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By
Bijon Sharma

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BDM Petroleum Technologies, Inc.
BDM-Oklahoma, Inc.
Bartlesville, Oklahoma

**National Petroleum Technology Office
U. S. DEPARTMENT OF ENERGY
Tulsa, Oklahoma**

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Maganom Software
User's Guide

By
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Work Performed Under Contract DE-AC22-94PC91008
(Original Report Number NIPER/BDM-0361)

Prepared for
U.S. Department of Energy
Assistant Secretary for Fossil Energy

Rhonda Lindsey, Technology Manager
National Petroleum Technology Office
P.O. Box 3628
Tulsa, OK 74101

Prepared by:
BDM Petroleum Technologies, Inc.
BDM-Oklahoma, Inc.
P.O. Box 2565
Bartlesville, OK 73005

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1.0 INTRODUCTION

1.1 Putting Magnetic Modeling into More Hands

In recent years, the oil and gas industry has seen increased use of high-speed computers to model high-resolution aeromagnetic data to provide information on depths down to the igneous basement rocks, thus locating and defining the extent of the sedimentary basins. Detailed modeling of high-resolution aeromagnetic data also has been used to map the configuration of the basement surface, such as topographic features on the basement that might affect the structure of the overlying sedimentary beds. Sedimentary rocks exert such small magnetic effects that nearly all magnetic effects are attributed either to variations in magnetization of the basement rocks or to intrusive igneous rocks having significantly higher magnetic properties (called magnetic susceptibilities and discussed later).

The modeling of magnetic data often is done in conjunction with the modeling of gravity data, and there is great deal of similarity between the two methods. Both methods are based on anomalies caused by variations in the physical properties of subsurface rocks. Both these methods have similar applications in oil and gas exploration. In the past, these methods were mainly used as reconnaissance tools. Now, with the availability of high resolution gravity and aeromagnetic data in recent years and significant improvement in the precision measurement of these fields through development of more sophisticated instrumentation, these methods are used more and more to resolve complex geological problems. Integration of gravity and aeromagnetic data have been highly successful in helping to resolve ambiguities in seismic interpretations.

Although gravity and magnetic methods employ similar techniques for interpretation, there are certain fundamental differences that should be recognized. The rock property that describes the magnetic properties of rocks, the intensity of magnetization (which depends upon the magnetic susceptibility of rocks discussed later), has both magnitude and direction. In contrast, gravitational effects are determined by the densities of rocks, and have only magnitude and no direction. Also, gravitational effects involve only attraction, whereas magnetic forces involve both attraction and repulsion. Magnetic forces are greatly affected by small quantities of certain minerals, such as magnetite, whereas small quantities of such minerals virtually have no effect on the gravitational attraction. Because of the more complex nature of a magnetic field, it is more difficult to model magnetic data compared to gravity data.

1.2 The Source of Magnetic Anomalies

The magnetic characteristics of rocks stem from the minor amounts of magnetic minerals contained in them. By far the most common magnetic mineral in rocks is magnetite. There are other minerals that are ferromagnetic, but none as much so as magnetite. The range of magnetic susceptibilities of rocks is very much greater, percentage-wise, than the range of densities. Susceptibilities of common igneous rocks range from the neighborhood of 2000×10^{-6} for granites or porphyries with high quartz content to around 15,000 for diorites and diabase.

The susceptibilities of sedimentary rocks, on the other hand, are very low, usually in the range of 0 to 50×10^{-6} . Thus, for most magnetic prospecting for oil or gas, the effect of the basement and the rocks below are considered, and the effect on the magnetometer of the sedimentary section is considered to be zero.

To calculate the magnetic anomaly of the basement structure using Maganom, one must provide the following information to the magnetic modeling program:

- Two-dimensional structure of the basement surface defined by the x and z coordinates of an n-sided polygon describing the basement surface
- Magnetic susceptibilities of the rocks (which can vary over a wide range)
- Inducing field of the earth in Oersteds, say 0.6 Oersteds
- Angles of inclination and declination of the earth's geomagnetic field in radians
- Strike of the body from magnetic north in radians

From the previous input data, Maganom computes the magnetic anomalies across the 2D structure. The magnetic quantities computed are the vertical component of the magnetic field, the horizontal component of the magnetic field along the surface of the earth, and the total intensity of the magnetic field.

1.3 The Magnetic Field

The magnetization observed in a rock is determined by two factors: the magnetic field applied to the rock and the occurrence of one or more processes by which materials become magnetized. Different magnetizing processes may operate on the rock at different times during its history, as the earth's magnetic field may change from time to time, and the magnetization acquired may not in all cases be parallel to the applied field.

The two components of magnetization to be distinguished are the induced magnetization and the remnant magnetization. The induced magnetization requires the presence of an inducing field; the remnant magnetization does not. For the most part, magnetic interpretation can be

made as if the rocks were polarized by the earth's field in its present direction. Calculations of anomalies from models to compare with those observed usually can be made on the assumption that the polarization is in the direction of the present earth's field.

Any magnetic material placed in an external earth's field will have magnetic poles induced upon its surface. In the case of the moderately magnetic materials and weak fields one is generally concerned with in geophysical work, this induced magnetization (I), sometimes called polarization, is in the direction of the applied field (H) and its strength is proportional to the strength of that field. In other words,

$$I = k H$$

Where k is the constant of proportionality, called the magnetic susceptibility, and is an intrinsic property of the rock.

1.4 Units of Measurement

In magnetic prospecting one usually measures the variations in the intensity or some component of the intensity of the earth's field (discussed later). The conventional unit of field intensity in cgs (centimeter, gram, second) units is the Oersted. The Oersted is too large a unit for practical use in prospecting, because the variations in which geophysicists are interested in is much smaller. The gamma, which is 10^{-5} Oersted, is a more convenient unit for measuring magnetic intensity and has been the standard for geophysical work. The total magnetic field of the earth is about 1/2 Oersted or 50,000 gammas. The gamma is equivalent to the nanotesla of the mks (meter, kilogram, second, ampere) system.

1.5 Magnetic Field Components Measured in Geophysical Studies

A magnetic needle free to rotate in the earth's magnetic field T will assume a position as shown in Figure 1-1. The magnetic field is a vector in space having both the magnitude and direction at every point in space.

The direction of the total magnetic field vector T will make an angle with the vertical, and its horizontal projection will make an angle with the north-south direction. It is customary to resolve the total field T into its vertical component Z and its horizontal component H . The horizontal component H is again separated into X (along the geographical north) and Y (along geographical east) components in the horizontal plane. The angle which the total field T makes with the horizontal component H is the *Inclination* and the angle between H and X is called the *Declination*.

Figure 1-1 Magnetic elements needed for computing magnetic anomalies with Maganom

The ground magnetometers used in oil prospecting in the past normally measured the vertical component Z . Instruments measuring the horizontal component H were also used in limited applications. Most commonly it is the total field intensity T that is measured in all aeromagnetic surveys used for oil and gas exploration.

The magnetic elements X, Y, Z, H, D, I and T are known as the magnetic elements and are related as follows:

$$H = T \cos I ; Z = T \sin I = H \tan I$$

$$X = T \cos D ; Y = T \sin D$$

$$X^2 + Y^2 = H^2 \quad X^2 + Y^2 + Z^2 = H^2 + Z^2 = T^2$$

1.6 What Maganom Can Do

Maganom is a computer program for modeling magnetic data over 2-D structures. The program computes the magnetic anomalies across 2-D structures (models) to allow you to compare observed and computed magnetic data across the model structure. If a match between the computed and the observed magnetic values is unsatisfactory, you construct a new model and rerun Maganom to recalculate new magnetic values. In this way, you can continue calculations until you obtain a satisfactory match between the observed and the calculated values.

For example, Figure 1-2 shows the map of the Black Mesa Basin in northeast Arizona. The line AB across the basin in this figure represents a line on the surface, and a geological model of all the subsurface magnetic rocks along this section can be modeled with the help of Maganom. As mentioned earlier, sedimentary rocks usually have no magnetic effect, and therefore are disregarded for modeling calculations. It is the magnetic basement and other intrusives that have magnetic susceptibilities that will contribute to the magnetic anomalies along profile A-B.

Figure 1-2 A 2-D sedimentary section along profile A-B

The variations of magnetic anomaly along profile AB can be modeled by variations in structures of basement rocks along AB. In this manner, structural and tectonic information of the basement surfaces at different places in the basin may be obtained with the help of Maganom.

Using your knowledge of geology, magnetic methods of exploration, and data from well logs, cores, and other sources, you first construct a polygon to represent the magnetic effect of an approximate basement structure. You specify the boundaries of the polygon using x, z coordinates (calculated from a point of origin located on the surface of the earth) and save this data in an input file. (You may construct the polygon with as many points as needed in order to accurately describe the geological structure, which can have a very irregular shape.)

You then specify the magnetic elements of the study area, which are known from published magnetic maps of that area. The magnetic elements needed for model calculation are the geomagnetic inclination (dip) and strike of the body from the magnetic north (st) measured clockwise from the earth's magnetic field (HE).

