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How To Find Abandoned Oil and Gas Wells

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HOW TO FIND ABANDONED OIL AND GAS WELLS

by

K. H. Johnston,[1] H. B. Carroll,[2] R. J. Heemstra,[3]
and F. E. Armstrong[4]

ABSTRACT

This guide was written to furnish the coal industry with a description of techniques, instruments, and clues on how to find abandoned oil and gas wells that have penetrated coal seams. The report includes specific information on searching techniques currently in use by several coal mining companies, gas-transmission companies, and waterflood operators, as well as information on State agencies responsible for the enforcement of laws and the preservation and distribution of data pertaining to the drilling, development, and abandonment of oil and gas wells. Comparative tests were performed with several commercial electronic metal detectors to determine the feasibility of using them to aid in the search for abandoned wells and to determine the instrument most suited for that particular use. The role of methane detectors to locate abandoned wells is described, including a case history. Tests were made to develop an efficient procedure to follow in systematically searching an area for metallic clues or hydrocarbon evidence to abandoned wells.

The guide describes, in detail, a search sequence, including the collection of basic data, preparation of the selected area, and the physical search. Methods are given for evaluating the results.

INTRODUCTION

Many petroleum exploratory and development wells, in areas where major bituminous coalfields overlie active oil- and gas-producing sections, were drilled through the coal seams and completed to produce fluid hydrocarbons from reservoirs underlying the coalbeds. The recoverable reserves of petroleum were soon exhausted, and many of these wells were abandoned; some were properly plugged but many were improperly plugged before abandonment.

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[1] Petroleum engineer (now retired).
[2] Research physicist.
[3] Research chemist.
[4] Project leader.

History

As early as February 7, 1913, the hazards and operating problems arising from oil and gas wells penetrating coalbeds, particularly in the Appalachian area, were discussed in a conference called by the Director of the Bureau of Mines. However, only limited effort was applied to this problem until changes in mining methods, particularly a trend to the longwall method, and updated mine safety regulations, specifically Section 317(a) of the Federal Coal Mine Health and Safety Act of 1969, made immediate action mandatory. Section 317(a) states: "Each operator of a coal mine shall take reasonable measures to locate oil and gas wells penetrating coalbeds or any underground area of a coal mine. When located, the operator is required to establish and maintain barriers around the wells in accordance with State laws and regulations. With few exceptions such barriers shall not be less than 300 feet in diameter. For average coalbeds (4.2 feet in thickness) this amounts to about 15,000 tons of coal per pillar; this may represent a considerable percent of the recoverable coal." Figure 1, a map covering about 35 acres, shows the barriers around wells left in a West Virginia coal mine.

Because these real and potential hazards fell under provisions of the Federal Coal Mine Health and Safety Act, a seminar sponsored by the Bureau of Mines, Division of Mining Research--Health and Safety, was held in Pittsburgh on March 26, 1970, to discuss these serious and age-old problems on oil and gas wells penetrating coalbeds. A followup meeting was held in Washington, May 26, 1972. A major difficulty confronting the seminars was the development of effective methods of locating wells penetrating coalbeds, because not all wells were charted during either drilling or abandonment and records showing well location for the period prior to about 1935 are essentially nonexistent.

Telltale scars are left on the earth leading to and around oil- and gas-producing operations. These signs are caused by the transportation, installation, servicing, use, and final disposition of the very heavy equipment. Although the major scars fade rapidly, traces of these activities usually are discernible to the trained observer for many years after operations are abandoned.

Through the years, engineers and scientists at the Bureau of Mines Bartlesville (Okla.) Energy Research Center have developed considerable expertise in locating wells abandoned on properties being redeveloped for secondary recovery of petroleum. Because of this specialized experience and the long association with drilling and producing problems, this research center was assigned the preparation of this guide.

Scope

The purpose of the guide is to furnish a source of information on ground surface search techniques, instruments, and clues useful for finding abandoned uncharted oil and gas wells. The scope of this guide has been intentionally limited to state-of-the-art techniques and instrumentation and its material content is directed to those who have the responsibility of finding abandoned wells which may intersect coalbeds. Because of rapid instrument development,

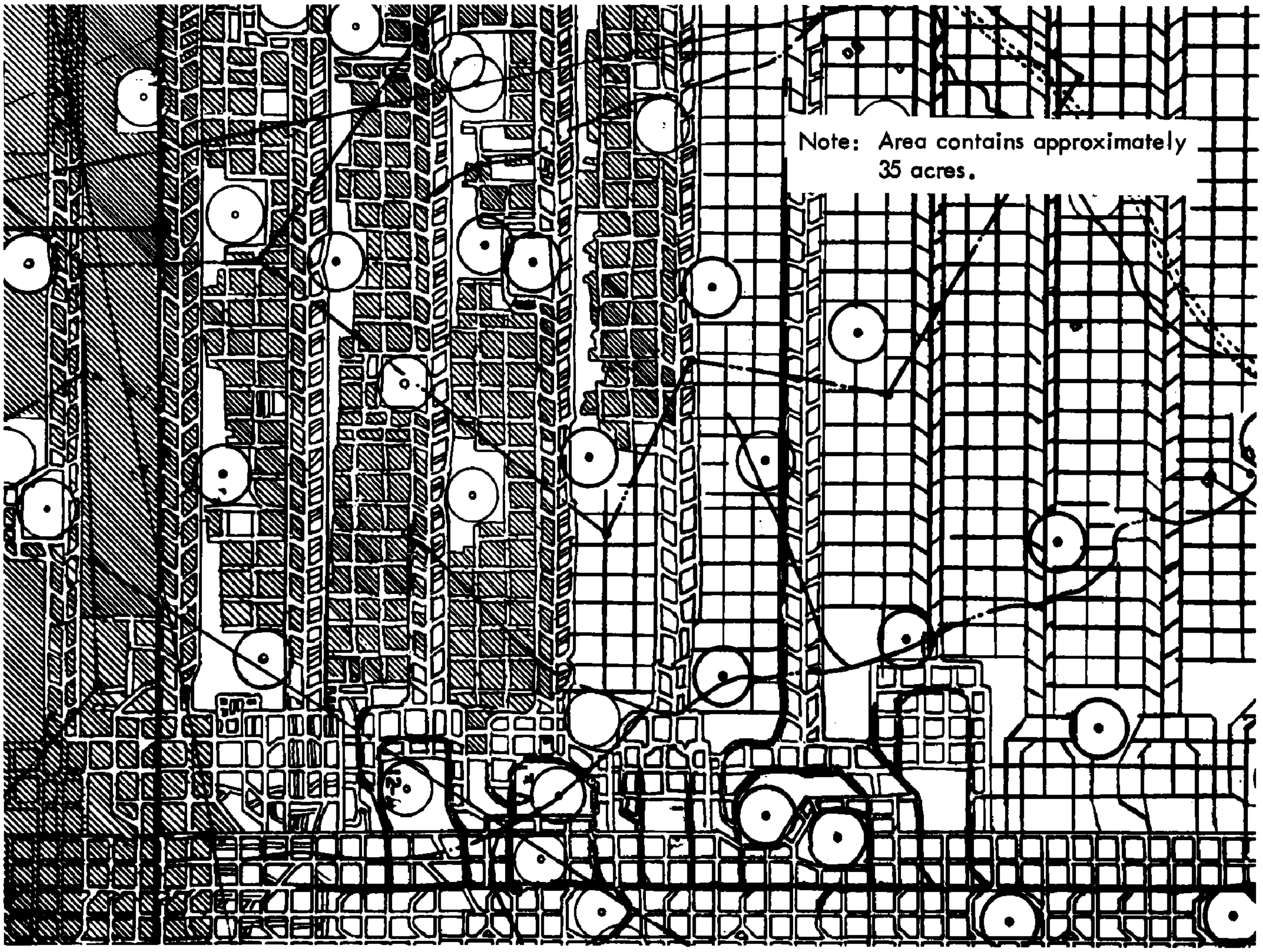

FIGURE 1. - Coal Mine in West Virginia Showing Barriers Left Around Abandoned Wells.
(Note: Area in photograph contains approximately 35 acres.)

many search techniques, as yet untried, may be applicable to the task of locating abandoned oil and gas wells in the near future.

Information on State agencies responsible for the enforcement of regulations and the preservation of data on oil and gas development is given in appendix A for six States that are most concerned. The searching methods currently in use and suggested searching techniques using metal detectors and a portable hydrocarbon detector are presented in the order that a searcher might find most useful. The search techniques described are preparatory to the use of shovel or bulldozer to excavate for the buried lost wellbore.

A search sequence would proceed as follows:

1. Collect basic data from agencies, companies, and local people.

2. Prepare the selected area and make a preliminary search for clues.

3. Use electronic metal detectors to make a physical search of the area chosen from collected data.

4. Choose most probable locations from histograms of results from the physical search, and examine these with the portable hydrocarbon detector.

5. Uncover the well site that has been pin-pointed or bulldoze a larger but still highly probable area.

Location

General areas of the United States where coal deposits are underlain by productive or depleted oil and/or gas sands are shown in figure 2. Of these, the largest and most pertinent one is the Appalachian area of Pennsylvania, West Virginia, eastern Ohio, and eastern Kentucky. The coal seams in this area have been penetrated by thousands of wellbores, many of which were drilled before or shortly after the turn of the century. Finding the location of these wells has been a major problem for the coal mine operators because few State regulations controlling location and abandonment procedures were passed prior to 1930, and enforcement of those that were passed was very poor until the early 1950's.

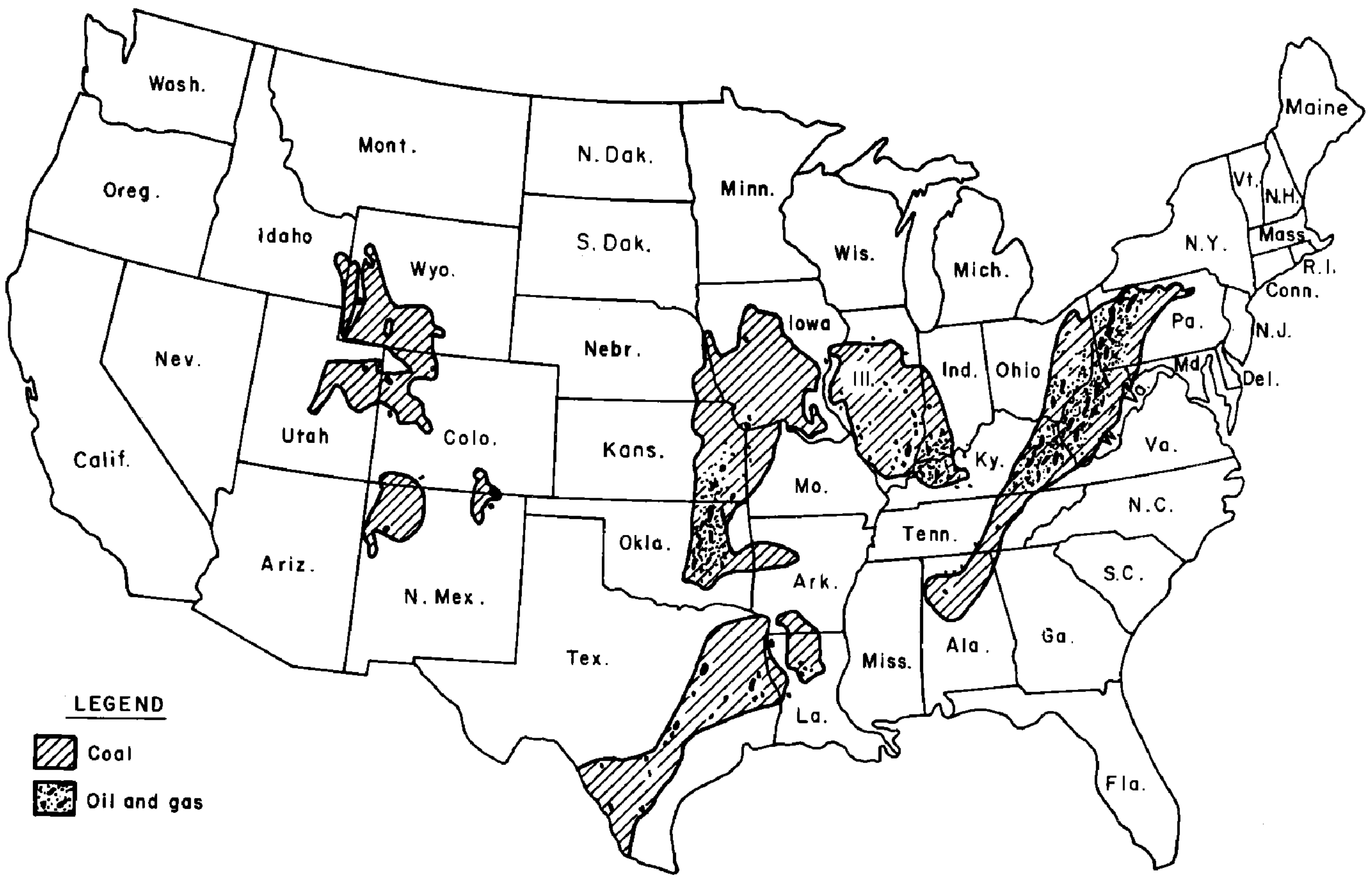

FIGURE 2. - Major Areas of the United States Where Oil and Gas Wells and Dry Holes Have Penetrated Coal Deposits.

Another area where oil and gas wells penetrated coalbeds is western Kentucky, southwestern Indiana, and southeastern Illinois. Coal mining in this area also has been hampered by the inability to find these wells, particularly those drilled during the early 1900's.

Most of the coal deposits shown in southeastern Kansas and eastern Oklahoma are shallow and have been strip mined. Deeper coal deposits are found in southeastern Oklahoma, and a few shaft mines are in operation, but uncharted drill holes have not hampered their operation.

The large coal deposit extending in a northeast-southwest direction across south Texas and the small deposit in north-central Louisiana and south-central Arkansas have not been developed. In the Rocky Mountain area, wells drilled in the few small oilfields and gasfields in Wyoming, Utah, Colorado, and New Mexico have not seriously hampered coal mining operations.

ACKNOWLEDGMENTS

This report was prepared by the Bartlesville (Okla.) Energy Research Center in cooperation with the Division of Mining Research--Health and Safety of the Bureau of Mines. The authors gratefully acknowledge the cooperation and assistance given by State agencies charged with the enforcement of regulations and the distribution of data on oil and gas well drilling and development in States where wells have penetrated active coal seams. Also gratefully acknowledged are F. W. Lewis, Texas Gas Transmission Co.; Bill Light and Frank Burchinal, Consolidation Coal Co.; and Terry Bernard and Dick Campbell, Peabody Coal Co., for their discussions of search procedures that their companies follow in locating abandoned wells.

PROCEDURE OF SEARCH

The following procedure should be followed in searching ahead of coal mining operations for wells that may have penetrated the productive coal seam. The procedure is based on information obtained from discussing techniques with operators of gas-storage reservoirs, major coal mining companies, waterflood operators, and information reported to State representatives (appendix A).

Collect Basic Data

State Agency Information

All available information, such as location plats, development maps, aerial photographs, well records, and any other information that shows the footage location of the wells should be collected from State and Federal agencies (appendix A), oil- and gas-producing companies, independent operators, commercial map makers, and libraries.

Many States require a certified location plat filed with an application for a permit to drill. These plats show the distance in feet of the proposed well from at least two property corners or bench marks. Unfortunately, many property corners and bench marks that used to locate the older wells have been destroyed, and it is not possible to locate the well accurately from footage descriptions. Also, not all wells were staked according to the footages reported on the plat because exceedingly rough terrain found in the field was not suitable for drilling a well, or the rig was skidded after drilling started because iron lost in the hole made continued drilling impractical. Although the well location was often changed several hundred feet, no revised copies of the location plat were furnished the responsible State agency.

Development maps prepared by production companies and area maps prepared by commercial companies are valuable sources of information for determining the number of wells drilled in a particular area but generally are inadequate for finding the physical location of a particular well.

Aerial photographs, particularly copies of older surveys, may be used to find scars left by old roads, pipelines, rod lines, previously cleared well sites, and other evidence of drilling and production operations. Scars are particularly noticeable from tree growth in wooded areas. Copies of aerial photographs are on file at most offices of the U.S. Department of Agriculture Soil Conservation Service and/or the Agricultural Stabilization and Conservation Service. These offices usually are located at the county seats in each State.

Drillers' logs occasionally show the footage location or legal description of the well. These are helpful in locating the general area, if not the actual location of the well.

Verbal Communication

After collecting available maps that show well locations, it is often helpful to visit the area and discuss the maps and possible well locations with people who might have worked in the field during early development. Former drillers, tool dressers, roustabouts, pumpers, and farmers are sources of information and usually are able to verify the number of wells and approximate locations shown on the maps.

Physical Search of Area

One of the more successful methods of finding uncharted wells is to hire several of the physically fit older people to walk through the property and point out well locations that they remember from the early days. Surprisingly they are frequently able to point out, within 20 to 30 feet, the actual location of many uncharted wells. The actual wellbore may be found in many instances by having a shovel crew or a ditching machine dig a trench, slightly deeper than normal coverage for water and oil lines in the area, in a 30-foot radius around the possible wellbore. A rust discoloration of the soil or pieces of rusted pipe may be evidence of an old water or oil line that served a well. A second trench should be dug along the radius from the evidence to the possible wellbore. Many uncharted wells have been found by this method.

