UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Federal Center, Denver, Colorado 80225

INTERPRETATION OF MAGNETIC SURVEYS IN INTERMONTANE VALLEYS OF NEVADA AND SOUTHERN NEW MEXICO

G. D. Bath

Open-file Report 76-440

1976

Prepared
for the
Air Force Weapons Laboratory
Kirtland Air Force Base, New Mexico

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS--Continued

TABLES

INTERPRETATION OF MAGNETIC SURVEYS IN INTERMONTANE VALLEYS OF NEVADA AND SOUTHERN NEW MEXICO

By

G. D. Bath

ABSTRACT

An evaluation of the magnetic method of geophysical exploration in intermontane valleys is made through examples of magnetic properties, magnetic surveys, reduction of data, and analysis of magnetic anomalies from some valley areas. Measurements of magnetic properties of samples collected along valley margins or from drill holes indicate that the anomaly-producing rocks are mostly Tertiary volcanic flows in Nevada and mostly Cretaceous-Tertiary intrusives in southern New Mexico. Aeromagnetic data were compiled as both observed and residual anomalies from surveys at various flight-line spacings and intervals from ground surface. Theoretical anomalies from known models were analyzed to recover data on depth, width, and magnetization of models and thereby establish reliability of methods used by certain investigators. These methods were then applied to measured anomalies to obtain information about the igneous rock structures that are buried beneath nonmagnetic valley alluvium. Recommendations made for future valley studies include aeromagnetic surveys flown 150 m above ground surface and at 800 m spacing; measurement of magnetic properties from outcrop samples, drill-core samples, and magnetometer logging of uncased drill holes; and use of the interpretation from gravity surveys in the same area.

INTRODUCTION

This report gives an evaluation of the magnetic method for geophysical exploration in intermontane valleys by presenting examples of magnetic properties, magnetic surveys, reduction of data, analysis of theoretical anomalies from known models, and analysis of magnetic anomalies measured in some valley areas of Nevada and New Mexico. Included in the evaluation are results of studies by Mattick, Olmstead, and Zohdy (1973) in the Yuma area of Arizona. Recommendations are made for the future magnetic exploration of intermontane valleys.

Aeromagnetic surveys have been made over several valley areas of central Nevada (U.S. Geological Survey, 1968), (Boynton and others, 1963a; 1963b; Boynton and Vargo, 1963a; 1963b) to gain information on magnetized igneous rocks buried beneath nonmagnetic valley fill. The studies were supported by the U.S. Atomic Energy Commission (now U.S. Energy Research and Development Administration). An aeromagnetic survey of the Tularosa Valley of New Mexico by the U.S. Naval Oceanographic Office in 1975-76 was supported by the Air Force Weapons Laboratory.

Positions of the areas investigated are shown in figure 1: Monitor Valley, Little Fish Lake Valley, Little Smoky Valley, Hot Creek Valley, Stone Cabin Valley, Yucca Flat, and Frenchman Flat in Nevada; Tularosa Valley in New Mexico; and Yuma area in Arizona.

The author extends personal thanks to Wilfred J. Carr, Frank M. Byers, Jr., and many other geologists of the U.S. Geological Survey for discussions of Nevada geology, and to Lt. Louis S. Karably of the Air Force Weapons Laboratory for discussions of New Mexico geology. Charles E. Jahren made many of the magnetic property measurements, and Frank W. Jones, Jr., assisted in the reduction and compilation of magnetic data.

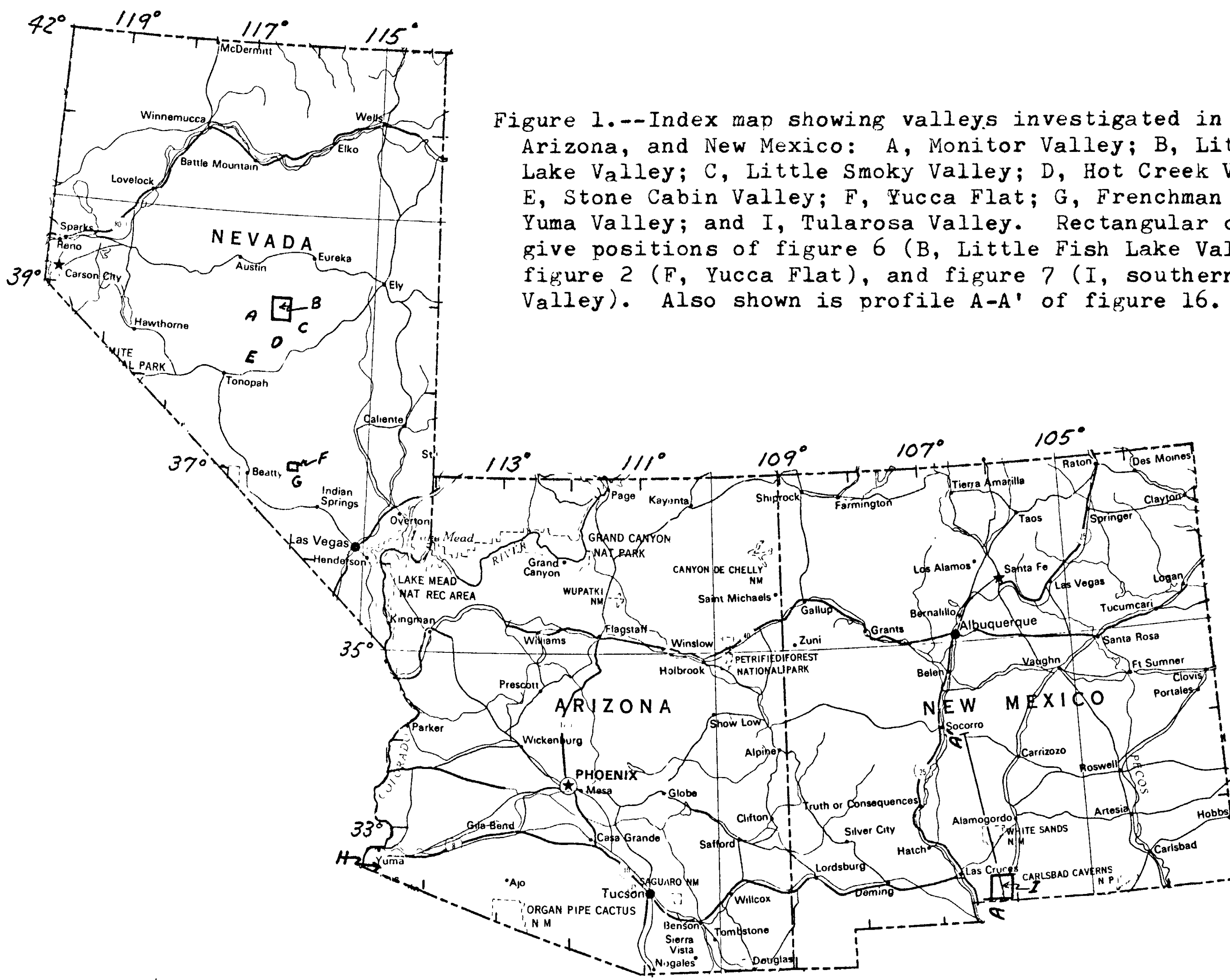

Figure 1.--Index map showing valleys investigated in Nevada, Arizona, and New Mexico: A, Monitor Valley; B, Little Fish Lake Valley; C, Little Smoky Valley; D, Hot Creek Valley; E, Stone Cabin Valley; F, Yucca Flat; G, Frenchman Flat; H, Yuma Valley; and I, Tularosa Valley. Rectangular outlines give positions of figure 6 (B, Little Fish Lake Valley), figure 2 (F, Yucca Flat), and figure 7 (I, southern Tularosa Valley). Also shown is profile A-A' of figure 16.

MAGNETIC PROPERTIES

A magnetic survey detects those geologic features that have magnetic properties unusual enough to cause a disturbance, or an anomaly, in the Earth's magnetic field. The anomaly arises when a geologic feature has an intensity of magnetization that differs by at least $1X10^{-4}$ cgs/cm^3 (centimetre-gram-second/cubic centimetres) from intensities of adjacent features. Also, large differences in direction of magnetization can cause anomalies. An evaluation of magnetization is obtained by measuring magnetic properties of rock samples or by logging uncased drill holes with a magnetometer. The samples are collected from surface exposures and drill holes; their magnetic properties are then measured in a laboratory.

Although rocks become magnetized in many different ways (Doell and Cox, 1967), only two ways are significant in magnetizing most anomaly-producing features: (1) rocks magnetized by the Earth's present magnetic field, and (2) rocks magnetized by the Earth's magnetic field in a previous geologic time. The first results in induced magnetization, a vector quantity related to the direction and intensity of the Earth's present magnetic field and to the magnetic susceptibility of the rocks. The second results in remanent magnetization, a vector quantity related to the direction of the ancient Earth's magnetic field and to the cooling history of the rocks. Remanent magnetization gives rocks a "memory," and it is this "record" of previous magnetizations that has been used to develop the new science of paleomagnetism (Irving, 1964).

Anomalies, too, can exhibit "records" of previous magnetizations. Anomaly (D) of figure 8 is an example of the positive anomaly caused by rocks having induced magnetization caused by Earth's present magnetic field. The strong negative anomaly of -1,120 gammas, shown on graph D of figure 9, is an example of the effects of rocks having a dominant remanent magnetization. The negative anomaly is caused by buried volcanic rocks that were extruded, cooled, and magnetized at a time when the Earth's magnetic field had a direction nearly opposite to the present field. Magnetizations along the present direction of the field are designated "normal," whereas magnetizations opposite to the present direction are designated "reversed."

Our limited investigations show a geologic setting of magnetized rock that changes from Nevada to New Mexico. In Nevada, a few magnetized intrusives extend to great depth, but the major rock units are the nonmagnetic sediments of Paleozoic and Precambrian ages that extend to great depth. Most magnetic anomalies come from Tertiary volcanic rocks that are positioned between Quaternary alluvium and the older nonmagnetic sediments. In southern New Mexico there are few magnetized volcanic rocks but many magnetized intrusives of Tertiary, Cretaceous, and Precambrian ages. Nonmagnetic sediments are present beneath the alluvium, but they have limited depth extent. No magnetic property data were reported by Mattick, Olmstead, and Zohdy (1973) for the Yuma Arizona, area. The geologic setting there is similar to that in southern New Mexico, except that the older nonmagnetic sediments are missing.

Yucca Flat

Measurement of magnetic properties in the Yucca Flat area reveal as nonmagnetic the Quaternary alluvium of the valley floor, much of the Tertiary volcanic rock penetrated during drilling, and the old sediments of Paleozoic age. The only important anomaly producer found was the Rainier Mesa ash flow. Figure 2 shows, along valley borders, the outlines of exposures of nonmagnetic sediment, normally magnetized volcanic rock, and the reversely magnetized Rainier Mesa Member of the Timber Mountain Tuff. To compile figure 2, geologic data were taken from the following 7½-minute quadrangles: Rainier Mesa by Gibbons, Hinrichs, Hansen, and Lemke (1963); Oak Spring, by Barnes, Houser, and Poole (1963); Jangle Ridge, by Barnes, Christiansen, and Byers (1965); Tippipah Spring, by Orkild (1963); Yucca Flat, by Colton and McKay (1966); and Paiute Ridge, by Byers and Barnes (1967).

