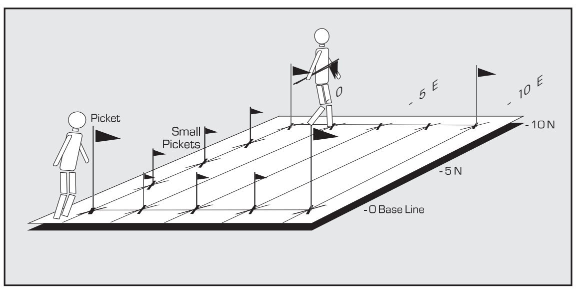
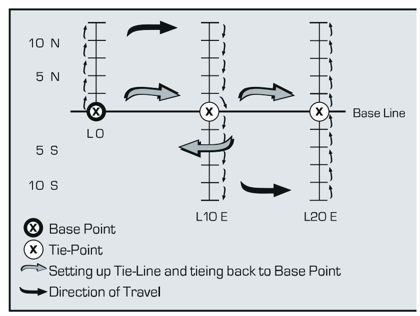
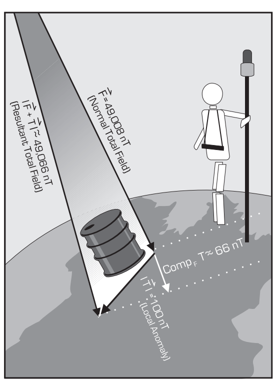
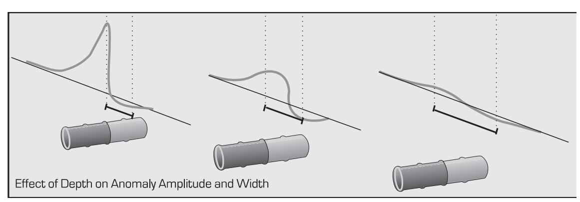
SCINTREX

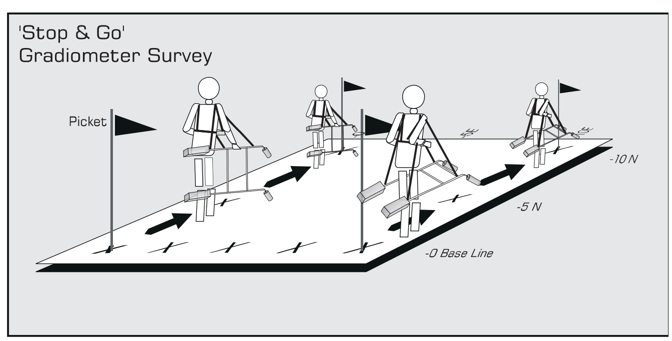
Magnetic Applications Guide











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Applications

Table of Contents

Magnetic Applications Guide

Magnetic surveying overview

Survey planning

Survey procedures and a sample survey

Applications

Chapter 1

MAGNETIC SURVEYING OVERVIEW

INTRODUCTION

These application notes review some of the numerous environmental applications for which the SMARTMAG and ENVI-MAG are designed. The first chapter will give a general overview of the purpose and scope of a magnetometer survey. In the second chapter, we shall discuss the planning of a magnetometer survey carried out with these environmental magnetometer/gradiometers, within a specific environmental application. The third and last chapter will be devoted to applications in the field. These applications will illustrate field results as well as the corresponding structures or objects creating the magnetic anomalies.

BASIC MAGNETIC THEORY

WHAT IS BEING MEASURED?

In a simple way, the Earth can be described as a large magnet with the north pole pointing south (that is why the needle on your compass points north because it is attracted by a magnetic pole of opposite sign). Figure 1 on page 2 illustrates the magnetic field of the Earth. The Earth's field at any given point on the Earth is *vector*, in that it has a preferred orientation (*direction*) and an amplitude (*intensity*). The *inclination* and *declination* describe the local orientation of the Earth's magnetic field vector.

The orientation and intensity of the Earth's field is quite well known. The map of the Earth's magnetic intensity is shown in Figure 3 on page 5. You will need to refer to this figure occasionally, in order to set the base-field parameters on the SMARTMAG. The magnetic field intensity is usually expressed in gammas or nanoTeslas. NanoTesla is the preferred SI nomenclature, however, a nT equals a gamma. The values of the Earth's magnetic field that you will typically observe should vary from 25,000 nT to 70,000 nT.

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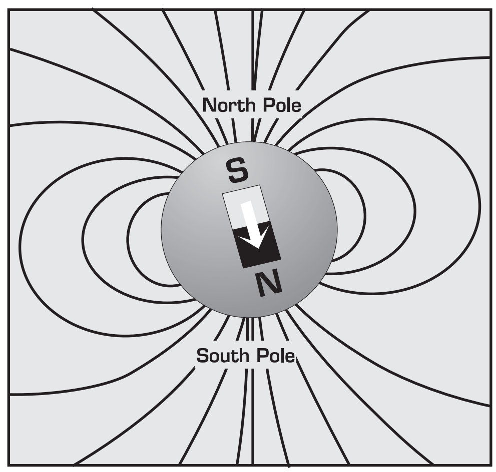

Figure 1 The magnetic field of the Earth.

The SMARTMAG and ENVI-MAG are *total-field* magnetometers, and optionally gradiometers. They use fundemental properties of either *cesium* or *hydrogen* atoms to measure the *scalar amplitude* of the magnetic field vector. This is explained with the aid of the diagram shown in Figure 2 on page 4. The predominant magnetic field is that of the Earth's (shown by the vector $\vec{\mathbf{F}}$ in the figure). A local magnetic disturbance has its own magnetic field (represented by the vector $\vec{\mathbf{T}}$ in the figure). This local vector adds to the Earth's field vector to produce the total-field vector $\vec{F} + \vec{T}$. What these magnetometers measure is the projected *amplitude* of the total-field $\vec{T}$ in the direction of the dominant Earth's field $\vec{F}$. This is displayed as the intensity in nanoTeslas by the instrument.

Note: No directional information concerning the field of the local magnetic disturbances can be inferred from a total-field intensity measurement.

With the SMARTMAG or ENVI-MAG, you can measure not only the total-field intensity, but also the vertical gradient (or *rate of change*) of the total field (if you have purchased the gradiometer option). The vertical gradient, as previously mentioned, is the rate of change of the total field with vertical distance. This measurement is accomplished by simultaneously reading the total magnetic field at two different elevations, and recording the difference. The usefulness of both these parameters will be explained in the next Chapter.

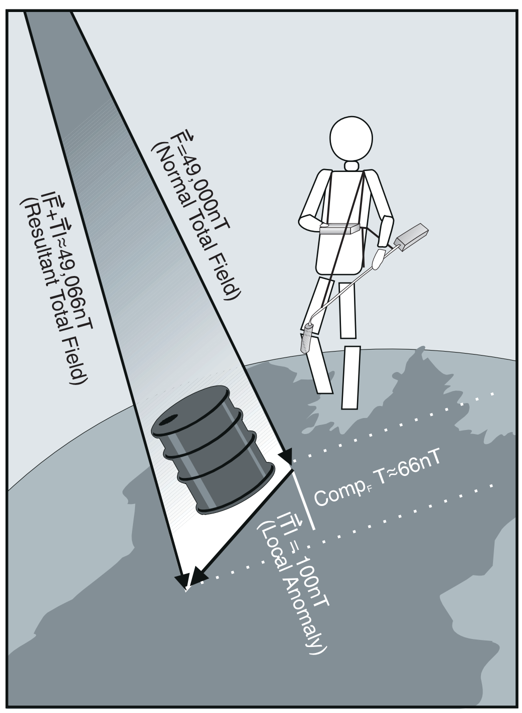

Figure 2 The Earth's magnetic field interacting with a magnetizable body.

ANOMALIES

An anomaly is created when the Earth's magnetic field is disturbed by an object that can be magnetized. The resultant anomaly can also be viewed in terms of vectors as previously described for Figure 2. When this is measured and plotted against the measuring location, you may see a profile of values as illustrated in Figure 2, showing a local disturbance of 10 nT. It is very important to note that the vector of the local disturbance can be in *any* direction. This is always the case with buried drums, as we shall see in Chapter 3.

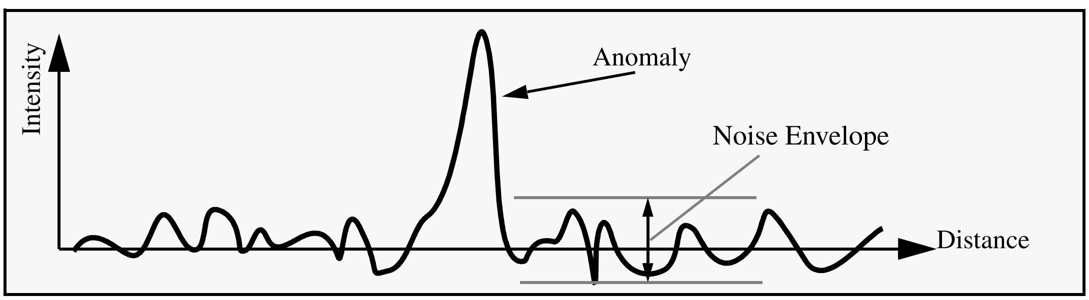

Figure 3 Typical anomalous signature.

