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WORLD-WIDE FEASIBILITY OF A PASSIVE MAGNETIC METHOD OF DETECTING BURIED NONMETALLIC LAND MINES

Project 8F07-1-001

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PREFACE

The authority for conducting the investigations covered in this report is contained in Project 8F07-11-001, "Mine Warfare Research." The work was done under Task 8F07-11-001-01. A copy of the project card appears as Appendix A to this report.

The period covered by this report was from May 1960 through November 1960.

Investigations were conducted by Stanley L. Carts, Jr, Senior Project Scientist, with geological and mineralogical studies by Philip K. Webb.

CONTENTS

SUMMARY

The investigation was made to determine the world-wide feasibility of a passive magnetic method for detection of nonmetallic land mines. The investigation included a determination of the natural restrictions imposed upon a passive magnetic detection system by the magnetic properties of soil containing buried mines.

The report concludes that: (a) Use of a passive magnetic mine detection system as a sole means of detection is not feasible because the detection principle is not practicable in 74 percent of the world's land surface: In 12 percent because of insufficient mine-soil susceptibility contrast alone; in 40 percent because of excessive magnetic anomalous (false) signal effects alone; and in 22 percent because of both insufficient contrast and excessive anomalies. (b) More sensitive instrumentation will not improve the world-wide feasibility of passive magnetic mine detection systems because severe restrictions are imposed on the use of passive magnetic phenomenon by natural magnetic soil properties and not by inadequate instrument sensitivity.

WORLD-WIDE FEASIBILITY OF A PASSIVE MAGNETIC METHOD OF DETECTING BURIED NONMETALLIC LAND MINES

I. INTRODUCTION

1. Subject. An investigation was made to determine the world-wide feasibility of a passive magnetic method (earth's field) for detection of buried nonmetallic land mines. This investigation included a determination of the natural restrictions imposed on a passive magnetic detection system by the magnetic properties of soil containing buried mines.

2. Background. The passive magnetic system has long been considered as a possible method for detecting nonmetallic mines. Unlike most other detection methods, a magnetic system is not affected by soil-moisture variations. Theoretical studies (1, 2, 3) have shown that both metallic and nonmetallic mines should be capable of detection by a passive detection system. Investigators recognized early that information on pertinent characteristics of soils *in situ* and on the characteristics of anomalous (false) signals was needed in order to evaluate the feasibility of a magnetic detection system. Most researchers, some as early as 1945 (4), have recognized that soil properties and natural soil inclusions can drastically inhibit the operation of magnetic detectors (1, 3, 4, 5, 6, 7, 8), but no quantitative studies relating to their character were attempted.

Some susceptibility data were collected at the time the invasion of Japan was contemplated during World War II. By then, it had become apparent that the effectiveness of mutual-induction-bridge-type mine detectors was seriously affected by the magnetic susceptibility of the soil over which they were used (4, 5, 6, 7). These data pertained to the SCR-625 mine detector (an active system).

Members present at the Third Consultants' Meeting on Magnetic Mine Detection of Land Mines on 24 January 1947 emphasized that the main problem in passive magnetic detection was no longer one of instrument sensitivity but rather of restrictions imposed by the soil, for example, the prevalence of many areas with unfavorable magnetic soil conditions.

These conditions depend on many factors, some of which are not ordinarily classified by geologists and agronomists. The simplest definitive test is the measurement of the performance of the passive magnetic detection system under various field conditions and determination of the relation of these conditions to broader existing classifications.

Early in 1958, the first detailed study of magnetic properties and anomalies of soils and their significance to passive magnetic mine detection was made by USAERDL. This work covered the soils of Virginia and West Virginia (9). Later, in the same year, studies were extended to cover representative soil regions of the Continental United States under Contract DA-44-009 Eng-3646 with the Southwest Research Institute of San Antonio, Texas (10).

These studies established relationships between geology and the weathering processes involved in the soil formation and the magnetic properties of the soil. Different relationships prevail where the weathering processes differ significantly from those in the United States. For this reason, in 1959, studies were extended by these Laboratories to typical tropical soils in the Panama Canal Zone (11).

The current report summarizes results of past investigations of performance of passive magnetic mine detection systems under field conditions, discusses significant soil factors that determine whether broad areas of the earth's surface are favorable or unfavorable for passive magnetic mine detection, and relates these factors to geologic and pedologic conditions.

II. INVESTIGATION

3. Procedure. A literature search was made for all previous work concerning magnetic detection devices and magnetic properties of soil material and mine material. The literature was examined to determine what factors had been found to be restrictive to performance of passive magnetic mine detection and to correlate these restrictions with geologic and pedologic features. The data and views presented by the different investigators were compared and combined to present a more complete picture of the natural restrictions on passive magnetic mine detection. The combined data were analyzed as a whole to determine general trends and information which were not apparent from the data considered as small separate units. All reports from which information was taken are listed in the Bibliography.

After the available data had been combined and analyzed, a method was developed to predict passive magnetic mine detection feasibility on a world-wide basis. This involved determining how often: (a) soil-mine susceptibility contrast was sufficient to produce detectable mine signals (2 gamma* or greater); and (b) false signals** seriously interfere with mine detection. An area which

* 1 gamma is 10^{-5} oersted.

**A false signal is defined as any signal other than the true mine signal which is equal to or greater than the maximum signal from a 50-cubic-inch nonmetallic mine buried in the same soil flush with the surface.

exhibits more than two false signals per 10 feet is considered unfavorable from a detection viewpoint.

Susceptibilities of soils developed from different materials were compared with latitude zones. These four soil parent material groups were selected on the bases of magnetic properties and consideration of normal geologic rock classification: (a) sedimentary and metasedimentary rocks; (b) basic rocks; (c) acid rocks; and (d) unconsolidated sediments. Latitude zones were used to reflect climatic influences on soil formation.

The breakdown into four latitude zones was based roughly on climate: (a) Frigid Zone, between 60° and 90°; (b) Upper Temperate Zone, 40° to 60°; (c) Lower Temperate Zone, 25° to 40°; and (d) Torrid Zone, 0° to 25°, in both Northern and Southern Hemispheres. The susceptibility of Frigid Zone soils was assumed to be extremely close to that of the parent rock because of slow chemical weathering. Little data were available on Frigid Zone soil susceptibility; therefore, the parent material value was considered also to be the soil value.

Average soil susceptibility for each parent material group was plotted against latitude zone, and the resulting curves were used to predict soil susceptibility in untested areas. A calculation of mine-soil susceptibility contrast for the different latitude zones was made, using the theory presented in Appendix B. Soil susceptibility had to be sufficient to produce a 2 gamma or greater signal for a region to be considered potentially feasible for mine detection by a passive magnetic method.

The prediction of false signal prevalence was based on soil stoniness; field studies showed that approximately 90 percent of the serious false signals were caused by stones in the soil matrix. This approach was supported by comparing stoniness of soils (percentage by counties) based on U. S. Department of Agriculture (USDA) soil surveys with average false signal frequencies by counties as determined in USAERDL field studies for Virginia and West Virginia (9). The comparison between stoniness and observed false signal frequency was also used to develop the criterion that when the average stony soils (as defined by USDA) exceed 5 percent in an area, the number of false signals will exceed the acceptable limit for detection of 50-cubic-inch, nonmetallic mines by a passive magnetic method. To develop criteria for predicting stoniness on a world-wide basis, USDA-published soil surveys for the mid-Appalachian region were also consulted to establish relationships between stoniness and elevation. Accordingly, a map was prepared to show the percentage of stoniness in zones of elevation in the mid-Appalachian region. From this map a correlation was established between the average stoniness and the mean elevation of each elevation band.

The relationship thus established between stoniness and elevation in the mid-Appalachian region was used to predict average soil stoniness on the basis of elevation in areas of the earth where direct information on stoniness was unavailable.

Soil susceptibility data and stoniness data were then combined as bases for prediction of world-wide feasibility of a passive method of nonmetallic mine detection.

4. Results. The analyses of data from previous investigations have shown that the following factors in Table I produced major restrictions on the passive magnetic method of detecting nonmetallic mines.

Table I. Soil Factors and Their Influences Upon a Passive Magnetic Method of Nonmetallic Mine Detection

Factor	Influence
Low Soil Susceptibility	Inadequate magnetic contrast between mine and soil.
Soil Inclusions (rocks and roots)	Anomalous mine signals.
a. Igneous rock	Large polarized signal even from small pebbles.
b. Sedimentary rock	Usually negative, unpolarized signal, size of which depends upon size of rock and depth.
c. Metamorphic rock	If basic, influence is like igneous rock; if acid, influence is like sedimentary rock.
d. Nonmetallic material	Negative signal, magnitude of which depends upon size, burial depth, and soil susceptibility.
Mineral Concentrations	Anomalous signals.
Soil Matrix Variations[(a)]	Frequent changes in background level which limit usable instrument sensitivity.
Surface Microrelief	Anomalous signals.
a. Mound or bump	Positive signal, size of which depends upon size of bump and soil susceptibility.
b. Depression	Negative signal, size of which depends upon size of hole and soil susceptibility.

(a) If it were not for this restriction, instrument sensitivity could be increased to provide sufficient mine-soil contrast for detection even in extremely low-susceptibility soils. This effect is probably caused by magnetic mineral variations.

The importance of soil susceptibility is given in Fig. 1 which shows the relationship between soil susceptibility and theoretical mine signal at a height of 6 inches above a 50-cubic-inch nonmetallic mine for four latitude zones. One observes that in the ± 60° to ± 90° zone (curve D) a soil susceptibility of at least 70-μcgs units is required to produce a 2 gamma signal, the minimum acceptable for reliable detection; in the ± 40° to ± 60° zone (curve C) a susceptibility of 80-μcgs units is needed; in the ± 25° to ± 40° zone (curve B) a susceptibility of 125-μcgs units is needed; and in the 0° to ± 25° zone (curve A) a susceptibility of 300-μcgs units is needed.

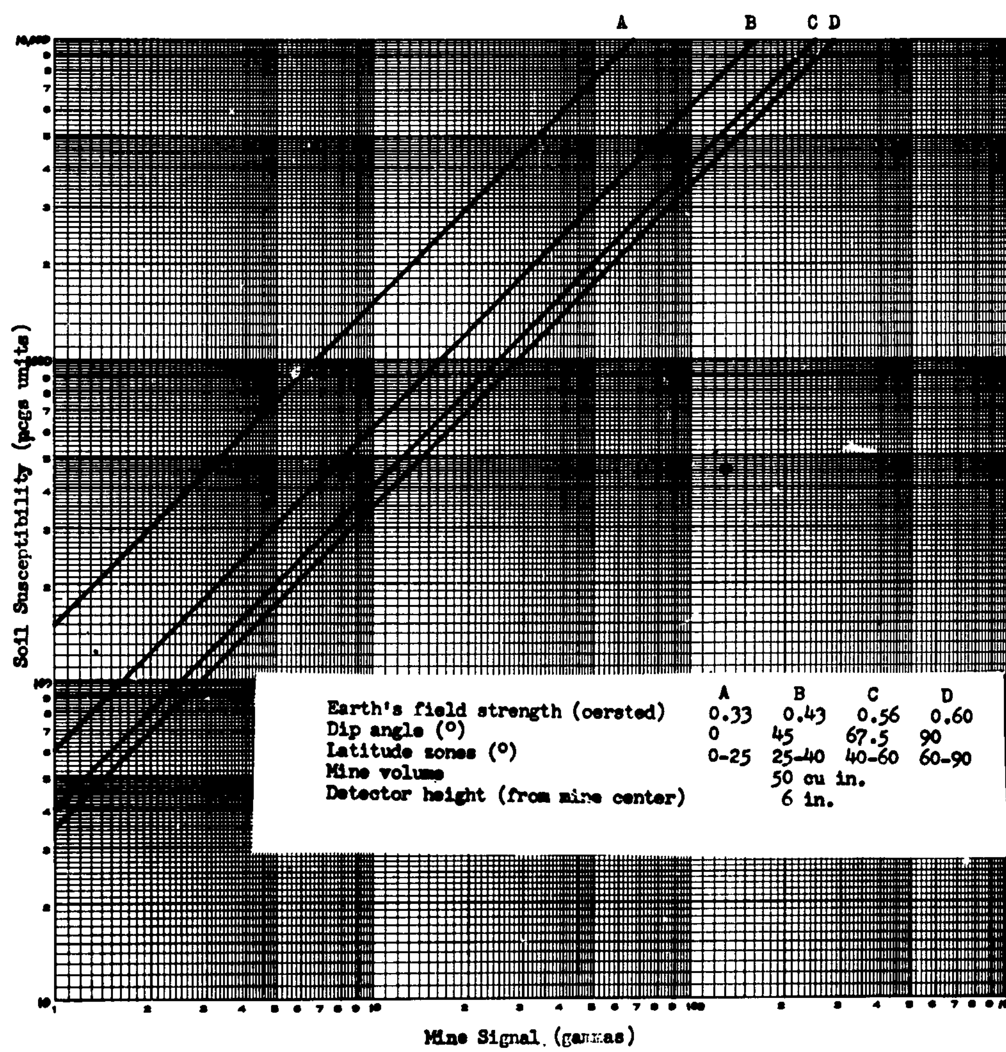


Fig. 1. Effects of soil susceptibility on nonmetallic mine signals.

A detailed summary of susceptibility of soil groups on a latitude basis is given in Table II. Little information is available on the thin soils of the 60° to 90° zone, and the soils are assumed to have the susceptibility of the parent materials because of extremely low chemical weathering. Data from Table II which are presented in Fig. 2 show that the susceptibility of soils developed from most types of parent material tends to decrease from the Frigid Zone toward the mid-latitudes (40° to 60°). However, still further toward the Torrid Zone a pronounced increase in soil susceptibility is noted for soils from all types of parent material. These trends are weakest for the soils developed from parent material with low magnetic mineral content (sedimentary, metasedimentary, and acid rocks) and become stronger as parent material magnetic mineral content increases (basic rocks and unconsolidated sediments).

Figure 3 illustrates the relationship between USDA-reported stoniness in Virginia and West Virginia and USAERDL-observed false signal frequencies in the field. This figure indicates that false signals exceed the feasibility limit of two per 10 feet when the average stoniness exceeds 5 percent in an area.

Figure 4 shows that in the Appalachian region of eastern United States land areas with elevation zones above 200 meters exhibit stoniness greater than 5 percent. Data extracted from Fig. 4 result in Fig. 5, which shows the relationship between elevation and stoniness.

Soil susceptibility data from Fig. 2 and stoniness data from Fig. 5 are combined and result in Table III. This table shows world-wide feasibility of a passive magnetic method of nonmetallic mine detection by parent material groups and latitude zones. This table predicts that approximately 74 percent of the land area of the world is unfavorable for a passive magnetic method of detecting 50-cubic-inch nonmetallic mines: 12 percent because of insufficient soil-mine contrast alone; 40 percent because of excessive stoniness alone; and 22 percent because of both lack of mine-soil contrast and excessive stoniness.

Detailed data from 441 field test sites are compiled in Appendix C.

Table II. Summary of Soil Susceptibility (K)[a] Classified by Parent Material[b]

Soil and Group No.	Parent Materials (group units)	60° to 90° Latitude No. Samples	60° to 90° Latitude Average K	40° to 60° Latitude No. Samples	40° to 60° Latitude Average K	25° to 40° Latitude No. Samples	25° to 40° Latitude Average K	0° to 25° Latitude No. Samples	0° to 25° Latitude Average K
Sedimentary and Metasedimentary Rocks (50% of World's Land Areas) (Group I)	**Limestone**	36	17	13	107	69	190	4	416
	Sandstone	22	11	9	35	37	70	2	275
	Quartzite	5	16	2	72	3	18	0	---
	Shale	13	18	3	124	24	80	2	500
	Slate	5	75	0	---	9	131	0	---
	Schist	4	47	3	123	23	59	4	49
	Group I Averages	85	30	30	92	165	91	12	310
Basic Rocks (12% of World's Land Areas) (Group II)	**Basic Ash**	4	346	0	---	0	---	9	210
	Diorite	9	2184	1	600	6	334	0	---
	Serpentine and Greenstone	8	1351	6	1618	11	861	5	5120
	Diabase	4	595	1	1440	6	307	2	575
	Basalt	22	2655	15	444	2	580	3	337
	Basic Igneous (undifferentiated)	21	2215	7	518	8	504	11	1848
	Gabbro	7	2624	6	725	2	498	2	34
	Dacite	1	2400	0	---	0	---	1	1000
	Agglomerate	3	2267	0	---	0	---	3	963
	Mafic Metamorphic (undifferentiated)	2	750	5	323	5	365	1	125
	Trachyandesite	---	---	0	---	0	---	2	760
	Group II Averages	81	1739	41	810	40	493	39	1097
Acid Rocks (13% of World's Land Areas) (Group III)	**Gneiss**	10	18	0	---	23	138	0	---
	Granite and Quartz Monsonite	3	2	2	174	12	39	1	150
	Tuff	6	109	3	155	0	---	2	294
	Acid Igneous (undifferentiated)	2	348	0	---	3	63	1	460
	Rhyolite	14	250	0	---	15	350	0	---
	Group III Averages	35	145	5	165	53	148	4	301
Unconsolidated Sedimentary Rocks (25% of World's Land Areas) (Group IV)	**Young Alluvium and Glacial Deposits**	---	---	11	289	4	195	5	250
	Old Alluvium and Coastal Plain Deposits	---	---	4	108	59	34	1	58
	Unconsolidated Sediments (undifferentiated)	---	---	10	64	44	214	0	---
	Beach Sands	---	---	0	---	0	---	13	2239
	Marine Unconsolidated Sediments	---	---	0	---	16	15	0	---
	Group IV Averages	---	---	25	154	123	115	19	849

(a) Susceptibility (K) is in μcgs units.
(b) Inferred from average parent material susceptibility.