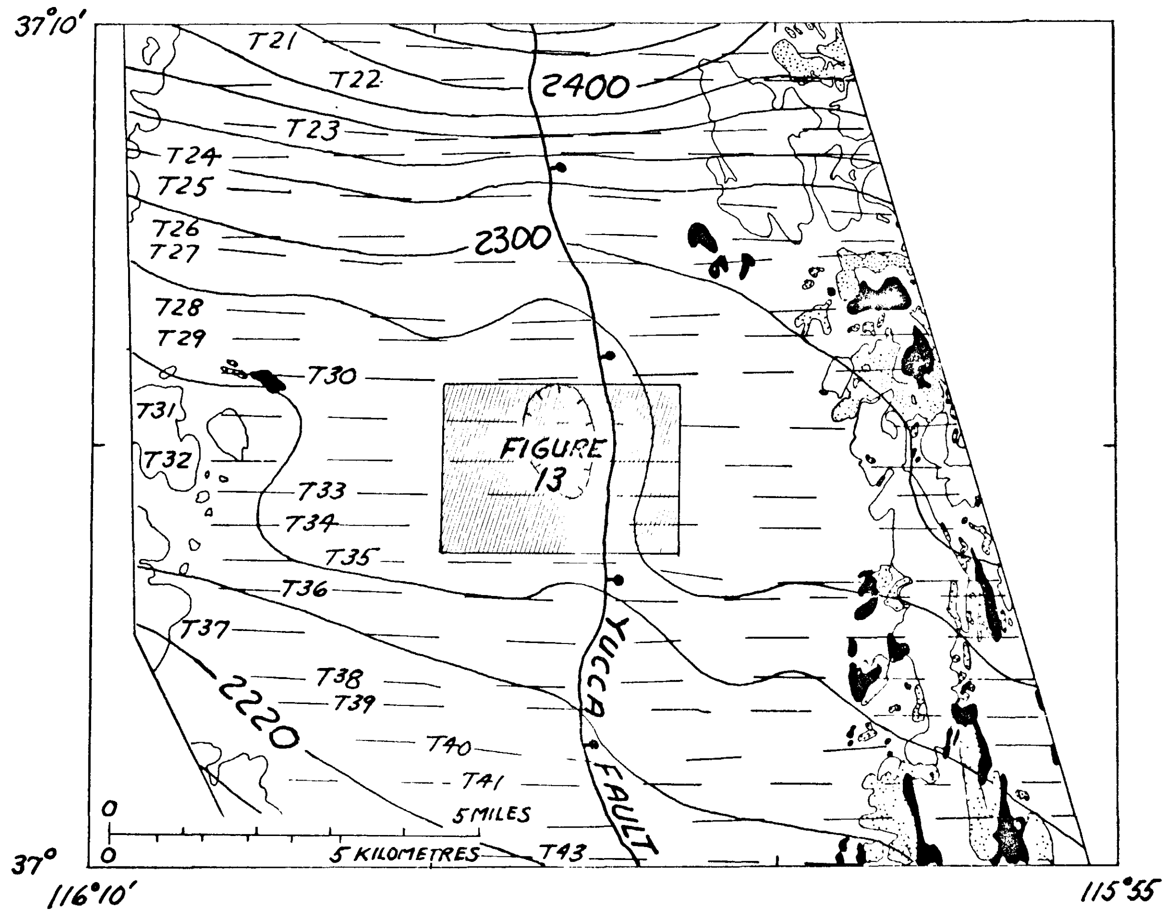

Figure 2.--Aeromagnetic and magnetization map of central part of Yucca Flat showing contours at a 20-gamma interval, flight-line paths, outlines (unshaded) of nonmagnetic Paleozoic sediments, outlines (dotted) of normally magnetized volcanic rock, outlines (black) of reversely magnetized Rainier Mesa Member, trace of Yucca fault, and outline of figure 13. Bar and ball are on the low-standing side of the Yucca fault.

The data (fig. 3) obtained from drill-core samples of the Rainier Mesa Member, collected near its type locality, were evaluated and show the extent of the magnetization of the Rainier Mesa and the porosity-derived division between its welded and nonwelded components. Intensities of induced magnetization are too low to make a significant contribution to magnetic anomalies. Intensities of remanent magnetization vary greatly. Some reach values of more than $100X10^{-4}$ cgs/cm^3; the average for the Rainier Mesa is $35X10^{-4}$ cgs/cm^3.

The holes were drilled vertically; and, by orienting core samples along the core axis, it was possible to measure inclination of remanence (Jahren and Bath, 1967). The magnetization vector was found to incline upward at about 50°, not downward at about 60° as would be expected from the direction of Earth's present magnetic field.

When drill core is not available, similar results can be obtained from roughhewn samples collected from cliffs or steep slopes where extensive surfaces of rock are exposed. A polarity instrument, similar to one described by Doell and Cox (1962), must be used to the disturbing effects of lightning bolts (Cox 1961). Plots of remanent magnetization for 21 large oriented samples of the Rainier Mesa Member, which average 1,150 cm^3 in volume and which were collected from a cliff on nearby Pahute Mesa, are shown in figure 4. The intensities here also vary greatly, reach values greater than $100X10^{-4}$ cgs/cm^3, and average $27X10^{-4}$ cgs/cm^3. The magnetization vector is inclined upward at about -50° and directed southward instead of northward.

Tularosa Valley

Measurement of magnetic properties for 90 roughhewn samples collected at 20 sites along the border of Tularosa Valley shows that intrusive rocks of Cretaceous and Tertiary ages produce the prominent anomalies observed over the valley. Induced, rather than remanent, is the dominant magnetization. Table 1 shows induced values for samples from Precambrian granite, Cretaceous-Tertiary intrusives, and metamorphosed Precambrian rocks. Volumes are given to indicate sample size, and densities are given to provide an independent parameter that could help in determining whether or not the selected rock samples were representative.

The magnetic mineral content in intrusive rock exposures is often decreased by near-surface weathering processes, and the magnetization of surface samples may not be representative of the large rock masses that produce magnetic anomalies. The true representative values are probably greater than those given in table 1, and Precambrian granite and metamorphosed rock may have values large enough to generate magnetic anomalies. Data from samples collected from less weathered rock, such as those from quarry excavations and drill core, should help answer this question.

Table 1.--Average induced magnetization, density, and volume of 90 roughhewn samples collected at 20 sites along border of Tularosa Valley

Rock sampled	Site	Latitude (N.)	Longitude (W.)	Number of samples	Volume (cm^3)	Density (g/cm^3)	Induced magnetization ($X10^4$ cgs/cm^3)
Precambrian	1	33° 11.5'	106° 36.6'	6	196	2.o3	0.2
granite	2	33° 11.5'	106° 36.6'	5	273	2.67	6.9
	3	33° 11.5	106° 36.6'	4	323	2.66	4.8
	4	33° 11.0'	106° 37.4'	3	443	2.65	1.2
	5	33° 11.0'	106° 37.4'	5	240	2.56	0.1
	6	33° 11.0'	106° 37.4'	6	189	2.59	0.4
	7	33° 11.0'	106° 37.4'	3	252	2.59	0.9
	8	33° 7.1'	106° 35.1'	5	177	2.62	0.1
	9	33° 7.1'	106° 35.1'	4	137	2.66	0.2
	10	32° 20.9'	106° 28.2'	5	268	2.57	2.0
	16	33° 16.2'	106° 32.0'	4	409	2.64	2.2
	17	33° 16.2'	106° 32.0'	4	253	2.98	0.2
		Average for 54 samples			253	2.65	1.6
Cretaceous-	11	32° 25.7'	106° 34.0'	5	166	2.66	13.5
Tertiary	12	32° 25.7'	106° 34.0'	4	372	2.58	13.9
intrusives	13	32° 25.7'	106° 34.0'	5	304	2.64	12.6
	21	32° 26.0'	106° 6.4'	5	278	2.84	23.2
	22	32° 25.3'	106° 6.8'	3	417	2.60	7.5
	23	32° 24.8'	106° 6.5'	3	400	2.66	12.2
		Average for 25 samples			307	2.67	14.8
Metamorphosed	14	32° 33.0'	106° 26.8'	6	207	2.68	2.0
Precambrian	15	32° 33.0'	106° 26.8'	5	204	2.91	2.2
rocks		Average for 11 samples			206	2.78	2.1

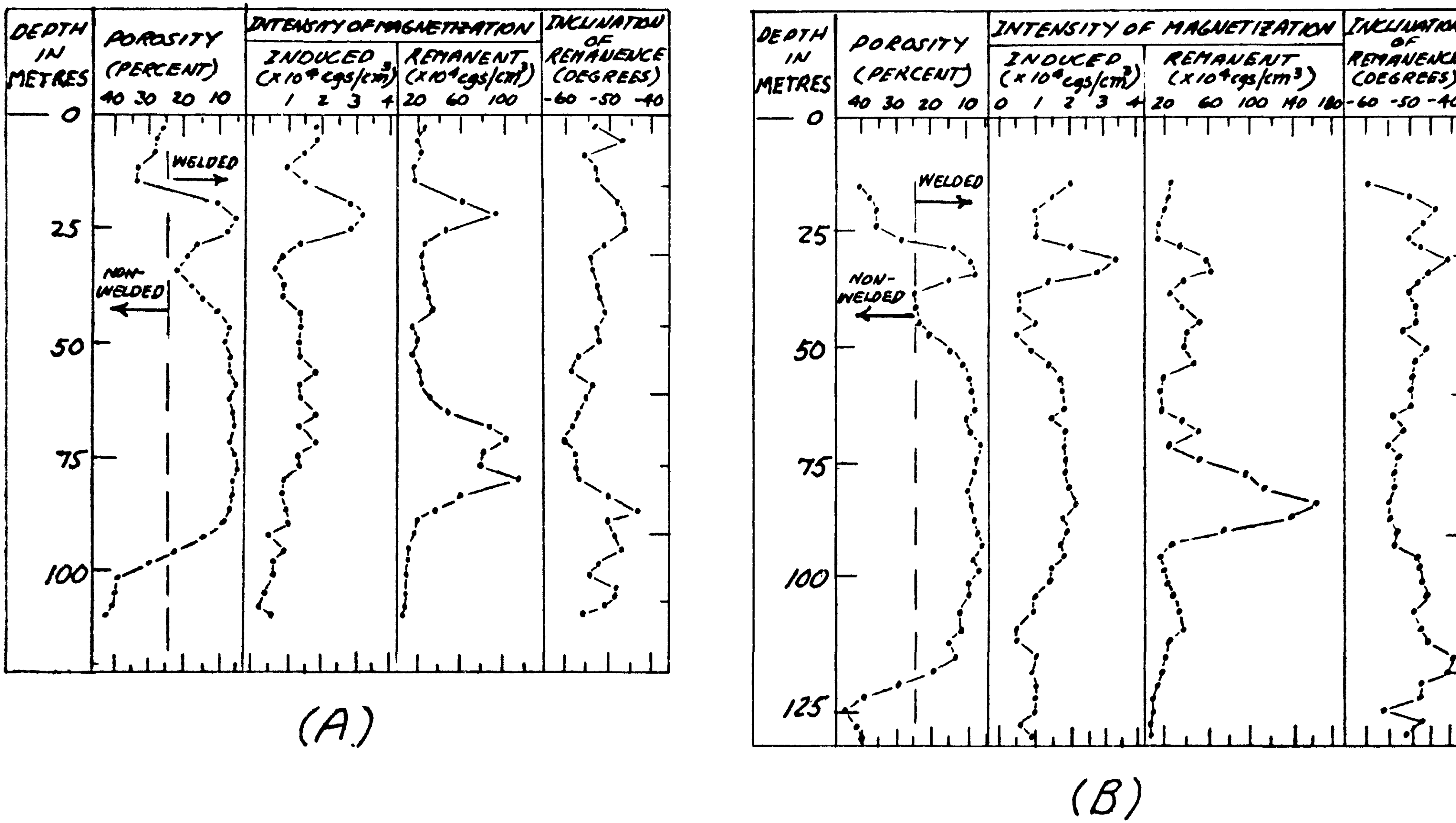

Figure 3.--Plots of induced and remanent magnetizations against depth for 36 core samples from drill hole A and 42 core samples from drill hole B. Holes penetrated the reversely magnetized Rainier Mesa Member near its type locality. A porosity of 24 percent divided the member into welded and nonwelded components.