Then the program calculates the combined magnetic anomalies of all the beds and prints the magnetic anomaly values at a set interval (say, every two kilometers or whatever matches the observed intervals) between points A and B along the earth's surface. You can then compare the Maganom-calculated result with the observed magnetic anomaly and refine your polygon models until there is a good match.

The computations are based on the technique given by Talwani and Heirtzler in "Computation of Magnetic Anomalies Caused by Two-Dimensional Bodies of Arbitrary Shape," a paper published in *Computers in the Mineral Industries, Part 1*; Stanford University Press, Geological Sciences, vol. 9, 1964.

1.7 Enhancements Planned

Enhancements to the software are planned for the future to increase user friendliness, such as by automating the input of data points using a digitizing tablet. Among the enhancements contemplated is 3-D modeling of structures, which will be useful for particular geological situations. As the accuracy of collecting magnetic data increases with better instrumentation, enhancements to the interpretive softwares to extract useful information from these data also may follow. Please check the NPTO Web site at <http://www.npto.doe.gov> from time to time for news on updates to this and other software packages.

2.0 GETTING STARTED

2.1 System Requirements

Check that your personal computer meets these minimum system and software requirements:

- ◆ Personal computer with a 386 or higher processor running DOS 4.0 or more advanced operating system
- ◆ 8 MB of memory (16 MB or more preferred)
- ◆ 20 MB of available hard-disk space for data storage and modeling (requirements vary with the complexity of the model)
- ◆ Maganom.exe (the executable program)

2.2 Other Requirements

You also will need the following:

- ◆ Reliable observed data—magnetic data measured or interpolated in gammas—along a straight line perpendicular to the strike of the geological structure that you wish to model. The source of this data may be the U.S. Geological Survey, state geological surveys, universities, or other sources.
- ◆ Graph paper for manual input or a digitizing tablet for automated input of x and z coordinates of the polygons that approximate the geological structures
- ◆ Knowledge of structural geology and some understanding of the magnetic method of exploration
- ◆ Information on subsurface magnetic susceptibility variations. This information may be obtained from susceptibility measurements on core and drill cuttings, published literature, etc.

2.3 How to Install the Program

Follow these steps to install the software:

1. Verify that there is adequate space (20 MB of available hard-disk space per model) on the drive to which you are trying to install the software.
2. Insert the disk containing Maganom.exe (the executable program) into your computer's diskette drive.

3. Follow these steps to install the software using DOS from disk:
 - a. Create the directory you wish to store the program in. For example, type the following to create the **magy** subdirectory on the **c:** drive:
md c:\magy<Enter>
 - b. Change to the floppy drive containing the disk. For example, to change to the **a:** drive, type:
a:<Enter>
 - c. Copy all files from the floppy diskette to your hard drive. For example, to change to the **c:** drive, **magy** subdirectory, type at the DOS prompt:
Copy *.* c:\magy<Enter>

NOTES:

Users can change the directory name to whatever is convenient.

Now go to Section 3.1 for detailed instructions on how to prepare the input files.

2.4 Technical Support Information

If you have any general questions or comments about the Maganom software, please contact Rhonda Lindsey (e-mail: rlindsey@npto.doe.gov, phone: 918-699-2037, fax: 918-699-2005) of the U.S. DOE.

If you have followed all the steps in this user's guide for using the program but still have problems or questions on how to use these programs, please contact Bijon Sharma of the Geology staff (e-mail: bsharma@bdm.com, phone: 918-338-4471, fax: 918-338-4561). When you call, fax, or send e-mail, please include answers to the following questions:

- ◆ Which version of the software you are using?
- ◆ Can you supply a brief and concise explanation of the question or problem that you are experiencing?
- ◆ What actions have you taken to correct the problem(s)?
- ◆ What is your phone number and time zone, fax number, and/or email address?

A copy of the source code for Maganom is available upon request from the National Petroleum Technology Office, U.S. Department of Energy, and from Robert Welch, director of Information Management, BDM Petroleum Technologies (e-mail: rwelch@bdm.com, phone: 918-338-4498, fax: 918-338-4543).

3.0 HOW TO USE MAGANOM

3.1 How to Prepare Input Data for Maganom

The input file for Maganom is an ASCII data file. You can construct and then save your input file with any standard editing program. The data in the file will be read sequentially by the program, so all data must be supplied in an exact order for the calculation to be meaningful. Each piece of data must be isolated by one or more spaces (represented in the following paragraphs by a gap). Follow this structure:

First Data Line

Number of beds (NB), number of points for calculation (NN), calculation interval in kilometers (CI), regional correction (GREG1), regional correction (GREG2), regional correction (GREG3)

NOTES: The numbers for NB and NN are whole numbers, but CI and GREG1, GREG2, and GREG3 are used in floating point calculations and must include a decimal point. The number for GREG may be positive, negative, or zero, and its unit is gammas. When GREG is used, it makes an adjustment uniformly across all intervals to compensate for special regional magnetic effects. Please note that negative CI indicates points of calculation in the increasing x direction. GREG1 refers to the correction for vertical field, GREG2 to the correction for the horizontal field, and GREG3 to the correction for the total field.

EXAMPLE:

2 30 1. 0. 0. 0.

This line states that the geological model has 2 beds whose magnetic field will have to be calculated, there are 30 points at which magnetic anomalies are to be calculated, the interval of calculation is every kilometer, and the calculation points are in the negative x direction from the origin. Also, there is no regional correction across all intervals.

EXAMPLE:

12 90 -2. 10. 10. 10.

This line states that there are 12 beds in the model, there are 90 points of calculation, the interval is every 2 kilometers in the positive x direction, and there is a regional correction (across all intervals) of 10 gammas for the vertical, horizontal, and the total intensity of the magnetic field.

Second Data Line (First Bed)

Magnetic field of the earth in Oersteds, the geomagnetic inclination in radians, strike of the body from geographic north measured in a counter-clockwise direction from the magnetic north in radians

EXAMPLE:

0.6 1.044 1.218

This line indicates that the magnetic field of the earth is 0.6 Oersteds, the inclination of the earth's field is at an angle of 1.044 radians (60°), and the model structure is inclined at an angle of 1.218 radians (70°).

Third Data Line (First Bed)

Number of points (vertices) in the polygon describing the first bed (NC) plus 1, magnetic susceptibility of this bed in cgs units (SUS)

NOTES: The number for NC is specified as a whole number. The number one is added because the first point in the polygon and the last point in the polygon are specified separately, even though they are the same point. The number for SUS is used in a floating point calculation and must include a decimal point.

EXAMPLE:

8 .0020

This line states that there are 7 points (vertices) on the polygon whose anomaly is to be calculated, and the magnetic susceptibility of the polygon is .0020 cgs units.

EXAMPLE:

50 0.15

This line states that there are 49 points (vertices) on the polygon, and the magnetic susceptibility of the polygon is 0.15 cgs units.

Coordinate Lines (First Bed)

x and z coordinates of the first vertex of the first polygon are input in kilometers (km), then repeat x and z for all the vertices in the polygon, clockwise

NOTES: List the coordinates of the polygon in a clockwise direction, starting at a point closest to 0,0 (the origin at the surface of the earth), and remember to close the polygon by listing the last coordinate. Therefore, a five-sided polygon will have six sets of x, z values, the first and the sixth set of points being the same.

EXAMPLE:

30. 2.5
50. 2.5
50. 2.7
30. 2.7
30. 2.5

These lines say that there are 4 points (vertices) on the first polygon.

Subsequent Beds (for Additional Polygons)

The data lines for each additional bed are in exactly the same format as for the first bed. For each additional bed, specify another:

- "Third Data Line" to specify the number of points in that bed (polygon) and the magnetic susceptibility
- "Coordinate Lines" to specify the x, z coordinates of that polygon

EXAMPLE:

6 .05
20. 1.5
40. 1.5
40. 1.7
30. 1.9
20. 1.7
20. 1.5

These 7 lines state that there are 6 points (vertices) on the 5-sided polygon to be calculated, the susceptibility of the first bed is 0.05 cgs units, and the 6 coordinates (x, z) of the points (vertices) on the polygon are 20. 1.5, 40. 1.5, 40. 1.7, 30. 1.9, 20. 1.7, and 20. 1.5.

Once you have created the input file, you will be ready to run the Maganom program for modeling calculations. Section 3.2 describes how to run the Maganom program. Later sections contain step-by-step examples of simple and increasingly complex and realistic modeling.

3.2 How to Run the Maganom Program

Once Maganom.exe has been installed in the **magy** subdirectory (described in Section 2.3), you are ready to run Maganom.

1. To run Maganom, go to the **magy** subdirectory and type at the DOS prompt:
Maganom <Enter>

NOTE: The screen will prompt: **enter input file name**

2. Type in the name of the input file and press <Enter>.

NOTE: The screen will prompt: **enter output file name**

3. Type in the name of the output file and press <Enter>.

NOTE: The resulting output file first lists the input data, followed by the calculated output data. The output data calculated from Maganom lists NN numbers of points—starting from the origin of calculations and corresponding to each point—with the vertical, the horizontal, and the total magnetic field intensities tabulated.

3.3 How to Calculate Magnetic Anomalies of a Rectangular Body

The following examples show how to compute the magnetic anomalies of **rectangular body ABCD** step by step with the help of Maganom.

