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LaGeo
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GRAVITY AND MAGNETIC METHODS

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ABSTRACT

Gravity and magnetic exploration, also referred to "potential fields" exploration is used to give geoscientists an indirect way to "see" beneath the Earth's surface by sensing physical properties of rocks (density and magnetization, respectively). Gravity and magnetic exploration can help locate minerals, faults, geothermal or petroleum resources, and ground-water reservoirs. Potential field surveys are relatively inexpensive and can quickly cover large areas of ground. The primary goal of studying potential fields is to provide a better understanding of the subsurface geology. The methods are relatively cheap, non-invasive and non-destructive environmentally speaking. They are also passive – that is, no energy needs to be put into the ground in order to acquire data. The small portable instruments (gravimeter and magnetometer) also permit walking traverses.

1. GRAVITY METHOD

1.1. Introduction

Gravity surveying measures variations in the Earth's gravitational field caused by differences in the density of sub-surface rocks. Gravity methods have been used most extensively in the search for oil and gas, particularly in the twentieth century. While such methods are still employed very widely in hydrocarbon exploration, many other applications have been found, some examples of which are (Reynolds, 1997):

- Hydrocarbon exploration
- Regional geological studies
- Isostatic compensation determination
- Exploration for, and mass estimation of, mineral deposits
- Detection of sub-surface cavities (microgravity)
- Location of buried rock-valleys
- Determination of glacier thickness
- Tidal oscillations
- Archaeogeophysics (micro-gravity); e.g. location of tombs
- Shape of the earths (geodesy)
- Military (especially for missile trajectories)
- Monitoring volcanoes.

Perhaps the most dramatic change in gravity exploration in the 1980's has been the development of instrumentation which now permits airborne gravity surveys to be undertaken routinely and with a high degree of accuracy. This has allowed aircraft-borne gravimeters to be used over otherwise inaccessible terrain and has led to the discovery of several small but significant areas with economic hydrocarbon potentials.

In geothermal application, the primary goal of studying detailed gravity data is to provide a better understanding of the subsurface geology. The gravity method is a relatively cheap, non-invasive, non-destructive remote sensing method that has already been tested on the lunar surface. It is also passive – that is, no energy needs to be put into the ground in order to acquire data; thus, the method is well suited to a populated setting. The small portable instrument also permits walking traverses, especially in view of the congested tourist traffic in some places.

Measurements of gravity provide information about densities of rocks underground. There is a wide range in density among rock types, and therefore geologists can make inferences about the distribution of strata. In our geothermal fields, we are attempting to map subsurface faults. Because faults commonly juxtapose rocks of differing densities, the gravity method is an excellent exploration choice. The equipment used for measuring the variation of the earth gravimetric field is the "gravity meter" or gravimeter.

Gravity survey - Measurements of the gravitational field at a series of different locations over an area of interest. The objective in exploration work is to associate variations with differences in the distribution of densities and hence rock types (Sheriff, 1994).

1.2 Basic theory

The basis on which the gravity method depends is encapsulated in two laws derived by Newton, namely his Universal Law of gravitation, and his Second Law of Motion. The first of these two laws states that the force of attraction between two bodies of known mass is directly proportional to the product of the two masses and inversely proportional to the square of the distance between their centres of mass. Consequently, the greater the distance separating the centres of mass, the smaller the force of attraction between them is.

Force = gravitational constant × mass of the earth (M) × mass (m) / (distance between masses (R))²

or

$$F = \frac{G \times M \times m}{R^2} \tag{1}$$

where the gravitational constant, $G = 6.67 \times 10^{-11}$ Nm^{2}kg^{-2}

Newton's law of motion states that a force (F) is equal to mass (m) times acceleration (Equation 2). If the acceleration is in a vertical direction, then it is due to gravity (g). In theoretical form Newton's *Second law of motion* states that:

Force (F) = mass (m) × acceleration (g)

or

$$F = M \times G \tag{2}$$

Equations 1 and 2 can be combined to obtain another simple relationship:

$$F = \frac{G \times M \times m}{R^2} = M \times g; \quad \text{thus} \quad g = \frac{G \times M}{R^2} \tag{3}$$

This shows that the magnitude of acceleration due to gravity on Earth (*g*) is directly proportional to the mass (M) of the Earth and inversely proportional to the square of the Earth's radius (*R*). Theoretically, acceleration due to gravity should be constant over the Earth. In reality, gravity varies from place to place because the earth has the shape of a flattened sphere, rotates, and has an irregular surface topography and variable mass distribution.