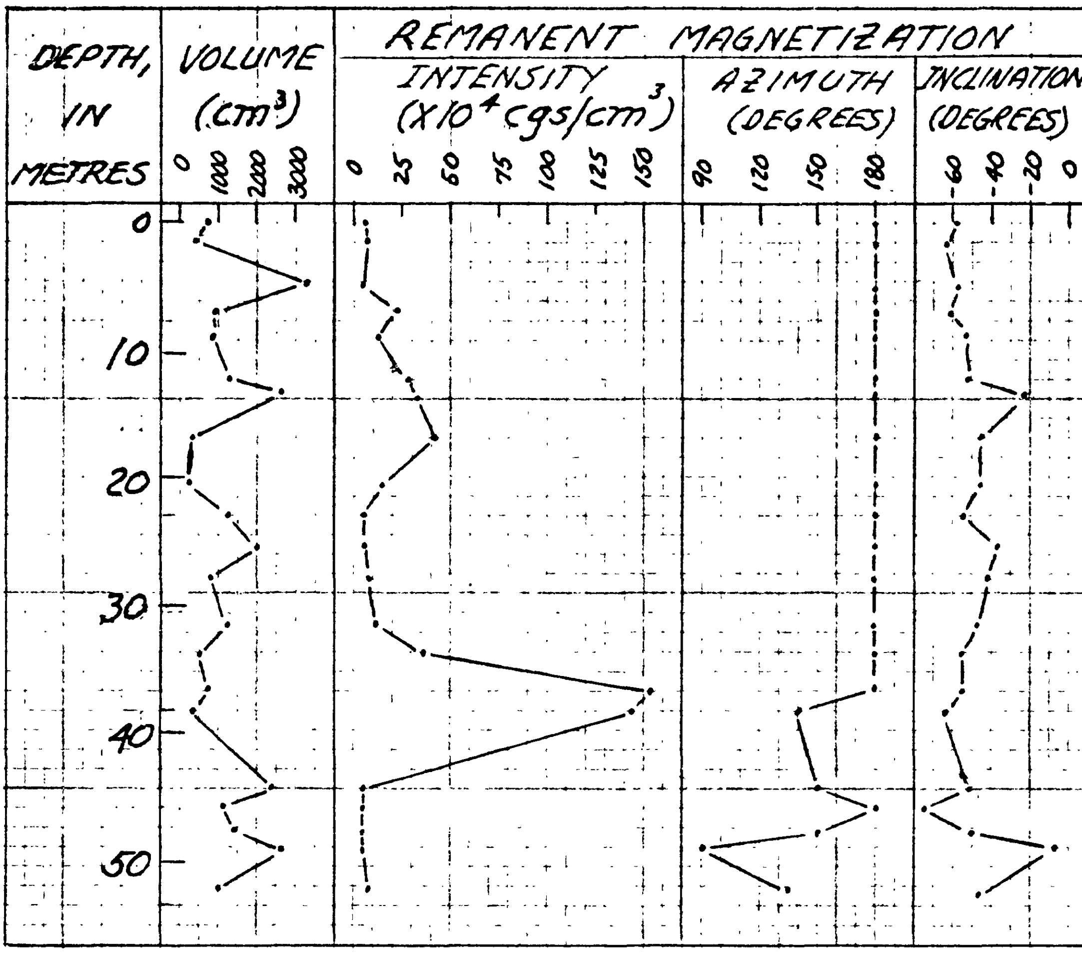

Figure 4.--Plot of remanent magnetizations and volumes against depth for 21 oriented roughhewn samples collected from an exposure of Rainier Mesa Member on Pahute Mesa. Depth measured from top of rock exposure.

MAGNETIC SURVEYS

As shown on figure 5, the aeromagnetic survey of Little Fish Lake Valley consists of 23 flight lines, numbered T54 through T73A, that were flown across the valley in east-west directions, and two lines, numbered T4 and T5, that were flown along the valley in northeast-southwest directions. The lines crossing the valley were flown 300 m above the surface to give data for compilation of an aeromagnetic map (fig. 6); the lines flown parallel to the valley were 150 m above the surface to define magnetic anomalies in greater detail near the drill-hole locations shown by Ekren and others (1974). The data are from the aeromagnetic survey of central Nevada (U.S. Geological Survey, 1968).

Aeromagnetic surveys of Tularosa Valley and part of Journada del Muerto (New Mexico) were made by the U.S. Naval Oceanographic Office in August 1975, and the map compiled for the southern part of the survey is shown as figure 7. The map consists of 15 flight lines, numbered T13 through T26 and T28, that were flown along a direction about 10° west of north and at a constant elevation of 1,700 m above sea level.

The aeromagnetic survey in the Yuma, Arizona, area (Mattick and others, 1973), consists of 29 flight lines that were flown along a direction about 37° east of north, about 800 m apart, and about 300 m above the surface.

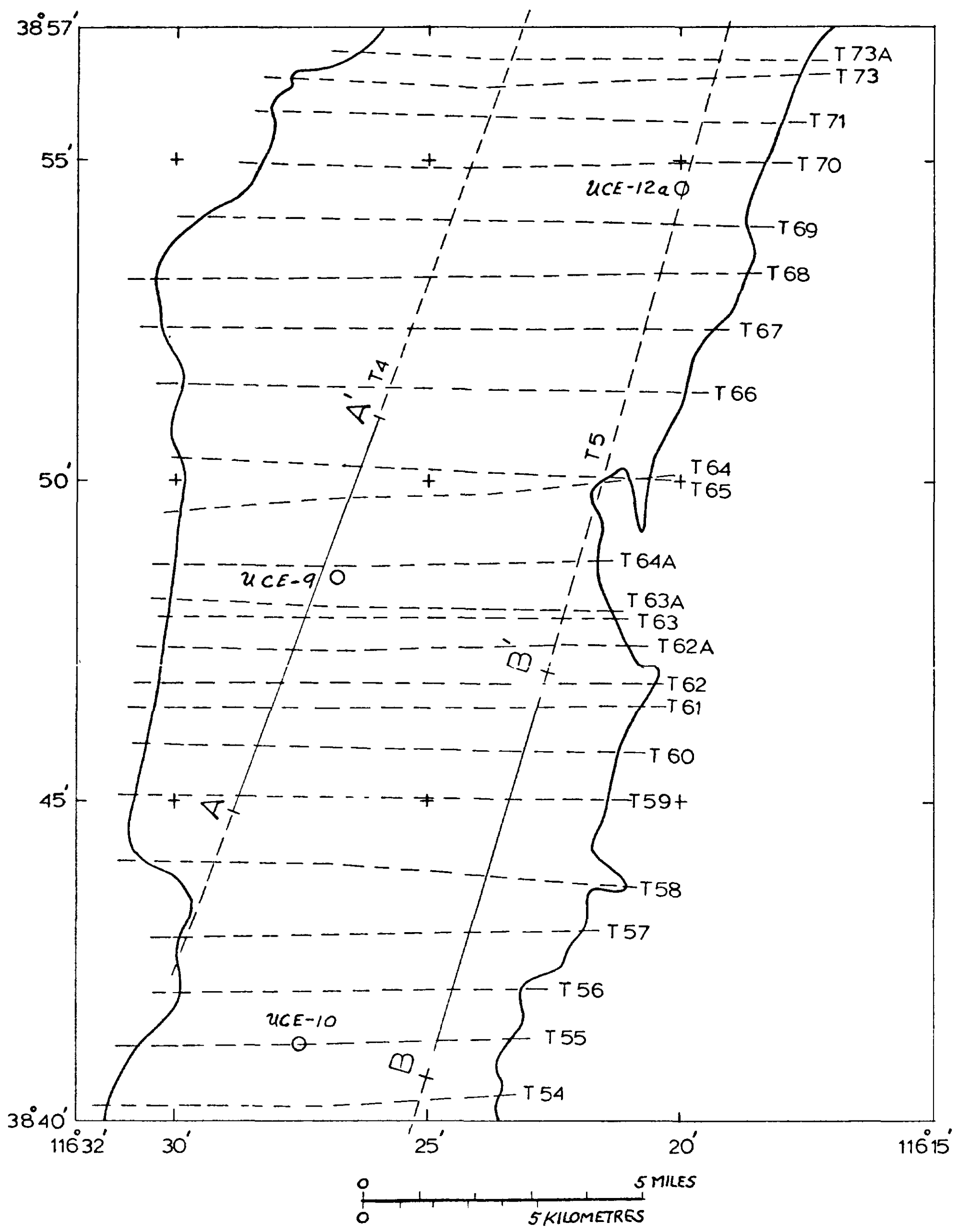

Figure 5.--Little Fish Lake Valley showing edges of valley, paths of 23 flight lines numbered T54 through T73A flown across the valley, paths of flight lines T4 and T5 flown along the valley, profile A-A' on T4, profile B-B' on T5, and positions of three drill holes reported by Ekren and others (1974).