After all possible information on the wells originally drilled on the property has been collected, the data, particularly maps and location plats, are taken into the field, and an effort is made to find the original property lines and bench marks. From descriptions given on location plats and drillers' logs, the distances from property corners are measured on the surface. These are only possible locations, and usually a thorough search of the area is necessary to verify a well location. The search often requires the use of shovels or bulldozers to find the actual wellbore.

Clues

There are many clues to aid an experienced searcher in locating an uncharted well site. Some of the clues that indicate a well was drilled in a particular area are as follows:

1. Evidence of old roads that served well sites during drilling operations often is found through a study of aerial photographs. In the Appalachian region and in hilly terrain, the roads were built above the well site, and the pipe and material were lowered down the side of a hill to the drilling rig.

2. A clue often found in the vicinity of the well is evidence of the water-supply and oil-storage tanks that were constructed during drilling and development. Often the location of these tanks is quite apparent because an area 15 to 20 feet in diameter was cleared and leveled for the tank base. These clearings or indentations made in the ground by the tanks are visible on aerial photographs, particularly in wooded areas where a difference in the growth in the trees can be detected. Tank markings such as indentations in the ground, pieces of redwood staves or pine plugs, and iron rods often indicate the location of a wooden tank. Clues indicating the location of steel tanks are nuts and bolts used in their construction and rusted pieces of metal fittings. Additional clues found in the area of an oil-storage tank are oil-saturated soil and a scarcity of vegetation. Unfortunately neither water nor oil-storage tanks were set at a uniform distance from the engine house or derrick floor. However, the oil-storage tank was always set beyond and below the well so that gravity flow could be used, and the water tank was always set near the engine house. When either one or both of the tank locations are found, a search is made of the area between the tanks or in a 100-foot radius of a single tank for rig marks, such as indentations in the ground from rig foundation sills, pieces of metal from drilling and producing operations (appendix B), and indications of water and gas service pipelines.

3. Frequently in wooded areas, trees are found with pieces of wire line imbedded in their trunks, or with scars and deformities caused from their use as anchors for guy wires supporting the drilling rig. If three or more scarred trees are found, the well may be located by triangulation; if only one or two trees are found, a search of the area must be made for additional clues.

4. An important clue often found in the vicinity of a well is evidence left by large timbers or sills used in the construction of the derrick and engine house foundations. These timbers, about 18 inches square in cross section, usually were hewed from hardwood trees available in the area. The positions of the various sills and their distance from the well on an 82-foot standard cable-tool rig are shown in figure 3. These distances will vary with

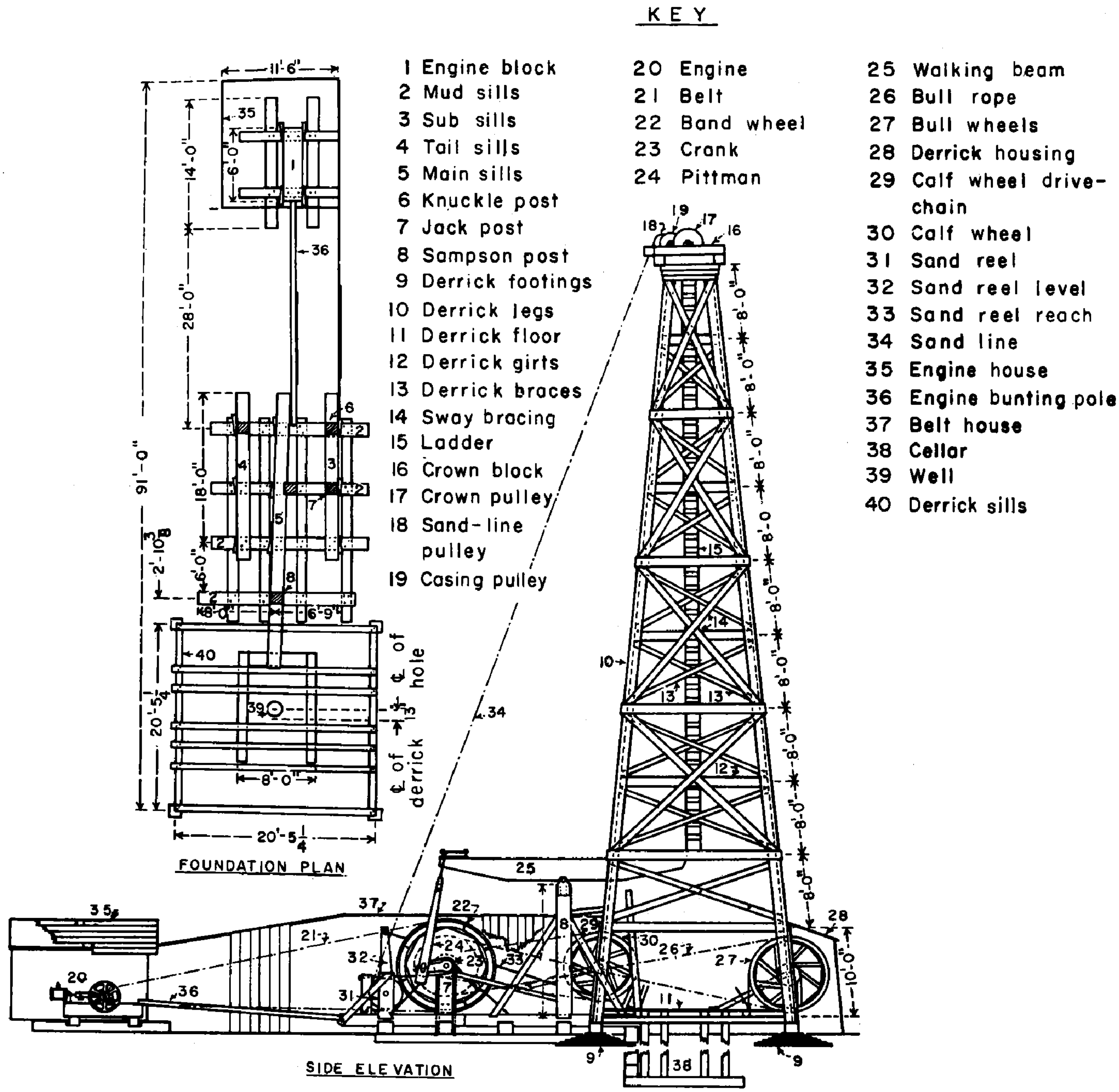

FIGURE 3. - Plan and Elevation of an 82-Foot Standard Cable-Tool Rig and Wooden Derrick.

the size of derrick required for drilling. In most cases, the only evidence of the sills are indentations made in the ground by the weight of the timbers. Occasionally, a few pieces of rotted wood are found.

5. During early development of the Appalachian areas, where many wells were drilled on the side of steep hills or mountains, the standard cable tool rigs for convenience were faced in the same direction. In most cases, when looking from the engine house toward the front of the rig, the right-hand shoulder of the viewer was on the uphill side. This, locally known as a

right-hand rig, placed the service road above and the bailer dump below the derrick. With this knowledge and evidence of the location of the engine house, water tank, or steam boiler, the probable location of the derrick floor, or possibly the actual wellbore may be found. If no evidence of the well is found, shovels, or in some areas bulldozers, are used to find additional clues, such as spillways where sand and shale cuttings from the bailer have run down the hillside, or pits where the cuttings were collected and retained. Greener grass than surrounding area is evidence of spillways, or if salt water was bailed from the well, barren ground with no vegetation. Old pits usually are indicated by depressions or sink holes. Since the bailer is dumped on the downhill side, the derrick floor is above or uphill from the spillway or pit.

6. Another clue found in the vicinity of a well is the presence of cinders or slag from the firebox of the steam boiler. However, there is no uniformity in the distance between the boilers and engine house, and a search of the area for additional clues is often needed.

7. In areas where land is under cultivation and no evidence of the well has been found, it often is useful to hire the farmer to plow his fields with deep furrows 16 inches or more deep. Men follow the plow looking for evidence, such as sand and shale cuttings, rust-colored soil, or pieces of metal.

One operator reports that it is advantageous to look for surface clues, such as old roadbeds, depressions left by water and oil storage tanks and indentations made by foundation sills during winter months when snow is on the ground. The indentations made in the ground are more apparent when covered with from 2 to 3 inches of snow than when covered with underbrush. When the snow is deeper than 3 inches, the depressions are not as apparent.

Electronic Metal Detectors

The arguments proposed in these seven clues have made it apparent that the location of metallic debris is extremely important to finding abandoned wells.

A tool that should be fully utilized in locating metallic objects is the electronic metal detector. Abandoned wells have, in general, one characteristic that makes them amenable to detection by electronic metal detectors. Usually there is a high population density of scrap metal in the vicinity and, occasionally, surface casing at a detectable depth. Locating the highly concentrated area of scrap metal with an electronic metal detector will narrow the search area considerably and, sometimes, reveal the exact location of the well.

Electronic metal detecting devices in various forms have been used for about 50 years. In the past, they have been large, bulky devices with varying degrees of response and sensitivity. In recent years, the advances in miniature electronic components have made it possible for the manufacture of lightweight, sensitive instruments with good detection reliability. Examples of several configurations commercially available are shown in figure 4.

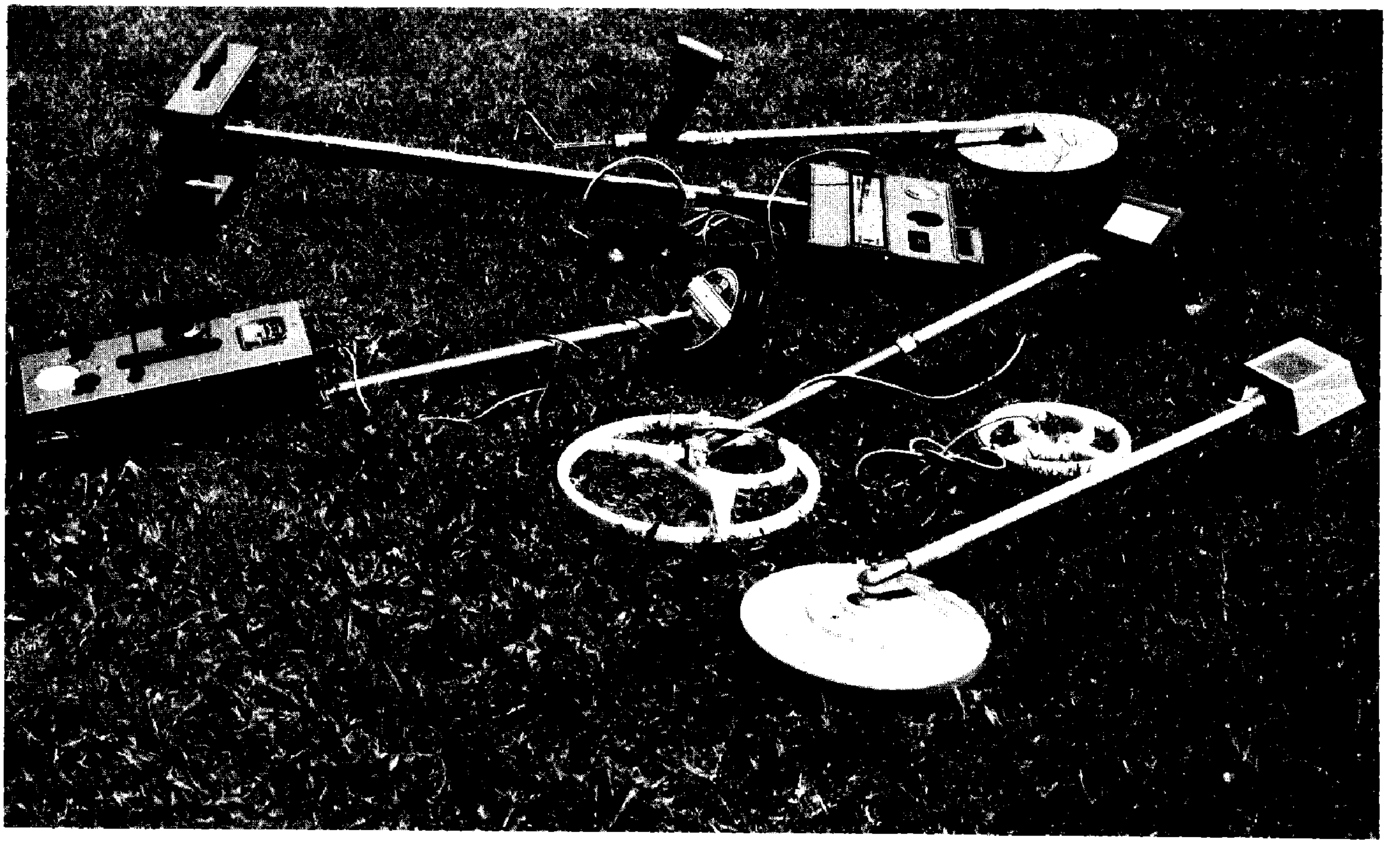

FIGURE 4. - Several Types of Electronic Metal Detectors.

Principles of Detection

A very brief description of how electronic metal detectors respond to buried metallic objects follows; however, to have a more complete understanding of them, the reader should refer to publications treating their design. Electronic metal detectors essentially consist of three basic systems: (1) An oscillator, (2) an antenna, and (3) a detector circuit. An oscillator is used to generate a fixed frequency current in the antenna loop, which radiates an electromagnetic field into the search area as shown in figure 5. Conductive masses within a detectable range of the instrument cause changes to occur in the field or in the inductance of the antenna. The detector circuit senses these changes and indicates them on a meter or by generating a signal in a loudspeaker or earphone.

Each metal detector, when placed into operation, must be adjusted to a coupled state or electronic balance between the detector's antenna and the ground until no target response is indicated. If this balance is altered by the target, a reaction is produced by the electronic metal detector and the presence of the target indicated.

Of the several variables influencing an electronic metal detector's reliability to detect metallic objects, soil effects, target size, and depth are most frequently encountered in actual searches. Others, such as oscillator

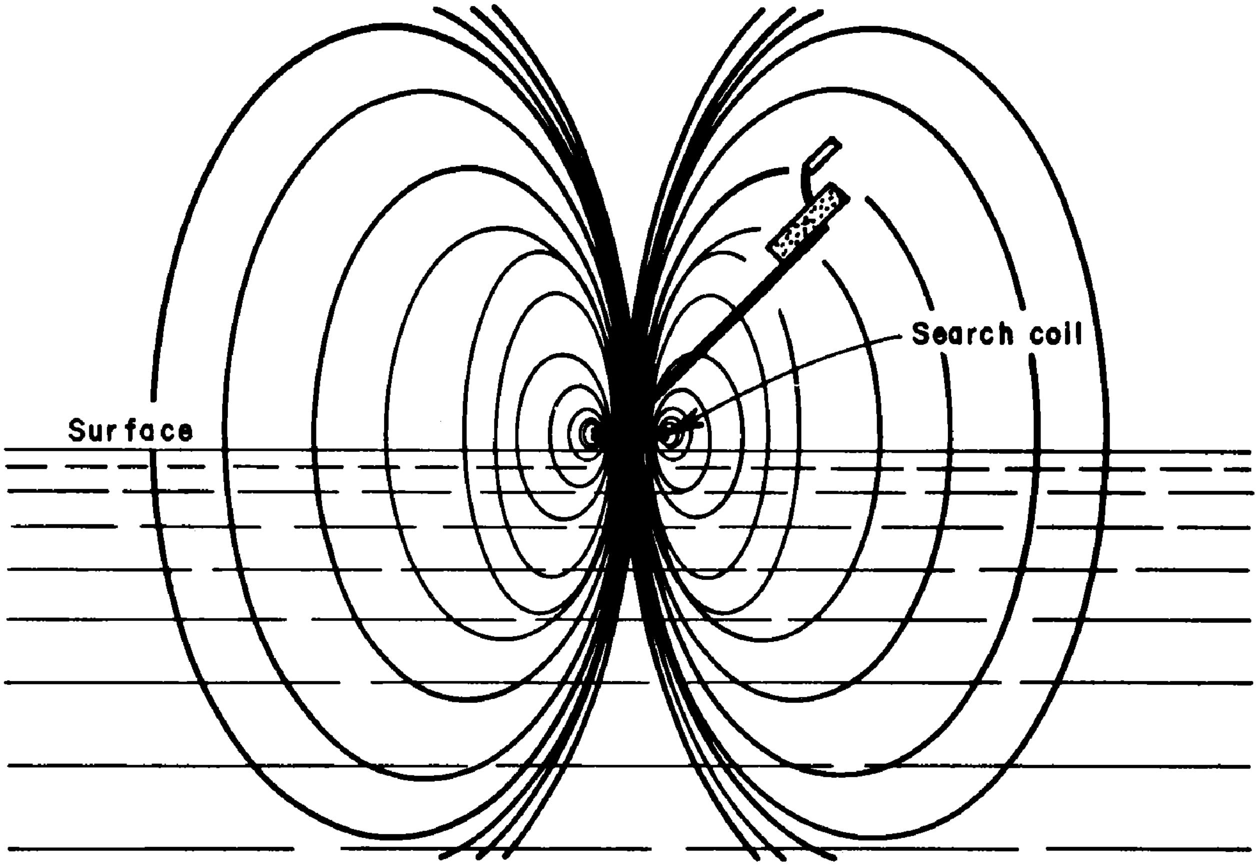

FIGURE 5. - Electromagnetic Field Radiated by the Search Coil.