The magnetic anomalies of a simple rectangular body with vertices A, B, C, and D (see Fig. 3-1) will be calculated. Geologically, a rectangular body may represent a horizontal intrusive mass or dike type of body having a magnetic susceptibility contrast with the surrounding beds. This body is assumed to have a magnetic susceptibility contrast of 0.05 cgs units. That is, say, the surrounding rocks have a magnetic susceptibility of 0.0 units (sedimentary rocks), and the intrusive mass has a magnetic susceptibility of 0.05 cgs units.

Figure 3-1 A rectangular body for computing magnetic anomalies

Use the following parameters for the input data file (parameters are annotated here in parentheses):

1 60 -1. 0. 0. 0. (NB or number of beds = 1, NN or total number of points of calculations on the surface = 60, CI or interval of calculations = 1 km, GREG1, GREG2, and GREG3 [regional corrections] = 0.)

0.6 1.044 0. (Magnetic field of the earth = 0.6 Oersteds, the inclination of the earth's field is 1.044 (60°), and the model is oriented along the magnetic north = 0.)

5 0.05 (NC = number of sides of the polygon +1 = 5, SUS = magnetic susceptibility of a body or contrast in susceptibility of the body with the surrounding rock mass = 0.05 cgs units)

20. 1.5 (coordinates of point A)

40. 1.5 (coordinates of point B)

40. 1.7 (coordinates of point C)

20. 1.7 (coordinates of point D)

20. 1.5 (coordinates of point A)

In this example, let us call the input file **Trial1M.in**, and its actual contents would be as follows:

1 60 -1. 0. 0. 0.

0.6 1.044 1.218

5 0.05

20. 1.5

40. 1.5

40. 1.7

20. 1.7

20. 1.5

NOTE: Although the polygon has 4 corners, it will have five x, z pairs of coordinates because the polygon has to be closed, and therefore the first and last coordinates are the same.

In this example, **Maganom** is loaded in the **C:** directory.

1. At the **C:** prompt, we type:

Maganom<Enter>

2. Maganom will ask for the input file name, so we type:

Trial1M.in<Enter>

3. Maganom will then ask for the output file name, so we type:

Trial1M.out<Enter>

Maganom will perform calculations and put the calculated values in **Trial1M.out**.

The output file, **Trial1M.out**, would first list the input information in this order: The first line will have values of NB, NN, CI, HE, DIP, ST, GREG1, GREG2, GREG3. The second line will have values of NC+1, susceptibility. The third line will have x, z coordinate pairs for the first polygon. For more than one polygon, lines 2 and 3 are repeated for each polygon. This input data is followed by the calculated output information. The output data lists NN points and the magnetic values calculated for each of those points based on your model. The output data file is as follows:

```
1 60 -1.000 0.600 1.044 1.218 0. 0. 0.
5 0.050000
```

```
-----
20.000 40.000 40.001 20.000 20.000 1.500 1.505 1.700
1.710 1.550
0.000 -36.657 19.358 -22.553
1.000 -39.090 21.082 -23.844
2.000 -41.805 23.054 -25.260
3.000 -44.848 25.327 -26.818
4.000 -48.276 27.967 -28.536
5.000 -52.161 31.059 -30.435
6.000 -56.588 34.718 -32.536
7.000 -61.669 39.096 -34.863
8.000 -67.541 44.402 -37.435
9.000 -74.380 50.926 -40.269
10.000 -82.407 59.091 -43.355
11.000 -91.902 69.517 -46.644
12.000 -103.209 83.156 -49.983
13.000 -116.721 101.524 -52.997
14.000 -132.770 127.144 -54.782
15.000 -151.241 164.423 -53.161
16.000 -170.142 221.372 -42.632
17.000 -180.451 312.464 -8.565
18.000 -148.026 457.436 87.862
19.000 20.032 628.784 313.977
20.000 332.715 637.211 588.243
21.000 570.297 407.316 685.150
22.000 562.885 147.964 556.380
23.000 473.269 16.586 416.930
24.000 395.615 -42.037 322.145
25.000 339.158 -69.917 260.189
26.000 298.962 -84.704 218.466
27.000 270.228 -93.784 189.343
28.000 249.686 -100.529 168.405
29.000 235.269 -106.688 153.036
30.000 225.697 -113.353 141.617
31.000 220.223 -121.415 133.082
32.000 218.471 -131.843 126.647
33.000 220.336 -145.958 121.600
34.000 225.892 -165.839 117.023
35.000 235.147 -195.099 111.219
36.000 247.175 -240.518 100.187
37.000 256.585 -315.489 72.950
38.000 238.613 -444.646 -3.522
```

39.000	96.425	-636.138	-216.779
40.000	-287.868	-655.659	-558.180
41.000	-476.804	-320.342	-563.297
42.000	-389.067	-97.973	-382.542
43.000	-286.627	-15.429	-255.046
44.000	-214.988	13.798	-179.330
45.000	-166.613	24.055	-132.675
46.000	-132.950	27.085	-102.146
47.000	-108.645	27.201	-81.082
48.000	-90.501	26.131	-65.903
49.000	-76.568	24.609	-54.576
50.000	-65.612	22.965	-45.881
51.000	-56.827	21.348	-39.050
52.000	-49.666	19.821	-33.581
53.000	-43.742	18.406	-29.128
54.000	-38.783	17.110	-25.452
55.000	-34.586	15.930	-22.381
56.000	-31.003	14.858	-19.790
57.000	-27.915	13.881	-17.581
58.000	-25.239	12.994	-15.686
59.000	-22.901	12.186	-14.047

3.4 How to Calculate the Magnetic Anomaly of a Cylindrical Body

The magnetic anomaly of a horizontal cylindrical body will be calculated with Maganom. The 2-D cross section sliced from a simple cylindrical body is shown in Figure 3-2. Geologically, such a body may represent a buried horizontal pipe, tunnel, or other intrusive mass having a magnetic susceptibility in contrast with its surroundings. In this example, the body is assumed to have a magnetic susceptibility contrast of 0.0033 cgs (i.e., if the surrounding rocks have a magnetic susceptibility of 0.0 units, the intrusive mass has a magnetic susceptibility of 0.0033 units).

For Maganom computations, the cylindrical section is approximated by an n-sided polygon. In Figure 3-2, the cylinder is approximated by a 9-sided polygon. The x and z coordinates of the 10 vertices of the 9-sided polygon (A, B, C, D, E, F, G, H, I, A) are computed using graph paper or a digitizing tablet.

As a double-check of the program, the exact vertical component of the magnetic anomaly (V) of a horizontal cylinder also can be computed from this theoretical formula:

$$V = \frac{2\pi R^2 S}{Z^2} \left[\frac{1 \pm \frac{x^2}{z^2}}{1 + \frac{x^2}{z^2}} \right]$$

$$= \frac{6.28R^2S}{Z^2} \left[\frac{1 \pm \frac{x^2}{z^2}}{1 + \frac{x^2}{z^2}} \right]$$

Where

R = radius of horizontal cylinder, km

S = magnetic susceptibility of cylinder, cgs units

x = distance of point of calculation of anomaly from origin, km

Z = depth to center of cylinder from surface, km

Figure 3-2 A cylindrical body for computing magnetic anomalies

Select the following parameters for the input file:

First Data Line

NB = number of beds = 1

NN = total number of points of calculations on the surface = 70

CI = interval of calculations in km (i.e., at what intervals are calculations made) = 1.0

GREG1, GREG2, and GREG3 (regional corrections for vertical, horizontal, and total magnetic, respectively) = 0.

Second Data Line

Earth's field = 0.6 Oersteds

Angle of inclination (in radians) of earth's magnetic field = 1.571 (90°)

Strike angle of body from magnetic north measured counterclockwise (in radians) = 0.0 (0°)

Third Data Line

NC = number of sides of the polygon +1 = 10

SUS = magnetic susceptibility of a body or contrast in magnetic susceptibility of body with the surrounding rock mass = 0.0333 cgs units

Coordinates Lines

x and z coordinates of the polygon describing the cylinder are then input in the clockwise direction with the last pair of coordinates repeating the first:

x and z coordinates of point A = 30. 12.1

x and z coordinates of point B = 38. 11.2

x and z coordinates of point C = 42.5 15

x and z coordinates of point D = 43.9 19.8

x and z coordinates of point E = 42.7 24.1

x and z coordinates of point F = 37.5 28

x and z coordinates of point G = 32. 27.6

x and z coordinates of point H = 27.2 24

x and z coordinates of point I = 26.5 17.5

x and z coordinates of point J = 30. 12.1

In this example, the input file is called **cylm.in**, and its contents would be as follows:

```
1 70 -1.0 0. 0. 0.
0.6 1.571 0.
10 .00333
30. 12.1
38. 11.2
42.5 15.
43.9 19.8
42.7 24.1
37.5 28.
32. 27.6
27.2 24.
26.5 17.5
0. 12.1
```


The theoretical and the computed magnetic anomalies across a horizontal cylinder are compared in Figure 3-3. Please note that in this calculation the angle of inclination $I = 90^\circ$, so the vertical and the total magnetic fields are the same. By taking a larger number of sides, the Maganom calculations may be made to approach the theoretical values to any desired level of accuracy. By taking, say, 30 sides, the polygon would approximate the horizontal cylinder much better, and the computed anomaly would be much closer to the theoretical anomaly.