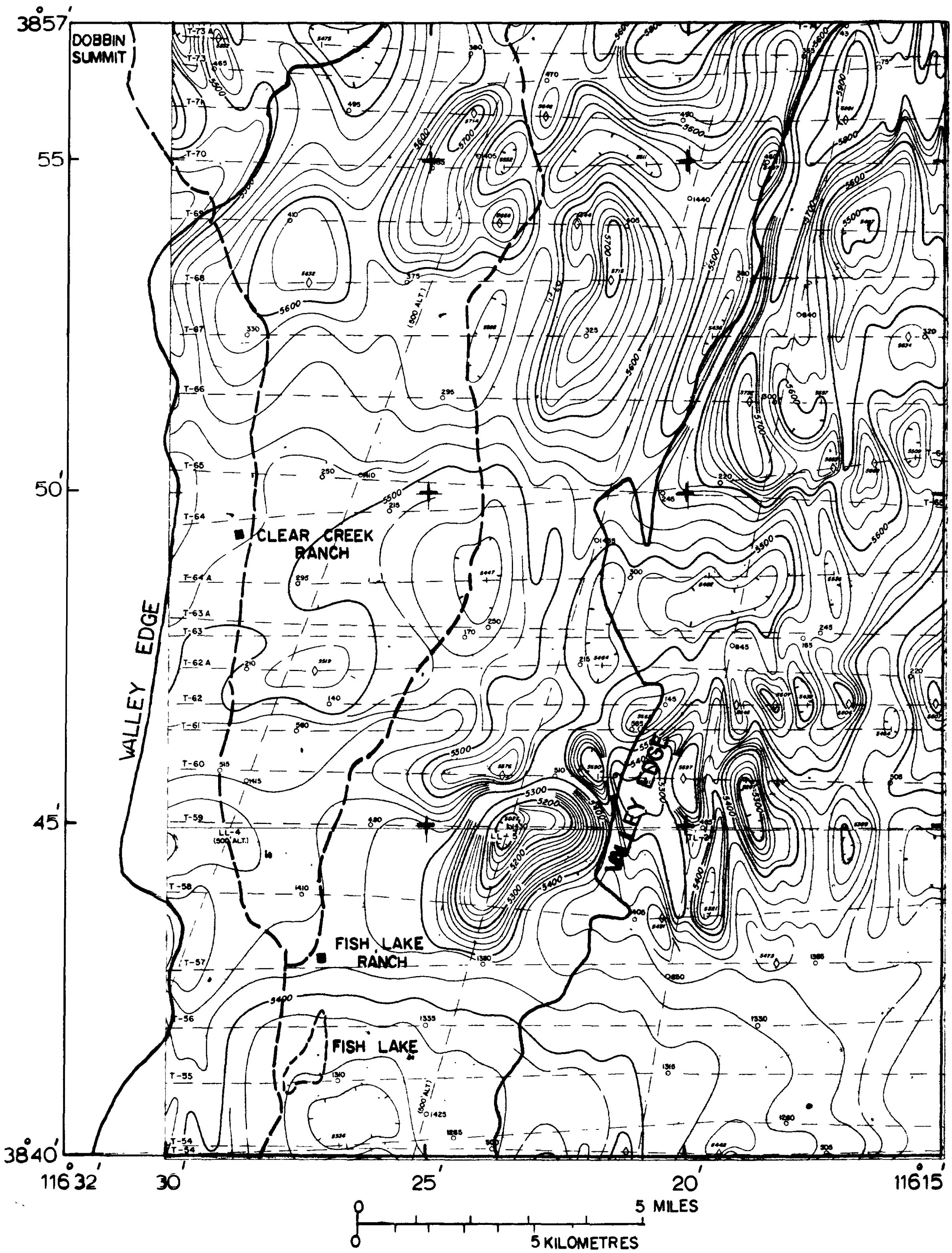

Figure 6.--Aeromagnetic map of Little Fish Lake Valley and area to east, showing observed anomalies at a 20-gamma contour interval, values of maxima and minima along flight lines, and unimproved-surface roads.

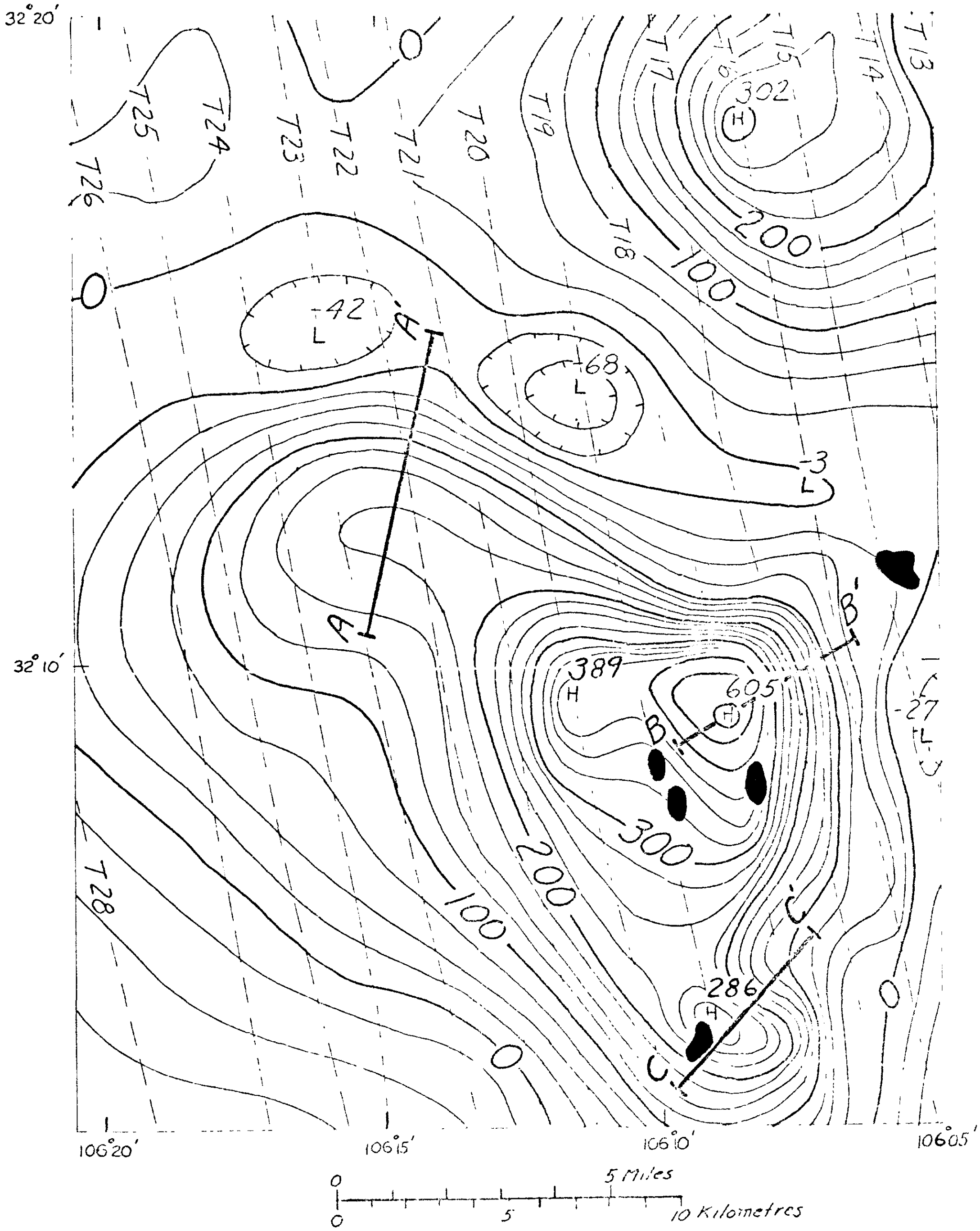

Figure 7.--Aeromagnetic map of southeastern part of Tularosa Valley, showing residual anomalies at a 25-gamma contour interval; paths of 15 flight lines numbered T13 through T26 and T28 flown along the valley; values of maxima, H, and minima, L, along flight lines; profiles A-A', B-B', and C-C'; and shaded outlines for exposures of old sediments reported by Dane and Bachman (1965).

Reduction of data

The data recorded by the magnetometer during an aeromagnetic survey consist of the combined residual and regional magnetic anomalies. Figure 6 is a map compilation of observed data, and figure 7 is a map compilation of the residual anomaly, or the anomaly remaining when the regional anomaly is subtracted from the observed anomaly. In valley areas, the residual anomalies are of particular interest because they are caused by features ranging in depth from zero to several kilometres below the surface. The regional anomaly is not important in geophysical exploration, because it comes from the northward increase in the intensity of the Earth's magnetic field and from rock sources too deep to investigate by drilling.

Geophysicists prepare residual maps to assign contour values that are about zero over very large areas of little or no magnetic anomaly and also over very thick accumulations of nonmagnetic rock. Assigned datums vary, therefore, from one magnetized rock mass to the next. It is anomaly analysis, rather than residual maps, that determine correct zero datums.

Bullard (1967) discussed the two methods used to eliminate the regional anomaly or, that not being possible, to reduce its contribution in a small area to a minimum. The first method is based on the data from an aeromagnetic survey, as explained by richards, Vacquier, and Van Voorhis (1967) and by Bhattacharyya and Leu (1975). For example, survey data for the Hot Creek Range retion of south-central Nevada (U.S. Geological Survey, 1968) were sampled at 1.61-km intervals to define the regional anomaly used to prepare residual anomalies B of figure 8 and B of figure 9: and survey data from Tularosa Valley area were sampled at 5-km intervals to define the regional anomaly used to prepare the residual map of figure 7.

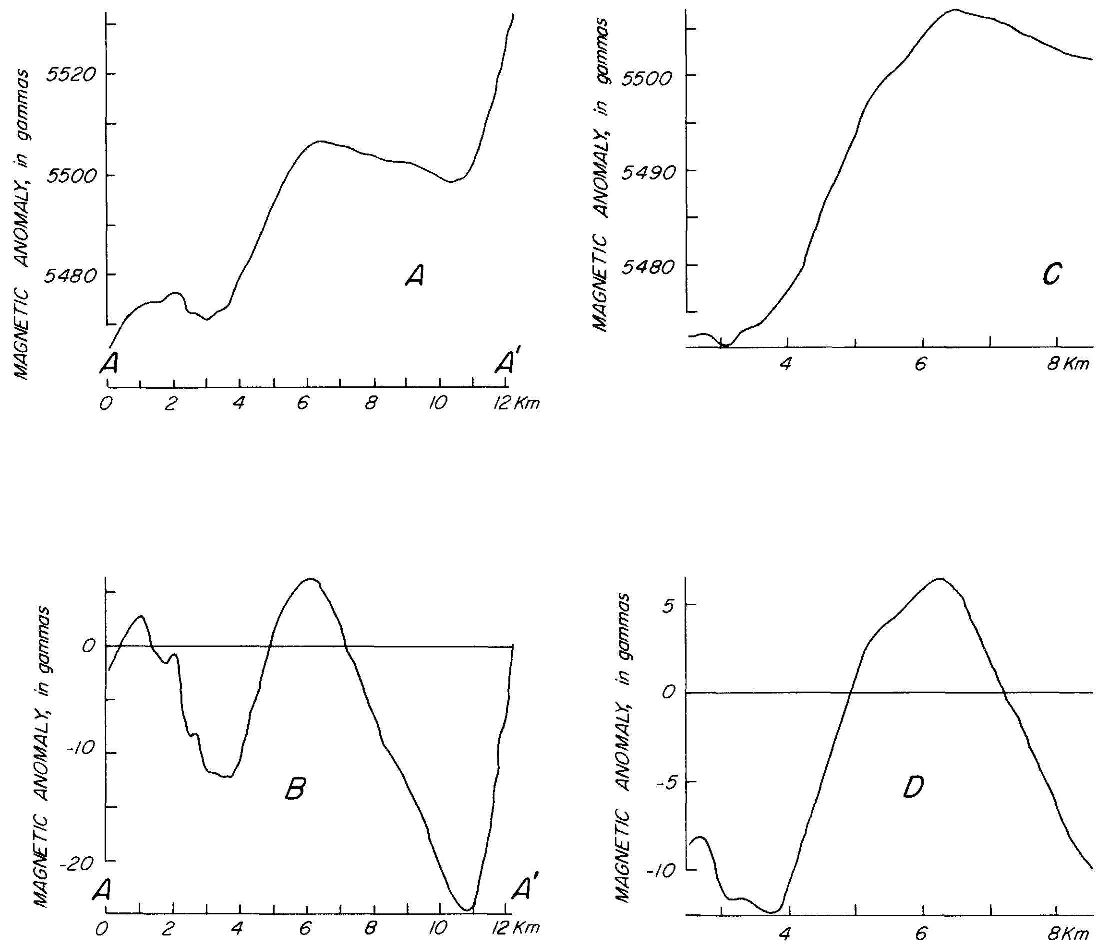

Figure 8.--Observed anomalies, A and C, and residual anomalies, B and D, along profile A-A' of figure 5. Anomalies A and B are displayed over a 12-km interval, and anomalies C and D are displayed over a 6-km interval. Anomalies C and D are produced by normally magnetized rock.