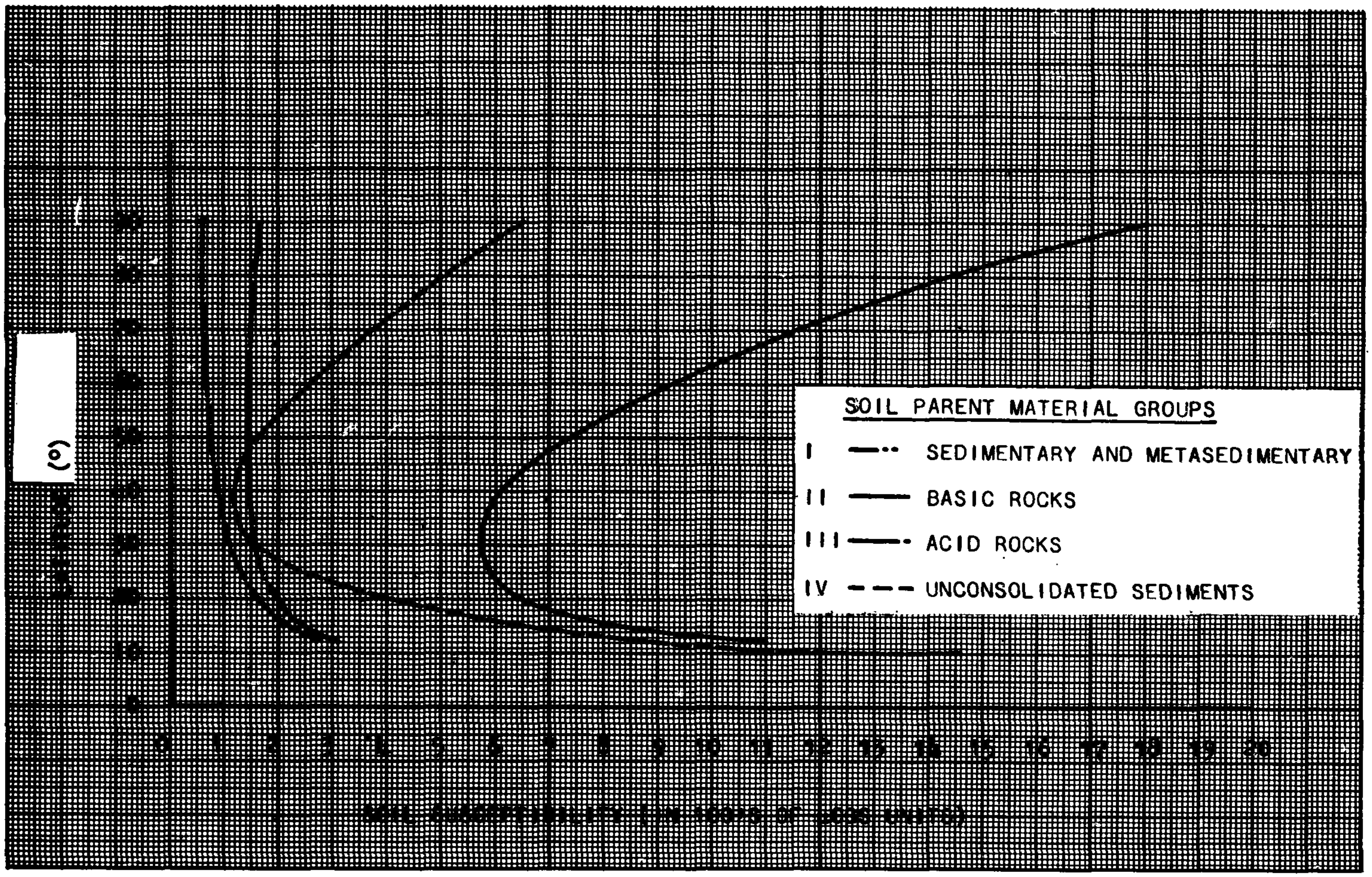


Fig. 2. Latitude vs. susceptibility of soils developed from four parent material groups.

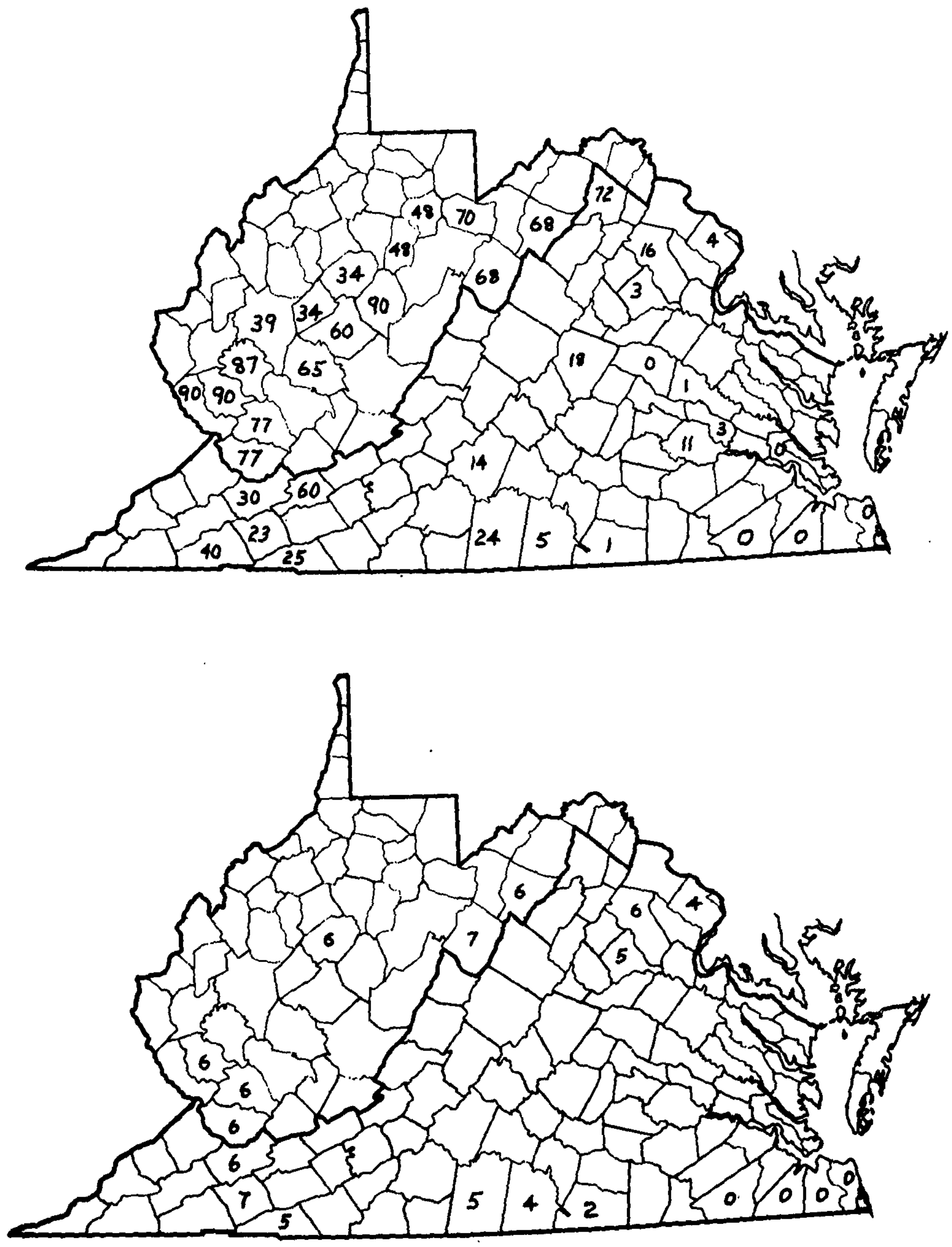


Fig. 3. Relationship between stony soils and magnetic anomaly frequency as noted during field studies in Virginia and West Virginia. Anomaly values have been adjusted to reflect residual soils only. Note that as stoniness (top) increases from coastal plain to mountains in west, frequency of anomaly occurrence (bottom) also increases.

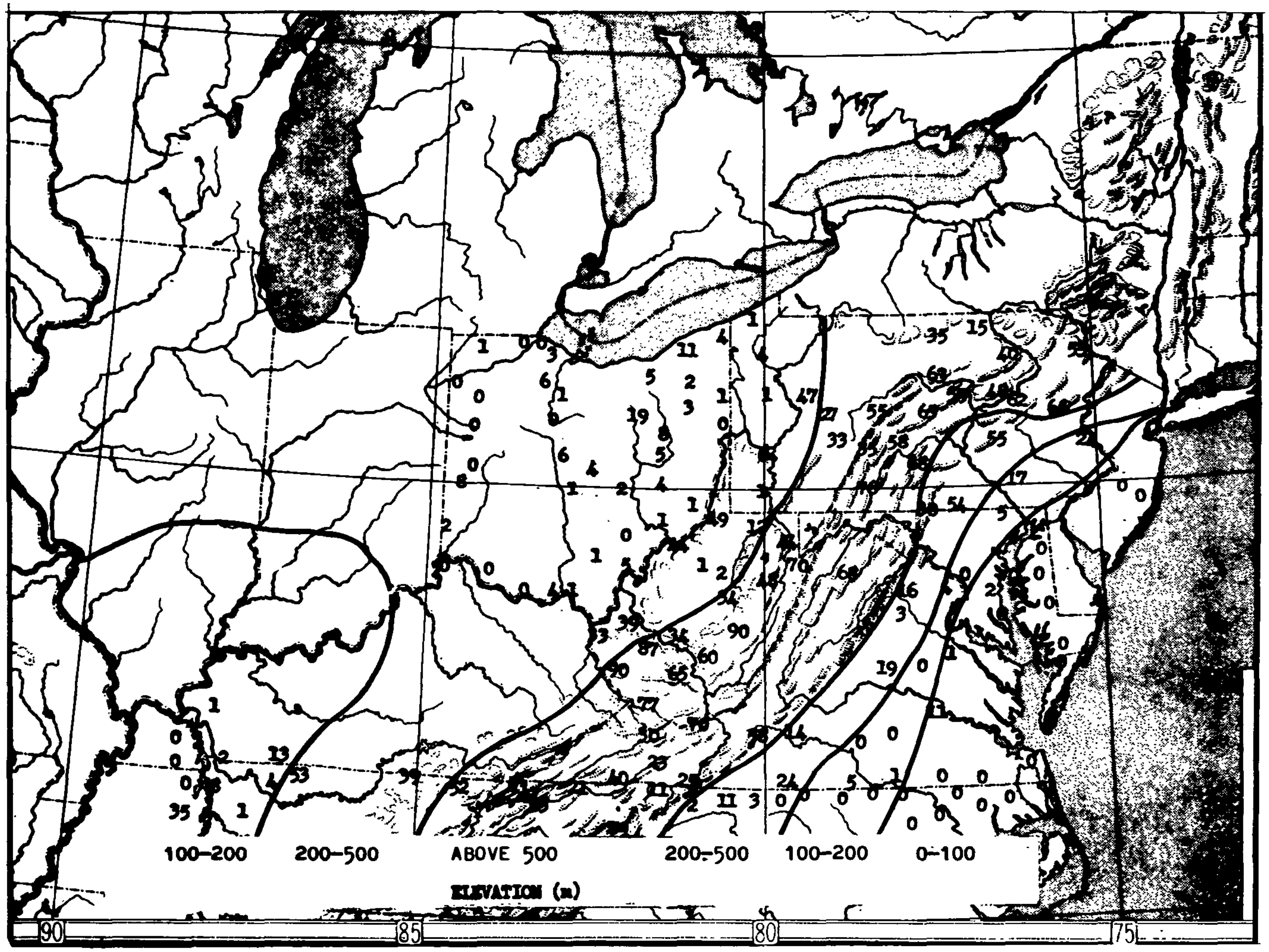


Fig. 4. Appalachian region of eastern United States land areas above elevation of 200 meters exhibits average stoniness greater than 5 percent.

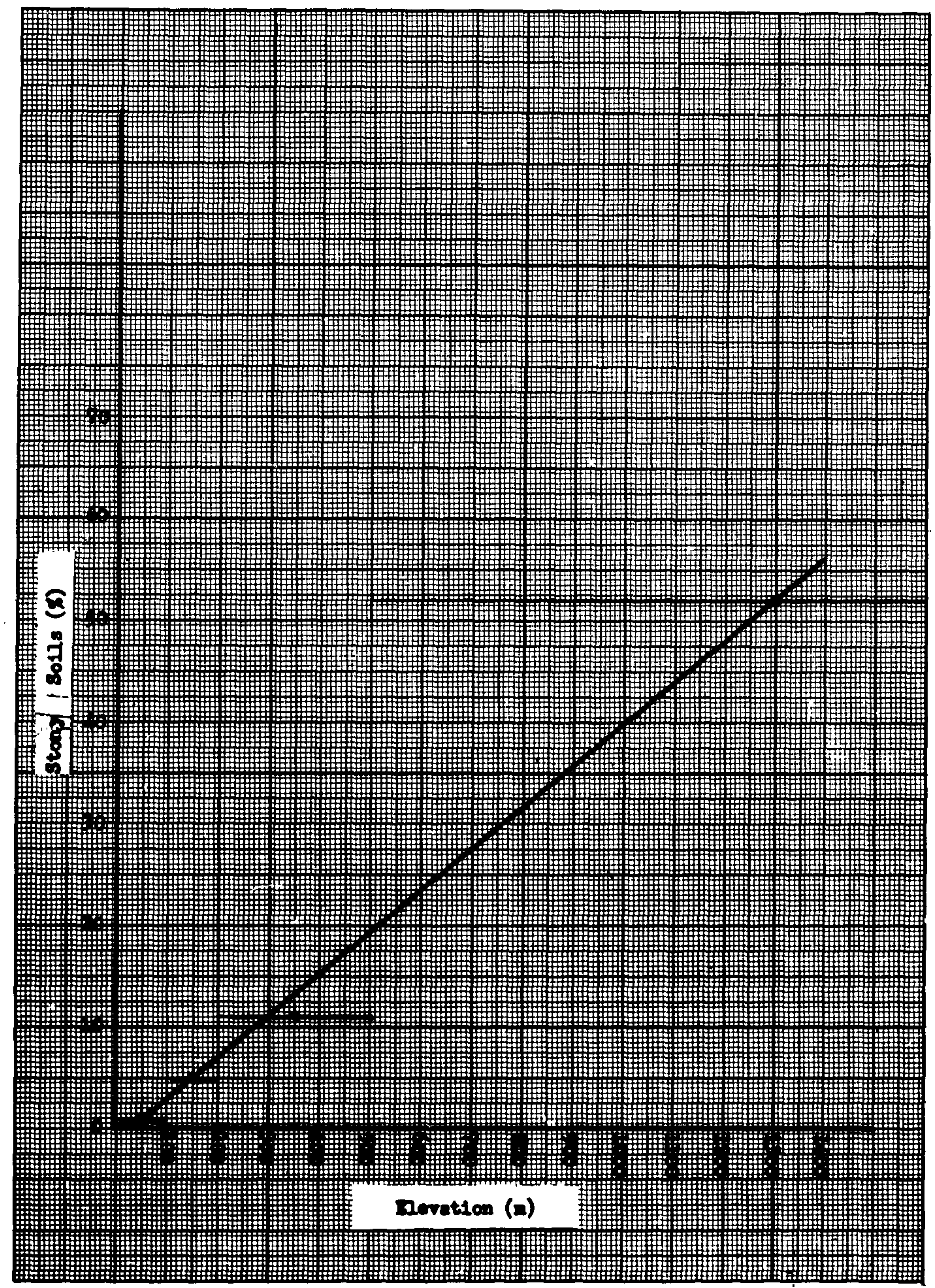


Fig. 5. Relationship between stony soils and elevation. Horizontal lines represent elevation zones. Note that elevation zones above 200 meters exhibit average stoniness values greater than 5 percent.

Table III. World-Wide Feasibility of Passive Magnetic Method of Detecting Nonmetallic Mines

Parent Material Groups	Latitude Zones(a),(b)			
	0° to 25°	25° to 40°	40° to 60°	60° to 90°
Group I	19 (11)	11 (7)(c)	10 (6)	10 (7)(c)
Group II	5 (3)(c)	3 (2)(c)	3 (2)	2 (1)
Group III	5 (3)(c)	3 (2)(c)	3 (2)	2 (1)
Group IV	9 (6)	5 (3)(c)	5 (3)	5 (3)
World Area by Zone (%)	38 (23)	22 (14)	21 (13)	19 (12)
Zone Above 200M (%)	60	61	64	66

(a) Numbers without parentheses indicate percentage of the world's land area within each group-zone.

(b) Numbers in parentheses indicate percentage of the world's land area within each group-zone having excessive stoniness.

(c) These values indicate group-zones which are not expected to have sufficient soil-mine contrast for reliable detection.

III. DISCUSSION

5. Evaluation of Results. Approximately three-fourths of the world's land areas are shown to be not feasible for a passive magnetic method of detection. The worst single restriction to this method is the prevalence of areas which exhibit excessive numbers of anomalous signals as a result of stones in the soil matrix. A predicted total 62 percent of the world consists of such areas. Furthermore, in these same areas, 22 percent of the world's land area exhibits not only excessive anomalies but also insufficient soil susceptibility needed for a detectable mine signal. In addition to the 62 percent having excessive stoniness, 12 percent of the land surface is free of anomalies but has insufficient mine-soil contrast.

Little hope of differentiating between mine and anomalous signals exists because of the similarity of the materials producing the signals and the ambiguity of magnetic signal interpretation; that is, more than one set of conditions which can produce any given magnetic signal always exists. Greater instrument sensitivity will not solve the mine-soil contrast problem in low-susceptibility areas because of the proportionally greater significance of soil matrix noise. In soils where instrument sensitivities greater than 1 gamma are needed, this background noise is equal to or greater than the mine signal.

