An Introduction to Application of Magnetometer for the Subsurface Exploration

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Abstract

Magnetometer is one of the geophysical instruments which play a vital role for the subsurface exploration. Magnetometer, model G- 859AP, is use for the subsurface mapping, locating the ore body, water depth and potential based on their different reflection signal wave and anomaly. The two type of measuring style include line scan and grid scan which can be operated by the magnetometer and mark the signal which is attached on the waist of the conductor. It is very useful for the mineral and petroleum exploration, geological mapping, search for buried or sunken objects, magnetic field mapping, geophysical research, magnetic observatory use, measurement of magnetic properties of rocks or ferromagnetic objects, paleomagnetism, archaeological prospecting, conductivity mapping, gradiometer surveying, and magnetic modeling. The terminology, units of measurement, and assumed prerequisite knowledge are those employed in the field of geology and geophysics. The direction of the field is vertical at the north and south magnetic poles, and horizontal at the magnetic equator. An understanding of this geometry is important with respect to interpretation of magnetic anomalies. A knowledge and experience will allows rapid and easy interpretation of anomalies of interest when numerous anomalies arising from various depths appear in the observed total intensity profile. Geological anomalies are interpreted in terms of much simplified geological models which very much facilitate interpretation procedures. Magnetization is uniform within some elementary prismatic form and that the magnetization is different outside this form, i.e., there is a magnetization contrast. A magnetometer, particularly one with higher sensitivity, i.e., 0.25 gamma, can be used for such a conductivity survey, rapidly, without orientation restrictions and without requiring contact with the ground surface. The marked data and measured array of the survey can be manipulated and calculated by the processing software “MagMap” and “MagPick”. Basically, different anomaly is due to different density of the measured materials and which can be interpreted as different layer of bed rock or different materials or water level etc.

Keywords: Magnetometer, anomaly, ferromagnetic, paleomagnetism, magnetization

Introduction

The secular variation which is formed by the earth’s internal or main field changes slowly over tens or thousands of years. The location of poles, inclination and intensity of the earth varies slowly through geologic history. Moreover, the field has reversed and it is very important to handle and apply to the Magnetometer.

Magnetic Minerals and Types of Magnetization

The application of magnetometers is the identification and description of spatial changes in the earth’s field. The anomalies that measured by the magnetometer and mapped for the applications might occur over several feet or several thousands of feet and are caused by an anomalous distribution of magnetic minerals or by iron objects or some man made materials. The naturally occurred magnetic minerals such as magnetite ($Fe\ Fe_2O_3$) or its related minerals, ulvospinel, titanomagnetite, maghemite, etc. are generally regarded as magnetite and which shows magnetic anomalies. Most of the rocks contain some magnetite vary from very small fractions of a percent up to several percent, and may contain several tens of percent, for example, magnetic iron ore deposits.

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Therefore, the distribution of magnetite or its magnetic properties can be utilized in exploration or mapping. In the earth's magnetic field, iron objects, whether something unearth or intentionally embedded for subsequent retrieval, would also create a detectable magnetic anomaly. Moreover, some cultural features associated with human activity can commonly be detected through magnetic surveys.

Induced Magnetization

There are two different kinds of magnetic anomalies namely; induced and remanent (permanent) magnetization in the earth's magnetic field. Induced magnetization mentions to the action of the field on the material wherein the ambient field is enhanced and the material itself acts as a magnet. The magnetization of such material is directly proportional to the intensity of the ambient field and to the ability of the material to enhance the local field- a property called magnetic susceptibility. The induced magnetization is equal to the product of the volume magnetic susceptibility, k, and the earth's or ambient field intensity, F, or

$$I_i = kF$$

where Ii is the induced magnetization per unit volume in cgs electromagnetic units, and F is the field intensity in gauss. (Note: in some texts, the specific magnetic susceptibility or susceptibility per unit weight (gram) is used). For most materials, k is much less than 1 and, in fact, is usually $\pm 10^{-6}$cgs or smaller. If k is small and positive, the material is said to be paramagnetic and, when negative, diamagnetic. For magnetite, *k is approximately* 0.3 cgs and is ferrimagnetic while for iron alloys, k may vary between 1 and 1,000,000 and such materials are called ferromagnetic. Both ferrimagnetic and ferromagnetic susceptibility are also a function of the field intensity in which they are measured.