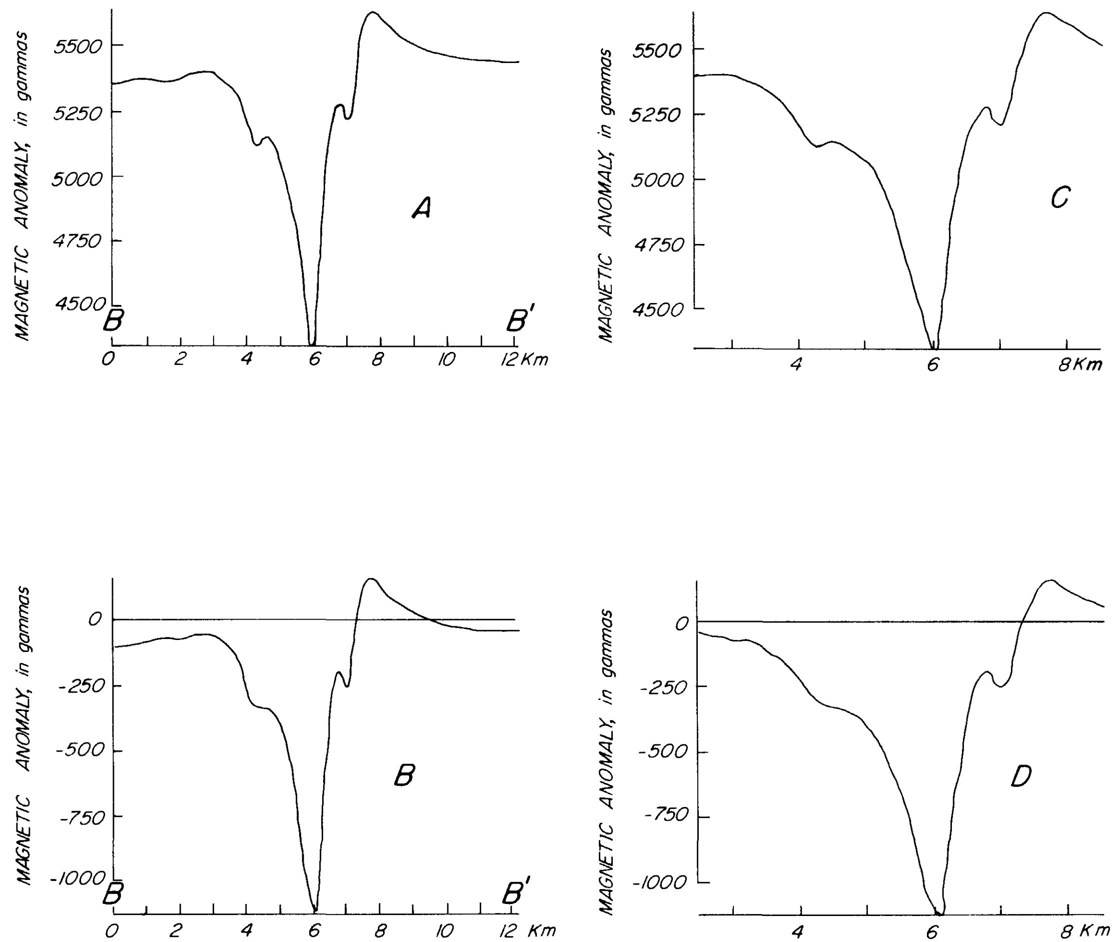

Figure 9.--Observed anomalies, A and C, and residual anomalies, B and D, along profile B-B' of figure 5. Anomalies A and B are displayed over a 12-km interval, and anomalies C and D are displayed over a 6-km interval. Anomalies C and D are produced by normally magnetized rock.

The second method is based on knowledge of the Earth's magnetic field that has been acquired from observations taken all over the world in recent years. Grid values for the Earth's field every 2° of latitude and longitude have been tabulated by Fabiano and Peddie (1969), and these are the values that were used to convert the observed data from the Tularosa Valley survey into the three residual-anomaly profiles shown in figure 10. These profiles have zero datums that are 180 gammas lower than those derived from the first method and shown as profiles A-A', B-B', and C-C' on figure 7. The first method gives a datum that is nearest zero over areas of little or no anomaly and areas of thick accumulation of nonmagnetic rock. Sauck and Sumner (1970) used the second method to prepare the residual aeromagnetic map of Arizona, and they stated that the zero datum should be raised 400 gammas.

Removing regional effects can help t sort out and identify individual magnetic anomalies from complex anomaly patterns found in some valley surveys. It is these individual anomalies that are displayed and analyzed to estimate the depth and geologic structure of buried magnetized rock. In figure 8, removing the regional from observed anomaly A over a 12-km interval identifies positive residual anomaly B, which is displayed for analysis over a 6-km interval as anomaly D; in figure 9, removing the regional from observed anomaly A over a 12-km interval identifies negative residual anomaly B, which is displayed over a 6-km interval as anomaly D. But anomaly D, of figure 9, is still considered a complicated anomaly, and display over a 3-km interval is required for the analysis made in A of figure 12.

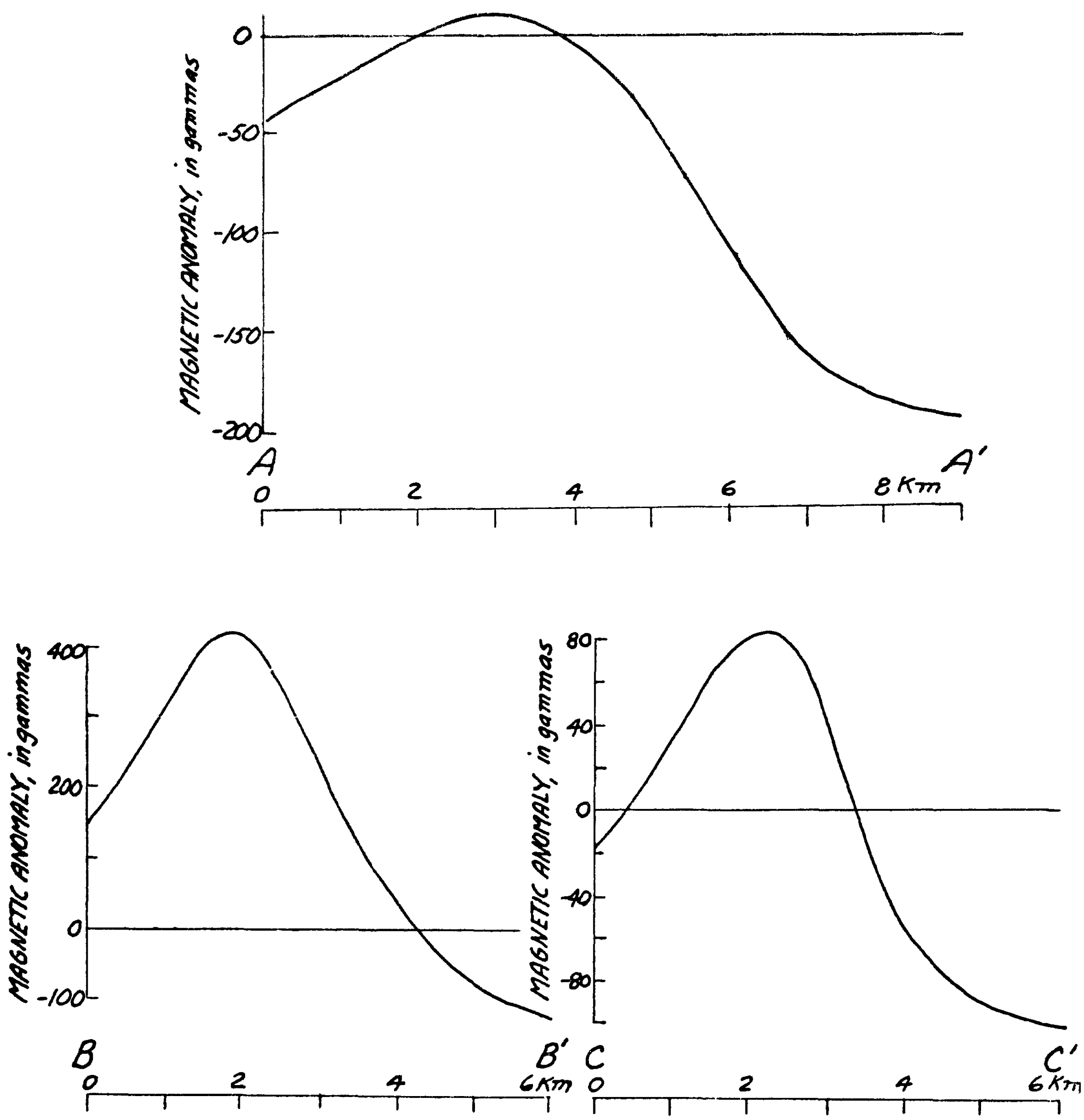

Figure 10.--Residual anomalies along profiles A-A', B-B', and C-C' of Tularosa Valley (fig. 7). These anomalies were computed by the second method, whereas anomalies of figure 7 were computed by the first method. The two methods are described on p. 16-19.

ANALYSIS OF MAGNETIC ANOMALIES

There is a remarkable difference between anomalies over Little Fish Lake Valley (fig. 6) and anomalies over Tularosa Valley (fig. 7). This indicates a significant difference in geology and magnetization, as the maps cover the same size areas and surveys were flown at similar heights and spacings. Little Fish Lake anomalies are numerous, having either positive or negative amplitudes and narrow wavelengths of a few kilometres. However, there are only two prominent anomalies over the portion of Tularosa Valley shown in figure 5, and they have large positive amplitudes and broad wavelengths of several kilometres. Anomalies arising from ash or lava flows are positive or negative in amplitude owing to direction of remanent magnetization, are numerous owing to complexity of geologic structure, and are narrow of wavelength owing to small thicknesses. Large intrusive masses give rise to anomalies that are positive due to induced magnetization in the direction of the Earth's field, that are few owing to mass size, and that are broad owing to large thicknesses. Ekren and others (1974) described the rock units present in the area of Little Fish Lake Valley and their geologic sections cross the valley at drill holes UCe-12a, UCe-9, and UCe-10 (fig. 5).

