Magnetic Investigation of the Hunting Hill Ultramafic Body in Montgomery County, Maryland

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ABSTRACT

A ground magnetic survey was undertaken to determine the nature of the contact between the Hunting Hill ultramafic body, in Montgomery County, Maryland, and the surrounding schist country rock. By knowing the contact characteristics, it will lead to a better understanding of the regional tectonics. Ground magnetic data was collected for four traverses across the contact using a proton precession magnetometer. From this data and previous published works, a simple model of the rocks and the serpentinite - schist contact was created for each traverse. All four traverses showed the same contact characteristic: a small spike in field intensity before a sudden drop off going from the serpentinite body to the country rock. Results indicate a sharp contact between the ultramafic body and the surrounding country rock, suggesting that the ultramafic body was tectonically emplaced.

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INTRODUCTION

An investigation of the Hunting Hill ultramafic body in Montgomery County, Maryland was initiated to study the nature of the contact between the ultramafic rock and the surrounding country rock. Understanding the nature of the contact has implications both tectonically and environmentally. From a tectonic standpoint, the implications could lead to a better understanding of regional tectonics. Juxtaposition of the ultramafic rocks and schist could have resulted from (a) intrusion of ultramafic magma into the sedimentary protolith or mica schist, or (b) by tectonic interleaving of disrupted lower portions of the oceanic crust/mantle (Alpine-type). Environmentally, knowing the contact could help with groundwater flow. Any fractures in the ultramafic body would allow for rapid movement of water and contaminants. The study area is located approximately 6.4 km west of downtown Rockville and about 27.4 km northwest of the Capitol in Washington, D.C (Figure 1). The ultramafic body is about 6.5 km long and 1.6 km wide (Cloos and Cooke, 1953). The Hunting Hill ultramafic body, which lies in the Piedmont Plateau region, was first noted by Cloos and Cooke (1953).

Ultramafic rocks such as dunite, peridotite, pyroxenite, and the hydrated product, serpentinite, produce many of the large magnetic anomalies encountered in geophysical exploration (Irwin and Bath, 1962; Gaucher, 1965; Saad, 1969). The Hunting Hill body is considered to be an Alpine type ultramafic body. These rocks are of importance because they are typically emplaced along continental margins in belts of highly deformed geosynclinal rocks. In addition, they are common in island arcs, trenches, and mid-oceanic ridges (Wyllie, 1967). Most of the Alpine type ultramafic intrusions have been tectonically emplaced upwards from the mantle (Burch, 1968).

During the winter of 2005, a ground magnetic survey was conducted, which detailed four traverses (Figure 2) across the contact between the ultramafic body and the surrounding country rock schist. These traverses were chosen primarily for easy accessibility, since most of the ultramafic body consists of a quarry and numerous housing developments, which limited areas where a good reading could be made.

Magnetometry is a well-known application for deducing geological structure (Gibson, 1996; Lee, 1987; Hildenbrand, 1985). This often takes form as aeromagnetic surveys, in which data are collected at a flying height of about 300m along 2km-spaced flight lines. This form of survey is advantageous due to the large area covered in a relatively short span of time. However, a disadvantage of these surveys is that while the overall structure of a region can be deduced, small-scale features can be completely missed. One way to negate this is by taking ground magnetometer traverses with closely spaced stations. A magnetic anomaly can take a number of forms – a gradual rise, a step across where background values change, or a narrow zone of anomalous readings.

This analysis presents explanations for the nature of the contact of the body using magnetic data. In the following sections, previous research was reviewed, followed by the geologic and structural characteristics of the Piedmont region. After discussing the physical setting, the magnetic investigation is explained.