1.3 Gravity units

The normal value of g at the Earth's surface is 980 cm/s^2. In honour of Galileo, the c.g.s. unit of acceleration due to gravity (1 cm/s^2) is Gal. Modern gravity meters (gravimeters) can measure extremely small variations in acceleration due to gravity, typically 1 part in 10^9. The sensitivity of modern instruments is about ten parts per million. Such small numbers have resulted in sub-units being used such as the:

milliGal (1 mGal = 10^{-3} Gal);
microGal (1 μGal = 10^{-6} Gal); and
1 gravity unit = 1 g.u. =0.1 mGal [10 gu =1 mGal]

1.4 Measurements of gravity

There are two kinds of gravitymeters. An absolute gravimeter measures the actual value of g by measuring the speed of a falling mass using a laser beam. Although this meter achieves precisions of 0.01to 0.001 mGal (miliGals, or 1/1000 Gal), they are expensive, heavy, and bulky. A second type of gravity meter measures relative changes in g between two locations, see Figure 1. The figure shows a local base station and a site measurement using the gravity meter model CG-5 from Scintrex, over a Momotomo Volcanao lava flow in a survey in Niacaragua. This instrument uses a mass on the end of a spring that stretches where g is stronger. This kind of a meter can measure g with a precision of 0.01 mGal in about 5 minutes.

FIGURE 1: A) Gravity at a base station opening loop, together with a remote reference GPS;
    B) A site measurement, gravity and position using double frequency GPS are measured

A relative gravity measurement is also made at the nearest absolute gravity station, one of a network of worldwide gravity base stations. The relative gravity measurements are thereby tied to the absolute gravity network *(www.usgs.gov)* (see Figure 2), which shows the absolute gravity station network of Central America.

Lateral density changes in the subsurface cause a change in the force of gravity at the surface. The intensity of the force of gravity due to a buried mass difference (concentration or void) is

FIGURE 2: Central American absolute gravity
station cities; taken from NOAA, 2001

superimposed on the larger force of gravity due to the total mass of the earth. Thus, the two components of gravity forces are measured at the Earth's surface: first, a general and relatively uniform component due to the total earth, and second, a component of much smaller size that varies due to lateral density changes (the gravity anomaly). By very precise measurements of gravity and by careful correction for variations in the larger component due to the whole Earth, a gravity survey can sometimes detect natural or man-made voids, variations in the depth to bedrock, and geologic structures of engineering interest.

The interpretation of a gravity survey is limited by ambiguity and the assumption of homogeneity. A distribution of small masses at a shallow depth can produce the same effect as a large mass at depth. External control of the density contrast or the specific geometry is required to resolve ambiguity questions. This external control may be in the form of geologic plausibility, drill-hole information, or measured densities.

The drawings in Figure 3 show the result of measurements, indicating the relative surface variation of gravitational acceleration over geologic structures. When the spatial craft passes over a denser body or crosses to another denser block of rocks the gravitational attraction is increased. Above, it also shows a curve, which describes the gravity behaviour.
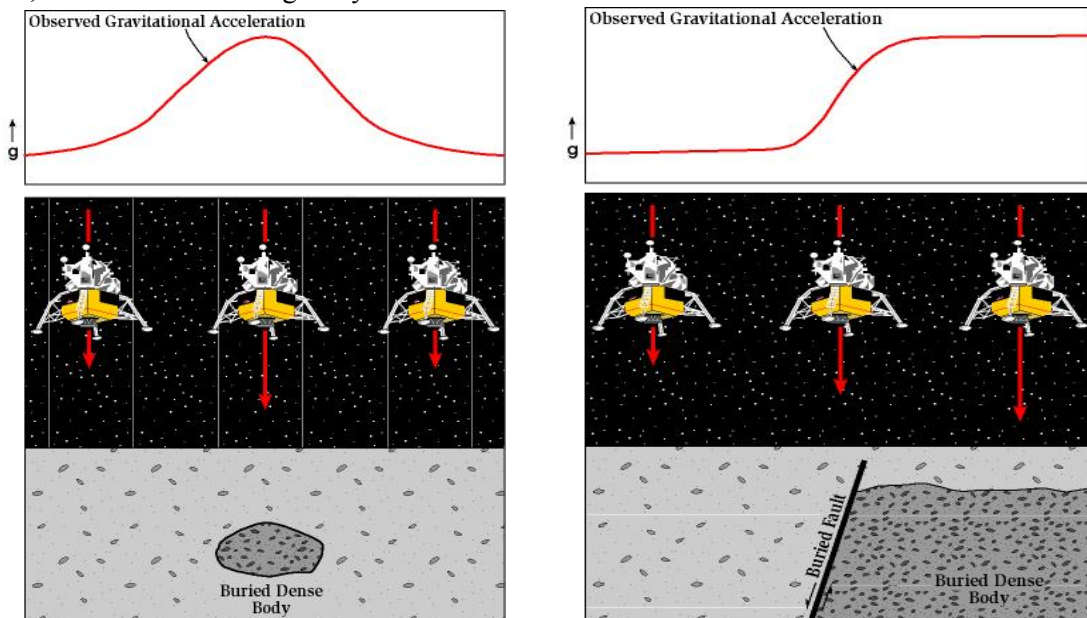

FIGURE 3: Cartoon illustrations showing the relative surface variation of
gravitational acceleration over geologic structures (taken from:
geoinfo.nmt.edu/geoscience/projects/astronauts/gravity method.html)

Gravity measurements, even at a single location, change with time due to Earth tides, meter drift, and tares. See an example of measurements at the same location in an office of LaGeo in Figure 4. These time variations can be dealt with by good field procedure. After elevation and position surveying, the actual measurement of the gravity readings is often accomplished by one person in areas where solo work is allowed.