In most valley studies, the objects of prime interest are the individual anomalies that are analyzed for the purpose of gaining information about the depth and geologic structure of buried magnetized rocks. In general, shallow magnetic sources give sharp anomalies and deep magnetic sources give broad anomalies. Numerous simple rules have been introduced to determine depth or some other dimension of the anomaly source (Vacquier and others, 1951; Grant and West, 1965). Most of these simple rules are made in accordance with some property of an anomaly and are calculated from models of varying depth, length, width, thickness, or magnetization. Often a property consists of the horizontal distance between two critical points of the anomaly.

More rigorous methods for analysis of individual anomalies include those developed by Koulomzine, Lamontagne, and Nadeau (1970), McGrath and Hood (1970), Naudy (1970), Johnson (1969), and Grant and Martin (1966). Filatov (1969), Talwani (1965), and many other investigators have developed methods for checking results of analysis by comparing observed anomalies with theoretical anomalies. The method of Koulomzine, Lamontagne, and Nadeau (1970) is applied to valley surveys because, as mentioned by Grant (1972), it has evolved over the past 50 years in a steady flow of published articles in geophysical journals, it is free of special assumptions, and it is easy to perform.

The Koulomzine method uses conjugate points on a residual magnetic anomaly to decompose an anomaly into symmetrical and antisymmetrical components. These components are then analyzed to obtain parameters that include depth, width, and magnetization inclination of the anomaly-producing model. Figure 11 was prepared to illustrate the application of Koulomzine's method, combined with the earlier method of Powell (1967), to the magnetic fields computed for four models. Models C and D may be of special interest because they were published by Vacquier, Steenland, Henderson, and Zeitz (1951) as their figures A61 and A63, respectively. Table 2 was prepared to illustrate how well the actual model parameters can be recovered through anomaly analysis. The Koulomzine method was designed for a dike of great length and thickness, and results are good for the dikelike model A. Results are acceptable for very thick prisms B and C, but correction must be applied to the depth obtained for the thin prism D. Geophysicists use thin prisms to represent configurations of geologic features like the ash and lava flows of the Little Fish Lake Valley area.

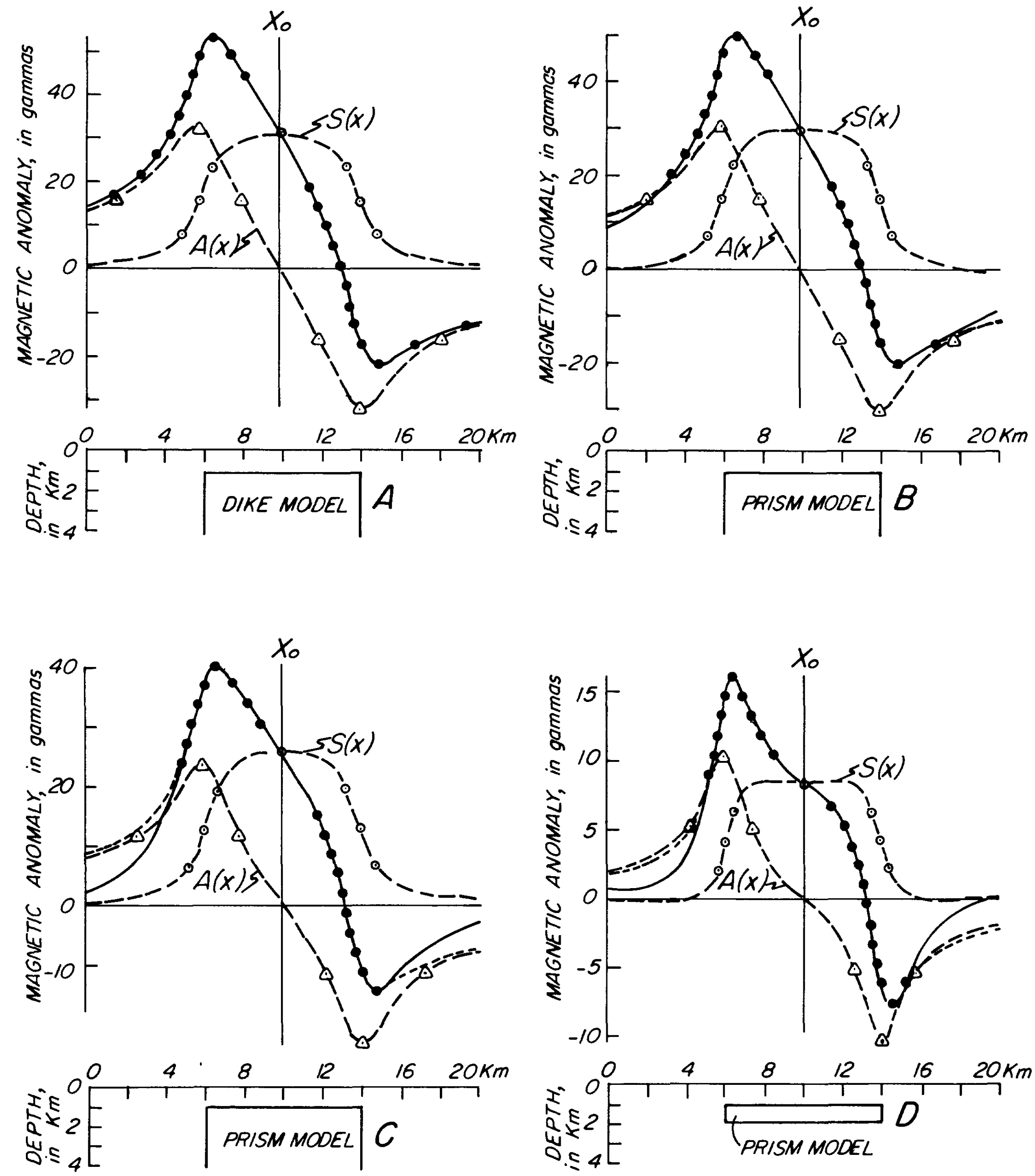

Figure 11.--Analysis of four computed anomalies to determine depth, width, and magnetization direction of anomaly-producing models. Small solid circles are the conjugate points used to decompose anomalies into symmetrical, S(X), and antisymmetrical, A(X), components. These components are then analyzed separately using points indicated as small open circles and triangles. Models A, B, C, and D are at a depth of 1 km, and they have dimensions as described on table 2.

Table 2.--Depth and widths of models and inclinations of magnetization that were determined by applying Koulomzine's method to computed anomalies of figure 12

[The anomalies were computed for models 8 km wide, having lengths and thicknesses as listed, buried to a depth of 1 km, and magnetized at an intensity of $1X10^{-4}$ cgs/cm^3 along the Earth's magnetic field, which is inclined at 62^o.]

Model				Parameters determined by analysis		
Name	Designation in figure 12	Length (km)	Thickness (km)	Depth (km)	Width (km)	Inclination of magnetization (degrees)
Dike	A	32	infinite	0.980	7.90	66
Prism	B	16	infinite	.875	7.95	67
Prism	C	8	7	.815	7.75	71
Prism	D	8	1	.360	7.85	68

The contours of figure 6 show negative magnetic anomalies along profile B-B' of figure 9 and also over the highlands east of the valley. Anomaly analysis indicates the presence of reversely magnetized rocks that are 225 m below the surface at profile B-B' (fig. 12A) and at or near the surface east of the valley. Ekren and others (1974) reported exposures of volcanic flows east of the valley; magnetic properties designate some of these flows as reversely magnetized, and it is likely that a thick volcanic flow is the anomaly producer that is buried out in the valley beneath profile B-B'.

The contours of figure 7 show positive magnetic anomalies that have amplitudes of 190, 605, and 286 gammas along profiles A-A', B-B', and C-C', respectively. The only exposures mapped in the valley floor, other than alluvium, are the nonmagnetic sediments of Dane and Bachman (1965); and the nearest magnetized rocks are Cretaceous-Tertiary intrusives in the highlands east of the valley. Anomaly analysis of figure 12 indicates the presence of normally magnetized rocks that are 2,500 m deep and 2,800 m wide along profile A-A', 1,000 m deep and 1.800 m wide along profile B-B', and 750 m deep and 2,000 m wide along profile C-C'. Anomaly amplitudes are too high to be explained by the weakly magnetized Precambrian intrusives of table 2, and it is likely that the anomaly producers are Cretaceous-Tertiary intrusives buried beneath nonmagnetic alluvium and older sediments.

Mattick, Olmstead, and Zohdy (1973) pointed out that their aeromagnetic map reveals the same major structural features as their gravity map. There are some exceptions in relatively small areas where the magnetic and gravity anomalies vary in both position and pattern.