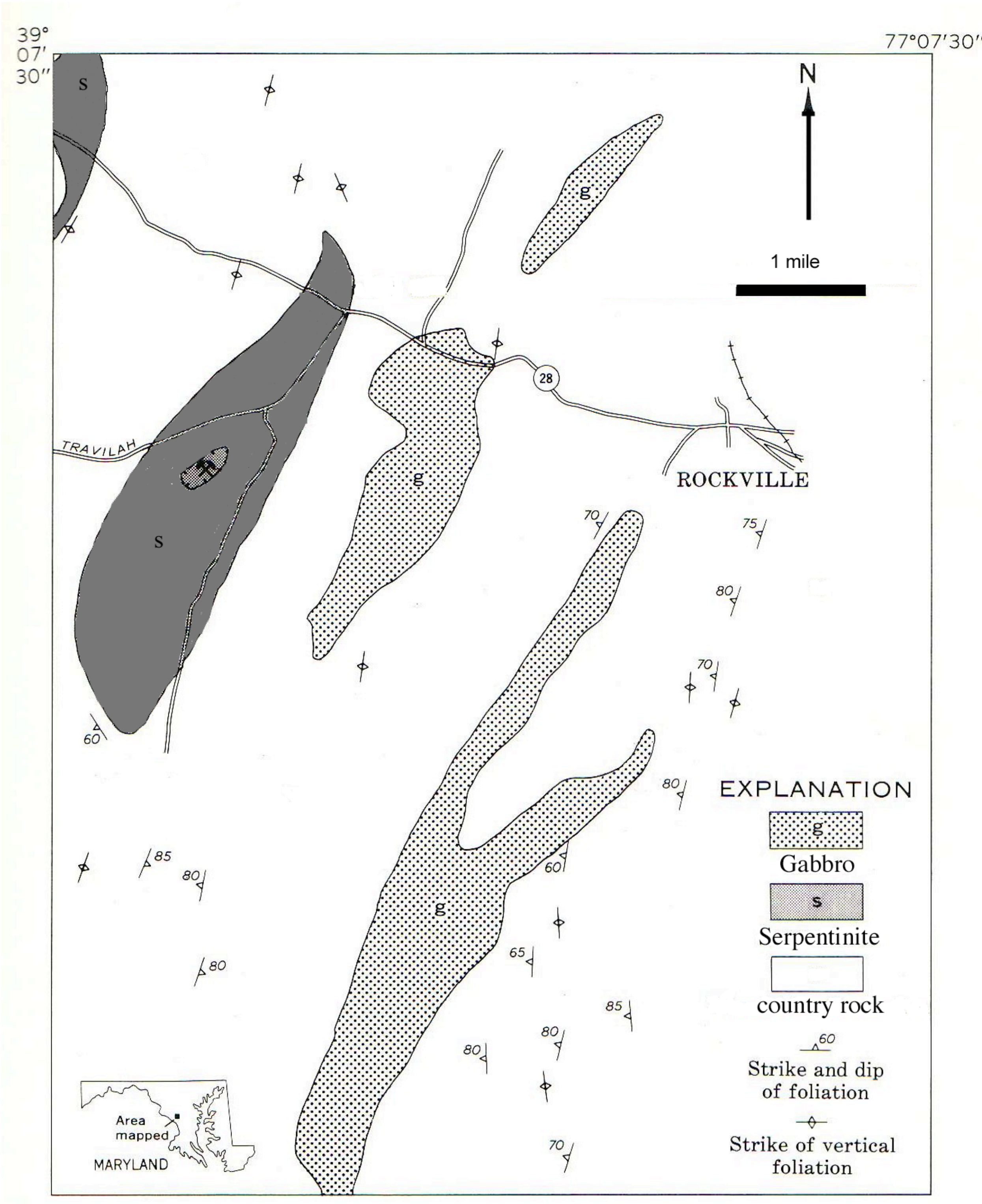

Figure 1. Map showing the location of the Hunting Hill ultramafic serpentinite body, Montgomery County, Maryland, and its relation to nearby serpentinite and gabbro masses. (Modified from Larrabee, 1969.)

GEOLOGIC SETTING

The Hunting Hill ultramafic body was first mapped by Cloos and Cooke in 1953. That ultramafic body consists of serpentinized dunite cut by gabbro dikes that have been metamorphosed to rodingite. This ultramafic body is one of several ultramafic bodies within the Liberty Complex and is part of a discontinuous belt of mafic and ultramafic rocks that extends from Georgia to New Jersey (Larrabee, 1969). The Hunting Hill ultramafic body is composed dominantly of massive to foliated serpentinite. This body is locally cut by dikes of gabbro and bodies of diorite. It is massive, hard and tough except at margins, which are schistose. The country rock is interlayered mica schist and metamorphosed graywacke. It is a thick sequence of metasedimentary rock, probably of lower Paleozoic and possibly Precambrian origin that is exposed in extensive areas of the Piedmont, including stretches of Virginia, Maryland, and Pennsylvania.

Montgomery County extends across two distinct and separate physiographic provinces: the Coastal Plain and the Piedmont. Outcrops of these provinces are rare and many have been destroyed by urbanization (Brooks, 1989). The Piedmont consists of gently rolling hills with thick soil cover. The Piedmont Plateau region is situated between the Blue Ridge and the Coastal Plain and is composed of late Precambrian to early Paleozoic metamorphic and igneous rocks (Candela & Wylie, 1989). Regional metamorphic facies vary from greenschist to amphibolite (Linder et al, 1992). The crystalline rocks in the Piedmont region of Montgomery County consist of schists, gneisses, metagraywackes, mafics, and ultramafics, which are part of an intensely folded mélange. The mélange is considered part of the Liberty Complex (Muller et al, 1989). The Liberty Complex includes rocks previously known as the Wissahickon and Sykesville Formations (Hopson, 1964).

According to Muller et al. (1989), there are at least four tectono-stratigraphic assemblages present in the Maryland Piedmont. Three of these assemblages are composed mostly of metaclastic rocks that have been included in the Glenarm Supergroup and various phyllite, quartzite, and metavolcanic units. The fourth assemblage is composed mainly of metavolcanic and metaplutonic rocks and includes rocks of the Baltimore Mafic- Ultramafic Complex and James Run Formation.

The Baltimore Mafic Complex (Drake et al., 1989) and the Liberty Complex (Linder et al. 1992 & Muller et al. 1989) consist of a broad north-northeast trending belt of mafic and ultramafic rocks about 150-km long, extending from southeast Pennsylvania through Maryland into central Virginia (Morgan, 1977). These complexes are interpreted to be a fragmented ophiolite sequence that was emplaced during early Paleozoic subduction. The ophiolite sequence has been severely deformed during later events associated with the development of the Appalachians. Geologic relations suggest that the minimum age of emplacement and metamorphism is no younger than late Ordovician. Due to the extensive chromite deposits, the serpentinized ultramafic rocks of the Baltimore Mafic Complex and the Liberty Complex have been studied since the 1820s, since chromite is the only ore of chromium. These chromite deposits were among the most productive in the United States at one time (Pearre and Heyl, 1960).

Ultramafic Body

Serpentinite makes up about 80 to 90 percent of the Hunting Hill ultramafic body, and is largely antigorite. The remainder is mostly rodingite. The serpentinite color ranges from dull green through gray to black. The serpentinite is of two types: (1) fine grained, gray to black rock, characterized by dusty magnetite and a few coarser aggregates of opaque altered chromite and magnetite, and (2) coarser, medium-gray or greenish-gray rock with magnetite aggregates. The chromite-magnetite relations are the same in both (Larrabee, 1969).

The rodingite is a medium- to coarse-grained gabbroic rock where the minerals have been altered to clinopyroxenes and grossularite. It is composed of bright green chromian diopside, brown to pink grossularite, white diopside, zoisite, and a little prehnite and hydrogrossularite (Brooks, 1989). The rodingite-serpentinite contacts tend to be sheared and usually contains chlorite, tremolite, and serpentine. Talc, calcite, dolomite, and picrolite may also be present (Larrabee, 1969).

