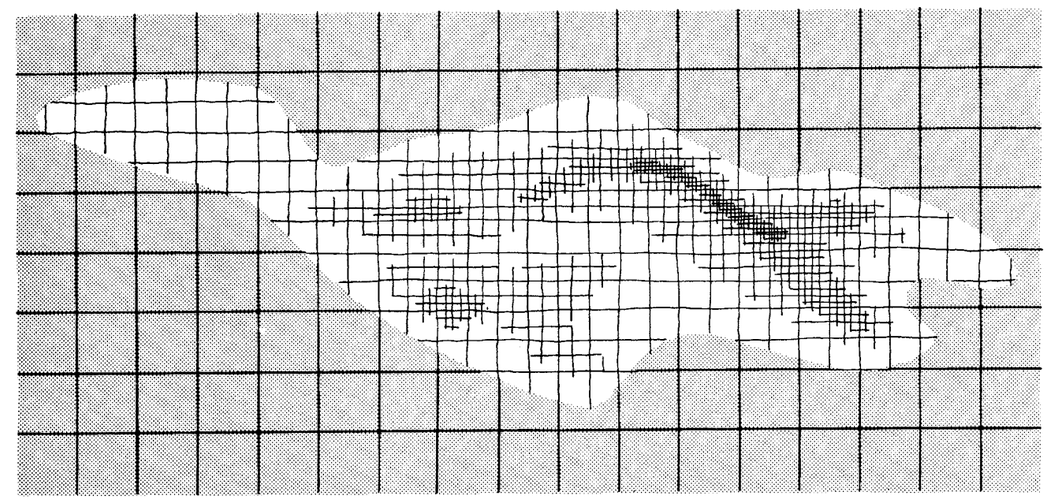
1977 Report of Investigation 16

A Ground Investigation of an Aeromagnetic Anomaly



In North Central Dickinson County, Michigan

Geological Survey Division
Michigan Department of Natural Resources

The Geology Division of the Michigan Department of Natural Resources collects, interprets, and disseminates basic information on the geology and mineral resources of Michigan.

Its activities are guided by public service available to all who are interested in the use or development of our resources, the protection of our environment, and sound land use management.

Geology Division

Report of Investigation 16

A GROUND INVESTIGATION OF AN AEROMAGNETIC ANOMALY IN NORTH CENTRAL DICKINSON COUNTY, MICHIGAN

by
David W. Snider
Geology and Minerals Research Unit

Lansing, Michigan
1977

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PREFACE

In July, 1975, a new unit was created in the Geology Division of the Michigan Department of Natural Resources and titled Geology and Minerals Research Unit. The research unit is part of the Economic and Environmental Geology Section.

The assigned responsibility of the research unit is:

> To conduct field, laboratory and related research oriented toward identifying metallic and nonmetallic mineral resources with the ultimate objective to stimulate exploration and development of these essential minerals of the State. In addition, such investigations will materially benefit effective land-use planning and add to the general geological knowledge of the State.

Pursuant to our assigned responsibilities, potential project areas were compiled and evaluated. Field investigations began in September 1975. The following report is the result of data generated during part of the 1975 field season. This and future reports from the research unit will be released periodically to the public through publication and/or placed on open-file status.

The author wishes to thank Mr. Jerry D. Lewis for his help in gathering field data. I am grateful to members of the Department of Geology at Michigan State University for their help in sample preparation and use of their X-ray equipment. Mr. Gary Aho, Cleveland Cliffs Iron Company, furnished advice and discussion on the interpretive theories of electromagnetic surveys. Mr. Robert C. Reed, Section Chief, suggested the project and provided assistance and guidance in this study.

David W. Snider
Geology & Minerals Research Unit

GEOLOGY DIVISION

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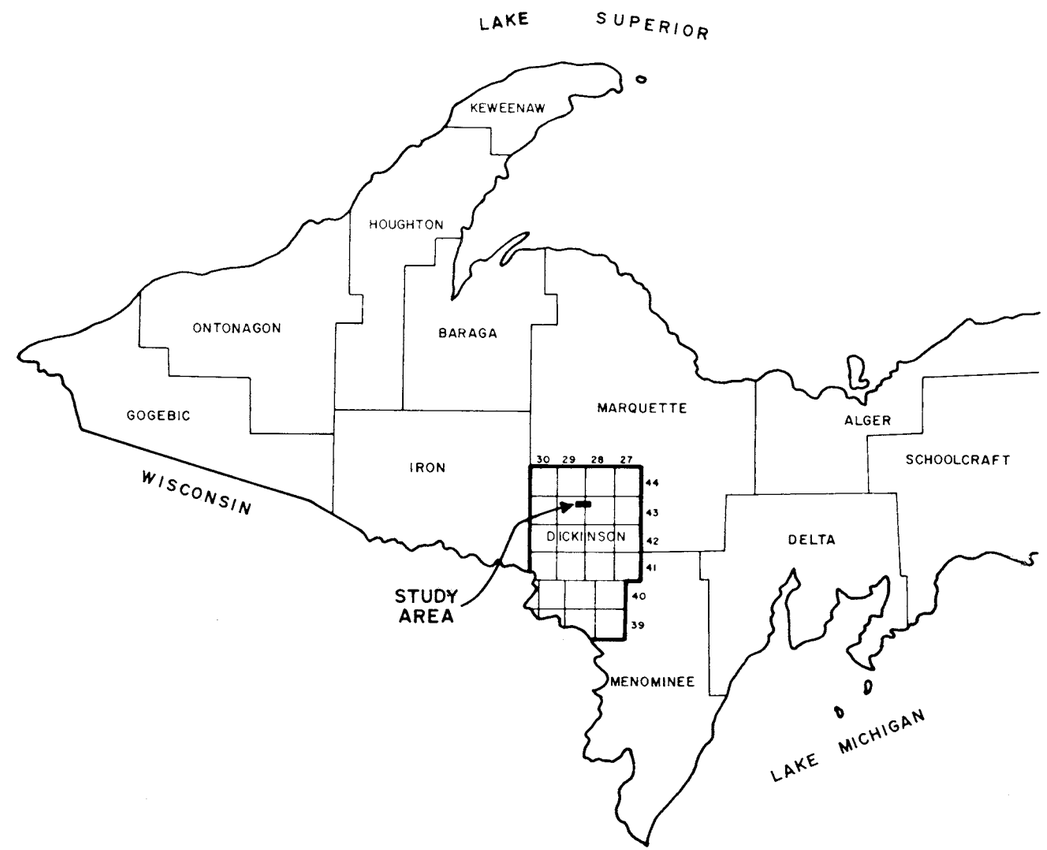

Figure 1 - Index map of the west portion of Northern Michigan showing the area of study.

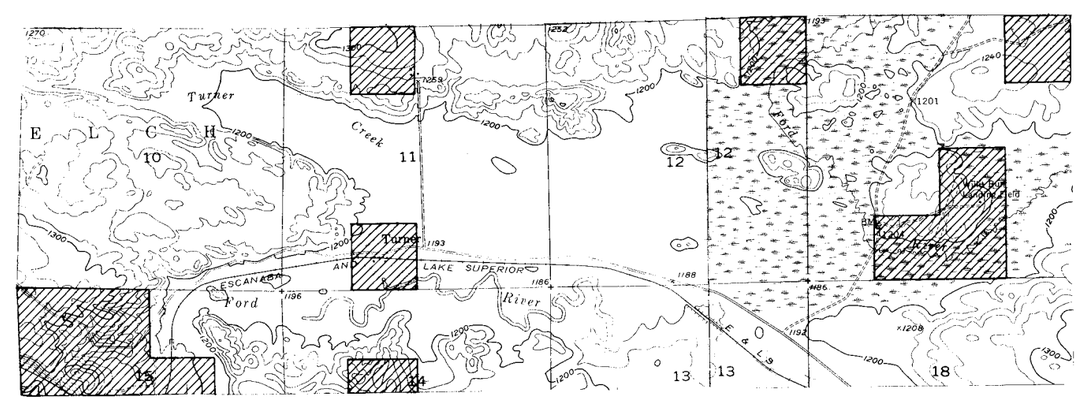

Figure 2 - Local topography and mineral ownership in the project area. Cross-hatched areas denote private ownership; all other areas denote State ownership of mineral rights. (Information from records of the Lands Division, Michigan Department of Natural Resources, January, 1976).