Areas in the world where passive magnetic methods would work satisfactorily do exist, but they are not sufficiently extensive to make the method practicable on a world-wide basis. Although feasibility was based on the detectability of the 50-cubic-inch mine, a large antipersonnel mine (antipersonnel mines of less than 5 cubic inches are presently in use), the feasibility of detecting only large antitank mines is not materially changed anywhere except in undetermined parts of the 12 percent of the world where low soil susceptibility is the limiting restriction. Under these conditions, more than 60 percent of the world would still not be feasible for a passive magnetic method of mine detection because of stoniness alone. More detailed discussion of the various factors influencing passive magnetic detection feasibility is presented in the following paragraphs.

6. Theory. The earth's field is essentially uniform where the soil surface is level and the soil is perfectly homogeneous magnetically. A surface irregularity or a region within the soil which differs in magnetic susceptibility from the surrounding soil causes a local distortion in the earth's field. The magnitude and the geometric distribution of the anomalous effect is dependent upon the size of the anomaly, the relative susceptibilities of the soil and of the anomalous material, and the strength of the earth's magnetic field. The susceptibility of a mine generally differs from that of the soil; hence, a nonmetallic mine should produce a signal that is detectable in a magnetically homogeneous soil.

An analytical derivation of the signal effects on the earth's field of a spherical object buried in soil of high homogeneity is given in Appendix B.

7. Detection Limits. The passive magnetic method of mine detection depends upon the ability to recognize small differences created by the mine in the earth's magnetic field. Local variations in the magnetic susceptibility of the soil also produce changes in the local magnetic field and some of these changes are similar to mine signals. Field measurements over various soil types indicate that two conditions are necessary for reliable detection: (a) Sufficient contrast must exist between the magnetic susceptibility of the mine and of the soil to produce a measurable local distortion in the earth's field; and (b) the soil must be relatively homogeneous magnetically so that signals resulting from soil susceptibility variations do not obscure mine signals.

A threshold susceptibility exists in each latitude zone below which detection of nonmetallic mines is not feasible because of a lack of susceptibility contrast. The effects of variation in soil matrix produce a background noise such that mine signals must be larger than 1 gamma to appear above this noise. Soil matrix noise is discussed in paragraph 10. Computations indicate that changes in detector height of 1 inch in a 40-μcgs soil produce a signal change of 2 gamma. Thus, signals from nonmetallic mines can easily be obscured by slight variations of detector height during a sweep operation. Experiences in the field substantiate this deduction. Distance above the soil was a critical factor in all field operations. Because of these factors a signal greater than 2 gamma will probably be necessary in practice to make detection and identification feasible. The significance of soil factors affecting detection capabilities is discussed in the following paragraphs.

8. Parent Material Susceptibility. To discuss the magnetic susceptibilities of soils and the factors which govern their values, one must necessarily start with a consideration of the magnetic susceptibilities of the soil parent material. Parent material distribution is a geographically independent variable; that is, theoretically any rock type may occur in any latitude. The susceptibility of the parent rock depends on the amount and type of magnetic mineral present. Three elements ordinarily are considered ferromagnetic: Iron, cobalt, and nickel, of which only iron is common in soils and rocks. However, all rock and soil minerals which contain iron do not necessarily have a high susceptibility, because susceptibility depends on the coordination of the iron in the crystal structure. In order of decreasing susceptibility the most important magnetic minerals are magnetite, maghemite, ilmenite, pyrrhotite (franklinite locally), and siderite. Usually, however, the magnetic susceptibility of rocks is largely a result of disseminated magnetite grains which commonly increase in abundance in the following order: (1) sedimentary rocks; (2) gneisses, schists, and slates; (3) granitic rocks; (4) basic intrusives; and (5) basic extrusives.

The percentage of magnetic minerals in any given parent rock may be highly variable. Igneous rocks constitute a group of solid melts which have formed from molten material that solidified on cooling and are most likely the least variable in the concentrations of magnetic minerals present in any given rock type. These rocks are generally considered to be of primary origin and are classified with their mineral content as a major consideration; hence, by classification into rock type, variability in expected mineral content is reduced. Granites, for example, usually contain only a small percentage of magnetic mineral material by volume and, therefore, generally have a relatively low susceptibility. Basalts, however, have much magnetic material and have high susceptibilities. A gradual change takes place in mineral type from basalts on the one hand to granites on the other. For this reason, most geologists divide igneous rocks into two categories: Acid or silica igneous rocks (granites and granodiorites); and basic igneous rocks (basalts, gabbros, and diorites).

Sedimentary rocks may be more variable by rock type than igneous rocks. Sedimentary rocks are generally classified by grain size or structure, genesis and mineral content. Sandstone, shale, and limestone are the three main groups of sedimentary rocks and all three characteristically have low susceptibility although sandstones have been found with susceptibilities as high as 1,800- μcgs units. Most sandstones, however, have susceptibilities close to 50 μcgs or lower. The reason for this variability of amount of magnetic material in sandstone lies in the fact that sandstones are secondary rocks; that is, they are derived from source material made up of igneous, sedimentary, and metamorphic rocks.

The last group of rocks to be discussed, and those which possibly manifest the greatest variability in susceptibility, are the metamorphics. Metamorphic rocks are classified on the basis of mineral composition, structure, and grain size. They are secondary rocks and result from the transformation of other primary or secondary rocks by means of changes in heat or pressure on the minerals present in the rocks before metamorphism.

9. Soil Susceptibility. The susceptibility of the soil derived from a given parent material depends upon the amount of magnetic material originally present in the parent rock and upon the effects which weathering and erosion have in the chemical reduction or physical concentration of the magnetic grains.

Magnetite, because of its prevalence and its high susceptibility, is generally the principal factor in the susceptibility of soils and rocks. Upon weathering, magnetite may change into iron oxides such as hematite and limonite which have lower susceptibilities. The chief control over weathering and erosion is climate. Topography and geographical position affect the local climate as well.

Climate controls hydrolysis, hydration, carbonation, and oxidation. The weathered materials are decomposed forming new compounds in the soil. In deserts and cold climates mechanical disintegration predominates over decomposition. In humid-temperate and humid-tropical climates, decomposition is rapid and usually the soil layer is deep.

In desert, dry temperate, and cold regions, chemical breakdown is slow, and the iron-bearing minerals may be relatively unchanged in the soil. As the mineralogy is but little changed, the susceptibility of the soil is similar to the susceptibility of the parent material.

In some humid-temperate and humid-tropical areas, iron is leached from the soil; but in others, the iron is concentrated. In the mid-latitudes, iron and alumina are leached from the upper soil profile, leaving silica. In the tropics, the reverse is true. The principal soil regions in which iron is concentrated are the Reddish- and Yellowish-Brown Lateritic and the Red and Yellow Podzolic Soils. A study of the iron oxides which form when iron is concentrated has shown that in addition to the limonitic oxides, two varieties of hematite are formed. In contrast to common hematite, gamma-hematite (maghemite) is highly magnetic. Maghemite appears to be formed from iron-bearing silicates, sulfides, carbonates, oxides, and hydroxides. It is believed that minerals containing ferrous iron are more likely to yield maghemite on weathering than minerals containing ferric iron.

The presence of organic material seems to be a necessary but not sufficient condition for the formation of magnetic hematite (14), because soils at the bottoms of slopes and in marshes are always much lower in susceptibility than those on the neighboring slopes.

The effects of vegetation and age on the soil profile are superimposed on the climatic effects and locally modify the type of soil (and, therefore, the amount of magnetic material) present. The effects of weathering become more pronounced as the parent rock breaks down into finer particles. Topography plays an important role by influencing the amount of water runoff or accumulation in some areas. On flat to gently sloping areas in humid lands, the soils are, for the most part, more deeply weathered than in wet lowlands where carbonaceous materials predominate.

In preparing the summary and plot of soil susceptibility versus latitude (Fig. 1 and Table III), it was assumed that the average parent material susceptibility value for each rock type was also the soil susceptibility in the Frigid Zone. The Torrid Zone values are derived from susceptibilities of soils measured in Luzon and Panama, and most of the values representing temperate soils are from U. S. test sites.

In the several sources of information tapped for Table II, it was found that authors used different classifications of parent material; therefore, the grouping of the units used in this report includes overlapping parent material types. The present authors have attempted to form classifications of soil parent material which closely reflect magnetic properties, yet maintain harmony with the common geologic groupings. As stated previously, the four parent material group classifications selected by the authors are: (1) sedimentary and metasedimentary rocks; (2) basic rocks; (3) acid rocks; and (4) unconsolidated sediments.

The soil parent materials which make up each major soil group shown in Table II includes gneiss with the acid rocks, because gneiss is normally akin to granite. Slate and schist are grouped with metasediments although it is understood that schists can be derived from fine-grained igneous rocks as well. The average susceptibilities of soils in the parent material groups given on Table II were used to plot Fig. 2, and the similarity in the shape of the curves is striking.

Because weathering effects are strongly influenced by climate, soil susceptibility of different parent materials might be shown according to climate. However, even though the general meaning of climate is clear, authorities use different combinations of variables to define various climates and available climate maps are often of such local detail that they are difficult to use on a large scale. For this reason, the present authors have used latitude zones, which generally reflect climate to show average weathering effects.

Group I (sedimentary and metasedimentary rocks) derived soils originate from limestone, shale, sandstone, quartzite, slate, and schist. Although these rocks are of low susceptibility, they generally produce soils of susceptibility higher than themselves. The soils average about 55-μcgs units in the $\pm 60^{\circ}$ to $\pm 90^{\circ}$ latitude zone, 92 μcgs in the $\pm 40^{\circ}$ to $\pm 60^{\circ}$ latitude zone, 97 μcgs in the $\pm 25^{\circ}$ to $\pm 40^{\circ}$ zone, and 310 μcgs in the 0° to $\pm 25^{\circ}$ zone. This increase in soil susceptibility as one approaches the Equator is primarily a result of the increase in chemical weathering in warmer latitude zones. The large increase in soil susceptibility in the tropics may be caused by the formation of gamma hematite, the highly magnetic compound mentioned previously as being formed under conditions of rapid chemical weathering and humus formation (14). The only members of Group I derived soils which do not exhibit the general increase in soil susceptibility moving towards the Equator are the soils derived from schists. The present authors can offer only a general possible explanation. Whereas oxides are mainly responsible for the susceptibilities in the other sedimentary and metasedimentary rocks, magnetic minerals in schists can be more complex silicates. Either the silica leaching in the tropics removes the whole complex because of stronger inter-atom bonding or LeBorne's process (14) of gamma hematite formation does not work with this group of minerals. Perhaps the complexes go to low-magnetic hematite.

The susceptibility curves of Fig. 2 for Group II (basic rocks), Group III (acid rocks), and Group IV (unconsolidated sedimentary rocks) derived soils exhibit a decrease in soil susceptibility from the Frigid Zone through the mid-latitude zone. This decrease in susceptibility is probably the result of a decrease in surface magnetic minerals resulting from an increased rate of chemical decomposition accompanied by iron leaching and iron concentration in lower layers.

In every group except Group II the soil susceptibility is higher than the average rock value in the Torrid Zone for a given rock grouping. This effect can be the result of the formation of new magnetic material by organic acids (14). Although Group II soils show the same trend, the large decreases in magnetic material brought about by rapid weathering in the Torrid Zone apparently accounts for a general decrease in susceptibility relative to the parent material susceptibility. An increase in susceptibility relative to the Temperate Zone is clearly illustrated.

If this information is to be used for susceptibility predictions on a smaller geographic scale, more attention must be given to the individual parent material units rather than the group, especially those in Group IV. For example, young alluvium and glacial deposit soils usually are appreciably higher in susceptibility than soils from older alluvium and coastal plain deposits.

It is estimated that about 50 percent of the world's land areas are covered by soils derived from the rocks of Group I; 12 percent, by the soils of rocks of Group II; 13 percent, by the soils of Group III; and 25 percent, by the soils derived from unconsolidated sediments.

10. Anomalous Signals.

a. Definition and Types. The presence of excessive numbers of anomalous magnetic signals is the most widespread and most limiting soil magnetic property encountered. Three sources of anomalous responses have been identified:

(1) Soil inclusive materials (rocks and roots) with magnetic susceptibilities different from the soil matrix.

(2) Changes of magnetic mineral concentration within the soil.

(3) Irregular soil surface relief.

b. Soil Inclusive Material. The most common anomalies found in field studies were those consisting of pieces of soil parent rock distributed throughout the soil. Probably as much as 90 percent of the anomalies affecting a passive magnetic detector can be attributed to stones in the soil matrix. These rock pieces may have either a higher or lower susceptibility than the soils developed from them. Whether they are higher or lower depends on the original mineralogy of the parent material and the soil-forming processes involved.

Field studies indicated a conspicuous absence of anomalies resulting from inclusions in soils developed from transported unconsolidated sediments. This held true for both marine and alluvial unconsolidated sediments, such as comprise most of the Atlantic Coastal Plain. Tests made in this province on both the Atlantic and Gulf coasts produced similar anomaly-free results (9, 10). Alluvial soils in stream valleys are usually free of rock-caused anomalies except in areas where cobbles and boulders are mixed with the soil. Usually, the sorting action of streams is apparent, and except for the present stream bed, the material is separated according to size.

Beach sands are extremely variable in rock content. Where the beach is closely associated with mountainous terrain, rock-caused anomalies are likely to be present on the beach. In areas such as the Atlantic Coastal Plain where the beach is preceded by gradual slopes of rock-free soils, the beaches are usually free from this type of false response.

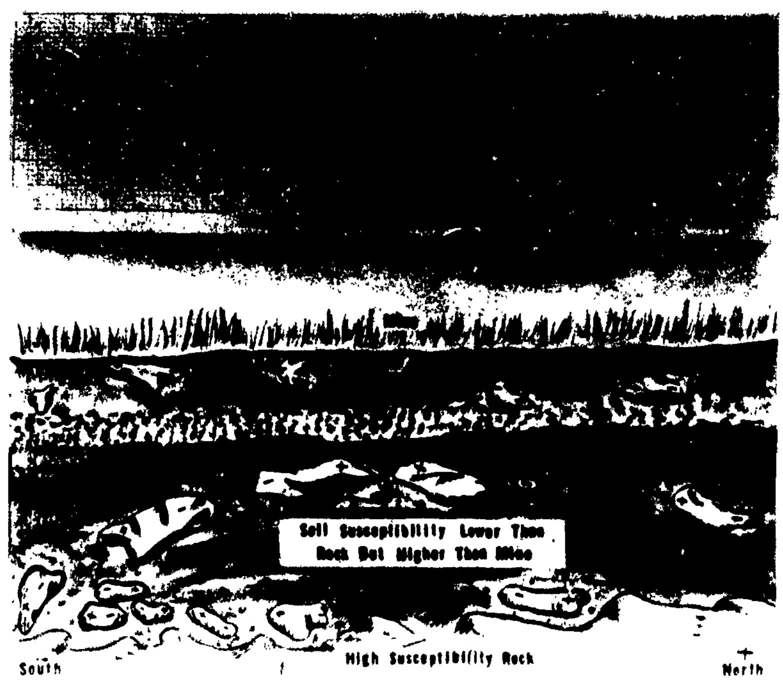
Stoniness values are erratic and dependent on the type of source area of glacial deposits in glaciated areas. New England glacial deposits exhibit extremely high values of stoniness, whereas the stoniness values in Minnesota are low.

In contrast to the transported soils, residual soils usually contain rock-caused anomalies. Soils developed from consolidated sediments usually have a higher susceptibility than the parent material. When pieces of such parent rock are present in the soil, they produce magnetic field distortions similar to nonmetallic mine signals. This situation is illustrated in Fig. 6. Such conditions are quite prevalent in limestone, sandstone, and shale soils. These conditions are of particular concern in mine detection because they can produce a negative anomaly of the same order of magnitude as a nonmetallic mine.

In residual soils developed from basic igneous and metamorphic rock, pieces of parent rock present even more complex effects. Such rocks are usually of high susceptibility and pieces of them exhibit magnetic polarization. This material produces spectacular anomalies often in the order of thousands of gamma. These anomalous effects can be in the form of negative peaks, positive peaks, or both, depending upon the orientation of the source rock. Anomalies of this type are illustrated in Fig. 7.

The effects of pieces of parent rock in residual soils derived from acid rocks are extremely variable and difficult to predict. In general, the effects are intermediate between the effects observed in soils from consolidated sediments and those from basic igneous and metamorphic rocks.

F2225
Fig. 6. Mine buried in soil developed from low-susceptibility rock.



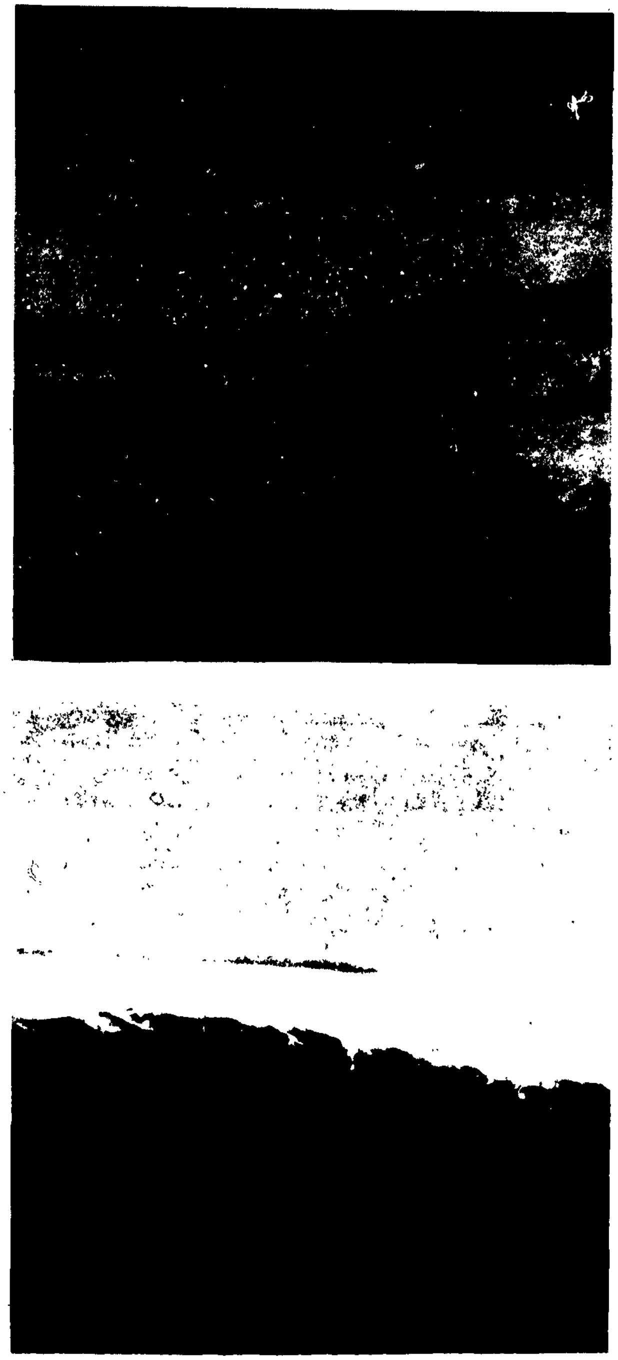
F2226
Fig. 7. Mine buried in soil developed from high-susceptibility rock.