Country Rock

The host rock is an albite-chlorite-muscovite-quartz schist, which was formerly considered the Upper Pelitic Schist of the Wissahickon Formation (Fisher, 1970). The schist is a foliated, silvery gray rock consisting of interlocking plates of mica or chlorite and minor amounts of other common rock-forming minerals. The foliation is the dominant planar texture and generally dips steeply east or west. This rock unit is folded and faulted with fractures commonly parallel to foliation. The schist weathers to a thick micaceous saprolite and soil (Froelich, 1975).

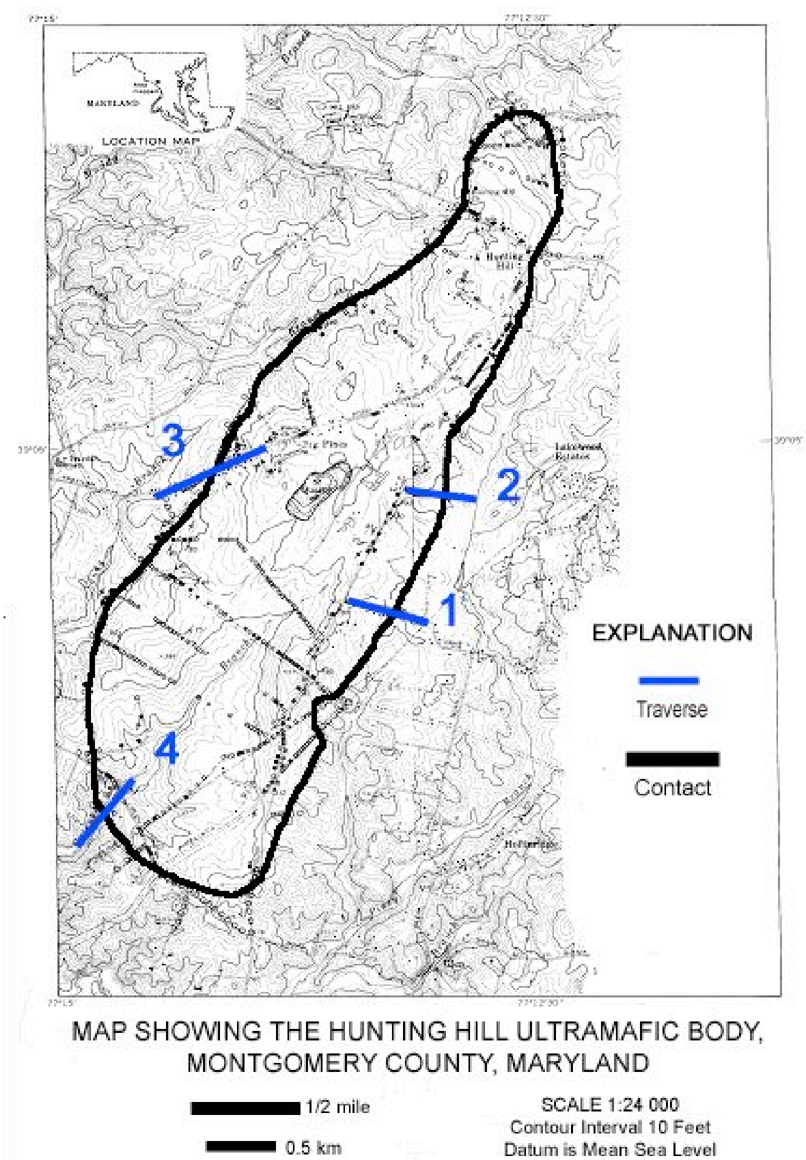

Figure 2. Map showing the Hunting Hill ultramafic body, Montgomery County, Maryland with traverses completed in this investigation. (Modified from Larrabee, 1969)

MAGNETOMETER

A proton precession magnetometer was used to collect all magnetic data. This type of magnetometer uses the precession of spinning protons or nuclei of the hydrogen atom in a sample of hydrocarbon fluid to measure the total magnetic intensity. The spinning protons behave as small, spinning magnetic dipoles. These magnets are temporarily aligned or polarized by the application of a uniform magnetic field generated by a current in a coil of wire. When the current is removed, the spin of the protons causes them to precess about in the direction of the earth's magnetic field. The precessing protons will generate a small signal in the same coil that was used to polarize them. The instrument measures the frequency of the signal generated by the precessions, which is proportional to the total magnetic field intensity (Breiner, 1973). The instrument records total magnetic field vector intensity but not its direction.

The instrument used in this survey was the Geometrics G-856 portable magnetometer. The sensor was located at the top of a staff 2.5m high. The instrument has an electronic readout and stores data so that the data can later be transferred to a computer. However, for this particular study, the magnetometer readings could not be successfully downloaded to a computer when attempted. It is possible that data transfer parameters were not compatible. The magnetic readings appeared to become corrupt during downloading. The data was entered into the computer manually.

MAGNETIC INVESTIGATION

Field Procedure

In order to study the orientation of the contact between the Hunting Hill ultramafic body and the schist, magnetic readings were taken over four traverses at 10m station increments. Terrain, sources of magnetic noise, and time constraints affected some of the station locations. Corrections for these small problems were adjusted for by moving the station location a meter or so from the actual station location point to obtain the reading.

To obtain the magnetic data, a Geometrics model G-856 proton precession magnetometer with the magnetic sensor mounted on a pole of 2.5 meters in height was used. The pole elevated the magnetometer above the ground where small magnetic particles could not disrupt the magnetometer readings. The manufacturer claims this model would return with results within one gamma. By taking multiple readings from the exact same location in rapid succession, it was determined that the accuracy of the unit, which is at least 20 years old, is closer to 10 gammas.

To assist in mapping of magnetic data, a Global Position System (GPS) receiver was used. The GPS provided a precise location within a meter under normal operating conditions. The value of every magnetometer data point and the GPS coordinates were logged into a field book. Caution had to be exercised when using the GPS in proximity of the magnetometer, since metal objects closer than a meter or two to the sensor will affect the readings by up to twenty to thirty gammas.

