APPENDIX C
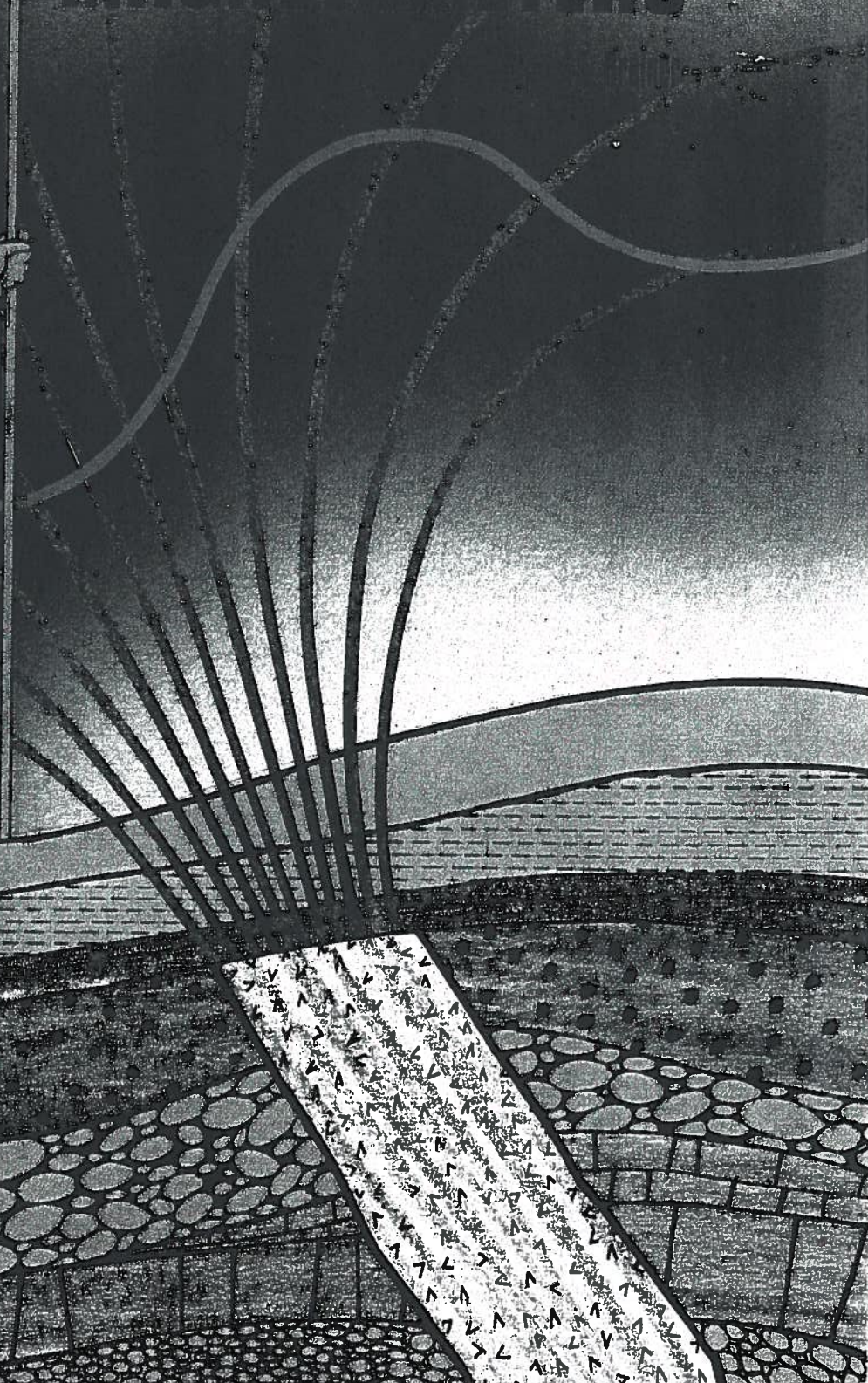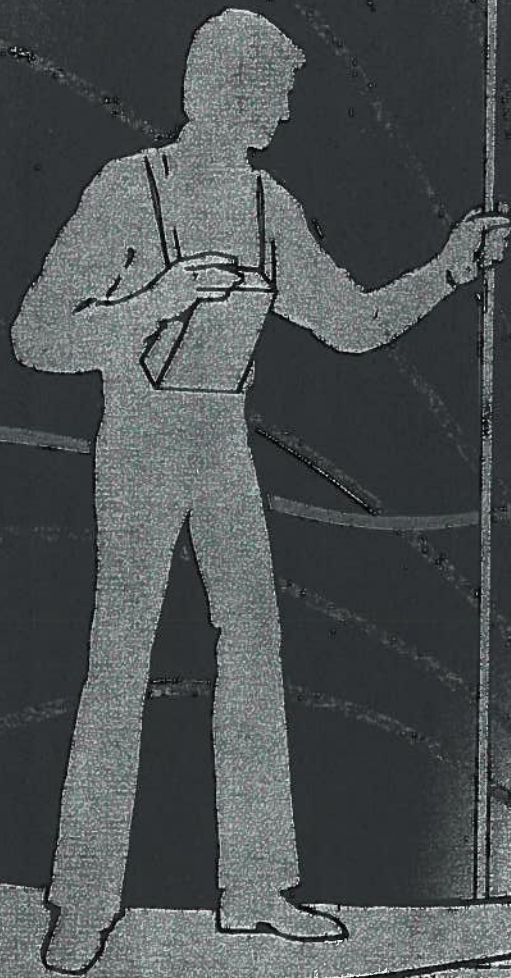
MAGNETIC INTENSITY METHODS

Applications Manual for
PORTABLE MAGNETOMETERS

APPLICATIONS MANUAL

FOR

PORTABLE MAGNETOMETERS

by

S. BREINER

GeoMetrics
395 Java Drive
Sunnyvale, California 94086
U.S.A.

V.

INTERPRETATION

Introduction

Total magnetic intensity disturbances or anomalies are highly variable in shape and amplitude; they are almost always asymmetrical, sometimes appear complex even from simple sources, and usually portray the combined magnetic effects of several sources. Furthermore, there are an infinite number of possible sources which can produce a given anomaly. The apparent complexity of such anomalies is a consequence of the net effect of several independent but relatively simple functions of magnetic dipole behavior. With an understanding of these individually simple functions however, and given some reasonable assumptions regarding the geology, buried object or whatever other source one is seeking to understand, a qualitative but satisfactory interpretation can usually be obtained for most anomaly sources.

The interpretation, explanation and guide presented here is directed primarily towards a qualitative interpretation for both geological reasons as well as search applications, i.e., an understanding of what causes the anomaly, its approximate depth, configuration, perhaps magnetite content or mass, and other related factors. But even if qualitative information is derived from the data, it is important to have applied a reasonable amount of care in obtaining precise measurements. Quantitative interpretations are possible, but are applied more to airborne data, entail relatively complex methods for depth determination, and are the basis for a relatively large body of literature on the subject, references to which are given in the Manual.

An anomaly represents a local disturbance in the earth's magnetic field which *arises from a local change in mag-netization, or magnetization contrast* as it is termed. A profile, for example over a very broad uniformly magnetic surface, although magnetic itself, will not exhibit a magnetic anomaly as there is no local change in magnetization. A local increase or even decrease on the other hand would constitute such a change and produce a locally positive or negative anomaly.

The observed anomaly expresses only the net effect of the induced and remanent magnetizations which usually have different directions and intensities of magnetization. Since the remanent magnetization is so variable and measurements of its properties seldom made, *anomalies are all interpreted* in practice as though *induced magnetization were the total source of the anomalous effects.*

Asymmetry

The asymmetrical nature of total field anomalies is primarily a consequence of the directions of the field lines of the locally created magnet or source and the earth's-field-component nature of a total field magnetometer in the usually-inclined direction of the earth's magnetic field. Recall that a total field magnetometer measures only the component of any local perturbation which is in the direction of the earth's magnetic field at that point. Anomalies in the earth's field, whether created by induced or permanent magnetization, exist as arrangements of magnetic dipoles, monopoles (effectively), lines of dipoles and monopoles and sheet-like distributions of such poles. It is important therefore to understand the nature of the dipole or monopole field as it will be shown that a summation of such elementary forms will explain the most complex characteristics of anomalies and facilitate their interpretation. Notice, for example in *Figure 13*, the con-
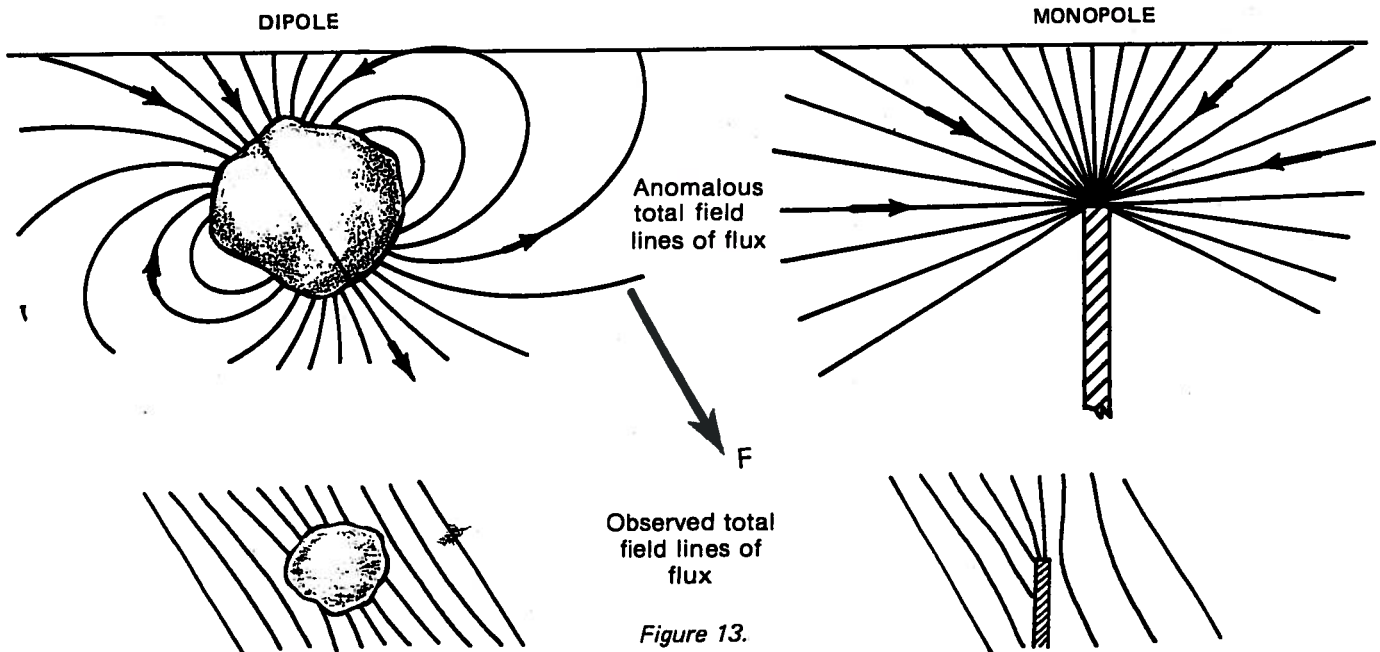
DIPOLE   MONOPOLE

Anomalous total field lines of flux

F

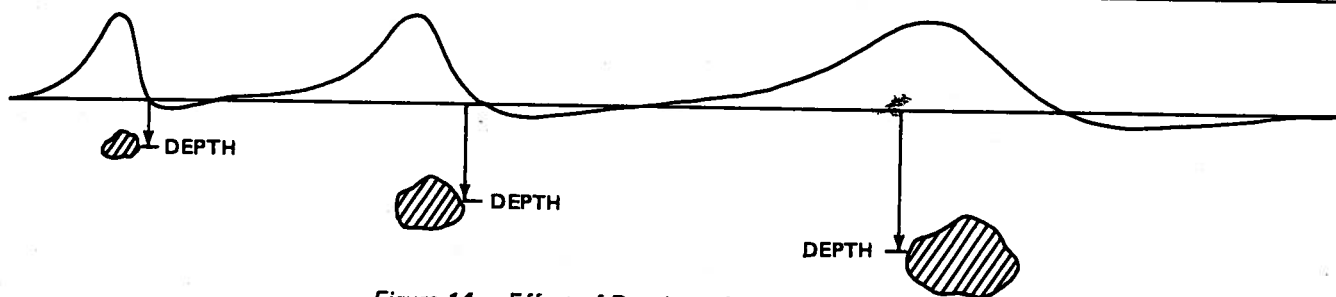Observed total field lines of flux

Figure 13.

17

Figure 14. Effect of Depth on Anomaly Width

figuration for such fields as they would appear if one were to measure the direction of the anomalous field.

Depth Dependence

Another significant characteristic of a magnetic anomaly is its variation with the depth between the magnetometer and source, the deeper the source, the broader the anomaly as expressed in *Figure 14*. It is this property which enables one to determine the approximate depth to the source independent of any other information concerning the source. *If one familiarizes himself with only one subject in this discussion on interpretation, it should be the general characteristics of anomaly wavelength, or width, as a function of depth.* A knowledge of this subject allows rapid and easy interpretation of anomalies of interest when numerous anomalies arising from various depths appear in the observed total intensity profile.

Other Anomaly Shape Factors

Other factors which affect the anomaly shape and amplitude are the relative amounts of permanent and induced magnetization, the direction of the former, and the amount of magnetite present in the source compared to the adjacent rocks. The actual configuration of the source, that is, whether it is narrow, broad or long in one dimension and its direction in the earth's field, also control the anomaly signature.

Geological Models

Geological anomalies are interpreted in terms of much simplified geological models which very much facilitate interpretation procedures. The first simplification is the assumption that magnetization is uniform within some elementary prismatic form and that the magnetization is different outside this form, i.e., there is a magnetization contrast. Typical of the kinds of geologic sources that are assumed to cause anomalies are those which are shown in *Figure 15.*

As was stated, in any potential field method the given magnetic signature can be produced by an infinite combination of sources so that there is no unique interpretation. For example, the same anomaly could be produced by the peculiar distribution of magnetite (unrealistic geologically), and a uniform distribution of magnetite within the prismatic form (realistic), both of which are shown in *Figure 16*. It must be emphasized that not only are simplifications required, but a reasonable geologic framework must be used as a guide when considering the various possible sources. A typical set of anomaly signatures of various sources might appear as in *Figure 17.*

Elementary Dipoles and Monopoles

Since anomalies are explained herein in term of various arrays of dipoles and monopoles, it is important to examine their geometry and intensity characteristics. A magnetic dipole produces a field with imaginary lines of flux as shown in *Figure 18*. The intensity of the field, which is proportional to the density of the flux lines is drawn as lines of equal intensity to express this relationship. From *Figure 18,* notice that 1) the intensity of the dipole is twice as large off the ends of the dipole as it is at the same distance off the side of the dipole. This explains, for example, why the earth's magnetic field is approximately 30,000 gammas at the magnetic equator and 60,000 gammas at its poles; 2) the direction of the field off the side of the dipole is parallel to the dipole itself, but opposite in sense; 3) the direction of the tangent of the field lines of a dipole are parallel along any radial line from the dipole.

A monopole has field lines which point radially in or out from the positive or negative monopole respectively. The intensity is constant at a given distance and any direction from a monopole. In actual fact, there are no magnetic monopoles, but only dipoles whose ends are far apart. For all practical purposes, however, monopoles exist in terms of the distance to the source and such geological configuration as shown in *Figure 13.*
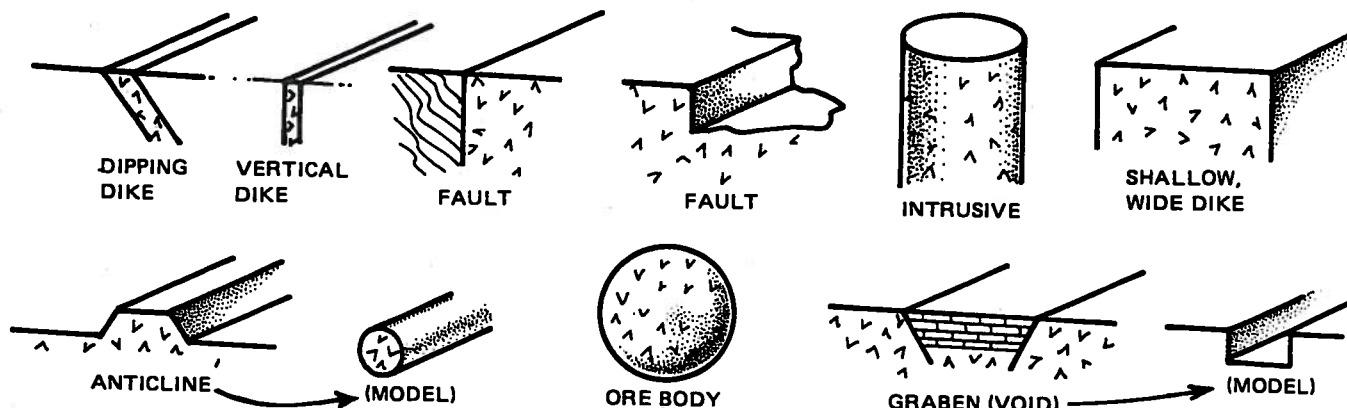

Figure 15. Geological Model Representations of Common Magnetic Anomaly Sources
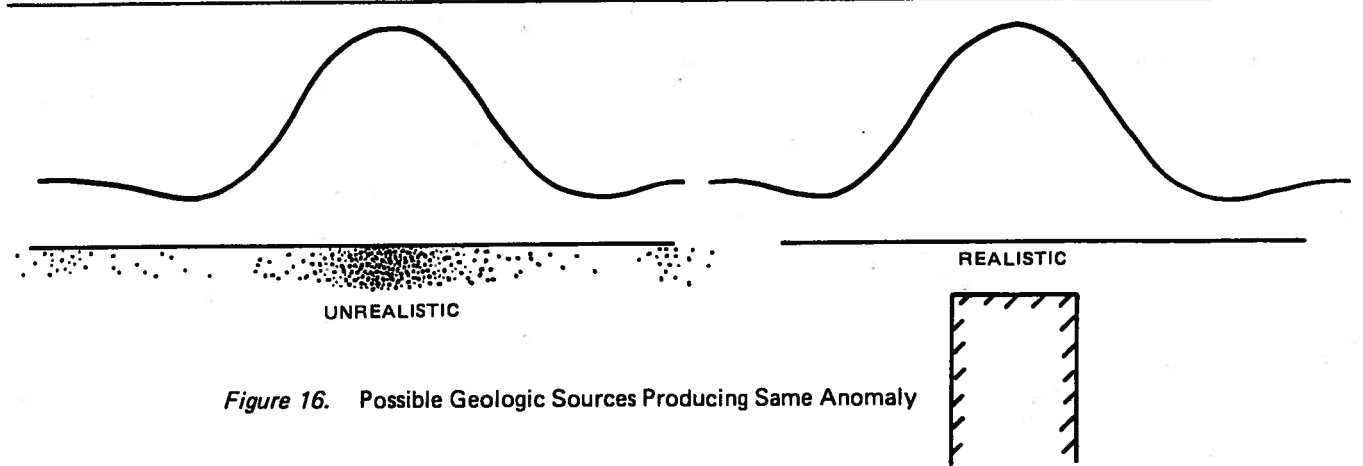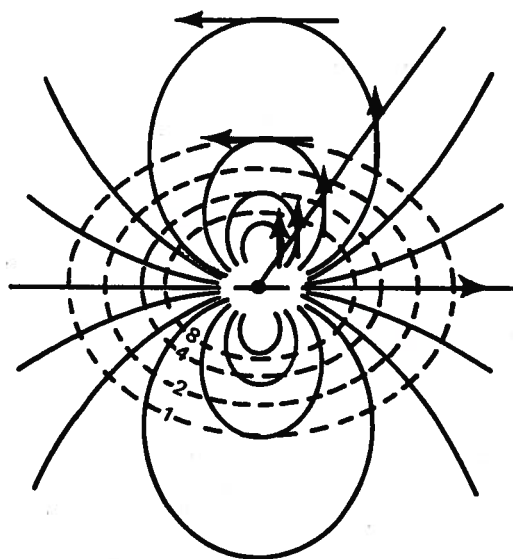
REALISTIC

UNREALISTIC

Figure 16.   Possible Geologic Sources Producing Same Anomaly

Having outlined the qualitative geometry of the intensity T from a dipole, the quantitative aspects can be considered as follows:

The intensity, T, from a dipole can be expressed as

$$T = \frac{2M}{r^3}$$ along the axis, i.e., off the end of the dipole,

and $T = \dfrac{M}{r^3}$ along a line at right angles to the dipole,i.e., off the side of the dipole,

and for a monopole

$$T = \frac{M}{r^2}$$ in any direction from a monopole, where

M = magnetic moment and r is the distance to the pole. A more detailed mathematical formulation for the intensity due to a dipole is given subsequently in this Chapter.