It was noted that as the soil depth decreased, the number of fragments of parent rock distributed within the soil increased. As a result, anomalies in the earth's magnetic field just above the soil surface were more prevalent in mountainous terrain where soils are usually shallow than in level areas where soils are usually deeper. It was also obvious that the frequency of such anomalies appeared to be much higher in the soils developed from the high-susceptibility basic rocks than the lower susceptibility rock soils. This is true because although even a very small pebble of high-susceptibility rock can cause a large anomalous signal, a rock of low susceptibility must be at least the same general size as a mine to produce a troublesome false signal.

For lack of better information during development of stoniness prediction methods, soil stoniness was plotted against elevation (Fig. 5) from values available in eastern United States. A more accurate prediction could be developed if stoniness were plotted against relief (or gradient of elevation). At the time of writing, accurate world relief values were not available to the authors. In general, elevation is a good index of relief; therefore, Fig. 5 represents a reasonable approximation for stoniness predictions.

c. Mineral Concentration. Local variations of magnetic mineral content produce magnetic field distortions which interfere with mine detection. Such a condition was observed in the beach sands of Little Island, Virginia. The sand contained a small fraction of ilmenite, which was normally well mixed with other components. However, in some areas where the wind had formed ripples, sorting had occurred, and the heavy ilmenite was concentrated in the dips and on windward slopes. This mechanism produced anomalous signals of 2 to 40 gammas, depending upon the efficiency of sorting.

The effect of variation in mineral concentration becomes more serious as the magnetic mineral content increases. In areas where beach sands are derived principally from volcanic rocks, the magnetic mineral content is usually high and areas of nearly pure magnetite are not uncommon. Wave and wind action sort the heavier magnetic minerals from the lighter quartz and shell grains, and alternate layers of magnetite and quartz or shell grains result. The effect is strikingly illustrated in Fig. 8. Similar conditions are reported for the Philippine Islands, areas of Japan, and volcanic islands in the Pacific. In such areas, the effect on detection of buried mines is detrimental, as extreme susceptibility variations occur within a few inches of lateral displacement. The Panama beach shown in Fig. 8 has variations of susceptibility from 50 to 300,000-μ cgs units within a lateral distance of a few inches.



G4568

G4567

Fig. 8. Pacific beach sand in Panama rich in magnetite. Top: Dark areas are nearly pure magnetite. Bottom: Cross section shows layers of magnetite between layers of nonmagnetic sand.

Although magnetite is the magnetic mineral most frequently found in such areas, maghemite, ilmenite, and olivine also occur as concentrations on beaches. Concentrations have not been found of magnetic materials in soils other than beach sands, possibly because most other soils are not so susceptible to sorting by wind and wave action.

d. Surface Microrelief. Measurements made over high-susceptibility soils showed that surface relief irregularities could cause anomalous signals greater than nonmetallic mine signals. Theoretically, when the upper horizon of the soil is considered an infinite horizontal homogeneous layer, the earth's field is highly uniform. This field will be distorted, however, in the neighborhood of discontinuities in the layer of soil. A positive correlation of position and amplitude between geomagnetic anomalies and microtopography has been generally noted in field studies by all investigators. Surface relief variations often produce anomalous signals similar to the signals from buried nonmetallic mines when the volume and form of the irregularity are similar to a mine. This condition is expected because a nonmetallic mine has extremely low susceptibility, essentially that of air. Therefore, signals of similar nature would be produced by a mine buried flush with the surface and by a mine-sized depression in the soil surface. If the mine is buried below the surface, the mine signal is smaller than the signal from a mine-sized depression. Although this effect is most easily observed in high-susceptibility soils, it holds true for soils of any susceptibility.

In some areas, visual inspection of the soil surface will disclose anomalous responses obviously caused by surface irregularities. In general, however, visual inspection cannot effectively alleviate this problem because (a) the mine may be buried on a rise or in a depression (under such conditions the mine signal will be mixed with the signal produced by surface effects); and (b) small bumps and dips of antipersonnel mine size are often obscured by vegetation coverage.

There appears to be no way to relate surface relief to any specific soil or geologic classifications; however, surface relief is reflected to some extent in land use. In most areas, irregularities the same size as antipersonnel mines are prevalent. Large animals, such as cattle or horses, leave tracks of nearly the same volume displacement as a mine. Livestock tracks are particularly troublesome in pasture and grazing lands.

In areas free of anomalies from other causes, microrelief-produced anomalies may be a serious problem; however, in most areas, microrelief effects are usually much smaller than other anomalous effects and are generally of only secondary importance.

Several times anomalous signals were suspected as originating from the lower surface of a shallow soil in contact with uneven bedrock having an appreciable susceptibility contrast. Where this effect was observed, relatively high-susceptibility, shallow-depth laterite soils were developed over low-susceptibility limestone. The anomalous responses caused by this condition are usually broad gentle irregularities which do not appreciably change as detector height is varied.

e. Soil Matrix Noise. In addition to the sources of localized anomalous signals discussed previously, variations of magnetic susceptibility exist within the soil matrix, itself. These variations are usually, but not always, gradual changes of soil susceptibility from place to place throughout the soil mass. Tests conducted by D. E. Wiegand of Armour Research Foundation (1) show changes in samples taken every foot over test sites in the vicinity of Fort Belvoir, Virginia. His tests indicated a definite trend toward greater variability of soil susceptibility with lower susceptibility soils. These variations become such a problem in the lower susceptibility soils that instrument sensitivities greater than 1 gamma were unusable. Field tests by other investigators (9, 11) have substantiated this observation.

IV. CONCLUSIONS

11. Conclusions. It is concluded that:

a. Use of a passive magnetic mine detection system as a sole means of detection is not feasible because the detection principle is not practicable in 74 percent of the world's land surface:

(1) In 12 percent because of insufficient mine-soil susceptibility contrast alone.

(2) In 40 percent because of excessive magnetic anomalous (false) signal effects alone.

(3) In 22 percent because of both insufficient contrast and excessive anomalies.

b. More sensitive instrumentation will not improve the world-wide feasibility of passive magnetic mine detection systems because severe restrictions are imposed on the use of passive magnetic phenomenon by natural magnetic soil properties and not by inadequate instrument sensitivity.

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APPENDICES

APPENDIX A

AUTHORITY

Item No. 2870
CETC Mtg. #315

R & D PROJECT CARD	TYPE OF REPORT: Rewritten	REPORT CONTROL SYMBOL: CSCRD-1 (R1)
1. PROJECT TITLE: MINE WARFARE RESEARCH	2. SECURITY OF PROJECT: Unclassified	3. PROJECT NO.: 8F07-11-001
	4. INDEX NUMBER: --	5. REPORT DATE: 19 April 1960
6. BASIC FIELD OR SUBJECT: Mines & Obstacles	7. SUB FIELD OR SUBJECT SUB GROUP: Research	7A. TECH. OBJ.: LC-7
8. COGNIZANT AGENCY: Corps of Engineers	12. CONTRACTOR AND/OR LABORATORY: US Army Engr. Res. & Dev. Labs Ft. Belvoir, Va.	CONTRACT/W. O. NO.
9. DIRECTING AGENCY: Res. & Dev. Div., OCE		
10. REQUESTING AGENCY: Office, Chief of Engineers		
11. PARTICIPATION AND/OR COORDINATION	13. RELATED PROJECTS	17. EST. COMPLETION DATES: RES. Cont.; DEV. Cont.; TEST Cont.; OP. EVAL. Cont.
	14. DATE APPROVED	18. FY. / FISCAL ESTIMATES: 60 983 M; 61 1199M; 62 1200M
	15. PRIORITY: 1-A / 16. MAJOR CATEGORY	
19. REPLACED PROJECT CARD AND PROJECT STATUS: This project supersedes Project No. 8-07-11-000, 31 December 1959.		Est. Rate P/A 1200M

20. REQUIREMENT AND/OR JUSTIFICATION The Combat Development Objectives Guide states objectives for development of highly effective and rapid mine detection and clearance equipment and improved equipment for the speedy laying of extensive minefields. It also includes specific materiel requirements for new and improved devices. Development based on the current state-of-the-art is limited in effectiveness to meet these objectives. There is an urgent need for fundamental scientific data upon which to base development of new items meeting established requirements and military characteristics.

21. BRIEF OF PROJECT AND OBJECTIVE

a. Brief:

(1) Objective: The objective of this project is the conduct of research directed toward new principles and techniques which can be utilized in the development of new and improved mine warfare equipment and systems.

(2) Military Characteristics: Not applicable.

(3) Security Classification: The security classification of the individual tasks of this project will be in accordance with their content.

22. OASD (R & D)	SN.	CN.	C.	X.	I.	C.

PAGE 1 OF 2 PAGES

DD FORM 1 APR 58 613
REPLACES DD FORM 613, 1 JAN 58.

DD PROJECT CARD
CONTINUATION SHEET

Item No. 2870
CETC Mtg #315

1. PROJECT TITLE	2. SECURITY OF PROJECT	3. PROJECT NO.
MINE WARFARE RESEARCH	Unclassified	8F07-11-001
	4. ---	5. REPORT DATE 19 April 1960

b. Approach: The approach to each task is set forth in the Task Cards as listed in paragraph 21c below.

c. Tasks: This project is composed of the tasks as listed herein. The completion of tasks and the establishment of new tasks will be recorded by the revision of this paragraph.

(1) Item No. 2147, Task No. 8F07-11-001-01, Mine Detection Research.

(2) Item No. 1037, Task No. 8F07-11-001-02, Special Mine Clearing Means.

(3) Item No. 2938, Task No. 8F07-11-001-03, Mine Clearing and Emplacement Research.

d. Other Information:

(1) Scientific Research: Scientific research tasks and contracts are performed under this project and will be reported under the applicable tasks listed in 21c above.

(2) References: None

(3) In the conduct of this project, full consideration will be given to any work being done in the field under ABC and NATO Standardization Programs, or Mutual Weapons Development Program.

APPENDIX B

MAGNETIC SIGNAL PRODUCED BY A SPHEROID BURIED IN HOMOGENEOUS SOIL

The earth's magnetic field is essentially uniform over a region in which the ground surface is smooth and the soil is perfectly homogeneous. If the soil is not perfectly homogeneous, a distortion in the earth's magnetic field will result. The inhomogeneity can be caused by a buried mine or some other anomalous object having sufficient magnetic susceptibility contrast with the normal soil matrix. If one assumes that the disturbing object is completely surrounded by homogeneous and isotropic soil and that the material and shape of the object are such that it can be replaced by a spheroid of homogeneous isotropic material, the anomalous field (vector difference between undisturbed field and field with anomaly in place) is given in vector form by:

$$\underline{H} = \frac{3(\underline{M}' \cdot \underline{r})\underline{r}}{r^5} - \frac{\underline{M}'}{r^3} \tag{1}$$

where: $\underline{H}$ is the anomalous field,

$\underline{M}'$ is the magnetic moment of the equivalent spheroid,

$\underline{r}$ is the vector distance from the center of the object to the point at which $\underline{H}$ is determined, and

r is the scalar length of $\underline{r}$.

If $\underline{M}'$ is expressed in cgs units and $\underline{r}$ in cm, $\underline{H}$ will be given in oersteds, and $\underline{M}'$ is given by:

$$\underline{M}' = \frac{V\ (\varepsilon_s - \varepsilon_m)\ \underline{H}_o}{1 + 4\pi\,\varepsilon_m + (\varepsilon_s - \varepsilon_m)\ N_o} \tag{2}$$

where: V is the volume of the spheroid,

ε_m is the magnetic susceptibility of the medium (soil),

ε_s is the magnetic susceptibility of the anomalous object,

$\underline{H}_o$ is the earth's field, and

N_o is the demagnetizing coefficient of the equivalent spheroid in the direction of the earth's field.

If V is expressed in cubic centimeters, κ_s and κ_m in cgs units, and $\underline{H}_o$ in oersteds, $\underline{M}'$ will be given in cgs units. Equation (2) can be greatly simplified if the terms κ_m and κ_s in the denominator are omitted. Previous studies show that under nearly all conditions, this approximation can be made with negligible error.

Combining the simplified form of equation (2) with equation (1) and expanding the result, the X, Y, and Z components of $\underline{H}$, H_1, H_2, and H_3, respectively, in terms of the coordinates and angles in Fig. 9 become:

$$H_1 = \frac{V\,(\kappa_s - \kappa_m)\,H_o}{z^3}\quad F_1 \tag{3}$$

$$H_2 = \frac{V\,(\kappa_s - \kappa_m)\,H_o}{z^3}\quad F_2 \tag{4}$$

$$H_3 = \frac{V\,(\kappa_s - \kappa_m)\,H_o}{z^3}\quad F_3 \tag{5}$$

where:

$$F_1 = \frac{1}{\left[\left(\frac{\rho}{z}\right)^2 + 1\right]^{3/2}} \left\{ \frac{3\left(\frac{\rho}{z}\right)^2 \cos^2\alpha \cos\delta + \frac{\rho}{z}\cos\alpha \sin\delta}{\left(\frac{\rho}{z}\right)^2 + 1} - \cos\delta \right\} \tag{6}$$

$$F_2 = \frac{3\,\frac{\rho}{z}\sin\alpha}{\left[\left(\frac{\rho}{z}\right)^2 + 1\right]^{5/2}} \left[\frac{\rho}{z}\cos\alpha\cos\delta + \sin\delta\right] \tag{7}$$

$$F_3 = \frac{1}{\left[\left(\frac{\rho}{z}\right)^2 + 1\right]^{3/2}} \left\{ \frac{3\left[\frac{\rho}{z}\cos\alpha\cos\delta + \sin\delta\right]}{\left(\frac{\rho}{z}\right)^2 + 1} - \sin\delta \right\} \tag{8}$$

Equations (6), (7), and (8) can be used to plot normalized contour maps which, with the aid of equations (3), (4), and (5), allow the convenient determination of the magnitude of components of $\underline{H}$ at any desired point with reference to the anomalous object. For example, a contour map is shown in Fig. 10 for F_3 at the magnetic North Pole or at $\delta = 90^o$. It is easy to see that the maximum value will occur over the center of the object where F_3 equals -2.0. The maximum point is displaced from the center of the object for locations

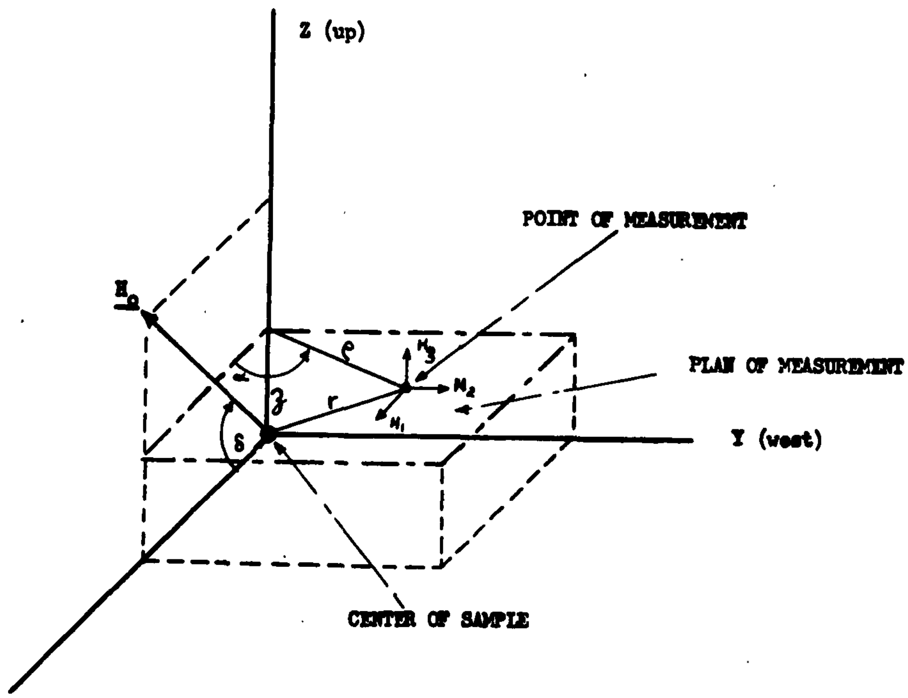

Fig. 9. Directions of anomalous field components and coordinate system for locating point of measurement.

other than the magnetic poles. In the Northern Hemisphere it is moved to the south and in the Southern Hemisphere it is moved to the north. The greatest displacement occurs at the Equator where there is a double maximum of F_3 at $\frac{\rho}{z} = 0.5$ North and 0.5 South. Table IV shows the results of such contour maps.