A parameter similar to k is the magnetic permeability, cc, which is the ratio of the magnetic induction, B, to the field intensity, F (Magnetic induction is the magnetization induced in the material). B includes not only the magnetization of the material, but also the effect of the field itself and is expressed by

$$B = F + 4\pi$$

where B is in gauss. Therefore as stated above,

and $$\mu = \frac{B}{F}$$

$$M = 1 + 4\pi k$$

Thus when k is very small, as in air, $\mu \approx I$ and when k is 0.1 or larger μ is generally one order of magnitude larger. The susceptibility k can be thought of as the absolute ability and μ the relative ability of a material to create local magnetization. The measurement of permeability is most often used for materials where μ is much greater than 1, typically iron, steel and other ferromagnetic alloys.

Magnetite and its distribution is of such great importance for a number of these applications, it is important to understand its relation to common rock types. The susceptibility k of magnetite was given as approximately 0.3 cgs which may actually vary between 0.1 and 1.0 depending upon its grain size and other properties. The magnetic susceptibility of a rock is simply related to the amount of magnetite it contains in the rock. For example, rock containing 7% magnetite will have a volume susceptibility of 3×10^{-3} cgs, etc.

Typically, dark, more basic igneous rocks possess a higher susceptibility than the acid igneous rocks and the latter, in turn, higher than sedimentary rocks.

Remanent or Permanent Magnetization

The remanent (ascribed to rocks) or permanent magnetization (to metals), I, is often the predominant magnetization (relative to the induced magnetization) in many igneous rocks and iron alloys. Permanent magnetization depends upon the metallurgical properties and the thermal, mechanical and magnetic history of the specimen, and is independent of the field in which it is measured. Magnetite may have a remanent magnetization, I_r, of perhaps 0.1 to 1.0 gauss, ordinary iron may have a permanent magnetization between 1 and 10, and a permanent magnet may be between 100 and 1,000 gauss or larger.

Geometric Geometer

In recent years, portable magnetometers are very usefully for exploring the materials which are buried, immersed, or otherwise hidden from view. A magnetic object can be found directly or where it may displace material which is otherwise uniformly magnetic. An object may be found indirectly when it produces a magnetic anomaly as a consequence of it being buried or emplaced. This research work is mainly based on the training and workshop of the Geometric Geometer (Model G- 859AP) (Fig. 1.a-d) at the San Joes City, Geometric Inc. Research Centre, USA and the usefulness of Geometric Geometer are discussed in detailed. In this regards, magnetometers are used for the locating and searching man-made iron or steel object, archaeological features, and geological mapping and subsurface exploration, relocation and exploration purposes. In fact, magnetometers have been used for searching: the buried materials which show direct and indirect magnetic properties in Archaeological studies and also for the exploration and geological mapping. In these cases, the objects could be search and estimated their depth and mass estimated if the conditions are favorable to magnetic properties and anomalies.

The techniques primarily for portable magnetometer are usually applicable on land but some diverse techniques such as marine exploration techniques involve other specific tactics, magnetometer sensors and cables designed for underwater use, and continuous recording displays.