A GROUND INVESTIGATION OF AN AEROMAGNETIC ANOMALY, DICKINSON COUNTY, MICHIGAN

Abstract

During the latter part of September, 1975, the Geology and Minerals Research Unit of the Michigan Geological Survey conducted a ground reconnaissance investigation of a small, closed aeromagnetic anomaly in north central Dickinson County. The purpose of the study was two-fold: (1) to determine what geologic feature caused the aeromagnetic anomaly, and (2) to investigate the mineral resource potential associated with the anomaly. Nearly all of the closed anomaly lies within an east-west trending swamp covering an area of nearly three square miles.

The method of field investigation consisted of geologic mapping, sampling outcrops for petrographic and chemical analyses, and ground magnetic and VLF-EM surveys.

The combined results of the study indicate that the closed, airborne anomaly is caused by the near surface occurrence of serpentinized peridotite that contains an appreciable amount of magnetite. This ultramafic body underlies most of the swamp area, strikes N75°-80°W and apparently dips to the south.

The objective of this report is to record the occurrence of the previously unidentified ultramafic rock body and to describe some of its chemical and geophysical parameters.

The results of the chemical analyses of rock specimens collected and analyzed show no anomalous Ni-Cu-Co values.

Most of the major VLF-EM anomalies generated in the project area were correlated with serpentinized peridotite and show a reverse cross-over anomaly form. The reverse crossovers, or negative in-phase anomalies, were interpreted as being the VLF-EM instrument response to the magnetic permeability of the rock rather than its conductivity. It is therefore concluded that the VLF-EM survey neither confirmed nor denied the presence of any conductive sulfide mineralization associated with the serpentinized ultramafic rock.

This occurrence of ultramafic rock should be investigated in more detail by others, using more discriminating EM methods which might better determine its economic potential.

INTRODUCTION

Location

The area of this investigation is in north-central Dickinson County (figure 1), sections 10, 11 and 12, the northern portions of sections 13 and 14, T43N, R29W and section 7, T43N, R28W.

Topography and Drainage

The regional topography in the area is relatively low-lying, often swampy valleys with adjacent hills, some of which are locally rugged with 100-200 feet of relief.

The project area is confined to a swampy low area with an average elevation of about 1200 feet. The hills and knobs within the swamp area generally correspond to outcrops of bedrock or are positive areas with bedrock cores.

The main streams in the area are the Ford River, the North Branch Ford River, and Turner Creek. The drainage pattern trends generally east. Stream velocities in the area are rather low because there is an average drop in elevation of only about 8 feet per mile.

The project area lies in the Sturgeon

River State Forest; surface and mineral rights, except for a few isolated areas, are owned by the State (figure 2).

Previous Work

No study has been published that deals solely with the closed aeromagnetic anomaly located in section 7, T43N, R28W and sections 10, 11 and 12, T43N, R29W. The area, however, has been briefly referred to in portions of other major works by various authors: Barrett, L. P. (1927); Wier, K. L., Balsley, J. R., and Pratt, W. P. (1953); Case, J. E., and Gair, J. G., (1965); Kruger, C. L., and Balsley, J. R. (1967). In general, these authors attribute the anomalous magnetic activity in the investigated area to local occurrences of greenstones.

Purpose and Scope of the Investigation

The purpose of this study is two-fold: (1) to investigate the geologic feature causing an isolated airborne magnetic anomaly, and (2) to assess any mineral resource potential associated with the anomaly.

Because this investigation is a reconnaissance study, various geologic interpretations based upon indirect evidence should be considered tentative and subject to change.

Field Methods

The field work on which this report is based was completed during the latter part of September, 1975, and lasted approximately ten days. Because the airborne magnetic anomaly displayed a general east-west trend, traverse lines were laid out in a north-south direction not only to cover most of the airborne anomaly but also to intersect known outcrop areas located by R. C. Reed during previous field seasons.

Rock exposures were scarce, but where outcrops existed the rock was described, samples were taken, the areal extent was plotted on the map, and joint lineation directions were recorded. The outcrop data, along with geophysical data, was then plotted on a base map to construct a generalized geologic map.

Ground magnetic investigations were conducted along six generally north-south lines (figure 14). It was hoped that by comparing the more precise anomalies generated by the ground magnetic survey with the outcrops in the area, the cause of the airborne magnetic anomaly could be determined.

A VLF-EM survey was also conducted to measure the electromagnetic response of underlying geologic features and to identify any potential mineral-bearing horizons.

Laboratory Methods

The petrographic observations in this report are based upon examination of thin sections of sampled rock exposures. The samples were observed with transmitted and reflected light. Grain size determinations were made through the use of a stage micrometer, and volume-percent mineralogy was determined through statistical point counting. Plagioclase determinations were made on albite twins using the Michel-Levy method, (Kerr, 1959).

Most of the rock samples processed for thin sections were also submitted to a commercial laboratory for chemical analysis. Seventeen samples were quantitatively analyzed for copper, nickel and cobalt. Four of the samples were also analyzed for ten major oxides as well as qualitative spectrographic analysis.

THE TARGET AEROMAGNETIC ANOMALY

The aeromagnetic anomaly (figure 3) displays distinct closure and has a relatively high intensity which reaches maximum values of more than 2,500 gammas. There is also a less intense linear magnetic trend extending from the main closure striking S 80° E. The western end of this linear feature appears to follow the course of Turner Creek in the northern half of section 10, T43N, R29W. The feature trends eastward along a portion of the creek valley through the main anomaly and continues on through parts of sections 8, 16, 15, 14 and 13, T43N, R28W, and sections 18 and 17, T43N, R27W (figure 4).

It is suggested that another, less distinct linear magnetic trend may exist, beginning within the main closed anomaly and extending southeast at an angle of about S 40 - 50° E. Both of the less-distinct linear trends may be the result of local faulting.

Although the entire anomaly has a strike length of more than 11 miles, time and allotted resources permitted the ground investigation of only the more intense, closed portion of the anomaly.