Table IV. Maximum F_3 Values

H_o, Total Earth's Field (oersted)	δ, Dip Angle, North or South (°)	F_3, Maximum Value
0.33	0 (magnetic Equator)	± 0.86
0.34	22.5	- 1.28
0.43	45.0	- 1.65
0.56	67.5	- 1.90
0.60	90.0 (magnetic North Pole)	- 2.00

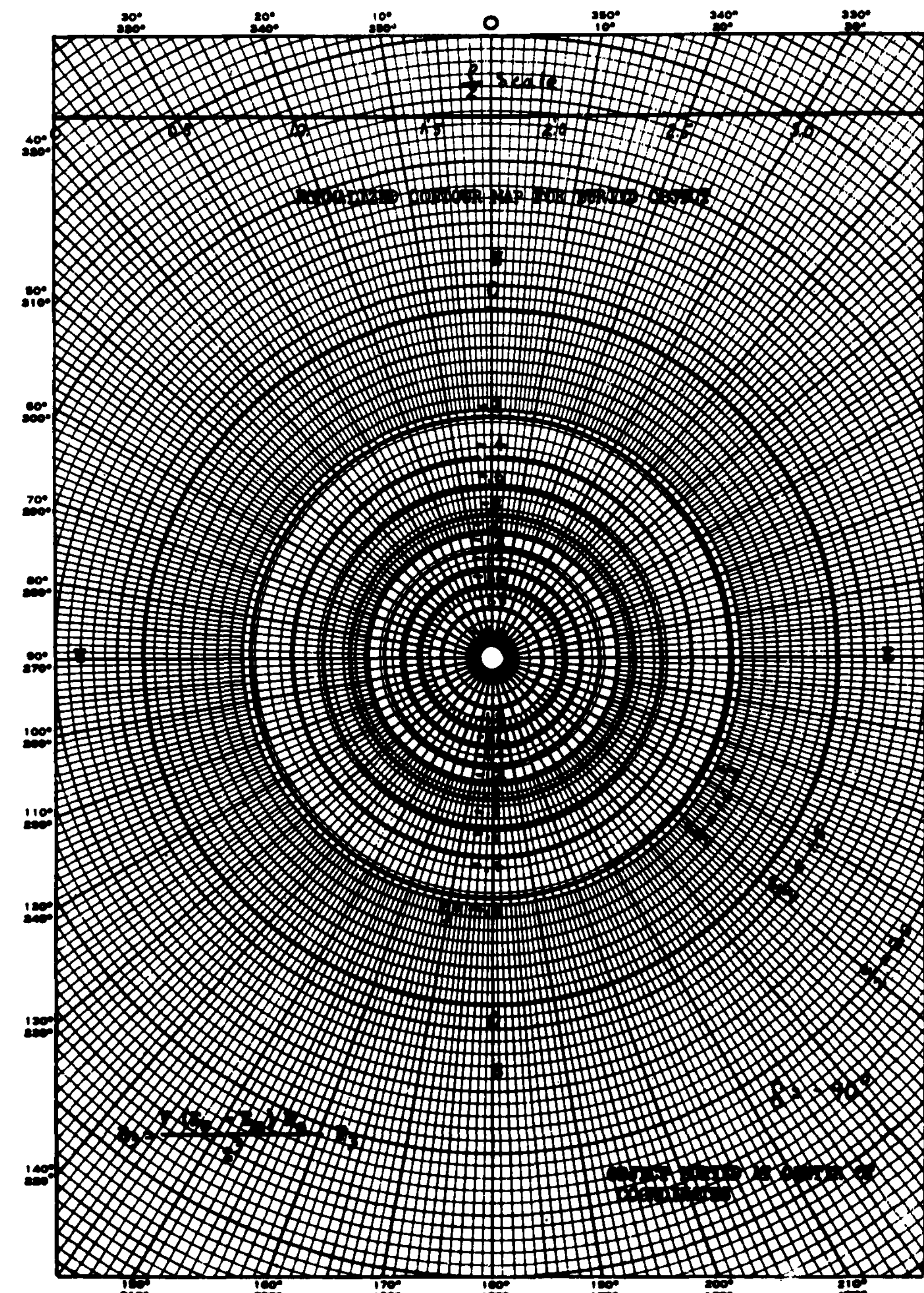

Fig. 10. Normalized contour map for buried object.

29	Granville Loam	Gry Brn PDZLC	Fairfax Co., Va	Sandstone, conglomerate, and shale	-	60	2
30	Conowingo Silt Loam	"	" " "	Serpentine, dark colored; igneous rock	-	220	5
31	Chester Loam	"	Chester, Pa	Gneiss, schist, and granite	-	90	2
32	Conowingo Clay	"	" "	Serpentine (greenstone)	2000	1500	3
33	Appling Fine Sandy Loam	Red & Yellow Soils	Mecklenburg, Va	Granite	-	20	(
34	Cecil Fine Sandy Loam	"	" "	Granite and gneiss	-	10	(
35	Orange Silt Loam	"	" "	Greenstone, schist, and slate	-	35	(
36	Georgeville Silt Loam	"	" "	Slate and schist	-	250	6
37	Mecklenburg Loam	"	" "	Basic igneous rocks	750	200	5
38	Worsham Fine Sandy Loam	"	" "	Colluvial (granite, gneiss, and slate)	-	1	(
39	Orange Silt Loam	"	" "	Slate, greenstone, and schist	-	200	5
40	Herndon Silt Loam	"	" "	Slate and schist	-	120	3
41	Congaree Silt Loam	"	Halifax Co., Va	Alluvial materials	-	30	(
42	Iredell Loam	"	" " "	Mafic rock	-	100	3
43	Appling Fine Sandy Loam	"	Pittsylvania Co., Va	Gneiss and some granite	1620	7	(
44	Louisa Fine Sandy Loam	"	" " "	Micaceous gneiss and schist	-	10	(
45	Lehigh Stony Silt Loam	"	" " "	Metamorphosed sandstone, shale, and mudstone	15	300	8
46	Iredell Sandy Loam	"	" " "	Diorite rock	-	60	2
47	Davidson Clay Loam	Gry Brn PDZLC	" " "	Dark colored igneous and metamorphic rock	900	300	8
48	Cecil Gravelly Fine Sandy Loam	"	" " "	Granite and gneiss	1700	175	5
49	Watt Silt Loam	"	Fauquier Co., Va	Black graphite slate	1	70	2
50	Porter Loam	"	Grayson Co., Va	Granite and gneiss	1	60	2
51	Muskingum Loam	"	" " "	Sandstone and slate	-	20	(c
52	Ashe Coarse Sandy Loam	"	" " "	Granite and gneiss	-	80	2
53	Talladega Loam	"	" " "	Schist	-	200	5
54	Chandler Silt Loam	"	" " "	Schist	12	7	(c
55	Ranger Silt Loam	"	" " "	Slate	275	60	2

fax Co., Va	Sandstone, conglomerate, and shale	-	60	2	No data	6	None
" "	Serpentine, dark colored; igneous rock	-	220	5		6	Contains highly magnetic inclusives occasionally
ter, Pa	Gneiss, schist, and granite	-	90	2		No data	None
"	Serpentine (greenstone)	2000	1500	36		8	Many pieces of greenstone, some lodestone
lenburg, Va	Granite	-	20	(0)		0	None
" "	Granite and gneiss	-	10	(0)		0	Numerous small quartz pieces
" "	Greenstone, schist, and slate	-	35	(1)		No data	None
" "	Slate and schist	-	250	6		6	Sample contained pea-sized parent rock
" "	Basic igneous rocks	750	200	5		6	Some dark mineral concretions, boulders of parent material on surface
" "	Colluvial (granite, gneiss, and slate)	-	1	(0)		0	None observed
" "	Slate, greenstone, and schist	-	200	5		8	None
" "	Slate and schist	-	120	3		8	Sample contained pieces of parent rock
ax Co., Va	Alluvial materials	-	30	(1)		0	None
" "	Mafic rock	-	100	3		10	Iron concretions and dark colored rocks scattered over surface
ylvania Co., Va	Gneiss and some granite	1620	7	(0)		4	Contained many stones on surface
" " "	Micaceous gneiss and schist	-	10	(0)		No data	Some quartz, schist, and gneiss pieces
" " "	Metamorphosed sandstone, shale, and mudstone	15	300	8		10	Contains numerous stones
" " "	Diorite rock	-	60	2		No data	Iron concretions in some places
" " "	Dark colored igneous and metamorphic rock	900	300	8		6	Boulders of parent rock scattered on surface
" " "	Granite and gneiss	1700	175	5		16	Gravel and pebbles on surface
ier Co., Va	Black graphite slate	1	70	2		8	Abundant slate chips
on Co., Va	Granite and gneiss	1	60	2		No data	A few rock fragments
" "	Sandstone and slate	-	20	(0)		6	Many rock fragments in soil
" "	Granite and gneiss	-	80	2		4	None
" "	Schist	-	200	5		4	A few rock fragments
" "	Schist	12	7	(0)		0	None
" "	Slate	275	60	2		No data	Very stony

APPENDIX C

TABLE V. FIELD TEST SITE DATA.

Test Site	Soil	Great Soil Group	Location	Parent Material	Susceptibilit in μcgs units Parent	Soi
	Data are taken from Carts and Duey, Magnetic Properties and Anomalies in Soils of Virginia and West Virginia and Sig					
1	Iredell Stony Silt Loam	Gry Brn PDZLC	Fauquier Co., Va	Diabase	-	120
2	Penn Silt Loam	"	" " "	Red shale	20	120
3	Goldvein Gritty Silt Loam	"	" " "	Quartz-monzonite	1	5
4	Montalto Silt Loam	"	Prince William Co., Va	Fine-grained diabase	770	500
5	Elbert Silt Loam	"	Fauquier Co., Va	Diabase	210	180
6	Fauquier Silt Loam	"	" " "	Greenstone sediments	2200	75
7	Sassafrass Loam	"	Fairfax Co., Va	Unconsolidated sediments	-	55
8	Coastal Beach Sand (Atlantic)	Red & Yellow Soils	Princess Anne Co., Va	Marine sands	1	5
9	Sassafrass Fine Sandy Loam	"	" " " "	Sandy marine deposits	-	35
10	Bayboro Silt Loam	"	" " " "	Sands, clays, and silts	-	30
11	Hyde Silty Clay Loam	"	" " " "	Organic rock	-	1
12	Bladen Silt Loam	"	" " " "	Fine-grained marine deposits	-	1
13	Norfolk Fine Sandy Loam	"	Nansemond Co., Va	Clays and sands	-	2
14	Onslow Fine Sandy Loam	"	" " "	Clays and sands	-	7
15	Lenoir Fine Sandy Loam	"	" " "	Sands and clays	-	1
16	Norfolk Fine Sandy Loam	"	Southampton Co., Va	Sands and clays	-	5
17	Moycock Fine Sandy Loam	"	" " "	Sands	-	2
18	Lenoir Very Fine Sandy Loam	"	" " "	Sands and clays	-	1
19	Congaree Silty Clay Loam	"	Fairfax Co., Va	Clays (alluvial)	-	15
20	Susquehanna Loam	Gry Brn PDZLC	" " "	Heavier coastal deposits	-	75
21	Chester Loam	"	" " "	Gneiss, schist, and granite	-	20
22	Bucks Silt Loam	"	Fauquier Co., Va	Red shales and sandstone	20	40
23	Dyke Silt Loam	"	" " "	Greenstone	-	2300
24	Elioak Silt Loam	"	" " "	Mica schist and gneiss	-	900
25	Chewacla Silt Loam	"	" " "	Recent alluvial	-	200
26	Manor Loam	"	Fairfax Co., Va	Mica schist and gneiss	-	310
27	Congaree Silt Loam	"	" " "	Recent alluvial	-	350
28	Louisa Loam	"	" " "	Schist, gneiss and granite	1600	900

APPENDIX C

TABLE V. FIELD TEST SITE DATA.

il	Location	Parent Material	Susceptibility in μcgs units(a) Parent	Susceptibility in μcgs units(a) Soil	Magnetic Effect in Gammas (10^{-5} oersteds) Small Box	Magnetic Effect in Gammas (10^{-5} oersteds) Large Box	Anomalies per 10 Ft Small Box	Inclusive Material
ic Properties and Anomalies in Soils of Virginia and West Virginia and Significance to Land Mine Detection.								
	Fauquier Co., Va	Diabase	-	120	3	No data	No data	None
	" " "	Red shale	20	120	3		2	Some shale fragments
	" " "	Quartz-monzonite	1	5	(0)(c)		0	Quartz, grit to cobbles
	Prince William Co., Va	Fine-grained diabase	770	500	12.5		10	Numerous pieces of diabase
	Fauquier Co., Va	Diabase	210	1800	45		6	Some weathered diabase
	" " "	Greenstone sediments	2200	750	19		14	Greenstone up to cobble size
	Fairfax Co., Va	Unconsolidated sediments	-	55	1		0	Some quartz gravel
ils	Princess Anne Co., Va	Marine sands	1	5	(0)		0	None
	" " " "	Sandy marine deposits	-	35	(1)		0	None
	" " " "	Sands, clays, and silts	-	30	(1)		0	None
	" " " "	Organic rock	-	1	(0)		0	Organic material
	" " " "	Fine-grained marine deposits	-	1	(0)		0	Small pebbles at times
	Nansemond Co., Va	Clays and sands	-	2	(0)		0	None
	" " "	Clays and sands	-	7	(0)		0	Has hardpan in some areas
	" " "	Sands and clays	-	1	(0)		0	None
	Southampton Co., Va	Sands and clays	-	5	(0)		0	None
	" " "	Sands	-	2	(0)		0	None
	" " "	Sands and clays	-	1	(0)		0	None
	Fairfax Co., Va	Clays (alluvial)	-	15	(0)		0	None
	" " "	Heavier coastal deposits	-	75	(2)		No data	May contain quartz gravel
	" " "	Gneiss, schist, and granite	-	20	(0)		0	None
	Fauquier Co., Va	Red shales and sandstone	20	40	1		0	None
	" " "	Greenstone	-	2300	55		10	Contains small greenstone pieces
	" " "	Mica schist and gneiss	-	900	22		2	Occasional small quartz and schist
	" " "	Recent alluvial	-	200	5		0	None
	Fairfax Co., Va	Mica schist and gneiss	-	310	8		6	A few pieces of quartz and schist
	" " "	Recent alluvial	-	350	9			None
	" " "	Schist, gneiss and granite	1600	900	22			A few small schist and quartz pieces

2

56	Montevallo Shaly Silt Loam	Gry Brn FDZLC	Smyth Co., Va	Shale and sandstone	10	70
57	Dunmore Stony Silt Loam	"	" " "	Limestone	1	30
58	Carbo Silty Clay Loam	"	" " "	Mixed limestone and shale	-	200
59	Lodi Loam	"	" " "	Limestone and sandstone	-	35
60	Holston Loam	"	" " "	Alluvial (sandstone and shale)	-	80
61	Masada Loam	"	" " "	Alluvial (limestone, sandstone and shale)	-	100
62	Tusquitee Stony Loam	"	" " "	Mainly igneous fragments	-	15
63	Ramsey Stony Loam	"	" " "	Slate, shale, and quartzite	10	120
64	Clarksville Cherty Silt Loam	"	" " "	Cherty limestone	1	70
65	Muskingum Stony Fine Sandy Loam	"	" " "	Sandstone	5	20
66	Lehew Very Fine Sandy Loam	"	Tazewell Co., Va	Sandstone	10	25
67	Hayter Stony Fine Sandy Loam	"	" " "	Sandstone	40	150
68	Pisgah Stony Silt Loam	"	" " "	Limestone	-	70
69	Frederick Cherty Silt Loam	"	" " "	Cherty limestone	-	80
70	Muskingum Stony Very Fine Sandy Loam	"	" " "	Sandstone	38	70
71	Bolton Loam	"	" " "	Sandstone and limestone	42 15	85 -
72	Upshur Stony Clay Loam	"	McDowell Co., W. Va	Red shale and sandstone	5	65
73	Holston Fine Sandy Loam	"	Wyoming Co., W. Va	Alluvial (sandstone)	-	15
74	Dekalb Stony Silt Loam	"	" " " "	Sandstone and shale	1 25	175 -
75	Huntington Fine Sandy Loam	"	Logan Co., W. Va	Alluvial (limestone, sandstone, and shale)	-	5
76	Dekalb Stony Silt Loam	"	" " " "	Sandstone and shale	14	55
77	Holston Silt Loam	"	Boone Co., W. Va	Alluvial (Dekalb material)	-	1
78	Holston Silt Loam	"	Lincoln Co., W. Va	" " "	-	20
79	Not available					
80	Upshur Silty Clay Loam	"	Braxton Co., W. Va	Red shales	40	37
81	Moshannon Silt Loam	"	" " " "	Alluvial (Dekalb and Upshur)	-	34
82	Pope	"	Webster Co., W. Va	Alluvial		10
83	Frederick Gravelly Fine Sandy Loam	"	Pendleton Co., W. Va	Limestone and sandstone	4	35
84	Huntington Fine Sandy Loam	"	" " " "	Recent alluvial	-	55