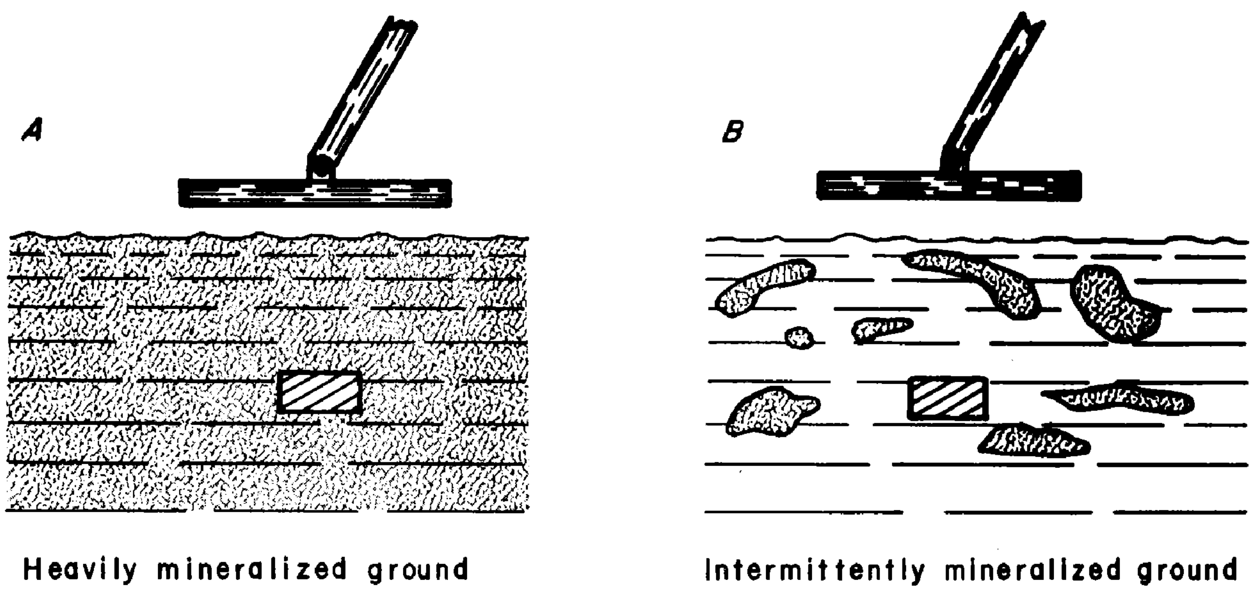

FIGURE 6. - Examples of Soil Representing Difficult Detection Areas.

frequency and search coil diameter, are usually fixed in the detector design. In general, the larger the surface area of the conductive mass projected into the plane of the search coil, the greater the response will be from any given electronic metal detector. However, size and depth are related in that a small object close to the surface may cause the detector to respond to the same degree as a large one at a greater depth. The detectability of iron objects is further influenced somewhat by the length of time such objects have been buried. An iron object that has been buried for many years is easier to detect since its effective size has increased due to the zone of rust around it in the soil.

Mineralization

The degree of mineralization of the soil affects target detection significantly. When operating an electronic metal detector in a highly mineralized region, as shown in figure 6A, the instrument has to be nulled to a point that results in a significant loss of sensitivity and consequently, metallic objects may be missed completely. Intermittently mineralized soil, as shown in figure 6B, also poses extremely difficult detection problems. Since these areas are randomly distributed in the soil, their effects cannot be nulled out. These small mineralized areas appear as metallic objects to the detector yielding many false signals which, if ignored, may result in overlooking an actual buried metallic object.

Detection Volume

Search-coil diameter affects the effective region of detection for a given metal detector. The interaction between the search-coil diameter and the target result in a detection volume for the instrument. For example, the instruments shown in figure 4 were found to have the effective detection volumes shown in figure 7 for several targets. Metallic objects with similar surface areas moved within this volume would be detected with a high degree of reliability.

Operation and Search With Electronic Metal Detectors

Searching with electronic metal detectors requires familiarity with instrument operation and performance as well as a method for systematically examining an area suspected of containing an abandoned well. Several operators, who have reported poor success from the use of detectors, have admitted little knowledge of detector operation and performance, or the operator failed to use a systematic method to scan an area suspected of containing an abandoned well. As with any instrumental system, successful metal detection depends upon the operator and a well-planned, systematic search procedure. Electronic metal detectors are supplied with specific operational instructions; therefore, only a generalized technique for their operation follows.

After the operator lowers the search coil to within an inch or two of the ground, the tuning control on the instrument being used should be adjusted to a null or balance for the instrument. The operator should sweep the search coil in an arc in front of him, keeping the coil at a constant height. Move

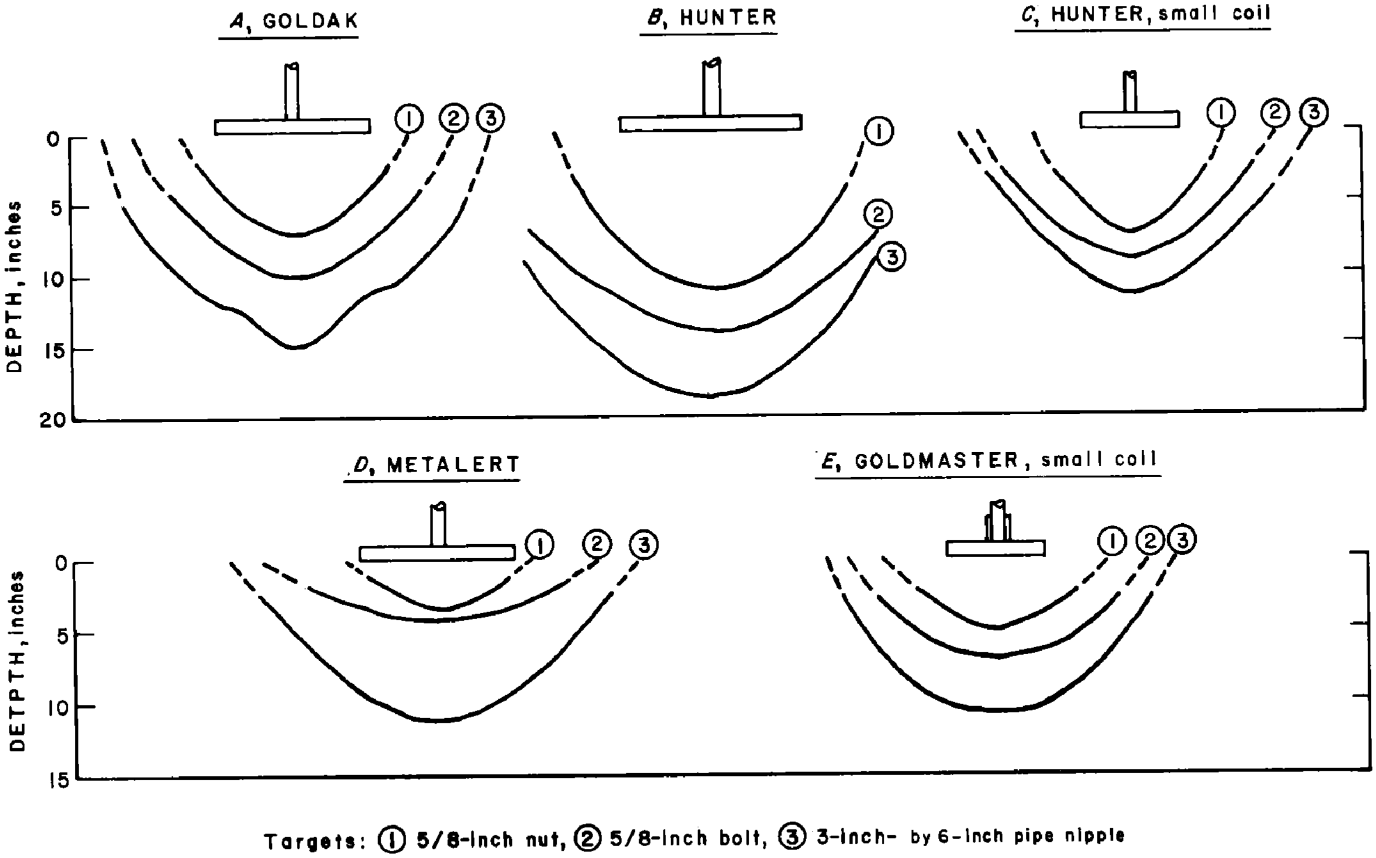

FIGURE 7. - Cross Sections of the Detection Volume for Several Electronic Metal Detectors and Metal Targets.

the coil at a slow sweep rate, then after becoming familiar with the instrument, increase the rate. The optimum sweep rate must be determined by each operator. If the search area is free of trees, rocks, and tall grass, the length of the arc is limited only by the length of the detector stem. For maximum depth penetration, the coil should be held and swept as close to the ground as possible.

An area to be searched must be scanned thoroughly to minimize the probability of missing buried metallic objects since each has an equal probability of being the well casing. An angular search pattern around a staked reference point will enable an operator to cover the area adequately. A constant radial distance from the reference point may be assured by using a light nylon rope with distance marked on it. The angular position may be read from a board placed over the reference stake, as shown in figure 8.

A search pattern is started by looping one end of the marked rope over the reference stake. With the rope held in one hand, the operator sweeps the detector from side to side in front of him, advancing the search coil at the end of each arc. The length of arc used must be constant and may be measured by means of markers on the rope. The search coil should be advanced approximately two-thirds the diameter of the coil being used. For example, if using a 12-inch search coil, advance an estimated 8 inches at the end of each arc. This keeps the operator moving ahead and allows some overlapping of each arc.

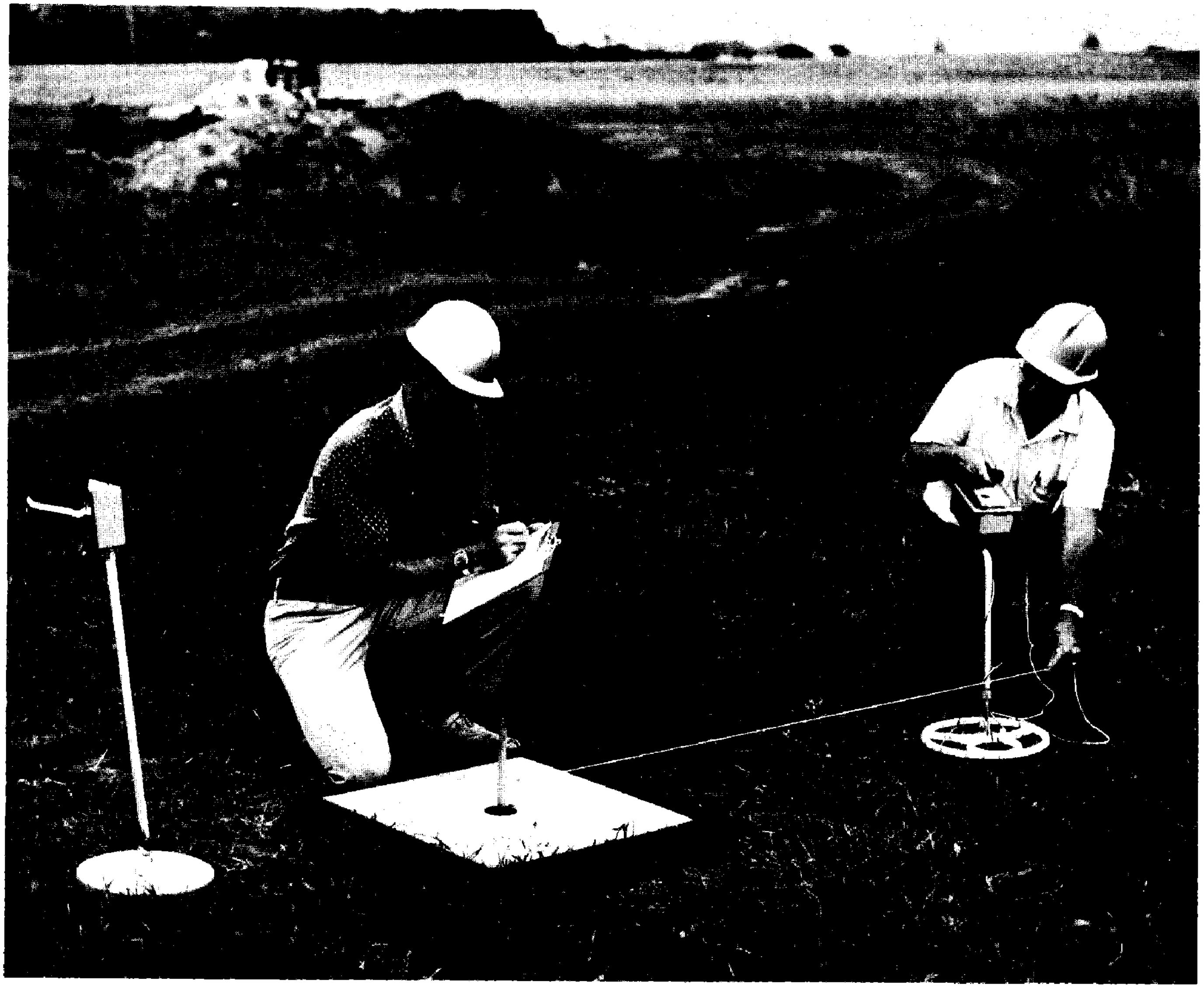

FIGURE 8. - Equipment for Estimating Target Position (Radius and Angle).

It is well to note here that the operator must not hurry when using the detector because the ground will not be adequately covered. Also, deeply buried objects produce weak signals which may be missed when moving the detector too fast. At the end of each complete revolution around the reference point, the operator moves out another radial increment along the rope.

Each target should be removed from the ground when found, and the exact radius and angular position of the find, tabulated. If the object is too deeply buried, such as a pipe stake or a pipeline, leave it uncovered until the search is over. After removing the object, scan the location again for objects that may have been overlooked.

To fully explore the feasibility of using metal detectors to examine areas suspected of containing abandoned wells, engineers made comparative field tests in both the midcontinent and Appalachian areas, which will be described later.

Portable Hydrocarbon Detector

Another characteristic of old abandoned oil and gas wells is the presence of hydrocarbons. In many cases improperly abandoned wells have substantial quantities of gaseous hydrocarbons (primarily methane) leaking to the surface. These hydrocarbons may be easily detected with a portable hydrogen flame ionization detector. One of the lightweight, sensitive instruments commercially available is shown in figure 9. Use of this relatively new electronic instrument has not become widespread in searching for abandoned oil and gas wells. Its application to the search has been proven useful, as will be shown.

Principle of Detection

The instrument uses the principle of hydrogen flame ionization for detection and measurement of organic vapors. Flames characteristically have electrical conductivity owing to the presence of ions generated from the burning fuel. The hydrogen flame has an exceptionally low electrical conductivity, which makes it ideal for use in a flame ionization detector.

The sample being measured is introduced into a small hydrogen flame within the detector chamber of the instrument. Trace amounts of organic material burn in the hydrogen flame producing ion concentrations proportional to the quantity and structure of the hydrocarbon compound present. An electric field in the chamber drives the ions to a collecting electrode, which causes a current to flow that is proportional to the ion concentration. This current is amplified and relates the instrument response to the hydrocarbon concentration in the sample. Neither carbon monoxide nor carbon dioxide produces appreciable ions in the detector flame; consequently, the presence of either or both of these compounds will not interfere with hydrocarbon measurements.

The instrument shown in figure 9 responds to methane in the range from 1 to 100,000 parts per million. The concentration is usually displayed on a hand-held meter. An audible detection alarm that can be preset to any desired hydrocarbon level may be provided.

Emissions From Abandoned Wells

A survey with the instrument of the hydrocarbon emissions from several abandoned wells, with and without surface pipe, has led to several generalizations. These generalizations will serve as a guide for operators to recognize the location of an abandoned well from the wellbore emissions.

Background hydrocarbon levels vary from one location to another because of both natural and industrial hydrocarbon emission, as well as varying degrees of atmospheric dispersion of those hydrocarbons. Emissions from abandoned wells add to the background level, which increases the ground-level hydrocarbon concentration in the immediate area of the well. Therefore, when searching for abandoned wells, only significant increases in hydrocarbon measurements above background level are considered as indicating the presence of a leaking wellbore.