REGIONAL GEOLOGIC SETTING

The project area is located on the northern flank of what is referred to by James and Pettijohn, (1961) as the Sagola Basin (figure 5). As indicated on figure 5 the area southwest of the study area is underlain by Middle Precambrian iron-formation (black), sedimentary and volcanic rocks (white). The stippled areas to the northeast are composed of Lower

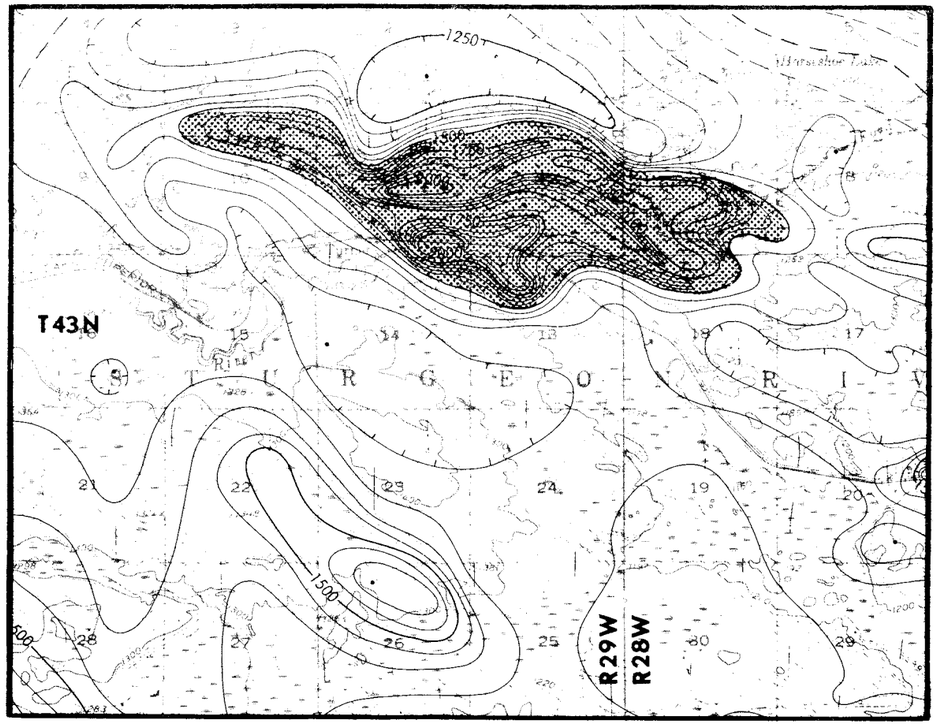

Figure 3 - A portion of U. S. Geological Survey Map GP-610 (1967) showing the location of the aeromagnetic anomaly (stippled area) that was the basis of this investigation. (Kruger, C. L., and Balsley, J. R., 1967).

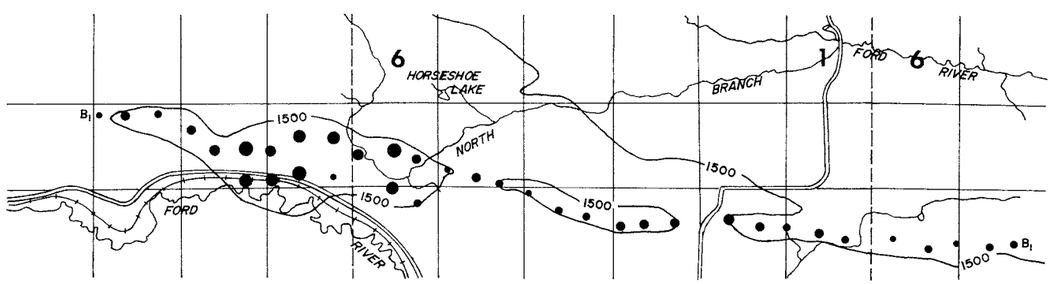

Figure 4 - A portion of U. S. Geological Survey Map GP-115 (1953) showing the location of Anomaly B_1, the western portion of which is also shown in Figure 3. The dots indicate the position of aeromagnetic anomaly peaks in the northern three tiers of sections in R27, 28 and 29W, T43N. (Wier, K. L., Balsley, J. R., and Pratt, W. P., 1953).

Precambrian igneous and metamorphic rocks. The area shaded in gray indicates Paleozoic sedimentary rock.

LOCAL GEOLOGY

The results of outcrop sampling in the project area as well as information compiled by L. P. Barrett (1927) are plotted on a general geologic map (figure 6). The information compiled by Barrett is included only to show the possible relationships of the sampled areas with other nearby rock types, and will not be discussed in detail.

The sampled outcrops indicate the presence of two rock types encompassed by the aeromagnetic anomaly. The first is a medium to fine-grained serpentinized ultramafic rock locally rich in magnetite; the second is rock of granitic composition varying in texture from gneissic to hypidiomorphic-granular to, locally, pegmatitic.

Metasedimentary rocks indicated in the southwest portion of the mapped area consist of slates, dolomite, and quartzites (Barrett, 1927), and apparently dip south to southwest.

Serpentinized Ultramafic Rock

Distribution

The apparent areal extent of the ultramafic rock is shown on figure 6. The outcrop areas are outlined and sample locations are plotted on the map. Geologic and ground and airborne magnetic evidence indicate that the ultramafic unit strikes approximately N 70° - 80° W and apparently dips to the south. The apparent surface width varies from about 1,000 feet in sections 7 and 10, to nearly 4,000 feet in parts of sections 11 and 12.

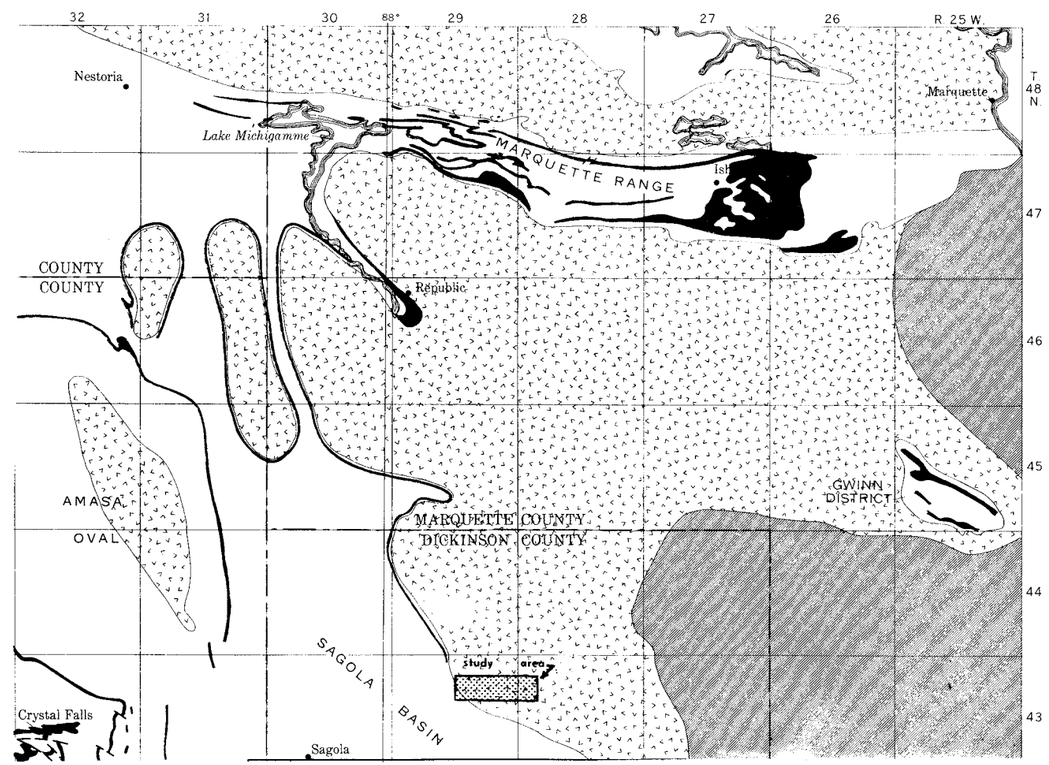

Figure 5 - Generalized geologic map of parts of Baraga, Iron, Marquette and Dickinson counties, Michigan, indicating the area of study. (James and Pettijohn, plate 2, 1961).

Description

The ultramafic rock has been extensively serpentinized and further altered by carbonate-rich fluids migrating through localized fracture systems. The serpentinization and the CO_2-rich fluid alteration have resulted in complete destruction of the original minerals. The resulting rock is composed principally of minerals belonging to the serpentine group with varying amounts of chlorite, sericite, carbonate and opaque minerals. Table 1 lists the volume-percent mineralogy of the serpentinized ultramafic rock.