Smyth Co., Va	Shale and sandstone	10	70	2	No data	No data	Very stony, full of shale and sandstone
" " "	Limestone	1	30	(1)		" "	Very stony (limestone)
" " "	Mixed limestone and shale	-	200	5		0	None
" " "	Limestone and sandstone	-	35	(1)		2	None
" " "	Alluvial (sandstone and shale)	-	80	2		4	In some places quartzite and sandstone gravel from ½-in. to 2-in. diameter
" " "	Alluvial (limestone, sand-stone and shale)	-	100	3		6	Some sandstone and quartzite fragments
" " "	Mainly igneous fragments	-	15	(0)		10	Many stones everywhere
" " "	Slate, shale, and quartzite	10	120	3		6	Many stones
" " "	Cherty limestone	1	70	2		10	Much chert and limestone
" " "	Sandstone	5	20	(0)		0	Very stony
Tazewell Co., Va	Sandstone	10	25	(0)		0	A few sandstone fragments
" " "	Sandstone	40	150	4		6	Numerous sandstone pieces
" " "	Limestone	-	70	2		0	Limestone outcrops and pieces
" " "	Cherty limestone	-	80	2			Many chert pieces on surface
" " "	Sandstone	38	70	2		8	Very stony everywhere
" " "	Sandstone and limestone	42 15	85 -	2 -		6	Contains small black concretions, also sandstone and chert pieces
McDowell Co., W. Va	Red shale and sandstone	5	65	2		6	Sandstone pieces are numerous
Wyoming Co., W. Va	Alluvial (sandstone)	-	15	(0)		No data	None
" " " "	Sandstone and shale	1 25	175 -	5 -		6	Many pieces of sandstone
Logan Co., W. Va	Alluvial (limestone, sandstone, and shale)	-	5	(0)		0	Some gravel in places
" " " "	Sandstone and shale	14	55	1		6	Contains numerous rocks
Boone Co., W. Va	Alluvial (Dekalb material)	-	1	(0)		0	Gravel and boulders may be present
Lincoln Co., W. Va	" " "	-	20	(0)		0	Some pebbles and small boulders
Braxton Co., W. Va	Red shales	40	37	(1)		3	Very stony, mixed sandstone, and shale
" " " "	Alluvial (Dekalb and Upshur)	-	34	(1)		0	A few 2-in. rocks widely scattered.
Webster Co., W. Va	Alluvial		10	(0)		0	None
Pendleton Co., W. Va	Limestone and sandstone	4	35	(1)		2	Contains rocks in surface
" " " "	Recent alluvial	-	55	1		0	Contains gravel and stones near streams

85	Hagerstown Stony Silty Clay Loam	Gry Brn PDZLC	Pendleton Co., W. Va	Shaly limestone	-	72
86	Dekalb Shaly Silt Loam	"	" " " "	Sandstone and shale	8	300
87	Monongahelia Silt Loam	"	Hardy Co., W. Va	Alluvial (sands and clay)	-	150
88	Westmoreland Silt Loam	"	" " " "	Calcareous shales and impure limestones	-	40
89	Meigs	"	" " " "	Red sandstones and shales	-	15
90	Not available					
91	Lindside Silt Loam	"	" " " "	Alluvial	-	20
92	Berks Silt Loam	"	" " " "	Shales	10	35
93	Moshannon Gravelly Fine Sandy Loam	"	" " " "	Alluvial	-	25
94	Not available	"	Culpepper Co., Va	Schist and greenstone	-	30
95	Cecil Fine Sandy Loam	"	" " "	Granite and gneiss	-	50

Data are taken from Carts, Orr, and MacCormac, The Effects of Soil Magnetic Properties and Natural Magnetic Micro-anomalies o Passive Magnetic Land Mine Detection Methods.

P-1	Arraijan Clay	RHLTSL	Canal Zone	Agglomerate	2800,900	1050
P-2	Arraijan Clay	RHLTSL	" "	"	3100	790
P-3	Paraiso Clay	RBHLTSL	" "	Limestone and tuff	3, 130	585
P-4	Arraijan Clay	RHLTSL	" "	Basalt	2200	2000
P-5	Ancon Stony Clay	YELBRNLTSL	" "	Dasite	2400	1000
P-6	Beach Sand	SAND	Republic of Panama	Basic igneous	-	4500
P-7	Beach Sand	"	" " "	Igneous, acid, and basic	265, 2850	460
P-8	Shell Beach Sand	"	Canal Zone	Sand	-	50
P-9	Beach Sand (light, dark)	"	Republic of Panama	Basic igneous	1200	50,000
P-10	Beach Sand	"	" " "	Sand	-	216
P-11	Alhajuela Clay	BRNHLTSL	" " "	Limestone	10	425
P-12	Gatuncillo Clay	REDBRNHLTSL	" " "	"	-	280
P-13	Gatuncillo Loam Clay	"	" " "	Shale	-	280
P-14	Gatuncillo Loam Clay	"	" " "	"	-	720
P-15	Frijoles Clay	REDHLTSL	" " "	Basic igneous	1100	750
P-16	Catival Clay	REDBRNHLTSL	Canal Zone	Limestone	-	375
P-17	Olivine Beach Sand	SAND	Republic of Panama	Basic igneous	[redacted]	10500
P-17A	Beach Sand (chips)	"	" " "	Sand	[redacted]	1850
P-18	Gatun Clay	REDHLTSL	Canal Zone	Sandstone, siltstone	[redacted]	200
P-19	Gatun Clay	"	" "	Sandstone	[redacted]	350

ileton Co., W. Va	Shaly limestone	-	72	2	No data	6	Very stony
" " " "	Sandstone and shale	8	300	8		8	Very shaly and stony
ly Co., W. Va	Alluvial (sands and clay)	-	150	4		No data	
" " "	Calcareous shales and impure limestones	-	40	1		0	
" " "	Red sandstones and shales	-	15	(0)		0	Very stony
" " "	Alluvial	-	20	-		No data	
" " "	Shales	10	35	(1)		4	
" " "	Alluvial	-	25	(0)		0	
epper Co., Va	Schist and greenstone	-	30	(1)		6	Small stones on surface and in soil
" " "	Granite and gneiss	-	50	1		4	

Effects of Soil Magnetic Properties and Natural Magnetic Micro-anomalies of Typical Tropical Soils on ive Magnetic Land Mine Detection Methods.

l Zone	Agglomerate	2800,900	1050	11	No data	10	
"	"	3100	790	8		10	
"	Limestone and tuff	3, 130	585	6		3	
"	Basalt	2200	2000	20		10	
"	Dasite	2400	1000	10		10	
blic of Panama	Basic igneous	-	4500	45		7	
" "	Igneous, acid, and basic	265, 2850	460	5		10	
l Zone	Sand	-	50	(0)		3	
blic of Panama	Basic igneous	1200	50,000	-		5	Also location with soil K of 150,000 (dark)
" "	Sand	-	216	2		10	
" "	Limestone	10	425	4		2	
" "	"	-	280	3		5	
" "	Shale	-	280	3		2	
" "	"	-	720	7		2	
" "	Basic igneous	1100	750	7		7	
l Zone	Limestone	-	375	4		5	
blic of Panama	Basic igneous	-	10500	120		1	
" "	Sand	-	1850	20		2	
l Zone	Sandstone, siltstone	-	200	2		3	
"	Sandstone	-	350	4		5	

P-20	Beach Sand Coral, Wet	SAND	Canal Zone	Sand	-	5000
P-20A	Beach Sand Coral, Dry	"	" "	"	-	275
P-21	Beach Sand	"	" "	"	-	1500
P-22	Green Beach Sand	"	Republic of Panama	"	-	6400
P-22A	Beach Sand (light)	"	" " "	"	-	5750
P-23	rraijan Clay	REDHLTSL	Canal Zone	Basalt	4750	400
P-24	Paraiso Clay	REDBRNHLTSL	" "	Acidic tuff	-	3

Data are taken from "Field Tests on Performance of SCR Mine Detector As Related to Varieties of Bed Rock and Soils," U.

1	Clayey Soil	Trop. Brn.	Luzon	Alluvium	No data	260
2	" "	Trop. Blk.	"	Andesitic tuff		38
3	" "	"	"	" "		50
4	" "	Trop. Brn.	"	" "		500
5	" "	"	"	" "		75
6	" "	Rd Brn Lat "	"	Andesitic tuff basalt and diabase		350
7	Loam, Silt Loam	Trop Brn Lat	"	Andesitic tuff		420
8	" " "	"	"	Very recent alluvium		425
9	" " "	"	"	Alluvium		180
10	" " "	"	"	"		45
11	Beach Sand	No data	"	-		2000
12	" "	" "	"	-		350

Data are taken from "Report on Use of SCR-625-C Mine Detector and Data to Serve as Basis for Prediction of Performance," Survey for Chief of Engineers, 1945.

13	**Neshaminy**	No data	Md	Hornblende-plag. rock	No data	400
14	"		"	" " "		530
15	Conowingo		"	Serpentine		450
16	Manor		"	Granite		42
17	Chester		"	Schist and granite		34
18	Loam		"	Old alluvium		36
19	Hagerstown		Va	Dolomite limestone		1000
20	"	[redacted]	"	" "		400
21	"		"	" "		870
22	Loam		"	Shale		37
23	Meyersville		"	Greenstone		540
24	"		"	"		2200
25	Mecklenberg		Va	Diabase		400

	Canal Zone	Sand	-	5000	50	No data	4
	" "	"	-	275	3		4
	" "	"	-	1500	15		1
	Republic of Panama	"	-	6400	65		3
	" " "	"	-	5750	58		3
	Canal Zone	Basalt	4750	400	4		10
3L	" "	Acidic tuff	-	3	0		No data

ance of SCR Mine Detector As Related to Varieties of Bed Rock and Soils," U. S. Geological Survey for Chief of Engineers, U. S. Army.

	Luzon	Alluvium	No data	260	3	No data	No data
	"	Andesitic tuff		38	0		
	"	" "		50	0		
	"	" "		500	5		
	"	" "		75	1		
	"	Andesitic tuff basalt and diabase		350	4		
at	"	Andesitic tuff		420	4		
	"	Very recent alluvium		425	4		
	"	Alluvium		180	2		
	"	"		45	0		
	"	-		2000	20		
	"	-		350	4		

5-C Mine Detector and Data to Serve as Basis for Prediction of Performance," by Military Geology Unit, U. S. Geological
ineers, 1945.

Md	Hornblende-plag. rock	No data	400	10	No data	No data
"	" " "		530	13		
"	Serpentine		450	11		
"	Granite		42	1		
"	Schist and granite		34	1		
"	Old alluvium		36	1		
Va	Dolomite limestone		1000	25		
"	" "		400	10		
"	" "		870	21		
"	Shale		37	1		
"	Greenstone		540	13		
"	"		2200	52		
Va	Diabase		400	10		

1	Silt	No data	Chekiang, China	Silt	No data	<10
1a	Bladen Fine Sandy Loam		McIntosh, Ga	Fine sandy loam		<10
1b	Waverly Silt Loam		Prane, Ark.	Silt		10
1c	Kalmia Fine Sandy Loam		Lincoln, La	Stream terrace		12
2	Myatt Silt Loam		Dallas, Tex.	Terrace		10
3	Crowley Silt Loam		Beauregard, La	Silt		10
4	Not available		Md	Alluvium (old)		18
5	Wickham Sandy Loam		Gainesville, Ga	Terrace		45
6	Ochlockonee Silt Loam		Dallas, Tex.	Flood plain		80
7	Not available		Upper Amazon, Peru	Flood plain		80
8	Cahaba Fine Sandy Loam		Lincoln, La	Flood plain		86
9	Orangeburg Fine Sandy Loam		" "	Sand and clay		15
10	Ruston Loamy Fine Sand		" "	Sand and clay		25
10a	Harris Clay		Victoria, Tex.	Clay		10
10b	Lake Charles Clay		" "	Clay		10
11	Blakely Loam		Peach, Ga	Heavy sandy clay		218
12	Susquehanna Fine Sandy Loam		Lincoln, Ga	Heavy clay		280
12a	Loam		Va	Shale		24
13	Not available		"	Red shale		295
14	Summerville Stony Loam		Cheboygan, Mich.	Limestone and dolomite		37
15	Duffield Silt Loam		Jefferson, W. Va	" " "		40
16	Strasburg		York, Pa	" " "		50
17	Hagerstown Silt Loam		" "	" " "		75
18	Duffield Silt Loam		Washington, Md	" " "		75
19	Hagerstown Silt Loam		Franklin, Pa	" " "		80
20	Posen Stony Loam		Menominee, Mich.	" " "		85
21	Hagerstown Silt Loam		Washington, Md	" " "		105
22	Frederick		" "	Shaly limestone and dolomite		115
23	Dunmore Silt Loam		Smyth, Va	Limestone and dolomite		136
24	Not available		Va	Dolomite limestone		145
25	Hagerstown Silt Loam		Hardin, Tenn.	Limestone and dolomite		155
26	Dewey Loam		Franklin, Ala.	" " "		165
27	Fullerton Cherty Silt Loam		Cranger, Tenn.	Cherty limestone and dolomite		170
28	Dewey Silt Loam		Jefferson, Tenn.	Limestone and dolomite		170
29	Lancaster, Pa		" "	" " "		210
30	Decatur Clay Loam		Floyd, Ga	" " "		245

	No data	Chekiang, China	Silt	No data	<10	0	No data	No data
ndy Loam		McIntosh, Ga	Fine sandy loam		<10	0		
oam		Prane, Ark.	Silt		10	0		
ndy Loam		Lincoln, La	Stream terrace		12	0		
m		Dallas, Tex.	Terrace		10	0		
oam		Beauregard, La	Silt		10	0		
		Md	Alluvium (old)		18	0		
Loam		Gainesville, Ga	Terrace		45	1		
lt Loam		Dallas, Tex.	Flood plain		80	1		
		Upper Amazon, Peru	Flood plain		80	1		
ndy Loam		Lincoln, La	Flood plain		86	1		
e Sandy Loam		" "	Sand and clay		15	0		
ine Sand		" "	Sand and clay		25	0		
		Victoria, Tex.	Clay		10	0		
lay		" "	Clay		10	0		
		Peach, Ga	Heavy sandy clay		218	4		
ne Sandy Loam		Lincoln, Ga	Heavy clay		280	5		
		Va	Shale		24	0		
		"	Red shale		295	7		
ony Loam		Cheboygan, Mich.	Limestone and dolomite		37	1		
oam		Jefferson, W. Va	" " "		40	1		
		York, Pa	" " "		50	1		
Loam		" "	" " "		75	2		
oam		Washington, Md	" " "		75	2		
Loam		Franklin, Pa	" " "		80	2		
m		Menominee, Mich.	" " "		85	2		
Loam		Washington, Md	" " "		105	3		
		" "	Shaly limestone and dolomite		115	3		
am		Smyth, Va	Limestone and dolomite		136	3		
		Va	Dolomite limestone		145	4		
Loam		Hardin, Tenn.	Limestone and dolomite		155	4		
		Franklin, Ala.	" " "		165	4		
y Silt Loam		Granger, Tenn.	Cherty limestone and dolomite		170	4		
		Jefferson, Tenn.	Limestone and dolomite		170	4		
		" "	" " "		210	5		
am		Floyd, Ga	" " "		245	4		

31	Hagerstown Loam	No data	Lehigh, Pa	" " "	No data	285
32	Hagerstown Silt Clay Loam		Washington, Md	" " "		290
33	Not available		Va	Dolomite limestone		300
34	Dewey Loam		Bartow, Ga	Limestone and Dolomite		300
35	Dewey Silty Loam		Colbert, Ala.	Limestone and Dolomite sandstone		395
36	Benevola Silty Clay		Washington, Md	Calcareous sand and sandy limestone		440
37	Decatur Clay Loam		Colbert, Ala.	Limestone and Dolomite		480
38	Not available		Va	" " "		500
39	Not available		Va	Dolomite limestone		545
40	Decatur Silty Loam		Washington, Md	Limestone and Dolomite		1660
41	Not available		Upper Amazon, Peru	Mica schist		20
42	Not available		Near Clarksville, Md	Injection schist		48
43	Not available		Va	Sericite schist		65
44	Madison Clay Loam		Warren, Ga	Quartz-mica schist		85
45	Glenelg Silt Loam		Lancaster, Pa	Mica schist		95
46	Manor Loam		" "	Schist		185
47	Durham Sandy Loam		Clarke, Ga	Granite gneiss		10
48	Appling Sandy Loam		Warren, Ga	Granite, gneiss, and schist		10
49			Md	Granite		45
49A	Loam		Hollandia, New Guinea	Granitic arkose		150
49B	Butte Gravelly Sand		Clear Lake Area, Cal.	Andesitic, rhyolite tuffs		50
49C	Butte Stony Loam		Napa Area, Cal.	Andesitic, rhyolite tuffs		75
50	Luzena Stony Loam		Hidalgo, N. M.	Rhyolite		580
51	Tijara Clay		Tijara, Costa Rica	Trachyandesite		720
52	Not available		Turrialba, Costa Rica	Volcanic (basic)		820
53	Luzena Sandy Loam		Gila Bend, Ariz.	Rhyolite		1400
54	Montalto		Va	Diabase		210
55	Montalto		Bucks, Pa	"		1440
56	Not available		Md	Gabbro		195
57	Neshaminy Silt Loam		Newark, Del.	Mafic metamorphic rocks		235
58	Chester Loam		Lancaster, Pa	Mafic metamorphic rocks	[redacted]	240
59	Montalto Silt Loam		Near Newark, Del.	" " "		360
60	Not available		Md	" " "		365
61	Bliock Silt Loam		Lancaster, Pa	" " "		390

n	No data	Lehigh, Pa	" " "	No data	285	7	No data	No data
: Clay Loam		Washington, Md	" " "		290	7		
		Va	Dolomite limestone		300	7		
		Bartow, Ga	Limestone and Dolomite		300	5		
m		Colbert, Ala.	Limestone and Dolomite sandstone		395	6		
Clay		Washington, Md	Calcareous sand and sandy limestone		440	11		
am		Colbert, Ala.	Limestone and Dolomite		480	8		
		Va	" " "		500	12		
		Va	Dolomite limestone		545	14		
oam		Washington, Md	Limestone and Dolomite		1660	43		
		Upper Amazon, Peru	Mica schist		20	0		
		Near Clarksville, Md	Injection schist		48	1		
		Va	Sericite schist		65	2		
am		Warren, Ga	Quartz-mica schist		85	1		
am		Lancaster, Pa	Mica schist		95	2		
		" "	Schist		185	5		
am		Clarke, Ga	Granite gneiss		10	0		
oam		Warren, Ga	Granite, gneiss, and schist		10	0		
		Md	Granite		45	1		
		Hollandia, New Guinea	Granitic arkose		150	1		
and		Clear Lake Area, Cal.	Andesitic, rhyolite tuffs		50	1		
		Napa Area, Cal.	Andesitic, rhyolite tuffs		75	1		
m		Hidalgo, N. M.	Rhyolite		580	9		
		Tijara, Costa Rica	Trachyandesite		720	8		
		Turrialba, Costa Rica	Volcanic (basic)		820	9		
m		Gila Bend, Ariz.	Rhyolite		1400	23		
		Va	Diabase		210	5		
		Bucks, Pa	"		1440	36		
		Md	Gabbro		195	5		
oam		Newark, Del.	Mafic metamorphic rocks		235	6		
		Lancaster, Pa	Mafic metamorphic rocks		240	6		
am		Near Newark, Del.	" " "		360	9		
		Md	" " "		365	9		
		Lancaster, Pa	" " "		390	10		