The data collected with the portable magnetometer were reduced using Excel spreadsheets in a manner consistent with standard USGS practice. The data were corrected for diurnal variations by comparison with base station data, and the International Geomagnetic Reference Field (IGRF) was removed.

Three readings were taken at each station. The average of the three readings was taken as a representative of the magnetic field at that location.

Data Presentation

Two traverses were done that were parallel to each other and perpendicular to the other two traverses. The ultramafic body had magnetic signatures ranging from 800nT to 2200nT. The surrounding country schist rock has readings less than 800nT. There were several signatures in both the ultramafic and country rock that fell outside the range. This was most likely due to some interference that was not accounted for, such as buried pipes or power lines.

The profile was created by doing a two point running average with the data collected. Data collected is portrayed on the profile as the data points. Error bars for each of the data points are small compared to the scale of the plot (1σ deviation: +/- 10nT). With each profile, the block diagrams are a possible configuration of the rocks based on the diagrams by Breiner (1973).

Magnetic Interpretation

For this exploration, it was assumed that major magnetic signatures result from induced magnetization of crystalline rock by the ambient magnetic field. The total field vector used has a magnitude of 52,000nT (based on NOAA) and is inclined at 70 degrees (Breiner, 1973) from horizontal. The declination of the vector is N7W (Rockville 7 1/2 minute Quadrangle). The overall mean for magnetic susceptibility for serpentinite is about 600 x 10^{-5} emu/cm^3 (Saad, 1969; Thompson and Robinson, 1975). The magnetic susceptibility for serpentinite is much greater than that of the country rock schist. This is to be expected since the magnetite volume in the serpentinite averages about 2.2% and only about 0.2% for the country rock schist (Freeman et al., 1988).

The signatures were superimposed on broader, regional trends. These long wavelength variations were removed graphically from the profile data. Then the amplitude, shape, and width of the residual anomalies were studied to get an approximation of the rock configuration.

ERROR

Global Magnetic Variations

A magnetometer survey measures the magnetic field on the surface of the earth at a given location and a given time. Unfortunately, the Earth's magnetic field does not stay constant over time.

The magnetic field measured on the ground depends not only on the strength of the magnetic field induced by forces within the Earth but also depends on the activity of the solar wind as it interacts with ions in the Earth's atmosphere. The solar wind adds to the magnetic field of the earth when measured on the surface. The effects of solar wind are more pronounced on the daytime side of the planet, so as the Earth rotates about its axis the observed magnetic field can change by as much as 100 gammas. In addition to these daily changes, dramatic solar storms can impact readings by several hundred gammas over a period of days to weeks. Longer-term cycles of sunspots and solar flares have changes that are more profound over the period of decades. If such catastrophic events weren't daunting enough to geologists hoping to use geomagnetic survey data, micropulsations, minor spikes in the magnetic field on the order of tenths to tens of gammas, can occur randomly and affect readings for a few seconds or a few minutes. Since the magnetometer study relies heavily on comparing relative magnetic fields, the ability to compare is hampered by these natural variations (Breiner, 1973; Teleford et al, 1976).

In order to effectively use geomagnetic survey data collected over any period of time, geologists should correct for these natural fluctuations. Accurate correction would involve the use of a base station to record fluctuations at a fixed location. In the absence of a site-specific base station, several geomagnetic survey stations record minute-by-minute magnetic field fluctuations. This correction scheme was not utilized, since there was only one magnetometer available for use.

However, data from the USGS magnetic field survey station in Fredericksburg, Virginia was examined, since this site was the closest with data accessible on the Internet. In most cases, the fluctuations within the measurement period were less than 50 gammas over a 24-hour period, and even less over the duration that data was recorded. For the purpose of the project, the daily fluctuations and micropulsations are within an acceptable level of error.

Instrument Precision

Magnetometer readings can usually be repeated to within one gamma in areas of low magnetic gradient and 10 gammas in areas where the magnetic field is changing abruptly with position. These repeatability errors are caused by the inability to hold the magnetometer in exactly the same location. Realistically, most readings could probably be repeated to within 30 gammas when attempting to return to the same location recorded at an earlier date. Such error is due to the small variations in the magnetic field with time and errors due to the non-homogeneous nature of the magnetic anomaly that are common in almost all areas. The error in reported positions is less than +/- 1 meter.

Magnetometer Resolution

A theoretical magnetometer would integrate the magnetic field over an infinite distance. However, the G-856 is not a theoretical magnetometer and has a more limited depth of resolution. The magnetometer measures the magnetic field intensity in a finite sphere. To interpret the magnetometer data, we need to know the approximate size of this sphere. If the magnetometer is affected by the magnetic field intensity in a very large radius, it will be more difficult to isolate the precise location of the contact.

Information about the radius would allow magnetic data to be used in interpreting the subsurface orientation of interformational contacts. Computer models for determining the dip of a contact using the observed magnetic intensities can be used, but these models rely on knowing this radius.

Precise determination of the radius of resolution of the magnetometer is beyond the scope of this project, but it is probably on the order of a few meters.

DATA

Profiles

In all the profiles, the serpentinite magnetic signature is greater than the country rock schist magnetic signature. A small bump in the magnetic contour at the contact is a characteristic shared with the four traverse profiles. When creating a broad profile, this small bump indicates a horizontal contact between the two materials. Although the gradients are different between the profiles, this reflects lower magnetic values in one profile for country rock relative to another. When observing all the profiles, the serpentinite contour dips less steeply than the schist contour. This is expected since the schist will have little to no magnetic material. The readings closer to the contact are slightly higher than the rest of the data, since the sensor is still reading some of the magnetic field from the serpentinite rocks.