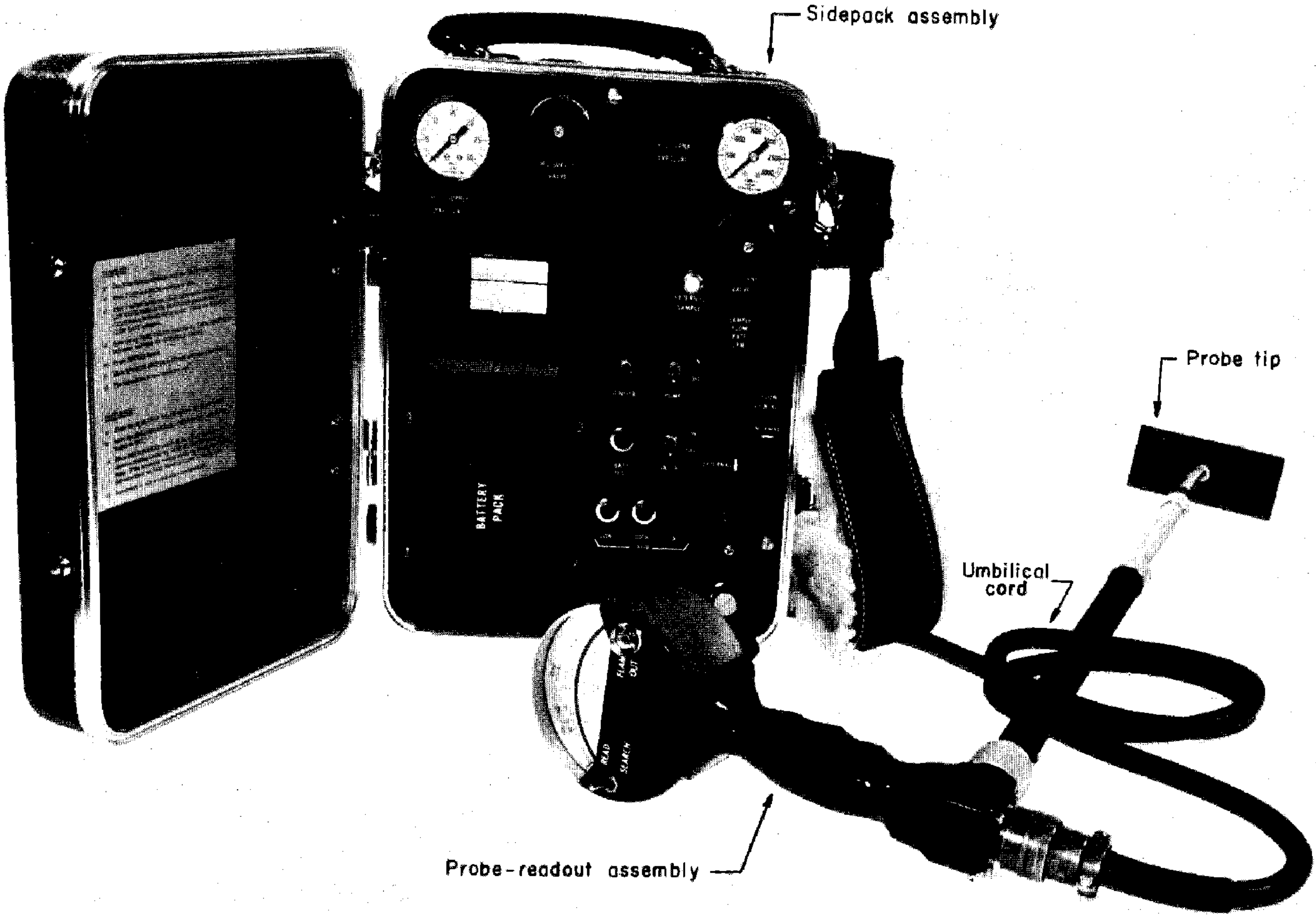

FIGURE 9. - Portable Hydrocarbon Detector.

Hydrocarbon emissions from abandoned oil wells vary, depending upon the efficiency in the original plugging operation and the subsequent pressure buildup in the wellbore. Methane concentrations of 5 percent at ground level have been observed at several wellbores in the midcontinent area. Even these high concentrations have been observed to be dispersed quickly by a light wind until at only a few inches above grass level only background concentration was observed.

Most of the emissions from oil wells examined came from the surface area immediately over the wellbore, and the diameter of the area is usually no more than from 1 to 2 feet, although this may vary with soil condition. Of the oil wells examined, none had detectable ground emissions at distances farther than 2 feet from the wellbore.

Operation and Search With a Hydrocarbon Detector

After the instrument has been turned on and calibrated according to the manufacturer's instructions, the meter should indicate the ambient background hydrocarbon level. The operator may then begin to familiarize himself with operation of the instrument by surveying an area known to have some methane emissions. For example, a gas meter usually has very slight leakage in its assembly and may be used as a methane source. When using the instrument outdoors, the output indicator will normally be quite variable due to the random variation of the wind in both intensity and direction.

Using one-hand operation, survey the area of interest while observing the meter and/or listening for the hydrocarbon indication audible alarm. When hydrocarbons are detected, the meter pointer will move upscale, and the audible alarm will sound when the present point is exceeded.

One thing is immediately noticed: The probe tip has to be moved only slightly to get a significant change in response on the instrument. This demonstrates that the instrument responds only to the gas in the immediate vicinity of the search probe tip. There are two reasons for this: (1) Methane emissions are dispersed relatively quickly by surface winds, and (2) the sampling area of the search probe tip is very small. Therefore, for broad surveys of areas suspected of containing an abandoned well, the instruments should be operated in the most sensitive mode and with the search probe tip relatively close to the surface of the ground. For pinpointing the location of the emission source or obtaining a quantitative measure of its hydrocarbon concentration, in most cases the least sensitive scale should be used.

Searching for abandoned wells with the portable hydrocarbon analyzer requires a systematic search pattern similar to the one used with electronic metal detectors. The search pattern described previously for electronic metal detectors can be applied equally well for this instrument system; the main difference is that no signal will be audible until an emission source has been found. Since the procedures are similar, only a brief résumé is given in this section, and the reader is referred to the preceding section on electronic metal detectors.

The area is scanned, as before, in an angular search pattern using a light rope to maintain a constant radial distance from a staked reference point. The probe of the detector is moved from side to side at a very slow sweep rate because of the time lag in the instrument response and also because of the relatively small sample flow rate. A record is kept of methane emission during the course of each complete revolution at a given radial increment.

In locating an emission point the wellbore is usually at the point of most intense methane emission. Final evidence of the exact location of the wellbore is sought by excavating. If the surface casing has not been uncovered near the ground surface, a 4- to 5-foot-diameter, 2- to 3-foot-deep hole should be dug. The rubble in the bottom of the hole should be cleaned and examined frequently for a typical contrasting area that will denote the wellbore. Occasionally a deeper and larger area may need to be excavated, in which case it would be necessary to use mechanized dirt-moving equipment.

A Case History

The oil well shown in figure 10 had been abandoned before 1910 and was recently found as the result of a search with the portable hydrocarbon

analyzer. The area in which the oil well was located had been a lawn for many years, and all evidence of the well's location had been removed. This oil well had an emission profile generally characteristic of other oil wells examined in this area.

Figure 11A shows the ground-level hydrocarbon-emission pattern as detected in a light wind about the wellbore. Note that the pattern is not completely symmetrical but elongated in the direction of the wind. As the detector probe was moved back and forth in the direction "A-A" of figure 11A, the hydrocarbon concentration shown in figure 11B was observed. The graphical representation of the ground-level hydrocarbon emissions illustrates the rapid decrease in concentration as the detector probe is moved away from the wellbore.

At the point of maximum emissions located on the surface, a large diameter hole was dug to locate the wellbore. As the depth of the hole was increased, the methane concentration increased. The earth removed from the

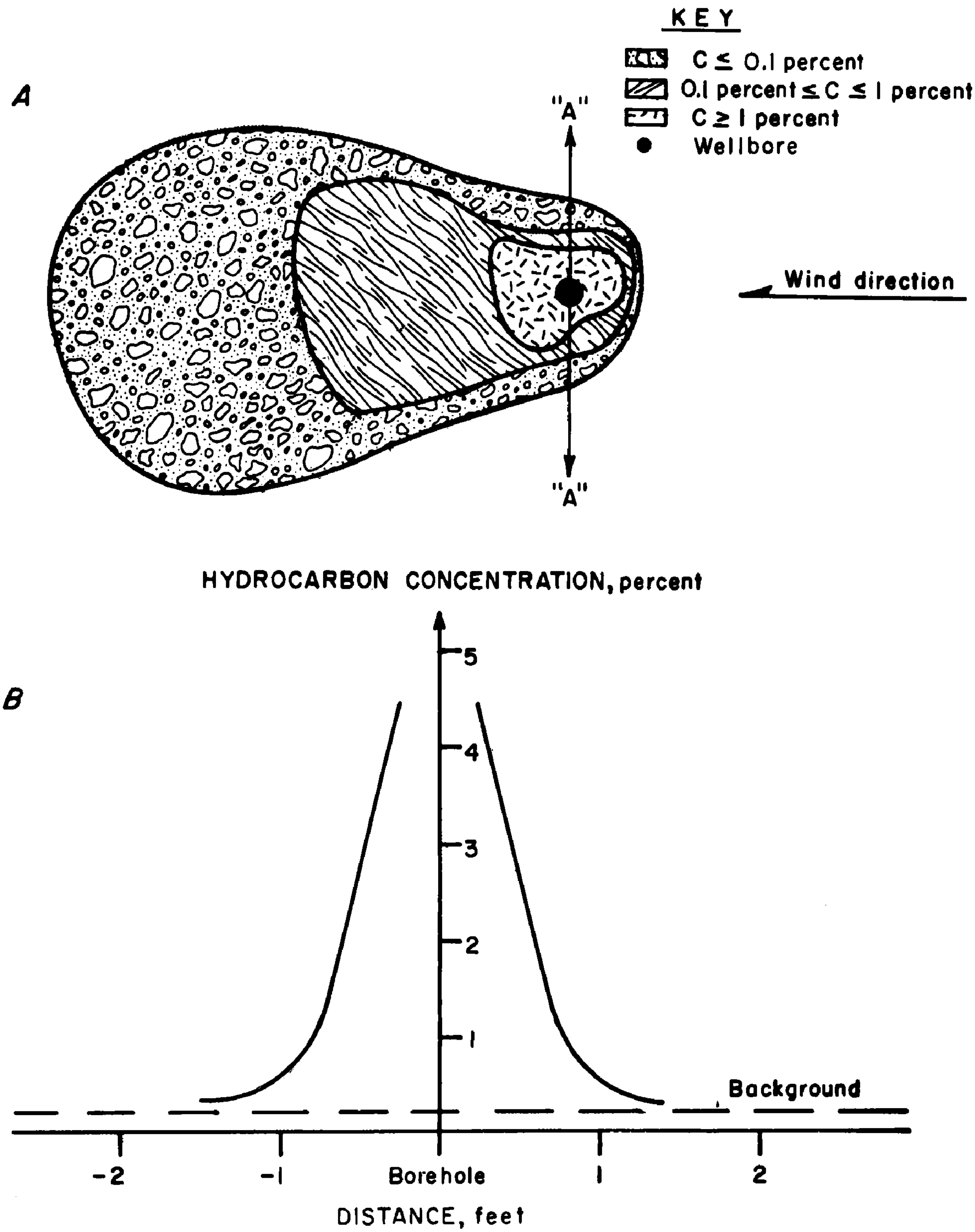

FIGURE 11. - Graphic Representation of Decrease in Methane Concentration as Search Probe Is Moved From Center of Wellbore.

location had a characteristic petroleum odor. At a depth of approximately 2 feet, the contrast in the composition of the earth in the bottom of the hole

FIGURE 12. - Wellbore Containing Wooden Stake.

indicated a small circular region outlining where the wellbore had been filled in. At a depth of approximately 3 feet, the position of the wellbore was located by several old wooden stakes, as shown in figure 12.

Figure 13 shows the results from an examination of the emissions at the bottom of the hole dug to reveal the wellbore. The emissions were coming from the central region of the wellbore, and as the detector probe was moved away from the center, the hydrocarbon concentration diminished. This was interpreted as further evidence that the hydrocarbon emissions may be used to pinpoint the wellbore location.

Combination of Methods

A method for locating abandoned oil and gas wells is to combine the technique for the use of electronic metal detectors with that for the portable

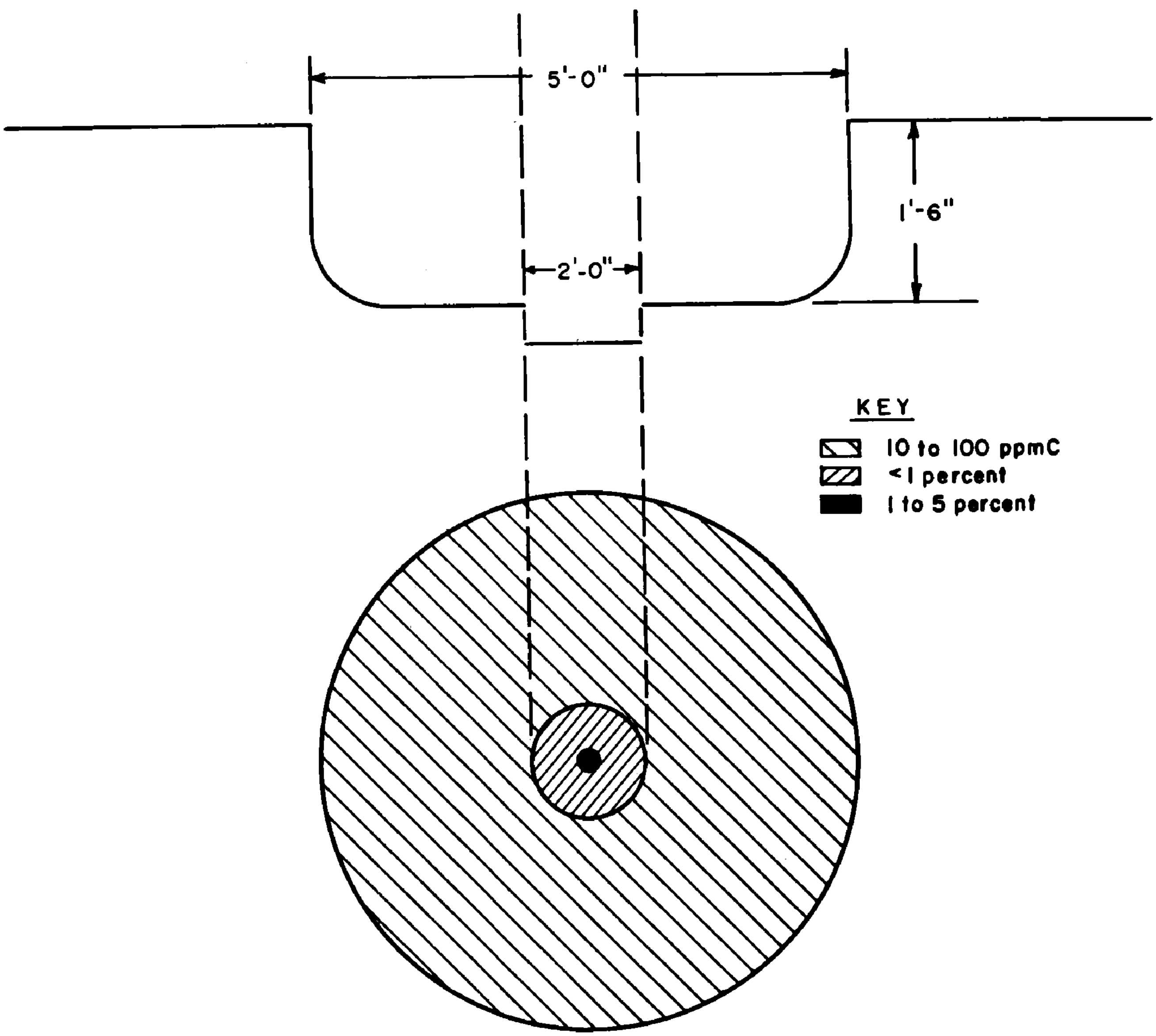

FIGURE 13. - Location of Abandoned Oil Well With Portable Methane Detector Showing Hole Dimensions and Showing the Methane Profile in the Hole.

hydrocarbon analyzer. A large field can be surveyed relatively quickly for smaller regions of high-metal concentrations with the large, two-box metal detector. Then systematically search these areas with the smaller horizontal coil detectors and plot the location of each target. Probable locations of the wellbore obtained from the plots can then be systematically surveyed with a portable hydrocarbon analyzer for the exact location of the wellbore.

As was shown in the survey of electronic metal detectors, scrap metal parts may be found just under the surface of the terrain around oil wells that have been produced. Even with the abundance of metal around the well, the surface casing may have been removed; consequently, the exact location of the wellbore may not be found. If all physical evidence of a well location had faded, then a thorough search of an area must be made. A chart of the target locations will indicate probable locations for the wellbore, and a search of these areas with the portable hydrocarbon analyzer will not only cut down on search time but also probably reveal the exact location of the wellbore.

Using a portable hydrocarbon analyzer to search a large area suspected of containing an abandoned oil or gas well could take an unreasonable length of time. Instrument parameters that contribute to the length of the search are relatively slow response time, low sampling rate, and the small area of the search probe head.

If no hydrocarbon emissions are found in the area, the results obtained with the electronic metal detectors may be used to locate a suspected area and the wellbore may be uncovered by excavation with a bulldozer.