62	Conowingo	No data	Baltimore, Md	Serpentine rock	No data	400
63	Not available		Bethesda, Md	Metagabbro		440
64	Davidson Clay Loam		Warren, Ga	Gabbro		1170
65	Not available		Bethesda, Md	"		2150
66	Guayama Clay		Humacao, Puerto Rico	Mafic metamorphic		125
67	Not available		Va	Metabasalt		210
67A	" "		Paricutin, Mex.	Basaltic ash		260
68	" "		Va	Metabasalt		950
69	Aiken		Lake, Cal.	Basic igneous rocks		1490
70	Not available		Md	Serpentine rock		250
71	Conowingo Barrens		Chester, Pa	" "		950
72	Conowingo Silt Loam		Lancaster, Pa	" "		1000
73	Not available		Webster, N. C.	Dunite		2000
74	Conowingo		Chester, Pa	Serpentine rock		2900
75	Rosales		Rosales, Puerto Rico	" "		3500
76	Nipe Clay		Mayaguez, Puerto Rico	" "		3600
77	Silt Loam		Hollandia, New Guinea	" "		7000
78	Collington Fine Sandy Loam		Blackwood, N. J.	Glauconite		15
79	Collington Fine Sandy Loam		Prince George, Md	Glauconitic sand		40
80	Red Bay Fine Sandy Loam		Sumpter, Ala.	" "		90
81	Red Bay Fine Sandy Loam		Hale, Ala.	" "		105
82	Orangeburg Very Fine Sandy Loam		Ruston, La	Sand and sandy clay		460
83	Nacogdoches Fine Sandy Loam		Garland, Tex.	Glauconitic clay		1530
84	Nacogdoches Fine Sandy Loam		" "	" "		1800
85	Red Bay, Fine, Sandy Loam, Gravelly		Ruston, La	Glauconite		3400

SUSCEPTIBILITY OF ROCKS FROM JAPAN

1	Not available		Fugi, Suruga	Basalt	1100	No data
2	" "		R. Gordsi	Quartz-bearing tuff	57	
3	" "		Tsubaki, Ugo, K. Niui	Tuff	24	
4	Not available		Sado Mine	Quartz-bearing tuff	225	
5	" "		Kamo, Izu	Tuff breccia	370	
6	" "		Shimonosiki, Nagato	Metamorphosed tuff	195	
7	" "		Sheobara or Mitachi	Tuff shale	25	
8	" "		Hodozawa, Musashi	" "	42	

	No data	Baltimore, Md	Serpentine rock	No data	400	10	No data	No data
		Bethesda, Md	Metagabbro		440	11		
		Warren, Ga	Gabbro		1170	19		
		ethesda, Md	"		2150	54		
		umancao, Puerto Rico	Mafic metamorphic		125	1		
		Va	Metabasalt		210	5		
		Paricutin, Mex.	Basaltic ash		260	3		
		Va	Metabasalt		950	24		
		Lake, Cal.	Basic igneous rocks		1490	25		
		Md	Serpentine rock		250	6		
		Chester, Pa	" "		950	24		
a		Lancaster, Pa	" "		1000	25		
		Webster, N. C.	Dunite		2000	40		
		Chester, Pa	Serpentine rock		2900	70		
		Rosales, Puerto Rico	" "		3500	35		
		Mayaguez, Puerto Rico	" "		3600	35		
		Hollandia, New Guinea	" "		7000	46		
dy Loam		Blackwood, N. J.	Glauconite		15	0		
dy Loam		Prince George, Md	Glauconitic sand		40	1		
Loam		Sumpter, Ala.	" "		90	1		
Loam		Hale, Ala.	" "		105	2		
e Sandy		Ruston, La	Sand and sandy clay		460	8		
ndy Loam		Garland, Tex.	Glauconitic clay		1530	26		
ndy Loam		" "	" "		1800	29		
y Loam,		Ruston, La	Glauconite		3400	54		
OCKS FROM JAPAN								
		Fugi, Suruga	Basalt	1100	No data	No data		
		R. Gordsi	Quartz-bearing tuff	57				
		Tsubaki, Ugo, K. Niui	Tuff	24				
		Sado Mine	Quartz-bearing tuff	225				
		Kamo, Izu	Tuff breccia	370				
		Shimonosiki, Nagato	Metamorphosed tuff	195				
		Sheobara or Mitachi	Tuff shale	25				
		Hodozawa, Musashi	" "	42				

2

Data are taken from "Performance of the SCR-625 Mine Detector over Different Rocks and Soils," by R. J. Roberts, E. Sampson, M. M. Striker, U. S. Geological Survey, and T. E. Stewart, USAERDL, 1949.

1	Posen	No data	Menominee, Mich.	Limestone	No data	100
2	Frederick		Morgan, Ind.	"		102
3	Fairmount		Brown, Ohio	Sandstone		50
4	Duffield		Limestone, Pa	Limestone		40
5	Hagerstown		Lancaster, Pa	"		210
6	Frederick		Washington, Md	"		140
7	Hagerstown		Bedford, Tenn.	"		200
8	Dewey		Roane, Tenn.	"		280
9	Dewey		Jefferson, Tenn.	"		50
10	Decatur		Hamblen, Tenn.	"		220
11	Dewey		Bartow, Ga	"		260
12	Blakely		Peach, Ga	"		200
13	Decatur		Colbert, Ala.	"		400
14	Chester		Bernardsville, N. J.	Mica schist		90
15	Chester		Baltimore, Md	" "		140
16	Manor		Fairfax, Va	Sericite schist		50
17	Chester		Stoke, N. C.	Mica schist		4
18	Granitic Arkose Soil		Hollandia, New Guinea	Granitic arkose		150
19	Soil from Mica Schist		Upper Amazon, Peru	Mica schist		15
20	Soil from Mica Schist		Upper Amazon, Peru	" "		12
21	Conowingo		Chester, Pa	Greenstone		740
22	Lloyd		Fairfax, Va	Greenstone		680
23	Not available		Lake, Calif.	Serpentine rocks	1400	2500
24	Rosales		Rosales, Puerto Rico	" "	710	3500
25	Not available		Hollandia, New Guinea	Altered serpentines	2000	8000
26	" "		Lake, Cal.	Quartzose volcanic	280	340
27	" "		" "	Volcanics		480
28	Fresh Volcanic Ash		Paricutin, Mex.	Volcanic ash	260	
29	Not available		Turrialba, Costa Rica	Weathered volcanics	2300	830
30	" "		Luzon, P. I.	Andesite tuff	340	75
31	" "		" " "	Volcanic tuff	480	210
32	" "		" " "	Volcanics		170
33	Iredell		Fairfax, Va	Diabase	1000	210
34	Mecklenburg		Leesburg, Va	"	400	400
35	Davidson		Bethesda, Md	Gabbro	2000	800

om "Performance of the SCR-625 Mine Detector over Different Rocks and Soils," by R. J. Roberts, E. Sampson, M. M. Striker, U. S. Geological Survey, and T. E. Stewart, USAERDL, 1949.

	No data	Menc :inee, Mich.	Limestone	No data	100	3	No data	No data
		Morgan, Ind.	"		102	2		
		Brown, Ohio	Sandstone		50	1		
		Limestone, Pa	Limestone		40	1		
		Lancaster, Pa	"		210	5		
		Washington, Md	"		140	3		
		Bedford, Tenn.	"		200	5		
		Roane, Tenn.	"		280	7		
		Jefferson, Tenn.	"		50	1		
		Hamblen, Tenn.	"		220	5		
		Bartow, Ga	"		260	4		
		Peach, Ga	"		200	3		
		Colbert, Ala.	"		400	6		
		Bernardsville, N. J.	Mica schist		90	3		
		Baltimore, Md	" "		140	3		
		Fairfax, Va	Sericite schist		50	1		
		Stoke, N. C.	Mica schist		4	0		
oil		Hollandia, New Guinea	Granitic arkose		150	1		
ist		Upper Amazon, Peru	Mica schist		15	0		
ist		Upper Amazon, Peru	" "		12	0		
		Chester, Pa	Greenstone		740	18		
		Fairfax, Va	Greenstone		680	16		
		Lake, Calif.	Serpentine rocks	1400	2500	32		
		Rosales, Puerto Rico	" "	710	3500	35		
		Hollandia, New Guinea	Altered serpentines	2000	8000	54		
		Lake, Cal.	Quartzose volcanic	280	340	5		
		" "	Volcanics		480	8		
		Paricutin, Mex.	Volcanic ash	260				
		Turrialba, Costa Rica	Weathered volcanics	2300	830	8		
		Luzon, P. I.	Andesite tuff	340	75	1		
		" " "	Volcanic tuff	480	210	2		
		" " "	Volcanics		170	2		
		Fairfax, Va	Diabase	1000	210	5		
		Leesburg, Va	"	400	400	10		
		Bethesda, Md	Gabbro	2000	800	20		

36	Davidson	No data	Chatham, N. C.	Mafic igneous	No data	540
37	"		Abbender, S. C.	" "		400
38	"		Lee, Ala.	" "		290
39	Soil over Glacial Till		Madison, Wis.	Glacial till		50
40	Soil over Igneous Terrace, Gravelly		Luzon, P. I.	Igneous gravel, terrace		340
41	Waverly		Prane, Ark.	Old alluvium		10
42	Bladen		McIntosh, Ga	" "		10
43	Myatt		Dallas, Tex.	" "		10
44	Red Bay		Hale, Ala.	" "		95
45	Ruston		Lincoln, La	" "		95
46	Crowley		Beauregard, La	" "		10
47	Kalmia		Lincoln, La	" "		12
48	Collington		Blackwood, N. J.	Glauconitic material		12
49	Orangeburg		Rustin, La	" "		450
50	Nagadoches		Garland, Tex.	" "		1530
51	Alluvium from Glacial Till		Cross Plains, Wis.	Poorly drained alluvium from glacial till		50
52	Poorly Drained Alluvium		Clarksville, Md	Mixed rock		36
53	Ocklocknee (alluvium)		Dallas, Tex.	Alluvium from coastal plain		60
54	Harris		Victoria, Tex.	Alluvium from coastal plain		10
55	Slowly Drained Alluvium		Marin, Cal.	Sedimentary and igneous		14
56	Gray Clayey Alluvium		" "	Serpentine and sediments		340
57	Gray Clayey Alluvium		" "	Quartz-bearing igneous		26
58	Cahaba (alluvium)		Beauregard, La	Coastal plain		18
59	Well-Drained Alluvium		Tingo Maria, Peru	Mixed rock		58
60	Alluvium		Chekiang Province, China			30
61	Fresh, Well-Drained Alluvium		Luzon, P. I.	Recent volcanics		340
62	Gravel and Sand in River		Luzon, P. I.	Diabase and andesite		800
63	Low, Well-Drained Levees		" " "	Mixed rock		710
64	High Levee, Intermediate Drained		" " "	" "		170
65	High Levee, Poorly Drained		" " "	" "		36
66	Wave Washed Fresh Beach Sand		" " "	No data		800
67	Well-Drained Loam Above Beach Sand		" " "			340
68	Poorly Drained Clay in Adjacent Shale		" " "			75

	No data	Chatham, N. C.	Mafic igneous	No data	540	13	No data	No data
		Abbender, S. C.	" "		400	7		
		Lee, Ala.	" "		290	5		
r Glacial Till		Madison, Wis.	Glacial till		50	1		
r Igneous Terrace,		Luzon, P. I.	Igneous gravel, terrace		340	3		
		Prane, Ark.	Old alluvium		10	0		
		McIntosh, Ga	" "		10	0		
		Dallas, Tex.	" "		10	0		
		Hale, Ala.	" "		95	2		
		Lincoln, La	" "		95	No data		
		Beauregard, La	" "		10			
		Lincoln, La	" "		12			
on		Blackwood, N. J.	Glauconitic material		12			
rg		Rustin, La	" "		450			
es		Garland, Tex.	" "		1530			
from Glacial Till		Cross Plains, Wis.	Poorly drained alluvium from glacial till		50			
ained Alluvium		Clarksville, Md	Mixed rock		36			
e (alluvium)		Dallas, Tex.	Alluvium from coastal plain		60			
		Victoria, Tex.	Alluvium from coastal plain		10			
ained Alluvium		Marin, Cal.	Sedimentary and igneous		14			
ey Alluvium		" "	Serpentine and sediments		340			
ey Alluvium		" "	Quartz-bearing igneous		26			
lluvium)		Beauregard, La	Coastal plain		18			
ned Alluvium		Tingo Maria, Peru	Mixed rock		58			
		Chekiang Province, China			30			
ll-Drained Alluvium		Luzon, P. I.	Recent volcanics		340			
d Sand in River		Luzon, P. I.	Diabase and andesite		800			
-Drained Levees		" " "	Mixed rock		710			
e, Intermediate Drained		" " "	" "		170			
e, Poorly Drained		" " "	" "		36			
ed Fresh Beach Sand		" " "	No data		800			
ned Loam Above d		" " "			340			
ained Clay in Shale		" " "			75			

69	Tide-Washed Fresh Beach Sediments	No data	Luzon, P. I.	No data		3280
	Data are taken from "Final Technical Report on SOIL MAGNETISM STUDIES," by John C. Cook, Southwest Research Institute,					
1	Monteola Gravelly Loam	RDZA	Bexar, Tex.	Limestone	0	-
2	San Saba Clay	"	" "	"	0	10
3	Crawford Clay	RDSH PRIE	" "	"	0	
4	Frio Silty Clay	RDSHCHSNT	" "	Quartzite	0	19
5	Uvalde Silty Clay Loam	" "	" "	Limestone	0	30
6	Crawford Clay	" PRIE	" "	"	0	115
7	Zapata Gravelly Loam	" "	" "	"	0	78
8	San Antonio Clay Loam	" CHSNT	" "	Sand		51
9	Louisville Silty Loam	RDZA	" "	Limestone	0	-
10	Austin Silty Clay Loam	RDZA	" "	"	5	79
11	Louisville Silty Clay Loam	RDSH PRIE	" "	"	0	69
12	Arelia Clay Loam	PRIE	" "	Limestone and flint	0	40
13	Duval Loamy Sand	RDSH CHSNT	" "	Sandstone	0	5
14	Goliad Fine Sandy Loam	" "	" "	"		210
15	Monteola Clay	RDZNA	" "	Limestone and flint	0	23
16	Medio Loamy Fine Sand	"	" "	Limestone and sandstone	0	30
17	Brackett Stony Clay Loam	RDSH BRN	Kinney, Tex.	Limestone and iron ore	0,110	55
18	Laredo Loamy Very Fine Sand	" "	Maverick, Tex.	Marl and chalk	0	184
19	Reagan Gravelly Loam	" "	" "	Limestone and felsites	0,430	87
20	Maverick Clay Loam	" "	" "	Limestone and chert	0	35
21	Reagan Gravelly Loam	" "	" "	Limestone and flint	0	165
22	Crystal Fine Sand	" "	Dimmit, Tex.	Sandstone	<10	10
23	Uvalde Silty Clay Loam	" "	" "	Limestone	0	30
24	Frio Clay Loam	RDSH CHSNT	Uvalde, Tex.	"	0	35
25	Wabash Clay	RDSH CHSNT	Wilson, Tex.	Unconsolidated sediments		25
26	Orelia Fine Sandy Loam	RZNA	Bee, Tex.	" "		10
27	Trinity Clay	ALUV	Victoria, Tex.	" "	0	10
28	Lake Charles Clay	SHMIBOG	" "	Marine clay	<5	5
29	Miller Clay	"	Matagordo, Tex.	Limestone	0	5
30	Crocket Fine Sandy Loam	YEL PDZIC	Washington, Tex.	Sandstone	<10	10
31	Lufkin Fine Sandy Loam	" "	" "	"	<15	15
32	Denton Stony Clay	RZNA	Williamson, Tex.	Limestone	0	340