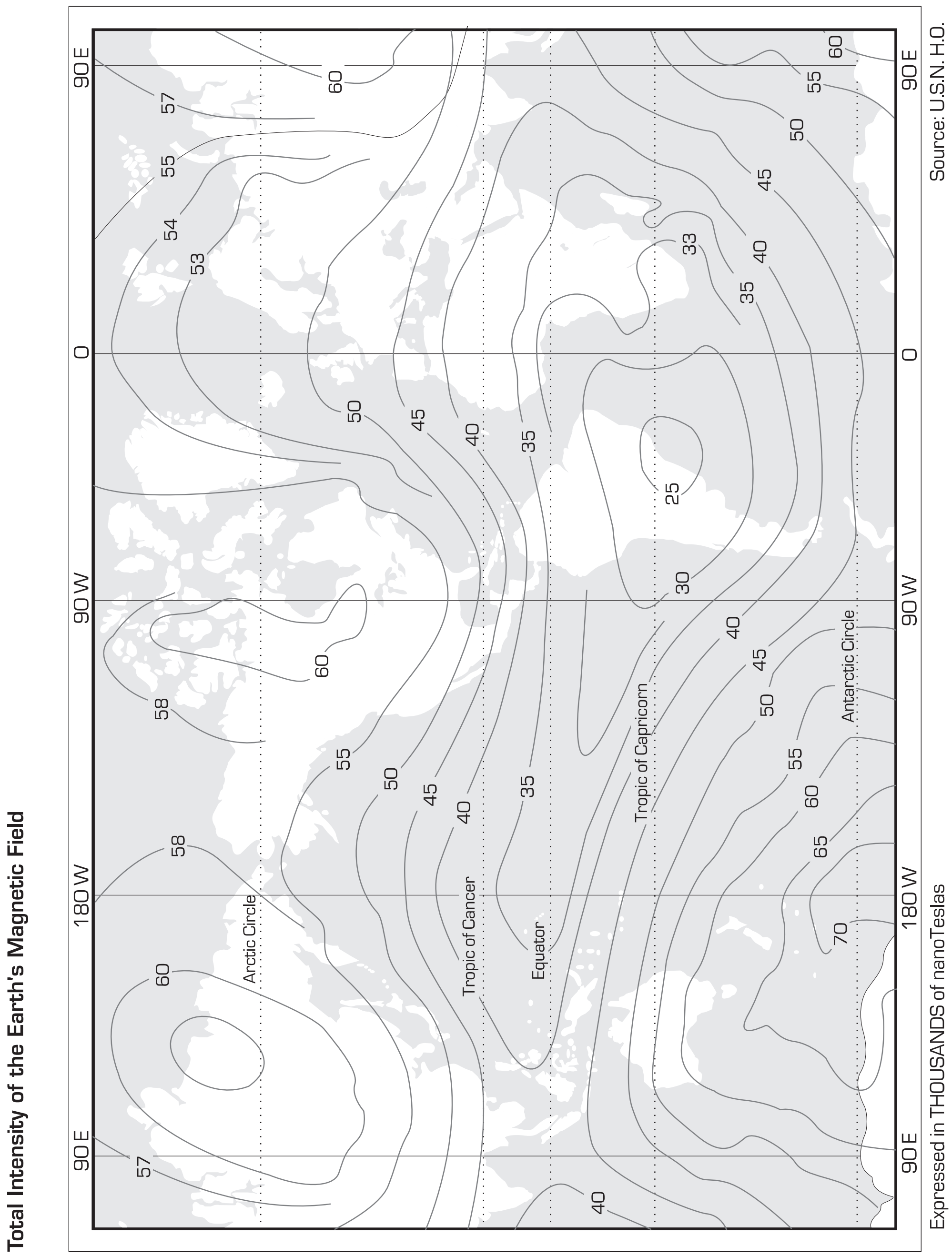

Figure 4 The intensity of the Earth's magnetic field.

Shape

The shape of a magnetizable body also determines the shape of the magnetic anomaly that you can measure. Compact bodies give rise to one shape of anomaly, while long thin bodies or flat, sheet-like bodies give rise to others. These different magnetizable bodies can be represented as simple assemblages of magnetic monopoles or dipoles. Figure 6 on page 7 illustrates the magnetic field lines around typical dipole and monopole bodies, and the resulting total field with the Earth's magnetic field added. A confined body is illustrated on the left whereas a long and infinite body is illustrated on the right.

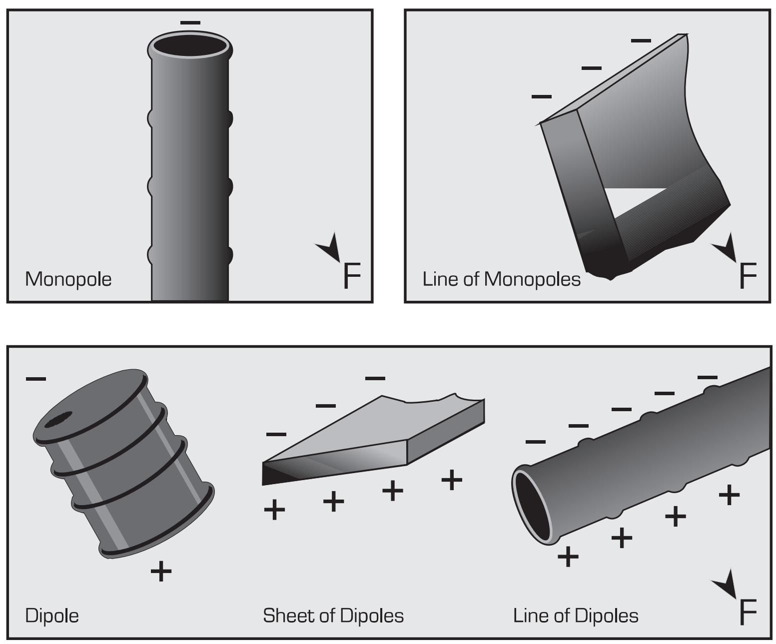

Figure 5 Typical targets.

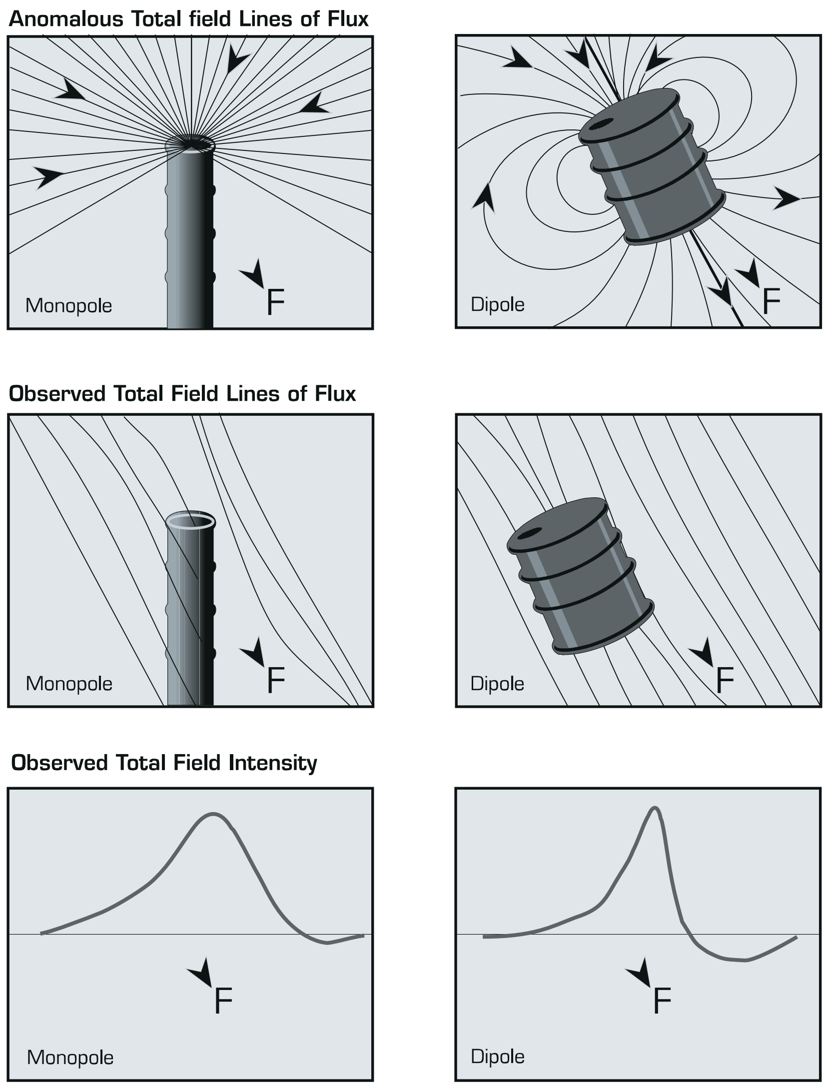

Figure 6 Typical monopole and dipole signatures.

Amplitude

As you have just seen, the shape of the anomaly is determined by the geometry of the causative body with respect to the direction of the Earth's magnetic field. The amplitude, on the other hand, is controlled by a combination of the susceptibility, permanent magnetization and the distance from the body that you are observing the response. The more magnetizable the object is the stronger and narrower the peak on the profile will be. The deeper the object, the weaker and broader the peak on the profile will be. This is illustrated in the following figure.

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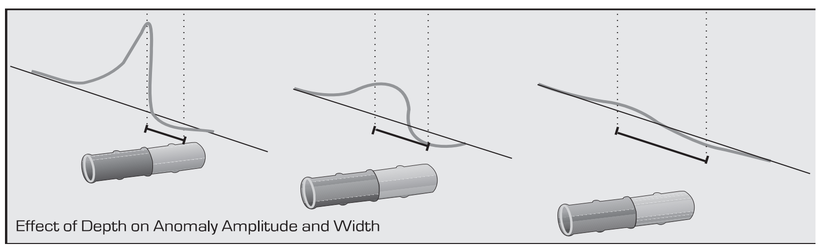

Figure 7 Variation of profile according to depth and magnetization.