EVALUATION OF INSTRUMENTS AND PROCEDURE

One search method, as described in the previous section, was used to compare several electronic metal detectors as potential instruments for locating abandoned wells. No comparative tests were made of portable hydrocarbon detectors. The following sections briefly examine several instruments' performance for use in locating abandoned wells and illustrate one search method used successfully.

Electronic metal detectors vary in performance characteristics as illustrated in figure 7. As a further illustration of variation in performance in actual field use, several electronic metal detectors were compared by locating evidence around abandoned wells. These surveys also serve as a test of the search procedure.

Comparative Tests

Midcontinent Area

To make the comparison, an abandoned well still containing the surface casing was used. The only apparent physical evidence of the well location was the old "pit" area and the surface casing immediately under ground level. The well had been abandoned for several years, and the site, located in the midcontinent area, had not been disturbed by other search methods. Each electronic metal detector was used to scan a 60-foot-diameter area, containing the well, for metal parts cast aside during drilling and producing operations.

Since the same site was to be used for all the detectors, it was important that the evidence remain undisturbed. The search procedure and equipment described in the previous section and illustrated in figure 8 were used except that the locations were not uncovered until all tests were completed. The location coordinates for each metallic object were tabulated. The same board position was maintained by alinement of the 180° mark on the board with the rope stretched between the reference stake and another one permanently placed approximately 20 feet away.

Results from the survey of the area with the electronic metal detectors are shown in figure 14. There is a slight degree of uncertainty to the exact location of the object; consequently, a concentration of points in a small region constitutes a find for all instruments. As may be noted, objects found by some instruments were missed by others.

Each of the instruments showed a concentration of objects in the same general area of the well casing. The frequency of occurrence charts, in small angular and radial intervals, of objects detected by two instruments are summarized in histograms plotted from these data (appendix C). Histogram examples shown in figure 15 reveal regions of high target density, which may be considered the most probable area for the well location. The angular distribution indicates a most probable location from approximately 160° to 200°, with the most probable radial location from 15 to 30 feet. This area encompasses the actual well location at 180° and 19 feet.

After completing the survey, targets were removed from the ground, and their exact location was tabulated. A plot of the locations, as shown in figure 16, was used to evaluate the finds made by each detector.

Since each target represents a potential position for the well, only the missed targets were scored wrong. Although a false signal or location is an error and annoying, it does not lessen the probability of finding the well location. Performance for the detector and operator was scored by the equation

$$\text{Score} = \left(1.0 - \frac{\text{number of locations missed}}{\text{total number of locations}}\right) \times 100.$$

Table 1 lists the score, the number of false signals, and the number of locations missed for each detector. The highest score in this test was achieved by the Goldak instrument. Only one operator was used with all the detectors.

TABLE 1. - Electronic metal detector performance around abandoned well

Detector[1]	Diameter of search coil, inches	Number of targets missed	Number of false signals	Score, percent
Garrett Electronics Hunter model.....	12	19	9	74
Do................................	8	28	10	61
Goldmaster........................	6	19	7	74
Goldak model 820..................	10	14	7	81
Metalert model 70.................	10	28	5	61

[1] Reference to specific equipment is made for identification only and does not imply endorsement by the Bureau of Mines.

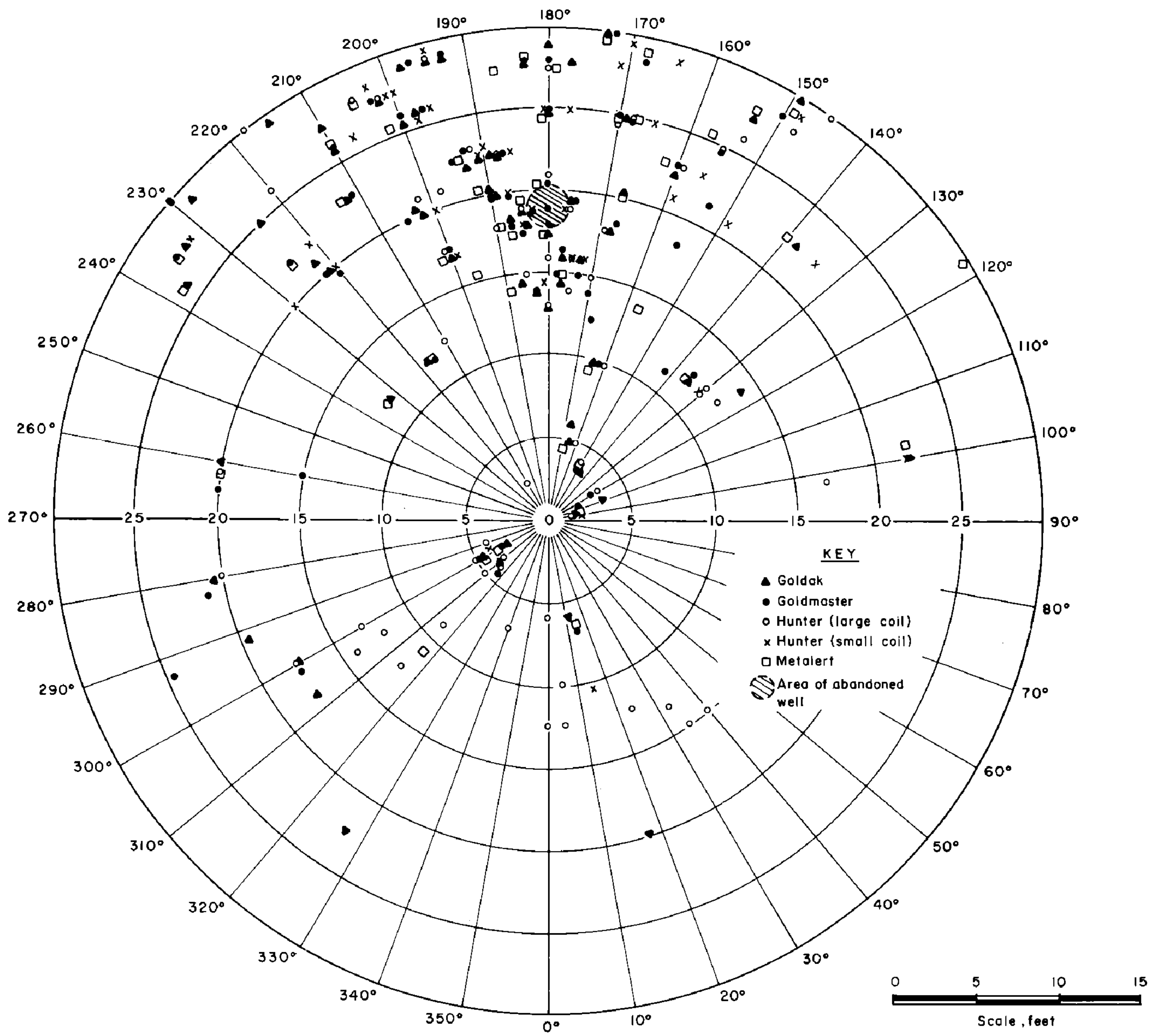

FIGURE 14. - Distribution of Data Points Obtained From Tests of Five Electronic Metal Detectors, Midcontinent Area.

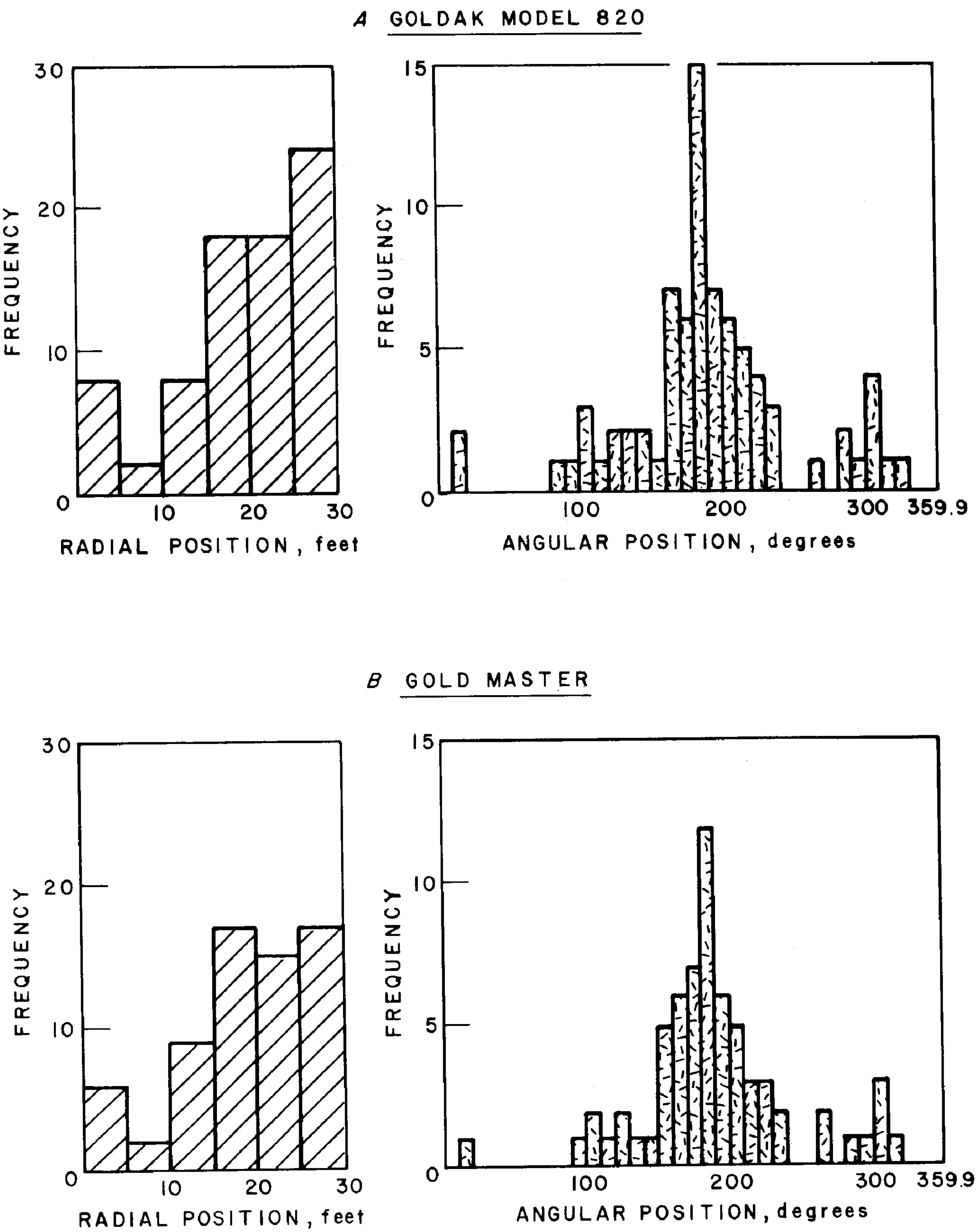

FIGURE 15. - Histograms of Data Obtained With Two of the Electronic Metal Detectors, Midcontinent Area.

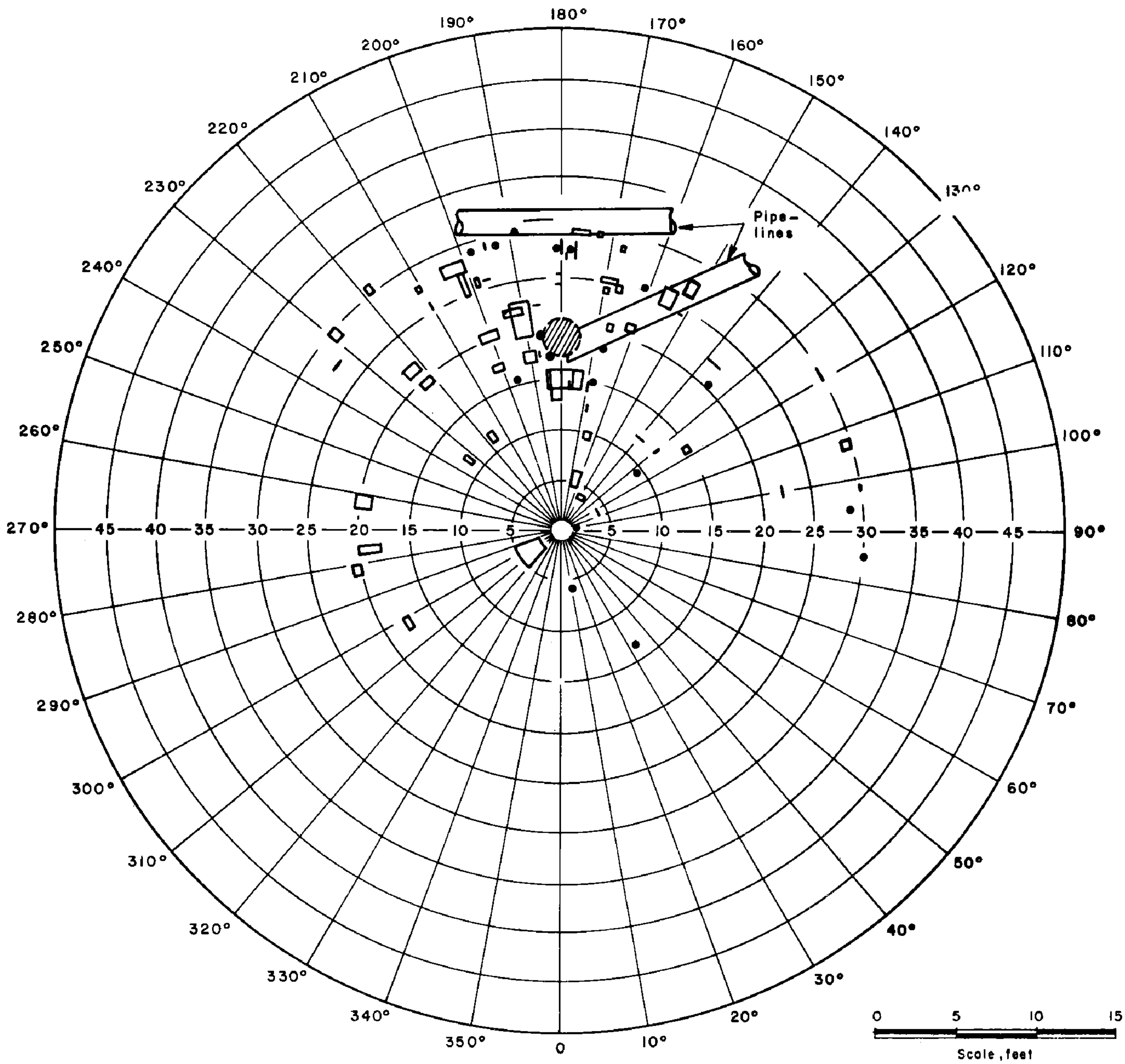

FIGURE 16. - Location of Metallic Objects Excavated From the Area Around Abandoned Well, Midcontinent Area.

As may be noted by the aforementioned analysis and the data in table 1, the operator may influence the results obtained with each detector to a considerable extent. Therefore, two operators were used to survey the area again with two of the instruments. An analysis of variance was applied to the results from this test (appendix D) and has shown the operator variance to have a significant effect on the success of target detection. Variances due to instrument-operator interactions were not found significant in this experiment; however, the rather limited experiment illustrates the importance of the operator to the successful location of evidence revealing an abandoned well position.