Figure 3-3 Total (or vertical) magnetic anomaly curves for theoretical and computed anomalies of a cylindrical body (angle of inclination of earth's field = 90°)

In this example, **Maganom** is loaded in the **C:** directory.

1. At the **C:** prompt, we type:
Maganom<Enter>
2. Maganom will ask for the input file name, so we type:
cylm.in<Enter>
3. Maganom will then ask for the output file name, so we type:
cylm.out<Enter>

The Maganom program will perform calculations and put the calculated values in **cylm.out**.

The contents of the output file, **cylm.out**, consist of the contents of the input file in the same order as discussed for the rectangular body (see page 14), plus four columns of output data. The first column shows the point of calculation from origin on the x axis. The second, third, and fourth columns are the vertical, horizontal, and total magnetic fields computed by Maganom.

```
1 70 -1.000 0.600 1.571 0.000 0. 0. 0.
10 0.003330
```

```
-----
30.000 38.000 42.500 43.900 42.700 37.500 32.000 27.200
26.500 30.000 12.100 11.200 15.000 19.800 24.100 28.000
27.600 24.000 17.500 12.100
0.000 -29.158 47.432 -29.158
1.000 -29.222 50.298 -29.222
2.000 -29.173 53.360 -29.173
3.000 -28.989 56.631 -28.989
4.000 -28.647 60.121 -28.647
5.000 -28.117 63.842 -28.117
6.000 -27.366 67.802 -27.366
7.000 -26.357 72.010 -26.357
8.000 -25.047 76.471 -25.047
9.000 -23.385 81.188 -23.385
10.000 -21.318 86.157 -21.318
11.000 -18.784 91.371 -18.784
12.000 -15.712 96.813 -15.712
13.000 -12.029 102.456 -12.029
14.000 -7.650 108.261 -7.650
15.000 -2.490 114.173 -2.490
16.000 3.545 120.118 3.545
17.000 10.545 126.000 10.545
18.000 18.602 131.696 18.602
19.000 27.796 137.056 27.796
20.000 38.194 141.894 38.194
21.000 49.838 145.992 49.838
22.000 62.734 149.100 62.734
23.000 76.840 150.938 76.840
24.000 92.054 151.205 92.054
25.000 108.199 149.592 108.199
26.000 125.015 145.805 125.015
27.000 142.154 139.581 142.154
28.000 159.184 130.726 159.184
29.000 175.604 119.136 175.604
30.000 190.866 104.823 190.866
31.000 204.410 87.930 204.410
32.000 215.700 68.740 215.700
33.000 224.259 47.660 224.259
34.000 229.706 25.216 229.706
35.000 231.784 2.019 231.784
36.000 230.383 -21.267 230.383
```

37.000	225.553	-43.960	225.553
38.000	217.503	-65.411	217.503
39.000	206.593	-85.045	206.593
40.000	193.301	-102.404	193.301
41.000	178.182	-117.171	178.182
42.000	161.824	-129.182	161.824
43.000	144.795	-138.419	144.795
44.000	127.614	-144.985	127.614
45.000	110.724	-149.082	110.724
46.000	94.478	-150.970	94.478
47.000	79.141	-150.949	79.141
48.000	64.893	-149.325	64.893
49.000	51.842	-146.400	51.842
50.000	40.034	-142.454	40.034
51.000	29.467	-137.738	29.467
52.000	20.105	-132.472	20.105
53.000	11.884	-126.843	11.884
54.000	4.726	-121.005	4.726
55.000	-1.456	-115.085	-1.456
56.000	-6.753	-109.182	-6.753
57.000	-11.257	-103.373	-11.257
58.000	-15.054	-97.715	-15.054
59.000	-18.227	-92.250	-18.227
60.000	-20.852	-87.007	-20.852
61.000	-22.999	-82.005	-22.999
62.000	-24.731	-77.252	-24.731
63.000	-26.103	-72.753	-26.103
64.000	-27.165	-68.507	-27.165
65.000	-27.962	-64.508	-27.962
66.000	-28.532	-60.750	-28.532
67.000	-28.909	-57.223	-28.909
68.000	-29.121	-53.917	-29.121
69.000	-29.195	-50.821	-29.195

3.5 How to Calculate the Magnetic Anomalies of a Magnetic Basement and the Overlying Sedimentary Structure

The computation of magnetic anomalies across 2-D sedimentary structures that are more relevant to oil and gas exploration—such as the section along profile AB in Figure 1-1—will now be discussed.

The structural section along profile AB across a 2-D sedimentary structure and the underlying magnetic basement rocks are shown in Figure 3-4. The structural section is made up of five sedimentary beds, each having a very small magnetic susceptibility and the igneous basement (bed 6 in Fig. 3-4) which has very high magnetic susceptibility values compared to the overlying sediments.

Figure 3-4 A section from a sedimentary structure consisting of six distinct beds

The x and z coordinates of the six beds are obtained using either graph paper or a digitizing tablet. Select the following parameters for the input file (and then run the program):

First Data Line

NB = number of beds = 6

NN = total number of points of calculations on the surface = 94

CI = interval of calculations in km (i.e., at what intervals are calculations made) = -2.0

GREG1, GREG2, GREG3 = regional correction, if any = 0. 0. 0.

Second Data Line (First Bed)

Magnetic field of earth (in Oersted) = 0.6

Inclination of earth's field (60° converted into radians) = 1.044

Strike of subsurface rocks from magnetic north (in degrees) = 0.

Third Data Line (First Bed)

NC = number of sides (75) of the polygon for bed 1 plus 1 = 76

SUS = magnetic susceptibility of bed 1 or contrast in magnetic susceptibility of bed 1 with the surrounding rock mass (in cgs units) = 0.000004

Coordinates Lines (First Bed)

x and z coordinates of the polygon describing the first bed are then input in the clockwise direction with the last coordinates repeating the first:

Subsequent Beds

Repeats the second data line and coordinate lines for each remaining bed.

The complete input data file and output data file are listed in the Appendix, Sections A and B, respectively. Figure 3-5 shows a plot of the data from the output file. Please note that plots of vertical, horizontal, and total intensity anomalies are shown, although for petroleum exploration use of total intensity values is the most common.

Figure 3-5 The Maganom-calculated vertical, horizontal, and total intensity magnetic anomaly values of the magnetic basement rocks and overlying sedimentary structure along profile AB (the output file was imported into a spreadsheet program and plotted)

APPENDIX MAGANOM DATA

A Input File for Modeling a Magnetic Basement and Overlying Sedimentary Rocks

The following data are the contents of the input data file **sed1rrm.in** for calculations described in Section 3-5. Please note that to save on space, the data have been rearranged into three pairs of columns on each page, where the bottom of each pair of columns continues at the top of the next pair of columns on that page.

6 94 -2. 0. 0. 0.	80.0000 4.38072	4.0000 3.24146
0.6 1.044 0.	78.0000 3.83036	-50. .05
76 .0000035	76.0000 3.29655	-50. .0001
-50. .0001	74.0000 3.21877	147 .000024
146. 0.001	72.0000 3.20068	-50. .05
146.0000 2.77210	70.0000 3.23377	4.0000 3.24146
144.0000 2.29730	68.0000 3.49820	6.0000 3.55125
142.0000 2.03176	66.0000 3.75604	8.0000 3.83401
140.0000 1.90724	64.0000 3.85403	10.0000 4.10718
138.0000 2.04475	62.0000 3.71146	12.0000 4.20278
136.0000 2.26771	60.0000 3.46495	14.0000 4.29498
134.0000 2.42238	58.0000 3.20496	16.0000 4.50349
132.0000 2.46913	56.0000 3.19449	18.0000 4.44455
130.0000 2.49919	54.0000 3.59125	20.0000 4.34308
128.0000 2.56880	52.0000 3.82128	22.0000 4.34562
126.0000 2.66267	50.0000 3.87810	24.0000 4.20136
124.0000 2.78727	48.0000 3.75369	26.0000 4.14498
122.0000 3.09791	46.0000 3.53060	28.0000 3.73292
120.0000 3.25879	44.0000 3.43142	30.0000 3.48229
118.0000 3.99186	42.0000 3.52370	32.0000 3.49279
116.0000 4.69291	40.0000 3.83421	34.0000 3.79760
114.0000 4.70857	38.0000 4.07840	36.0000 4.13112
112.0000 4.30694	36.0000 4.13112	38.0000 4.07840
110.0000 3.93801	34.0000 3.79760	40.0000 3.83421
108.0000 3.34397	32.0000 3.49279	42.0000 3.52370
106.0000 3.13499	30.0000 3.48229	44.0000 3.43142
104.0000 3.03547	28.0000 3.73292	46.0000 3.53060
102.0000 3.01033	26.0000 4.14498	48.0000 3.75369
100.0000 3.00921	24.0000 4.20136	50.0000 3.87810
98.0000 3.02297	22.0000 4.34562	52.0000 3.82128
96.0000 3.11856	20.0000 4.34308	54.0000 3.59125
94.0000 3.79581	18.0000 4.44455	56.0000 3.19449
92.0000 4.30622	16.0000 4.50349	58.0000 3.20496
90.0000 4.88501	14.0000 4.29498	60.0000 3.46495
88.0000 5.52059	12.0000 4.20278	62.0000 3.71146
86.0000 5.72620	10.0000 4.10718	64.0000 3.85403
84.0000 5.49428	8.0000 3.83401	66.0000 3.75604
82.0000 4.93374	6.0000 3.55125	68.0000 3.49820