Simplified Method for Total Field Signature

From the above description of a dipole and monopole and with the knowledge of the earth's-field-component-nature of the total field magnetometer, it is possible to sketch the signature of an anomaly for any given orientation of the dipole (orientation caused by field direction, the direction of remanent magnetization, or by the configuration of the geology). It is helpful to draw such signatures at various inclinations of the magnetic field to understand where the sources would be located with respect to the signature, the dip of the magnetization producing the anomaly, and even for information related to the depth of the source. Remember that all anomalies can be considered as caused by various distributions of dipolar and monopolar sources and it is possible to produce any anomaly simply by the super-position of such dipole or monopole signatures derived here.
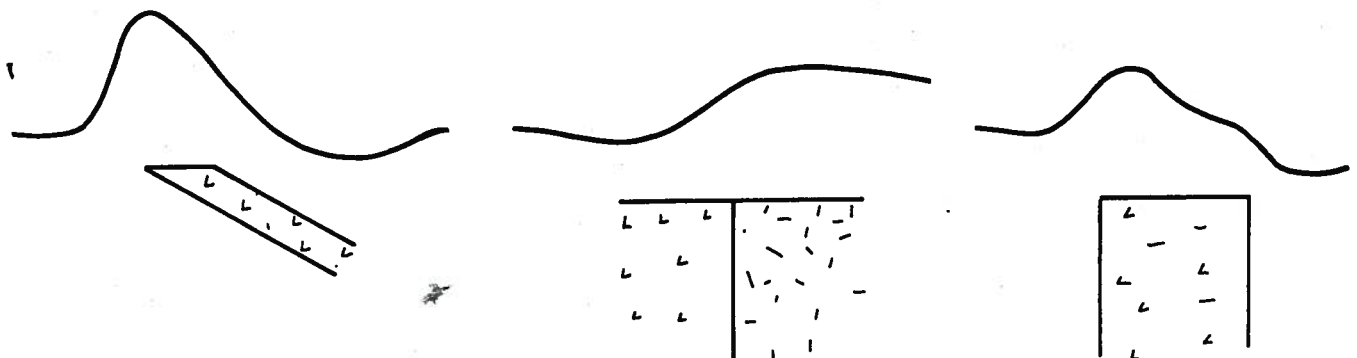

LINES OF FLUX (———)
AND
LINES OF EQUAL INTENSITY (— —)
FOR A DIPOLE

Figure 18.

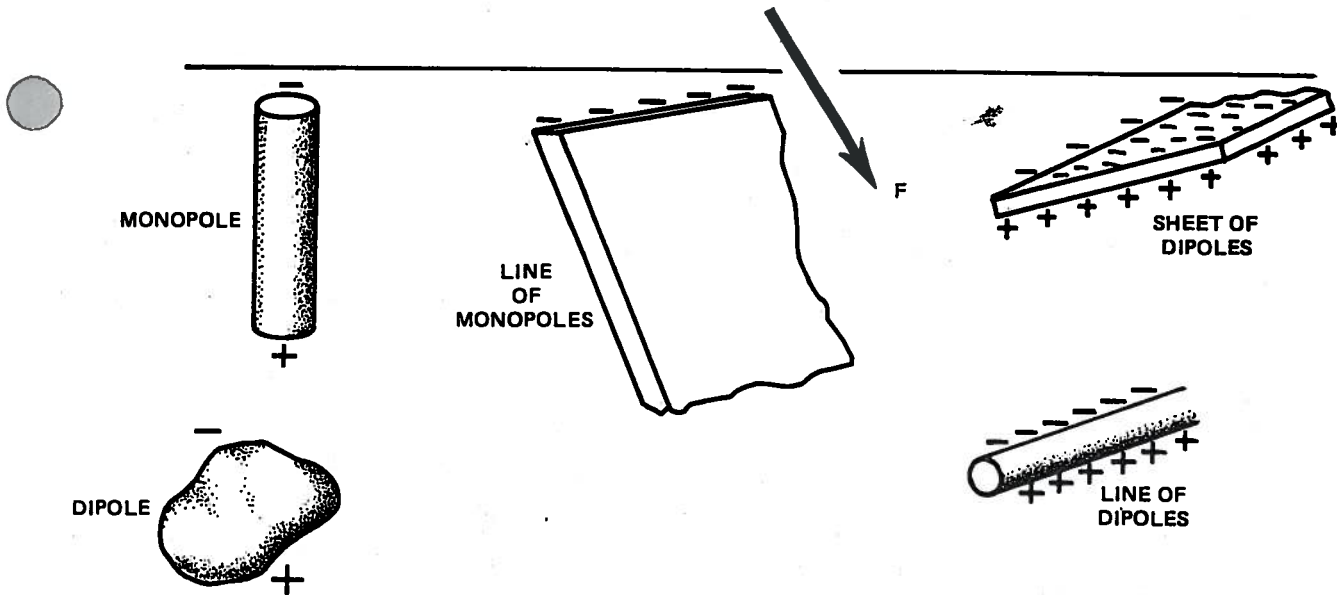Figure 17.   Typical Anomalies for Simple Geologic Models

Figure 19.

Earth's Field Component Behavior

This method of predicting or drawing the anomaly signature depends upon one property of the field, namely, inclination, and three properties peculiar to the dipole or monopole source, whichever is assumed. The dip of the earth's field is first considered because this is the direction, the only direction, of the components of any local magnetic anomalies which are measured by a total field magnetometer. (If one is using a vertical component magnetometer, this guide still applies except that instead of using the earth's field as the direction of measurement, simply use the vertical.) In other words, the magnetometer will only measure the component of a local perturbation in this direction, i.e., as projected into this direction. See *Figure 20.*

Dipoles vs. Monopoles vs. Arrays of Poles

The decision to use dipoles, monopoles, or other configurations as the model is based upon the manner in which the earth's field induces a local field and this in turn depends upon the configuration of the geologic body which exhibits the magnetization contrast and the direction of the field. For example, a long body which nearly parallels the earth's field will tend to be magnetized along its long dimension. Furthermore, if the body is sufficiently long with one end near the magnetometer, the anomaly will appear as a monopole seeing only the upper pole with the lower pole removed effectively to infinity. If the same long, thin body were normal to the field, it would then be magnetized through its thinest dimension producing the sheet-like array of dipoles as shown in *Figure 19.*

One may wish to draw on the typical models depicted in *Figure 15*, the array of poles from a uniform earth's field at various inclinations and orientations of the source. Whether the monopoles or the dipoles (and its equivalent line or sheet distributions) are close or far apart, determines if the model is to be considered a dipole or monopole, respectively *(see, for example, Figure 34).*

Configuration of Field Lines

The first property of the dipole or monopole which is to be considered is the configuration of the field lines *(see*

Figure 13). When superimposed upon the component which is measured by the total field magnetometer, it can be seen that the relative lengths of the disturbance vectors that are measured are those shown in *Figure 21* for an induced dipole and monopole source. It is the relative length of these disturbance vectors drawn along the total field direction that is measured, each disturbance vector, in turn, weighted by the intensity functions described below.

Dipole and Monopole Fall-Off Factor

The next factor to be considered is the variation of intensity with distance, i.e., $1/r^3$ and $1/r^2$ factors for the dipole or monopole fields respectively and as expressed in the preceding equations. The relative intensity for dipoles or monopoles as a function of distance to their centers as would be observed along a traverse is presented in *Figure 22* and described mathematically under "Anomaly Amplitude" below. This factor multiplies the length of net vectors in *Figure 21.*

Dipole Factor-of-Two

The last consideration really only applies to the dipole and that is a factor of 2 when one is off the end of the dipole compared to a position off the side. In other words, at a given distance, the intensity varies by a factor of 2 as a function of the angle between the radial line to the dipole and the dipole axis. This function is shown approximately in *Figure 23* for the dipole used in the example. The monopole possesses radial symmetry and therefore requires no such consideration.

Application of Method

A dipole and monopole signature is thus constructed in *Figure 24.* The amplitude is dimensionless, but can be compared to a real anomaly by multiplying by a single factor derived below from considerations of volume, susceptibility, etc. However, applying these factors even qualitatively should allow one to draw the dipole and monopole signatures for variously inclined fields and geometries. *Figure 25*, for example, is drawn free-hand for anomalies in vertical field (90° inclination), magnetic equator and mid-southern latitudes. By simply sketching in the earth's field direction and the dipole's field lines
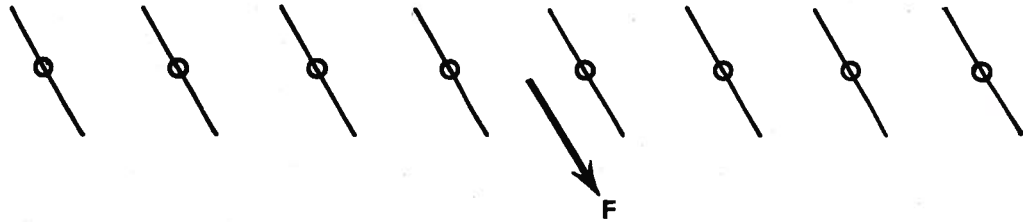
Figure 20.   Direction of Components Measured by Total Field Magnetometer
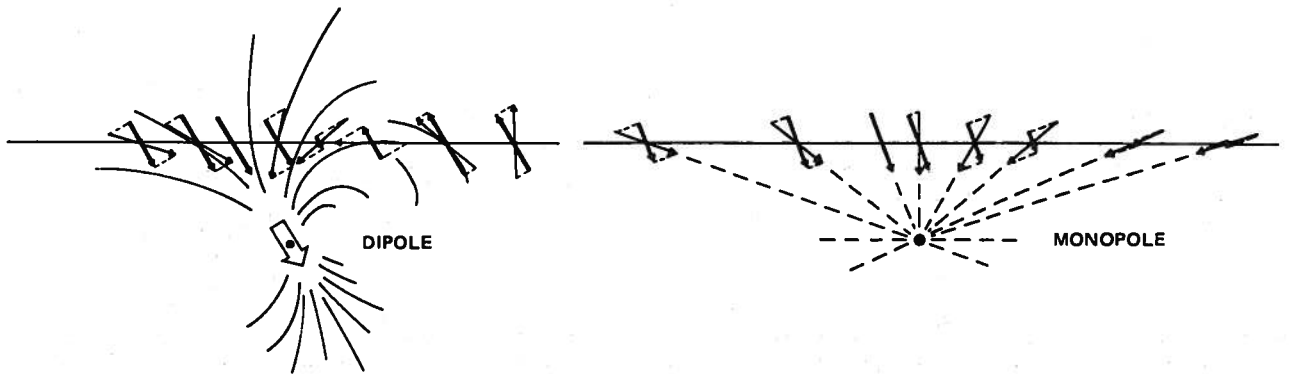
Figure 21.   Total Field Components of Tangent to Field Lines of Dipole and Monopole
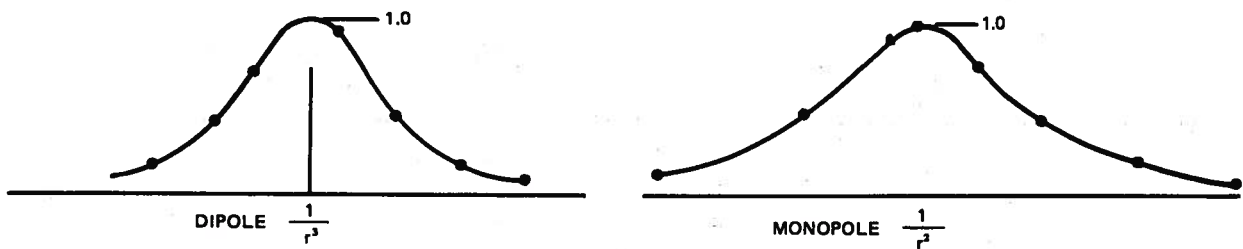
Figure 22.   Fall-off Rate
(Relative intensity or length of vectors in Figure 21)
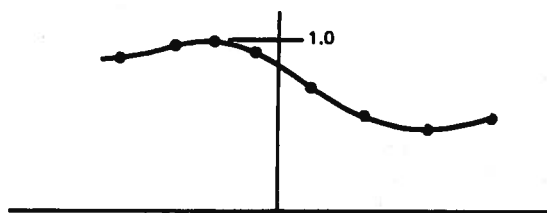
Figure 23.   Aspect Factor
(Relative Intensity of Dipole of Figure 21 with Respect to Angle from Axis at Various Points Along Profile)
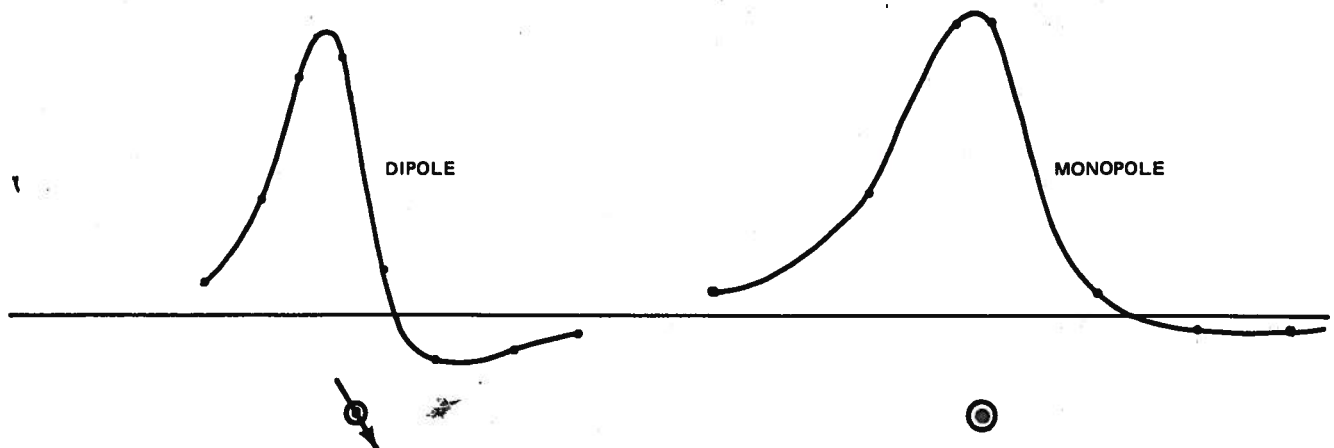
Figure 24.   Dipole and Monopole Signatures (Constructed from Figures 20-23 according to methods described in text.)

without consideration of the other last two factors, it is possible to appreciate the basis for:

a negative anomaly over sources at the magnetic equator,

absence of anomalies in the central portion of elongate N-S anomalies at the equator,

both positive and negative fields for almost any anomaly,

changes in anomaly character for different directions of the dipole,

asymmetry of anomalies,

monopole which has only positive sense yet for most inclinations still produces a total intensity anomaly with both positive and negative portions.

The simple exercise of drawing such anomalies may also elucidate other characteristics of signatures, which to many not familiar with magnetics or such behavior as shown here, appear to be complex and difficult to comprehend.

Based upon the above procedures, applied qualitatively, and upon the manner in which lines of flux are induced in various configurations of geologic bodies and ambient field directions and inclinations, it is possible to derive the various signatures shown in *Figure 26* (drawn freehand). By varying the effect of depth as it produces an anomaly of longer wavelength, and by building composite anomalies such as summing the effect of 2 faults to create a single wide, shallow dike, it is also possible to generate a composite curve demonstrating the effect of different sources and different depths which is the typical observation.

Contour Presentation of Dipole and Prism Anomalies

Profiles of total intensity are usually the only form of presentation from ground measurements even when data are taken on a 2-dimensional array. If measurements are taken properly, however, it is possible to construct a contour map by the methods described in Chapter IV. It is therefore useful to examine a few special cases of contour maps that would be expected over simple sources such as a dipole and a wide, vertical prism in various latitudes. Such a contour map also allows one to extract, even by simple inspection, how a given profile would appear at various positions over such simple-shaped forms which is useful information both in search and in
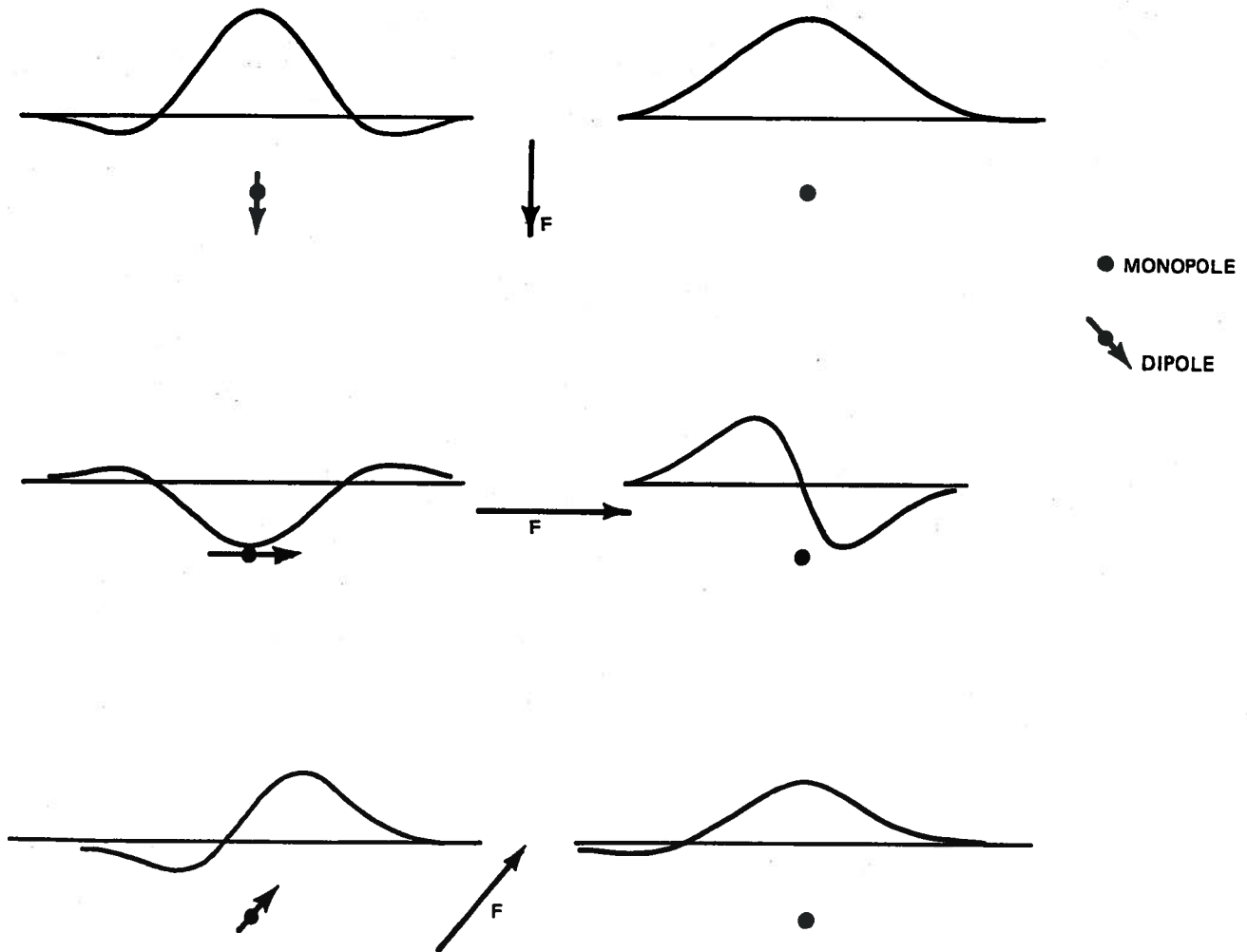
Figure 25.   Free Hand Sketch of Dipole and Monopole for Various Inclinations

ANTICLINE
OR
RIDGE
(HORIZONTAL CYLINDER)

SILL OR
VOLCANIC FLOW

DIPPING DIKE

DIPPING DIKE

GRADUALLY SLOPING
SURFACE

SPHERE

DIKE
(VERTICAL SHEET)

WIDE DIKE

TYPICAL ANOMALIES FROM
VARIOUS GEOLOGIC BODIES
(SHOWN FREE HAND – DO NOT
USE AS QUANTITATIVE REFERENCE)

ALL ANOMALY SOURCES EXCEPT
SPHERE AND VERTICAL CYLINDER
ARE INFINITELY LONG NORMAL
TO THE PLANE OF THIS PAGE.