No data	Luzon, P. I.	No data		3280	No data	No data	No data	
l Report on SOIL MAGNETISM STUDIES," by John C. Cook, Southwest Research Institute, Contract No. DA-44-009-ENG-3646, 1960.								
DZA	Bexar, Tex.	Limestone	0	-	0	1	(?)	
"	" "	"	0	10	(1)	1	0	
DSH PRIE	" "	"	0					
DSHCHSNT	" "	Quartzite	0	19	0	1,-1/2	(?)	
" "	" "	Limestone	0	30	0	3	3	
" PRIE	" "	"	0	115	3	7	1	
" "	" "	"	0	78	3	9	3	
" CHSNT	" "	Sand		51	1	6	(3)	
DZA	" "	Limestone	0	-	-	-	2	
DZA	" "	"	5	79	2	8	-	
DSH PRIE	" "	"	0	69	5	19	2	
RIE	" "	Limestone and flint	0	40	(1)	71/2	4	
DSH CHSNT	" "	Sandstone	0	5	0	(2)	(4)	
" "	" "	"		210	2	(19)	3	Sandstone, well rounded, K is 1,800.
DZNA	" "	Limestone and flint	0	23	(1)	4	2	
"	" "	Limestone and sandstone	0	30	(3)	(3)	(4)	
DSH BRN	Kinney, Tex.	Limestone and iron ore	0,110	55	3	5	3	
"	Maverick, Tex.	Marl and chalk	0	184	4	16	3	
"	" "	Limestone and felsites	0,430	87	?	(25)	(?)	
"	" "	Limestone and chert	0	35	0	1	2	
"	" "	Limestone and flint	0	165	4	10	3	
"	Dimmit, Tex.	Sandstone	<10	10	0	1	(2)	
"	" "	Limestone	0	30	(1)	6	2	
SH CHSNT	Uvalde, Tex.	"	0	35	2	5	1	
SH CHSNT	Wilson, Tex.	Unconsolidated sediments		25	1	7	4	Iron pellets, susceptibility of 54,000
NA	Bee, Tex.	" "		10	(1)	3	1	Steel, susceptibility of 460,000
UV	Victoria, Tex.	" "	0	10	0	(1)	3	
MIBOG	" "	Marine clay	<5	5	0	(0)	1	
"	Matagordo, Tex.	Limestone	0	5	0	(0)	2	
L PDZIC	Washington, Tex.	Sandstone	<10	10	0	(1)	3	
"	" "	"	<15	15	0	(2)	2	
NA	Williamson, Tex.	Limestone	0	340	5	45	4	

2

33	E. Beach Sand	SAND	Galveston, Tex.	Marine sand	0	0	
34	Tidal Marsh	MARSH	" "	" "	0	0	
35	Galveston Fine Sand	SAND	" "	" "		10	
36	Harris Fine Sand	"	" "	" "		5	
37	W. Beach Sand	"	" "	" "	0?	5	(
38	Acadia Clay	SEMIBOG	" "	Marine clay	0?	5	(
39	Lake Charles Very Fine Sandy Loam	"	" "	" "	0?	5	(
40	Reagan Gravelly Loam	RDSH BRN	Brewster, Tex.	Chert and shale	11	82	1
41	Verhalen Gravelly Loam	" "	" "	" " "	approx 10 (?)	80	8
42	Ector Stony Loam	RED DES	" "	Rhyolite	220,200,175	105	
43	Brewster Stony Loam	RDSH BRN	" "	"	200,200,234	330	5
44	Rough Stony Land	LTHSL	" "	"	350	320	(
45	Verhalen Clay Loam	RDSH BRN	" "	"	350	340	(
46	Toyah Undifferentiated	" "	" "	Diorite	1410	520	5
47	Reagan Silty	" "	" "	Rhyolite	220	384	7
48	Rough Stony	RED DES	" "	Diorite	820,900,960	356	(
49	Reagan Silty Clay Loam	RDSH BRN	Jeff Davis, Tex.	Rhyolite	250	180	1
50	Verhalen Clay	" "	" " "	"	420,380,175	250	1
51	Reeves Fine Sandy Loam	RED DES	Culbertson, Tex.	Metamorphics	60,75,40	115	5
52	Reeves Gravelly Loam	" "	Hudspeth, Tex.	Felsites		88	8
53	Reeves Silty Clay Loam	" "	" "	Limestone	5	100	7
54	Gila Silt Loam	ALUV	El Paso, Tex.	Alluvium		88	5
55	Anthony Clay Loam	RED DES	" " "	"		175	7
56	Reeves Fine Sand	SAND	El Paso, Tex.	Wind-blown sand		200	6
57	Gypsum; Playa	SLNTZ	Hudspeth, Tex.	Gypsum	<10	15	1
58	Peat	BOG	Chaves, N. Mex.	Peat	<10	15	1
59	Reeves Chalk	DESERT	" " "	Gypsum	"	115	17
60	Springer Loam	RED DES	Lea, N. Mex.	Limestone	0	20	3
61	Scab Loam	LTHSL	" " "	"	0	50	4
62	Windhorst Gravelly Loam	YEL PDZLC	Brown, Tex.	Sandstone		42	(1
63	Valera Silty Clay	RDSH PRIR	" "	Limestone	0	115	8
64	Nimrod Fine Sand	YEL PDZLC	" "	Sandstone	(10)	16	2

[redacted]

SAND	Galveston, Tex.	Marine sand	0	0	0	(0)	0	
MARSH	" "	" "	0	0	0	(0)	(?)	
SAND	" "	" "		10	1/2	(1)	4	
"	" "	" "		5	0	(0)	(1)	
"	" "	" "	0?	5	0	(0)	(2)	
SEMIBOG	" "	Marine clay	0?	5	0	(0)	(1)	
"	" "	" "	0?	5	0	(0)	(1)	
RDSH BRN	Brewster, Tex.	Chert and shale	11	82	17	21	1	
" "	" "	" " "	approx 10 (?)	80	8	9	1	
RED DES	" "	Rhyolite	220,200,175	105	(5)	20	3	
RDSH BRN	" "	"	200,200,234	330	50	60	2	
LTHSL	" "	"	350	320	(50)	600	4	
RDSH BRN	" "	"	350	340	(30)	(30)	4	
" "	" "	Diorite	1410	520	50	100	1	
" "	" "	Rhyolite	220	384	70	80	1	Basic melts, K of 2,000 and 1,200
RED DES	" "	Diorite	820,900,960	356	(60)	(100)	5	Another piece of diorite showed K of 1,950
RDSH BRN	Jeff Davis, Tex.	Rhyolite	250	180	18	33	1	
" "	" " "	"	420,380,175	250	18	35	4	
RED DES	Culbertson, Tex.	Metamorphics	60,75,40	115	5	17	2	
" "	Hudspeth, Tex.	Felsites		88	8	25	3	
" "	" "	Limestone	5	100	7	15	3	
ALUV	El Paso, Tex.	Alluvium		88	5	15	6	Basalt K of 14,000; diorite K of 220 and 410
RED DES	" " "	"		175	7	15	4	Phosphate rock K of 760; basic igneous K of 3,200 and 3,300.
SAND	El Paso, Tex.	Wind-blown sand		200	6	13	1	
SLNTZ	Hudspeth, Tex.	Gypsum	<10	15	1	4	2	
BOG	Chaves, N. Mex.	Peat	<10	15	1	3	1	
DESERT	" " "	Gypsum	"	115	17	20	1	
RED DES	Lea, N. Mex.	Limestone	0	20	3	9	2	
LTHSL	" " "	"	0	50	4	8	4	
EL PDZIC	Brown, Tex.	Sandstone		42	(10)	(10)	5	
RDSH PRIE	" "	Limestone	0	115	8	(25)	3	
EL PDZIC	" "	Sandstone	(10)	16	2	5	3	

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65	Bastrop Fine Sandy Loam	RDSH CHSNT	Taylor. Tex.	Limestone	0	30
66	Simmons Clay	" "	" "	Limestone and sandstone	0	35
67	Vernon Very Fine Sandy Loam	" "	Nolan, Tex.	Sandstone		50
68	Roscoe Clay	" "	" "	Limestone	0	45
69	Richfield Fine Sandy Loam	BRN	Midland, Tex.	Wind-blown sand		38
70	Dune Sands	SAND	Ward, Tex.	Wind-blown sand	(0)	2
71	Amarillo Fine Sandy Loam	RDSH CHSNT	Lubbock, Tex.	Sandstone		45
72	Clovis Fine Sandy Loam	" "	Curry, N. Mex.	"		88
73	Tivoli A-P Complex	SAND	" " "	"		80
74	(Alpine Plateau)	BRN	Jeff, Colo.	Basalt	2500	2220
75	Larimer Gravelly Loam	"	" "	Quartzite	21	93
76	Fort Collins Loam	"	" "	Basalt	7200	1080
77	Greely Silty Clay Loam	"	" "	Granite		330
78	Larimer Gravelly Loam	"	" "	Basalt	8900	83
79	(Alpine Valley)	WSNBDN	Clear Creek, Colo.	Granite	5	17
80	Dune Sand	SAND	Hayes, Neb.	Wind-blown sand		75
81	Keith Silty Loam	CHSNT	" "	Loess		126
82	Rosebud Sandy Loam	"	Hitchcock, Neb.	Sandstone		91
83	Holdredge Sandy Loam	CHNZM	Furnas, Neb.	Loess		61
84	Hall Silty Loam	"	" "	Unconsolidated Sediments		103
85	Hayes Loamy Fine Sand	"	Ford, Kan.	Loess		75
86	Renfro Silty Loam	RDSH PRIE	Kingman, Kan.	Sandstone		14
87	Norfolk Fine Sand	YEL PDZLC	Van Zandt, Tex.	"	20	47
88	Nevada Silty Clay Loam	" "	Nevada, Ark.	Alluvium	[redacted]	4
89	Eldon Cherty Silty Loam	RDSH PRIE	Jasper, Mo.	Cherty limestone	[redacted]	80
90	Putnam Very Fine Sandy Loam	PLNSL	Madison, Ill.	Alluvium	[redacted]	5
91	Carrington Loam	PRIE	Sangamon, Ill.	Alluvium	[redacted]	47
92	Clinton Loamy Clay	GB PDZLC	Peoria, Ill.	Basalt	[redacted]	48
93	Boone Fine Sand	PRIE	Monroe, Wis.	Sandstone	[redacted]	37
94	La Crosse Sandy Loam	"	" "	"		11
95	Clarion Loam	"	Hennepin, Minn.	Glacial unconsolidated sediments		25
96	Hayden Loam	PDZLC	" "	Glacial unconsolidated sediments		97
97	Onamia Very Fine Sandy Loam	PDZL	Pine, Minn.	Igneous till	1300	190
98	Askan Fine Sandy Loam	"	" "	" "	2000	115

SNT	Taylor. Tex.	Limestone	0	30	(2)	9	4	
'	" "	Limestone and sandstone	0	35	2	11	2	
'	Nolan, Tex.	Sandstone		50	7	10	1	
'	" "	Limestone	0	45	11	17	1	
	Midland, Tex.	Wind-blown sand		38	6	13	1	
	Ward, Tex.	Wind-blown sand	(0)	2				
NT	Lubbock, Tex.	Sandstone		45	4	27	1	
	Curry, N. Mex.	"		88	10	22	1	
	" " "	"		80	2	5	1	
	Jeff, Colo.	Basalt	2500	2220	(100)	(150)	2	
	" "	Quartzite	21	93	7	20	6	
	" "	Basalt	7200	1080	60	240	2	
	" "	Granite		330	6	32	2	
	" "	Basalt	8900	83	2	20	5	
	Clear Creek, Colo.	Granite	5	17	(1/2)	(1)	5	
	Hayes, Neb.	Wind-blown sand		75	5	20	3	
	" "	Loess		126	7	30	3	
	Hitchcock, Neb.	Sandstone		91	8	20	1	
	Furnas, Neb.	Loess		61	5	13	3	
	" "	Unconsolidated Sediments		103	(4)	13	6	
	Ford, Kan.	Loess		75	5	12	2	
:	Kingman, Kan.	Sandstone		14	(1)	15	2	
:	Van Zandt, Tex.	"	20	47	(0)	-5	5	
	Nevada, Ark.	Alluvium		4	0	0	4	
:	Jasper, Mo.	Cherty limestone		80	-10	-30	5	
	Madison, Ill.	Alluvium		5	(-3)	(-2)	5	
	Sangamon, Ill.	Alluvium		47	-1	-13	3	
	Peoria, Ill.	Basalt	5000	48	-3	-4	4	Also K of 8000 and 1800
	Monroe, Wis.	Sandstone		37	-1	-3	3	
	" "	"		11	(-1/2)	-2	3	
	Hennepin, Minn.	Glacial unconsolidated sediments		25	-3	-7	0	
	" "	Glacial unconsolidated sediments		97	-8	-17	0	
	Pine, Minn.	Igneous till	1300	190	-5	-23	2	
	" "	" "	2000	115	-10	-55	4	

99	Hermon	"	St. Louis, Minn.	Basic igneous	4000	350
100	Ore dust (hematite)		" " "	Iron ore	1300	630
101	Ontonagon Sand	SAND	" " "	Metamorphic	1000	65
102	Hermon Rocky Sand	PDZL	" " "	Glacial diorite	5000	600
103	Fargo Clay	CHNZM	Cass, N. D.	Organic sediments		10
104	Greenville Loamy Sand	RED PDZIC	Decatur, Ga	Quartzite	5	16
105	Barnes Loam	CHNZM	Cass, N. D.	Sandstone	2	45
106	Otero Sand	BRN	Yellowstone, Mont.	"		12
107	Manhattan Very Fine Sandy Loam	"	Gallitin, Mont.	Igneous ash	5000	320
108	Peat	GRYBRNPDZL	Bonner, Idaho	Peat		<5
109	Bonner Silty Loam	"	" "	Glacial drift	5	175
110	Winchester Sands	NORGRYDES	Grant, Wash.	Basalt	3000	460
111	Ephrata Sandy Loam	"	" "	Basalt and glacial drift	340,328,	500
112	Naches Fine Sand	BRN	Kittitas, Wash.	Basalt and sediments	1500,440	340
113	Swank Loam	GRYBRNPRIE	" "	Basic rocks and glacial drift	1700,3000	390
114	Loam	GRYBRNPDZIC	Yakima, Wash.	Gabbro	2500,5500	1060
115	Loam	BRNPDZIC	Lewis, Wash.	"	1400,1050	390
116	Scab Land on Basalt Flow	LTHSL	Columbia, Ore.	Basalt	1650	525
117	Clatsop Beach Sand	SAND	Clatsop, Ore.	"	900	330
118	Loamy Sand	GYBRNPDZIC	Columbia, Ore.	Clay	2	110
119	Jordan Silty Loam	GRY DES	Elko, Nev.	Limestone	<5	118
120	Jacksonville Beach Sand	SAND	St. Johns, Fla		<1	<1
121	Coral Beach Sand	"	Monroe, Fla	Marine sediments	<1	<1
122	Rockdale Stony Loam	LTHSOL	" "	Coral limestone	80,100,15	<5
123	Leon Sand (dark phase)	SAND	Collier, Fla	Marl	<3	<1
124	Leon Sand (light phase)	"	Lee, Fla	"	5	<1

(a) Susceptibilities listed under parent rock are not always the true parent materials but sometimes are just material picked up at the test site.

(b) The magnetic effect produced by the small box is usually that value measured at the test site. However, when field data were lacking, the calculated theoretical maximum mine signal for that soil susceptibility was used. The small box volume is 50 cubic inches. The large box is approximately 600 cubic inches.

(c) Parentheses indicate approximations by the authors.

[redacted]

"	St. Louis, Minn.	Basic igneous	4000	350	?	(-220)	4	Also K of 3500 and 5000
	" " "	Iron ore	1300	630	800	1300	0	Also K of 1600 and 150
SAND	" " "	Metamorphic	1000	65	-31	-125	1	Also K of 1000 and 500
PDZL	" " "	Glacial diorite	5000	600	(-25)	-22	2	Also K of 5000 and 4400
CHNZM	Cass, N. D.	Organic sediments		10	(-1)	-2	0	
RED PDZIC	Decatur, Ga	Quartzite	5	16	?	2	7	
CHNZM	Cass, N. D.	Sandstone	2	45	-2	-8	0	
BRN	Yellowstone, Mont.	"		12				
"	Gallitin, Mont.	Igneous ash	5000	320	10	35	4	Also K of 6000
GRYBRNPDZL	Bonner, Idaho	Peat		<5	0	0	(3)	
"	" "	Glacial drift	5	175	3	35	3	
NORGRYDES	Grant, Wash.	Basalt	3000	460	45	60	0	
"	" "	Basalt and glacial drift	340,328,	500	50	(150)	3	Also K of 300 and 525 in parent rock
BRN	Kittitas, Wash.	Basalt and sediments	1500,440	340	(0)	80	4	Also K of 1320
GRYBRNPRIE	" "	Basic rocks and glacial drift	1700,3000	390	25	80	2	Also K of 600
GRYBRNPDZIC	Yakima, Wash.	Gabbro	2500,5500	1060	50	225	2	Also K of 5000 in parent material
BRNPDZIC	Lewis, Wash.	"	1400,1050	390		20	4	Also K of 920 in parent material
LTHSL	Columbia, Ore.	Dasalt	1650	525		100	4	K of 390 in weathered material, 188 in shale
SAND	Clatsop, Ore.	"	900	330	20	30	0	
GYBRNPDZIC	Columbia, Ore.	Clay	2	110	3	25	2	
GRY DES	Elko, Nev.	Limestone	<5	118	5	30	2	
SAND	St. Johns, Fla		<1	<1	0	0	?	
"	Monroe, Fla	Marine sediments	<1	<1	0	0	(4)	
LTHSOL	" "	Coral limestone	80,100,15	<5	(8)	(4)	5	Also 350, magnetite in coral
SAND	Collier, Fla	Marl	<3	<1	0	0	?	
"	Lee, Fla	"	5	<1	0	0	?	

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Category 4 - Electrical Equipment

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TITLE World-Wide Feasibility of a Passive Magnetic Method of Detecting Buried Nonmetallic Land Mines

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Report 1683-RR, 31 Jul 61, 48 pp, 5 tables, 10 illus
DA Task 8F07-11-001-01 Unclassified Report

Report covers an investigation to determine the world-wide feasibility of a passive magnetic method for detection of nonmetallic land mines. The work included ascertaining the natural restrictions imposed upon a passive magnetic detector system by the magnetic properties of soil containing buried mines. The report concludes that: (a) Use of a passive magnetic mine detection system as a sole means of detection is not feasible because the detection principle is not practicable in 74 percent of the world's land surface: In 12 percent because of insufficient mine-soil susceptibility contrast alone; in 40 percent because of excessive magnetic anomalous (false) signal effects alone; and in 22 percent because of both insufficient contrast and excessive anomalies. (b) More sensitive instrumentation will not improve the world-wide feasibility of passive magnetic mine detection systems because severe restrictions are imposed on the use of passive magnetic phenomenon by natural magnetic soil properties and not by inadequate instrument sensitivity.

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