Determination of Object Magnetism

It is important that it must first be determined whether the object (direct or indirect) of the search is truly magnetic or not. Iron and steel are the only metals which are ferromagnetic and, among these, stainless steel (300 series) can usually be considered non-magnetic. All naturally-occurring rocks and soils are weakly magnetic as a consequence of the amount of naturally-occurring magnetite present. Moreover, when such materials are heated, they attain a much higher magnetism upon cooling from a high temperature as would occur naturally in igneous rocks or artificially in kiln-baked clay. Magnets and coils carrying direct current are also detectable with a magnetometer. Buried chambers, tombs, some caverns, lava tubes and other subsurface voids are also detectable if they occur at a shallow depth in an otherwise uniformly magnetic material.

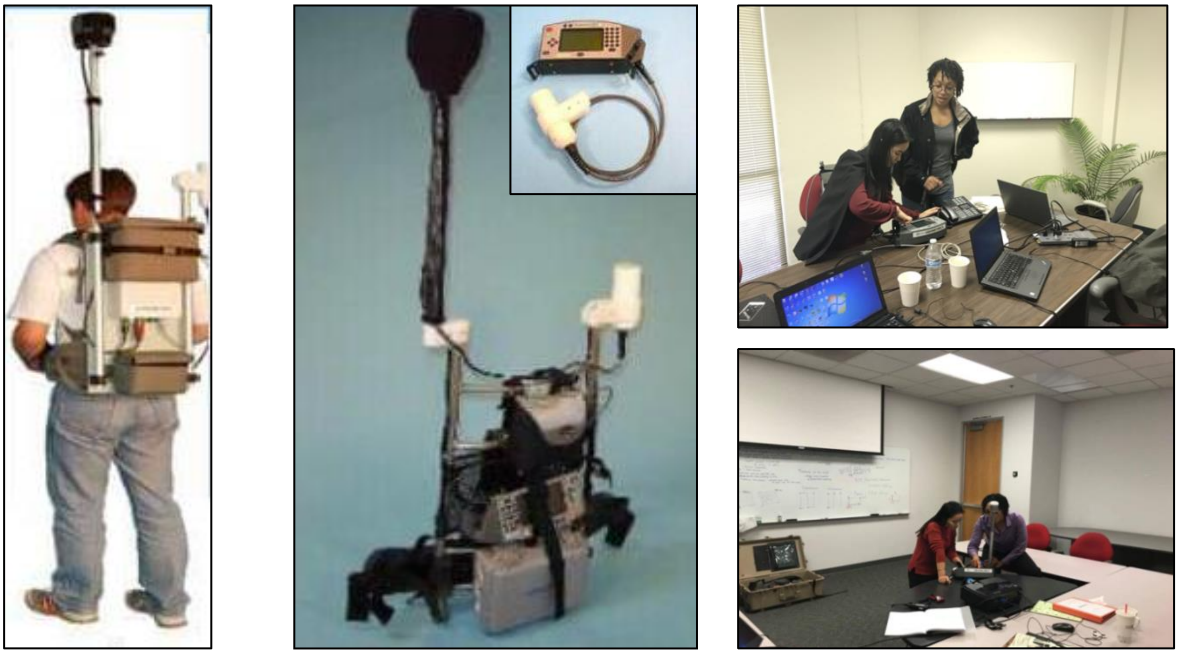

Figure (1). (a), (b), (c) & (d) Geometric Geometer (Model G- 859AP) and training

Detectability

The most important single factor affecting detectability with a magnetometer is the distance between the magnetometer and the object; for, most anomalies in a search vary inversely as the cube of this distance, i.e., $T = M/r3$. Thus, any effort made towards reducing this distance greatly increases the likelihood and one's ability in finding the object of search. The next most important consideration is the amount of ferromagnetic material associated with the object in contrast with the surrounding material. The effective magnetic mass (magnetic moment) of the object can be considered to be the degree of magnetism of the material times the volume of such material (e.g., a small magnet can be as magnetic as an automobile or a very large cavern).