Appalachian Area

Most well sites in the Appalachian area are in densely wooded mountains and are not suitable for testing electronic detectors by the procedure shown in figure 8. However, an abandoned well located on the side of a hill in an area covered by low underbrush and few trees was found suitable for the test site after being cleared of underbrush. Figure 17 shows the results of a survey of the site using two operators and two small horizontal coil detectors. The data indicate that the large area of targets is composed of several smaller areas containing a high density of targets. The wellbore is contained

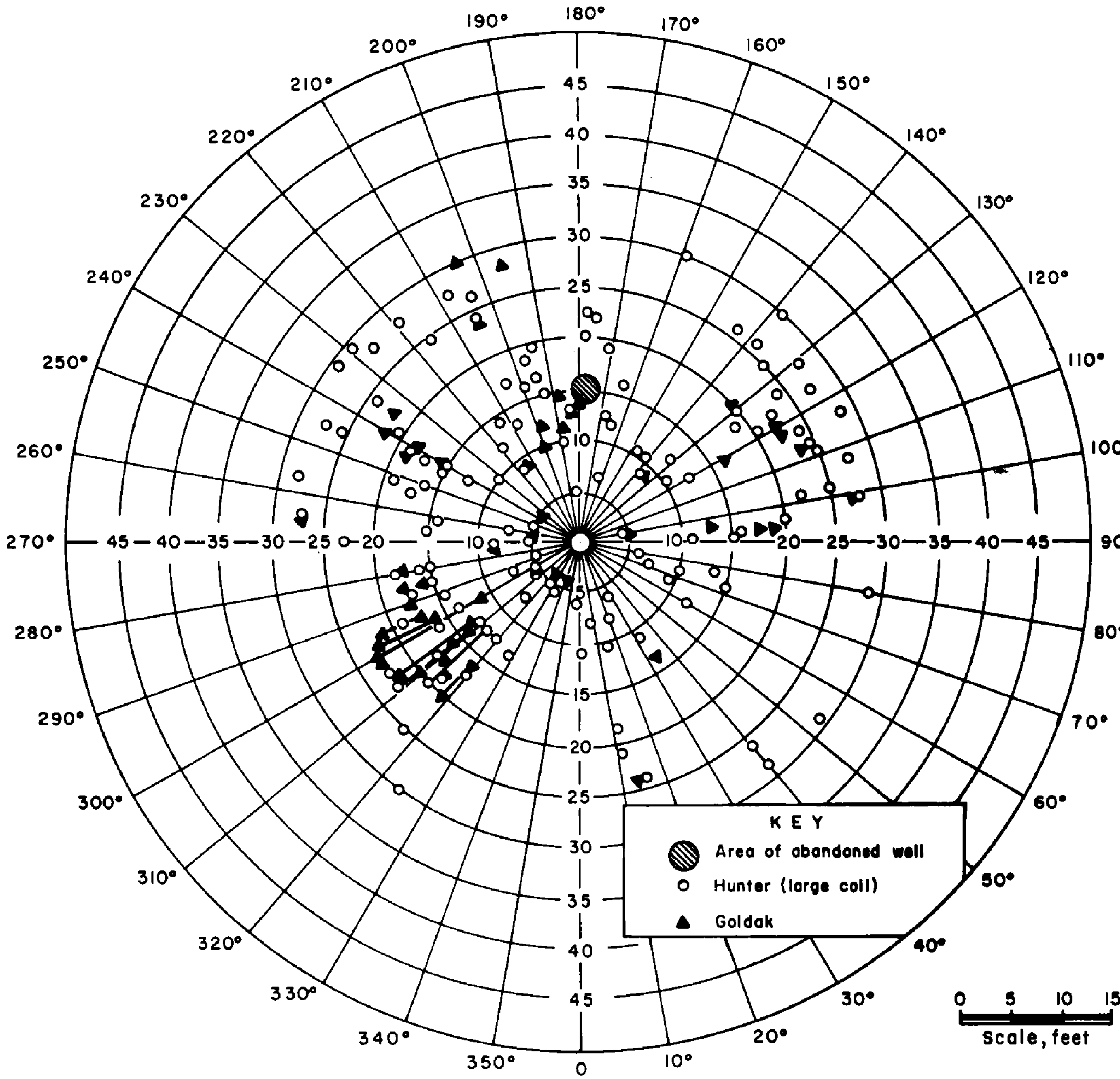

FIGURE 17. - Distribution of Data Points Obtained From Tests of Two Electronic Metal Detectors, Appalachian Area.

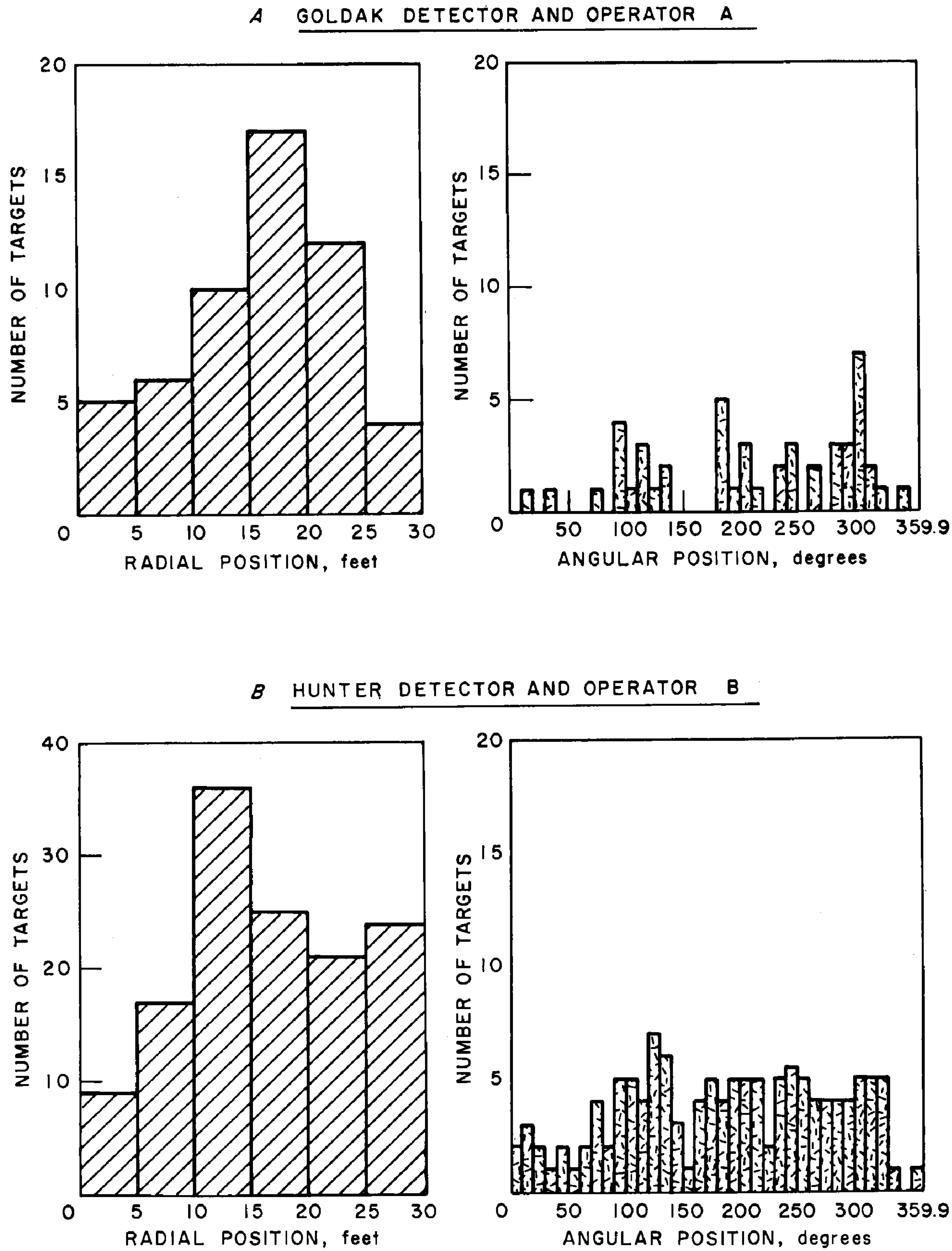

FIGURE 18. - Histograms of the Data Obtained With Two Electronic Metal Detectors, Appalachian Area.

in one of these smaller areas. The data from this survey were treated in a manner similar to that of the midcontinent area. The results are shown plotted as a histogram in figure 18. The angular and radial distributions reveal regions of high target density, which may be interpreted as most probable locations for the wellbore. Although for this test case the location of the well is known, similar techniques may be used for unknown well locations.

A plot of the actual target locations as shown in figure 19 was used to evaluate operator-instrument performance as before. Scoring of the results gave a score of 47 percent for the Goldak detector and 91 percent for the

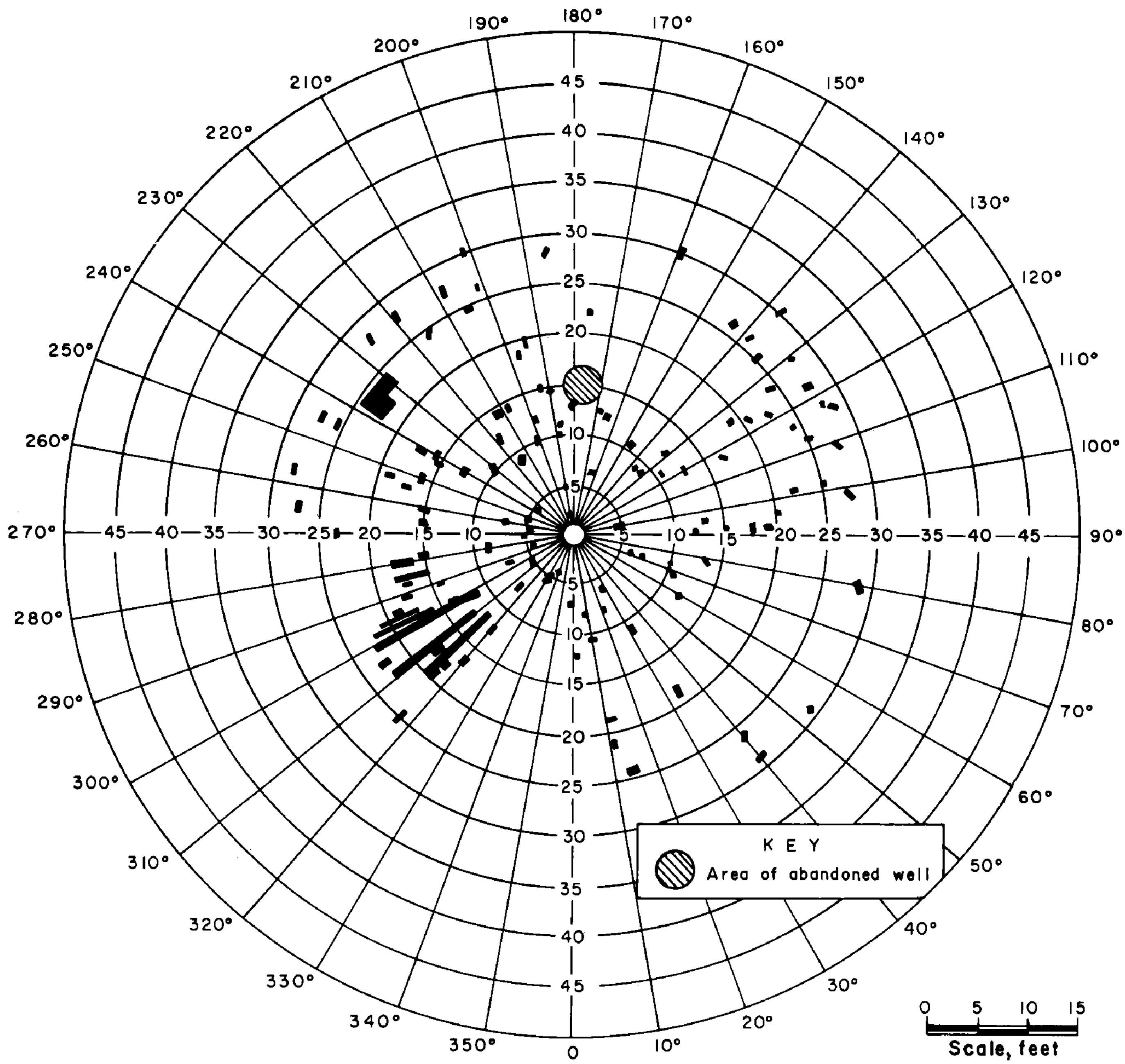

FIGURE 19. - Location of Metallic Objects Excavated From the Area Around Abandoned Well, Appalachian Area.

Hunter large coil detector. Based on this survey, the Hunter instrument was more efficient in locating the targets.

Examination of Evidence

Examination of the evidence excavated around an abandoned well site in the midcontinent area has led to the following generalizations: First, the frequency of occurrence of metallic objects appears to be the greatest in the immediate vicinity of the well. Second, most of the evidence for the oil well location appears to have accumulated from its production period rather than the drilling operation. For example, a concrete and metal foundation for the pumping unit, pipelines, pump parts, and metal stakes were found close to the wellbore. Part of the scrap metal that was removed from the ground is shown in figure 20. Third, as each object was located and recovered, its depth was measured. A histogram of this data (fig. 21) indicates most of the evidence to be less than 10 inches deep. Each of the metal detectors used had an ideal detection depth extending beyond this (fig. 7). Finally, pipelines located in the area were perhaps the best evidence of the well location. The exact position for the abandoned well could be found by following them with an electronic metal detector.

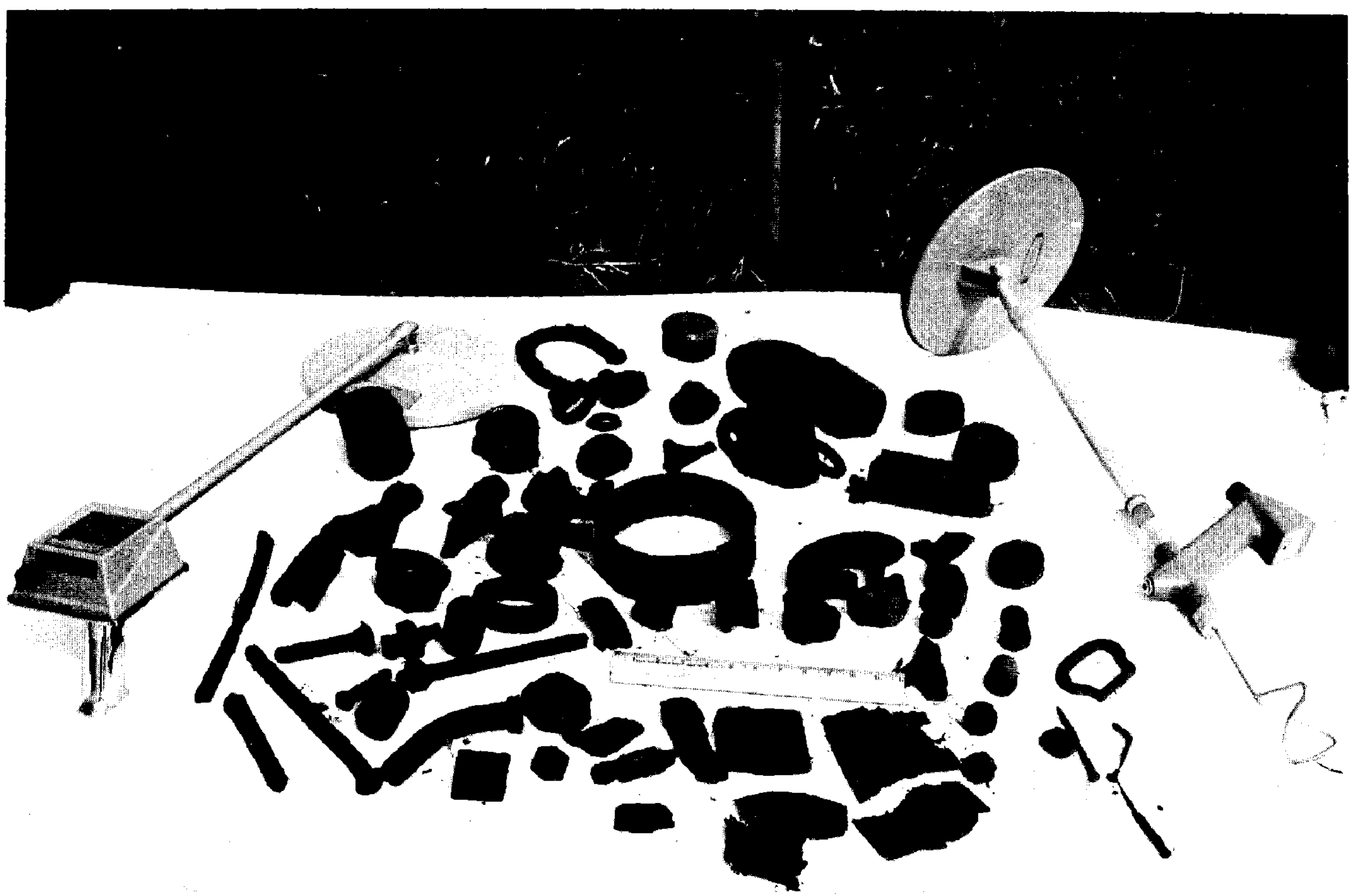

FIGURE 20. - Metallic Evidence Uncovered in Vicinity of Abandoned Well, Midcontinent Area.

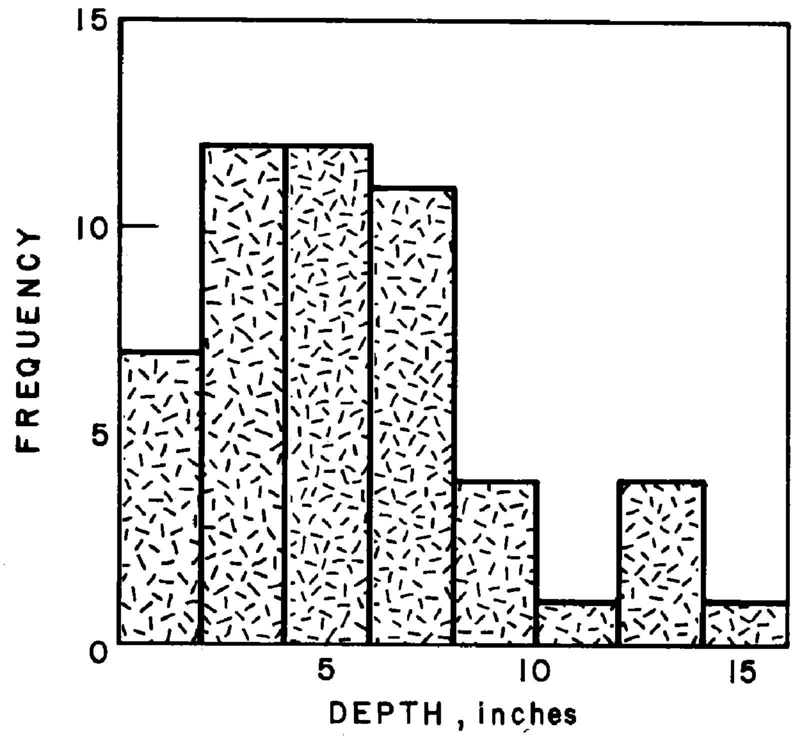

FIGURE 21. - Depth at Which Targets Most Frequently Occurred, Midcontinent Area.