Serpentine Minerals. The most common serpentine mineral occurring in the ultramafic rocks is antigorite. The antigorite varies in form from a fine-grained fibrous aggregate mass (figure 7) to bastite, (figure 8). Chrysotile, an asbestiform serpentine mineral, is present in trace amounts and is relatively unaltered. The unaltered chrysotile is found in small veinlets or fracture fillings averaging about 1.0 mm in width. There is considerable evidence, however, suggesting that more chrysotile existed than is presently indicated. The other occurrences of apparent asbestos noticeable in the hand sample (i.e. vein width of 5 to 8 mm) were restricted to fracture-fillings in areas of severe shearing. After microscopic observation, however, it was determined that most of the chrysotile had been altered to carbonate, chlorite and sericite. The carbonate replacement preserved the asbestiform texture of the original chrysotile. It may be reasonable to assume that the carbonate replacement of the asbestos is a surface feature and unaltered chrysotile in the 5 to 8 mm vein widths may exist at depth.

The relatively large amounts of antigorite as well as relic outlines of pyroxene and olivine defined by fine grained magnetite, suggest that the original rock was certainly ultramafic, and most likely a peridotite.

Chlorite. Nearly all occurrences of chlorite minerals as well as carbonate and sericite are apparently alteration products of serpentine. The amount of chlorite varied from a trace to 41 percent. Chlorite appeared to be directly related to the intensity of shearing present in the outcrop. This indicates that the fluids responsible for the alteration of serpentine were introduced via the shear-controlled conduit system.

Carbonate. Most of the carbonate minerals found in samples of serpentinized ultramafic are the result of carbonate-precipitating fluids which entered the rock after fracturing. Figure 9 is a photomicrograph of fracture-filling material composed of dolomite and minor amounts of chlorite. The carbonate species were determined by X-ray diffraction. The rock containing this fracture-filling material was not only in an area of severe shearing which resulted in chloritization of the serpentine minerals, but also contained the highest percentage of carbonate minerals disseminated throughout the specimens, suggesting a

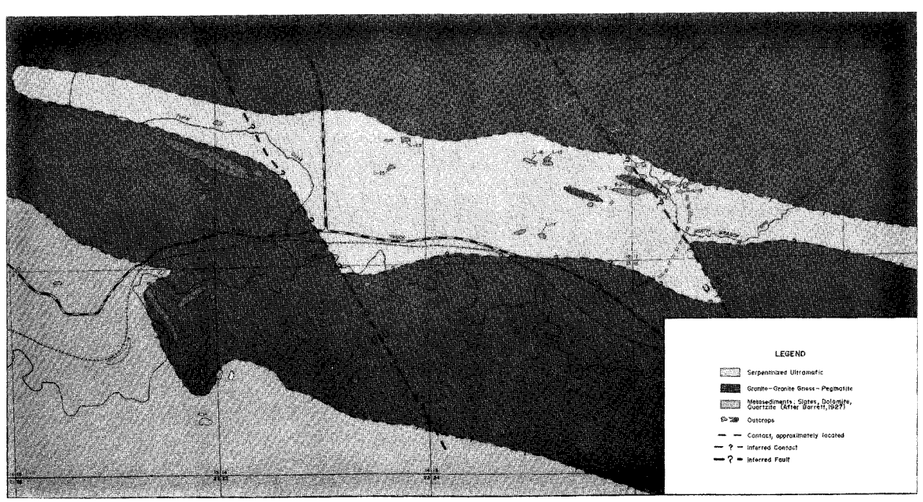

Figure 6 - Generalized geologic map of the project area.

Figure 7 - Photomicrograph of fine-grained aggregate antigorite XN.

Figure 8 - Photomicrograph of bastite form of antigorite XN.

Figure 9 - Photomicrograph of fracture-filling material composed of carbonate (white to gray) and chlorite (black) XN.

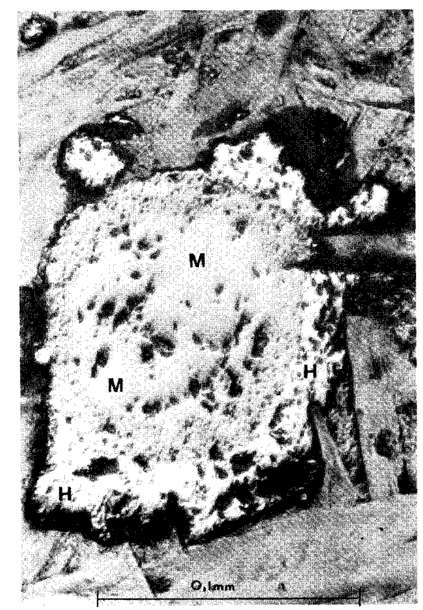

Figure 10 - Photomicrograph of magnetite (M) with rim of hematite (H) reflected light.

minor metasomatic effect. Carbonate mineralization was also found in small vugs and locally in a series of parallel microfractures spaced about 3 mm apart.

Sericite. The distribution of sericite is also restricted to samples of ultramafic rock that have been intensely fractured or sheared. The amount of sericite varied from a trace to nearly 50 percent. Sericite appears to be an alteration product of chlorite; the samples containing the most sericite also contained appreciable chlorite.

Opaques. The amount of opaque minerals varies from five percent to more than 25 percent. A large percentage exists as small subhedral grains 0.2 mm to 1.0 mm in diameter. The opaques are distributed along fracture and cleavage planes as well as around grain boundaries of what evidently were the parent mafic minerals. A second stage of opaque mineral formation appears to be related to the carbonate-precipitating fluids. This later stage of opaque mineralization is restricted to small fractures within the rock usually associated with carbonate minerals and, to a lesser degree, chlorites.

The most abundant variety of opaque minerals is magnetite. Magnetite locally contains inclusions of ilmenite or leucoxene. The magnetite displays varying stages of oxidation to hematite (figure 10). The presence of magnetite in greater or lesser amounts causes hand samples to be magnetized to varying degrees. Field work on various outcrops composed of the more magnetic rock disclosed that direct measurements of joint or fracture lineation with the magnetic compass were impossible owing to deflections of the compass needle.

There is no doubt that the near-surface occurrence of this locally magnetite-rich serpentinized ultramafic rock caused the main aeromagnetic anomaly upon which this report is based.

Chemical Analysis

Fourteen samples of serpentinized ultramafic rock were submitted to a commercial laboratory for atomic absorption analysis for copper, nickel and cobalt. The results are listed in Table 2. Except for sample No. L-25-2 (fracture-filling material), no anomalous Cu-Ni-Co values were reported.

The results of the whole rock analyses are presented in Table 3. All values are consistent with norms for serpentine as reported by Johnson (1975). There is a slight increase, however, in the CaO content in sample No. L-25-1. This increase is most likely the result of carbonate-precipitating fluids that locally moved through the fracture system.

The results of the qualitative spectrographic analyses of four samples of ultramafic rock are listed in Table 4. The calcium content in L-25-1, as mentioned previously, reflects local CO_2 metasomatism because the outcrop is severely sheared and contains localized carbonate-chlorite fracture-filling material.

Granitic Rock

Distribution

As indicated on the generalized geologic map, the east-west trending serpentinized ultramafic is bounded to the north and south by masses of granitic rocks. These rocks generally outcrop in the higher areas bordering the swamp.

The granite in the project area was mapped on the criterion of general composition rather than texture or age. Considering the scope and purpose of this investigation, there was no attempt to correlate the granitic rock in the project area with other mapped areas to the south.