1.5 Variation of gravity with latitude

The value of acceleration due to gravity varies over the surface of the Earth for a number or reasons, one of which is the Earth's shape. As the polar radius (6,357 km) is 21 km shorter than the equatorial radius (6,378 km) the points at the poles are closer to the Earth's centre of mass and, therefore, the value of gravity at the poles is greater than that at the equator. There in another aspect, as the Earth rotates once per sidereal day around its north-south axis, there is a centrifugal acceleration

FIGURE 4: Two days cycling mode gravity measurements at the same site (August, 29-31, 2008); raw grav in mG; instrumental measurement

acting which is greatest where the rotational velocity is largest, namely at the equator (1,674 km/h; 1,047 miles/h) and decrease to zero at the poles.
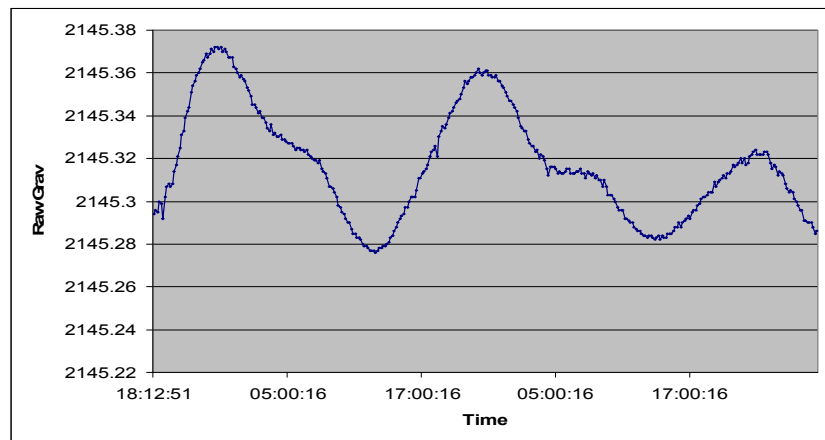
Gravity surveying is sensitive to variations in rock density, so an appreciation of the factors that affect density will aid the interpretation of gravity data.

1.6 Reduction of data

Gravimeters do not give direct measurements of gravity. Rather, a meter reading is taken which is then multiplied by an instrumental calibration factor to produce a value of observed gravity (g_{obs}). The correction process is known as *gravity data reduction or reduction to the geoid*. The various corrections that can be applied are the following.

Instrument drift: Gravimeter readings change (drift) with time as a result of elastic creep in the springs, producing an apparent change in gravity at a given stations. The instrumental drift can be determined simply by repeating measurements at the same stations at different times of the day, typically every 1 – 2 hours.

Earth's tides: Just as the water in the oceans responds to gravitational pull of the Moon, and to a lesser extent of the Sun, so too does the solid earth. ET give rise to a change in gravity of up to three g.u. with a minimum period of about 12 hours. Repeated measurements at the same stations permit estimation of the necessary correction for tidal effects over short intervals, in addition to determination of the instrumental drift for a gravimeter.

Observed gravity (g_{obs}) - Gravity readings observed at each gravity station after corrections have been applied for instrument drift and earth tides.

Latitude correction (g_n) - Correction subtracted from g_{obs} that accounts for Earth's elliptical shape and rotation. The gravity value that would be observed if Earth were a perfect (no geologic or topographic complexities), rotating ellipsoid is referred to as the *normal gravity*.

$$g_n = 978031.85\ (1.0 + 0.005278895\ sin^2(lat) + 0.000023462\ sin^4(lat))\ (mGal)$$

where *lat* is latitude

Free-air corrected gravity (g_{fa}) - The free-air correction accounts for gravity variations caused by elevation differences in the observation locations. The form of the free-air gravity anomaly, g_{fa}, is given by:

$$g_{fa} = g_{obs} - g_n + 0.3086h \text{ (mGal)}$$

where *h* is the elevation (in m) at which the gravity station is above the datum (typically sea level).

Bouguer slab corrected gravity (g_b) - The Bouguer correction is a first-order correction to account for the excess mass underlying observation points located at elevations higher than the elevation datum (sea level or the geoid). Conversely, it accounts for a mass deficiency at observation points located below the elevation datum. The form of the Bouguer gravity anomaly, g_b, is given by:

$$g_b = g_{obs} - g_n + 0.3086h - 0.04193r\, h \text{ (mGal)}$$

where *r* is the average density of the rocks underlying the survey area.

