Open File 339

AEROMAGNETIC GRADIOMETER SURVEY
WHITE LAKE, ONTARIO (NTS 31F/7SE)

Peter Hood, P. Sawatzky, L. J. Kornik, P. H. McGrath

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To accompany Open File release

consisting of:

1)	Total Magnetic Field	(500')
2)	Residual Magnetic Field	(500')
3)	Calculated Vertical Gradient	(500')
4)	Vertical Gradient	(500')
5)	Total Magnetic Field	(1000')
6)	Residual Magnetic Field	(1000')
7)	Calculated Vertical Gradient	(1000')
8)	Vertical Gradient	(1000')
9)	Flight Line Map	(500')
10)	Flight Line Map	(1000')
11)	Geology of White Lake Area	

INTRODUCTION

The Geological Survey of Canada has been involved in the development of aeromagnetic surveying instrumentation and techniques since the late 1940's. This development work and its subsequent use in actual aeromagnetic surveys eventually led in 1961 to an aeromagnetic survey program being launched for the whole of the Canadian Precambrian Shield. The program was jointly funded by the federal and provincial governments, and has been entirely carried out under contract. To date some 4.5 million line miles have been flown by aeromagnetic survey aircraft and more than 7,000 contour maps have been published at a total expenditure of $20 million dollars. The program has been completed in all provinces except for portions of Labrador, Quebec and British Columbia. Large areas of northern Canada are also unsurveyed at the present time.

Most of the data used to compile the magnetic maps were obtained using fluxgate and proton precession magnetometers with sensitivities usually about one gamma; the flight elevation was 1,000 feet, the line spacing 1/2 of a mile. With the introduction of a new type of sensitive magnetometer in the early 1960's, there began a revolution in the aeromagnetic survey technique. These high resolution surveys have necessitated that the data be recorded in a digital format on magnetic tape rather than in the more classical way on a roll of chart paper in order that the small differences in the earth's magnetic field could be accurately recorded. Digital recording has permitted the subsequent mapmaking process to be carried out by the computer and the resultant contour maps to be accurately drawn using automated plotting devices. In addition, digital recording allowed modern techniques of data storage, transmittal and numerical filtering to be utilized.

One problem that has been troublesome over the years is the elimination of the small, time-variable variations of the earth's magnetic field due to sunspot activity, which are unavoidably recorded during aeromagnetic surveys in addition to the magnetic anomalies due to the underlying geological formations. This problem becomes more serious when high resolution aeromagnetic surveys are carried out, and the diurnal activity itself can be quite strong especially in northern Canada. The most direct way of removing the effect of such diurnal activity is to make gradient measurements using two magnetic sensors separated by a short distance. In addition to the elimination of the diurnal field variations, gradiometer measurements have a number of other advantages which relate to their value in geological mapping and mineral exploration programs.

In the United States, soon after the introduction of optical absorption magnetometers, a helicopter-borne gradiometer system was constructed by Varian Associates for Pure Oil Company and a fixed-wing system was also fabricated for Aero Service Corporation. Both of these systems utilized free-flying birds separated by approximately 150 feet so that both these towed gradiometer systems were limited by air turbulence. The vertical gradient was obtained by subtracting the two total field magnetic measurements obtained simultaneously by the two magnetic sensors and by dividing the resultant difference by the separation distance between the two sensors. It should be pointed out that the use of a towed bird system avoided compensation for the magnetic effects of the aircraft, and that a large vertical separation was necessary to obtain the gradient sensitivity necessary for oil exploration surveys. The large separation meant however that in mineral exploration surveys of Precambrian areas that the difference between the two magnetometer readings would deviate somewhat from the true gradient.

Some years ago the Geological Survey of Canada purchased a light twin-engine aircraft, a Beechcraft B80 Queenair, to carry out experimental high resolution aeromagnetic surveys. During the past two years the development of an inboard digital-recording vertical gradiometer system has been undertaken. The purpose of this open file is to summarize our experiences to date with this new system and to indicate some of the capabilities of the technique.