70.0000	3.23377	118.0000	5.51139	12.0000	5.9115
72.0000	3.20068	116.0000	6.12705	10.0000	5.1018
74.0000	3.21877	114.0000	5.90878	8.0000	5.7572
76.0000	3.29655	112.0000	5.54215	6.0000	4.9572
78.0000	3.83036	110.0000	5.32176	4.0000	4.1370
80.0000	4.8072	108.0000	4.57184	-50. .1	
82.0000	4.3374	106.0000	4.40316	-50. .05	
84.0000	5.49428	104.0000	4.34160	147 .000255	
86.0000	5.72620	102.0000	4.31956	-50. .1	
88.0000	5.52059	100.0000	4.1640	4.0000	4.1370
90.0000	4.88501	98.0000	4.2075	6.0000	4.9572
92.0000	4.30622	96.0000	4.6879	8.0000	5.7572
94.0000	3.79581	94.0000	5.5047	10.0000	5.1018
96.0000	3.11856	92.0000	5.6911	12.0000	5.9115
98.0000	3.02297	90.0000	6.6994	14.0000	5.5070
100.0000	3.00921	88.0000	6.2465	16.0000	5.4299
102.0000	3.01033	86.0000	7.4536	18.0000	5.8226
104.0000	3.03547	84.0000	6.8200	20.0000	5.6653
106.0000	3.13499	82.0000	6.5000	22.0000	5.9756
108.0000	3.34397	80.0000	5.0183	24.0000	5.5446
110.0000	3.93801	78.0000	5.5926	26.0000	5.4820
112.0000	4.30694	76.0000	4.6084	28.0000	4.5611
114.0000	4.70857	74.0000	4.7947	30.0000	4.6785
116.0000	4.69291	72.0000	4.4929	32.0000	4.5766
118.0000	3.99186	70.0000	5.1595	34.0000	5.1643
120.0000	3.25879	68.0000	5.8843	36.0000	5.4078
122.0000	3.09791	66.0000	5.1828	38.0000	5.2514
124.0000	2.78727	64.0000	5.9579	40.0000	5.4422
126.0000	2.66267	62.0000	5.5518	42.0000	5.5272
128.0000	2.56880	60.0000	4.3262	44.0000	5.0047
130.0000	2.49919	58.0000	4.8459	46.0000	5.0748
132.0000	2.46913	56.0000	5.0842	48.0000	5.8883
134.0000	2.42238	54.0000	5.2632	50.0000	5.3604
136.0000	2.26771	52.0000	5.8226	52.0000	5.8226
138.0000	2.04475	50.0000	5.3604	54.0000	5.2632
140.0000	1.90724	48.0000	5.8883	56.0000	5.0842
142.0000	2.03176	46.0000	5.0748	58.0000	4.8459
144.0000	2.29730	44.0000	5.0047	60.0000	4.3262
146.0000	2.77210	42.0000	5.5272	62.0000	5.5518
146.0000	3.20927	40.0000	5.4422	64.0000	5.9579
144.0000	2.80823	38.0000	5.2514	66.0000	5.1828
142.0000	2.54881	36.0000	5.4078	68.0000	5.8843
140.0000	2.46436	34.0000	5.1643	70.0000	5.1595
138.0000	2.55656	32.0000	4.5766	72.0000	4.4929
136.0000	2.75235	30.0000	4.6785	74.0000	4.7947
134.0000	3.02941	28.0000	4.5611	76.0000	4.6084
132.0000	3.24021	26.0000	5.4820	78.0000	5.5926
130.0000	3.35552	24.0000	5.5446	80.0000	5.0183
128.0000	3.49400	22.0000	5.9756	82.0000	6.5000
126.0000	3.65658	20.0000	5.6653	84.0000	6.8200
124.0000	3.82593	18.0000	5.8226	86.0000	7.4536
122.0000	4.50275	16.0000	5.4299	88.0000	6.2465
120.0000	4.70975	14.0000	5.5070	90.0000	6.6994

92.0000 5.6911
 94.0000 5.5047
 96.0000 4.6879
 98.0000 4.2075
 100.0000 4.1640
 102.0000 4.1956
 104.0000 4.4160
 106.0000 4.0316
 108.0000 4.7184
 110.0000 5.2176
 112.0000 5.4215
 114.0000 5.0878
 116.0000 6.2705
 118.0000 5.1139
 120.0000 4.0975
 122.0000 4.0275
 124.0000 3.2593
 126.0000 3.5658
 128.0000 3.9400
 130.0000 3.5552
 132.0000 3.4021
 134.0000 3.2941
 136.0000 2.5235
 138.0000 2.5656
 140.0000 2.6436
 142.0000 2.4881
 144.0000 2.0823
 146.0000 3.0927
 146.0000 3.9624
 144.0000 3.9846
 142.0000 3.6522
 140.0000 3.7407
 138.0000 3.3368
 136.0000 3.8471
 134.0000 3.6518
 132.0000 4.0279
 130.0000 4.0130
 128.0000 4.2913
 126.0000 4.0726
 124.0000 4.2677
 122.0000 5.6545
 120.0000 5.0675
 118.0000 7.8165
 116.0000 7.3489
 114.0000 7.4748
 112.0000 7.3828
 110.0000 6.2036
 108.0000 6.3882
 106.0000 5.9449
 104.0000 5.6863
 102.0000 5.3438
 100.0000 5.6176
 98.0000 5.9145

96.0000 6.0105
 94.0000 6.7993
 92.0000 7.3545
 90.0000 7.0295
 88.0000 8.0126
 86.0000 8.6923
 84.0000 8.4739
 82.0000 7.8222
 80.0000 6.0103
 78.0000 6.3903
 76.0000 5.2567
 74.0000 5.5904
 72.0000 5.5729
 70.0000 6.7415
 68.0000 6.5597
 66.0000 6.0785
 64.0000 6.7881
 62.0000 6.0326
 60.0000 5.9556
 58.0000 5.2174
 56.0000 6.9949
 54.0000 6.3272
 52.0000 6.5715
 50.0000 6.5217
 48.0000 6.4646
 46.0000 6.9867
 44.0000 6.8148
 42.0000 6.5609
 40.0000 6.8082
 38.0000 6.5180
 36.0000 6.0908
 34.0000 6.0557
 32.0000 6.0156
 30.0000 6.9203
 28.0000 6.8102
 26.0000 6.4395
 24.0000 6.9476
 22.0000 6.9992
 20.0000 6.9679
 18.0000 6.1367
 16.0000 6.5508
 14.0000 6.0291
 12.0000 6.1984
 10.0000 6.2382
 8.0000 5.6941
 6.0000 5.8847
 4.0000 5.3798
 -50. .2
 -50. .1
 147 .00026
 -50. .20
 4.0000 5.3798
 6.0000 5.8847

8.0000 5.6941
 10.0000 6.2382
 12.0000 6.1984
 14.0000 6.0291
 16.0000 6.5508
 18.0000 6.1367
 20.0000 6.9679
 22.0000 6.9992
 24.0000 6.9476
 26.0000 6.4395
 28.0000 6.8102
 30.0000 6.9203
 32.0000 6.0156
 34.0000 6.0557
 36.0000 6.0908
 38.0000 6.5180
 40.0000 6.8082
 42.0000 6.5609
 44.0000 6.8148
 46.0000 6.9867
 48.0000 6.4646
 50.0000 6.5217
 52.0000 6.5715
 54.0000 6.3272
 56.0000 6.9949
 58.0000 5.2174
 60.0000 5.9556
 62.0000 6.0326
 64.0000 6.7881
 66.0000 6.0785
 68.0000 6.5597
 70.0000 6.7415
 72.0000 5.5729
 74.0000 5.5904
 76.0000 5.2567
 78.0000 6.3903
 80.0000 6.0103
 82.0000 7.8222
 84.0000 8.4739
 86.0000 8.6923
 88.0000 8.0126
 90.0000 7.0295
 92.0000 7.3545
 94.0000 6.7993
 96.0000 6.0105
 98.0000 5.9145
 100.0000 5.6176
 102.0000 5.3438
 104.0000 5.6863
 106.0000 5.9449
 108.0000 6.3882
 110.0000 6.2036
 112.0000 7.3828