In Profile #1, the serpentinite ranges from 1000nT to 1700nT. The country schist rock is less than 800nT. The dip in the middle of the ultramafic body is consistent with a fracture or an intrusion of less magnetic material. In Profile #2, the serpentinite ranges from 1000nT to 1900nT. The schist is less than 700nT. In Profile #3, the serpentinite ranges from 1300nT to 2200nT. The schist is less than 800nT. In Profile #4, the serpentinite ranges from 800nT to 1600nT. The schist is less than 600nT. The lower magnetic readings are most likely due to oxidation of magnetite by the stream.

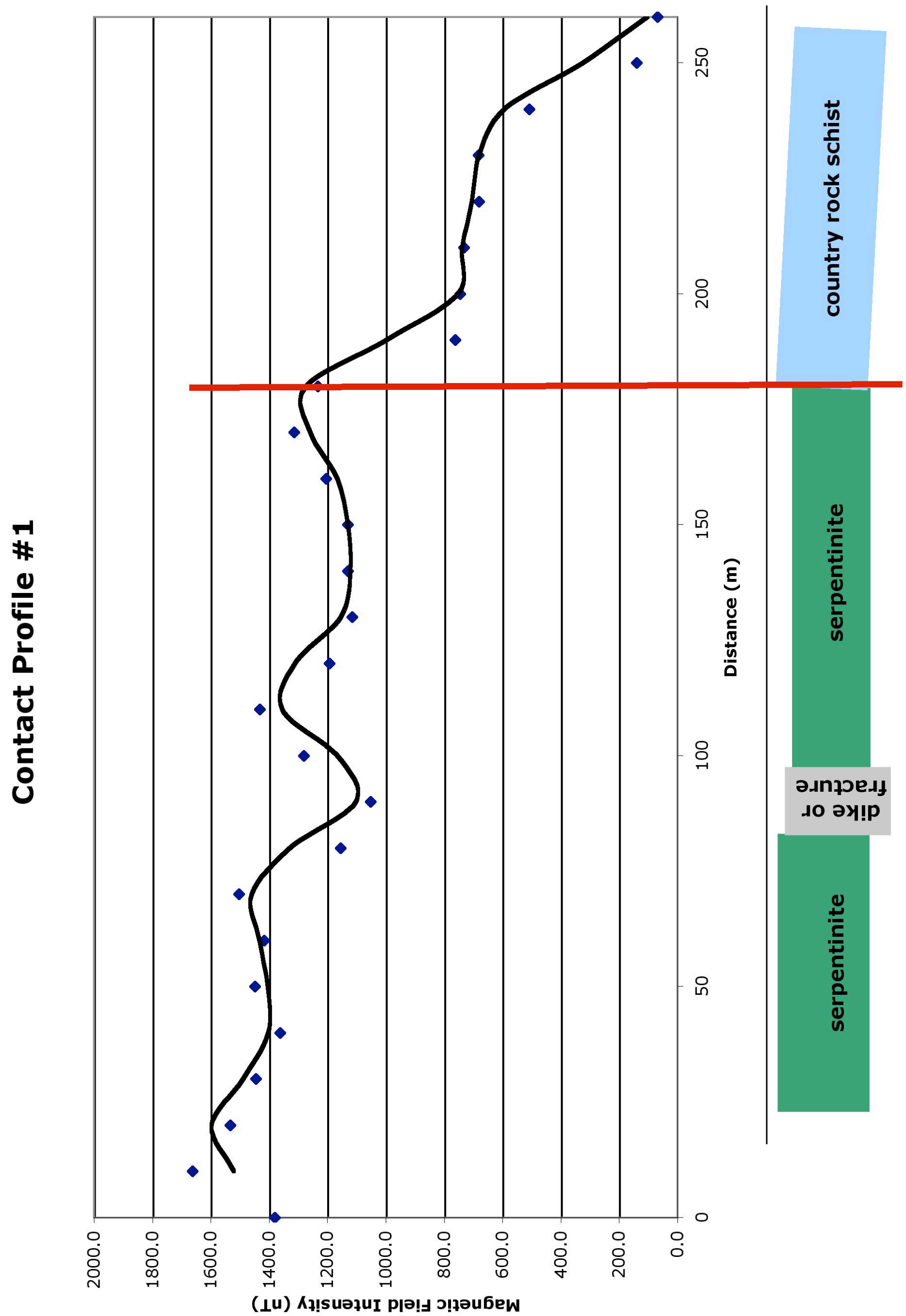

Figure 3. Profile #1 with an approximation of the rock distribution based on magnetic data.