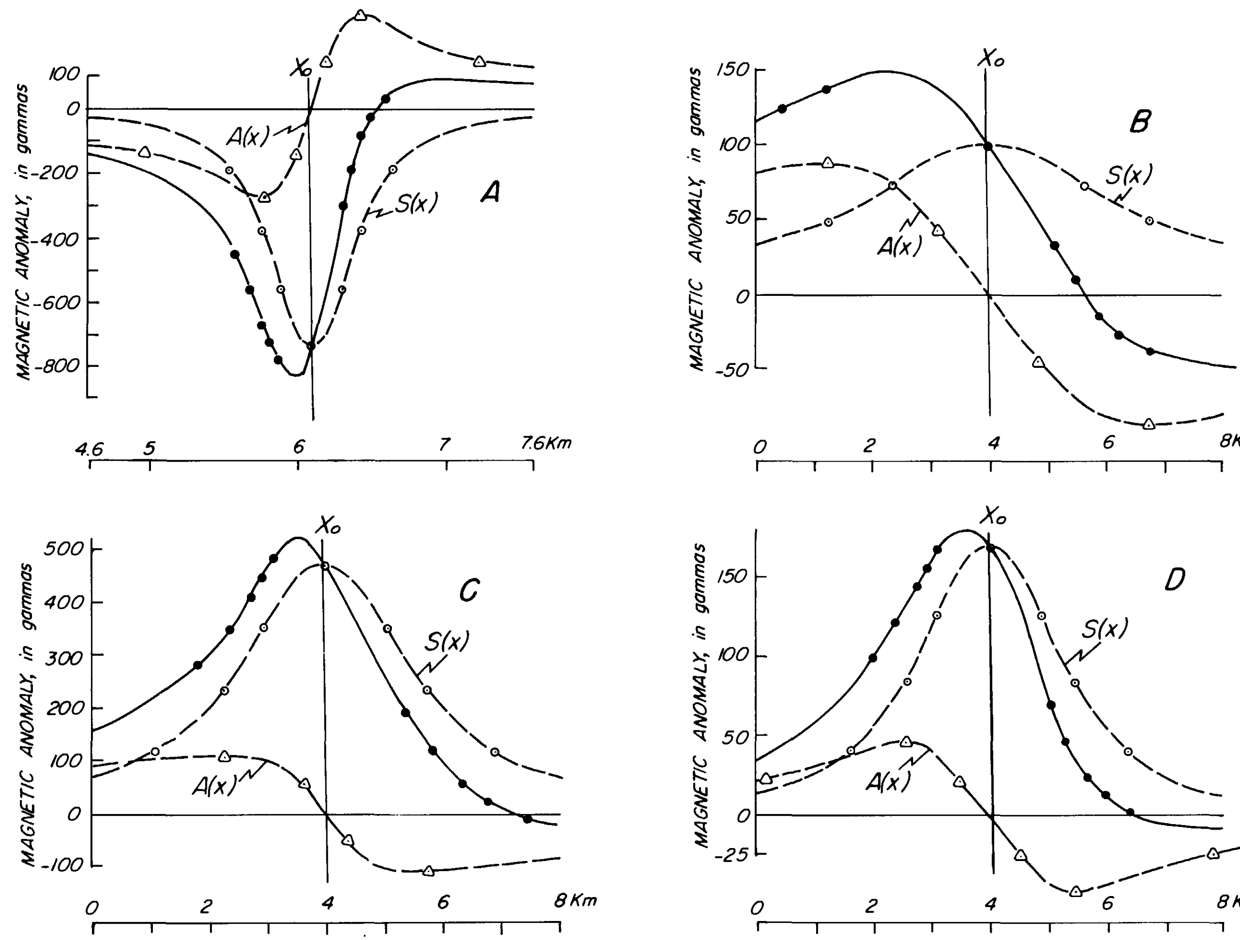

Figure 12.--Analysis of four measured magnetic anomalies by methods of Koulomzine, Lamontagne, and Nadeau (1970) to determine depth, width, and magnetization direction of buried magnetized rocks: A, anomaly along section of profile B-B' in figures 5 and 9; B, anomaly along section of profile A-A' in figures 7 and 10; C, anomaly along section of profile B-B' in figures 7 and 10; and D, anomaly along section of profile C-C' in figures 7 and 10. See figure 11 for explanation of symbols and P. 25 of text for results of analysis.

RECOMMENDATIONS FOR FUTURE SURVEYS

Aeromagnetic surveys of valley areas should be flown near the valley floor and along narrowly spaced flight lines to relate magnetic anomalies to buried geologic structure. For example, the contours in the aeromagnetic map (fig. 2) show very little relation to Yucca fault, a major structure that displaces the Rainier Mesa ash flow a vertical distance of more than 300 m in the central part of the valley. The spacing of the 23 flight lines is close, but they were flown about 1,000 m above the valley. Reducing the interval between airplane and ground surface to 150 m gives the excellent relation shown in the aeromagnetic map (fig. 13). The prominent minimum anomaly found over the high-standing side of the fault follows along the known fault trace for several kilometres beyond the limits of figure 13. An even better resolution of this relation of anomaly to fault is given in contours of the ground magnetic survey (fig. 14).

Magnetometer logging is a new technique for investigating magnetizations of rocks penetrated in uncased drill holes. The anomalies differ from those shown in aeromagnetic surveys. The magnetometer is placed very close to the rock, and this results in large and abrupt anomaly changes at tops and bottoms of magnetized units. Also, negative anomalies are found within normally magnetized units, and positive anomalies are found within reversely magnetized units.

The magnetometer logs of figure 15 are from holes UE8e-1 and UE8e, drilled at locations 60 m apart in Yucca Flat. The positive anomalies within the Rainier Mesa Member reached maxima of about 5,000 gammas. Average magnetization values for that portion of the member penetrated in each drill hole were obtained by comparing theoretical with residual anomalies. An inspection of the in-hole anomalies suggested that the member could be divided into six units of differing thickness and magnetization values. Magnetization values

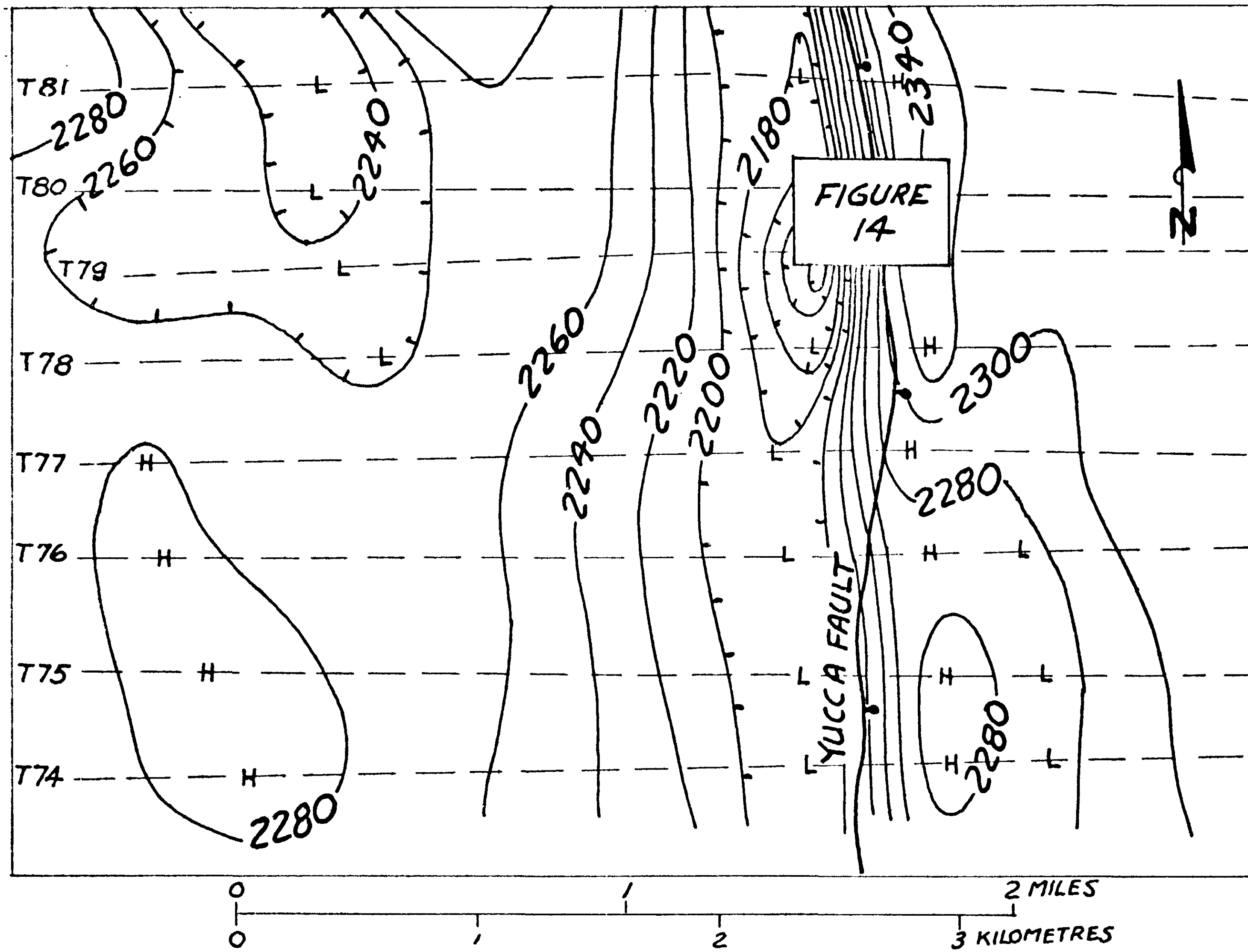

Figure 13.--Aeromagnetic map of area outlined on figure 2, showing contours at a 20-gamma interval; flight-line paths, with H marking points of maximum anomaly and L marking points of minimum anomaly; trace of Yucca fault; and outline of figure 14.

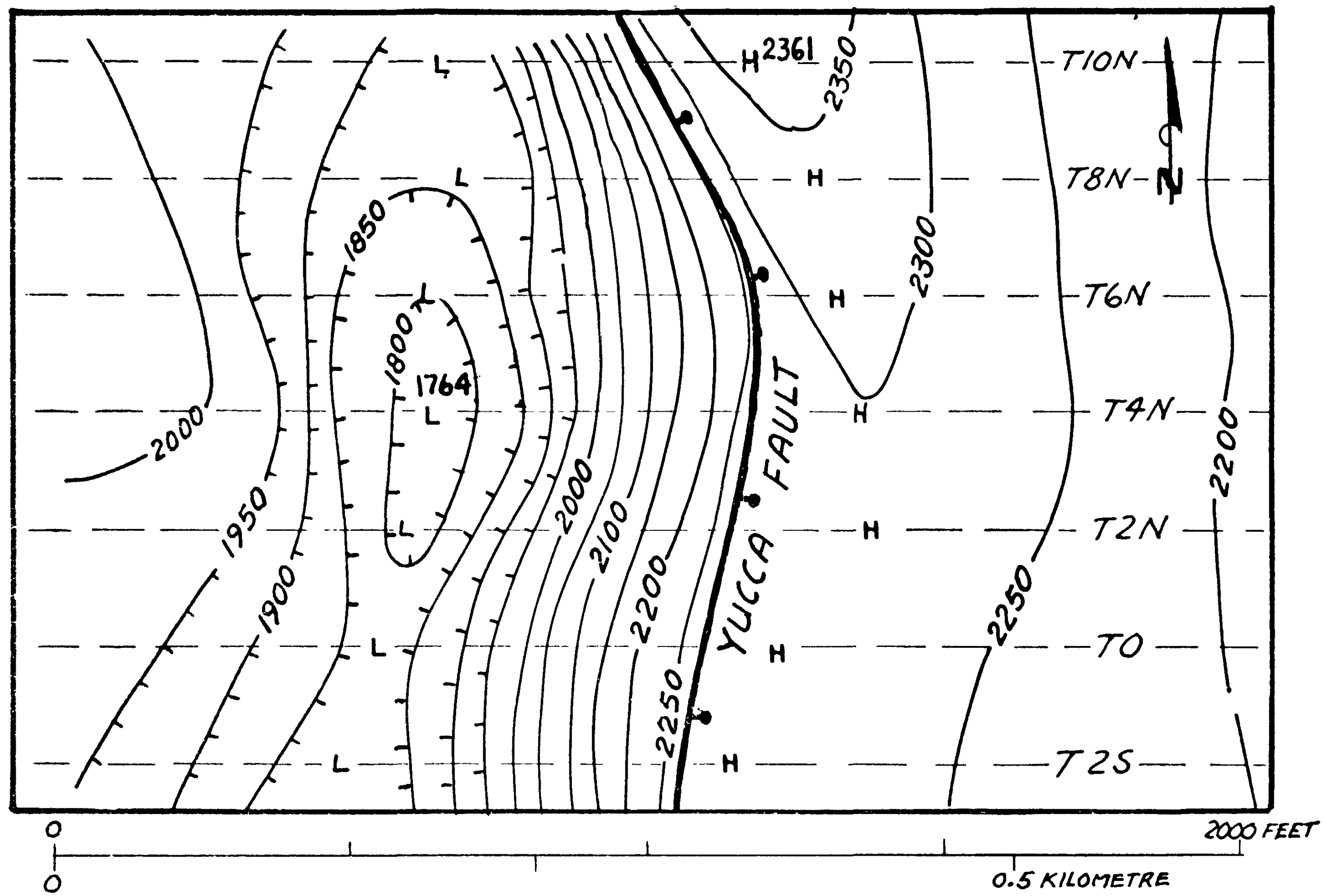

Figure 14.--Ground magnetic map of area outlined on figure 13, showing contours at a 50-gamma interval; flight-line paths, with H marking points of maximum anomaly and L marking points of minimum anomaly; and trace of Yucca fault.