Although granite gneiss was found locally throughout the area mapped as "granitic", there was a noticeable concentration of gneissic textures in the southern two-thirds of section 10 which extended into the southwest quarter of section 11. This rock unit also forms the linear highland area immediately south of the swamp in sections 10 and 11 with a strike S75°E. The strike of the highland is coincident with the lineation of the minerals in the gneissic rock, as delineated by bands of biotite. The granite gneiss body in sections 10 and 11 is cut locally by small pegmatites which also strike generally S75°E. The pegmatite bodies vary in width from one to three feet.

Description

Except for the previously mentioned localized granite gneiss, the remaining area mapped as granitic rock varies from gneissic to granitoid.

The amount of quartz in the granitic rock varies from 15 to 34 percent and typically displays internal fracturing. The average grain size is about 2 to 3 mm in diameter. The amount of K-feldspar varies from 46 to 80 percent with microcline being the most common variety. The amount of plagioclase varies from 2 to 16 percent and is in the oligoclase composition range. The accessory minerals typically include biotite, trace amounts of zircon and varying amounts of sericite and

Minerals	Sample Number												
	L-23-1	L-24-1	L-25-1	L-25-2*	L-15-1	L-16-1	S-2-1	L-3	L-3A	L-18-1	L-19-1	L-19-2	L-20-1
Serpentine	85	77	62	3	85	77	66	82	73	31	78	4	25
Chlorite			7	7						41		25	34
Opaques	14	22	5	4	15	23	22	14	27	21	16	10	15
Carbonate	1	1	26	(Dolo.) 86			12	4	Tr		5	11	1
Quartz									Tr				
Muscovite, including sericite										7	1	49	25

* fracture-filling material

Table 1 - Volume-percent mineralogy of the sampled serpentinized ultramafic rock.

Sample No.	Rock Type	ppm Copper	ppm Nickel	ppm Cobalt
L-3	Serpentinized Ultramafic	-5	1600	150
L-3A	Serpentinized Ultramafic	-5	1500	130
L-15	Serpentinized Ultramafic	-5	1800	145
L-16	Serpentinized Ultramafic	-5	1700	125
L-17	Serpentinized Ultramafic	-5	1700	135
L-18	Serpentinized Ultramafic	-5	1400	95
L-19-1	Serpentinized Ultramafic	5	1600	135
L-19-2	Serpentinized Ultramafic	-5	1200	140
L-20	Serpentinized Ultramafic	-5	1200	100
L-23	Serpentinized Ultramafic	-5	1300	95
L-24	Serpentinized Ultramafic	-5	1700	145
L-25-1	Serpentinized Ultramafic	5	1300	140
L-25-2	Carbonate fracture filling material	5	330	70
S-2-1	Serpentinized Ultramafic	5	1700	140

Table 2 - Atomic absorption analysis for copper, nickel and cobalt in the serpentinized ultramafic rock.

Sample No.	Rock Type	% P_2O_5	% TiO_2	% Loss on Ignition	% SiO_2	% Al_2O_3	% Manganese	% Magnesium	% CaO	% K_2O	% Na_2O	% Fe_2O_3	Total
L - 15	Serpentinized Ultramafic	-.03	.14	9.41	41.1	2.5	.125	31.5	.11	.063	.16	10.4	96
L - 17	Serpentinized Ultramafic	-.03	.11	10.28	41.1	2.6	.088	32.3	.043	.004	.006	10.9	97.5
L - 24	Serpentinized Ultramafic	-.03	.14	10.28	40.8	2.1	.13	33.2	.18	.002	.004	10.9	98
L - 25-1	Serpentinized Ultramafic	-.03	.11	8.90	40.5	2.9	.12	30.7	.81	.005	.011	11.0	95

Table 3 - Results of the whole rock analysis of four samples of serpentinized ultramafic rock.

clay minerals. The volume-percent mineralogy is listed in Table 5.

Locally, the granitic rocks, like the ultramafic rocks, have been sheared or fractured. Microscopically, the fracturing resulted in various crushed and fractured grains, deformed twins in plagioclase lathes, and bent or otherwise deformed biotite plates. Thin sections from highly fractured outcrops show a slight increase in the amount of carbonate minerals.

Chemical Analyses

Three samples of granitic rock were analyzed for selected trace elements by atomic absorption methods. No anomalous values were reported. The results of the analyses are listed in Table 6.

Metadiabase

Specimens of metadiabase were obtained by R. C. Reed on previous trips to the area. The area sampled is located in the NE¼ SW¼ SE¼ NE¼ of section 11, T43N, R29W. No other outcrops sampled by the writer contained diabasic rock. Although no additional metadiabase was located in the course of the field work associated with this reconnaissance study, more detailed investigations might reveal further occurrences.

Two samples of metadiabase from the same general location were submitted to the writer. They were similar in texture and mineralogy. The texture is generally ophitic with lathes of plagioclase (AN $_{40-60}$) embedded in, and, locally, partially enclosing anhedral masses of green hornblende. The hornblende is most likely an alteration product of the original pyroxene. Individual plagioclase lathes average about 0.5 mm in width and 2.0 mm in length, appear to be zoned, and are about 50 percent altered to sericite. The relative abundance of the minerals in volume-percent is as follows:

green hornblende - 49%
plagioclase 36%
biotite 6%
minor amounts of leucoxene, muscovite, quartz and opaques.

Sample No.	Rock Type	(+1%) Major	(.01% to 1%) Minor	(less than .01%) Trace
L - 15	Serpentinized Ultramafic	Aluminum (low) Iron Magnesium Silicon	Calcium Chromium Manganese Nickel Potassium Sodium	Boron Cobalt Copper Lead Titanium Zinc
L - 17	Serpentinized Ultramafic	Aluminum Iron Magnesium Silicon	Calcium Chromium Manganese Nickel Potassium	Boron Cobalt Copper Lead Titanium Vanadium Zinc
L - 24	Serpentinized Ultramafic	Aluminum Iron Magnesium	Calcium Chromium Manganese	Boron Cobalt Copper Lead Titanium Vanadium Zinc
L - 25 - 1	Serpentinized Ultramafic	Aluminum Calcium Iron Magnesium Silicon	Chromium Manganese Nickel Potassium	Boron Cobalt Copper Lead Titanium Vanadium Zinc

Table 4 - Qualitative Spectrographic Analyses.

Minerals	Sample number and rock type				
	L-9-1 Crush Breccia Pegmatite	L-10-1 Granite Gneiss	L-11-1 Granite Gneiss	S-2-2 Granite	L-22-1 Pegmatite
Quartz	5	33	34	29	15
K-feldspar	65	17	46	58	80
Plagioclase	7(Olig.)		2(Olig.?)	2(Olig.?)	
Biotite	14(Green)	13	4		
Muscovite (including sericite)		29	Tr	11	3
Zircon	Tr	Tr			
Carbonate	9	2			
Opaques	Tr	Tr			
Chlorite			Tr		

Table 5 - Volume percent mineralogy of granitic rocks. (Tr = less than 1%)

Element (ppm)	Sample number and rock type		
	L-7 Granite	L-8 Smokey Quartz (Vein)	L-9 Granite (Pegmatite)
Copper	-5	---	5
Lead	--	---	10
Zinc	--	---	35
Molybdenum	--	---	--
U_3O_8	--	-10	--
Gold	ND	ND	--
Silver	-1	-1	--
Nickel	--	---	10

Table 6 - Atomic absorption analyses of three samples of granitic and related rock.