The variation with depth of the amplitude of the local disturbance vector is a function of the distance between the sensor and the target. This variation with depth is called the fall-off rate. The fall-off rate for a dipole varies as a cube power ($1/r^3$), while that of a monopole would fall-off as a square power ($1/r^2$). The intensity of the local disturbance varies from one model to another.

Variations in the Earth's magnetic field

The Earth's magnetic field *varies* with time, i.e. it is not constant. As the Earth rotates, the outer layers of the ionosphere interact with the solar wind to cause minor fluctuations in the magnetic field. Depending upon the frequency, duration and intensity of these fluctuations, they are given different names.

Diurnal variation

Fluctuations with a period lasting of several hours to one day are called *diurnal variations*. These can be considered much like tides that ebb and flow during the course of a day. However, they are not predictive and are usually not a problem when conducting magnetic surveys. This diurnal drift can cause a variation of the order of 50 nT per hour. The following figure illustrates a typical diurnal variation of the total field.

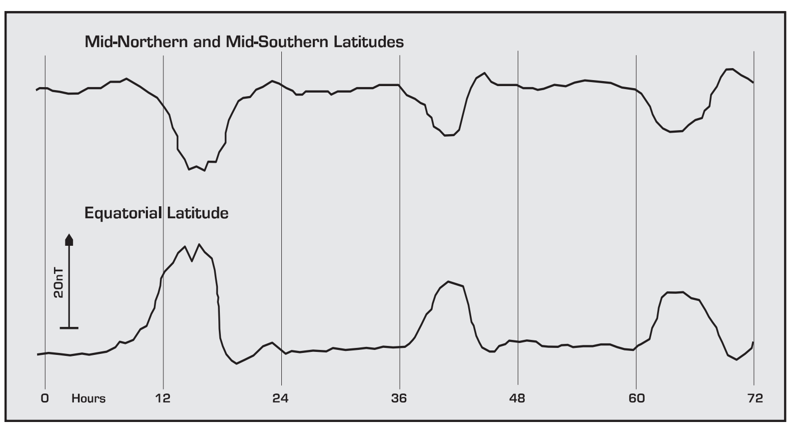

Figure 8 Typical diurnal variation.

Micro-pulsations

Erratic, short-term blips or spikes in the magnetic field are called micro-pulsations. These can range in intensity from a few through to tens, or even hundreds, of nanoTeslas in intensity, as can be seen in the next figure. These variatins can present a problem when you are surveying in that they may appear similar to anomalies caused by buried objects.

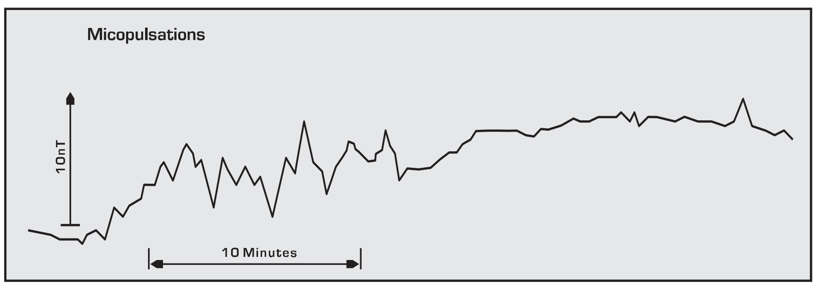

Figure 9 Typical micro-pulsations.

Magnetic storms

When the amplitude and duration of micro-pulsations becomes severe it is then called a magnetic storm. Typical micro-pulsations last a few hours whereas magnetic storms can last for days. The next figure (Figure 10 on page 11) illustrates a hypothetical magnetic storm. Needless to say, it is not recommended to conduct a total-field survey during a magnetic storm, as you may not be able to remove all of the rapidly changing variations in the magnetic field, giving rise to perhaps false anomalies.

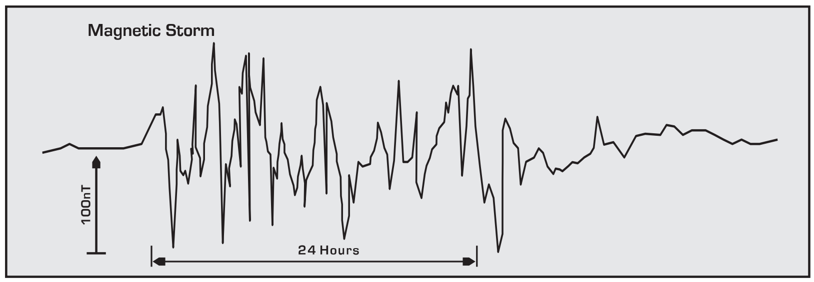

Figure 10 Typical magnetic storm.

You can obtain magnetic activity forecasts (much like weather forecasts) from several agencies worldwide, through an international network of centres called the IUWDS, (International Ursigrams and World Days Services). There exist ten regional warning centres (RWC's) that provide geomagnetic activity information to the scientific and user communities within their own region. Please note that not all of these centres provide the same services and forecasts. However, all of them have access to all information provided by the other centres.

The following table gives a list of contact telephone, facsimile and telex numbers for each of these regions. In Canada, geomagnetic forecasts are available through the Geophysics Division of the Geological Survey of Canada, while in the United States this information is available from NOAA. This information will greatly help you in planning your magnetometer survey.

Regional Warning Centres for geomagnetic forecasts

Location	Telephone	Fax	Telex	
Boulder, USA	303 497 3171	303 497 3137	888776	(NOAA BLDR)
Ottawa, Canada	613 837 3527	613 824 9803	0533117	(EMAR)
Sydney, Australia	612 4148329	612 4148331	20663	(IPSO AA220663)
Tokyo, Japan	81 292 657121	81 292 657209	3632125	(CRLHI J)
Paris, France	14507 7770	14507 7959	631812	(FCMEU X)
Prague, Czech Rep.	422 762548	422 762528	121546	(IONP C)
Delhi, India	5721436	9111572678	3177384	(RSD IN)
Moscow, Russia			411914	(ZEMLA SU)
Warsaw, Poland	403 766	121273	825670	(CBK PL)
Beijing, China	2551968	281261	22040	(BAOAS CN)

Removing magnetic variations

Depending upon the requirements of your site survey, you may choose to remove, or not to, these variations in time of the magnetic field from your collected magnetic data.

There are three ways in which you can remove these variations:

1. **Use a base station magnetometer** to record all the changes in time and then use this data to remove the change from the readings in the field magnetometer. This is the most accurate way of doing it, but also it is more expensive, as two complete instruments are required.
2. **Use a tie-point method** while doing the total field survey. This assumes that the field is changing slowly and evenly between the first time you measured the value at a station and the next time you check-in to that station again. This method is

not as accurate as using a base-station, but if the field is not changing rapidly, it is quite adequate to locate an anomaly. This technique may be the most cost-effective, as it only requires one magnetometer.

3. **Perform a vertical gradient survey.** Since you are measuring the rate of change between two sensors, any changes in the background field will apply to both sensors and you will not see any of these noise effects. This technique is quite effective for near-surface anomalies.

The different correction methods, such as the base-station and tie-line methods, are explained extensively in the next chapter of this manual. Most environmental applications do not require the use of a base station, as the grids are relatively small and can be covered in a very short time. Consequently, tie-point *line* or *loop* methods are quite adequate.

MAGNETIC TARGETS

What do drums, pipelines and sheet metal look like "magnetically"? Westphalen and Rice (1992) have shown that a single 55 (U.S.) gallon steel drum buried at a depth of 3 metres (10 feet) will give rise to an anomaly of 10 nT. Also, Benson et al., 1982 have calculated that the total field response in nT for different target distance and mass. This is show in the form of a chart presented in Figure 11 on page 14.

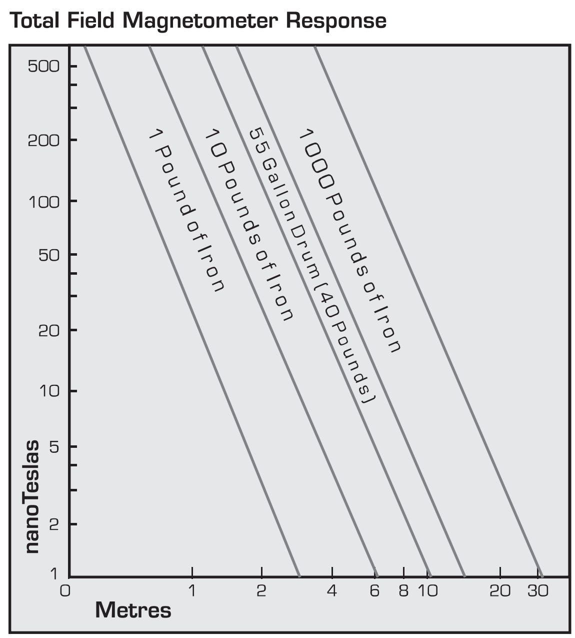

Figure 11 Total field response for different target distance and mass (after Benson et al., 1982).

The above information should give you a feel for the amplitude of the anomaly to expect in typical environmental applications. But it can be slightly misleading. These values are for the magnetic intensity that is induced in the material by the Earth's magnetic field. Unfortunately all man-made metallic objects carry with them a magnetic memory of their orientation when they were created, and this can lead to complications.

INDUCED AND REMANENT MAGNETISM

The local disturbance caused by a buried drum, a pipeline or a sheet can be represented as a vector. The disturbance can also be further decomposed into two components: an induced and a permanent (or *remanent*) component. The ability of a ferrous object to be magnetized is termed its susceptibility. The intensity of the induced magnetization is directly related to the ambient field by the susceptibility, and is therefore the induced part of the disturbance. Susceptibilities are measured in cgs units.