NARROW INTRUSIVE
(VERTICAL CYLINDER)

FAULT
(WITHIN ONE ROCK UNIT)

$2k_1$ k_1

FAULT
(INVOLVING TWO
ROCK UNITS)

LEGEND

1) $\downarrow$F

2) \F   OR   \F   TRAVERSE N–S
    (N→)   (N→)

3) \F   OR   \F   TRAVERSE E–W
    (i.e., PROJECTION OF FIELD INTO
    PLANE OF THIS PAGE IS VERTICAL)

4) →F TRAVERSE N–S
    (N→)

5) →F TRAVERSE E–W
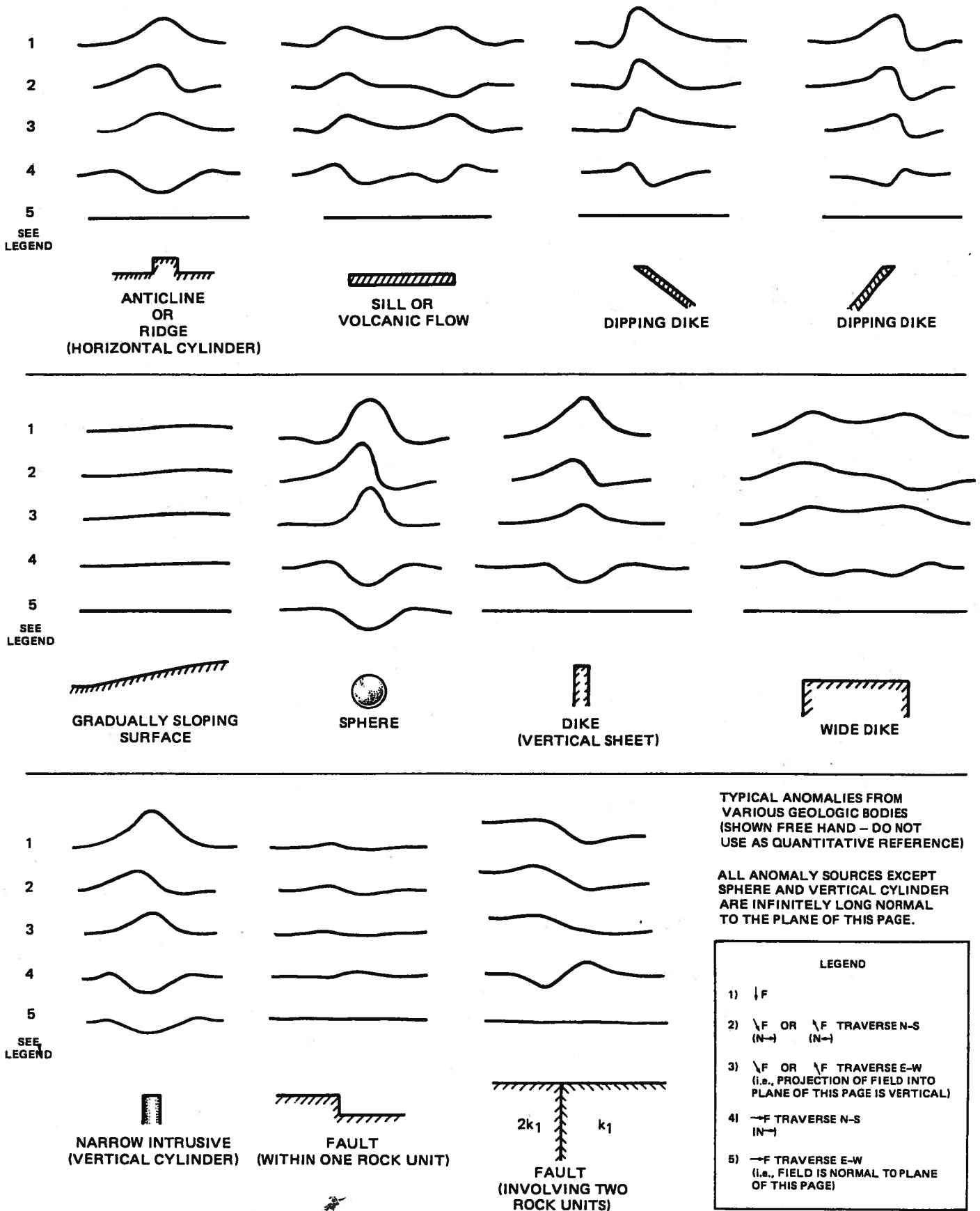   (i.e., FIELD IS NORMAL TO PLANE
    OF THIS PAGE)

Figure 26.   Anomalies for Geologic Bodies at Various Orientations and Different Inclinations of the Field

geological exploration. Contour maps and selected profiles drawn across the anomaly are sketched in *Figure 27*.

Anomaly Amplitude

Amplitude Estimates for Common Sources

The large amplitude commonly observed anomalies (several hundred gammas or larger) are almost always the result of a large magnetization contrast, i.e., change in lithology where one igneous rock is in juxtaposition with another or with a sedimentary or metamorphic rock of much lower susceptibility. It must be remembered that magnetization of common rocks varies over 6 orders of magnitude. Anomalies due to structure alone, i.e., varying configuration of a uniformly magnetized rock, seldom produces anomalies larger than 10 or 100 gammas.

The relative amplitude of a given anomaly (signature) has been shown to be a function of the earth's field direction, the configuration of the source and the remanent magnetization if any. The *maximum* amplitude of an anomaly is, on the other hand, largely a function of the depth and the contrast in the mass of magnetite (or iron, etc. in the case of search), and to a lesser extent, the configuration of the source. It is of interest to be able to estimate the maximum amplitude for a given source in order to 'model' it for the sake of interpretation. This estimated amplitude can be used with the normalized, i.e., dimensionless, anomaly signatures above and in *Figure 26* to produce the anomaly one wishes for comparison with the observed. Estimation of the maximum anomaly amplitude is also useful in planning a survey or planning the grid and coverage necessary in search applications.

For a few generalized configurations, it is relatively simple to estimate the maximum anomaly amplitude (at a single point above the source) assuming a depth, susceptibility and much simplified shape of the source. Expressions are given in the literature for calculation of anomalies of more complex figures and later in this section the calculation of the complete signature, i.e., the amplitude as a function of distance along the profile for a few simple forms. The methods described herein are merely order-of-magnitude techniques, but are useful for the applications covered by the Manual.

Estimation of the maximum anomaly for comparison with a given source requires first that the signature be studied for the nature of the source; namely, whether the source can be approximated as an isolated dipole, monopole, or line or sheet-like array of such. In the case of the latter two, adjacent traverses or a contour map may be required to determine if it is 2-dimensional, i.e., very long normal to the traverse. A depth is then assumed or crudely estimated (according to procedures that follow). In addition, the susceptibility is assumed or if source rocks are accessible, it is measured following methods outlined in Chapter VI. The formulae below can then be used remembering that they are based upon simplifications and assumptions and are often no better than a factor of two.

The basic expression for estimating the maximum amplitude of any anomaly is

$$T = \frac{M}{r^n}$$

where T is the anomaly, M the magnetic moment, r the distance (depth) to the source, and n a measure of the

rate of decay with distance, or fall-off rate (n = 3 for a dipole, n = 2 or a monopole, etc.).

Since the magnetic moment M (and k) is usually given in centimeter-gram-second (cgs) units, r must be in centimeters, n is dimensionless and T is in gauss. To express T in gammas, multiply M by 10^5; if r is in feet, multiply r by 30 and raise the quantity 30r to the exponent n, e.g., if the source is a dipole, then n = 3, and if say, r = 2 feet, M = 1000 cgs,

$$\text{then } T = \frac{1000 \times 10^5}{(2 \times 30)^3} = 460 \text{ gammas .}[1]$$

Dipole and Monopole Signatures in Vertical and Horizontal Fields

The very generalized expression for the maximum anomaly one may expect from a dipole or monopole was presented above in its very simplest form. It may be of interest, however, to construct the signature of a dipole or monopole in a vertical or horizontal earth's field as would be observed by a total field magnetometer along a traverse over the source.

Apart from any total field considerations, a dipole has a field with magnitude and direction given by the radial and tangential components, T_r and T_θ, according to the following expression and for the geometry shown.

$$T_r = \frac{2M \cos \theta}{r^3}$$

$$T_\theta = -\frac{M \sin \theta}{r^3}$$

Where the earth's field is vertical or nearly vertical (dip 70° to 90°), the dipole, if induced, would also be vertical and the total field magnetometer would measure the component, T_z, along this vertical direction, where

$$T_z = T_r \cos \theta + T_\theta \sin \theta$$

$$= \frac{2M \cos^2 \theta - M \sin^2 \theta}{r^3}$$

$$= \frac{M (2z^2 - x^2)}{(x^2 + z^2)^{5/2}}$$
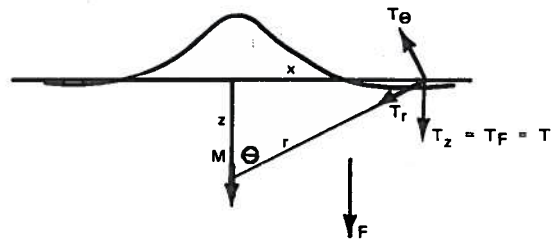
As before, $T_z = T_F = T$, the anomaly.

At x = 0, $\qquad T = \dfrac{2M}{z^3}$

at x = ±z, $\qquad T = \dfrac{0.175M}{z^3}$

at x = ±√2 z, $\qquad T = 0$

at x = ±2z $\qquad T = \dfrac{-0.04M}{z^3}$
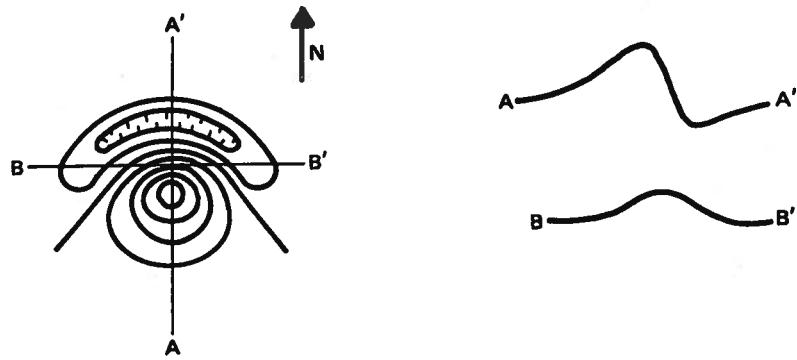
DIPOLE, INCLINATION OF F, 60°
(FOR INCLINATION −60°, I.E., SOUTHERN HEMISPHERE, N IS ↓)
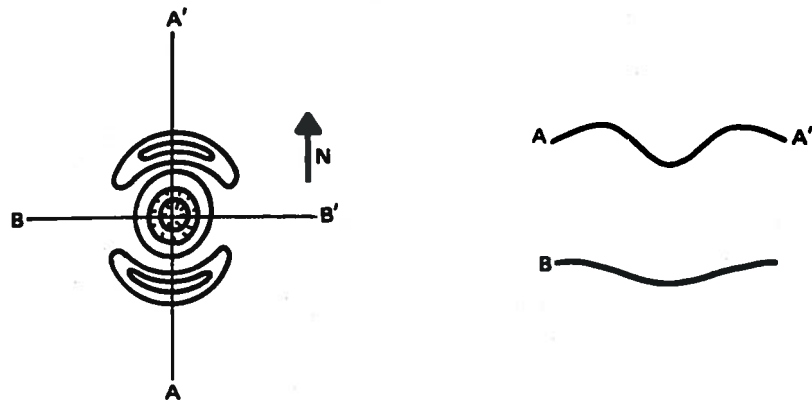
DIPOLE, HORIZONTAL FIELD
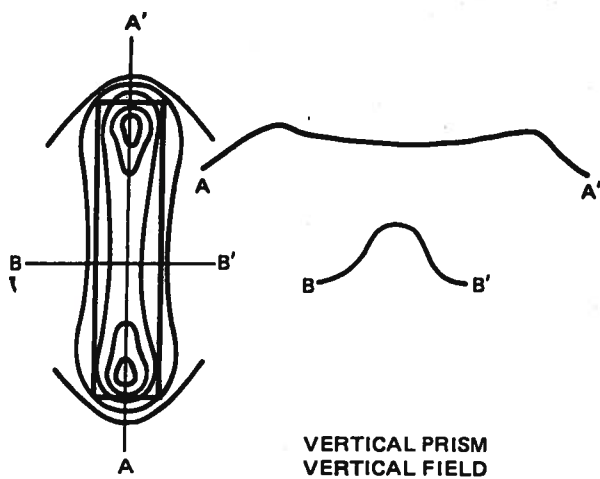
VERTICAL PRISM
VERTICAL FIELD
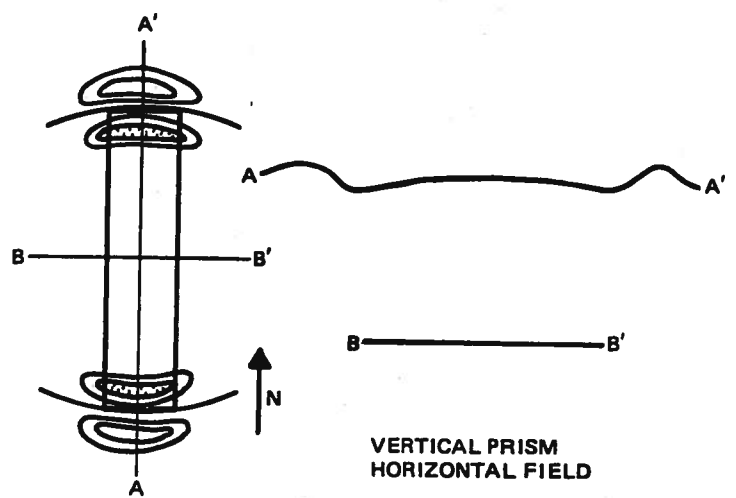
VERTICAL PRISM
HORIZONTAL FIELD

Figure 27.   Contour Maps of Total Intensity

For magnetic equatorial fields, the induced anomaly is horizontal and the total field magnetometer would measure the components shown and expressed by

$$T_x = T_r \cos \theta + T_\theta \sin \theta$$

$$= \frac{2 M \cos^2 \theta - M \sin^2 \theta}{r^3}$$
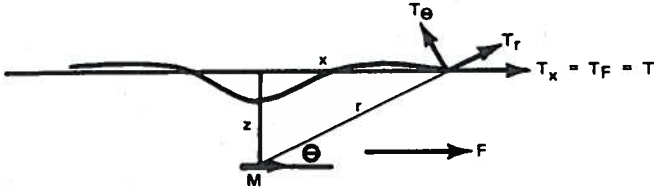
$$= \frac{M (2x^2 - z^2)}{(x^2 + z^2)^{5/2}}$$

as before, $T_x = T_F = T$ the total field anomaly, where,

at $x = 0$,

$$T = -\frac{M}{z^3}$$

at $x = \pm \dfrac{z}{\sqrt{2}}$,

$$T = 0$$

at $x = \pm z$,

$$T = \frac{0.175 M}{z^3}$$

at $x = \pm 2 z$,

$$T = \frac{0.125 M}{z^3}$$

The monopole shown here has only radial components whose intensity is expressed by

$$T_r = \frac{M}{r^2}$$

The monopole anomaly in a vertical field as measured by a total field magnetometer would be the component in the z direction (vertical) or

$$T_z = T_r \cos \theta$$

$$= \frac{M \cos \theta}{r^2}$$

$$= \frac{Mz}{(x^2 + z^2)^{3/2}}$$
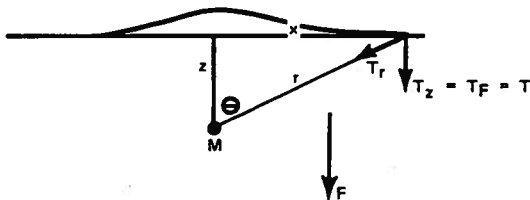
assigning $T_z = T$, the anomaly

at $x = 0$,

$$T = \frac{M}{z^2}$$

at $x = \pm z$,

$$T = \frac{0.35 M}{z^2}$$

at $x = \pm 2 z$,

$$T = \frac{0.09 M}{z^2}$$

The monopole field in a horizontal field would be measured by a total field magnetometer as the horizontal component, T_x where

$$T_x = T_r \sin \theta$$

$$= -\frac{M}{r^2} \sin \theta$$

$$= -\frac{Mx}{(x^2 + z^2)^{3/2}}$$
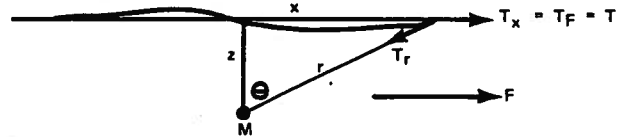
Again, $T_x = T_F = T$, the anomaly, where

at $x = 0$,

$$T = 0$$

at $x = z$,

$$T = -\frac{0.35 M}{z^2}$$

at $x = -z$,

$$T = \frac{0.35 M}{z^2}$$

at $x = 2 z$,

$$T = -\frac{0.18 M}{z^2}$$

at $x = -2z$,

$$T = \frac{0.18 M}{z^2}$$

**Maximum Amplitude Given
Magnetization and Generalized Form**

The magnetic moment M is more usefully expressed as

$$M = IV$$

where I is the magnetization (i.e., magnetization contrast) per unit volume and V the volume. This magnetization is composed of a usually unknown proportion of remanent magnetization, I_r, and induced magnetization I_i. The latter as expressed in Chapter III is

$$I_i = kF$$

where k is the magnetic susceptibility per unit volume and F the earth's field or ambient inducing field. (NOTE: Since I_r is seldom known, an effective magnetization, $I = I_i + I_r$, will always be used. Also it is assumed that $k < 10^{-2}$, i.e., the source under consideration contains less than 10% magnetite; then one can ignore what is known as demagnetization effects in the calculation of anomaly amplitude).