114.0000	7.4748	74.0000	6.9703	30.0000	6.8734
116.0000	7.3489	72.0000	7.3721	32.0000	7.6863
118.0000	7.8165	70.0000	7.6643	34.0000	7.2952
120.0000	5.0675	68.0000	7.9716	36.0000	7.2634
122.0000	5.6545	66.0000	7.0115	38.0000	7.6970
124.0000	4.2677	64.0000	7.4314	40.0000	7.7533
126.0000	4.0726	62.0000	6.6256	42.0000	6.7524
128.0000	4.2913	60.0000	6.8705	44.0000	6.1254
130.0000	4.0130	58.0000	6.9542	46.0000	6.2376
132.0000	4.0279	56.0000	6.9215	48.0000	6.5651
134.0000	3.6518	54.0000	7.9153	50.0000	7.3347
136.0000	3.8471	52.0000	7.0159	52.0000	7.0159
138.0000	3.3368	50.0000	7.3347	54.0000	7.9153
140.0000	3.7407	48.0000	6.5651	56.0000	6.9215
142.0000	3.6522	46.0000	6.2376	58.0000	6.9542
144.0000	3.9846	44.0000	6.1254	60.0000	6.8705
146.0000	3.9624	42.0000	6.7524	62.0000	6.6256
146.0000	4.3295	40.0000	7.7533	64.0000	7.4314
144.0000	4.3178	38.0000	7.6970	66.0000	7.0115
142.0000	3.1183	36.0000	7.2634	68.0000	7.9716
140.0000	3.9216	34.0000	7.2952	70.0000	7.6643
138.0000	4.4095	32.0000	7.6863	72.0000	7.3721
136.0000	4.0172	30.0000	6.8734	74.0000	6.9703
134.0000	4.0317	28.0000	6.3032	76.0000	6.3683
132.0000	5.2828	26.0000	6.8947	78.0000	7.8321
130.0000	5.5486	24.0000	6.0113	80.0000	7.5150
128.0000	5.0629	22.0000	7.7121	82.0000	8.7922
126.0000	5.6782	20.0000	7.4908	84.0000	8.0023
124.0000	5.0110	18.0000	7.8225	86.0000	9.3112
122.0000	6.1224	16.0000	7.4416	88.0000	8.3235
120.0000	6.2509	14.0000	7.2477	90.0000	8.6466
118.0000	8.5153	12.0000	7.2168	92.0000	7.7940
116.0000	9.0249	10.0000	6.1759	94.0000	7.6992
114.0000	8.7653	8.0000	6.0807	96.0000	6.3263
112.0000	8.2773	6.0000	6.0944	98.0000	6.6044
110.0000	7.7849	4.0000	6.1076	100.0000	6.4407
108.0000	6.6617	-50.	00.28	102.0000	6.7403
106.0000	6.9246	-50.	.10	104.0000	6.1596
104.0000	6.1596	147	.000265	106.0000	6.9246
102.0000	6.7403	-50.	.28	108.0000	6.6617
100.0000	6.4407	4.0000	6.11076	110.0000	7.7849
98.0000	6.6044	6.0000	6.30944	112.0000	8.2773
96.0000	6.3263	8.0000	6.60807	114.0000	8.7653
94.0000	7.6992	10.0000	6.1759	116.0000	9.0249
92.0000	7.7940	12.0000	7.2168	118.0000	8.5153
90.0000	8.6466	14.0000	7.2477	120.0000	6.2509
88.0000	8.3235	16.0000	7.4416	122.0000	6.1224
86.0000	9.3112	18.0000	7.8225	124.0000	5.0110
84.0000	8.0023	20.0000	7.4908	126.0000	5.6782
82.0000	8.7922	22.0000	7.7121	128.0000	5.0629
80.0000	7.5150	24.0000	6.0113	130.0000	5.5486
78.0000	7.8321	26.0000	6.8947	132.0000	5.2828
76.0000	6.3683	28.0000	6.3032	134.0000	4.0317

136.0000 4.0172
 138.0000 4.4095
 140.0000 3.9216
 142.0000 3.1183
 144.0000 4.3178
 146.0000 4.3295
 146.0000 4.8715
 144.0000 4.4189
 142.0000 4.8944
 140.0000 4.1236
 138.0000 4.9035
 136.0000 4.0319
 134.0000 4.5646
 132.0000 5.3911
 130.0000 5.0649
 128.0000 5.2297
 126.0000 5.9059
 124.0000 5.9202
 122.0000 6.4201
 120.0000 6.6612
 118.0000 8.7020
 116.0000 9.1675
 114.0000 8.0045
 112.0000 8.0411
 110.0000 7.5492
 108.0000 6.5300
 106.0000 6.7898
 104.0000 6.1246
 102.0000 6.6804
 100.0000 6.4542
 98.0000 6.4183
 96.0000 6.2522
 94.0000 7.5813
 92.0000 8.8222
 90.0000 9.1571
 88.0000 9.8756
 86.0000 11.7540
 84.0000 9.4779
 82.0000 8.6796
 80.0000 7.8445
 78.0000 7.2784
 76.0000 7.3285
 74.0000 7.2987
 72.0000 7.2134
 70.0000 7.9398
 68.0000 8.3839
 66.0000 8.8857
 64.0000 7.3980
 62.0000 7.1428
 60.0000 6.1814
 58.0000 6.7451
 56.0000 6.9495
 54.0000 7.7794

52.0000 7.4231
 50.0000 7.2728
 48.0000 6.1811
 46.0000 6.0258
 44.0000 6.6380
 42.0000 6.8220
 40.0000 8.0819
 38.0000 8.4720
 36.0000 8.6827
 34.0000 8.6627
 32.0000 7.1785
 30.0000 7.3231
 28.0000 7.7998
 26.0000 7.3930
 24.0000 7.5605
 22.0000 7.1805
 20.0000 7.5954
 18.0000 7.2027
 16.0000 7.0958
 14.0000 7.4324
 12.0000 7.9925
 10.0000 7.2288
 8.0000 7.1895
 6.0000 6.1178
 4.0000 6.8296
 -50. .35
 -50. .28
 76 .1
 -50. .1
 4.0000 6.8296
 6.0000 6.1178
 8.0000 7.1895
 10.0000 7.2288
 12.0000 7.9925
 14.0000 7.4324
 16.0000 7.0958
 18.0000 7.2027
 20.0000 7.5954
 22.0000 7.1805
 24.0000 7.5605
 26.0000 7.3930
 28.0000 7.7998
 30.0000 7.3231
 32.0000 7.1785
 34.0000 8.6627
 36.0000 8.6827
 38.0000 8.4720
 40.0000 8.0819
 42.0000 6.8220
 44.0000 6.6380
 46.0000 6.0258
 48.0000 6.1811
 50.0000 7.2728

52.0000 7.4231
 54.0000 7.7794
 56.0000 6.9495
 58.0000 6.7451
 60.0000 6.1814
 62.0000 7.1428
 64.0000 7.3980
 66.0000 8.8857
 68.0000 8.3839
 70.0000 7.9398
 72.0000 7.2134
 74.0000 7.2987
 76.0000 7.3285
 78.0000 7.2784
 80.0000 7.8445
 82.0000 8.6796
 84.0000 9.4779
 86.0000 10.7540
 88.0000 9.8756
 90.0000 9.1571
 92.0000 8.8222
 94.0000 7.5813
 96.0000 6.2522
 98.0000 6.4183
 100.0000 6.4542
 102.0000 6.6804
 104.0000 6.1246
 106.0000 6.7898
 108.0000 6.5300
 110.0000 7.5492
 112.0000 8.0411
 114.0000 8.0045
 116.0000 9.1675
 118.0000 8.7020
 120.0000 6.6612
 122.0000 6.4201
 124.0000 5.9202
 126.0000 5.9059
 128.0000 5.2297
 130.0000 5.0649
 132.0000 5.3911
 134.0000 4.5646
 136.0000 4.0319
 138.0000 4.9035
 140.0000 4.1236
 142.0000 4.8944
 144.0000 4.4189
 146.0000 4.8715
 146. 9.5
 -50. 9.50001
 -50. .35