The remanent magnetic component of a magnetized body is a function of the orientation of the magnetic field at the time the object was cooled below 550°C. This temperature is called the Curie Point. While the metal, of which the drum, pipeline or sheet metal were made of, was at a temperature above the Curie Point, the magnetic dipoles were aligned in a random fashion. As the temperature of the metal approaches the Curie Point, these dipoles tend to align themselves in the direction of the dominant magnetic field (usually the Earth's) at that point in time.

In some mineral applications and most environmental applications, the remanent component predominates. This component can have any orientation and intensity. Therefore the resulting total-field vector $\vec{T}$ can have any orientation and intensity, which can have serious consequences on your magnetometer survey. Remember that it is the projected vector $\mathbf{COMP_F}$ that is measured by the magnetometer.

Consider for instance the examples illustrated in Figure 12 on page 16. You can see that depending upon the orientation of your traverse and the direction of magnetization of the body, you will get a completely different shape of profile for the same body at the same depth!

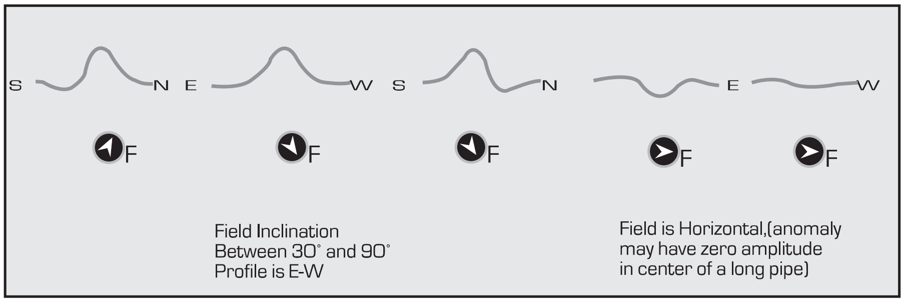

Figure 12 Effects of orientation and magnetization on anomaly shape.

Another example is shown in Figure 13. This simplifies the previous example by keeping the orientation of the traverse line and the depth of the body constant, i.e. the measuring geometry. The only parameter that is varying is the direction of the permanent magnetization.

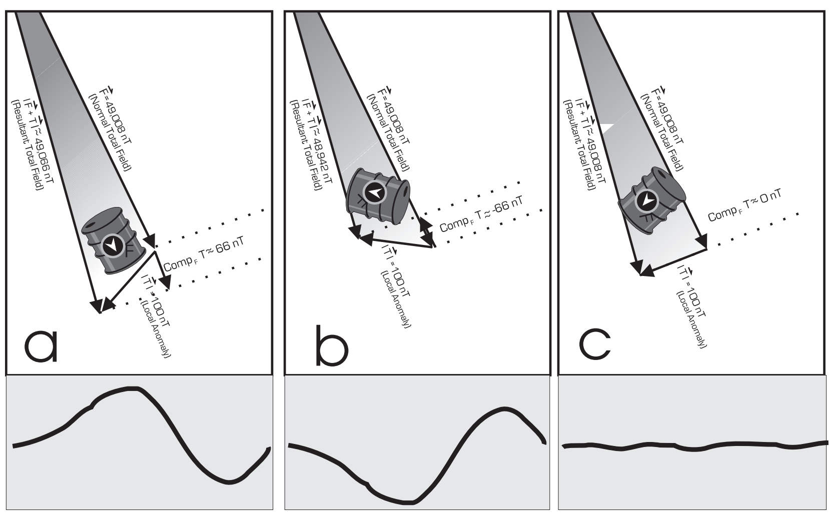

Figure 13 Orientation and anomaly amplitude: a) Positive, b) negative and c) null anomalies.

In case **a)**, the projection is in the same direction as the undisturbed total field, resulting in a positive anomaly. In case **b)**, the direction is opposite to the undisturbed total field, resulting in a negative anomaly. In case **c)**, however, the direction happens to be perpendicular to the undisturbed total field, resulting in no anomaly at all.

Case **c)** is the most interesting because even though an anomaly exists, it cannot be measured. You may want to keep this in mind when carrying out a magnetometer survey for buried drums, pipelines or metal sheets.

These are only simplified examples. Some situations, for instance a collection of drums, each having it's own orientation and intensity for the local disturbance vector, will possibly exhibit a very complex anomaly vector. When this is added to the Earth's magnetic field and then measured only as the scalar amplitude, the results may not be exactly as expected.

Applications

Chapter 2

SURVEY PLANNING

INTRODUCTION

There are very specific criteria that need to be considered when carrying out a magnetic survey for environmental applications:

- ▲ the estimated depth at which the targets are and their nature (buried drums, steel pipes or sheet metal),
- ▲ the precision and accuracy required of the surveys,
- ▲ the orientation of the target, i.e. is it elongated? This needs to be considered for objects having a linear surface expression, such as pipes and sheets of metal.

SAMPLING INTERVALS

Objects disposed of and/or buried by man are usually not at great depths; within the first ten metres of the surface. The anomalies created by such buried drums, pipelines or sheets of metal can produce relatively intense and narrow anomaly profiles. However, as mentioned in the previous chapter (page 8), the deeper the target, the broader the anomaly will be. Further, the anomaly will become less intense when the magnetized body is at greater depths. Larger targets will have broader anomalies and more intensely magnetized bodies will have larger amplitudes.

These relationships of body size, depth and magnetization all have a direct consequence on the station and line spacing, i.e. the density of the survey grid. For instance, if an anomalous peak is only 2 metres in width or length and data points are taken only every five metres in a square grid pattern, there is a very good chance that the peak will be missed altogether!

LINE AND STATION SPACING VS. ANOMALY WIDTH

To be certain that you have detected an anomaly, you need a minimum of two data points to define it. In order to get at least two data points to position an anomaly along the survey line, the station spacing should be less than half the expected width of the target. In order to determine the strike length of a body, the same holds true for the line spacing—it should be less than half the expected length of the target, in order to have at least two survey lines crossing the target. This *detectability* threshold of twice the sample spacing is also referred to as the *Nyquist frequency*. Figure 14 illustrates these points.

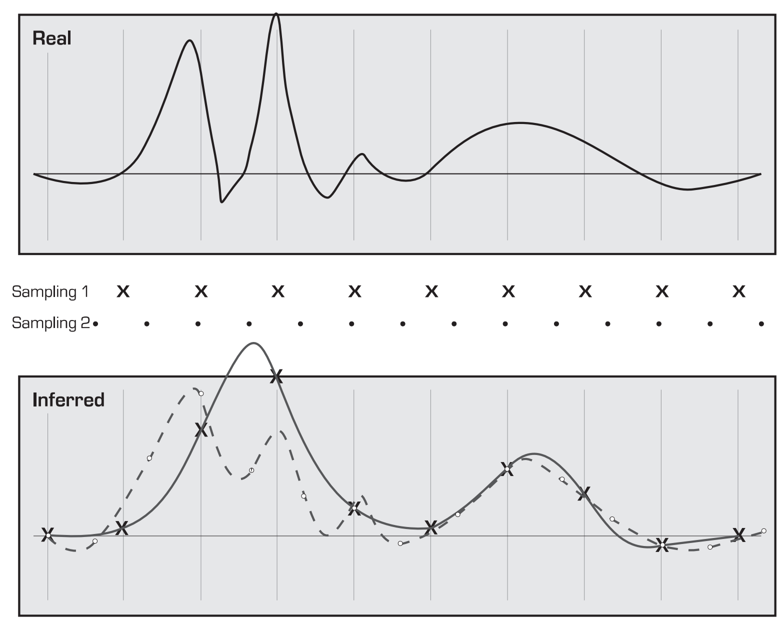

Figure 14 Sampling interval and anomaly resolution.

PRECISION AND ACCURACY OF SURVEYS

Once you have determined the line and station spacing, you should also take into consideration the sources of *noise* (both natural or man-made). Once you have made a decision regarding the accuracy and precision of the data you require, then you can consider the method of surveying best suited to give those results.

NOISE

The most commonly encountered sources of noise in the data are the time-based (diurnal) variations we had discussed in "Variations in the Earth's magnetic field" on page 9. These are natural variations and can be removed using either base-station corrections, tie-line corrections or by measuring the vertical gradient of the magnetic field. The procedures to carry out these correction methods will be discussed in the next chapter.

Of the man-made sources of noise, or *cultural* noise, the most prevalent are electromagnetic and electrical fields. These sources, if strong enough, can seriously hamper *any* magnetometer survey. Therefore, surveying directly under power lines, since they will disturb the magnetic field you are trying to measure, can be problematic. Other sources of cultural noise in typical waste dumps are the many buried ferrous objects near the surface. Some of these objects, such as tin cans, bed springs, appliances, etc., can introduce unwanted magnetic spikes in the overall results.

As previously mentioned, you may want to remove the natural time-based variations from your data. You may choose to perform these corrections in the tie-line mode or base-station mode or perform a gradiometer survey. However, each of these methods has a *cost* associated with it. The tie-line method is *less* accurate than the base-station, especially if a long period of time has elapsed between tie-points. The base-station method, on the other hand, requires the use of *two* magnetometers and this may not be a feasible alternative in certain cases. The gradiometer approach is intermediate in cost, as only one unit is required, but you are compromising your ability to detect deep and subtle anomalies, since you are only measuring the rate of change of the field.

Another source of noise, affecting only proton-precession magnetometers (i.e. the ENVI-MAG) is *Doppler noise*. This is caused by the the rotation of the sensor in the Earth's field while walking (i.e. in the WALKMAG mode only).

SURVEY MODE

Once you have determined the degree to which you need noise removed from the data, you will need to select the appropriate survey mode.