Therefore, for a dipole which can always be assumed for a source all of whose dimensions are small with respect to the distance (less than $\frac{1}{5}$ or $\frac{1}{10}$) to the magnetometer,

$$T = \frac{M}{r^3} = \frac{IV}{r^3} = \frac{kFV}{r^3}$$

If the source is approximately spherical, then

$$T = \frac{kF\left(\frac{4}{3}\pi R^3\right)}{r^3}$$

where R is the radius of the source as in *Figure 28*

If the measurement is made along the axis of the dipole (see *Figure 29*), then

$$T = \frac{2kF\left(\frac{4}{3}\pi R^3\right)}{r^3}$$

$$T = \frac{kF\left(\frac{4\pi R^3}{3}\right)}{r^3}$$
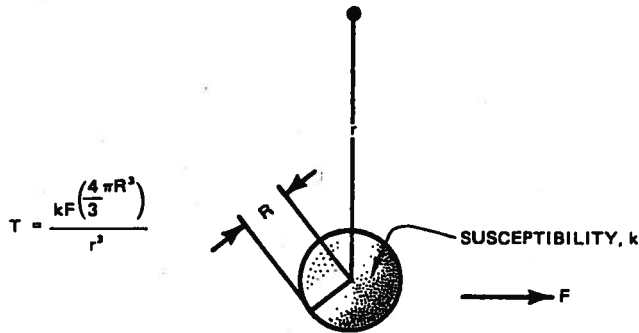
Figure 28. Anomaly of Sphere in Horizontal Field

$$T = \frac{2kF\left(\frac{4\pi R^3}{3}\right)}{r^3}$$
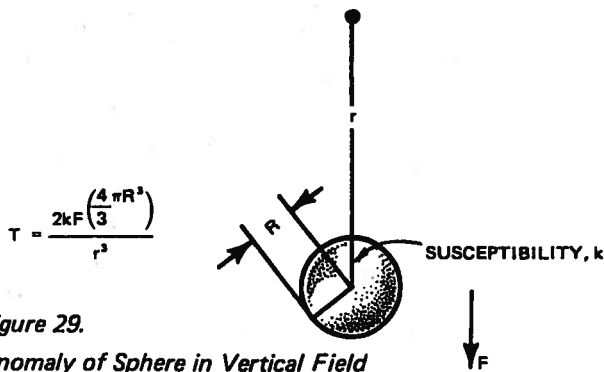
Figure 29.

Anomaly of Sphere in Vertical Field

As an example, consider an ore body 100 feet wide (R = 50), 500 feet deep comprised of 10% magnetite (k = 0.3), in a steeply dipping field (60° to 90° latitude) in a field of 60,000 gammas:

$$T = 2\,(0.10 \times 0.3) \times 6 \times 10^4 \left(\frac{4\pi}{3}\right)\left(\frac{50}{500}\right)^3 = 14.4 \text{ gammas}$$

$$T = \frac{kF\ \pi R^2}{r^3}$$
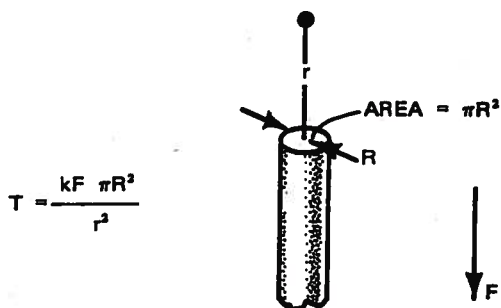
(NOTE: ALSO VALID FOR END OF N-S HORIZONTAL CYLINDER IN HORIZONTAL FIELD)
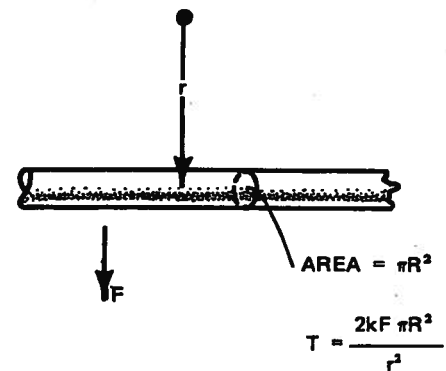
For the same ore body in an equatorial field where F = 30,000 gammas and the induced dipole is now observed at a point on a line normal to the axis (no factor of 2)

T = - 3.6 gammas

Thus a given dipolar source in an equatorial field will have only ¼ the maximum anomaly amplitude it would have in a polar region.

The above expressions are usually valid only for such sources as a small distant ore body (containing magnetite), small structure in deep basement, or most objects involved in search applications (see Chapter VII). The magnetization is expressed in gauss or gammas as desired. Since the anomalies are also expressed in terms of magnetic units, it follows that the units of dimension in the numerator must be of the same order as the denominator since they must cancel. Therefore, for a dipole whose anomaly varies as $\frac{1}{r^3}$ (said to have a fall-off of $\frac{1}{r^3}$), the volume, V, has dimensions of R³. In the case of a monopole, which varies as $\frac{1}{r^2}$, the magnetic moment, M, is equal to IA where A is surface area and has dimensions of R². Consider for example, a vertical basement intrusive in a polar region with an upper surface 1000 feet in diameter at a depth of 5000 feet, with a susceptibility contrast of 10^{-2} in a field of 60,000 gammas. Thus,

$$T = \frac{kF\ \pi R^2}{r^2} = 10^{-2} \times 6 \times 10^4 \times \pi\left(\frac{50}{500}\right)^2 = 18 \text{ gammas.}$$

Horizontal prisms or cylinders also vary as $\frac{1}{r^2}$, with magnetic moment M equal to 2IA (IA for E-W horizontal prisms in equatorial regions) where A is the cross-sectional area of the prism *(see Figure 30)*. (NOTE: The long horizontal prism varies as $\frac{1}{R^2}$ not because it appears to be comprised of a monopole, but because it is a line of dipoles (in steeply dipping fields) and the effect of adjacent dipoles along an infinitely long line is 'seen' more by the magnetometer at a distant point of measurement than if all the magnetization were concentrated at a point as in an isolated dipole).

$$T = \frac{2kF\ \pi R^2}{r^3}$$

(NOTE: ALSO VALID FOR E-W HORIZONTAL CYLINDER IN HORIZONTAL FIELD)

Figure 30. Anomaly of Vertical and Horizontal Cylinders

A narrow, vertical dike in steep field or the edge of a horizontal sheet in a horizontal field can be considered as a line of monopoles varying as 1/r which is a lower rate of fall-off than a single monopole for the same reasons given above for a horizontal cylinder *(see Figure 31)*. The magnetic moment M = It where t = width of dike. Since the anomaly varies as 1/r, the dimensions of t are simply length. As an example, a vertical dike might be 100 feet wide, at a depth of 500 feet, with k = 10^{-3} in a field of 50,000 gammas, or

$$T = \frac{kFt}{r} = \frac{10^{-3} \times 5 \times 10^4 \times 10^2}{5 \times 10^2} = 10 \text{ gammas}$$

$$T = \frac{kFt}{r}$$

WHERE t < r
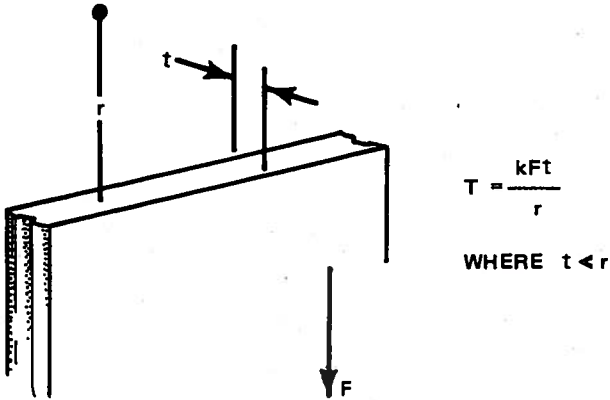
Figure 31.   Anomaly of Narrow Vertical Dike

A common point of ambiguity arises with such simplified schemes as these in the case of a dike which is nearly as wide as it is deep. In this case, the anomaly is approximated as something between a line of monopoles as above and a sheet of monopoles as shown in the following. Moreover, as the dike is even wider than its depth, it can be approximated simply by 2 faulted contacts with 'no anomaly' in between.

For a semi-infinite slab of material such as a rock surface of great thickness and breadth in a non-horizontal field, the flux lines do not vary in direction or density above the slab, therefore the field does not vary at all with distance to its surface (similar to the limit of the spherical dipole above where R = r) so that

$$T = \frac{M}{r^0} = \frac{2\pi I}{1}, \text{ or } T = 2\pi kF$$

which is useful in estimating the magnitude of the anomaly at a vertical fault *(see Figure 32)*. For example, consider two rock types at a vertical contact of k = 10^{-3} and k = 10^{-5} for an effective susceptibility contrast of k = 10^{-3} ($10^{-5} \approx 0$ relative to 10^{-3}) and where F = 50,000 gammas. Thus

$$T = 2\pi \times 10^{-3} \times 5 \times 10^4 = 300 \text{ gammas}$$

If the rocks had k = 10^{-4} and 10^{-3}, the effective susceptibility contrast would be

$$10^{-3} - 10^{-4} = 10 \times 10^{-4} - 10^{-4} = 9 \times 10^{-4} \text{ and}$$

$$T = 2\pi \times 9 \times 10^{-4} \times 5 \times 10^4 = 270 \text{ gammas}$$

This simple example of two adjacent rock types is probably applicable in more instances in interpretation than any of the other geometries discussed above.

$$T = 2\pi kF$$
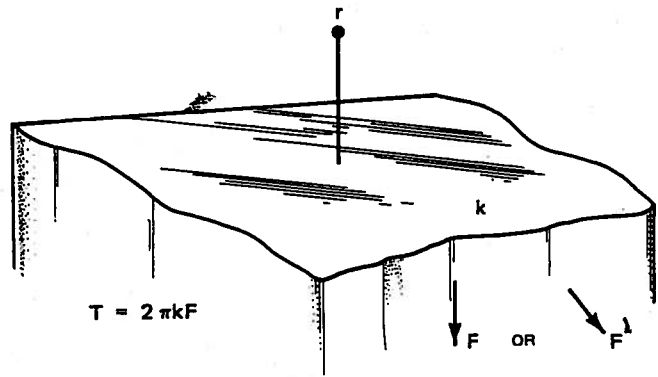
Figure 32.   Anomaly of Semi-infinite Slab

Anomaly Depth Characteristics

In a very approximate fashion, the wavelength, or, effective width (or 'half-width' described in the following) of the anomaly and, with more accuracy, the width of certain characteristics of the anomaly such as slope, are measures of the depth to its source. However, recognition of the anomaly, the anomaly 'zero' and certain slopes would not only appear as different values as determined by different interpreters, but they also depend upon what is removed as the regional gradient. More objective criteria are used in some cases such as the nearly straight portions of a slope, and distances and angles between inflection points, peak values and other anomaly characteristics.

Anomaly Width

In general, the anomaly width as shown in *Figure 33* is on the order of 1 to perhaps 3 times the depth. Thus, when an anomaly appears to have a width as such of 100 feet, it is definitely not produced by a source at 1000 feet or at 10 feet, but more likely by a source between 30 and 100 feet deep (or distant). Such criteria, approximate as it is, is nevertheless useful for cursory interpretation of profiles and maps.

Anomaly Depth Estimation

Much is written on the variety and relative merit of methods for estimating the depth to the source of anomalies. Since the magnetometer is primarily a tool for subsurface mapping and detection, it follows that determination of the depth as well as edges of bodies is important in its application to geological exploration and search. The basis for depth determination is presented here in brief which, together with the foregoing background on anomaly behavior, should allow one to at least appreciate how a variation in depth affects an anomaly. In most cases, one needs only to apply this knowledge qualitatively through visual inspection of a profile. Whatever the requirement, depths may be estimated by visual inspection, several rules of thumb, modeling (i.e., calculation of assumed source and comparison with observed), measured gradient techniques (see Chapter VIII), or various computer-oriented procedures. As was demonstrated earlier, a given anomaly could have an infinite number of possible sources and source depths, but the realistic models that are assumed usually produce maximum depth estimates.

Knowledge of the depth of a particular formation or source may have considerable geological significance as it determines the nature or configuration of a forma-
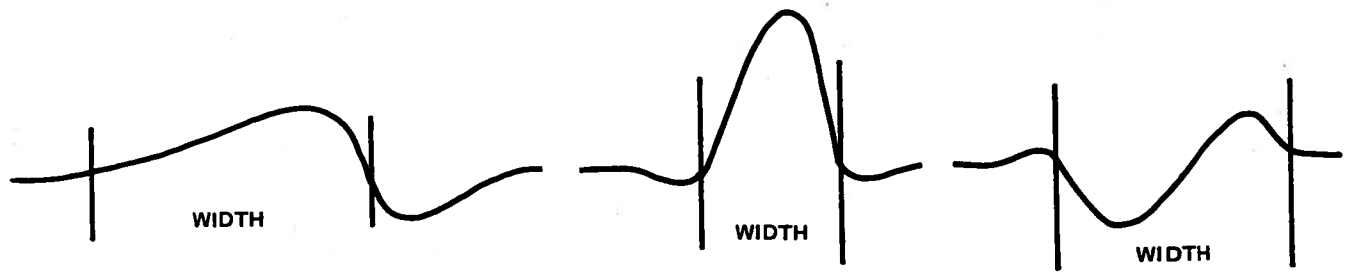
Figure 33.   Anomaly 'Width'

tion, the slope of its surface and its discontinuities. The depth to various points on the surface of crystalline rock or magnetic basement allows one to map that surface and its topography and structures to depths exceeding 30,000 feet and to infer thickness of sediments or conformable sedimentary structures above it for exploration of petroleum, sedimentary ores, placer deposits or groundwater. Areas underlain by pediment or other sedimentary deposits may be ruled economic or non-economic according to depth. The depth to ore deposits associated with pyrrhotite, magnetite or ilmenite may be estimated as an aid to a drilling program or even for estimation of total tonnage of magnetic iron ore deposits. Black sand deposits of rutile, zircon, monazite, diamonds, gold, platinum, etc. are often associated with other high density, very resistant yet magnetic minerals, namely, magnetite or ilmenite. The depth to objects of search whether buried iron or man-made structures is invaluable in guiding the subsequent excavation efforts.

Identification of Anomaly

The anomaly of interest must be identified and discriminated against the obscuring effects of others. Recognition of the anomaly itself is usually the most difficult aspect of depth determination because of the composite effects of multiple sources, sources at various depths and at various distances in any direction from the magnetometer. Only the net effect of all anomalies are measured by the magnetometer since it has no inherent discrimination ability at the disposal of the operator. The anomaly should be inspected to ascertain the probable source and, if complex, the possible combination of sources. For example, a wide, shallow dike will appear as two anomalies which may or may not coalesce depending upon the relative width and depth. A very broad anomaly or regional gradient (described in Chapter IV). is usually caused by anomalies which are extremely deep or distant or by the normal variation in the earth's magnetic field. If one wishes to remove this gradient, it can be done either by drawing a straight line through the non-anomalous portions of the profile (away from the anomaly of interest) or by drawing a very smooth but broad wavelength curve through the \data of much longer wavelength than any anomalies of interest. This regional gradient or background is then subtracted from the anomaly and the remaining, or residual anomaly, replotted. It is this anomaly which is then interpreted for either depth or for amplitude or general configuration of sources as described in Chapter IV.

Fall-Off Rate

The variation of anomaly amplitude with distance, or fall-off rate, is important in the interpretation of anomalies for it relates the anomaly to depth, it describes in a general way the configuration of the source, and it

assists in determining susceptibility and mass of the causative magnetite. Recall that the anomaly from a dipole varies as $\frac{1}{r^3}$ and that of a monopole as $\frac{1}{r^2}$. The fall-off rate, in actual practice, does not involve precisely such factors or exponents but, in fact, is typically $\frac{1}{r^{2.5}}, \frac{1}{r^{0.6}}$ etc., or even $\frac{1}{r^0}$ as described above. In other words, various configurations of dipoles, monopoles, lines and sheet-like distributions of these poles constitute a continuous series of fall-off rates even in the vicinity of a single anomaly as one is much closer or further away from the source.

Representing various geologic sources as simple prismatic bodies, one may assume the following fall-off rates: a dipole will be produced by a source all of whose dimensions are small (less than $\frac{1}{10}$ compared to the distance between the source and magnetometer). Such a body is rarely seen in nature except as a very confined, usually magnetite-rich ore body. A monopole varying as $\frac{1}{r^2}$ will be produced by a long, thin, vertical prism, such as a narrow vertical intrusive in steeply dipping fields or a horizontal cylinder striking N-S in equatorial fields (e.g., a N-S anticlinal structure on the basement, one end of which is near the magnetometer). A line of dipoles is produced by a long, horizontal cylinder magnetized through its short dimension as in steeply dipping latitudes or striking E-W in equatorial regions. Such a cylinder will also vary as $\frac{1}{r^2}$. A line of monopoles would effectively be observed near one edge of a dike dipping in the direction of the field and would vary approximately as $\frac{1}{r}$. At a point above a horizontal semi-infinite sheet, the field would vary inversely as $\frac{1}{r^0} = 1$, which is another way of expressing the fact that the field does not vary at all with distance from a horizontal semi-infinite sheet of monopoles or dipoles. A wide vertical dike in a steep field or the edge of a fault might represent combinations between a line of dipoles or sheet-like distribution of monopoles and may thus vary as $\frac{1}{r^2}$ or $\frac{1}{r^{0.5}}$ or less. *Figure 34* indicates these variations.

Assumptions on Maximum Amplitude and Depth Estimates

Unless the remanent magnetization is actually measured, it is generally disregarded, and only the induced magnetization and susceptibility are utilized in these expressions. The magnetic anomaly calculated from these

Figure 34. Field Lines and Fall-Off Rates of Various Geologic Models

(FLUX LINES SUPERIMPOSED ON REPRESENTATIVE GEOLOGIC MODELS FOR VARIOUS ORIENTATIONS OF INDUCING FIELD. ANOMALY AMPLITUDE PROPORTIONAL TO INDICATED TERM OF 1/r^n.)

SPHERE (DIPOLE)	Z =	2X$_{\frac{1}{2}}$
VERTICAL CYLINDER (MONOPOLE)	Z =	1.3X$_{\frac{1}{2}}$
EDGE OF NARROW DIKE (LINE OF MONOPOLES)	Z =	X$_{\frac{1}{2}}$
HORIZONTAL CYLINDER (LINE OF DIPOLES)	Z =	2X$_{\frac{1}{2}}$

Figure 35. Half-width Rules — Vertical Field

Figure 36. Half-width Rules — Horizontal Field (Equatorial)

highly simplified expressions represents the maximum amplitude from the local zero, non-anomalous field to the positive peak value in the northern and sourthern latitudes and to the minimum negative value in equatorial regions. It does not represent the peak-to-peak value which includes both positive and negative portions of the anomaly signature. The depth estimates derived from any of the techniques described are seldom more accurate than 10% of the actual depth and sometimes as poor as 50%. By theory most of the estimates are maximum estimates so that the actual source will actually be at a shallower depth. Moreover, the 'poles' or source described frequently throughout their chapter are within the geologic body or object of search and not simply on the surface; therefore, such depths are again maximum depths.