B Output File for a Sedimentary Structure

The following data are the contents of the output data file **sed1rrm.out** for the example discussed in Section 3-5. Please note that the output data file starts with listing the following input data: NB, NN, CI, HE, DIP, ST, GREG1, GREG2, GREG3. Next, the NC+1, the susceptibility values, and the coordinates for each bed follow. Finally, the four columns of data following this input data give the computed output. The first column gives the location of point of calculation, the second, third, and fourth columns, respectively, the vertical, horizontal, and total magnetic intrusion of the model in that example.

```

6 94 -2.000 0.600 1.044 0.000 0. 0. 0.
76 0.000004
-----
-50.000 146.000 146.000 144.000 142.000 140.000 138.000 136.000
134.000 132.000 130.000 128.000 126.000 124.000 122.000 120.000
118.000 116.000 114.000 112.000 110.000 108.000 106.000 104.000
102.000 100.000 98.000 96.000 94.000 92.000 90.000 88.000
86.000 84.000 82.000 80.000 78.000 76.000 74.000 72.000
70.000 68.000 66.000 64.000 62.000 60.000 58.000 56.000
54.000 52.000 50.000 48.000 46.000 44.000 42.000 40.000
38.000 36.000 34.000 32.000 30.000 28.000 26.000 24.000
22.000 20.000 18.000 16.000 14.000 12.000 10.000 8.000
6.000 4.000 -50.000 -50.000 0.000 0.001 2.772 2.297
2.032 1.907 2.045 2.268 2.422 2.469 2.499 2.569
2.663 2.787 3.098 3.259 3.992 4.693 4.709 4.307
3.938 3.344 3.135 3.035 3.010 3.009 3.023 3.119
3.796 4.306 4.885 5.521 5.726 5.494 4.934 4.381
3.830 3.297 3.219 3.201 3.234 3.498 3.756 3.854
3.711 3.465 3.205 3.194 3.591 3.821 3.878 3.754
3.531 3.431 3.524 3.834 4.078 4.131 3.798 3.493
3.482 3.733 4.145 4.201 4.346 4.343 4.445 4.503
4.295 4.203 4.107 3.834 3.551 3.241 0.050 0.000
147 0.000024
-----
-50.000 4.000 6.000 8.000 10.000 12.000 14.000 16.000
18.000 20.000 22.000 24.000 26.000 28.000 30.000 32.000
34.000 36.000 38.000 40.000 42.000 44.000 46.000 48.000
50.000 52.000 54.000 56.000 58.000 60.000 62.000 64.000
66.000 68.000 70.000 72.000 74.000 76.000 78.000 80.000
82.000 84.000 86.000 88.000 90.000 92.000 94.000 96.000
98.000 100.000 102.000 104.000 106.000 108.000 110.000 112.000
114.000 116.000 118.000 120.000 122.000 124.000 126.000 128.000
130.000 132.000 134.000 136.000 138.000 140.000 142.000 144.000
146.000 146.000 144.000 142.000 140.000 138.000 136.000 134.000
132.000 130.000 128.000 126.000 124.000 122.000 120.000 118.000
116.000 114.000 112.000 110.000 108.000 106.000 104.000 102.000
100.000 98.000 96.000 94.000 92.000 90.000 88.000 86.000
84.000 82.000 80.000 78.000 76.000 74.000 72.000 70.000
68.000 66.000 64.000 62.000 60.000 58.000 56.000 54.000

```

52.000	50.000	48.000	46.000	44.000	42.000	40.000	38.000
36.000	34.000	32.000	30.000	28.000	26.000	24.000	22.000
20.000	18.000	16.000	14.000	12.000	10.000	8.000	6.000
4.000	-50.000	-50.000	0.050	3.241	3.551	3.834	4.107
4.203	4.295	4.503	4.445	4.343	4.346	4.201	4.145
3.733	3.482	3.493	3.798	4.131	4.078	3.834	3.524
3.431	3.531	3.754	3.878	3.821	3.591	3.194	3.205
3.465	3.711	3.854	3.756	3.498	3.234	3.201	3.219
3.297	3.830	4.807	4.337	5.494	5.726	5.521	4.885
4.306	3.796	3.119	3.023	3.009	3.010	3.035	3.135
3.344	3.938	4.307	4.709	4.693	3.992	3.259	3.098
2.787	2.663	2.569	2.499	2.469	2.422	2.268	2.045
1.907	2.032	2.297	2.772	3.209	2.808	2.549	2.464
2.557	2.752	3.029	3.240	3.356	3.494	3.657	3.826
4.503	4.710	5.511	6.127	5.909	5.542	5.322	4.572
4.403	4.342	4.320	4.164	4.207	4.688	5.505	5.691
6.699	6.247	7.454	6.820	6.500	5.018	5.593	4.608
4.795	4.493	5.160	5.884	5.183	5.958	5.552	4.326
4.846	5.084	5.263	5.823	5.360	5.888	5.075	5.005
5.527	5.442	5.251	5.408	5.164	4.577	4.678	4.561
5.482	5.545	5.976	5.665	5.823	5.430	5.507	5.912
5.102	5.757	4.957	4.137	0.100	0.050		

147 0.000255

-50.000	4.000	6.000	8.000	10.000	12.000	14.000	16.000
18.000	20.000	22.000	24.000	26.000	28.000	30.000	32.000
34.000	36.000	38.000	40.000	42.000	44.000	46.000	48.000
50.000	52.000	54.000	56.000	58.000	60.000	62.000	64.000
66.000	68.000	70.000	72.000	74.000	76.000	78.000	80.000
82.000	84.000	86.000	88.000	90.000	92.000	94.000	96.000
98.000	100.000	102.000	104.000	106.000	108.000	110.000	112.000
114.000	116.000	118.000	120.000	122.000	124.000	126.000	128.000
130.000	132.000	134.000	136.000	138.000	140.000	142.000	144.000
146.000	146.000	144.000	142.000	140.000	138.000	136.000	134.000
132.000	130.000	128.000	126.000	124.000	122.000	120.000	118.000
116.000	114.000	112.000	110.000	108.000	106.000	104.000	102.000
100.000	98.000	96.000	94.000	92.000	90.000	88.000	86.000
84.000	82.000	80.000	78.000	76.000	74.000	72.000	70.000
68.000	66.000	64.000	62.000	60.000	58.000	56.000	54.000
52.000	50.000	48.000	46.000	44.000	42.000	40.000	38.000
36.000	34.000	32.000	30.000	28.000	26.000	24.000	22.000
20.000	18.000	16.000	14.000	12.000	10.000	8.000	6.000
4.000	-50.000	-50.000	0.100	4.137	4.957	5.757	5.102
5.912	5.507	5.430	5.823	5.665	5.976	5.545	5.482
4.561	4.678	4.577	5.164	5.408	5.251	5.442	5.527
5.005	5.075	5.888	5.360	5.823	5.263	5.084	4.846
4.326	5.552	5.958	5.183	5.884	5.160	4.493	4.795
4.608	5.593	5.018	6.500	6.820	7.454	6.247	6.699
5.691	5.505	4.688	4.207	4.164	4.196	4.416	4.032
4.718	5.218	5.421	5.088	6.271	5.114	4.098	4.027
3.259	3.566	3.940	3.555	3.402	3.294	2.523	2.566
2.644	2.488	2.082	3.093	3.962	3.985	3.652	3.741
3.337	3.847	3.652	4.028	4.013	4.291	4.073	4.268

5.654	5.067	7.816	7.349	7.475	7.383	6.204	6.388
5.945	5.686	5.344	5.618	5.915	6.011	6.799	7.354
7.029	8.013	8.692	8.474	7.822	6.010	6.390	5.257
5.590	5.573	6.742	6.560	6.079	6.788	6.033	5.956
5.217	6.995	6.327	6.572	6.522	6.465	6.987	6.815
6.561	6.808	6.518	6.091	6.056	6.016	6.920	6.810
6.439	6.948	6.999	6.968	6.137	6.551	6.029	6.198
6.238	5.694	5.885	5.380	0.200	0.100		

147 0.000260

-50.000	4.000	6.000	8.000	10.000	12.000	14.000	16.000
18.000	20.000	22.000	24.000	26.000	28.000	30.000	32.000
34.000	36.000	38.000	40.000	42.000	44.000	46.000	48.000
50.000	52.000	54.000	56.000	58.000	60.000	62.000	64.000
66.000	68.000	70.000	72.000	74.000	76.000	78.000	80.000
82.000	84.000	86.000	88.000	90.000	92.000	94.000	96.000
98.000	100.000	102.000	104.000	106.000	108.000	110.000	112.000
114.000	116.000	118.000	120.000	122.000	124.000	126.000	128.000
130.000	132.000	134.000	136.000	138.000	140.000	142.000	144.000
146.000	146.000	144.000	142.000	140.000	138.000	136.000	134.000
132.000	130.000	128.000	126.000	124.000	122.000	120.000	118.000
116.000	114.000	112.000	110.000	108.000	106.000	104.000	102.000
100.000	98.000	96.000	94.000	92.000	90.000	88.000	86.000
84.000	82.000	80.000	78.000	76.000	74.000	72.000	70.000
68.000	66.000	64.000	62.000	60.000	58.000	56.000	54.000
52.000	50.000	48.000	46.000	44.000	42.000	40.000	38.000
36.000	34.000	32.000	30.000	28.000	26.000	24.000	22.000
20.000	18.000	16.000	14.000	12.000	10.000	8.000	6.000
4.000	-50.000	-50.000	0.200	5.380	5.885	5.694	6.238
6.198	6.029	6.551	6.137	6.968	6.999	6.948	6.439
6.810	6.920	6.016	6.056	6.091	6.518	6.808	6.561
6.815	6.987	6.465	6.522	6.572	6.327	6.995	5.217
5.956	6.033	6.788	6.079	6.560	6.742	5.573	5.590
5.257	6.390	6.010	7.822	8.474	8.692	8.013	7.029
7.354	6.799	6.011	5.915	5.618	5.344	5.686	5.945
6.388	6.204	7.383	7.475	7.349	7.816	5.067	5.654
4.268	4.073	4.291	4.013	4.028	3.652	3.847	3.337
3.741	3.652	3.985	3.962	4.330	4.318	3.118	3.922
4.410	4.017	4.032	5.283	5.549	5.063	5.678	5.011
6.122	6.251	8.515	9.025	8.765	8.277	7.785	6.662
6.925	6.160	6.740	6.441	6.604	6.326	7.699	7.794
8.647	8.323	9.311	8.002	8.792	7.515	7.832	6.368
6.970	7.372	7.664	7.972	7.011	7.431	6.626	6.870
6.954	6.921	7.915	7.016	7.335	6.565	6.238	6.125
6.752	7.753	7.697	7.263	7.295	7.686	6.873	6.303
6.895	6.011	7.712	7.491	7.822	7.442	7.248	7.217
6.176	6.081	6.094	6.108	0.280	0.100		