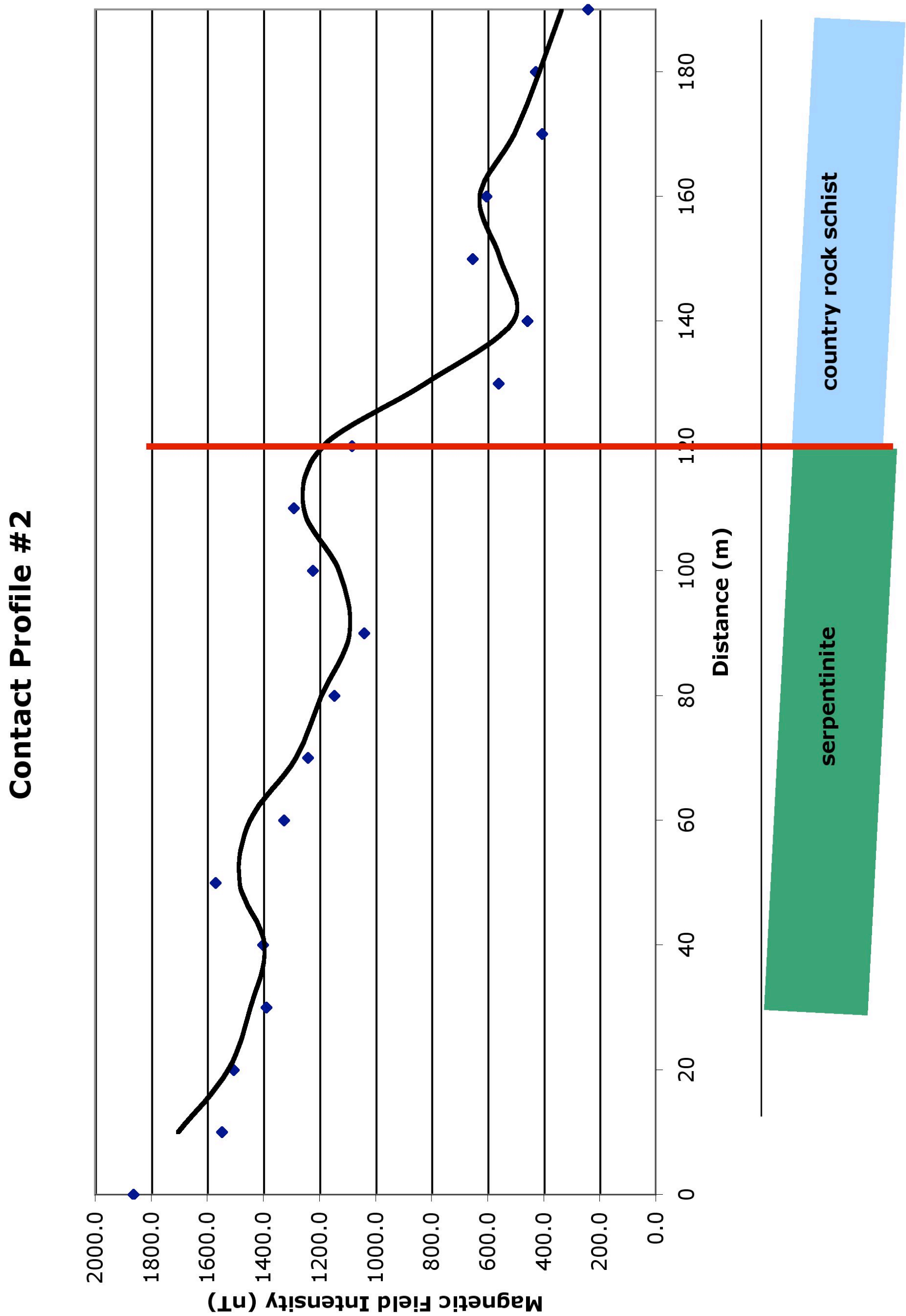

Figure 4. Profile #2 with an approximation of the rock distribution based on magnetic data.

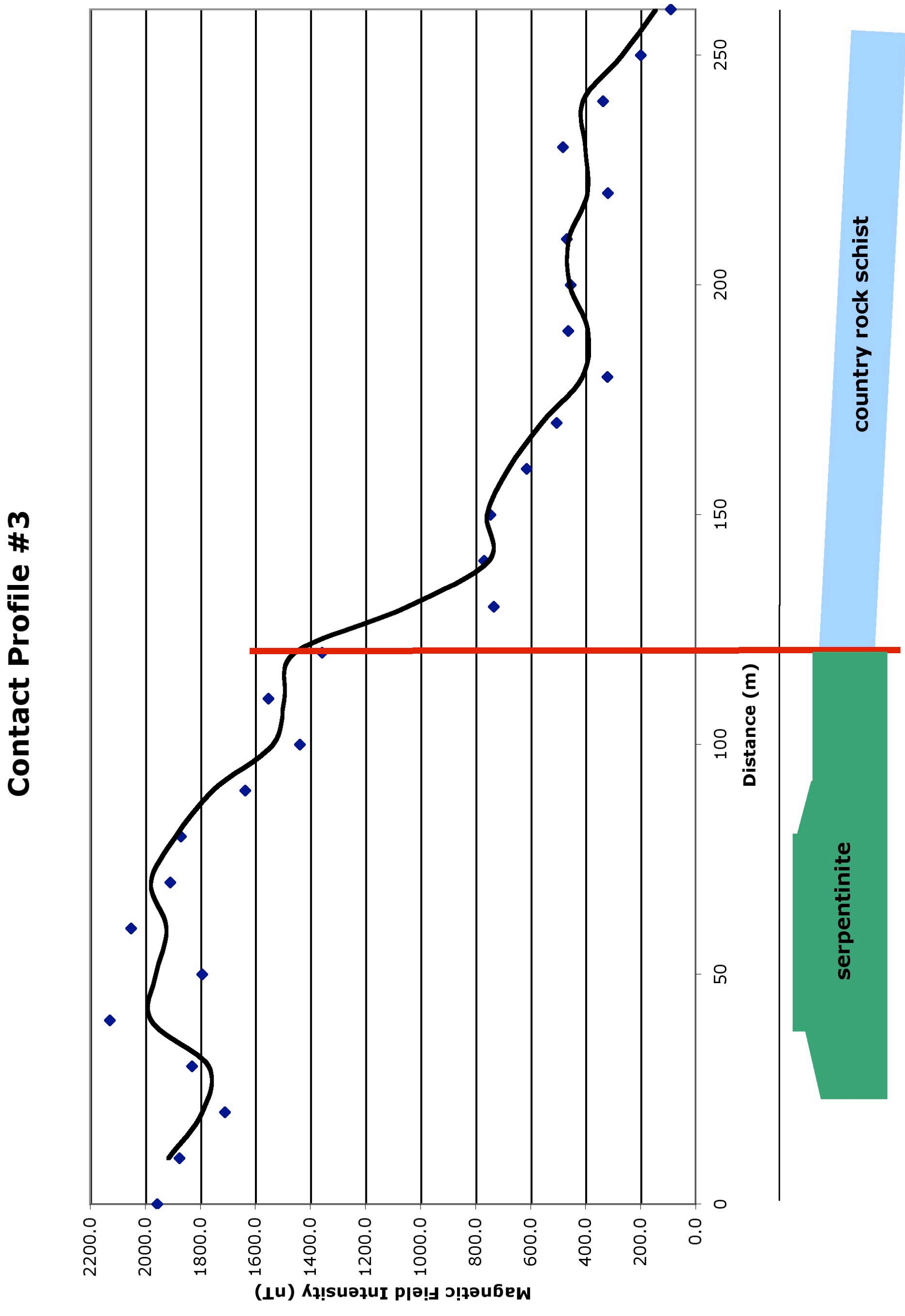

Figure 5. Profile #3 with an approximation of the rock distribution based on magnetic data.

