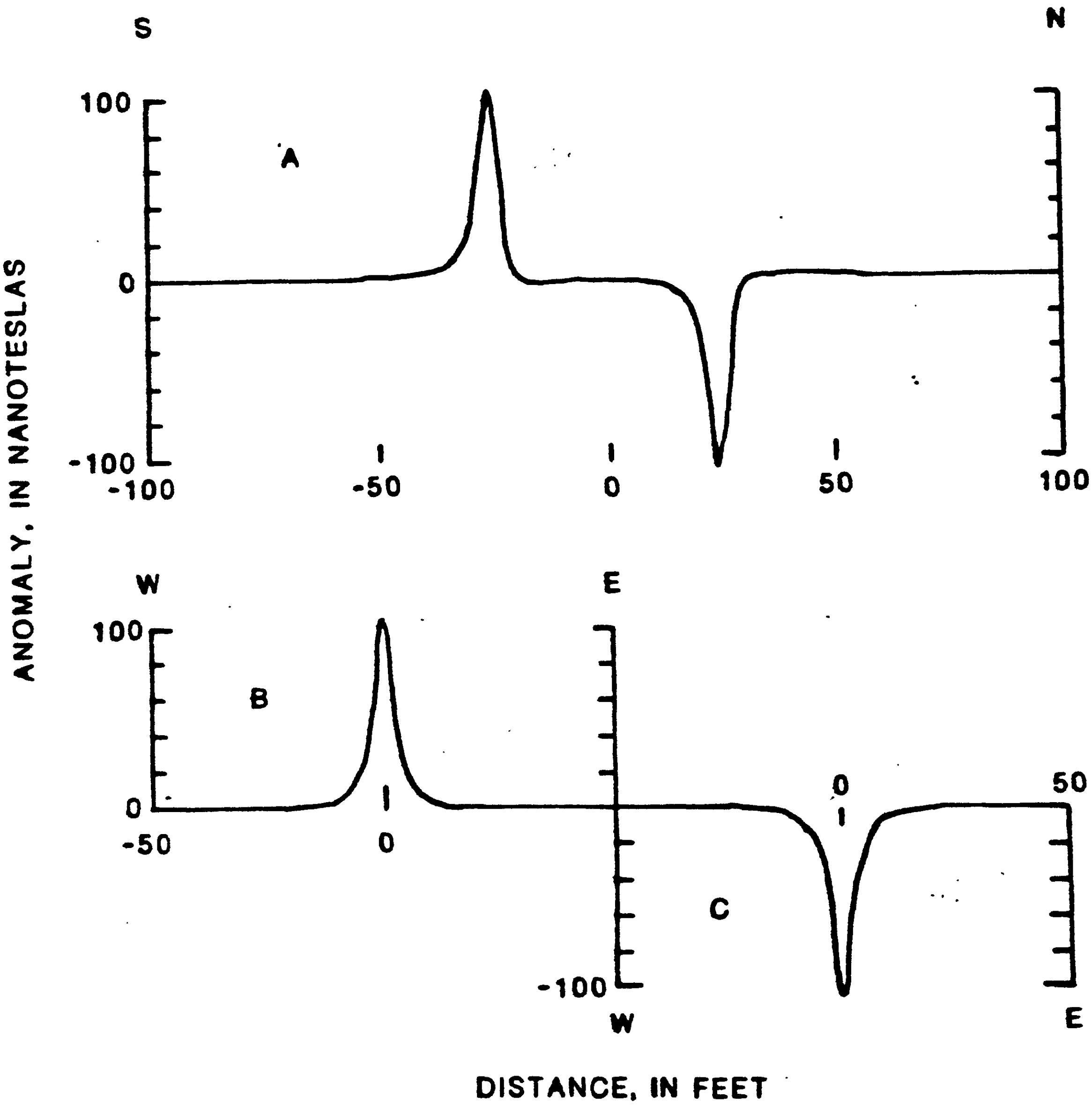

Figure 4. Example of theoretical magnetic profiles over a buried 50-ft long horizontal pipe oriented in a magnetic north-south direction and buried 3 ft beneath the sensor. Note the similarity between the shapes of the end point anomalies and the typical well casing anomalies shown in Figures 1 and 3. The end point anomalies are narrower than the well-casing anomalies because the horizontal pipe is shallower than the tops of the well casings. A) North-south profile. B) East-west profile across south end. C) East-west profile across north end.