Half-Width Rules

In vertical or horizontal fields, it can be shown, from the previous expressions for dipoles and monopoles, that for simple forms of anomaly sources, the depth to their centers is related to the half-width of the anomaly. The half-width is the horizontal distance between the principal maximum (or minimum) of the anomaly (assumed to be over the center of the source) and the point where the value is exactly one-half the maximum value *(see Figure 35).* This rule is only valid for simple-shaped forms such as a sphere (dipole), vertical cylinder (monopole), and the edge of a narrow, nearly vertical dike (line of monopoles) in the polar regions. At the magnetic equator, the half-width rules are somewhat different with the sphere remaining unchanged, an E-W horizontal cylinder being a line of dipoles, a N-S cylinder being a monopole, and the edge of an E-W striking horizontal sheet representing a line of monopoles. The rules presented in *Figure 36* apply according to the corresponding array of poles and in the case of the latter two, the half width being the horizontal distance between the point of maximum (or minimum) and zero anomaly. The half width rules are derived from formulae given above in "Dipole and Monopole Signatures in Vertical and Horizontal Fields".

Slope Techniques

Perhaps the most commonly used set of methods for estimating depth are those which utilize criteria involving the measurement of the horizontal gradient or slope at

the inflection points of the anomaly. Based upon empirical observations utilizing computed models, these slopes are measured according to the horizontal extent of the 'straight' portion of the slope *(see Figure 37)* or the horizontal extent determined by different combinations of the tangent or slope at the inflection point, maximum of the anomaly and half slopes, etc. Each of these horizontal distance measurements when multiplied by an empirically-determined factor equals the depth to the top of the anomaly source. (The straight-slope, for example, is multiplied by a factor between 0.5 and 1.5). Detailed explanations of these methods are available in the references cited.
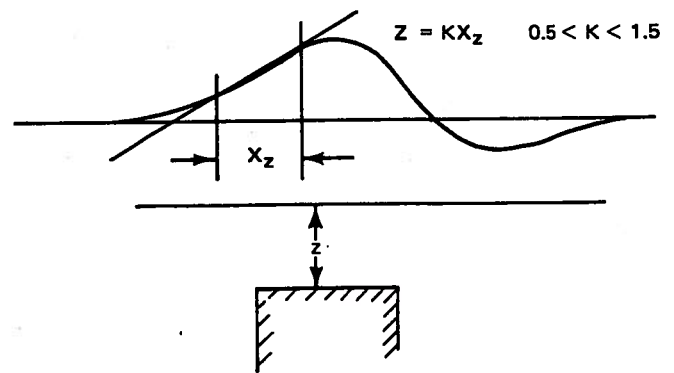
Figure 37.

Other Depth Estimating Methods

Modeling techniques require that one examine the observed anomaly for its likely source configuration. A model is assumed, the anomaly calculated, compared with the observed and repeatedly altered until a satisfactory fit to the observed data is finally achieved, with such work usually performed on a computer. Other computer-oriented depth estimating methods include programs utilizing Fourier and Hilbert transforms, convolution and other semi-automated programs which are usually applied to large volumes of data. Gradiometer measurements made with sensors at two points usually vertically arranged can also be used for depth estimates (see Chapter VIII).

Interpretation Summary

Interpretation is facilitated if one can thoroughly familiarize himself with how and why a given source produces an anomaly in the earth's field, the nature of total field measurements and the general behavior of an anomaly signature with increasing depth. What at first may have appeared complex in the interpretation of field profiles and maps is more readily understood when the above phenomena are examined one at a time.

The first procedure that should be followed in the interpretation of a given profile is to focus on the anomaly width and shape and attempt to construct at least a mental image of the source in realistic geologic terms (or object in the case of search) and its depth. Use the eye to discriminate against noise and the regional gradient or filter by one of the suggested techniques. Anomalous horizontal gradients should then be used, for lack of any other specific criteria, as an indicator of the edge of subsurface structures producing a magnetization contrast. Most anomalies on any given profile or map represent a simple contrast in magnetization or lithology, i.e., the edge of a body. Attempt to correlate such features on adjacent lines or interpret them as contacts on a total intensity contour map. The cessation, displacement or interruption of otherwise long or continuous features may also represent significant geologic structural information. However, one must realize also that a magnetic survey is only able to map a contact where there is a magnetization contrast so that, for example, different lithologies on either side of a long continuous fault will be mapped only in segments where such contrasts occur.

Changes in the character of the short wavelength anomalies (noise) may also represent mappable information if one is careful to evaluate their typical depth so as not to be mapping irrelevant soil anomalies. Negative anomalies arising from features of locally lower magnetization are as important geologically as the more common positive anomalies. Furthermore, the *most geologically significant anomalies on a given map are probably the more subtle ones and not necessarily the largest, most prominent anomalies*. Lastly, the total intensity profiles and maps are not an end in themselves, but are rendered usable only when expressed in terms of geology (or objects of a search). The more geological information one has (or size, magnetic or depth information for an object of search) the more valuable the total intensity data becomes and vice-versa.
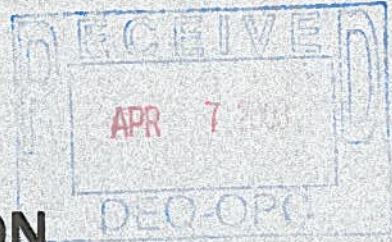
SITE INVESTIGATION REPORT

PREPARED FOR:

■HERCULES, INC.

CHEMICAL SPECIALTIES

HATTIESBURG, MISSISSIPPI

APRIL, 2003

PREPARED BY:

Eco·Systems, Inc.

Consultants, Engineers and Scientists

439 KATHERINE DRIVE, SUITE 2A
JACKSON, MISSISSIPPI 39232
(601) 936-4440

JACKSON, MS • MOBILE, AL • HOUSTON, TX

TABLE OF CONTENTS

TABLES

FIGURES

APPENDICES

1.0 INTRODUCTION

1.1 BACKGROUND

Eco-Systems, Inc (Eco-Systems) has been retained by Hercules, Incorporated (Hercules) to conduct site investigations at the Hercules plant in Hattiesburg, Mississippi. The site location is shown on Figure 1. This report documents site investigations conducted in accordance with *Hercules' Site Investigation Work Plan* (Eco-Systems, February 1999) and additional comments of the Mississippi Department of Environmental Quality (MDEQ) approval letter dated April 5, 1999, as amended.

The work described in the approved work plan centered on efforts to determine whether Dioxathion, the miticide contained in Delnav, was present in site soil and groundwater. The work plan included installation of piezometers, monitoring wells, and staff gauges to provide hydrogeologic and groundwater quality information near the former Dioxathion production area and near former wastewater sludge pits. These monitoring wells supplemented the previously existing monitoring wells at the site. Monitoring well and piezometer locations are shown on Figure 2. The original staff gauges were washed out, or otherwise destroyed, between the time of their installation and the present. However, new staff gauges were installed in Green's Creek on March 4, 2003, and an elevation survey was conducted on March 5, 2003 to link the staff gauge elevations to the monitoring well and piezometer elevations.

Installation of the temporary piezometers was conducted in April/May 1999. Installation of monitoring wells was conducted in February 2000. However, prior to sampling the additional monitoring wells, questions arose regarding analytical methods for Dioxathion and the quality of Dioxathion for use as a laboratory standard. In the ensuing months, Hercules, in conjunction with MDEQ's consultant, Mississippi State University (MSU) developed analytical protocols for soil and groundwater (Appendix A). Since the quality of available analytical standards was questionable, Hercules contracted with Sigma-Aldrich Chemicals to synthesize Dioxathion standards. In August 2002 Dioxathion had been manufactured of a suitable quality to be used as laboratory standard, and Hercules and the MDEQ had agreed to a laboratory protocol. In October 2002, groundwater samples were collected from four selected wells, and those samples were analyzed by Bonner Analytical and Testing Company (BATCO) and the Mississippi State Chemical Laboratory (MSCL) to test the newly established laboratory protocol. The methods and results of protocol sample collection and analysis are discussed in this report.

On December 4 and 5, 2002, groundwater samples were collected from the eleven site monitoring wells, and those samples were analyzed for Dioxathion. At the request of the MDEQ, samples from the wells installed in 2000 (MW-7 through MW-11) were also analyzed for volatile organic compounds (VOC) and semi-volatile organic compounds (SVOC). Hercules submitted the results of the December 2002 sampling event to the MDEQ in the *Interim Groundwater Monitoring Report* (Eco-Systems, January 2003). In the *Interim Groundwater Monitoring Report*, Hercules recommended that, prior to conducting a full mobilization to

complete the February 1999 work plan, selected wells be re-sampled to confirm results. The MDEQ responded to the *Interim Groundwater Monitoring Report* in a letter dated February 3, 2003 which requested that the selected wells be re-sampled, the remaining work plan tasks be completed, a supplemental work plan be prepared to delineate constituents detected in groundwater, and a geophysical survey be conducted in the former landfill area.

On February 11, 2003, the selected wells were re-sampled and surface water and stream sediment samples were collected from Green's Creek. The additional groundwater samples were analyzed for volatile organic compounds (VOC). At the request of the MDEQ, surface water and sediment samples from Green's Creek were analyzed for Dioxathion and VOC. This *Site Investigation Report* has been prepared to document the work conducted under the February 1999 work plan.

1.2 PURPOSE AND SCOPE

The purpose of this investigation has been to investigate the presence and extent of Dioxathion in soil and groundwater at the site. This investigation also included investigation of the groundwater flow regime and refining the hydrogeologic model of the site. The scope of this investigation included the following elements:

- Installation of fourteen (14) piezometers to provide hydrogeologic information in the uppermost saturated interval beneath the site,
- Installation of five (5) monitoring wells to provide information regarding groundwater quality,
- Installation of four (4) stream gauges Green's Creek to provide information regarding the possibility of groundwater discharge from the site to the creek,
- Collection and analysis of groundwater samples, surface water samples, and stream sediment samples for laboratory analysis of Dioxathion and other parameters as requested by the MDEQ, and
- Preparation of this report.

Work plan elements for investigation of the former landfill are being addressed in a supplemental work plan that will include a geophysical survey, as well as elements for slug tests and physical soil parameters.

2.0 SITE CONDITIONS

2.1 FACILITY LOCATION AND SITE DESCRIPTION

The Hercules facility is located on approximately 200 acres of land north of West Seventh Street in Hattiesburg, Forrest County, Mississippi. More specifically, the Site is located in Sections 4 and 5, Township 4 North, Range 13 West, just north of Hattiesburg, Mississippi (Figure 1). The facility has been in operation since 1923. The facility is bordered to the north by Highway 43 and Illinois-Central & Gulf Railroad, along with various residential and commercial properties. The southern property boundary is bordered by 7th Avenue; and by a cemetery and Zeon Chemical Company to the southwest. Across from these locations are residential areas. The eastern and western boundaries are bordered by sparsely populated residential areas.

The facility's historical operations consisted of wood grinding, shredding extraction, fractionation, refining, distillation, and processing of rosin from pine tree stumps. Historically, over 250 products were produced from the above-referenced operations and included: modified resins, polyamides, ketene dimer, crude tall oil wax emulsions, synthetic rubber, and Delnav, an agricultural miticide. Structures at the facility include offices, laboratory, powerhouse, production buildings, wastewater treatment plant, settling ponds, landfills, and central loading and packaging areas.

2.2 TOPOGRAPHY AND SURFACE DRAINAGE

Surface water drainage patterns at the Site conform generally to the topography which slopes toward Green's Creek from either side (Figure 2). Topography slopes generally to the south in the Wastewater Sludge Disposal Area, and to the north/northwest in the Former Industrial Landfill Area and the Former Delnav Production Area. A topographic divide located south/southwest of the Former Delnav Production Area separates north flowing surface water drainage to more east/southeast-trending drainage. The east trending, perennial stream Green's Creek and its natural and man-made tributaries are the main surface drainage features in the area. Green's Creek leaves the Site at its northeast corner and subsequently runs into Bowie River, located approximately one (1) mile to the north/northeast.

2.3 REGIONAL GEOLOGY AND HYDROGEOLOGY

According to the Mississippi State Geological Survey Bulletin Number 44, Forrest County Mineral Resources (Foster, 1941), the site is located within the Pine Hills physiographic region of the Coastal Plain physiographic province. The topography if the region is characterized by a maturely dissected plain which slopes generally to the southeast. The topography is dominated by the valleys of the Bowie and Leaf Rivers coupled with the nearly flat or gently rolling bordering terrace uplands.

The geologic formations beneath the site are as follows (in descending order): Pleistocene alluvial and terrace deposits, the Miocene-aged Hattiesburg and Catahoula Sandstone formations, the Oligocene-aged Baynes Hammock Sand and Chickasawhay Limestone formations, and the Oligocene-aged Bucatunna Clay member of the Byron formation of the Vicksburg group. A generalized cross section of the regional geology is shown on Figure 3.

The recent-aged alluvial and terrace deposits consist of flood plains and gravel, silts, and clays. The thicknesses of the alluvial and terrace deposits are variable due to erosion. Based upon driller's logs of wells located in the vicinity of the Site, thickness of the alluvial and terrace deposits is estimated to be approximately 50 feet.

Beneath the alluvial and terrace deposits lies the Hattiesburg formation, which is comprised predominantly of clay. Regionally, beneath Forrest County, the formation contains at least two (2) prominent sand beds from which a viable water supply is obtained. Logs from area wells indicate that the Hattiesburg formation ranges from approximately 130 feet to 260 feet in thickness.

The Catahoula sandstone underlies the Hattiesburg formation. It is not exposed near the facility, but is penetrated by numerous wells in the area. A driller's log of a municipal well approximately 1.25 miles northwest of the facility indicated that approximately 770 feet of Catahoula sandstone was encountered.

Near the Site, the Catahoula sandstone overlies the Chickasawhay limestone. Neither the Chickasawhay limestone nor the Bucatunna formation are considered to be very viable aquifers. The Bucatunna formation is comprised of clay and effectively acts as a confining layer for the underlying Oligocene aquifer.

The Miocene aquifer is comprised of both the Hattiesburg and Catahoula sandstone formations. The aquifer system is composed of numerous interbedded layers of sand and clay. Because of their interbedded nature, the Hattiesburg and Catahoula sandstone cannot be reliably separated. The formations dip southeastward approximately 30 feet to 100 feet per mile. While this dip steepens near the coast, the formations thicken. The shallowest portions of the aquifer system are unconfined with the surficial water table ranging from a few inches to greater than six (6) feet below land surface. Deeper portions of the aquifer are confined, with artesian conditions common.

2.4 SITE GEOLOGY AND HYDROGEOLOGY

Borings installed during this investigation encountered soils that are generally described as gray and tan, fine-grained, sand with varying amounts of silt, clay and gravel from the surface to depths ranging from 5 feet below ground surface to greater than 18 feet below ground surface. These sandy soils are typical of the alluvial and terrace deposits discussed in Section 2.2. Underlying the sandy soils is a gray to orange-brown, stiff, silty and/or sandy clay. Descriptions of the clay are consistent with descriptions of the Hattiesburg formation described in Section 2.3.

In the boring for piezometer TP-13, which is adjacent to Green's Creek, the top of the stiff clay was encountered at an approximate depth of 10 feet below ground surface. This is approximately the depth of the creek bottom at staff gauge SG-3, which is located immediately south of piezometer TP-13. The clay formation encountered in site borings and observed in the bottom of Green's Creek may serve as a confining unit for groundwater in the uppermost saturated interval. Copies of boring logs and construction diagrams for piezometers and monitoring wells installed during this investigation are included in Appendix B. A geologic cross section of the site is shown on Figure 4.

Water level information was collected from monitoring wells MW-1 through MW-6, the 14 piezometers, and the four (4) staff gauges on March 5, 2003. Based on the surveyed elevations of the wells, piezometers, and staff gauges, water level elevations were calculated. A summary of the water level information data is provided in Table 1. Based on the water level information, a potentiometric surface map has been prepared for the uppermost saturated interval and Green's Creek. The potentiometric surface map is shown on Figure 5.

Groundwater in the uppermost, saturated interval beneath the site tends to mimic surface topography. In the active portions of the plant operations, which are located in the southeastern portion of the site, the potentiometric surface indicates the presence of a southwest to northeastward trending divide. The potentiometric surface map indicates that groundwater located to the northwest of the divide would tend to move northwestward towards Green's Creek. Likewise, groundwater southeast of the divide would tend to move southeastward. On the north side of Green's Creek, the potentiometric surface indicates that groundwater in the uppermost, saturated interval moves generally southward towards Green's Creek.

Surface water enters the site on the west side of the property via Green's Creek. Green's Creek flows towards the east in the northern portion of the property. Elevations of the stream surface are significantly lower than the groundwater. This indicates that, while groundwater may contribute to flow in Green's Creek, hydraulic connection between the uppermost saturated interval and Green's Creek is retarded. The retardation of the water moving from the sand to the creek is likely due to silt and clay in the sand adjacent to the creek.

3.0 FIELD ACTIVITIES

3.1 PIEZOMETER AND MONITORING WELL INSTALLATION

In April 1999, fourteen (14) piezometers, TP-1 through TP-14, were installed to evaluate groundwater flow conditions in the uppermost saturated interval beneath the site. Piezometers were placed in key locations across the site to provide broad coverage of groundwater flow conditions. In February 2000, monitoring wells MW-7 through MW-11 were installed to monitor groundwater quality in locations selected based on work plan objectives and groundwater flow data obtained from the previously installed monitoring wells (MW-1 through MW-6), and the 14 piezometers discussed above. Monitoring wells MW-7, MW-8, and MW-9 were installed to monitor groundwater quality at points near the former Delnav production area. Monitoring wells MW-10 and MW-11 were installed to monitoring groundwater quality between the sludge disposal pits and Green's Creek.

3.1.1 Piezometer and Well Installation Procedure

Piezometers were completed by installing an appropriately sized (3/4-inch to 2-inch diameter) PVC screen and riser at least five (5) feet into the upper-most water-bearing interval. A filter sock was applied and secured to the screened interval prior to installation into the borehole. 20/40 silica sand was added around the screen to a depth of approximately two feet above the top of the screen. A two-foot bentonite seal was placed in the annulus above the sand, and the remaining portion of the open hole was filled with a high solids bentonite seal. Piezometers are protected at the surface with a hinged and lockable metal shroud set within a 2 foot x 2 foot 2 x 4-inch concrete pad and surrounded by 3-inch x 5-foot steel bollards.

Monitoring wells installed in February 2000 were installed in accordance with EPA Region IV's Standard Operating Procedures and Quality Assurance Manual (May, 1996). Each well was protected at the surface with a hinged and lockable metal shroud set within a 2 foot x 2 foot 2 x 4-inch concrete pad and surrounded by 3-inch x 5-foot steel bollards. Following installation, monitoring wells were developed to minimize turbidity and maximize well performance in preparation for groundwater sampling. Well development consisted of an initial purge of the well sump to clear heavy solids that may have entered the well. A one-inch PVC actuator rod equipped with a two-inch surge block was inserted to the base of the well, and manual surging was initiated across the entire water-bearing portion of the screened interval moving in two- to three-foot intervals. Subsequently, the purge pump was again placed at the base of the screened interval, and high-rate evacuation was initiated across each two-foot screened interval until particulates were minimized in each interval.