WALKMAG

The most commonly used mode of operation in environmental applications is the WALKMAG mode. With the SMARTMAG, the operator can take almost continuous readings (at sampling rates of up to every 0.1 seconds) in this mode. For a walking pace of 3 km (2 miles) per hour, data will be collected at approximately every 10 cm. This tight spacing of data is necessary for the very shallow targets that are usually encountered in environmental applications. With the ENVI-MAG sampling rates of 0.5 seconds can be used. this equivalent to readings approxiamtely every 0.5m at the same walking pace.

Figure 15 on page 24 illustrates the set-up for a WALKMAG survey.

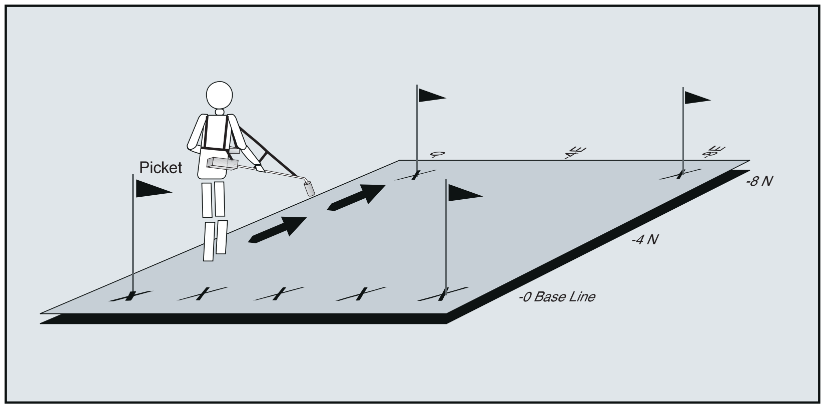

Figure 15 Set-up for a WALKMAG survey.

Stop-and-Go

For larger and deeper targets; at depths below 30 metres (100 feet), such as those more often encountered in mineral exploration applications, it is possible to operate in the *stop-and-go* mode with automatic station incrementing. Data for this case would be taken typically at a 15 metre (50 feet) station spacing—remember, you need at least two points to define an anomaly, which is why the station spacing is half that of the expected depth. This is illustrated in Figure 16 on page 25, which shows the set-up of a stop-and-go survey.

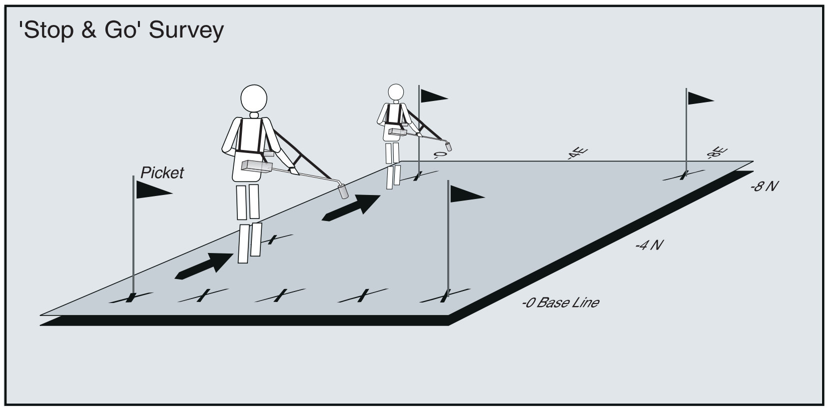

Figure 16 Set-up for a Stop-and-Go survey.

Gradiometer

You can also perform the survey using the gradiometer mode. The gradiometer survey is carried out using either two vertically or horizontally spaced sensors.typically the vertical gradiometer sensor spacing is one metre (3 feet). The magnetic field reading is taken for each sensor and the difference is divided by the distance. The measured value of a gradiometer survey is expressed as nanoTeslas per metre (nT/m). This mode has the advantages of being totally independent of time-based variations, since it measures a *difference* in magnetic fields.Also, for the ENVI-MAG, the gradiometer mode suppreses the motion (or Doppler) noise. However, especially for environmental applications, this mode is more sensitive to near-surface objects, which can be a disadvantage. Figure 17 on page 26 illustrates the set-up for a gradiometer survey.

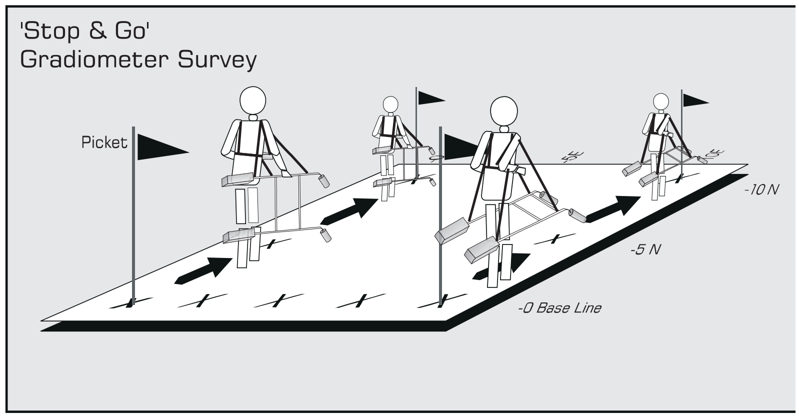

Figure 17 Set-up for a gradiometer survey in the Stop-and-Go mode.

FIELD OBSERVATIONS

Finally, to help in the interpretation of the final data, it is very important to *note* all possible sources of noises, i.e. *cultural* features, encountered during your survey. When you are examining the data after it has been plotted, the ability to correlate *known* noise sources with the anomalies on your map aids in the proper identification of the *buried* targets.

GRID LAYOUT AND ORIENTATION

The underlying principle behind the layout of a survey grid is that the survey lines should cross linear bodies at or close to 90 degrees. For very long and narrow structures, such as are encountered in mineral exploration applications, the survey lines are laid out along lines that are perpendicular to the strike of suspected body. This optimizes the coverage of each line.

Long structures or bodies which are aligned in a parallel fashion are not usually encountered in environmental applications (except pipelines). The direction of the targets are most often random. Consequently, most environmental grids are laid out in square pattern.

SURVEY PROCEDURES AND A SAMPLE SURVEY

INTRODUCTION

Once you have considered all the factors as to the type of magnetometer survey required, then you are ready to design and lay out a grid to cover the area of interest. This chapter will cover some aspects of laying out a grid and actually conducting a survey. Finally, a brief discussion of an actual survey undertaken of the Columbia test site at the University of Waterloo in Ontario, Canada, will be presented.

SURVEY DO'S AND DON'TS

LAYING OUT THE GRID

A survey grid usually consists of a base line and one or several tie lines. The base line serves as a zero reference line for the grid, and the tie lines serve to correct the skewness of the survey lines. From the base line are drawn survey lines perpendicular to the base line.

With a square survey grid, the station separation on each line is identical to the line separation.Therefore, every data point collected is on a corner of a square. Typical environmental grids consist of survey lines spaced every metre or two, with data points every metre. The following figure (Figure 18), illustrates a typical survey grid, with base lines at 0 and 40 and survey lines every two metres.

Typical Survey Grid

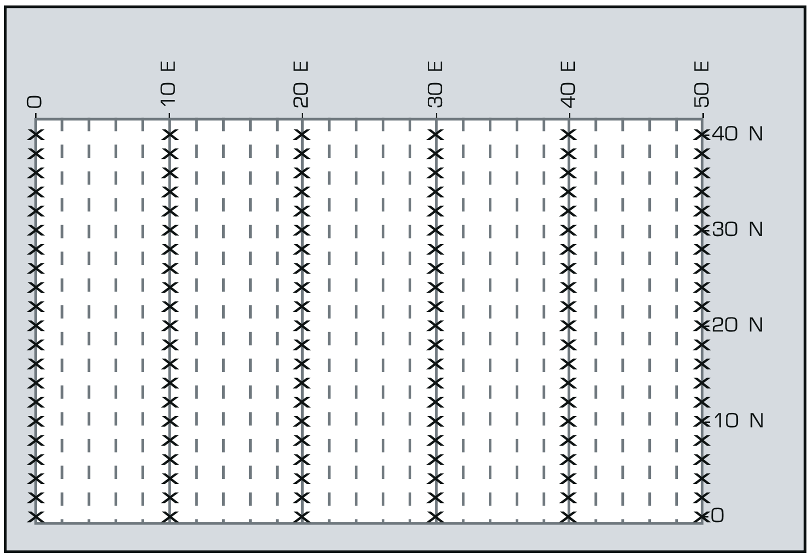

Figure 18 Typical survey grid for environmental applications.

A typical sequence to lay out a grid is as follows:

1. First you must lay in the base line; this is done using a chain (50 or 100 metre measuring tape). Major intervals such as 5 or 10 metre lines can be marked with pickets or flags for a more prominent visual reference.
2. Then mark each survey line with wooden stakes driven into the ground. The heads of the stakes should preferably be marked with fluorescent paint. The base line implementation is illustrated in the following figure (Figure 19).

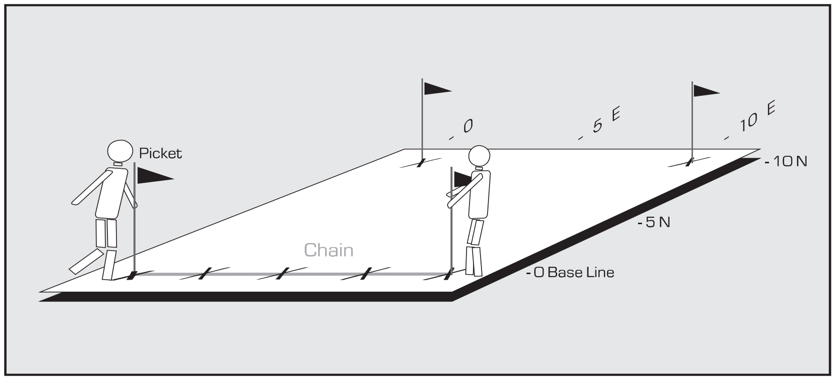

Figure 19 Base line implementation.