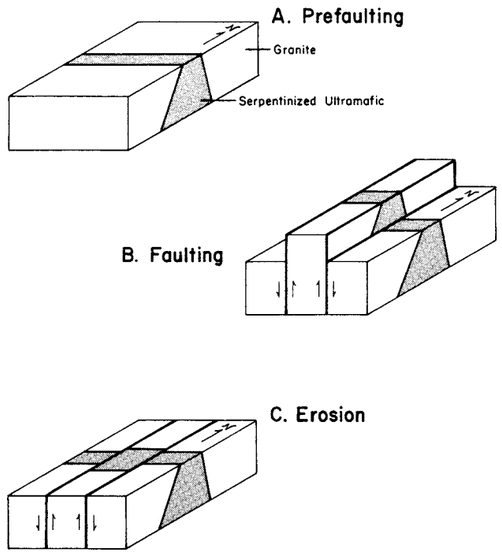

Figure 11 - Sketch illustrating one possible mechanism of movement that produced an apparent local widening of the surface distribution of the serpentinized ultramafic rock in the project area.

Unlike the specimens of serpentinized ultramafic rock, the hand samples of diabase generated no response from a hand-held magnet.

Structure

The eastern portion of the investigated aeromagnetic anomaly extends an additional seven miles, terminated by the map boundary (figure 4). This anomaly extension is assumed to be caused by a similar extension of the ultramafic body. The eastern extension, as well as perhaps a slight westward extension, has an apparent anomaly width of only about 1,000 feet, whereas the width of the main closed portion of the anomaly varies from 3,000 to 4,000 feet.

In an attempt to explain the apparent widening, various structural models were applied to the area. A structural model that seemed to present the most reasonable explanation was one that illustrated the effects of a faulted section which increases in thickness with depth and dips to the south. Figure 11 is a sketch of such a model.

Although the model is simplified, it illustrates a possible mechanism which could result in a surface distribution of ultramafic rock similar to that in the project area. It also suggests the possibility that the ultramafic body is substantially thicker at depth. This interpretation concerning the subsurface distribution of ultramafic rock is purely speculative and is offered here only as one possible interpretation.

Secondary Evidence Suggesting Faulting

Although no direct evidence of faulting was observed (i.e. actual displacement of some contiguous rock unit), various secondary features in the area tend to suggest faulting. The first is the relatively wide, linear aeromagnetic anomaly extending from the main closed anomaly. This magnetic trend extends southeast at an angle of about S40° - 50°E. The extension is most noticeable in the northwest quarter of section 13, T43N, R29W (figure 3) and generally follows the course of a low swampy area which is part of the Ford River Valley. This trend is located mainly within portions of sections 19, 28, 29, 33, and 34, T43N, R28W. It is suggested that this anomaly pattern may indicate a fault or fault zone striking generally S40° - 50°E.

A study of the direction and intensity of shear patterns also suggests some faulting. The ultramafic and granitic rock commonly displayed evidence of shearing. However, the intensity of the shearing varied throughout the area. Shearing resulted in fractured blocks of rock ranging in size from about 30 cm x 20 cm in areas of moderate shearing, to rhombic blocks 10 cm x 6 cm in severely sheared areas. Severely sheared areas were generally restricted to outcrops of serpentinized ultramafic rock. Figure 12 shows the results of 168 measurements of shear fracture directions. Although the pattern is somewhat cluttered, one fracture direction is clearly dominant over the others. Hills (1963), among others, has shown that the most strongly developed shear plane often indicates faulting in that direction; the trend, in this case, is again S40° - 50°E.

Inasmuch as the local widening of the serpentinized ultramafic rock is confined to a swamp, a regional study of total surface water occurrences was conducted under the hypothesis that there may be some positive correlations between bedrock lineaments and the distribution of swamps, streams, etc. The study was relatively elementary and consisted of shading in all areas of swamps, streams and lakes found in the Ralph 15' quadrangle. Figure 13 shows the results of this compilation. The center of the project area is located five miles east of the western map border and 9.5 miles north of the south border. There appears to be, among others, a rather strongly defined regional linear that extends out from the swamp of the project area in a southeasterly direction. It is suggested that this linear as defined by swamp and stream trends may be a surface indication of faulting.

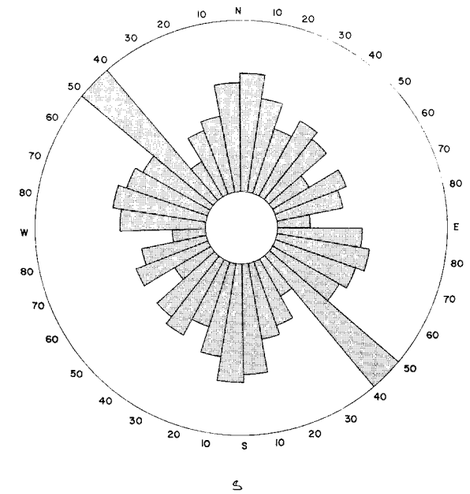

Figure 12 - Fracture-lineation pattern observed on outcrops in the project area. (168 readings)

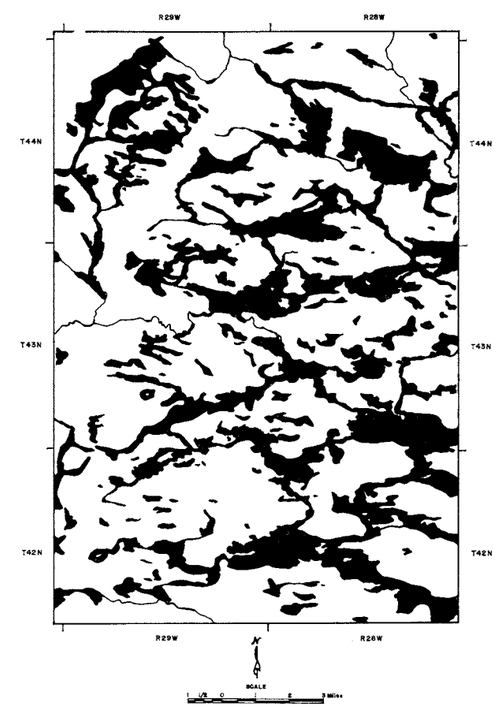

Figure 13 - Distribution of swamps, streams and lakes in the Ralph 15-minute quadrangle.

The prediction of faulting by this method is admittedly highly speculative, and is included only to suggest the possibility that, in this case, bedrock lineaments might be expressed at the surface through surface water distribution patterns.

Metamorphism

The mineral assemblages associated with the granitic and ultramafic rock indicate a metamorphic grade characteristic of the Greenschist Facies (Hietanen, 1967).

GROUND GEOPHYSICAL INVESTIGATIONS

Both ground magnetic surveys and VLF-EM surveys were conducted on the same grid. The gravel road extending east-west through the southern part of the project area was selected as the base line. Six lines were surveyed northward from the base line, and traverses were made along those lines for distances of 3,000 to 4,500 feet (figure 14). Because the survey was for reconnaissance purposes, the lines were spaced so they would intersect outcrop areas as well as generally cover the aerial distribution of the anomaly. Stations were located every 100 feet. Geophysical and geological observations were recorded along lines C, CX, D, E, F and G. Although line G is not in a direct north-south direction, all instrument readings were taken facing north, and the resulting data is correlative with the other lines.

Magnetics

The instrument used in the ground magnetic field with a sensitivity of ± gamma throughout its range of 20,000 to 90,000 gammas. Readings were taken facing north at 100-foot stations along the survey lines.

Depth estimates for the magnetic bodies were calculated by using the half-width rule as applied to the profile of the narrow dike model (line of monopoles) (Breiner, 1973). Nearly all large magnetic anomalies indicated that the magnetic bodies exist at depths of 100 feet or less. The profiles indicate an apparent south dip.

The results of the magnetic survey are plotted on consecutive profiles (figures 15, 16, and 17) and on a map of the area (figure 18). They clearly indicate a direct correlation between high magnetic readings and outcrops of serpentinized ultramafic rock.