Magnetic Anomaly Signatures

The typical object of search is relatively small with respect to the distance between it and the magnetometer. Irrespective of its shape, the object would then behave as a magnetic dipole. Typical dipole anomaly signatures (anomalies) expressed as profiles and contour maps at various orientations of the magnetic moment of the object and at various inclinations of the field. The anomaly shape expressed primarily a function of the magnetic latitude and the direction of the permanent (remanent) magnetic moment. For example, given a magnetic profile or map over any dipole and some familiarity with total field magnetics one should be able to recognize the inclination of the field and perhaps also the orientation of the object as a dipole.

Depth/Amplitude Behavior

The anomaly will appear broader proportionately as the object is deeper or more distant (NOTE: the object is not always beneath a given traverse, but more than likely is at a distance to one side of the traverse). The distance between magnetometer and object herein referred to as depth may, in fact, only represent the 'closest approach' requiring perhaps another traverse to be truly 'over' the object). This anomaly width/depth characteristic of magnetic anomaly behavior serves as a means for determining the depth to the source which can be used to one's advantage in a search. The amplitude of the anomaly will, as stated, also decrease inversely as the cube of this distance. An example of anomaly depth and amplitude behavior is shown in (Fig. 2 a-c and Fig. 3) which can be extrapolated to the other signatures.

Magnetic Markers

It is often of interest to be able to relocate oneself or an object over a long period of time. The purpose may be to locate a survey benchmark, an important junction in a pipeline, or a point in shallow marine waters. In some cases, it may be reasonable to bury several magnets oriented to produce maxima or minima or in a pattern to assure easy relocation or to differentiate one magnetic marker from another. Given a specialized requirement, a solenoid coil or single long wire with an applied direct current may also serve such a relocation purpose.

Software and Procedure

The terminology, units of measurement, and prerequisite knowledge are those employed in the field of geology and geophysics. The direction of the field is vertical at the north and south magnetic poles, and horizontal at the magnetic equator. A knowledge and experience will allows rapid and easy interpretation of anomalies of interest when numerous anomalies arising from various depths appear in the observed total intensity profile. Geological anomalies are interpreted in terms of much simplified geological models which very much facilitate interpretation procedures (Figs. 4 & 5).

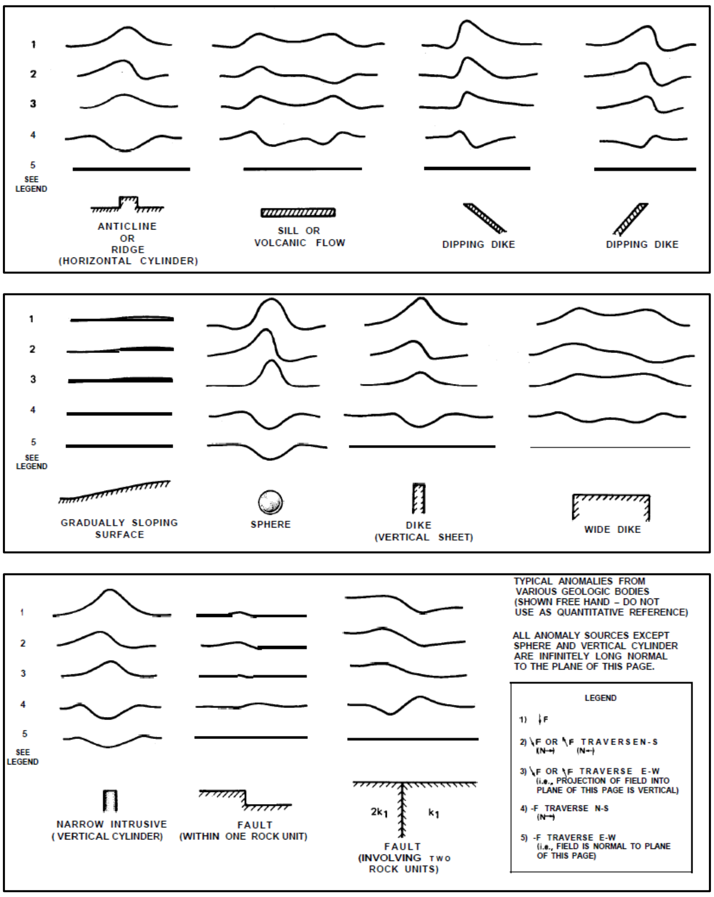

Figure (2). (a), (b) & (c) Anomalies for Geologic bodies at various orientation and different inclinations of the field (after Breiner, 1999).