The Queenair aircraft is equipped with two single-cell self-orienting optical absorption magnetometers mounted at the ends of the twin tail booms. The sensors are vertically separated by approximately two metres. The total field values, ΔT_1 and ΔT_2, measured by each magnetometer are recorded digitally on magnetic tape. The vertical gradient, which is also recorded, is obtained by a digital subtraction of ΔT_1 and ΔT_2. The gradient values are subsequently divided by 2.08 metres, the sensor separation, during compilation of the data. The gradient and either of the total field measurements are displayed in the aircraft in order that the operator may monitor the system for malfunctions. Great care was taken in the magnetic compensation of the aircraft. Two nine-term compensators built by Canadian Aviation Electronics of Montreal were installed, one in each tail boom, in order to remove aircraft manoeuver noise from the data. The present effective sensitivity of the installed gradiometer system is 0.02 gammas per metre. The aircraft is also equipped with a 35 mm camera system and a VLF navigation system for flight path recovery.The altitude of the aircraft is determined using a radar altimeter. The sampling interval is about 130 feet with a half second sampling rate. The time is obtained from a 10 megahertz crystal oscillator which is manually set each day. Flight tests have shown that the Queenair aircraft handles well, but it is slower by about 10 percent because of the addition of the upper tail boom.

In a typical vertical gradient profile over a wide steeply dipping dike at high magnetic latitudes the zero crossover of the anomaly curve tends to outline the contacts of the causative body (see Fig. 1). The