Terrain corrected bouguer gravity (g_t) - The terrain correction accounts for variations in the observed gravitational acceleration caused by variations in topography near each observation point. Because of the assumptions made during the Bouguer Slab correction, the terrain correction is positive regardless of whether the local topography consists of a mountain or a valley. The form of the Terrain corrected, Bouguer gravity anomaly, g_t, is given by:

$$g_t = g_{obs} - g_n + 0.3086h - 0.04193r\, h + TC \text{ (mGal)}$$

where *TC* is the value of the computed terrain correction.

Assuming these corrections have accurately accounted for the variations in gravitational acceleration they were intended to account for, any remaining variations in the gravitational acceleration associated with the terrain corrected Bouguer gravity can be assumed to be caused by a geologic structure.

Once the basic latitude, free-air, Bouguer and terrain corrections are made, an important step in the analysis remains. This step, called regional-residual separation, is one of the most critical. In most surveys and in particular those engineering applications in which very small anomalies are of greatest interest, there are gravity anomaly trends of many sizes. The larger sized anomalies will tend to behave as regional variations, and the desired smaller magnitude local anomalies will be superimposed on them.

1.7 Bouguer anomaly

The main end-product of gravity data reduction is the *Bouguer anomaly*, which should correlate only with lateral variations in density of the upper crust and which is of most interest to applied geophysicist and geologists. The Bouguer anomaly is the difference between the observed gravity value (gobs), adjusted by the algebraic sum of all the necessary corrections, and that of a base station (gbase). The variation of the Bouguer anomaly should reflect the lateral variation in density such that a high-density feature in a lower-density medium should give rise to a positive Bouguer anomaly. Conversely, a low-density feature in a higher-density medium should result in a negative Bouguer anomaly. See example in Figure 5.
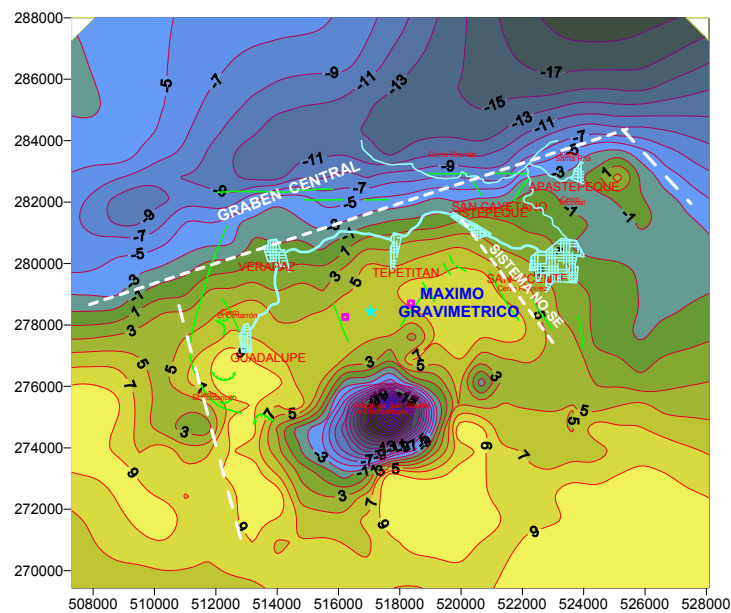
FIGURE 5: Bouguer anomaly map of the
San Vicente geothermal area

2. MAGNETIC METHOD

2.1 Introduction

The magnetic method is a very popular and inexpensive approach for near-surface metal detection. Engineering and environmental site characterization projects often begin with a magnetometer survey as a means of rapidly providing a layer of information on where utilities and other buried concerns are located (*www.aoageophysics.com*).

The principal of operation is quite simple. When a ferrous material is placed within the Earth's magnetic field, it develops an induced magnetic field. The induced field is superimposed on the Earth's field at that location creating a magnetic anomaly. Detection depends on the amount of magnetic material present and its distance from the sensor. The anomalies are typically presented on colour contour maps.

Common uses of magnetometers include:

- locating buried tanks and drums
- fault studies
- mineral exploration
- geothermal exploration
- mapping buried utilities, pipelines
- buried foundations, fire pits for archaeological studies

In geothermal application the main objective of the magnetic study is to contribute with information about the relationship among the geothermal activity, the tectonic and stratigraphy of the area by means of the anomalies interpretation of the underground rocks' magnetic properties (Escobar, 2005). Most of the rocks are not magnetic; however, certain types of rocks contain enough minerals to originate significant magnetic anomalies. The data interpretation that reflects differences in local abundance of magnetization is especially useful to locate faults and geologic contacts (Blakely, 1995).