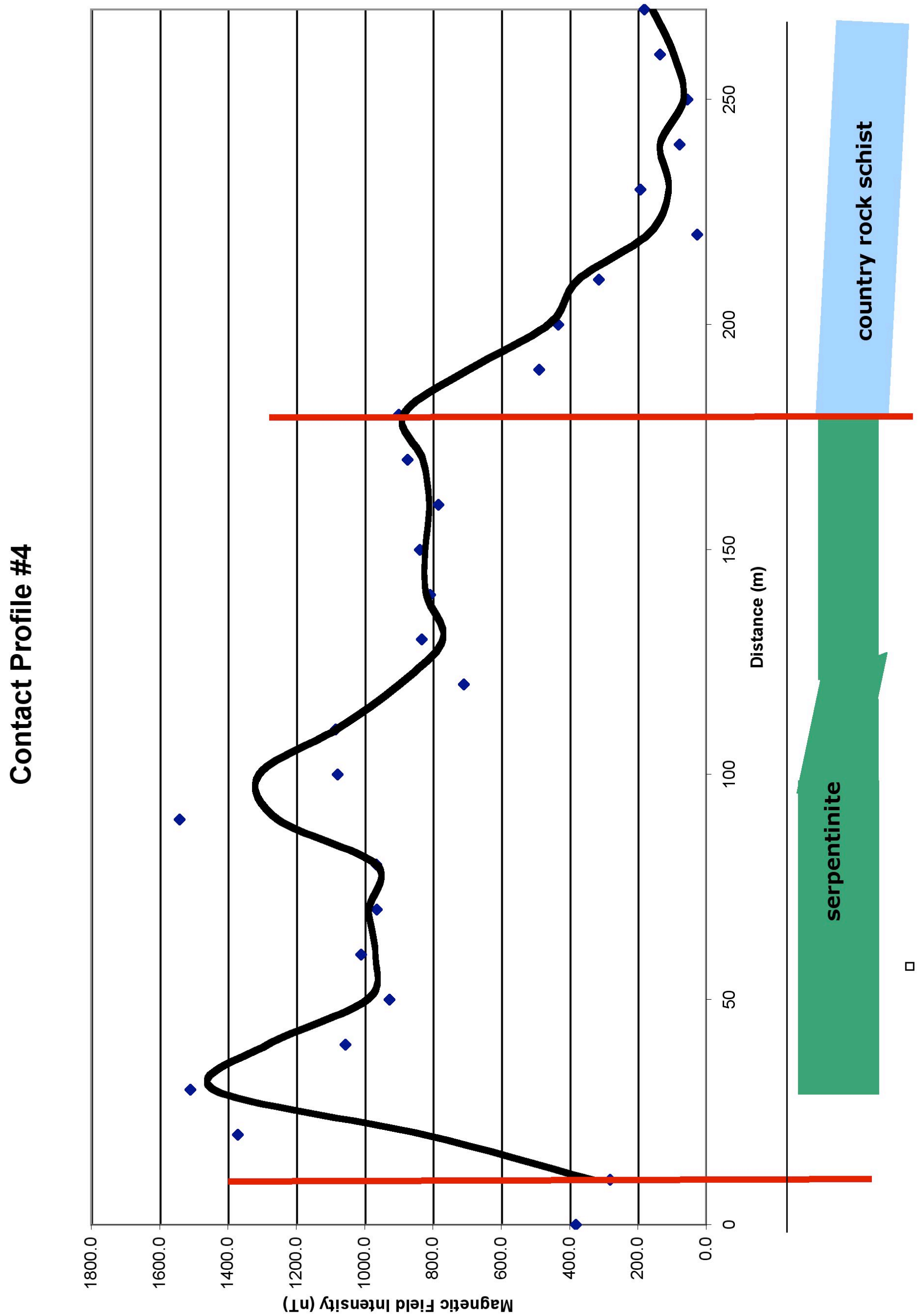

Figure 6. Profile #4 with an approximation of the rock distribution based on magnetic data.

CONCLUSIONS

A magnetic anomaly results solely from a rock's magnetic mineral content. Varying that content has a pronounced effect on a rock's magnetic signature (Breiner, 1973; Telford et al., 1976). The ultramafic rocks of this study have strong magnetic signatures that can be directly related to the magnetite content of the rocks in relation to that of the surrounding schist. Less iron is admitted into the structure of the serpentine and associated magnesian secondary minerals than occurs with the olivine and orthopyroxene of the ultramafic protolith (Moody, 1976). Therefore, during the serpentinization process, the iron released from the olivine forms tiny grains of magnetite. In rocks studied, magnetite occurs as fine dust and as coarser grains formed during late stages of serpentinization (Saad, 1969; Coleman, 1971). The large amount of magnetite in the serpentinite is responsible for the contrast in magnetic reading between the ultramafic rocks and the country rock schist.

Magnetometry data is difficult to interpret because there are so many small heterogeneities. Many of these variations in the data would make it very difficult to determine fault locations mechanically based purely on magnetic field intensity contours. However, in the vicinity of a serpentinite contact, magnetometry data can be used to precisely determine the location of a contact to within three meters or so.

The graphic representations of the contacts approximate the shapes of serpentinites and schists. A gravity survey would have to be undertaken to obtain a better representation of the bodies. The precise shape is not an accurate representation. The actual bodies are likely to be more irregular than is any modeled polygon with sharp angles.