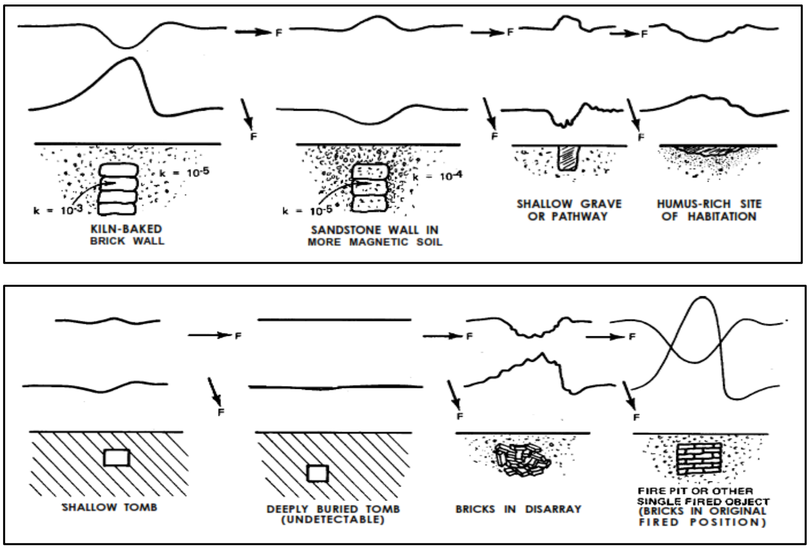

Figure (3). Typical Magnetic Anomalies of Common Archaeological Features (after Breiner, 1999).

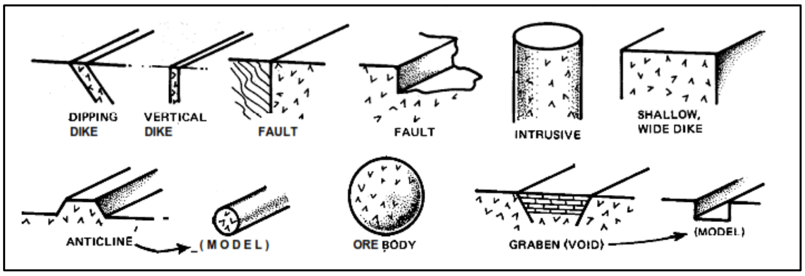

Figure (4). Geological model Representation of common rock forming minerals (after Breiner, 1999).

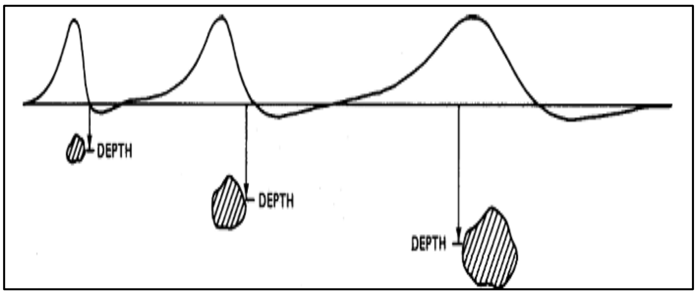

Figure (5). Affect of depth on Anomaly width (Breiner, 1999)

Magnetization

Magnetization is uniform within some elementary prismatic form and that the magnetization is different outside this form, i.e., there is a magnetization contrast. A magnetometer, particularly one with higher sensitivity, i.e., 0.25 gamma, can be used for such a conductivity survey, rapidly, without orientation restrictions and without requiring contact with the ground surface. The marked data and measured array of the survey can be manipulated and calculated by the processing software “MagMap” and “MagPick”.