The magnetic anomalies can be originated from a series of changes in lithology, variations in the magnetized bodies thickness, faulting, pleats and topographical relief. A significant quantity of information can leave a qualitative revision of the residual magnetic anomalies map of the total magnetic field. In this sense, we can say that the value of the survey does not finish with the first interpretation, but rather it increases as more geology is known.

It is more important, at the beginning, to detect the presence of a fault or intrusive body, than to determine their form or depth. Although, in some magnetic risings, such determination cannot be made in a unique manner, the magnetic data has been useful because the intrusive is more magnetic than the underlying lava flows. The faulting creates spaces so that the warm fluids displace and therefore alter the guest rocks. The hydrothermal system temperature and the oxygen volatility will determine the quantity of present loadstone in the area of faults and therefore, their magnetic response.

2.2. Basic theory

If two magnetic poles of strength m_1 and m_2 are separated by a distance r, a force, F, exists between them. If the poles are of the same polarity, the force will push the poles apart, and if they are of opposite polarity, the force is attractive and will draw the poles together. The equation for F is the following:

$$F = \frac{m_1 m_2}{4 \pi \mu^2} \tag{4}$$

where μ is the magnetic permeability of the medium separating the poles; m_1 and m_2 are pole strengths and r the distance between them.

2.3 Magnetic units

The magnetic flux lines between two poles per unit area, is the flux density **B** (and is measured in weber/m^2 = Tesla). **B**, which is also called the "magnetic induction", is a vector quantity. The unit of Tesla are too large to be practical in geophysical work, so a sub-unit called a nanotesla (1 nT = 10^{-9} T) is used instead, where 1 nT is numerically equivalent to 1 gamma in c.g.s. units (1 nT is equivalent to 10^{-5} gauss).

The magnetic field can also be defined in terms of a force field which is produced by electric currents. This magnetizing field strength **H** is defined, following Biot-Savart's Law, as being the field strength at the centre of a loop of wire of radius r through which a current I is flowing such that $H = I/2r$. Consequently the units of the magnetizing field strength **H** are amperes per metre (A/m). The ratio of the flux density **B** to the magnetizing field strength **H** is a constant called the absolute magnetic permeability (μ).

2.4. The Earth's magnetic field

The geomagnetic field at or near the surface of the Earth originates largely from within and around the Earth's core. The geomagnetic field can be described in terms of the declination, **D**, inclination, **I**, and the total force vector **F** (Figure 6). The vertical component of the magnetic intensity of the Earth's magnetic field varies with latitude, from a minimum of around 30,000 nT at the magnetic equator to 60,000 nT at the magnetic poles.

2.5. Magnetics instruments

Magnetometers used specifically in geophysical exploration can be classified into three groups: the torsion (and balance), fluxgate and resonance types, of which the last two have now completely superseded the first. Torsion magnetometers are still in use in 75% of geomagnetic observations,
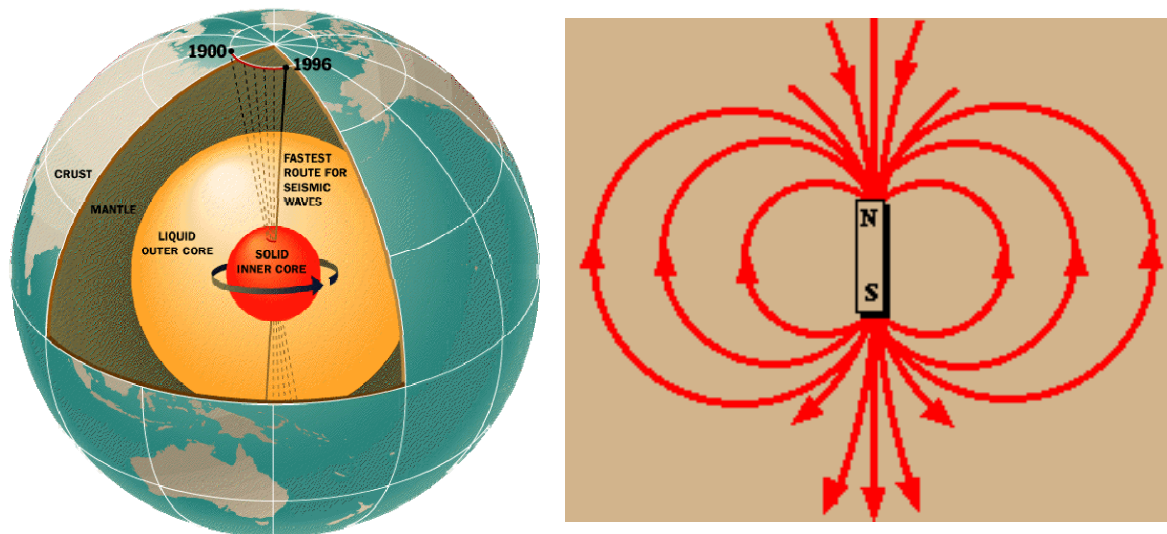
FIGURE 6: Left: Origin of the Earth's magnetic field. Right: Displacement of the force
lines of the Earth's magnetic field, equivalent to the ones of the magnet

particularly for measurements of declination. Magnetometers measure horizontal and/or vertical components of the magnetic field or the total field.