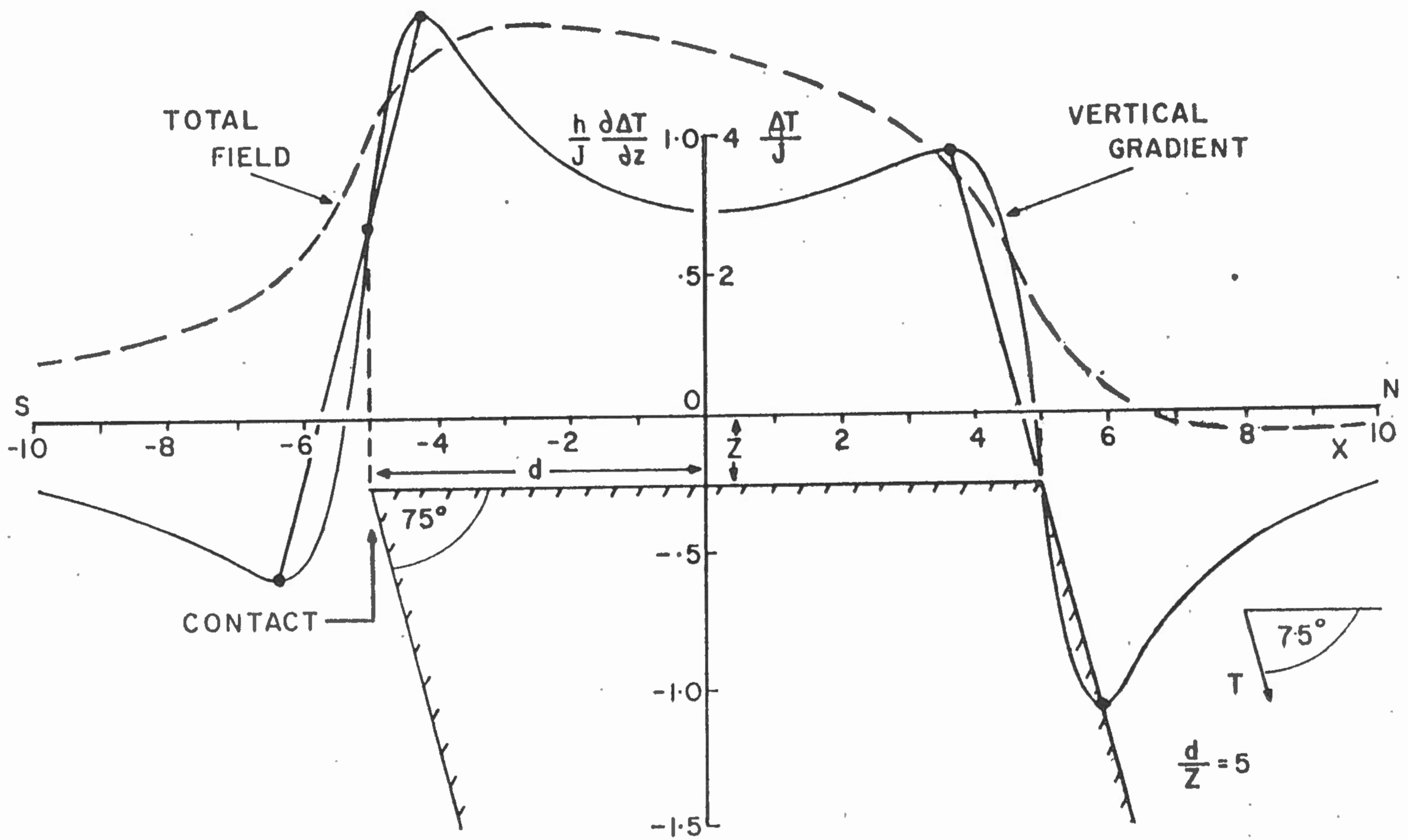

FIGURE 1. Theoretical vertical gradient and total field curves over a wide dipping dyke. The units on the horizontal and vertical axes are dimensionless.

actual position of the contact is defined by the intersection of the straight line joining the appropriate maximum and minimum gradient values with the vertical gradient anomaly. The Geological Survey of Canada's vertical gradiometer system was designed to map near vertical contacts between large outcropping rock formations having a minimum effective susceptibility contrast of about 50 X 10^{-6} emu/cc, which is typically the case for many areas of the Canadian Precambrian Shield. Such a model yields a maximum gradient of about 0.33 gammas per metre, or a difference of 0.68 gammas between the two magnetic sensors installed in the tail booms of the aircraft.

WHITE LAKE GRADIOMETER SURVEY

The first experimental survey with the GSC gradiometer system was carried out in the White Lake area of Ontario, 40 miles west of Ottawa during the summer of 1975.

Figure 2 presents a profile of both the total field measured by the lower magnetic sensor and the vertical gradiometer data along a flight line of the White Lake survey area. Sampling noise which results from the 0.004 gamma/metre sensitivity of the gradiometer system is present on the vertical gradient profile as high frequency small-amplitude hash. Before compiling the profile data into map form it is first necessary to remove the sampling noise. To accomplish this it is desirable that the vertical gradient anomalies be over-sampled during the survey in order that the noise and geological signal be spectrally separate; then, the data can be filtered by computer using a one-dimensional low-pass digital operator.

Another important property of vertical gradient data for the mapping geologist and mineral explorationist is that the shallower, short wavelength features tend to be emphasized at the expense of the deeper, long wavelength features so that the gradiometer effectively acts as a high-pass filter on the magnetic anomalies. Thus, short wavelength anomalies due to near-surface magnetic bodies which are partially obscured by large regional gradients are enhanced by the gradiometer. In addition, because of this filtering effect, the influence of the main earth's field which is generated near the earth's core is also eliminated in the gradient data, except for a very small component (about 0.03 gammas/metre) which is constant over large dis-

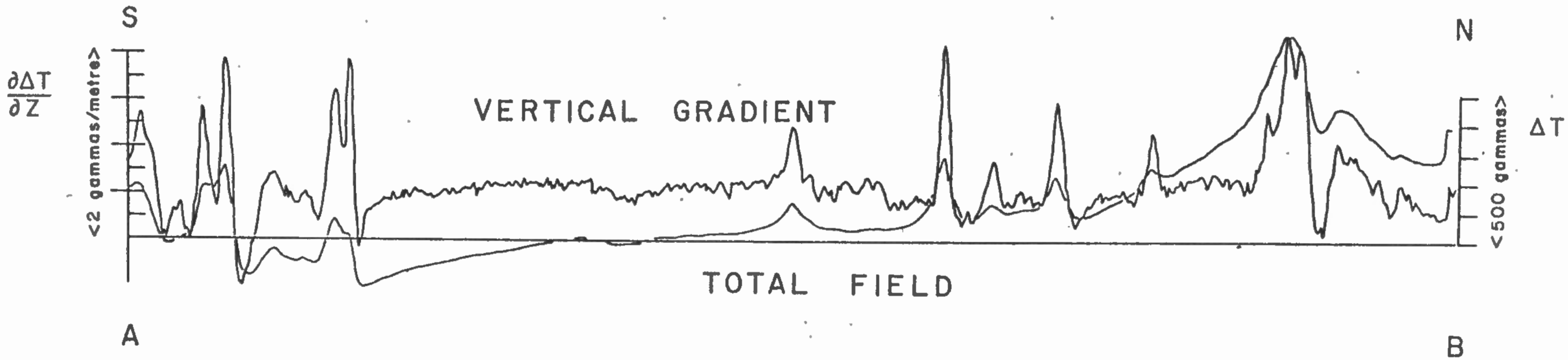

FIGURE 2. Profile flown at 5ØØ feet (152m) across the White Lake granite which compares the total field and vertical gradient results obtained by the GSC Queenair aeromagnetic survey aircraft.

tances. Note in the accompanying maps that the regional gradient in the total field data which increases from southeast to northwest is not present in the vertical gradient data.