147 0.000265

-50.000	4.000	6.000	8.000	10.000	12.000	14.000	16.000
18.000	20.000	22.000	24.000	26.000	28.000	30.000	32.000
34.000	36.000	38.000	40.000	42.000	44.000	46.000	48.000
50.000	52.000	54.000	56.000	58.000	60.000	62.000	64.000

66.000	68.000	70.000	72.000	74.000	76.000	78.000	80.000
82.000	84.000	86.000	88.000	90.000	92.000	94.000	96.000
98.000	100.000	102.000	104.000	106.000	108.000	110.000	112.000
114.000	116.000	118.000	120.000	122.000	124.000	126.000	128.000
130.000	132.000	134.000	136.000	138.000	140.000	142.000	144.000
146.000	146.000	144.000	142.000	140.000	138.000	136.000	134.000
132.000	130.000	128.000	126.000	124.000	122.000	120.000	118.000
116.000	114.000	112.000	110.000	108.000	106.000	104.000	102.000
100.000	98.000	96.000	94.000	92.000	90.000	88.000	86.000
84.000	82.000	80.000	78.000	76.000	74.000	72.000	70.000
68.000	66.000	64.000	62.000	60.000	58.000	56.000	54.000
52.000	50.000	48.000	46.000	44.000	42.000	40.000	38.000
36.000	34.000	32.000	30.000	28.000	26.000	24.000	22.000
20.000	18.000	16.000	14.000	12.000	10.000	8.000	6.000
4.000	-50.000	-50.000	0.280	6.111	6.309	6.608	6.176
7.217	7.248	7.442	7.822	7.491	7.712	6.011	6.895
6.303	6.873	7.686	7.295	7.263	7.697	7.753	6.752
6.125	6.238	6.565	7.335	7.016	7.915	6.921	6.954
6.870	6.626	7.431	7.011	7.972	7.664	7.372	6.970
6.368	7.832	7.515	8.792	8.002	9.311	8.323	8.647
7.794	7.699	6.326	6.604	6.441	6.740	6.160	6.925
6.662	7.785	8.277	8.765	9.025	8.515	6.251	6.122
5.011	5.678	5.063	5.549	5.283	4.032	4.017	4.410
3.922	3.118	4.318	4.330	4.872	4.419	4.894	4.124
4.904	4.032	4.565	5.391	5.065	5.230	5.906	5.920
6.420	6.661	8.702	9.168	8.005	8.041	7.549	6.530
6.790	6.125	6.680	6.454	6.418	6.252	7.581	8.822
9.157	9.876	11.754	9.478	8.680	7.845	7.278	7.329
7.299	7.213	7.940	8.384	8.886	7.398	7.143	6.181
6.745	6.949	7.779	7.423	7.273	6.181	6.026	6.638
6.822	8.082	8.472	8.683	8.663	7.178	7.323	7.800
7.393	7.561	7.181	7.595	7.203	7.096	7.432	7.992
7.229	7.189	6.118	6.830	0.350	0.280		
76	0.100000						

-50.000	4.000	6.000	8.000	10.000	12.000	14.000	16.000
18.000	20.000	22.000	24.000	26.000	28.000	30.000	32.000
34.000	36.000	38.000	40.000	42.000	44.000	46.000	48.000
50.000	52.000	54.000	56.000	58.000	60.000	62.000	64.000
66.000	68.000	70.000	72.000	74.000	76.000	78.000	80.000
82.000	84.000	86.000	88.000	90.000	92.000	94.000	96.000
98.000	100.000	102.000	104.000	106.000	108.000	110.000	112.000
114.000	116.000	118.000	120.000	122.000	124.000	126.000	128.000
130.000	132.000	134.000	136.000	138.000	140.000	142.000	144.000
146.000	146.000	-50.000	-50.000	0.100	6.830	6.118	7.189
7.229	7.992	7.432	7.096	7.203	7.595	7.181	7.561
7.393	7.800	7.323	7.178	8.663	8.683	8.472	8.082
6.822	6.638	6.026	6.181	7.273	7.423	7.779	6.949
6.745	6.181	7.143	7.398	8.886	8.384	7.940	7.213
7.299	7.329	7.278	7.845	8.680	9.478	10.754	9.876
9.157	8.822	7.581	6.252	6.418	6.454	6.680	6.125
6.790	6.530	7.549	8.041	8.005	9.168	8.702	6.661
6.420	5.920	5.906	5.230	5.065	5.391	4.565	4.032

4.904	4.124	4.894	4.419	4.872	9.500	9.500	0.350
0.000	-90.223	-2446.167	-77.990				
2.000	-225.155	-2232.159	-194.629				
4.000	-289.897	-2080.629	-250.593				
6.000	-397.923	-2027.645	-343.974				
8.000	-637.896	-1939.550	-551.412				
10.000	-893.164	-1679.493	-772.071				
12.000	-996.563	-1299.242	-861.451				
14.000	-907.852	-958.410	-784.767				
16.000	-731.010	-769.473	-631.901				
18.000	-592.078	-707.209	-511.805				
20.000	-520.359	-688.845	-449.810				
22.000	-491.616	-680.594	-424.964				
24.000	-498.396	-675.559	-430.825				
26.000	-534.776	-664.485	-462.272				
28.000	-599.363	-653.439	-518.103				
30.000	-729.436	-641.030	-630.541				
32.000	-969.058	-545.496	-837.675				
34.000	-1240.452	-230.270	-1072.275				
36.000	-1339.153	322.485	-1157.593				
38.000	-1103.187	955.759	-953.619				
40.000	-514.183	1435.759	-444.471				
42.000	289.426	1551.631	250.186				
44.000	1045.891	1215.143	904.091				
46.000	1463.609	531.926	1265.176				
48.000	1381.556	-170.849	1194.248				
50.000	976.956	-532.466	844.503				
52.000	631.073	-500.365	545.513				
54.000	576.731	-314.651	498.539				
56.000	784.342	-270.325	678.003				
58.000	1017.581	-532.700	879.620				
60.000	984.539	-1014.734	851.057				
62.000	583.703	-1404.267	504.566				
64.000	21.706	-1445.686	18.763				
66.000	-398.795	-1149.683	-344.728				
68.000	-498.812	-728.926	-431.185				
70.000	-305.752	-443.859	-264.299				
72.000	-12.513	-446.889	-10.816				
74.000	158.844	-714.585	137.309				
76.000	72.645	-1108.741	62.796				
78.000	-312.087	-1458.560	-269.775				
80.000	-945.415	-1586.020	-817.237				
82.000	-1672.863	-1360.578	-1446.060				
84.000	-2287.806	-766.451	-1977.631				
86.000	-2615.898	99.244	-2261.240				
88.000	-2560.543	1077.188	-2213.391				
90.000	-2100.977	1994.712	-1816.131				
92.000	-1273.826	2676.185	-1101.124				
94.000	-204.055	2935.599	-176.390				
96.000	834.808	2668.984	721.626				
98.000	1544.768	2020.359	1335.331				
100.000	1864.167	1275.838	1611.427				
102.000	1914.425	576.508	1654.872				

104.000	1746.407	-81.687	1509.633
106.000	1318.740	-642.220	1139.948
108.000	653.223	-971.120	564.661
110.000	-137.931	-945.519	-119.231
112.000	-867.350	-516.591	-749.757
114.000	-1349.344	257.370	-1166.403
116.000	-1432.305	1248.172	-1238.116
118.000	-1020.501	2232.477	-882.144
120.000	-193.458	2932.636	-167.229
122.000	792.497	3216.595	685.052
124.000	1722.468	3171.698	1488.940
126.000	2556.541	2933.104	2209.931
128.000	3303.261	2525.034	2855.413
130.000	3895.080	2031.610	3366.993
132.000	4517.975	1600.510	3905.438
134.000	5407.312	879.697	4674.201
136.000	6043.511	-487.585	5224.145
138.000	6062.122	-1945.910	5240.233
140.000	5835.762	-3412.250	5044.562
142.000	5097.079	-5011.497	4406.028
144.000	3647.082	-6470.351	3152.619
146.000	1376.383	-7166.755	1189.776
148.000	-818.654	-6501.945	-707.663
150.000	-2074.050	-5140.876	-1792.855
152.000	-2518.714	-3845.930	-2177.233
154.000	-2541.092	-2853.484	-2196.576
156.000	-2390.659	-2141.818	-2066.539
158.000	-2186.410	-1637.598	-1889.981
160.000	-1978.591	-1277.140	-1710.338
162.000	-1786.161	-1015.060	-1543.997
164.000	-1614.722	-820.840	-1395.801
166.000	-1464.410	-674.144	-1265.869
168.000	-1333.356	-561.357	-1152.582
170.000	-1219.137	-473.191	-1053.849
172.000	-1119.359	-403.242	-967.599
174.000	-1031.886	-346.967	-891.985
176.000	-954.861	-301.140	-825.403
178.000	-886.725	-263.423	-766.505
180.000	-826.171	-232.053	-714.161
182.000	-772.119	-205.730	-667.437
184.000	-723.648	-183.443	-625.538
186.000	-680.007	-164.434	-587.814