There are two main types of resonance magnetometer: the proton free-precession magnetometer, which is the best known, and the alkali vapour magnetometer. Both types monitor the precession of atomic particles in an ambient magnetic field to provide an absolute measure of the total magnetic field, **F**.

The proton magnetometer has a sensor which consists of a bottle containing a proton-rich liquid, usually water or kerosene, around which a coil is wrapped, connected to the measuring apparatus. Each proton has a magnetic moment M and, as it is always in motion, it also possesses an angular momentum G, rather like a spinning top. Figure 7 shows examples of field measurements with a magnetometer model GEM-19T from GEM System, owned by LaGeo in a survey in the Sa Vicente volcano area.

FIGURE 7: Examples of a field measurement with a magnetometer model GEM-19T from
GEM System, owned by LaGeo; a magnetic survey in the San Vicente volcano area

2.6. Magnetic surveying

Local variations, or anomalies, in the Earth's magnetic field are the result of disturbances caused mostly by variations in concentrations of ferromagnetic material in the vicinity of the magnetometer's sensor. Magnetic data can be acquired in two configurations:

1) A rectangular grid pattern
2) Along a traverse

Grid data consists of readings taken at the nodes of a rectangular grid; traverse data is acquired at fixed intervals along a line. Each configuration has its advantages and disadvantages, which are dependent upon variables such as the site conditions, size and orientation of the target, and financial resources. An example of a grid along lines is shown in Figure 8. This took place in the Chinameca geothermal area in El Salvador.
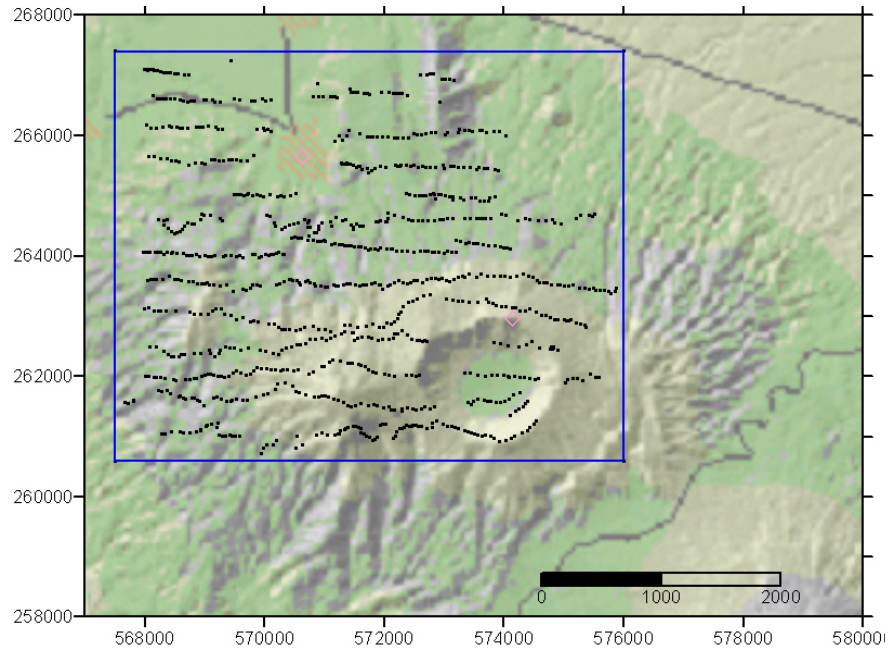

FIGURE 8: Land magnetic survey at Chinameca geothermal area; location of lines and measure site are shown

In both traverse and grid configurations, the station spacing, or distance between magnetic readings, is important. "Single-point" or erroneous anomalies are more easily recognized on surveys that utilize small station spacing.

Ground magnetic measurements are usually made with portable instruments at regular intervals along more or less straight and parallel lines that cover the survey area. Often the interval between measurement locations (stations) along the lines is less than the spacing between lines. It is important to establish a local base station in an area away from suspected magnetic targets or magnetic noise and where the local field gradient is relatively flat. The base-station memory magnetometer, when used, is set up every day prior to the collection of the magnetic data. Ideally the base station is placed at least 100 m from any large metal objects or travelled roads and at least 500 m from any power lines when feasible. The base station location must be very well described in the field book, as others may have to later locate it based on the written description.

There are certain limitations in the magnetic method. One limitation is the problem of "cultural noise" in certain areas. Man-made structures that are constructed using ferrous material, such as steel, have a detrimental effect on the quality of the data. Features to be avoided include steel structures, power lines, metal fences, steel reinforced concrete, surface metal, pipelines and underground utilities. When these features cannot be avoided, their locations should be noted in a field notebook and on the site map.