The main magnetic feature in the area is the linear magnetic trend striking N70° - 80°W. This feature probably delineates the magnetic-rich portion of the ultramafic body. The

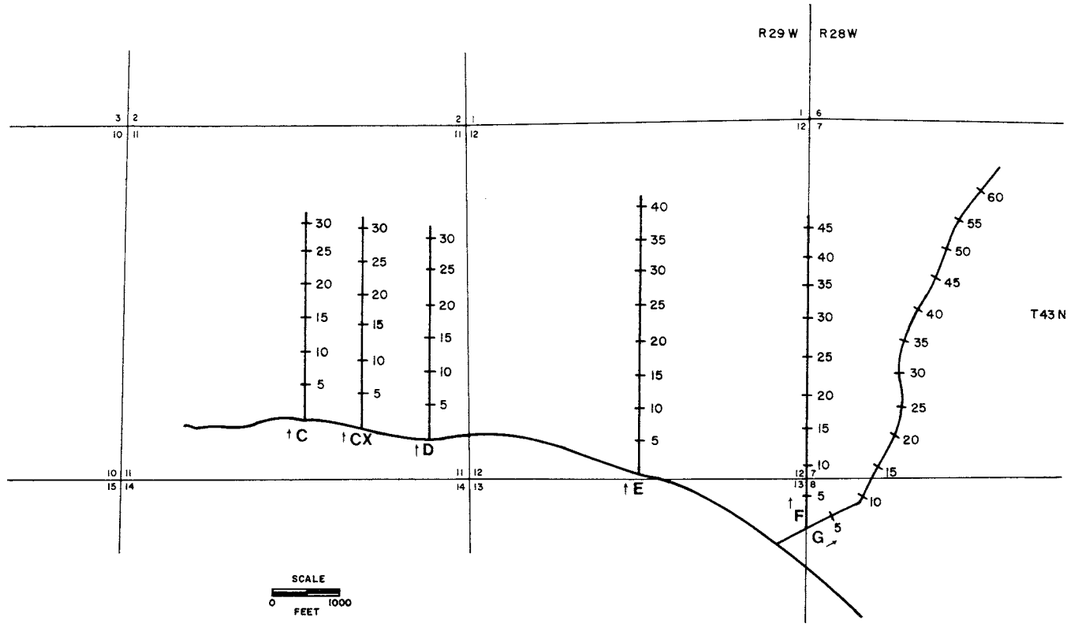

Figure 14 - Map showing spacing of geophysical lines.

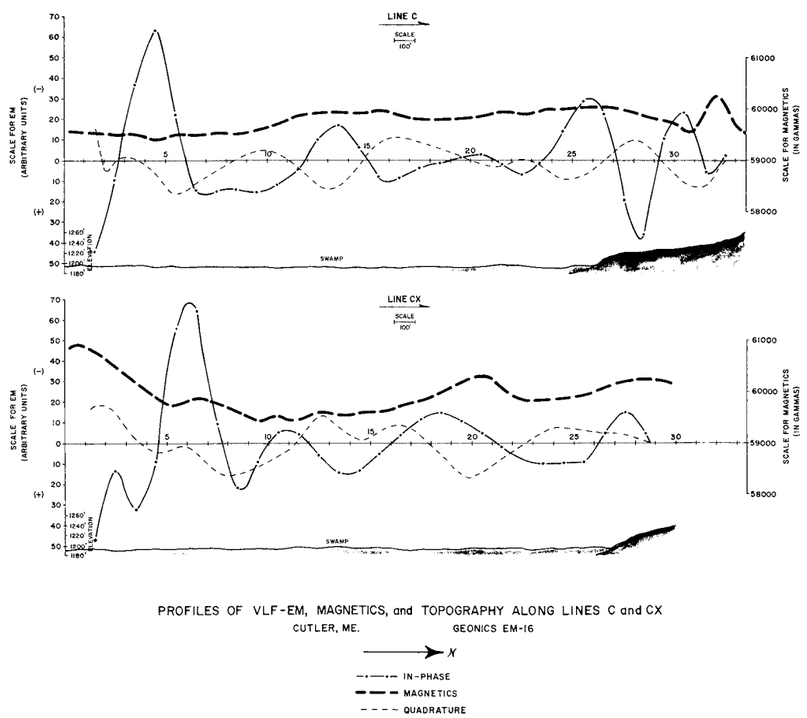

Figure 15 - Profiles of VLF-EM (filtered values), magnetics and topography along lines C and CX. (VLF transmitter, NAA, Cutler, Me., 17.8 kHz, 1,000 kw.)

magnetic pattern is interrupted in the eastern half of section 11, and it is suggested that this interruption is caused by faulting in the immediate area.

The relatively isolated anomaly located in the center of the southern portion of section 12 is also related to an outcrop of serpentinized ultramafic rock. The small northwesterly trend near the four-corners area of sections 12, 7, 13 and 18 is interpreted as being related to a fault striking in the same direction as that in the eastern part of section 11.

A rather strong local magnetic reversal appears at a point 2,500 feet north along line E. The cause of this reversal is unexplained at this time. The outcrop corresponding to the reversal area was sampled, but analyses of the samples yielded no enlightening data. Further investigation of this anomalous feature is needed to understand the cause of the reversal.

VLF-EM

The VLF-EM survey was run concurrently with ground magnetic survey. As was the case with the magnetics, stations were located at intervals of 100 feet along lines C, CS, D, E, F and G. All readings were taken facing north.

The data generated by the VLF-EM Unit were plotted initially in the form of raw profiles. For this report however, the VLF-EM in-phase data has been filtered mathematically using a slight modification of Fraser's filter process (1969). The filter process essentially changes the form of the VLF-EM profiles from antisymmetric to symmetric. The resulting filtered profile can more easily be compared to the magnetic profile.

The purpose of the VLF-EM survey was to attempt to locate any buried, conductive sulfide mineralization which might be associated with the ultramafic body.

The principle of the VLF-EM system,

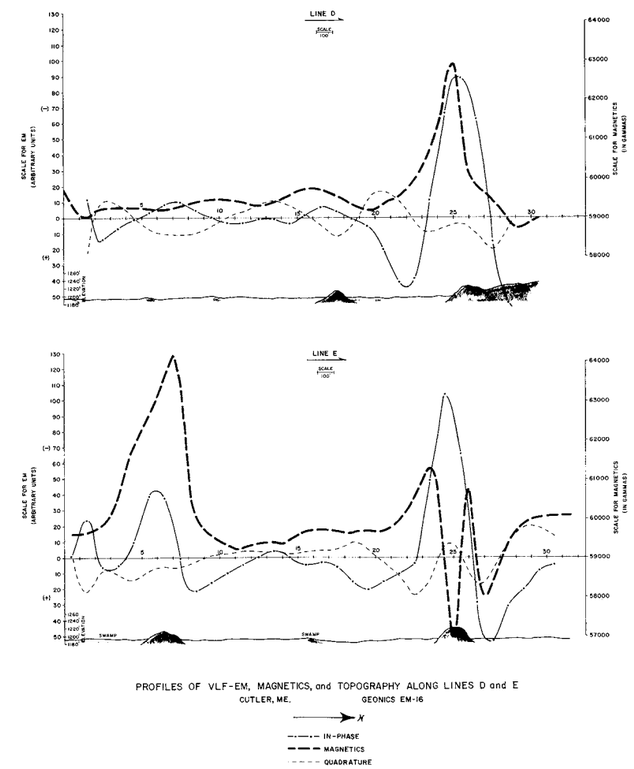

Figure 16 - Profiles of VLF-EM (filtered values), magnetics and topography along lines D and E. (VLF transmitter, NAA, Cutler, Me., 17.8 kHz, 1,000 kw.)

simply stated, is as follows:

> Several VLF-transmitting stations exist throughout the world, used primarily for military communication purposes. The transmitters use a vertical antenna which creates a horizontal magnetic field. When these magnetic fields intersect a conductive body in the ground, secondary fields radiate outward from the conductive body. The VLF-EM instrument used in this project measures the vertical components of those secondary fields. Conductive bodies typically generate in-phase values which, after filtering, result in a symmetrical positive "peak" over the conductor when plotted on a profile.