SOURCES CITED

1. Breiner, S., 1973, Applications Manual for Portable Magnetometers. Geometrics, U.S.A., 58 p.
2. Brooks, J.R., 1989, The Industrial Minerals and Rodingite Dikes of the Hunting Hill Serpentinite Mass, Montgomery County, Maryland, July 12, 1989, Field Trip Guidebook T243. American Geophysical Union, Washington, D.C., 5 p.
3. Burch, S.H., 1965, Tectonic emplacement of the Burro Mountain ultramafic body, southern Santa Lucia Range, California: Ph.D. thesis, Stanford University, Stanford, California.
4. Candela, P.A. and Wylie, A.G. 1989, Ultramafite-associated Cu-Fe-Co-Ni-Zn deposits of the Sykesville District, Maryland Piedmont: 28th International Geological Congress Field Trip Guidebook T241, American Geophysical Union, 10 p.
5. Cloos, E., and Cooke, C.W., 1953, Geologic map of Montgomery County and the District of Columbia: Baltimore, Maryland Dept. of Geology, Mines, and Water Resources, scale 1:62,500.
6. Coleman, R.G., 1971, A chemical study of serpentinization; Burro Mountain, California: Journal of Petrology, v.12, p.311-328.
7. Crowley, W.P., 1976, The geology of the crystalline rocks near Baltimore and its bearing on the evolution of the eastern Maryland Piedmont: Maryland Geol. Survey Report of Investigation No. 27, 40p.
8. Dobrin, M.B., 1976, Introduction to Geophysical Prospecting. McGraw-Hill, p.476, 535-546.
9. Drake, A.A., Sinha, A.K., Laird, J., Guy, R.E., 1989, The Taconic Orogen, *in* Hatcher, R.D., Thomas, W.A., and Viele, G.W., eds., The Appalachian-Ouachita Orogen in the United States, The Geology of North America, Vol. F-2, Geological Society of American, Boulder, Colorado, p. 101-177.
10. Fisher, G.W., 1970, The metamorphosed sedimentary rocks along the Potomac River near Washington, D.C., *in* fisher, G.W., Pettijohn, F.J., Reed, C.J. Jr., and Weaver, K.N., eds., Studies of Appalachian geology: central and southern, Intersciences Publishers, New York, New York, p, 299-315.
11. Freeman, M.J., Palmer, D.F., and Heimlich, R.A., 1988, Magnetic Survey of the Western Serpentinite Belt, Northern Harford County, Maryland: Southeastern Geology, v.29, p.103-128.
12. Froelich, A.J., 1975, Bedrock map of Montgomery County, Maryland, U.S. Geological Survey Miscellaneous Investigations Series, Map I-920-D, scale 1:62,500.
13. Gaucher, E.H.S., 1965, Quantitative interpretation of the “Montagne du Sorcier” magnetic anomaly, Chibougamau, Quebec: geophysics, v.30, p. 762-782.
14. Gibson, P.J., 1996, Ground-based magnetic patterns across selected Irish rocks and structures, Irish Journal of Earth Sciences, v.15, p. 129-143.
15. Hildenbrand, T.G., 1985, Rift structures of the Northern Mississippi Embayment from the analysis of gravity and magnetic data. Journal of Geophysical Research, v.90, p. 12607-12622.

16. Hopson, C.A., 1964, The crystalline rocks of Howard and Montgomery Counties, *in* The geology of Howard and Montgomery Counties: Baltimore, Maryland Geol. Survey, p. 27-215.
17. Irwin, W.P., and Bath, G.D., 1962, Magnetic anomalies and ultramafic rocks in northern California: U.S. Geological Survey Professional Paper 450-B, p.65-67.
18. Larrabee, D.M., 1969, Serpentinite and rodingite in the Hunting Hill Quarry, Montgomery County, Maryland: U.S. Geol. Survey Bulletin 1282, 33p.
19. Lee, M.K., 1987, Geophysical investigations in the Strath Halladale-Altnabreac district (northeast Scotland) in relation to radioactive waste disposal, Journal of Geophysical Research, v.92, p. 7807-7819.
20. Linder, D.E., Wylie, A.G., and Candela, P.A., 1992, Mineralogy and origin of the State Line talc deposit, Pennsylvania: Economic Geology, 87. p.1607-1615.
21. Moody, J., 1976, An experimental study on the serpentinization of iron-bearing olivines, Canadian Mineralogist, v.14, p. 462-478.
22. Morgan, B.A., 1977, The Baltimore Complex, Maryland, Pennsylvania and Virginia, *in* Coleman, R.G., and Irwin, W.P., eds., North American Ophiolites: Oregon Department of Geology and Mineral Industries Bulletin, 95, p.41-49.
23. Muller, P.D., Candela, P.A., and Wylie, A., 1989, Liberty Complex: Polygenetic mélange in the central Maryland Piedmont: Geological Society of America Special Paper 228, p. 113-134.
24. Pearre, N.C., and Heyl, A.V., Jr., 1960, Chromite and other mineral deposits in serpentinite rocks of the Piedmont Upland, Maryland, Pennsylvania, and Delaware: U.S. Geol. Survey Bulletin. 1082-K, p.707-833.
25. Saad, A.H., 1969, Magnetic properties of ultramafic rocks from Red mountain. California: Geophysics, v.34, p.974-987.
26. Teleford, W.M., Geldart, L.P., Sheriff, R.E., and Keys, D.A., 1976, Applied Geophysics. Cambridge University Press. p. 105-201.
27. Thompson, G.A., and Robinson, R., 1975, Gravity and magnetic investigations of the Twin Sisters dunite, northern Washington, Geological Society of America Bulletin, v.86, p, 1413-1422.
28. Wyllie, P.J., ed., 1967, Ultramafic and Related Rocks: New York, John Wiley and Sons, 464p.

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HONOR PLEDGE

I pledge on my honor that I have not given or received any unauthorized assistance on this assignment. – Jennifer L. Harvey