The incorporation of computers and non-volatile memory in magnetometers has greatly increased their ease of use and data handling capability. The instruments typically will keep track of position; prompt

for inputs, and internally store the data for an entire day of work. Downloading the information to a personal computer is straightforward, and plots of the day's work can be prepared each night.

To make accurate anomaly maps, temporal changes in the Earth's field during the period of the survey must be considered. Normal changes during a day, sometimes called diurnal drift, are a few tens of nT, but changes of hundreds or thousands of nT may occur over a few hours during magnetic storms. During severe magnetic storms, which occur infrequently, magnetic surveys should not be made. The correction for diurnal drift can be made by repeating measurements of a base station at frequent intervals. The measurements at field stations are then corrected for temporal variations by assuming a linear change of the field between repeat base station readings. Continuously recording magnetometers can also be used at fixed base sites to monitor the temporal changes. If time is accurately recorded at both the base site and field the location, the field data can be corrected by subtraction of the variations at the base site.

Some QC/QA procedures require that several field-type stations be occupied at the start and end of each day's work. This procedure indicates that the instrument is operating consistently. Where it is important to be able to reproduce the actual measurements on a site exactly (such as in certain forensic matters), an additional procedure is required. The value of the magnetic field at the base station must be asserted (usually a value close to its reading on the first day) and each day's data corrected for the difference between the asserted value and the base value read at the beginning of the day. As the base may vary by 10 to 25 nT or more from day to day, this correction ensures that another person using the same base station and the same asserted value will get the same readings at a field point to within the accuracy of the instrument. This procedure is always a good technique but is often neglected by persons interested in only very large anomalies (> 500 nT, etc.).

Intense fields from man-made electromagnetic sources can be a problem in magnetic surveys. Most magnetometers are designed to operate in fairly intense 60-Hz and radio frequency fields. However, extremely low frequency fields caused by equipment using direct current or the switching of large alternating currents can be a problem. Pipelines carrying direct current for cathodic protection can be particularly troublesome. Although some modern ground magnetometers have a sensitivity of 0.1 nT, sources of cultural and geologic noise usually prevent full use of this sensitivity in ground measurements.

The magnetometer is operated by a single person. However, grid layout, surveying, or the buddy system may require the use of another technician. If two magnetometers are available, production is usually doubled as the ordinary operation of the instrument itself is straightforward.

2.3. Distortion

Steel and other ferrous metals in the vicinity of a magnetometer can distort the data. Large belt buckles, etc., must be removed when operating the unit. A compass should be more than 3 m away from the magnetometer when measuring the field. A final test is to immobilize the magnetometer and take readings while the operator moves around the sensor. If the readings do not change by more than 1 or 2 nT, the operator is "magnetically clean." Zippers, watches, eyeglass frames, boot grommets, room keys, and mechanical pencils can all contain steel or iron. On very precise surveys, the operator effect must be held at under 1 nT.

Data recording methods will vary with the purpose of the survey and the amount of noise present. Methods include taking three readings and averaging the results, taking three readings within a meter of the station and either recording each or recording the average. Some magnetometers can apply either of these methods and even do the averaging internally. An experienced field geophysicist will specify which technique is required for a given survey. In either case, the time of the reading is also recorded unless the magnetometer stores the readings and times internally.

Sheet-metal barns, power lines, and other potentially magnetic objects will occasionally be encountered during a magnetic survey. When taking a magnetic reading in the vicinity of such items, describe the interfering object and note the distance from it to the magnetic station in your field book. Items to be recorded in the field book for magnetic include:

a) Station location, including locations of lines with respect to permanent landmarks or surveyed points;
b) Magnetic field and/or gradient reading;
c) Time:
d) Nearby sources of potential interference.

The experienced magnetic operator will be alert for the possible occurrence of the following:

1. Excessive gradients may be beyond the magnetometer's ability to make a stable measurement. Modern magnetometers give a quality factor for the reading. Multiple measurements at a station, minor adjustments of the station location and other adjustments of technique may be necessary to produce repeatable, representative data.
2. Nearby metal objects may cause interference. Some items, such as automobiles, are obvious, but some subtle interference will be recognized only by the imaginative and observant magnetic operator. Old buried curbs and foundations, buried cans and bottles, power lines, fences, and other hidden factors can greatly affect magnetic readings.

2.4. Data reduction and interpretation

The data should be corrected for diurnal variations, if necessary. If the diurnal does not vary more than approximately 15 to 20 gammas over a one-hour period, correction may not be necessary. However, this variation must be approximately linear over time and should not show any extreme fluctuations.

The global magnetic field is calculated through a previous established model (IGRF-International Geomagnetic Reference), Figure 9, and obtained analytically with the help of field observations. Due to the fact that the global magnetic field is variable, these maps are generated every 5 years.