A residual magnetic field map was derived from the total field magnetic map by the application of a digital operator. This operator removed the regional magnetic variations and long wavelength magnetic features. The residual magnetic map presents the short wavelength magnetic features which are produced by the underlying near-surface local geology. A comparison of the residual map with the total field map illustrates the improved definition and continuity of local magnetic anomalies on the residual map. Also apparent is the suppression of contour irregularities and herring-bone patterns (due to levelling inaccuracies) which are present on the total field map but are largely removed from the residual magnetic map by the filtering process.

A calculated vertical gradient map derived from the gridded residual total field data using a two-dimensional 177-point spatial operator is also presented together with the measured vertical gradient results as obtained by the gradiometer system.

The difference between these two maps is that the small amplitude anomalies on the calculated gradient map have greater continuity than corresponding anomalies on the measured vertical gradient map. The measured vertical gradient map on the other hand has more small amplitude anomaly detail. Sufficient experience has not been obtained to fully understand the difference in detail between the two maps. However, it is apparent that the measured vertical gradient map contains more useful information.

A comparison of the total field to the residual total field and vertical gradient maps illustrates the superior resolution of the vertical gradient anomalies as compared with the high sensitivity total field anomalies recorded by a single sensor. The narrower vertical gradient anomalies delineate more precisely the location and width of individual geological units and provide greater detail on individual anomalies.

GEOLOGICAL INTERPRETATION

Two weeks in the Fall of 1975 were spent to ground-truth some of the magnetic features present in the White Lake granite, the granitic body which dominates the south-eastern portion of the survey area. The two strong east-west linear anomalies which transect the granitic body were verified as previously unmapped diabase dykes from outcrop checks in several locations. Traverses over selected areas of the White Lake granite indicated the presence of amphibolitic relicts ranging from layered amphibolite gneiss to highly digested wispy traces of former layering. These zones of relatively higher concentration of mafic minerals produce low amplitude magnetic anomalies with trends parallel to the granite boundaries. These traverses also indicate the presence of numerous linear zones of epidotized and chloritized granitic material. The zones are interpreted as faults and shears which appear as discontinuities or linear trends of the magnetic anomalies.

The maps presented in this open file were examined to determine what additional geological detail was present which was not available from standard sensitivity total field aeromagnetic maps. A study and a correlation of the four types of maps, the total field, the residual magnetic, the calcul-ted vertical gradient and the vertical gradient obtained from the gradiometer system underlines the fact that each map type contributes to the interpretation. The total field and residual maps establish the gross features and the continuity of the larger geological structures. The calculated vertical gradient map and the vertical gradient map obtained from the gradiometer respectively reveal increasingly more detail and discontinuities within the geological structures.

Several levels of geological information are available from these maps. Firstly, the large primary features such as the position of the boundaries of the granitic body and diabase dykes are discernible on all the maps with varying degrees of clarity. Secondary magnetic features caused by zones of more abundant mafic minerals within the granite are indicated on all but the total field map. The residual total field map establishes the continuity of the main conformable compositional zoning within the granite. However, only the two vertical gradient maps contain sufficient magnetic anomaly detail to delineate discontinuous trends of the compositional zoning within the granitic body. The two vertical gradient maps also reveal the third level of geological information, the discontinuity, termination and alignment of terminations of magnetic anomalies. These features are the magnetic expression of faults within the granitic body. Again, the (measured) vertical gradient map obtained from the gradiometer system is the most useful for delineating the faults within the granite.

Figure 3 illustrates the geological features interpreted from the measured vertical gradient map. The two previously unmapped diabase dykes are readily discernible. The trends of the compositional zoning within the granite are clearly established. Discontinuities indicated in Figure 3 are interpreted as faults and shears within the granite. These faults and shears occur as discontinuities of magnetic anomaly trends or termination or alignment of terminations of magnetic anomaly trends.

In summary, although all four types of maps contribute to some aspect of the interpretation, the (measured) vertical gradient map contains the greatest amount of detail and is thus the most useful for delineating detailed geological structures.