3. Once the survey lines are marked on the base line, then you should lay in the survey lines, using wooden stakes or flagging tape to mark you survey stations. For typical environmental applications, the stations may be at every 10 metres. You may also choose not to mark every survey line, but only survey lines every 5 metres. The position of the intermediary survey lines would be approximated by the operator. This is illustrated in the following figure (Figure 20).

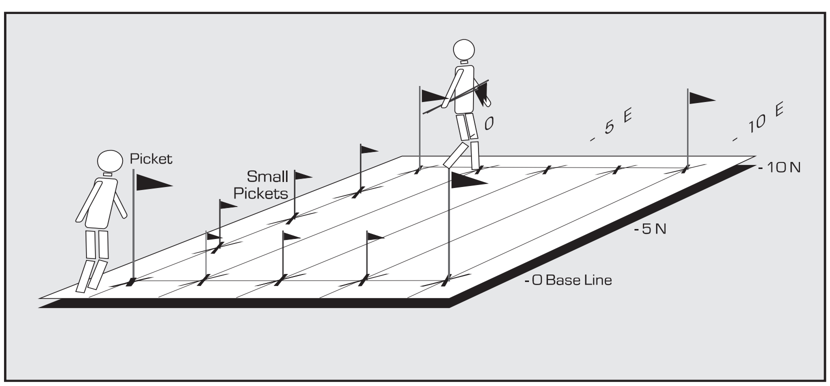

Figure 20 Typical flagged survey line.

These survey stations will serve as reference points to locate your data points on the survey grid and eventually to locate data points on a scaled map of your data. This map will in turn be used for your interpretation of the data.

As illustrated in Figure 20 on page 30, survey lines and stations are usually labelled in the manner **NN D**, where **NN** represents the major digits of the distance and **D** represents the direction of the line. For example, a typical environmental grid with survey lines oriented in a north-south directions located every metre and with marked stations every 10 metres would have survey lines labelled 1E, 2E, 3E, etc. and stations along these survey lines labelled 10N, 20N, 30N,...etc.

Multiple grids

As is often the case, you may want to survey several grids in the course of a single day without having to dump the data after each grid. The SMARTMAG and ENVI-MAG do not store any information about which grid a particular set of lines belong to. If identical line numbers are present on different grids, we strongly recommend that you enter a *different* line number for the second identical line. You can systematically shift the line by either adding a digit in the least significant location or offsetting the line by adding a large value, such as 1000. For instance, if you have two lines 100E, one on grid A and one on grid B, the second line 100E on grid B could be entered as either Line 101E or 1100E instead, to avoid confusion when processing the data.

Diurnal corrections vs. Survey pattern

The type of data correction procedure you will be using, also influences the *survey pattern*, i.e. sequence of lines and stations occupied. The base-station and gradiometer methods let you cover the grid in any sequence you wish. The tie-line and loop methods, on the other hand, require fixed patterns to be effective.

Base-station corrections

In some specific situations you may choose to use a second magnetometer as a base-station, which will measure the magnetic field for time-based variations at specific time intervals—every 20 seconds, for instance. As its name implies, this base-station magnetometer is located at a fixed location.

The magnetometers *must* be synchronized to the same time to allow for proper corrections when removing the time-based variations. If the two magnetometers are not properly synchronized, you may end up effectively *adding* noise to the corrected survey data. This synchronization should be done at the beginning of every survey day.

Once the magnetometers are synchronized and the base-station started, then the survey can be carried out. The base station is taking measurements independently of the survey magnetometer. Therefore, the survey can proceed without any undue time constraints, nor are you required to follow a specific line and station pattern to cover the grid. We shall see in the next section that this is not always the case for tie-point corrections methods.

Tie-point Line and Loop mode corrections

If you want to remove the time-based variations, but only have one magnetometer, you could choose to carry out either a tie-line survey in line or loop mode. If you a fairly small area to survey, i.e. can be done quickly, then the loop method is adequate. For larger grids, the line mode is recommended. However, it should ne noted that neither of these methods are as accurate or precise as the base-station correction. A technical paper on this subject (*Magnetic Correction Techniques*) is available from SCINTREX.

The tie-point line method uses data collected along the base line (or rarely, tie-lines) as reference points to correct for the diurnal drift of magnetic data. The following figure (Figure 21 on page 33) illustrates a typical tie-point line method survey.

The basic sequence is to survey the base-line as quickly as possible, taking readings at every line that crosses the base-line. This data is entered into a special memory section when recorded with the "TIE-PT" key. You then proceed to survey the grid on a systematic basis. As you proceed along the grid, you will then be occasionally taking readings at known stations (those collected with the "TIE-PT"). This repeating of measurements at certain stations is then used by the correcting procedures (performed after the survey) to remove any diurnal variations detected.

If you will be surveying a large grid, that may take more than one day (or more than one instrument's memory capacity), then you *must* record all of your tie-line data *before* any other grid survey data is collected. This ensures that the data from the second and subsequent days (or second memory full) are reduced to the *same* set of correction values..

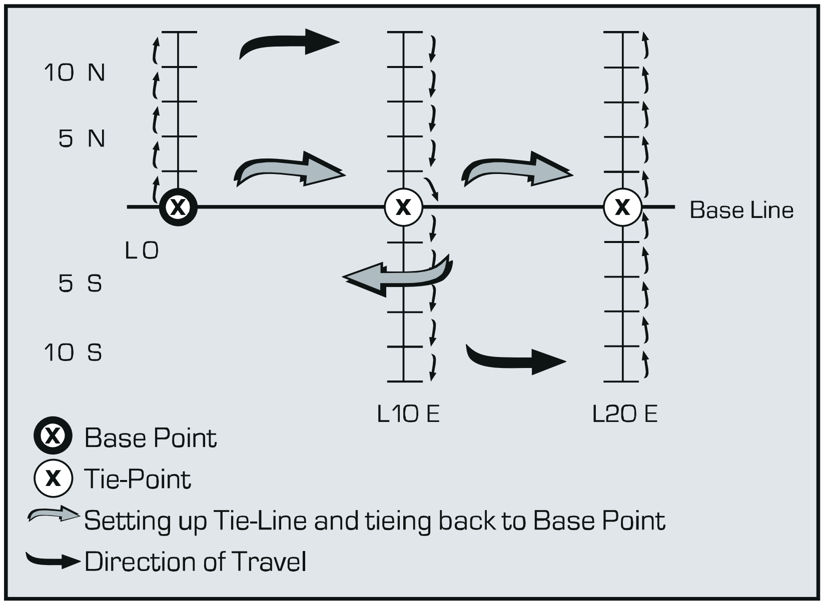

Figure 21 Typical tie-point method in line mode survey.

The tie-point loop method requires a *single* reference point to be resurveyed many times to correct for diurnal drift. The sequence of collecting data for this method is illustrated in Figure 22. You may note that the more lines you have to survey, the longer it will take for you to get to the reference station to get the control reading. Compare this to the tie-point line method shown in the Figure 21 on page 33

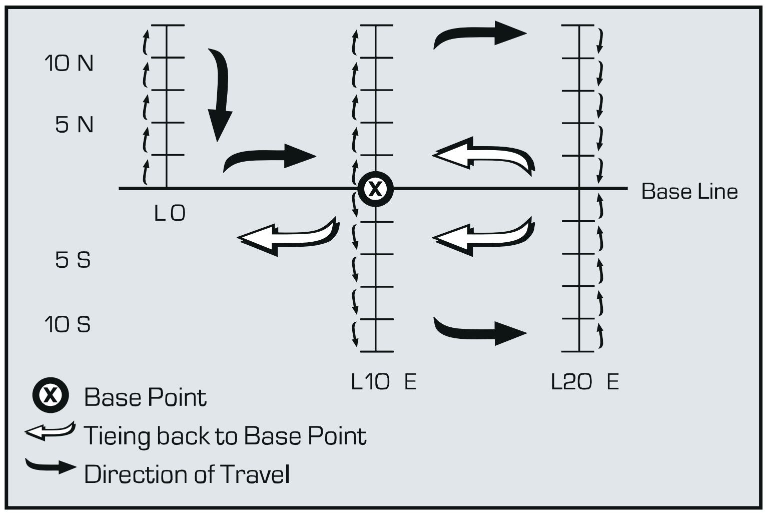

Figure 22 Typical tie-point method in loop mode survey.

SEARCH MODE

Another useful survey mode for the rapid detection of near-surface ferrous objects is the *search* mode. This mode is a variation of the base-station mode with the data being displayed on the instrument screen as it is collected. This can be very useful for metal ordnance detection. A detailed explanation of using this mode is explained in the operations manual.

NOTE TAKING

Recording field information, i.e. *notes*, is very important for the subsequent interpretation of the magnetic survey results.

Typical cultural features that should be noted are: fences, power lines, surface debris, roads and buildings. These features should be noted when they are in close proximity to the point at which you are taking a reading.,You are then relating the disturbance in the magnetometer data with a specific cultural feature. If this is not done, and you don't happen to remember what was present at the specific location, you run the risk of having the cultural feature mistaken for a real anomaly.

The taking of notes is done quite easily with the console for either the SMARTMAG or ENVI-MAG using the "NOTE" key. You can pre-enter a choice of five cultural noise sources (*macros*) that you are most likely to encounter during the survey. The complete description of setting up this feature can be found in the instrument section.

SURVEYING IN THE WALKMAG MODE

There are some very interesting features about the SMARTMAG. First and foremost, it is a true WALKMAG type magnetometer, with nearly continuous readings (every 0.1 seconds). This allows you to produce a continuous profile of your magnetic data collected along the survey line. The WALKMAG feature also allows you to update the major station locations. This updating is performed manually when you cross the stations separated by the distance increment—each 10-metre station for instance.