3.2 GROUNDWATER MONITORING

Groundwater sample collection (Protocol, December 2002, and February 2003) was conducted in accordance with the work plan and the EPA Region IV's <u>Standard Operating Procedures and Quality Assurance Manual</u> (November 2001). Groundwater samples were collected using a peristaltic pump and Teflon® tubing. Low flow/low stress sampling techniques were utilized for wells where there was sufficient recharge. If there was insufficient recharge for low flow/low stress sampling techniques to be utilized, traditional volume-based sampling techniques were used. Copies of the sample collection logs for both the protocol sampling and the groundwater monitoring are included in Appendix C.

Groundwater samples were collected directly from the discharge tubing into containers provided by BATCO. A BATCO representative was on site during sample collection and samples to be analyzed by BATCO were delivered directly to the BATCO site representative. Chain-of-custody documentation was maintained for all samples collected.

3.2.1 Protocol Sampling

Prior to sampling the additional monitoring wells, surface water and stream sediment, questions arose regarding analytical methods for Dioxathion and the quality of Dioxathion for use as a laboratory standard. In the ensuing months, Hercules, in conjunction with MDEQ's consultant, Mississippi State University (MSU) developed analytical protocols for soil and groundwater (Appendix A). Since the quality of available analytical standards was questionable, Hercules contracted with Sigma Aldritch to synthesize Dioxathion standards. In August 2002 Dioxathion had been manufactured of a suitable quality to be used as laboratory standard, and Hercules and the MDEQ had agreed to a laboratory protocol.

Groundwater samples were collected to evaluate the Dioxathion analytical protocol on October 14, 2002 from the selected monitoring wells MW-1, MW-4, and MW-5. Quality assurance/ quality control (QA/QC) samples were also collected. The QA/QC samples included a rinsate blank and a duplicate sample for MW-4. All samples were analyzed for Dioxathion by both BATCO and the Mississippi State Chemical Laboratory (MSCL). At the request of the MDEQ, samples were also collected from monitoring wells MW-5 and MW-6 for VOC and SVOC analyses. Samples submitted for VOC and SVOC analysis were analyzed by BATCO. Representatives of the MDEQ were on site during protocol sample collection but did not elect to split samples.

During the protocol sampling an equipment rinsate blank, a matrix spike sample (MS) and a matrix spike duplicate (MSD) sample were collected to provide quality assurance and quality control (QA/QC) during the protocol sampling. A trip blank, which remained in the sample cooler, was also provided by BATCO. The rinsate blank sample was collected by pouring deionized water over, and through a piece of disposable tubing and collecting the rinsate in a sample container. MS and MSD samples were collected by alternating aliquots into the containers for the monitoring well sample, the MS sample and MSD sample.

3.2.2 December 2002 Sampling Event

On December 4 and 5, 2002, Eco-Systems collected groundwater samples from the eleven groundwater monitoring wells at the site in accordance with the February 1999 work plan for Dioxathion, isomers, and Dioxenethion analysis. As with the protocol sampling, QA/QC samples were also collected and included rinsate blank, trip blank, blind duplicate, matrix spike and matrix spike duplicate samples. At the request of the MDEQ, the sample collected from MW-4 was also analyzed for VOCs and samples collected from monitoring wells MW-7, MW-8, MW-9, MW-10 and MW-11 were also analyzed for VOCs and SVOCs. Samples were delivered to the BATCO site representative for analysis. Representatives of the MDEQ were on site December 4, 2002 and collected a split sample from monitoring well MW-11.

During the December 2002 sampling event an equipment rinsate blank, a field duplicate, a matrix spike sample, and a matrix spike duplicate sample were collected to provide QA/QC for the monitoring event. A trip blank, which remained in the sample cooler, was also provided by BATCO. The rinsate blank and MS/MSD were collected as described in Section 3.2.1. The field duplicate sample was collected in the same fashion as the MS/MSD samples.

3.2.3 February 2003 Sampling Event

On February 11, 2003, Eco-Systems collected groundwater samples from MW-4, MW-8, MW-9, and MW-11 to provide confirmation of the detections of VOCs that were detected in the groundwater samples from those same wells during the December 2002 sampling event. Samples were collected from monitoring wells MW-4, MW-8, MW-9, and MW-11 and analyzed for VOCs. Samples were delivered to the BATCO site representative for analysis. A MDEQ representative was on site on February 11, 2003, but did not elect to split the groundwater samples.

As with the protocol sampling, QA/QC samples were also collected and include rinsate blank, trip blank, and a field duplicate. These samples were collected as described in Sections 3.2.1 and 3.2.2.

3.3 SURFACE WATER AND STREAM SEDIMENT SAMPLING

On February 11, 2003 surface water and sediment samples were collected from Green's Creek and analyzed for VOC and Dioxathion. QA/QC samples were also collected. Surface water and stream sediment samples were collected from locations CM-1, CM-2, CM-3, CM-4, and CM-5. Stream sampling locations are shown in Figure 2. A MDEQ representative was on site during the stream sampling, and the MDEQ collected a duplicate sample of the surface water and stream sediment at location CM-3.

Surface water was collected from Green's Creek by submerging the sample container into the flow of the creek to a depth sufficient to fill the containers. Samples were collected beginning downstream and working upstream to mitigate the potential for cross-contamination related disturbed materials from drifting downstream to subsequent sampling locations. Sample location CM-5 is located downstream from the other four locations and was therefore sampled first. Sample collection progressed in an upstream manner beginning with CM-5. To prevent disturbed particles from entering the sample containers, the samples were taken upstream of the sampler. Surface water was placed into containers provided by BATCO and delivered to the BATCO site representative for laboratory analysis.

Stream sediment was sampled in a sequence identical to the surface water collection. Sediments to be analyzed for Dioxathion were collected using a stainless steel spade. The spade was decontaminated prior to use and between each sample collection. Sediments to be analyzed for VOC were collected using sampling syringes provided by BATCO. Each syringe was used only once. Sediments were placed into containers provided by BATCO and delivered to the BATCO site representative for laboratory analysis.

During the surface water and stream sediment sampling an equipment rinsate blank, a field duplicate sample of surface water, and a field duplicate sample of stream sediment were collected to provide QA/QC during the surface water and stream sediment sampling. A trip blank, which remained in the sample cooler, was also provided by BATCO. The rinsate blank sample was collected by pouring deionized water over the stainless steel scoops used to collect the stream sediment samples and collecting the rinsate in a sample container. The field duplicate sample of the surface water and the duplicate sample collected for the MDEQ were collected in the same manner as the original sample and collected from the same location. The field duplicate sample of the stream sediment sample and the duplicate sample collected for the MDEQ were collected by obtaining additional stream sediments from the same location as the original sample.

3.4 DECONTAMINATION

Drilling equipment used to collect subsurface soil and groundwater samples (drill rods, hydraulic probe rods, and samplers, screens points (stainless and PVC)) were decontaminated initially by high-pressure steam cleaning. Decontamination between sampling intervals was also performed to mitigate vertical cross-contamination between sample intervals/locations. For stainless-steel sampling equipment specifically used for collecting soil samples (e.g., trowels, bowls, etc.), decontamination will be accomplished by the following procedure:

1) Phosphate-free detergent wash.
2) Potable water rinse.
3) Deionized water rinse.
4) Isopropanol rinse.
5) Organic-free water rinse or air dry.
6) Individual tin foil wrap.

For boring activities, separate decontaminated samplers were used between sample intervals within the same boring, thereby requiring decontamination between boring locations only.

3.5 DERIVED WASTE MANAGEMENT

Investigative-derived waste, IDW, (e.g., soil cuttings, plastic sampling tubes, decontamination water, well purge water, personal protective equipment, etc.) were containerized immediately following generation and staged in a readily-accessible area to facilitate subsequent management. Best Management Practices (BMPs), as outlined in the <u>Environmental Investigations Standard Operating Procedures and Quality Assurance Manual</u> (EPA Region IV, November 2001), were followed to minimize waste volumes and minimize client liability. These BMPs were based on review of historical analytical data and qualitative and quantitative field screening results.

4.0 LABORATORY ANALYTICAL RESULTS

Samples were analyzed for Dioxathion according to the analytical protocol established by Hercules and approved by the MDEQ. Samples submitted for VOC and SVOC analysis were analyzed according to U.S. EPA SW-846 methods 8260B for volatile compounds and 8270C for semi-volatile compounds, respectively. Analytical data are discussed below and summarized in Tables 2, 3, 4, 5, and 6. Copies of the laboratory analytical reports are included in Appendix D. Sample locations are shown on Figure 2.

The following sections are intended to provide a brief overview of the laboratory analytical results, and not an exhaustive discussion of the analytical data.

4.1 PROTOCOL SAMPLING

Samples collected for evaluation of the Dioxathion protocol were analyzed for cis-Dioxathion, trans-Dioxathion, and Dioxenethion. Analysis of the protocol samples by the MSCL was conducted by both high performance liquid chromatography/mass spectrometry (HPLC/MS) methods and ultraviolet (HPLC/UV) methods. Analysis of the protocol samples by BATCO was conducted by Gas Chromatography/Mass Spectrometry (GC/MS). The results of the Dioxathion analyses are shown in Table 2. Based on the agreement between Hercules and the MDEQ, the samples collected in this investigation were analyzed by GC/MS methods.

Groundwater samples were also collected in October 2002 for monitoring wells MW-5 and MW-6 for VOC and SVOC analysis. No detections of VOC or SVOC were identified above the MDL as reported in the case narrative by Bonner (Appendix D).

4.2 DECEMBER 2002 GROUNDWATER MONITORING

Samples collected during the December 2002 groundwater monitoring event were analyzed using GC/MS methods by BATCO. Analytical results are shown in Table 3. Concentrations of cis-Dioxathion were detected in the groundwater samples collected from monitoring wells MW-4 and MW-9. Concentrations of trans-Dioxathion were detected in the groundwater sample collected from monitoring well MW-8. Concentrations of total Dioxathion (i.e. the sum of the concentrations of cis-Dioxathion and trans-Dioxathion) above the target remediation goal (TRG) of 54.8 parts per billion (ppb) were not detected in the groundwater samples collected from the site. The TRGs are found in the Tier 1 Target Remedial Goal Table of the Final Regulations Governing Brownfields Voluntary Cleanup And Redevelopment In Mississippi, published by the Mississippi Commission on Environmental Quality and adopted May 1999 and revised March 2002.

Concentrations of Dioxenethion were detected in the groundwater samples collected from monitoring wells MW-4, MW-6, MW-7, MW-8, MW-9, and MW-11. A TRG for Dioxenethion has not been published.

Neither Dioxathion nor Dioxenethion were detected in the groundwater samples collected from MW-1, MW-2, MW-3, MW-5, and MW-10.

Eight VOCs were detected in the groundwater sample collected from MW-4. Four of the eight VOCs, Benzene, Carbon Tetrachloride, Chloroethane, and Chloromethane were detected at concentrations exceeding their respective TRGs.

Twenty-eight VOCs were detected in the groundwater sample collected from MW-8. Fourteen of the 28 VOCs were detected at concentrations above their respective TRGs. Those 14 VOCs are 1,1-Dichloroethane, Benzene, Trichloroethene, Chlorobenzene, Bromodichloromethane, Carbon Tetrachloride, Chloroethane, Chloroform, Chloromethane, Dibromochloromethane, 1,2-Dichloroethane, Methylene Chloride, Naphthalene, and Tetrachloroethene.

Three VOCs were detected in the groundwater sample collected from MW-9. One of the three VOCs, Benzene, was detected in the sample collected from MW-9 at concentration above the applicable TRG.

Two VOCs were detected in the groundwater sample collected from MW-11. One of the two VOCs, Benzene, was detected in the groundwater sample collected from MW-11 at a concentration above the applicable TRG.

VOCs were not detected in the groundwater samples collected from monitoring wells MW-7 and MW-10. Groundwater samples collected during the December 2002 sampling event from monitoring wells MW-1, MW-2, MW-3, MW-5 and MW-6 were not analyzed for either VOC or SVOC.

One SVOC was detected in the groundwater sample collected from MW-8 at a concentration less than its TRG. SVOC were not detected in the groundwater samples collected from MW-7, MW-9, MW-10, and MW-11.

4.3 FEBRUARY 2003 GROUNDWATER MONITORING

On February 11, 2003, samples were collected from monitoring wells MW-4, MW-8, MW-9, and MW-11 to confirm the concentrations of VOCs detected in the samples collected from those same wells during the December 2002 sampling event. Analytical data from samples collected during this event are summarized on Table 4 for data that was detected above the PQL.

Three VOCs were detected in the February 2003 groundwater sample collected from monitoring well MW-4. Therefore, the concentrations of VOCs detected in the sample collected from MW-4 in December 2002 are unconfirmed. One of the three VOCs, Napthalene, was detected in the groundwater sample collected from MW-4 at a concentration above the applicable TRG.

Twenty-six VOCs were detected in the February 2003 groundwater sample collected from MW-8. Ten of the 26 VOCs detected in the February 2003 groundwater sample collected from MW-8 were above the applicable TRGs.

Thirteen VOCs were detected in the February 2003 groundwater sample collected from MW-9. Five of the thirteen VOCs detected in the groundwater sample collected from MW-9 were above the applicable TRG.

Four VOCs were detected in the February 2003 groundwater sample collected from MW-11. Two of the four VOCs detected in the groundwater sample collected from MW-11 were above the applicable TRG.

4.4 SURFACE WATER MONITORING

During the February 2003 sampling event, five surface water samples were collected from Green's Creek and those samples were analyzed for VOCs and Dioxathion. Analytical results for these samples are summarized in Table 5 and Table 6 for parameters detected above the PQL.

The VOC Benzene was detected in the surface water samples collected from the five sampling locations at concentrations ranging from 1.17 ppb in the sample collected from CM-2 to 4.04 ppb in the sample collected from CM-5.

The VOC Carbon Tetrachloride was detected in the surface water samples collected from CM-1 and CM-2. The concentration of Carbon Tetrachloride in the sample collected from CM-2 was slightly lower than the concentration of Carbon Tetrachloride detected in the sample collected from CM-1. Carbon Tetrachloride was not detected in the surface water samples collected from CM-3, CM-4, and CM-5.

The VOC Chloroethane was detected the surface water samples collected from CM-1, CM-2, CM-3, and CM-4. The concentrations of Chloroethane detected in the four samples were highest at CM-1, the upstream sample. The concentration of Chloroethane decreased with each successive sample moving downstream. Chloroethane was not detected in the surface water sample collected from CM-5. This suggests that the Chloroethane originates at a point upstream of CM-1, and concentrations are below detection where the stream exits the site.

The VOC Chloroform was detected in the surface water sample collected from CM-1. Chloroform was not detected in the surface water samples collected from CM-2, CM-3, CM-4, and CM-5.

The VOC Napthalene was detected in the surface water sample collected from CM-1, CM-2, CM-3, CM-4, and CM-5. Concentrations are not believed to be accurate due to the presence of Napthalene in the laboratory method blank.

The VOC 1,2,3-Trichlorobenzene was detected in the surface water sample collected from CM-1, CM-2, CM-3, CM-4, and CM-5. Concentrations are not believed to be accurate due to the presence of 1,2,3-Trichlorobenzene in the laboratory method blank.

The VOC 1,2,4-Trichlorobenzene was detected in the surface water sample collected from CM-1, CM-2, CM-3, and CM-4. Concentrations are not believed to be accurate due to the presence of 1,2,4-Trichlorobenzene in the laboratory method blank.

Dioxenethion was detected in the surface water samples collected from locations CM-3, CM-4, and CM-5. Dioxenethion was not detected in the surface water samples collected from CM-1 and CM-2.

Cis-Dioxathion was detected in the surface water sample collected from CM-2. Trans-Dioxathion was not detected in the surface water sample collected from CM-2. Neither cis-Dioxathion nor trans-Dioxathion were detected in the surface water samples collected from CM-1, CM-3, CM-4, and CM-5.

Total organic carbon (TOC) was measured in the stream water at concentrations ranging from 74.6 to 218.5 μ/g (parts per million – ppm).

4.5 STREAM SEDIMENT MONITORING

During the February 2003 sampling event, five stream sediment samples were collected from locations CM-1, CM-2, CM-3, CM-4, and CM-5 in Green's Creek. These samples were analyzed for Dioxathion and VOCs. Analytical data from these samples are summarized in Table 5 and Table 6 for parameters detected above the PQL.

Ten VOCs, Benzene, n-Butylbenzene, tert-Butylbenzene, 1,3-Dichlorobenzene, n-Propylbenzene, Napthalene, 1,2,3-Trichlorobenzene, 1,2,4-Trichlorobenzene, 1,2,4-Trimethylbenzene, and 1,3,5-Trimethylbenzene, were detected in the stream sediment sample collected from CM-1. In general, the concentrations of the VOCs detected in the stream sediment sample collected from CM-1 were either absent in downstream samples or present at lesser concentrations than in downstream samples, which indicates a possible source upstream from CM-1.

Eight VOCs, Bromomethane, n-Butylbenzene, 1,3-Dichlorobenzene, Napthalene, 1,2,3-Trimethylbenzene, 1,2,4-Trimethylbenzene, 1,2,4-Trimethylbenzene, and 1,3,5-Trimethylbenzene, were detected in the stream sediment sample collected from CM-2.

Six VOCs, 1,3-Dichlorobenzene, Napthalene, 1,2,3-Trichlorobenzene, 1,2,4-Trichlorobenzene, 1,2,4-Trimethylbenzene, and 1,3,5-Trimethylbenzene, were detected in the stream sediment sample collected from CM-3.

Six VOCs, Benzene, 1,3-Dichlorobenzene, Napthalene, 1,2,3-Trichlorobenzene, 1,2,4-Trichlorobenzene, 1,2,4-Trimethylbenzene, and 1,3,5-Trimethylbenzene, were detected in the stream sediment sample collected from CM-4.

Eight VOCs, Bromomethane, 1,3-Dichlorobenzene, 1,4-Dichlorobenzene, Napthalene, 1,2,3-Trichlorobenzene, 1,2,4-Trichlorobenzene, 1,2,4-Trimethylbenzene, and 1,3,5-Trimethylbenzene, were detected in the stream sediment sample collected from CM-5.

Trans-Dioxathion was detected in the stream sediment samples collected from CM-1, CM-3, and CM-5. Trans-Dioxathion was not detected in the stream sediment samples collected from CM-2, and CM-4. Neither cis-Dioxathion nor Dioxenethion were detected in any of the five stream sediment samples.

Total organic carbon (TOC) was measured in the sediment at concentrations ranging from approximately 2 to 7 ppm.

Grain size analyses were performed for sediment samples collected from CM-3, CM-4, and CM-5 sampling locations. CM-1 and CM-2 sediments were similar to those at CM-3. CM-3 showed primarily silt and clay with 97.4% of the sample passing through the #200 sieve. CM-4 showed primarily sand and gravel with 95.9% of the sample retained by the #200 sieve. CM-5 showed primarily sand and gravel with 93.7% of the sample retained by the #200 sieve.

4.6 QA/QC SAMPLES

The results of the QA/QC samples are summarized in Tables 2 and 3 with the corresponding analytical results. In general, Eco-Systems concluded that the laboratory analyses were conducted under well-controlled conditions, and with sufficient precision and accuracy to provide accurate analytical results.

Eco-Systems reviewed the case narrative for the surface water and sediment analytical results prepared by Bonner Analytical Testing Company. The case narrative notes that all QA.QC data were found to pass guidelines according the EPA Method 8000, with the exception of the sediment sample and its duplicate for the CM-3 sediment sample.