The results of the VLF-EM survey in the area are presented on figures 15, 16 and 17. The profiles show topographic cross-sections along the individual lines, plus results of the ground magnetic and VLF-EM surveys. The filtered VLF-EM values are presented on the profiles in such a way that the negative values are plotted *above* the axis and positive values plotted below.

The filtered data was plotted in this manner in order to emphasize the rather direct correlation of total field magnetic intensities and negative VLF-EM anomalies with outcrops of ultramafic rock.

As can be seen on the profiles, the VLF-EM survey in this investigation produced abnormal negative anomalies rather than positive ones. It appears likely that the instrument responded essentially to the magnetic rather than the conductive properties of the serpentinized peridotite. There are possibly other geologic situations which may cause negative VLF-EM anomalies; however, this and subsequent projects have shown that the magnetic permeability of a rock body is one feature that can cause negative VLF-EM in-phase anomalies.

A few areas, however, produced positive anomalies, indicating anomalous conductivity. The first is centered about 2,850 feet north along line C. The cause of this anomaly remains unexplained. A second conductive zone is centered about 3,350 feet north along line G. This second anomaly is probably an indication of conductive clays and not to a buried sulfide body.

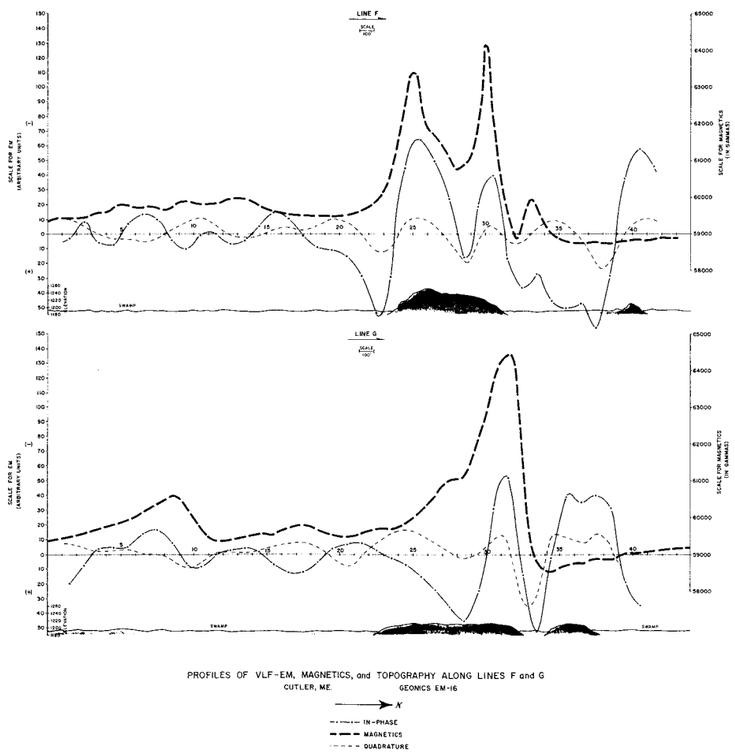

Figure 17 - Profiles of VLF-EM (filtered values), magnetics and topography along lines F and G. (VLF transmitter, NAA, Cutler, Me., 17.8 kHz, 1,000 kw.)

There is a distinct possibility that the conductivity of the clays in swampy areas prevented a very deep penetration of the VLF-EM instrument investigation. It is suggested that deeper penetrating, more discriminating electromagnetic methods should be used in this area to fully evaluate its economic potential.

CONCLUSIONS

The results of this investigation indicate that the geologic feature causing the aeromagnetic anomaly is the near-surface occurrence of serpentinized ultramafic rock locally rich in magnetite.

The Cu-Ni-Co values determined by chemical analysis on various samples of the ultramafic rock showed no anomalous results. The serpentinized ultramafic rock is thought to have been a peridotite originally. The serpentinized ultramafic rock strikes generally N80°W and apparently dips to the south. The body appears to have a strike-length of up to 12 miles, and the surface distribution may be locally increased in the project area by faulting.

Although more information is now known about the ultramafic body, the question of its economic potential still remains essentially unanswered. The VLF-EM surveys neither confirmed nor denied the presence of any subsurface sulfide bodies. In order to test more fully the presence of subsurface conductive bodies, more discriminating electrical methods are needed.

There is also a need to assess the asbestos potential of the ultramafic body. The surface occurrences of asbestos in fracture fillings 8-10 mm wide are altered and therefore noneconomic. There is, however, a possibility that unaltered material exists in the subsurface that may be economic and therefore deserves further study.

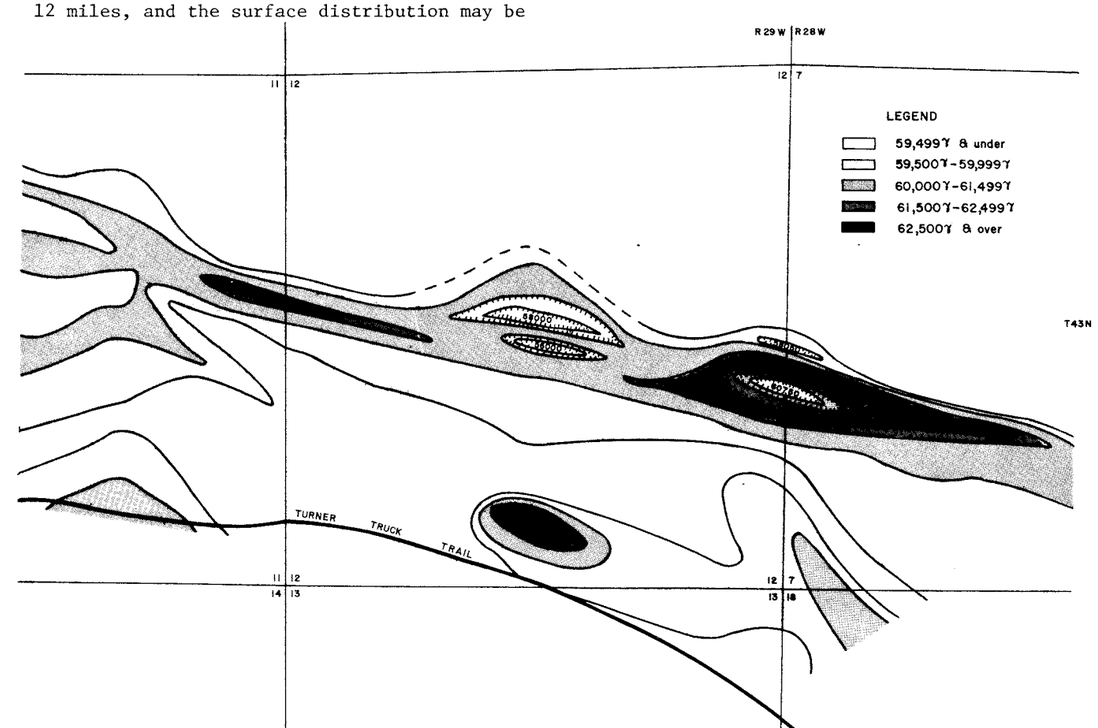

Figure 18 - Map showing the results of the ground magnetic survey (Total magnetic field in gammas, values are absolute.)

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