The ENVI-MAG has the same features, except that it will take readings at the fastest rate of 0.5 second intervals. The back-pack mounted sensor is used in this mode with the ENVI-MAG and is illustrated in the following figure (Figure 23).

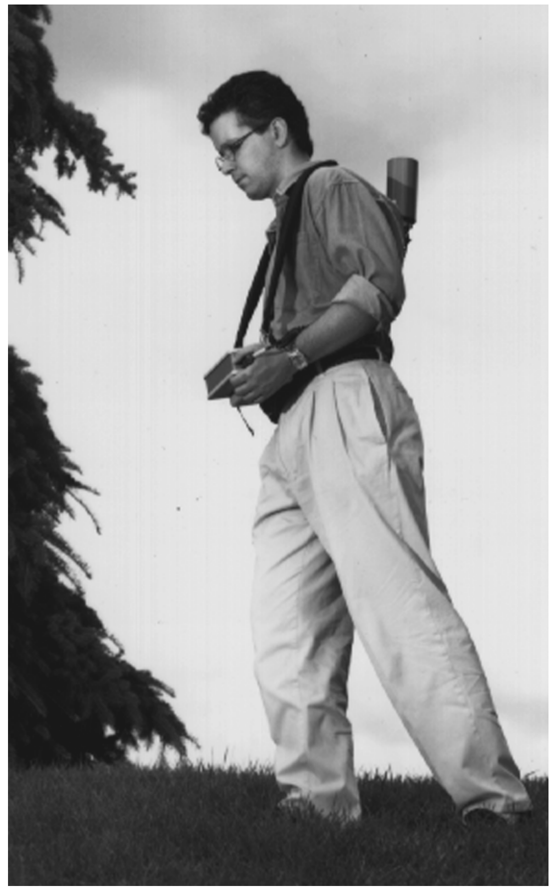

Figure 23 ENVI-MAG back-pack mounted sensor for the WALKMAG mode.

Rough Terrain

You may find that in certain circumstances, such as sloped terrain where progress is much slower than on flat terrain, it is quite difficult to maintain the same station density — as you slow down, more data is being collected over the same amount of lateral coverage as on level terrain. To even out this coverage, you can specify a longer cycling time (greater than the 0.5 seconds you have chosen, for example). Alternatively, you can introduce an additional delay in the cycle time, (the "CYCLE DELAY" feature), prolonging the time interval between readings and allowing you to maintain a more even coverage of your grid.

Station lag and Herring-boning

The measurement that you make with the either the ENVI-MAG or SMARTMAG does not take place immediately due to the cycle time of the instrument, which is at best 0.1 seconds. Consider also, that during a WALKMAG survey you, the operator, are continuously moving. Is there going to be a problem when you change directions? With some other instruments, this inherent *lag* in the data would create very distinct *herring-bone* patterns in the contoured data, as illustrated in the following figure.

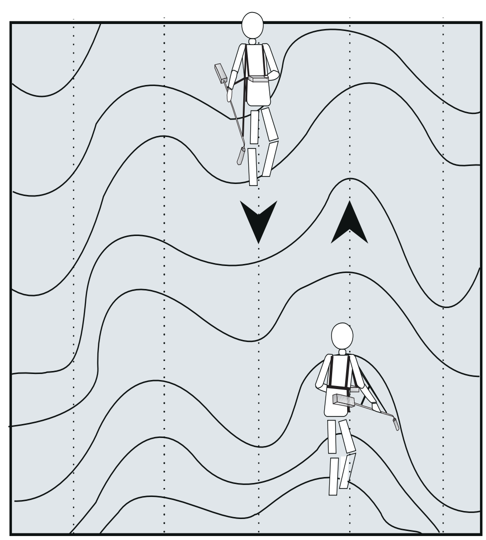

Figure 24 Typical herring bone patterns in contoured data.

This pattern is present to some degree in all surveys with continuous data collection, where the sensors and instruments are not exactly *spatially* coincident. To minimize any problems, the internal software in the ENVI-MAG and SMARTMAG automatically tries to correct this lagging phenomenon.

SURVEYING IN THE STOP-AND-GO MODE

You can also acquire data in the stop-and-go mode with automatic station increments. This mode is most commonly used in mineral exploration surveys, where the targets are usually larger and deeper than in environmental applications.

Figure 25 SMARTMAG (wide horizontal gradient configuration) being used in the Stop-and-Go mode.

Important: It is very important that the sensor be maintained in a constant and proper orientation for each line.

Magnetic cleanliness

Certain precautions must be observed before taking readings with a magnetometer. You, as an operator, should be devoid of any metallic objects on your person, such as belt buckles, rock picks, steel-toe boots and compasses. These metallic objects will interfere with the normal reading taken by the magnetometer and produce spurious data.

Monitoring your data

Once data have been collected, either on a single line or the entire grid, you can review the data on the console's display screen. This will allow you to visually locate anomalies, as well as, determine the intensity of the anomalies. This is done using the SMARTMAG or ENVI-MAG console's graphic display capabilities of the data.

You can also visually monitor the magnetic activity at your base station with this feature. These features are well explained in the operations manual section and you should refer to this section starting for further details.

POST-SURVEY PROCEDURES

CLEAN-UP SITE IF REQUIRED

Once the data is collected, it is a good procedure to remove all stakes and markings left behind, therefore avoiding further damaging the environment.

DATA CORRECTION

The survey data collected should be corrected at the end of the survey day or the end of the grid. The procedures to perform data correction are explained at length in the instrument operation section. However, there are some points that are useful to mention at this stage.

Data correction is done automatically while the survey is carried out in the tie-line mode. However, when using a base station the survey data is corrected with the data from the base station.

Warning: Once the data has been corrected with the base station, the raw uncorrected survey data can no longer be retrieved.

DATA TRANSFER

It is a good procedure at the end of each survey day to transfer the data acquired during the day. You can keep the equivalent of two days' data for a typical environmental survey in the magnetometers' memory, but it is not considered good procedure. The instructions to transfer (or dump) the data are explained in the operations manual.

The data can either be dumped on a line-by-line basis or as an entire data set. You would normally perform a line-by-line dump, if you intended to produce individual profiles. Alternatively, you would do an entire data dump, if you intended to produce a contour map.

PROCESSING DATA

Once the data is dumped, you can perform many procedures to enhance the presentation of the data. Data can be presented as contour maps or as profiles of the measured values. In the case of multiple grids it is recommended that processing be done for each grid separately. You will have to manually edit your data file into separate data files for each grid.

The steps to producing a contour map or individual profiles are well explained in the third section of the manual on the ENVIMAP software.

Further processing of the data can be carried out using the *optional* GEOSOFT map processing software. This optional software allows you to create colour plots, image maps and 3-D presentations, as well as providing enhanced gridding, modelling and interpretation tools. Contact your SCINTREX representative for more details.

FIELD EXAMPLE

COLUMBIA TEST SITE – WATERLOO, ONTARIO

The Columbia test site is located on the grounds of the University of Waterloo, in Waterloo, Ontario, Canada. Three different types of targets are buried at this site: 45 gallon steel drums, pipes and sheets of metal. These targets are buried at different depths and in different groupings. A sketch map of the Columbia test site is shown in the following figure

Columbia Test-Site: Plotted next to the hazards are their burial depths.

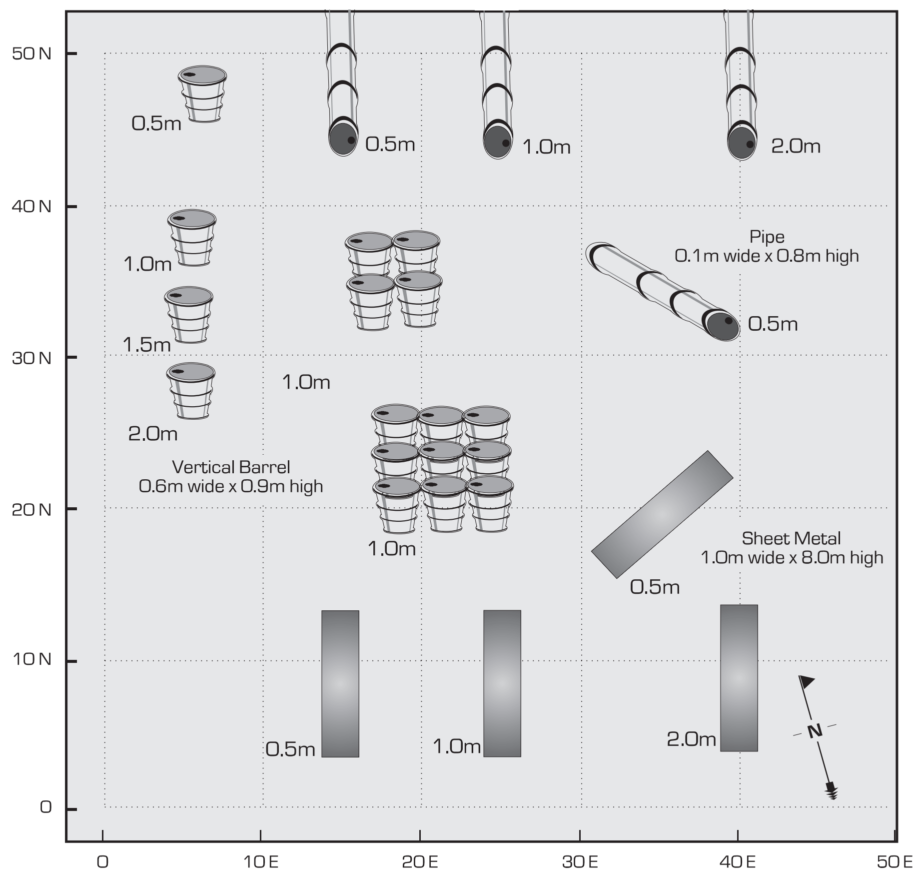

Figure 26 Columbia test-site.