In conclusion, the results obtained to date by the Geological Survey of Canada demonstrate that a vertical aeromagnetic gradiometer system is a superior tool both for detailed geological mapping and for mineral exploration programs as compared to the single sensor magnetometer surveys. The gradiometer enhances magnetic anomalies caused by contact zones and faults, and helps establish a continuity over metamorphic terrains as well as in low gradient areas such as are found over many granitic bodies.

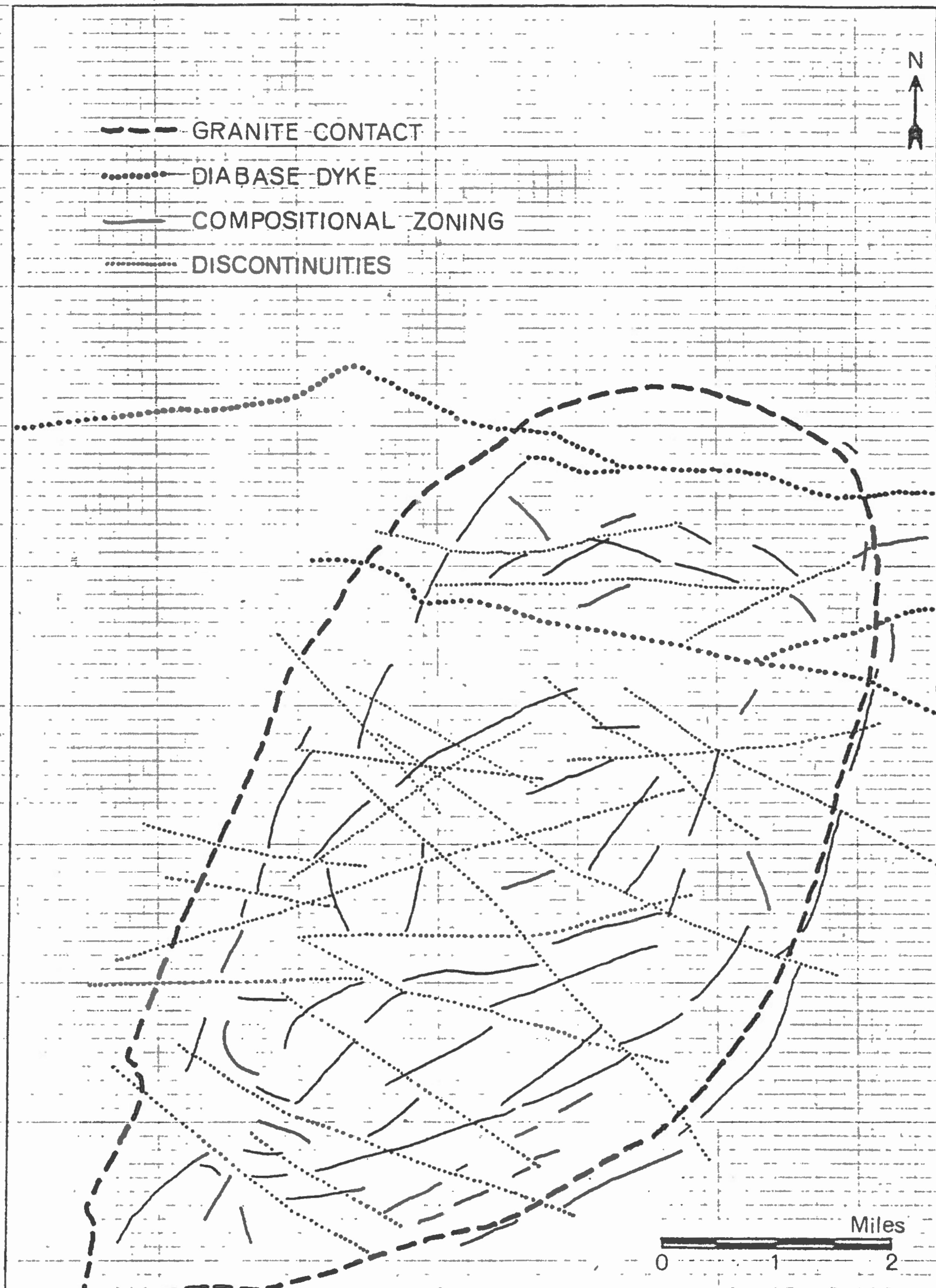

FIGURE 3. Geological features interpreted from the measured vertical gradient map.