5.0 FINDINGS AND CONCLUSIONS

The findings and conclusions of this report are based on, or reasonably ascertainable from, published information, field observations, and the results of specific laboratory analyses.

5.1 GEOLOGY AND HYDROGEOLOGY

- Soils encountered beneath the site were described as silty sands, clayey sands, and gravelly sands from the surface to a depth of five feet below ground surface to greater than 18 feet below ground surface, depending on location. The sandy soils are interpreted to be alluvium and terrace deposits. Gray, sandy clay, interpreted as the Hattiesburg formation, was encountered beneath these sandy soils and also observed in the bottom of the Green's Creek at the three upstream locations CM-1, CM-2, and CM-3.

- Surface water in Green's Creek enters the site in the west, flows eastward, and leaves the site in the northeast.

- Groundwater occurs in the sandy soils overlying the clays of the Hattiesburg formation, which likely serves as a confining unit throughout the site.

- Groundwater and surface water elevations from measurements made on March 5, 2003 have been used to construct the potentiometric surface map shown on Figure 3. Figure 3 indicates that the potentiometric surface tends to mimic surface topography. In the active portions of the plant operations, the potentiometric surface indicates the presence of a southwest to northeast trending divide. Groundwater northwest of the divide would tend to move northwestward towards Green's Creek. Groundwater southeast of the divide would tend to move southeastward. North of Green's Creek, the potentiometric surface indicates that groundwater moves generally southward towards Green's Creek.

5.2 GROUNDWATER, SURFACE WATER AND STREAM SEDIMENT QUALITY

5.2.1 Dioxathion

- During the Protocol sampling conducted in October 2002 and the groundwater monitoring conducted in December 2002, isomers of Dioxathion were detected in groundwater samples collected from MW-4, MW-5, MW-8, MW-9, and MW-11. None of the detections of Dioxathion were above the TRG of 54.8 micrograms per liter (ppb).

- During the Protocol sampling and the December 2002 monitoring event, Dioxenethion was detected in groundwater samples collected from MW4, MW-5, MW-6, MW-7, MW-8, MW-9, and MW-11. A TRG for Dioxenethion has not been published.

- Cis-Dioxathion was detected in the surface water sample collected from location CM-2 in Green's Creek.
- Dioxenethion was detected in the surface water samples collected from locations CM-3, CM-4, and CM-5.
- Trans-Dioxathion was detected in the stream sediment samples collected from locations CM-1, CM-3, and CM-5.

5.2.2 Volatile Organic Compounds

- During the December 2002 sampling event, concentrations of VOCs above applicable TRGs were detected in the groundwater samples collected from monitoring wells MW-4, MW-8, MW-9, and MW-11. The greatest number of detected VOCs and the highest concentrations of VOCs were detected in the groundwater sample collected from monitoring well MW-8, which is located in the former dioxathion production area.
- During confirmation sampling conducted in February 2003, VOCs were not detected in the groundwater sample collected from MW-4.
- During confirmation sampling conducted in February 2003, concentrations of VOCs above applicable TRGs were detected in the groundwater samples collected from MW-8, MW9, and MW-11. As with the December 2002 samples, the greatest number of VOCs and the highest concentrations of VOCs were detected in the groundwater sample collected from MW-8. However, both the numbers of VOCs detected and the concentrations of many of the detected VOCs, were notably less than from the December 2002 sampling event.
- Concentrations of seven VOCs, Benzene, Carbon Tetrachloride, Chloroethane, Chloroform, Napthalene, 1,2,3-Trichlorobenzene, and 1,2,4-Trichlorobenzene, were detected in one or more of the surface water samples collected from the five surface water sampling locations. The greatest number of VOCs and, in general, the highest concentrations of VOCs were detected in the surface water sample collected from location CM-1, which is the westernmost stream sampling location. An upstream source for the VOCs detected in the surface water samples may be indicated.
- Concentrations of twelve VOCs were detected in one or more of the stream sediment samples collected from the five stream sediment sampling locations. The greatest number of VOCs and, in general, the highest concentrations of VOCs were detected in the stream sediment sample collected from location CM-1, which is the westernmost stream sampling location. An upstream source for the VOCs detected in the stream sediment samples may be indicated.

5.2.3 Semi-Volatile Organic Compounds

- During the December 2002 sampling event, one SVOC, 4-Methylphenol was detected in the groundwater sample collected from MW-8 at a concentration less than the applicable TRG.

6.0 RECOMMENDATIONS

Based on the information obtained during the completed portions of the site investigation Eco-Systems recommends the following:

- As requested by MDEQ, prepare a work plan for supplemental site assessment to address the extent of VOCs detected in site monitoring wells.

TABLES

TABLE 1
GROUNDWATER ELEVATION DATA SUMMARY - MARCH 5, 2003
HERCULES, INC.
HATTIESBURG, MISSISSIPPI

WELL NO.	TOC ELEVATION (ft.)[1]	WATER DEPTH (ft)[2]	GROUNDWATER ELEVATION (ft.)
PERMANENT MONITOR WELLS			
MW-1	174.12	4.25	169.87
MW-2	160.07	4.70	155.37
MW-3	160.03	5.23	154.80
MW-4	159.75	9.32	150.43
MW-5	160.99	7.48	153.51
MW-6	174.05	6.80	167.25
PIEZOMETERS			
TP-1	172.18	3.86	168.32
TP-2	171.72	10.26	161.46
TP-3	169.74	7.26	162.48
TP-4	163.64	3.14	160.50
TP-5	160.54	6.52	154.02
TP-6	158.63	5.42	153.21
TP-7	167.17	8.01	159.16
TP-8	183.79	13.07	170.72
TP-9	163.44	5.23	158.21
TP-10	179.69	13.36	166.33
TP-11	162.26	7.15	155.11
TP-12	159.95	9.31	150.64
TP-13	156.99	6.22	150.77
TP-14	164.35	5.65	158.70
STAFF GAUGES			
SG-1	150.11	0.54	150.65
SG-2	145.13	0.42	145.55
SG-3	144.03	0.40	144.43
SG-4	137.80	0.53	138.33

[1] TOC = "top of casing" measured relative to mean sea level (ft. MSL).

[2] Water depth is a relative depth measured from the TOC.

[3] Date water level survey was completed is presented in parentheses for each site.

		Concentrations in parts per billion (*ppb*)		
		MSCL[1]		BATCO[2] GC/MS
Well	Isomer	HPLC/MS	HPLC/UV	
MW-1	Dioxenethion	nd[3]	nd	nd
	cis-Dioxathion	nd	nd	nd
	trans-Dioxathion	nd	1.5	nd
MW-4	Dioxenethion	32	25	19.22
	cis-Dioxathion	nd	nd	4.80
	trans-Dioxathion	nd	nd	1.61
MW-5	Dioxenethion	nd	nd	5.09
	cis-Dioxathion	nd	nd	1.70
	trans-Dioxathion	0.92	10	1.44
Rinsate	Dioxenethion	nd	nd	nd
	cis-Dioxathion	nd	nd	nd
	trans-Dioxathion	nd	nd	nd
MW-4 Dup	Dioxenethion	na[4]	na	20.7
	cis-Dioxathion	na	na	4.71
	trans-Dioxathion	na	na	1.75

TABLE 2
SUMMARY OF PROTOCOL SAMPLING ANALYTICAL RESULTS - OCTOBER 14, 2002
HERCULES, INC.
HATTIESBURG, MISSISSIPPI

Notes:

[1] MSCL = Mississippi State Chemical Laboratory

[2] BATCO = Bonner Analytical & Testing Compay

[3] nd = Analyte not detected at or above the method detection limit.

[4] na = not analyzed

TABLE 3
SUMMARY OF GROUNDWATER SAMPLE ANALYTICAL RESULTS - DECEMBER 4 AND 5, 2002
HERCULES INC.
HATTIESBURG, MISSISSIPPI
Concentrations in parts per billion (*ppb*)

Analytes	MW-1	MW-2	MW-3	MW-4	MW-5	MW-6	MW-7	MW-8	MW-9	MW-10	MW-11	TRG[1]
Dioxathion												
cis-Dioxathion	nd	nd	nd	3.34	nd	nd	nd	nd	12.8	nd	5	
trans-Dioxathion	nd	nd	nd	nd	nd	nd	nd	53.9	nd	nd	nd	
total	nd	nd	nd	3.34	nd	nd	nd	53.9	12.8	nd	5	54.8
Dioxenethion	nd[2]	nd	nd	12.9	nd	1.12	9.57	94.3	5.9	nd	50.3	na
Volatiles												
1,1-Dichloroethene	na[3]	na	na	nd	na	na	nd	17	5.92	nd	nd	7
Benzene	na	na	na	14	na	na	nd	6900	9.15	nd	114	5
Trichloroethene	na	na	na	nd	na	na	nd	5.8	nd	nd	nd	5
Toluene	na	na	na	nd	na	na	nd	28	nd	nd	nd	1000
Chlorobenzene	na	na	na	1.81	na	na	nd	290	nd	nd	nd	100
Bromodichloromethane	na	na	na	nd	na	na	nd	6.84	nd	nd	nd	0.168
Bromomethane	na	na	na	nd	na	na	nd	4.07	nd	nd	nd	8.52
Carbon Tetrachloride	na	na	na	10	na	na	nd	16000	nd	nd	nd	5
Chloroethane	na	na	na	63	na	na	nd	66	nd	nd	nd	3.64
Chloroform	na	na	na	nd	na	na	nd	1800	nd	nd	nd	0.155
Chloromethane	na	na	na	1.72	na	na	nd	39.2	nd	nd	nd	1.43
Dibromochloromethane	na	na	na	nd	na	na	nd	4.45	nd	nd	nd	0.126
1,2-Dichlorobenzene	na	na	na	nd	na	na	nd	2.71	nd	nd	nd	600
1,3-Dichlorobenzene	na	na	na	nd	na	na	nd	3.75	nd	nd	nd	5.48
1,4-Dichlorobenzene	na	na	na	nd	na	na	nd	3.8	nd	nd	nd	75
1,2-Dichloroethane	na	na	na	nd	na	na	nd	20	nd	nd	3.11	5
cis-1,2-Dichloroethene	na	na	na	nd	na	na	nd	19	nd	nd	nd	70
Ethyl Benzene	na	na	na	nd	na	na	nd	55.6	nd	nd	nd	700
Isopropylbenzene	na	na	na	1.26	na	na	nd	4.6	2.48	nd	nd	679
p-Isopropyltoluene	na	na	na	nd	na	na	nd	23.9	nd	nd	nd	na
Methylene Chloride	na	na	na	nd	na	na	nd	26.1	nd	nd	nd	5
Naphthalene	na	na	na	5.38	na	na	nd	9.14	nd	nd	nd	6.2
Tetrachloroethene	na	na	na	nd	na	na	nd	8.51	nd	nd	nd	5

TABLE 3 - CONTINUED

SUMMARY OF GROUNDWATER SAMPLE ANALYTICAL RESULTS - DECEMBER 4 AND 5, 2002

HERCULES INC.

HATTIESBURG, MISSISSIPPI

Volatiles - continued											
1,2,3-Trichlorobenzene	na	na	1.81	na	na	nd	2.55	nd	nd	nd	na
1,2,4-Trichlorobenzene	na	na	nd	na	na	nd	2.86	nd	nd	nd	70
1,2,4-Trimethylbenzene	na	na	nd	na	na	nd	1.81	nd	nd	nd	12.3
Xylenes (total)	na	na	nd	na	na	nd	79	nd	nd	nd	10000
Vinyl Chloride	na	na	nd	na	na	nd	1.62	nd	nd	nd	2
Semi-Volatiles											
4-Methylphenol	na	na	nd	na	na	nd	13.16	nd	nd	nd	183

NOTES:

[1] Target Remediation Goals are taken from the Tier 1 Target Remedial Goals Talbe of the Final Regulations Governing Brownsfields Voluntary Cleanup and Redevelopment In Mississippi, MDEQ, March 2001. Bold text indicates concentrations above applicable TRGs.

[2] nd = Analyte not detected at or above the method detection limit

[3] na = Not analyzed

TABLE 4
SUMMARY OF GROUNDWATER SAMPLE ANALYTICAL RESULTS - FEBRUARY 11, 2003
HERCULES, INC.
HATTIESBURG, MISSISSIPPI

Analytes	PQL[1] (*ppb*)	MW-1	MW-2	MW-3	MW-4	MW-5	MW-6	MW-7	MW-8	MW-9	MW-10	MW-11	TRG[2]
Volatiles													
1,1-dichloroethene	10.00	na[3]	na	na	nd[4]	na	na	na	1.85 J[5]	nd	na	nd	7
benzene	10.00	na	na	na	nd	na	na	na	12000	64.3	na	6.39 J	5
trichloroethene	10.00	na	na	na	nd	na	na	na	3.2 J	nd	na	nd	5
toluene	10.00	na	na	na	nd	na	na	na	35.4	nd	na	nd	1000
chlorobenzene	10.00	na	na	na	nd	na	na	na	230 J	5.85 J	na	nd	100
bromodichloromethane	10.00	na	na	na	nd	na	na	na	4.72 J	nd	na	nd	0.168
carbon tetrachloride	10.00	na	na	na	nd	na	na	na	12000	20.7	na	nd	5
chloroethane	12.00	na	na	na	nd	na	na	na	85.5	19.7	na	nd	3.64
chloroform	10.00	na	na	na	nd	na	na	na	1300	9.83 J	na	nd	0.155
chloromethane	10.00	na	na	na	nd	na	na	na	3.34 J	nd	na	nd	1.43
1,2-dichlorobenzene	10.00	na	na	na	nd	na	na	na	2.22 J	nd	na	nd	600
1,4-dichlorobenzene	10.00	na	na	na	nd	na	na	na	3.14 J	nd	na	nd	75
1,1-dichloroethane	10.00	na	na	na	nd	na	na	na	nd	2.23 J	na	nd	798
1,2-dichloroethane	10.00	na	na	na	nd	na	na	na	79.8	1.43 J	na	nd	5
cis-1,2-dichloroethene	10.00	na	na	na	nd	na	na	na	17.5	nd	na	nd	70
ethyl benzene	10.00	na	na	na	nd	na	na	na	67.5	1.53 J	na	nd	700
isopropylbenzene	10.00	na	na	na	nd	na	na	na	4.35 J	1.92 J	na	nd	679
p- isopropyltoluene	10.00	na	na	na	nd	na	na	na	23.8	1.8 J	na	nd	na[5]
napthalene	11.00	na	na	na	34.4 B[6]	na	na	na	25.0 B	31.7 B	na	42.6 B	6.2
styrene	10.00	na	na	na	nd	na	na	na	1.25 J	nd	na	nd	100
tetrachloroethene	10.00	na	na	na	nd	na	na	na	48.9	nd	na	nd	5
1,2,3-trichlorobenzene	10.00	na	na	na	45.9 B	na	na	na	25.3 B	36.8 B	na	53.4 B	na
1,2,4-trichlorobenzene	10.00	na	na	na	9.79 B	na	na	na	5.73 B	4.98 B	na	13.55 B	70
1,1,1-trichloroethane	10.00	na	na	na	nd	na	na	na	1.50 J	nd	na	nd	200
1,2,4-trimethylbenzene	10.00	na	na	na	nd	na	na	na	1.92 J	nd	na	nd	12.3
1,3,5-trimethylbenzene	10.00	na	na	na	nd	na	na	na	1.8 J	nd	na	nd	12.3
xylenes (total)	15.00	na	na	na	nd	na	na	na	62.4	nd	na	nd	10000

Concentrations in parts per billion (*ppb*)

TABLE 4 - CONTINUED

SUMMARY OF GROUNDWATER SAMPLE ANALYTICAL RESULTS - FEBRUARY 11, 2003

HERCULES, INC.

HATTIESBURG, MISSISSIPPI

Notes:

[1] PQL = Laboratory Method Practical Quantitation Limit and represents the minimum concentration for which a sample can reliably be quantified.

[2] Target Remediation Goals (TRG) are taken from the Tier 1 Target Remedial Goal Table of the Regulations Governing Brownsfield Voluntary Cleanup and Redevelopment in Mississippi MDEQ, March 2001. Bold text indicates concentrations above applicable TRGs.

[3] na = "not analyzed".

[4] nd = "not detected" at or above the method detection limit.

[5] J = Data flag for data for which the concentration is "estimated" because the level is below the PQL, but was detected.

[6] B = Data flag for data for which was also detected in the associated method blank sample. Analyte was in blank greater than 5% of sample.

		TABLE 5

TABLE 5

STREAM SEDIMENT AND SURFACE WATER ANALYTICAL RESULTS FOR DIOXATHION - FEBRUARY 11, 2003

HERCULES, INC.

HATTIESBURG, MISSISSIPPI

TAGET PARAMETER	PQL (ppb)[1]	Concentration in parts per billion (ppb)[2]				
		CM-1	CM-2	CM-3	CM-4	CM-5
SURFACE WATER						
Dioxenethion	2.19	nd[3]	nd	3.16	BPQL[4]	3.07
Dioxathion (cis)	4.75	nd	8.72	nd	nd	nd
Dioxathion (trans)	3.04	nd	nd	nd	nd	nd
STREAMBED SEDIMENT						
Dioxenethion	170	nd	nd	nd	nd	nd
Dioxathion (cis)	134	nd	nd	nd	nd	nd
Dioxathion (trans)	149	790	nd	1370	nd	448

Notes:

[1] Represents the reporting limit or practical quantitation limit (PQL) of the analytical method in parts per billion (ppb).

[2] Results are presented in ppb with reference to the stream location (CM) from which the sample was collected.

[3] nd = "Not Detected" at or above the method detection limit.

[4] BPQL = "Below the Practical Quantitation Limit" of the analytical method in ppb.

TABLE 6
SURFACE WATER AND STREAM SEDIMENT SAMPLE ANALYTICAL RESULTS FOR VOC - FEBRUARY 11, 2003
HERCULES, INC.
HATTIESBURG, MISSISSIPPI

TARGET PARAMETER	PQL (ppb)[1]	Concentration in parts per billion (ppb)[2]				
		CM-1	CM-2	CM-3	CM-4	CM-5
VOLATILE ORGANICS SURFACE WATER						
Benzene	10.00	2.82 J[3]	1.17 J	3.66 J	2.25 J	4.04 J
Carbon Tetrachloride	10.00	3.03 J	1.48 J	nd[4]	nd	nd
Chlorethane	12.00	20.50	15.60	8.42 J	3.43 J	nd
Chloroform	10.00	2.34 J	nd	nd	nd	nd
Napthalene	11.00	25.7 B[5]	20.3 B	20.1 B	13.0 B	7.51 B
1,2,3-Trichlorobenzene	10.00	32.2 B	24.8 B	23.0 B	12.2 B	5.54 B
1,2,4-Trichlorobenzene	10.00	3.36 B	2.37 B	2.13 B	1.26 B	nd
VOLATILE ORGANICS STREAMBED SEDIMENT						
Benzene	na[6]	3.1 J	nd	nd	1.53 J	nd
Bromomethane	na	nd	3.1 J	nd	nd	2.11 J
n-Butylbenzene	na	3.97 J	1.65 J	nd	nd	nd
Tert-Butylbenzene	na	1.76 J	nd	nd	nd	nd
1,3-Dichlorobenzene	na	3.35 J	3.96 J	5.07 J	1.72 J	3.19 J
1,4-Dichlorobenzene	na	nd	nd	nd	nd	3.11 J
n-Propylbenzene	na	2.31 J	nd	nd	nd	nd
Napthalene	na	17.4 B	19.8 B	14.7 B	5.87 B	10.8 B
1,2,3-Trichlorobenzene	na	18.0 B	23.8 B	21.3 B	9.26 B	15.1 B
1,2,4-Trichlorobenzene	na	10.2 B	9.13 B	6.1 B	2.10 B	3.64 B
1,2,4-Trimethylbenzene	na	14.6 J	5.36 J	4.87 J	1.88 J	2.59 J
1,3,5-Trimethylbenzene	na	11.8 J	4.29 J	3.82 J	nd	2.24 J

Notes:

[1] Represents the reporting limit or practical quantitation limit (PQL) of the analytical method in parts per billion (ppb).