There are filters used for highlighting the contrast of anomalies; these are:

- Derivatives of different order or gradients
- Upward or downward continuation regarding the anomaly
- Band pass or high pass filters
- Pole reduction

After all corrections have been made, magnetic survey data are usually displayed as individual profiles or as contour maps. Identification of anomalies caused by cultural features, such as railroads, pipelines, and bridges is commonly made using field observations and maps showing such features.

2.5. Presentation of results

The final results are presented in profile and contour map form. Profiles are usually presented in a north-south orientation, although this is not mandatory. The orientation of the traverses must be indicated on the plots. A listing of the magnetic data, including the diurnal monitor or looping data should be included in the report. The report must also contain information pertinent to the instrumentation, field operations, and data reduction and interpretation techniques used in the investigation.
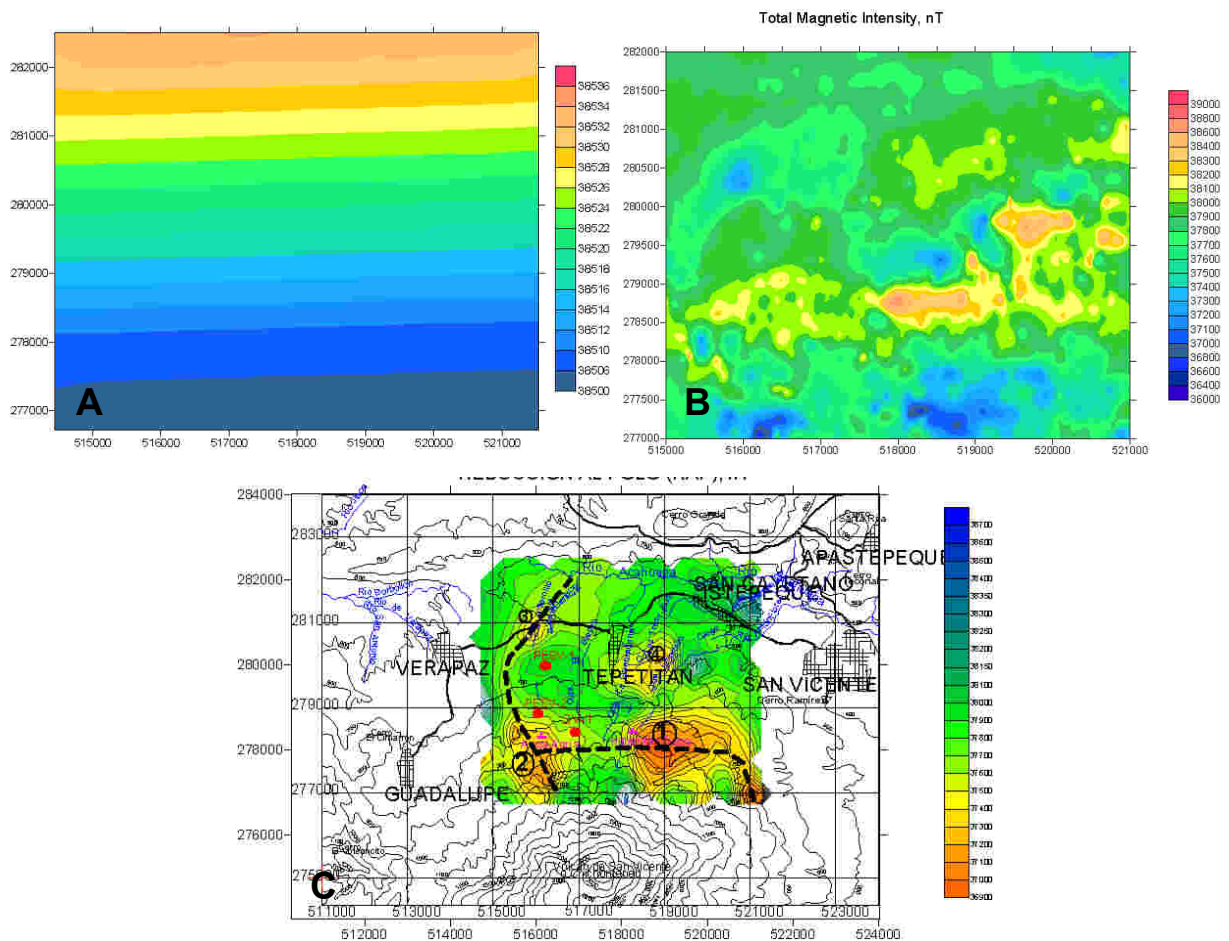
FIGURE 9: Examples of magnetic maps. A) Regional magnetic field in the San Vicente
geothermal area (IGRF); B) Total magnetic field intensity, C) Pole reduction
in the San Vicente magnetic survey

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