MagMap

MagMap is a software that can generated and plotted the measured data with the Magnetic Magnetometer (Model-G- 859AP). It can be used to import the data by G-859/ASCII, G-859, G-856 and RBS data. The downloading procedure is shown in (Fig. 6. a to w). Firstly, turn on G-859, and Select data transfer Menu and press enter. Then select PC controlled transfer and pressed enter and then click “ok”.

The measuring procedure can be regarded as line scan and grid scan. The grid can be classified as Shit Grid, Reserve Grid, Rotate Grid and Grid Setting. The measured data can be plotted as Mag Field, Mag Field in 2D in Colours, Mag Field in 3D surface and Stack Profile on Top of Map. The grid interval can be set up as 5, 10, 15 or 20 etc. The measured data ae potted by using the Magmap software for analyzing the subsurface profile. The plotted data can be set up by the Sensors that the measurement taken up with the measured GPS coordinates.

In the GPS tab, new map using GPS data and the feature of a regular 85.8 survey and Mag.og NT survey can be created. These measured data set can be plotted on the appropriate coordinate and it can be filtered by using the filter tab. Then the interval for contour is selected and the anomaly map for plotting Magnetic field with 2D contour for measured data with each sensor. The created contours map can be exported as “dat” format for further manipulation process.

Application

Archaeological Exploration

In archaeological sites, magnetometers is essential for exploration especially for detecting the features such as buried walls and structures, pottery, bricks, roof tiles, and numerous objects submerged in water such as ships, ballast stones, iron, cannon, amphora, various potsherds, etc. Most of these objects were detected and mapped by using their magnetic that can use to compare the surrounding or covering material. Some few features such as certain buried walls and tombs were not, themselves, magnetic, but displaced a uniformly magnetic soil which presently covers them. Some historical and archaeological sites have iron objects which are easily detectable with magnetometer for their exploration.

Geological Mapping and Exploration

The last significant criterion for detectability is the expected background magnetic noise arising from such sources as geology or man-made materials and electric current. In general, volcanic or dark-colored igneous rocks and soils derived from such rocks are very magnetic and difficult to detect a small, subtle anomaly. Some common artificial features produces sources of noise include power lines, direct current electric cables and trains, iron and steel debris and major cultural features including buildings, roads, fences, pipelines, reinforcing steel in concrete, etc. Most sedimentary rocks: sandstone, shale, limestone, and their metamorphic equivalents, salt or fresh water or air do not alter the magnetic anomaly in any way; it is then simply the distance between the sensor and object that is important when buried in such materials. Therefore, magnetic anomalies that had been measured by the Magnetometer can be used to manipulate for the subsurface geological mapping, rock differentiation and ore and mineral exploration.

Basically, different anomaly is due to different density of the measured materials and which can be interpreted as different layer of bed rock or different materials or water level etc.

Figure (6). (a), (b), (c), (d), (e), (f), (g), (h), (i), (j), (k), (l), (m), (n), (o), (p), (q), (r), (s), (t), (u), (v) & (w) Step by step procedures for the MagMap software

Conclusion

In recent years, magnetometers play a vital role for the geological mapping, mineral and ore exploration and subsurface mining. Moreover, it is also applicable to the exploration of archaeological sites and buried materials underneath. The application of Geometric Geometer is mainly based on the knowledge that had been obtained from the Workshop and training from Geometric Inc, San Joes City, USA. In August, 2018 which is useful for not only in teaching but also in the research works that will be conducted by the future generation.

Acknowledgements

I would like to express my sincere thanks to Professor and Head, Dr Day Wa Aung and Prof Dr Htay Lwin from the Department of Geology, University of Yangon for their kind permission. U Nyi Nyi Minn, Managing Director, Amigos International Co. Ltd. is also acknowledged for his kind support.

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