Grid layout

The shallow burial depths of the targets, between 0.5m and 2.0m, required a tight grid spacing be chosen. Ideally a square grid with a line spacing of one (1) metre should be used for this type of site. This was the case. For the same reason, the WALKMAG mode with readings taken every 0.1 seconds and stations updated every 10 metres was used for this type of site.

The following figure shows a site being surveyed in the standard WALKMAG, as well as the automatic gradiometer mode.

Figure 27 Surveying a test site in the Gradiometer (left) and WALKMAG (right) modes (SCINTREX SMARTMAG).

The results of an ENVI-MAG survey over the Columbia test site are presented in the following captions in contoured data form for the total field survey and in profile form for the gradiometer survey. Figure 28 on page 46 illustrates the contoured total field data and Figure 29 on page 47 the contoured vertical gradiometer data.

BIBLIOGRAPHY

Benson, R., Glaccum, R.A., Noel, M.R., 1982, *Geophysical Techniques for Sensing Buried Wastes and Waste Migration,* National Ground Water Association, Dublin, Ohio, 236 pp.

Landry, B., Mercier, M., 1983, *Notions de Géologie, Modulo diteur,* Outremont, Québec, 426 pp.

Westphalen, O. and Rice, J., 1992, Drum Detection: EM vs. Mag. Some revealing tests*; Proceedings of the 6th National Outdoor Action Conference,* p.665-688.

Telford, W.M., Geldart, L.P., Sheriff, R.E., Keys, D.A., 1976, *Applied Geophysics,* Cambridge University Press, New York, 860 pp.

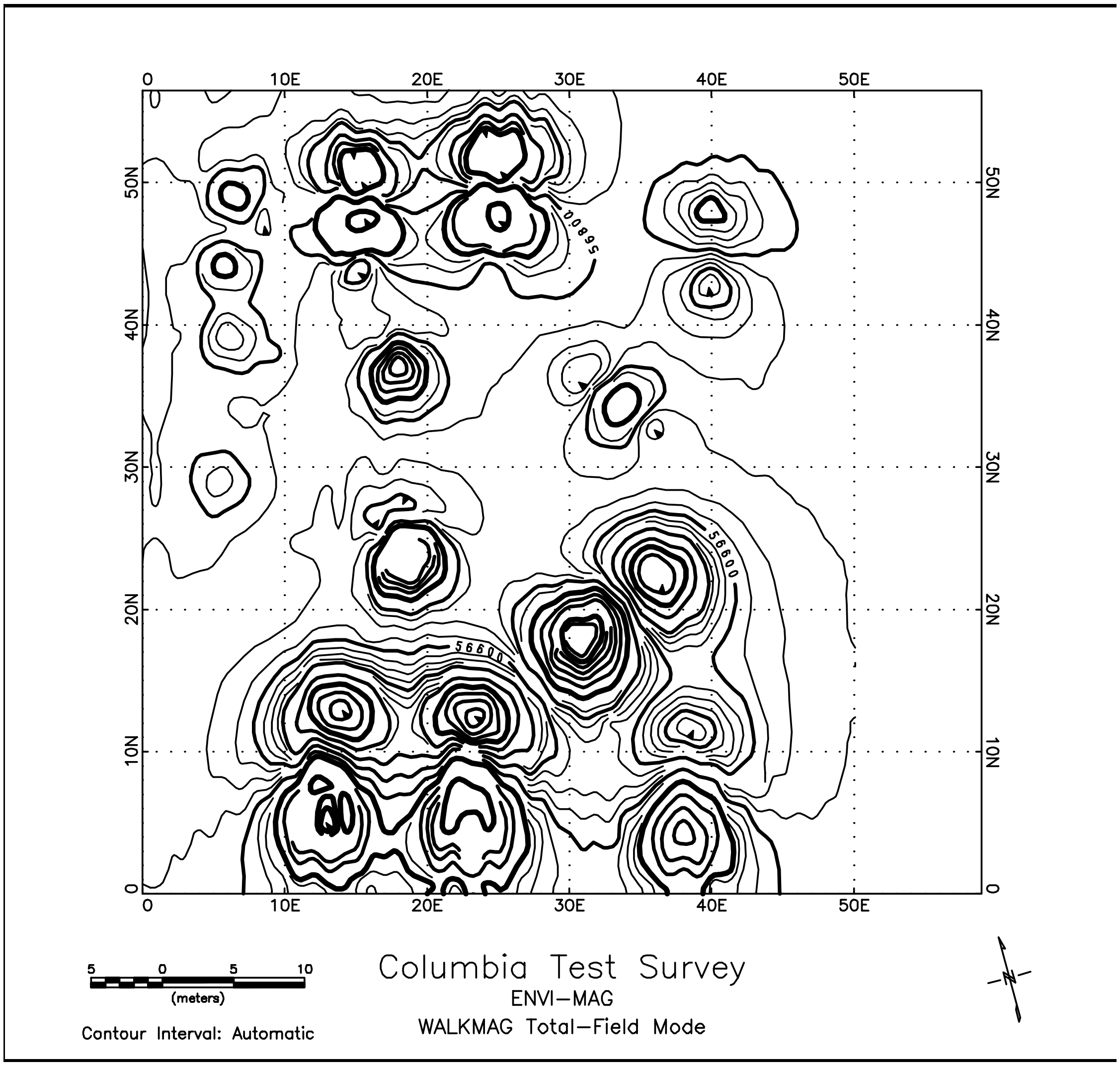

Figure 28 Columbia test site total-field contoured data.

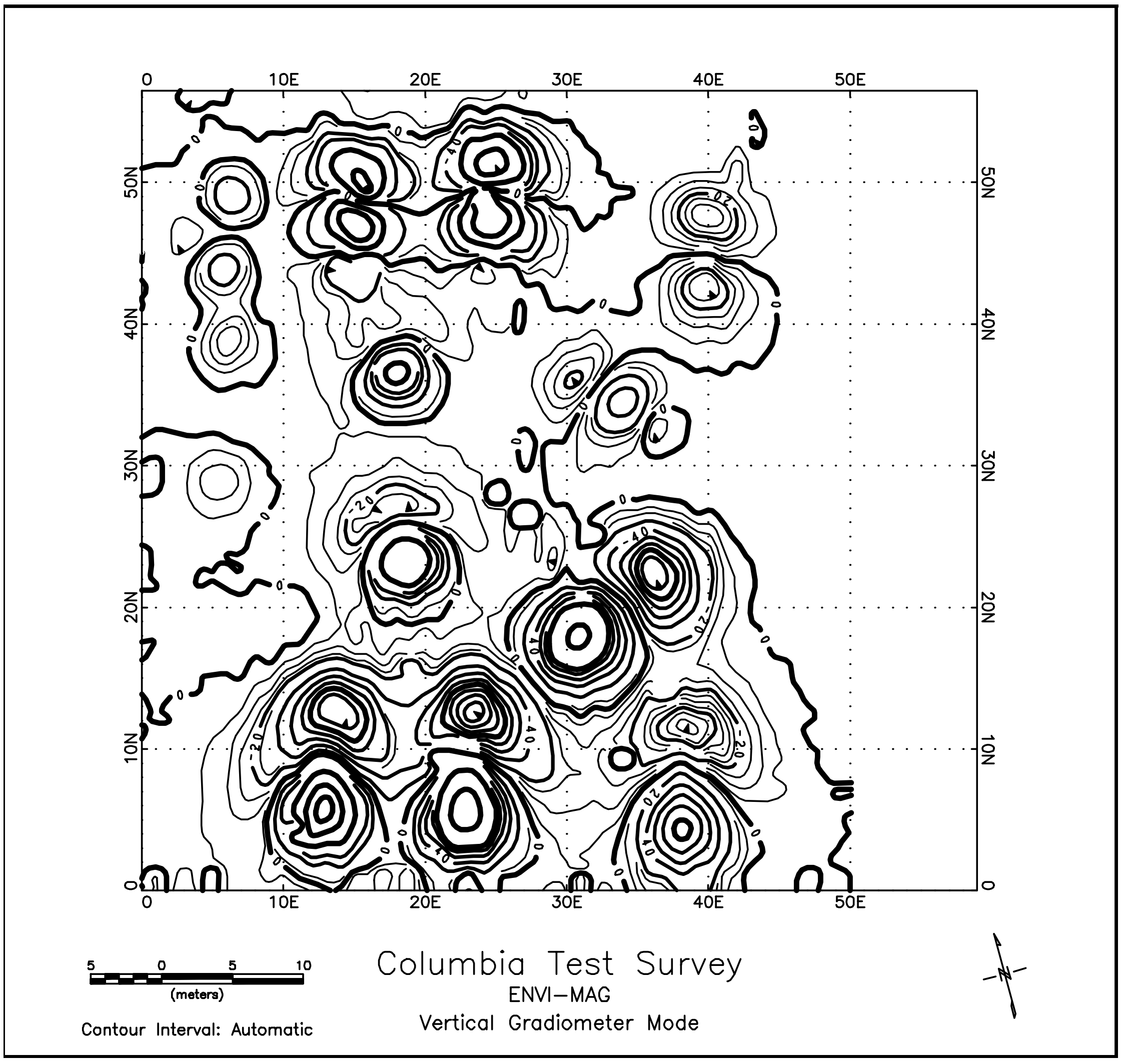

Figure 29 Columbia test site vertical gradient contoured data.

Index