Evidence uncovered around the well sites in the Appalachian area consisted of nails, bolts, slag from coal-fired steam boilers, large piece of sheet metal, and pieces of scrap iron, wire line, babbitt, and pipe fittings. Some of the uncovered metal clues are shown in figure 22.

Actual Search for Abandoned Wells

Midcontinent Area

The previously described search procedure was used to search for three abandoned wells in the midcontinent area. These wells had been abandoned for many years, and the only evidence of their existence was locations plotted on development maps. One of the wells was drilled in an area that has been under cultivation for many years and another in an area where the ground had been severely disturbed by a bulldozer. The third well is in an area that has not been disturbed by cultivation or bulldozer. Casing was pulled at abandonment from all the wells.

Since the distribution of evidence was seriously disturbed and the casing pulled, it was not possible to find the wellbore or, with any assurance, the general area where the first two wells were located. However, a systematic search of the third possible well site revealed many metallic clues, a few of which are shown in figure 23. The pipe anchors and the pumping unit foundation shown in the figure were found from 8 to 10 inches below the surface. After examining the relative position of these evidences and considering the probable position of the power source, a hole dug immediately in front of the foundation revealed hardened drilling mud at a depth of approximately 18 inches and soft mud at 24 inches. The entire length of a probe 6 feet in length was inserted into the hole with relative ease. The operator of a

FIGURE 22. - Metallic Evidence Uncovered in Vicinity of Abandoned Well, Appalachian Area.

waterflood is now replugging this well. Most of the evidence found around the probable well site was contained in an area approximately 25 feet in diameter.

Appalachian Area

Many wells in the Appalachian area of Pennsylvania and West Virginia were drilled in densely wooded mountains where it is impracticable to use an angular search pattern. In these areas, a preliminary survey may be made with the large two-box detector (a super X-500, upper left instrument, fig. 4) using a grid-type search pattern modified to conform with the heavily wooded terrain. Areas where signals indicate the presence of metallic objects may be cleared of underbrush and reexamined with one of the smaller horizontal coil instruments. This procedure was used to scan an area in southern Pennsylvania where an old map indicated the location of an abandoned oil well. The preliminary survey with the large detector indicated a target area, which was later cleared and reexamined with a smaller instrument. Targets uncovered were a 10-1/2-inch thread protector, a 2-inch pipe stake, and two 3/4- by 16-inch bolts. Further search of the area, with both the large and small detectors, located other targets such as pieces of babbitt, scrap iron, pipe fittings, and scrap iron from a steel tank, ball-peen hammer head, and accumulations of slag. The radius and angular position of each find with reference to an

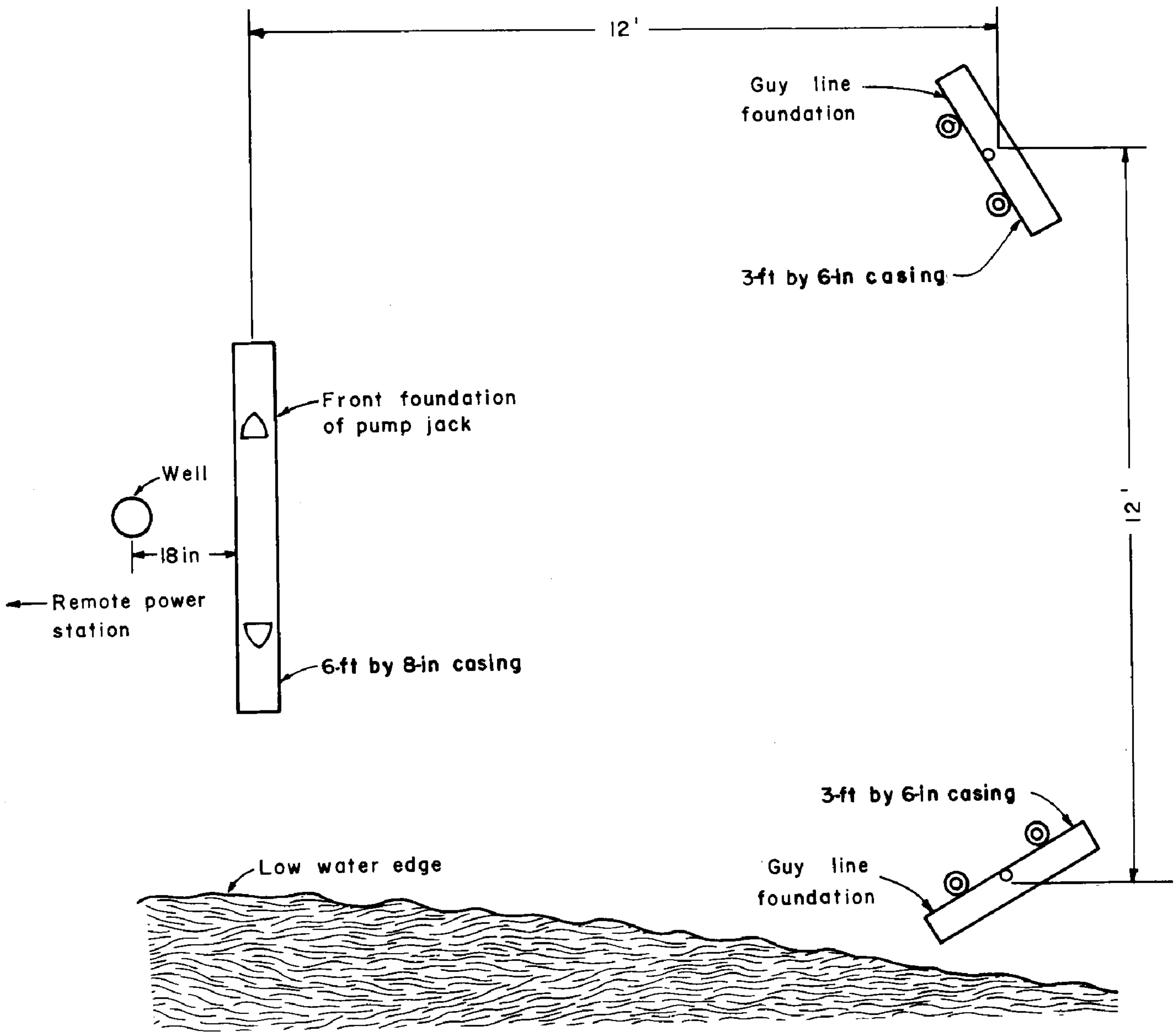

FIGURE 23. - Pumping Well Foundation Found at Abandoned Well Site, Midcontinent Area.

arbitrarily set stake was found by using the nylon rope and board shown in figure 8. These data were plotted on polar coordinate paper as shown in figure 24. The target shown at 315° and 63 feet from the reference stake is an accumulation of slag. Examination of this area with the smaller detector resulted in finding at 330° a popoff valve from a steam boiler, which indicated the probable location of the boiler used for power. The exact location of the well was not determined.

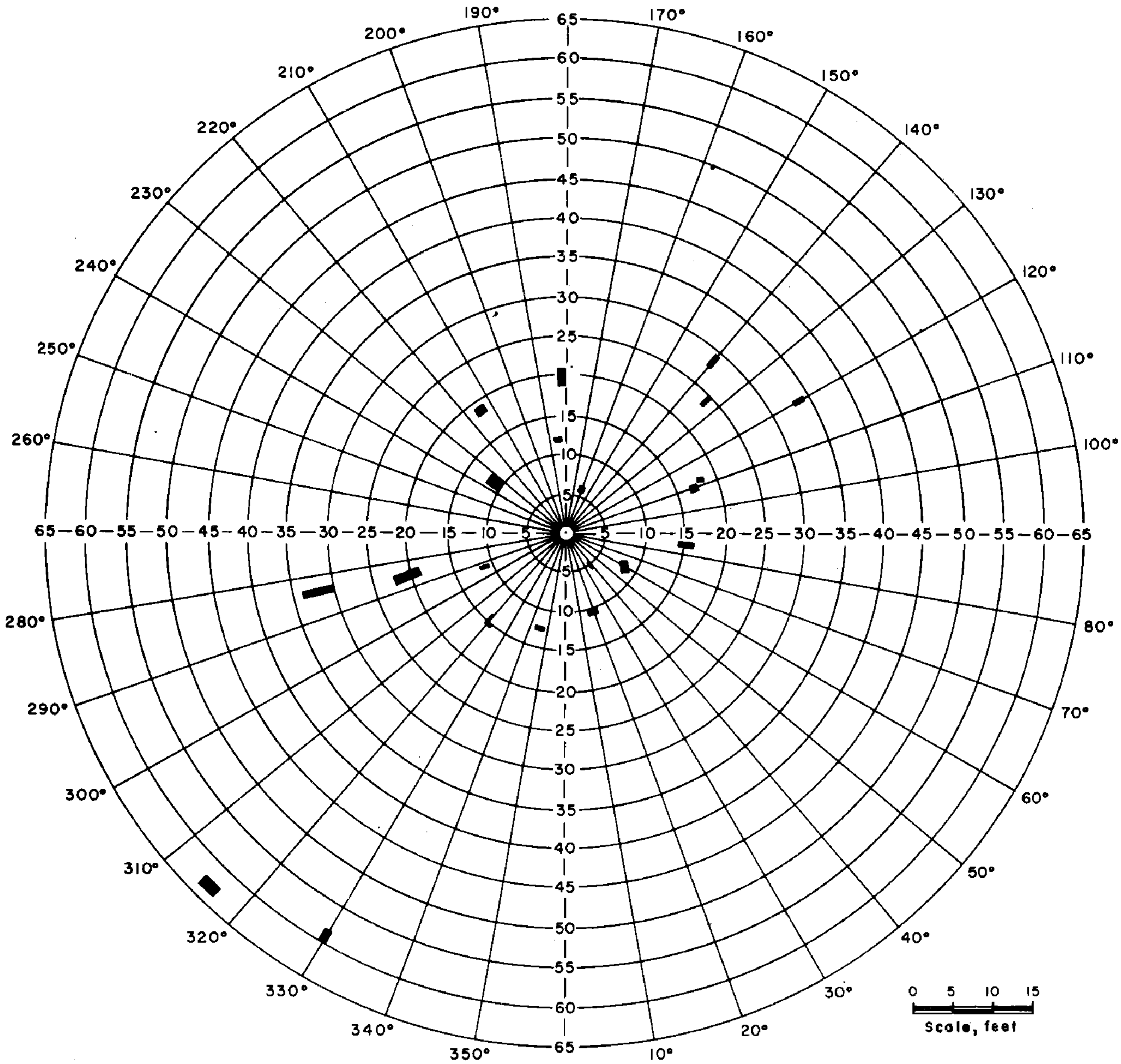

FIGURE 24. - Location of Metallic Objects Excavated From Area Around Probable Site of Abandoned Well, Appalachian Area.

SUMMARY

Each abandoned well poses a unique location problem because of variations in terrain and site conditions. The searching techniques described in the text are the most practical methods used by mining, petroleum, and gas-storage companies to locate old abandoned wells. The procedure includes the collection of pertinent information such as well-location plats, county and/or company development maps, drillers' logs showing footage location, and other data that may be available pertaining to the actual well location from State agencies or company offices. Aerial photographs, which may be obtained from county offices of the U.S. Department of Agriculture for most areas, are often helpful in locating scars left by roads, pipelines, clearings for well sites, and other evidence of drilling and development operations. A very important source of information is verbal communication and physical search of an area with individuals who have worked on wells or lived in the field during early drilling and development. Often these people can point out the exact location of the well and usually are able to locate the well site within a 20- to 30-foot diameter. Experience gained from many years of searching and knowledge of the procedure and equipment used in drilling and producing wells are probably the most important tools available for locating wells.

Tests performed in the Appalachian and midcontinent areas indicate that electronic metal detectors and portable hydrocarbon analyzers used to scan probable well locations in a systematic pattern are useful instruments. These instrument systems have limitations that are related to the location of the search area, condition of the abandoned well, and the amount of methane emission.

A higher probability exists for locating the abandoned well if it was in production for a number of years. If the well position is not located precisely by finding the surface casing, an examination of the tabulated data in the form of frequency distributions may reveal the most probable sites for deeper excavation.

Operators searching for abandoned wells with electronic metal detectors and the portable hydrocarbon detector must be experienced in using them and interpreting the resulting data. A systematic search procedure assures the operator of complete coverage of a probable area.

Performance of electronic metal detectors will vary depending upon the terrain, search depth, and operator. The detectors examined in the midcontinent survey have been rated as follows:

1. Goldak model 820.

2. Hunter (12-inch coil) or Goldmaster.

3. Metalert or Hunter (8-inch coil).

However, the Hunter metal detector was found to give the greatest efficiency in target detection in the Appalachian area. Both Hunter and Goldak are found to be relatively stable, convenient instruments for detecting metal around abandoned well sites.

The large two-box detector did not display the convenience and precision necessary for resolving the location of relatively small targets in high target density areas. However, in scanning large areas, this detector has been found very useful, especially in the heavily wooded mountains of the Appalachian areas. The detector displays potential for locating abandoned wells containing metal at depths greater than 2 or 3 feet or for locating areas to be examined more closely with smaller horizontal coil instruments.

A comparison of metallic evidence found in the two areas indicates that the major difference is an abundance of slag or cinders from coal-fired steam boilers in the Appalachian area. The slag, which is a product of combustion, contains sufficient concentration of iron to be readily detectable with metal detectors. The usual source of fuel for boilers in the midcontinent area is gas or oil, which forms no slag accumulations. Except for the accumulation of slag, which was scattered throughout the area surrounding the reference stake, the targets found in the two areas were quite similar and consisted mainly of pieces of babbitt, tank siding, line pipe, ells, tees and flanges, and large bolts and nails. The only other difference in evidence was that a quantity of ball and seats from subsurface pumps was found in the vicinity of the midcontinent well, and several pieces of wire drilling line were found in the area around the Appalachian well.

For each of the wells examined in both the Appalachian and midcontinent areas, the wellbore was within the region of high target density, and most of the metallic targets were contained within a 60-foot diameter of the reference stake. Therefore, there is a high probability that in other areas where the angular search pattern is used, a 300-foot-diameter pillar of coal, concentric with the 60-foot-diameter target area, would contain the actual wellbore.

In the Appalachian area many of the early drilled wells were completed with wooden casing, and in the midcontinent area, the casing either was pulled or cut off many feet below the surface; therefore, the exact location of the wellbore may not be found with an electronic metal detector. Surveying the area with a portable hydrocarbon analyzer will probably reveal the exact location of the wellbore, since many abandoned wells have measurable methane emissions. If no methane emissions are detected, then continuation of the electronic metal detector procedure will reveal the most probable location for the well. Examination of evidence excavated from a 60-foot-diameter area around two known abandoned well sites in the form of frequency distribution indicated that the frequency of occurrence of metallic objects was greater in the immediate vicinity of the wellbore. This information should be most helpful to mine operations to isolate wells that have penetrated coal seams.

APPENDIX A.--INFORMATION SOURCES, BY STATE

State Agencies

Illinois

Enforcement Agency

Director
Department of Mines and Minerals, Division of Oil and Gas
State Office Building
Springfield 62706

Sources of Information

Chief, Oil and Gas Section
Chief, Coal Section

State Geological Survey
Natural Resources Building
University of Illinois
Urbana 61801

The Mining Board of the Department of Mines and Minerals is the regulatory body charged with the duty of enforcing the Oil, Gas, Coal, and Other Surface and Underground Resources Act of 1941. The act requires the well operator to submit, on forms required by the Mining Board, an application for a permit to drill, deepen, or convert a well to the Oil and Gas Division of the Department. The application includes the name of the leaseholder and the exact location, by plat, of the proposed well and the approximate location of producing wells previously drilled to the same formation, together with approximate location of offset wells or wells on adjoining property. Application for permit must be certified by a registered Illinois land surveyor or professional engineer. In mining areas, an agreement must be reached with mine owners before the Mining Board will approve the permit.

The State Geological Survey is the repository for data furnished the various State agencies by well operators. Copies of drilling permits, drillers' logs, abandonment records, and scouting tickets, as well as geological data, are kept on file for public use in the Petroleum Section of the Survey. Detailed oil and gas development maps showing the location of all known wells drilled in the State also are on file. There are 82 of these maps, each covering nine townships.

Indiana

Enforcement Agency

Director
Department of Natural Resources, Division of Oil and Gas
State Office Building
Indianapolis 46204

Sources of Information

Chief, Petroleum Section
Chief, Coal Section

State Geological Survey
611 N. Walnut Grove Ave.
Bloomington 47405

The Commission of the Department of Natural Resources is the regulatory body charged with the duty of enforcing rules and regulations affecting the oil and gas industry in Indiana. The Commission may enforce or cause the laws and regulations to be enforced by the Oil and Gas Division of the Department. Rules and regulations affecting the oil and gas industry were enacted in 1947, and supplemental acts were passed in 1951 and 1963. The laws required well operators to submit an application for a permit to drill, deepen, or convert an oil, gas, or test well. The application is accompanied by a plat showing the nearest three boundary lines of the tract and the footage location of the proposed well in two directions from a corner of the tract and from the nearest quarter post or lot corner. The application for a permit is approved in active coal-mining areas only after a satisfactory agreement on the well location is reached between the coal mining company and the well operator. The law also requires the coal mining companies to furnish up-to-date maps showing the working limits of their mines to the Oil and Gas Division.