[2] Results are presented in ppb with reference to the stream location (CM) from which the sample was collected.

[3] J = Data flag for data for which the concentration is "estimated because the level is below the PQL, but above the Method Detection Limit.

[4] nd = "Not Detected" at or above the Method Detection Limit.

[5] B = Data flag for data which was also detected in te associated method blank sample.

[6] PQL values vary for each sample. See laboratory analytical data sheets.

BORING LOG

PROJECT NAME _Task 2- RI Hercules_

PROJECT LOCATION _Hattiesburg, MS_

PROJECT NUMBER _HBR-95_

GEOLOGIST _Sartor_

CLASSIFICATION SCHEME _USCS_

DRILLER _G+E Services_

DRILL METHOD _HSA w/ 3-spoons_

WEATHER _Sunny/Hot_

BORING IDENTIFICATION _TP-10_

BORE HOLE DIAMETER _6"_

BORING START TIME _1058_ DATE _7-29-95_

BORING COMPLETED TIME _1115_ DATE _7-29-95_

FINAL BORING DEPTH _17 16.5'_

GROUNDWATER

INITIAL DEPTH _~11_

DEPTH AFTER ___ MINUTES ___

FREE PRODUCT

THICKNESS ___

VOLUME ___

RECOVERY (INCHES)	DEPTH IN FEET	SYMBOL	LITHOLOGY	Description
22"	0.0	3/4 6/5		Dry Loose Brown/Black (rf fl) Si Sa (fr 11)
12"	0.5	6/6 8/3		Damp (f-med)
12"	1.0	3/3 6/3		Moist Firm -5' organic odor Gray Silt w/clay
14"	2.0	3/4 4/6		Moist Loose Si gray/tn (stf) Si Sa
12"	2.4	3/4 4/5		Moist Loose
10"	2.6	7/9 12/12	0.D.E. 0.0.0	wet (stn'd) medium dense tan (f-m) Cl Si Sa t fine
20"	2.8	10/10 14/17	0.0 0.0.0	saturated
				no Sample 14-14.5
20"	16	1/1 4/5		saturated damp stiff gray w/ mottling (f-m) Cl Sa w/silt Si Cl w/Sm
	18			
	10			
	15			

- Completed well 1115 @ 16.5' TD (14.5-17)
- Convert to TP-10 (8-14.5')
- 20/40 to 5½'
- Seal to 4½'
- 1' of Cave in to 13.5'

TEMPORARY MONITORING POINT COMPLETION FORM

PROJECT NAME _Hercules_

LOCATION _Hattiesburg, MS_

DATE COMPLETED _4/29/99_   BOREHOLE DEPTH _____

DRILLER _GtE Services_   DRILL METHOD _HSA_

GEOLOGIST _R Sartor_

INSPECTED BY _____   DATE _____

PAGE _1_ OF _1_

WELL NO. _TP-11_

BOREHOLE WATER LEVEL _____

STATIC WATER LEVEL _____

SCREEN INTERVAL _8-13_

ELEVATION OF TOP OF SURFACE CASING/RISER PIPE _162.26_

HEIGHT OF TOP OF SURFACE CASING/RISER PIPE ABOVE _NA_ GROUND SURFACE

TYPE OF SURFACE SEAL _NA_

DEPTH OF SURFACE SEAL BELOW GROUND SURFACE _NA_

INSIDE DIAMETER OF SURFACE CASING _NA_

TYPE OF PROTECTIVE CASING _NA_

DEPTH OF PROTECTIVE CASING BELOW GROUND _NA_

INSIDE DIAMETER OF RISER PIPE _1"_

TYPE OF RISER PIPE _PVC_

DIAMETER OF BOREHOLE _6"_

TYPE OF BACKFILL _High Solids Bentonite Grout_

ELEVATION / DEPTH TOP OF SEAL _5.5_

TYPE OF SEAL _Bent Chips_

ELEVATION / DEPTH BOTTOM OF SEAL _6.5_

DEPTH OF TOP OF SAND PACK _6.5'_

TYPE OF SAND PACK _20/40 Sand (4' of fallback)_

ELEVATION / DEPTH TOP OF SCREENED SECTION _8'_

FILTER SOCK _No!_

TYPE OF SCREENED SECTION _10 slot_

DESCRIBE OPENINGS _10 slot screen_

INSIDE DIAMETER OF SCREENED SECTION _1"_

ELEVATION / DEPTH BOTTOM OF SCREENED SECTION _13'_

LENGTH OF BLANK SECTION _Flush_

ELEVATION/DEPTH BOTTOM OF PLUGGED BLANK SECTION _13'_

ELEVATION/DEPTH BOTTOM OF SAND COLUMN _15'_

TYPE OF BACKFILL BELOW OBSERVATION PIPE _Native_

ELEVATION/DEPTH OF HOLE _15'_

SEE BORING LOG FOR STRATIGRAPHY

Eco-Systems, Inc.
Environmental Engineers and Scientists

02/15/1999 10:27 M:\DRWG2\FORMS\FRM005

S.M.

BORING LOG

PROJECT NAME _Task 2 - RI Hercules_
PROJECT LOCATION _Hattiesburg, MS_
PROJECT NUMBER _AER-99_
GEOLOGIST _Ryan_
CLASSIFICATION SCHEME _USCS_
DRILLER _G+E Services_
DRILL METHOD _HSA w/ s-spoons_
WEATHER _sunny/hot_

BORING IDENTIFICATION _TP-11_
BORE HOLE DIAMETER _6"_
BORING START TIME _1735_ DATE _4/25/99_
BORING COMPLETED TIME _1735_ DATE _4/29/99_
FINAL BORING DEPTH _15'_

GROUNDWATER	FREE PRODUCT
INITIAL DEPTH _7.5'_	THICKNESS ___
DEPTH AFTER ___ MINUTES ___	VOLUME ___

RECOVERY (INCHES)	DEPTH IN FEET	SYMBOL	LITHOLOGY	
20'	2	3/1 2/4		damp loose no odor blk S.Sa/gravel
	3 4 5		NS	no sample 5-7
12"	6 7 8 9	2/2 4/5		moist loose no odor tan S.Sa/gravel water @ 8.5
	10		NS	no sampling 7-10
22"	12	3/3 5/9		saturated loose no odor gray after S.Sa/gravel
20"	14	7/7 13/13		saturated fine no odor gray S.Cl.

- Completed @ 15 ft bgs
- TP-11 screen @ 8-13'
- Cave in to 9'
- 20/40 to 6.5'
- Seal to 5.5'

TEMPORARY MONITORING POINT COMPLETION FORM

PROJECT NAME __Hercules__
LOCATION __Hattiesburg, MS__
DATE COMPLETED __4/29/99__   BOREHOLE DEPTH _____
DRILLER __G+E Services__   DRILL METHOD __HSA__
GEOLOGIST __R Sartor__   DATE _____
INSPECTED BY _____

PAGE __1__ OF __1__
WELL NO. __TP-12__
BOREHOLE WATER LEVEL __~ 7'__
STATIC WATER LEVEL _____
SCREEN INTERVAL __5-13'__

SEE BORING LOG FOR STRATIGRAPHY

ELEVATION OF TOP OF SURFACE CASING/RISER PIPE __159.95__

HEIGHT OF TOP OF SURFACE CASING/RISER PIPE ABOVE __2.5'__
GROUND SURFACE

TYPE OF SURFACE SEAL __NA__
DEPTH OF SURFACE SEAL BELOW GROUND SURFACE __NA__
INSIDE DIAMETER OF SURFACE CASING __NA__
TYPE OF PROTECTIVE CASING __NA__
DEPTH OF PROTECTIVE CASING BELOW GROUND __NA__
INSIDE DIAMETER OF RISER PIPE __1"__
TYPE OF RISER PIPE __1" PVC__
DIAMETER OF BOREHOLE __6"__

TYPE OF BACKFILL __High Solids Bentonite Grout__
ELEVATION / DEPTH TOP OF SEAL __3'__
TYPE OF SEAL __Bentonite chips__
ELEVATION / DEPTH BOTTOM OF SEAL _____
DEPTH OF TOP OF SAND PACK __Native to 8' bgs, 20/40 Sand to 4'__
TYPE OF SAND PACK __20/40 Sand__
ELEVATION / DEPTH TOP OF SCREENED SECTION __5'__

FILTER SOCK __Yes__

TYPE OF SCREENED SECTION __10-slot 1" PVC__

DESCRIBE OPENINGS __10-slot__
INSIDE DIAMETER OF SCREENED SECTION __1"__

ELEVATION / DEPTH BOTTOM OF SCREENED SECTION __13'__
LENGTH OF BLANK SECTION __Flush__
ELEVATION/DEPTH BOTTOM OF PLUGGED BLANK SECTION __13'__
ELEVATION/DEPTH BOTTOM OF SAND COLUMN __17'__
TYPE OF BACKFILL BELOW OBSERVATION PIPE __Native__

ELEVATION/DEPTH OF HOLE __17'__

Eco-Systems, Inc.
Environmental Engineers and Scientists

BORING LOG

PROJECT NAME __Task 2 -RI Hercules__
PROJECT LOCATION __Hattiesburg, MS__
PROJECT NUMBER __HER-99__
GEOLOGIST __Ryan /Sartor__
CLASSIFICATION SCHEME __USCS__
DRILLER __G+E Services__
DRILL METHOD __HSA w/ s-spoons__
WEATHER __sunny/hot__

BORING IDENTIFICATION __TP-12__
BORE HOLE DIAMETER __6"__

BORING START TIME __925__ DATE __4-29-99__

BORING COMPLETED TIME __0945__ DATE __4-29-99__

FINAL BORING DEPTH __17'__

GROUNDWATER
INITIAL DEPTH __~7'__

DEPTH AFTER _____ MINUTES _____

FREE PRODUCT
THICKNESS _____

VOLUME _____

RECOVERY (INCHES)	DEPTH IN FEET	SYMBOL	LITHOLOGY	(notes)
6-2	22"	2,7 / 2	3/3 / 3/3		Damp Loose brown to 6 (A) orange
2-4	18"	0,5 / 4 / 6	2/3 / 3/4		No Sampling to 7' orange stiff Si Sand tan to 6 (A)
4-6	18"	6	3/6		tan uf/lt Si Sa bag
NS	8		NS	No Sampling 6-10' saturated loose tan (f/m)Si Sa m/gravel
22"	10 / 4 / 12	5/9 / 12/13		no sampling 12-15 the @ 13' (driller said top clay). Si Cl
	14		NS	
16"	16	6/7 / 8/10		Damp med stiff gray w/ Si,A orangish
	18			TD=17'
	20			• Convert to TP-12 fio 5'-13'
				• Native to 8'
				• 20/40 to 4'
	15			• Seal to 3'

TEMPORARY MONITORING POINT COMPLETION FORM

PROJECT NAME Hercules

LOCATION Hattiesburg, MS

DATE COMPLETED 4/29/99

DRILLER G+E Services

GEOLOGIST J Ryan

INSPECTED BY _____

BOREHOLE DEPTH _____

DRILL METHOD HSA

DATE _____

PAGE 1 OF 1

WELL NO. TP-13

BOREHOLE WATER LEVEL ~5'

STATIC WATER LEVEL _____

SCREEN INTERVAL 4-11'

SEE BORING LOG FOR STRATIGRAPHY

ELEVATION OF TOP OF SURFACE CASING/RISER PIPE 156.99

HEIGHT OF TOP OF SURFACE CASING/RISER PIPE ABOVE 3'
GROUND SURFACE

TYPE OF SURFACE SEAL NA

DEPTH OF SURFACE SEAL BELOW GROUND SURFACE NA

INSIDE DIAMETER OF SURFACE CASING NA

TYPE OF PROTECTIVE CASING NA

DEPTH OF PROTECTIVE CASING BELOW GROUND NA

INSIDE DIAMETER OF RISER PIPE 1"

TYPE OF RISER PIPE 1" PVC

DIAMETER OF BOREHOLE 6"

TYPE OF BACKFILL High Solids Bentonite Grout

ELEVATION / DEPTH TOP OF SEAL 1'x5 2'

TYPE OF SEAL Bentonite Chips

ELEVATION / DEPTH BOTTOM OF SEAL 3'

DEPTH OF TOP OF SAND PACK 3'

TYPE OF SAND PACK 20/40 Sand (No Native) 3'

ELEVATION / DEPTH TOP OF SCREENED SECTION 4'

FILTER SOCK Yes

TYPE OF SCREENED SECTION 10-slot 1" PVC

DESCRIBE OPENINGS 10-slot

INSIDE DIAMETER OF SCREENED SECTION 1"

ELEVATION / DEPTH BOTTOM OF SCREENED SECTION 11'

LENGTH OF BLANK SECTION Flush

ELEVATION/DEPTH BOTTOM OF PLUGGED BLANK SECTION 11'

ELEVATION/DEPTH BOTTOM OF SAND COLUMN 14'

TYPE OF BACKFILL BELOW OBSERVATION PIPE Sand 20/40

ELEVATION/DEPTH OF HOLE 14'

Eco-Systems, Inc.
Environmental Engineers and Scientists

S.M. 02/15/99 10:27 M:\DRWG2\FORMS\FRM005

BORING LOG

SHEET 1 OF ___

PROJECT NAME __Task 2 - RI Hercules__   BORING IDENTIFICATION __TP-13__

PROJECT LOCATION __Hattiesburg, MS__   BORE HOLE DIAMETER __6"__

PROJECT NUMBER __HER-99__

GEOLOGIST __Sartor__   BORING START TIME __810__ DATE __4-29-99__

CLASSIFICATION SCHEME __USCS__

DRILLER __G+R Services__   BORING COMPLETED TIME __835__ DATE __4-29-99__

DRILL METHOD __HSA w/ S-spoons__

WEATHER __Sunny/hot__   FINAL BORING DEPTH __14'__

GROUNDWATER	FREE PRODUCT
INITIAL DEPTH ~5'	THICKNESS _____
DEPTH AFTER ___ MINUTES ___	VOLUME _____

RECOVERY (INCHES)	DEPTH IN FEET	SYMBOL	LITHOLOGY	
18"	0.6 / 2	5/4 5/6	SC	DRY, Loose, brn-gray, CL/a (0-2')
19"	1.0 / 4	4/4 4/4	SC	v. Damp Loose, clay(kaolin), CLSa (2'-5') w/gravel
8"	16.4 / 6	4/4 3/5	SM	Saturated (5') Med-dense (vf-f) Si.Sa w/trace gravel (5'-7')
18"	0.4 / 8	6/17 16/18	SPc	(f-med) Gravelly Sand w/Si (7-10')
12"	1.1 / 10	3/5 6/12	SPo	Loose (f) V.Gravelly Sand w/Si.+Cl
10"	8.1 / 12	3/2 4/7	Cl	Damp Stiff brown/gray mottling, S.Cl 10-14.5'
14"	0.0 / 14	2/5 3/8	Cl	
	16			
	18			
	-20-			
	-15-			

• Convert to TP-13 from 4-11'.
• Add filter sock + 20/40 from TD.

TD = 14'

TEMPORARY MONITORING POINT COMPLETION FORM

PROJECT NAME _Hercules_

LOCATION _Hattiesburg, MS_

DATE COMPLETED _5/10/95_

DRILLER _G&E Services_

GEOLOGIST _J Ryan_

INSPECTED BY _____

BOREHOLE DEPTH _____

DRILL METHOD _HSA_

DATE _____

PAGE _1_ OF _1_

WELL NO _TP-14_

BOREHOLE WATER LEVEL _____

STATIC WATER LEVEL _____

SCREEN INTERVAL _____

SEE BORING LOG FOR STRATIGRAPHY

ELEVATION OF TOP OF SURFACE CASING/RISER PIPE _164.84_

HEIGHT OF TOP OF SURFACE CASING/RISER PIPE ABOVE _2.6'_
GROUND SURFACE

TYPE OF SURFACE SEAL _NA_

DEPTH OF SURFACE SEAL BELOW GROUND SURFACE _NA_

INSIDE DIAMETER OF SURFACE CASING _NA_

TYPE OF PROTECTIVE CASING _NA_

DEPTH OF PROTECTIVE CASING BELOW GROUND _NA_

INSIDE DIAMETER OF RISER PIPE _1"_

TYPE OF RISER PIPE _PVC_

DIAMETER OF BOREHOLE _6"_

TYPE OF BACKFILL _High Solids Bentonite Grout_

ELEVATION / DEPTH TOP OF SEAL _1'_

TYPE OF SEAL _Bentonite Pellets_

ELEVATION / DEPTH BOTTOM OF SEAL _3'_

DEPTH OF TOP OF SAND PACK _5.0'_

TYPE OF SAND PACK _20/40 Sand_

ELEVATION / DEPTH TOP OF SCREENED SECTION _7.6'_

FILTER SOCK _Yes_

TYPE OF SCREENED SECTION _10-slot 1" PVC_

DESCRIBE OPENINGS _10-slot_

INSIDE DIAMETER OF SCREENED SECTION _1"_

ELEVATION / DEPTH BOTTOM OF SCREENED SECTION _12.6"_

LENGTH OF BLANK SECTION _Flush_

ELEVATION/DEPTH BOTTOM OF PLUGGED BLANK SECTION _12.6"_

ELEVATION/DEPTH BOTTOM OF SAND COLUMN _14'_

TYPE OF BACKFILL BELOW OBSERVATION PIPE _Native_

ELEVATION/DEPTH OF HOLE _14"_

Eco-Systems, Inc.
Environmental Engineers and Scientists

02/15/1999 10:27 M:\DRWG2\FORMS\FRM005

BORING LOG

PROJECT NAME __Task 2 - RI Hercules__
PROJECT LOCATION __Hattiesburg, MS__
PROJECT NUMBER __HER-95__
GEOLOGIST __Ryan__
CLASSIFICATION SCHEME __USCS__
DRILLER __G+E Services__
DRILL METHOD __HSA w/ s-spoons__
WEATHER ___

BORING IDENTIFICATION __TP-14__
BORE HOLE DIAMETER __3"__
BORING START TIME __0830__ DATE __5-10-99__
BORING COMPLETED TIME __1650__ DATE __5-10-99__
FINAL BORING DEPTH ___

RECOVERY (INCHES)	DEPTH IN FEET	SYMBOL	LITHOLOGY	GROUNDWATER		FREE PRODUCT	
				INITIAL DEPTH ~7'		THICKNESS ___	
				DEPTH AFTER ___ MINUTES ___		VOLUME ___	

Lithology notes:

DAMP, firm, brown, CCSa
moist (6z) black-stained - Fill ov C2 (4.5'-0.1)
DAMP (3S) Loose, lt. brn, SiSa tr. cL (3.1'-5)
moist (5'), firm, brown, CfSa (5'-7')
wet-sat, Loose, lt. Sen, SiSa f-med (free gravel)
Sat tan

w/ gravel @ 10.5'

TP-14   TD = 14'

Native @ 9.3'

TP-14
Pellets to 1.3' B/s
20/40 - 5'
7.6'
BoS - 12.6'   6' screen

TJ-74'