The Oil and Gas Division of the Department of Mines is the repository for most permanent records pertaining to the oil and gas industry. Plugging records, applications for permits to drill and deepen wells, and surveyors plats are filed in their offices. The Petroleum Section of the State Geological Survey has prepared exploration maps by counties that show the footage location and elevation of wells drilled in the State. The footage locations of all wells on the map have been physically checked in the field. These maps, which are revised each year, are available for a small fee. The Survey also has on file folders for each well showing the footage location and driller's log.

Kentucky

Enforcement Agency

Director
Department of Mines and Minerals, Oil and Gas Division
120 Graham Ave., P.O. Box 680
Lexington 40501

Source of Information

Chief
State Geological Survey, Oil and Gas Division
University of Kentucky
Lexington 40506

The Division of Oil and Gas, Department of Mines and Minerals, is the regulatory body responsible for the enforcement of oil and gas laws in Kentucky. Prior to the enactment of revised statutes controlling oil, gas, and salt water wells in 1944, only general laws with no enforcement clauses were in effect to control oil and gas well drilling and abandonment. The laws passed in 1944 required the well operator, if the well was to extend through a coal-bearing strata, to furnish the Department of Mines and Minerals and each operator mining coal from beneath the tract with a plat showing the proposed well location. Regulations were amended in 1961 to require location plats certified as accurate and correct by an engineer registered in Kentucky when it is known that well location is underlain by a coal-bearing strata. Plats for other wells may be certified by applicant, a qualified employee, a person approved by the Department, or a registered engineer.

The State Geological Survey is the repository for information on oil and gas operations. The Oil and Gas Section has on file copies of location plats, well logs, county oil and gas development maps, maps prepared by private companies, and scouting reports on drilling operations that have been collected since about 1918. Well locations in western Kentucky are shown on maps, locally known as Keller Farm maps, which have been prepared since the late 1940's. These maps, which are quite accurate, often show location of wells not shown on the Survey county maps. The Kentucky Natural Gas Co. has prepared maps showing the location of wells that were drilled in the early 1940's, soon after the discovery of oil in western Kentucky. Well records identified by serial numbers of wells shown on map were microfilmed and furnished, along with copies of the map, to the Survey office for public use.

The Kentucky-West Virginia Gas Co. has prepared maps showing the location of all wells drilled in eastern Kentucky since the early 1920's. Copies of these maps were not furnished the Survey, but the company has been very cooperative with coal mine operators in the area interested in locating uncharted wells.

The Survey has prepared county oil and gas maps since the early 1920's and has maps of the 1920-30 era available for a small fee. Location plats and applications to drill collected by the Department of Mines from 1944 to 1948 were destroyed by fire. The Survey has made an effort to replace these records.

Ohio

Enforcement Agency

Chief
Department of Natural Resources, Division of Oil and Gas
1500 Dublin Road
Columbus 43215

Sources of Information

Director
Department of Natural Resources, Division of Geological Survey
1207 Grandview Ave.
Columbus 43212

Chief
Department of Industrial Relations, Division of Mines
220 Parsons St.
Columbus 43215

The Oil and Gas Division, Department of Natural Resources, is the regulatory body in Ohio responsible for the enforcement of oil and gas regulations. Prior to 1955, the Division of Mines, Department of Industrial Relations, was the regulatory body responsible for these regulations. Laws controlling the drilling and abandonment of oil and gas wells were enacted in 1917. These laws required the submission of a location plat, prepared by a certified surveyor, for wells drilled in coal-bearing counties but did not require certified plats for wells drilled in other parts of the State. A supplemental law was passed in 1931 requiring operators to prepare and submit a copy of a driller's log for all wells drilled in the coal-bearing area to the Division of Mines. The law was amended in 1933 to include all wells drilled in the State. The Division of Mines enforced the laws very effectively, particularly in coal-bearing areas; and as a result records are quite complete from about 1928 to the present. These data were furnished the newly organized Oil and Gas Division in 1955.

Since 1955, all applications to drill wells in coal-bearing areas have been sent to the Division of Mines for its approval before a permit to drill is issued by the Division of Oil and Gas. Inspectors from the Division of Mines witness the plugging and abandonment of all wells penetrating coal seams. They also have maps showing the surface location of all abandoned mines in the State. These maps are of the utmost value to operators who are locating proposed oil and gas wells in mined-out areas. By careful study of these maps, the well may be located so that it is drilled through a pillar of coal instead of the mine shaft and thus eliminate the necessity for sealing off the drill hole through the shaft. The Division of Mines also has a map available indicating the coal- and mineral-bearing townships in the State, which is of value to the operator as a guide in the drilling of wells.

The Division of the Geological Survey is the repository for data on oil and gas operations in Ohio. Legislation requires the Oil and Gas Division to furnish the Survey with copies of all permits to drill; location plats; well logs, both drillers' and electric; and other data furnished by the operator. In addition the Survey has township plats showing the location of wells drilled since 1917. Each well on the maps is assigned a key number, and all data pertaining to that well are filed under the same number. In addition, the Survey has on file copies of maps, locally known as Pepper maps, which were prepared during the 1940's on U.S. Geological Survey topographic sheets. These maps, which are available for a slight fee, often show well locations not shown on the township maps.

Pennsylvania

Enforcement Agency

Deputy Director
Department of Mines and Mineral Industries, Oil and Gas Division
1205 State Office Building
Pittsburgh 15222

Source of Information

Chief
State Geological Survey, Oil and Gas Division
401 State Office Building
Pittsburgh 15222

Laws concerning the drilling of oil and gas wells were passed as early as 1878 in Pennsylvania. However the enforcement of these laws and later amendments was very poor until the Oil and Gas Division of the Department of Mines and Minerals was formed and made the regulatory body responsible for the enforcement of oil and gas laws by legislation passed in late 1955. A shortage of operating funds restricted the enforcement of these laws until additional funds were appropriated in 1966. The act of November 1955 required a well operator to submit a plat, prepared by a competent engineer or surveyor, showing lease boundaries, name of the lessor, name of the owner or operator of all known underlying coal seams, and the footage location of the proposed well to the Division of Oil and Gas. When the proposed well is located in a coal-producing area, a copy of the plat is forwarded to coal mine operators, who have 10 days to approve or disapprove the location. If no objections are received, the Division issues a permit to drill.

The Oil and Gas Division of the State Geological Survey is the repository for data received by State agencies on oil and gas developments in Pennsylvania. Copies of location plats, drilling permits, drillers' logs, development maps, and other data furnished by well operators, as well as geological information, are kept on open file for public use.

West Virginia

Enforcement Agency

Deputy Director
Department of Mines, Oil and Gas Division
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Source of Information

Director and State Geologist
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The regulatory body in West Virginia for the enforcement of oil and gas laws is the Oil and Gas Division of the Department of Mines. Laws controlling the drilling and abandonment of oil and gas wells were enacted in 1929. Since that time, laws have been enforced requiring the well operator to submit to the Oil and Gas Division an application for a permit to drill and a well-location plat prepared by a competent surveyor or engineer. Also applications to deepen, plug back, fracture, or abandon wells originally drilled prior to June 1929 are required to include well-location plats.

The West Virginia Geological and Economic Survey is the repository for data received by State agencies on oil and gas operations. Open files are kept on drillers' logs, drilling permits, and location plats that have been submitted to the Department of Mines since 1929, plats showing the location of wells that have been abandoned since 1937, and copies of mechanical logs for many recently drilled wells. The location of wells drilled each year from 1911 to 1929 were plotted on 15° U.S. Geological Survey topographic sheets. These data will be available soon in an open file. Beginning in 1907, county geologic maps showing the location of all known oil and gas wells were published periodically. To date, 20 counties have been covered by this series, and copies of the maps are available for public use. A program has been started to microfilm, by county, available data on all wells in the State.

APPENDIX B.--TYPICAL ITEMS FOUND AROUND AN ABANDONED WELL

Examples of the more common items that might appear on the surface or buried in the vicinity of an abandoned well are shown in figure B-1. The names of these items are as follows: A-1, stuffing-box gland; A-2, stuffing box; A-3, box end of sucker-rod coupling; A-4, box end of polish rod to sucker-rod coupling; A-5, pin end of sucker rod; A-6, sidepull tank fastener; A-7, polish rod clamp. B-1, pitman; B-2, turnbuckle; B-3, combination clamp; B-4, turnbuckle eye; B-5, knock-off anchor bolt. C-1, ball and seat; C-2, upper cage of traveling valve; C-3, standing valve adapted for pressure release; C-4, valve cups. D-1, gas-engine cylinder lubricator; D-2, sight-feed oiler; D-3, grease cups; D-4, rod bearing with grease cup. E-1, belt clamps; E-2, combination clamp; E-3, wire rope clip; E-4, pull-rod coupling; E-5, cast-iron washers; E-6, alligator belt lacer. F-1, Flagg union; F-2, pin-end thread protector for cable-drilling tool; F-3, box-end thread protector for cable-drilling tool; F-4, bolt and nut; F-5, half pipe union; F-6, cotter key. G-1, wood auger; G-2, sucker rod safety elevator; G-3, open-end wrench; G-4, latch jack fishing tool; G-5, open-end sucker rod hook; G-6, hook jaw for pipe wrench. H-1, Fair's pattern elevator; H-2, perforated nipple. I-1, cable-tool bit gages; I-2, drill-bit cradle; I-3, bailer dart; I-4, top journal bearing; I-5, self-fabricated hold-down clamp for top journal bearing; I-6, hub cap; I-7, part of pitman bearing.

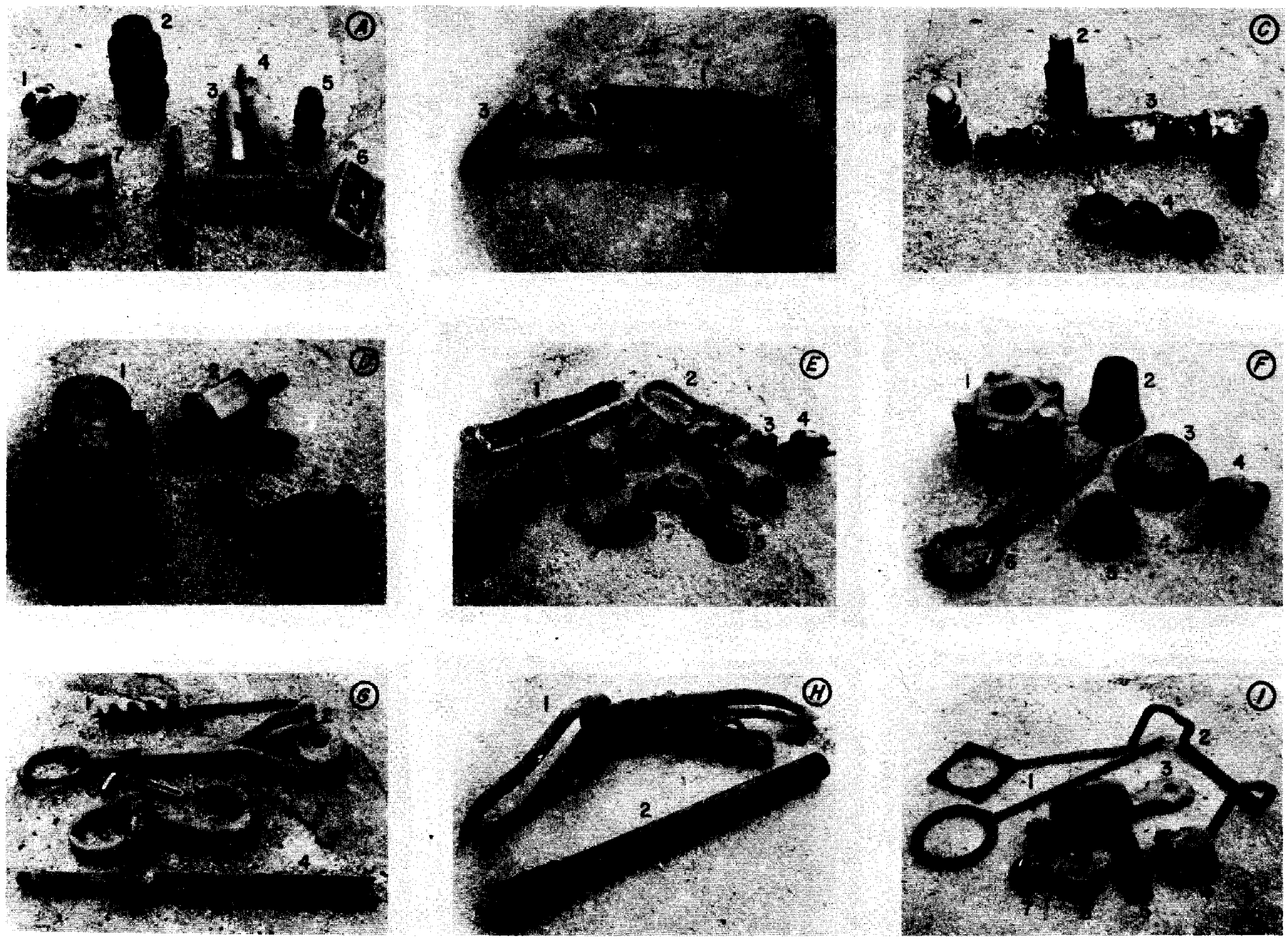

FIGURE B-1. - Typical Items Found Around an Abandoned Well.

APPENDIX C.--EXAMPLE OF DATA TREATMENT: DATA FROM GOLDAK MODEL 820 TESTS

Radial interval, feet	Tally	Frequency	Angular interval, degrees	Tally	Frequency
0.0- 5.0	~~IIII~~ III	8	0.0- 9.9		
5.1-10.0	II	2	10.0- 19.9	II	2
10.1-15.0	~~IIII~~ III	8	20.0- 29.9		
15.1-20.0	~~IIII~~ ~~IIII~~ ~~IIII~~ III	18	30.0- 39.9		
20.1-25.0	~~IIII~~ ~~IIII~~ ~~IIII~~ III	18	40.0- 49.9		
25.1-30.0	~~IIII~~ ~~IIII~~ ~~IIII~~ ~~IIII~~		50.0- 59.9		
	IIII	24	60.0- 69.9		
			70.0- 79.9		
			80.0- 89.9	I	1
			90.0- 99.9	I	1
			100.0-109.9	III	3
			110.0-119.9	I	1
			120.0-129.9	II	2
			130.0-139.9	II	2
			140.0-149.9	II	2
			150.0-159.9	I	1
			160.0-169.9	~~IIII~~ II	7
			170.0-179.9	~~IIII~~ I	6
			180.0-189.9	~~IIII~~ ~~IIII~~ ~~IIII~~	15
			190.0-199.9	~~IIII~~ II	7
			200.0-209.9	~~IIII~~ I	6
			210.0-219.9	~~IIII~~	5
			220.0-229.9	IIII	4
			230.0-239.9	III	3
			240.0-249.9		
			250.0-259.9		
			260.0-269.9	I	1
			270.0-279.9		
			280.0-289.9	II	2
			290.0-299.9	I	1
			300.0-309.9	IIII	4
			310.0-319.9	I	1
			320.0-329.9	I	1
			330.0-339.9		
			340.0-349.9		
			350.0-359.9		

APPENDIX D.--ANALYSIS OF VARIANCE FOR EFFECTS OF INSTRUMENTS AND OPERATORS ON PERCENT SUCCESS IN TARGET DETECTION AT THE 95-PERCENT CONFIDENCE LEVEL

TABLE D-1. - Two-way classification with replication, percent

Replicates	Hunter (large coil)		Goldak model 820	
	Operator A	Operator B	Operator A	Operator B
1	58	64	68	81
2	53	74	57	72

TABLE D-2. - Analysis of variance

Source of variability	Sum of squares	Degrees of freedom	Mean square	Mean square ratio
Among operators.............	378.125	1	378.125	9.251
Among instruments...........	105.125	1	105.125	2.572
Interaction.................	.125	1	.125	.003
Subtotal...............	483.375	3	-	-
With treatments.............	163.500	4	40.875	-
Total..................	646.875	7	-	-

TEST FOR INTERACTION:

$$F = \frac{0.125}{40.875} = 0.003 \quad \text{and} \quad F_{0.05(1,4)} = 7.71;$$

therefore no significant interaction exists.

TEST FOR OPERATOR EFFECTS:

$$F = \frac{378.125}{40.875} = 9.251 \quad \text{and} \quad F_{0.05(1,4)} = 7.71;$$

therefore the difference between operators is significant.

TEST FOR INSTRUMENT EFFECTS:

$$F = \frac{105.125}{40.875} = 2.572 \quad \text{and} \quad F_{0.05(1,4)} = 7.71;$$

therefore the difference between instruments is not significant.

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