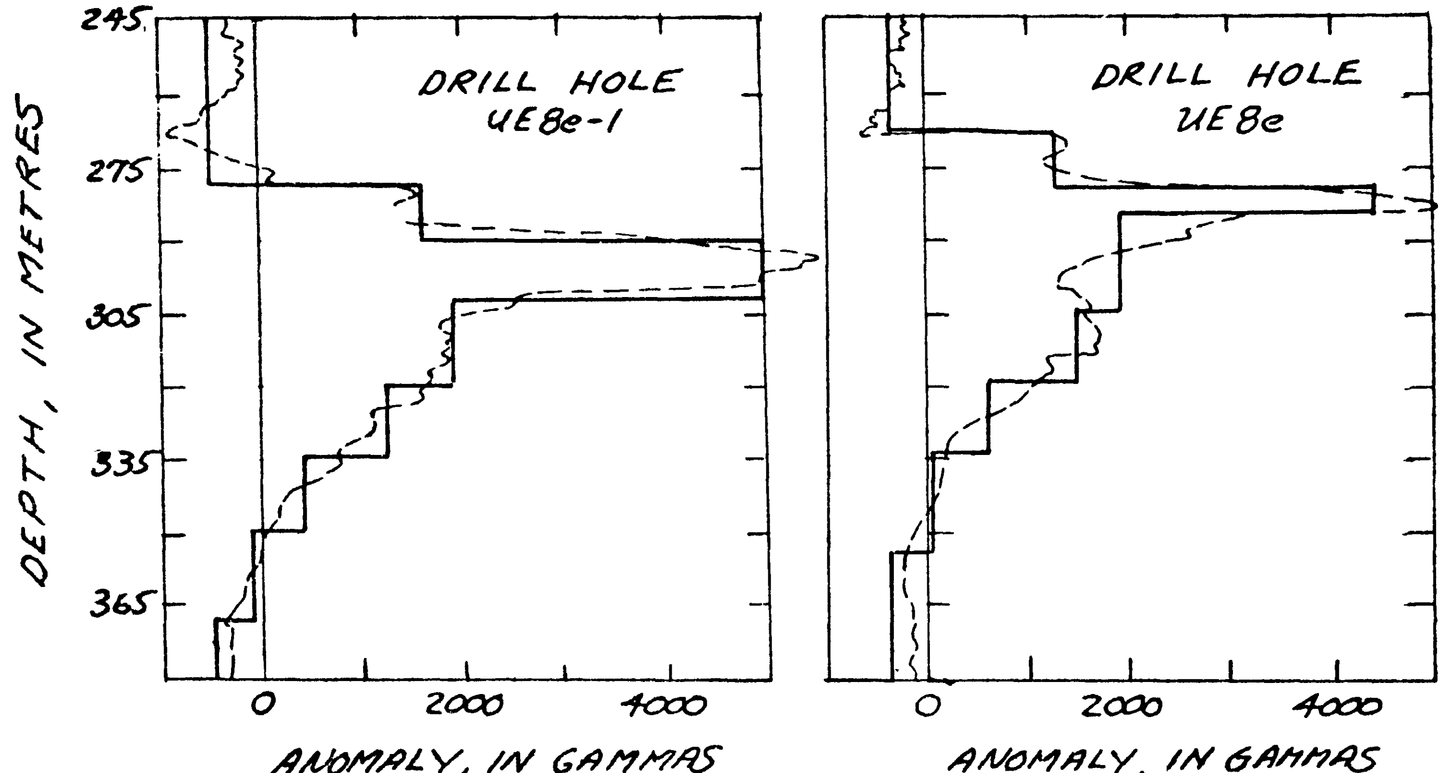

Figure 15.--Magnetic anomalies (dashed) found in drill holes UE8e-1 and UE8e that penetrated the Rainier Mesa Member, Timber Mountain Tuff at Yucca Flat, Nevada. Straight lines were drawn to approximate the shape of the anomalies, and to provide a basis for computing values of magnetization.

were then varied and theoretical anomalies computed to find the values that permitted a close comparison between theoretical and in-hole anomalies. Average intensities of magnetization were $26X10^{-4}$ cgs/cm^3 for the member penetrated in drill hole UE8e-1 and $22X10^{-4}$ cgs/cm^3 for the member penetrated in drill hole UE8e.

Interpretation of gravity along with magnetic surveys can give a better understanding of the rock structures buried in valley areas. Gravity interpretations usually determine depth and configuration of the boundary between low-density materials like alluvium and volcanic rock, and high-density materials like older sediments and intrusives (D. L. Healey, written commun., 1976); whereas magnetic interpretations determine depth and configuration of magnetized materials like volcanic flows and intrusives that may be positioned above, below, or along the low/high-density boundary. For example, the dip of the Yucca fault (fig. 2) can be estimated by analyzing (1) magnetic anomaly produced by the terminated Rainier Mesa Member to find the near-surface position and elevation of the fault, and (2) gravity anomaly produced by the faulted density boundary to find the deeper position and elevation of the fault. As another example, the residual gravity and magnetic anomalies are shown along profile A-A' of figures 1 and 16 for a distance of 215 km. Profile A-A' is drawn on figure 7 as flight line T20. The gravity and magnetic data reveal the same major structural features: higher values are over near-surface rock of figure 7 and the San Andres Mountains, and the lower values are over Tularosa Valley and Journada del Muerto. But, like the relation noted in the Yuma area by Mattick, Olmstead, and Zohdy (1973), there are local areas where gravity and magnetic anomalies vary in both position and pattern.

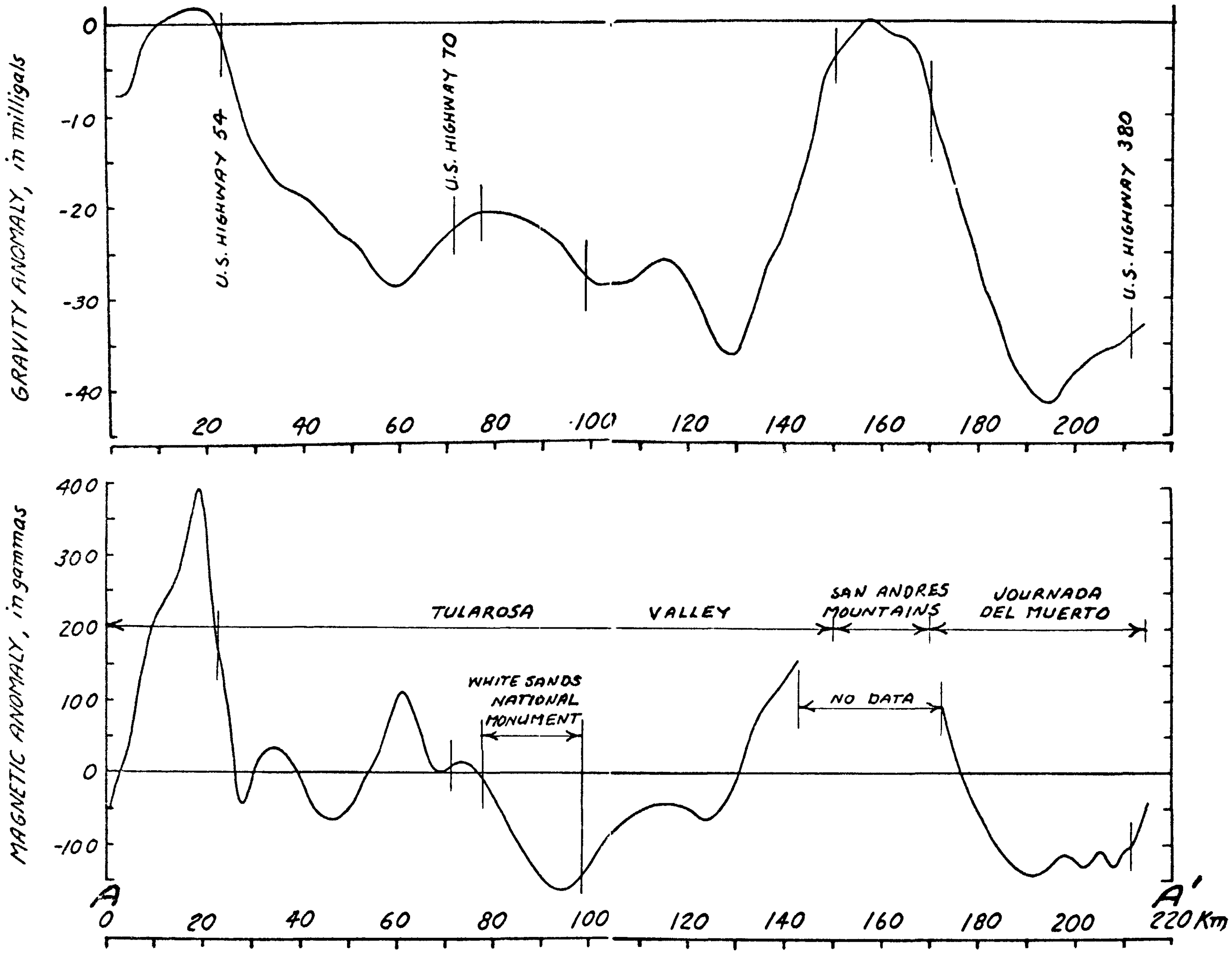

Figure 16.--Residual gravity and magnetic anomalies shown along profile A-A' of figure 1 for a distance of 215 km: starting at Texas-New Mexico line; extending northward across Tularosa Valley, White Sands National Monument, San Andres Mountains west of Mockingbird Gap, and Journada del Muerto; and ending near U.S. Highway 380.

The recommendations for future surveys can be summarized as follows:

1. Lines should be flown 150 m above the surface, 800 m apart, and perpendicular to valley's axis in order to define individual aeromagnetic anomalies. Some variance may be necessary owing to cost. Surveys that total several thousand kilometres cost at least two dollars per linear kilometre. Ground magnetic surveys are usually restricted to small areas where additional data are needed to define near-surface structural effects.

2. Magnetic properties should be investigated to identify probable anomaly-producing rocks and to determine their intensities and directions of magnetization. Early in the study, possibly during the planning stage, roughhewn samples can be collected from exposures near valley borders and from attainable drill core. In-hole magnetometer logs are particularly useful when a contour map includes anomalies that are difficult to explain with data from accessible rock samples.

3. Magnetic interpretations should be combined with geologic studies and results of gravity interpretations in the same area.

REFERENCES CITED

Barnes, Harley, Christiansen, R. L., and Byers, F. M., Jr., 1965 Geologic map of Jangle Ridge quadrangle, Nye and Lincoln Counties, Nevada: U.S. Geol. Survey Geol. Quad. Map GQ-363.

Barnes, Harley, Houser, F. N., and Poole F. G., 1963, Geologic Map of the Oak Spring quadrangle, Nye County, Nevada: U.S. Geol. Survey Geol. Quad. Map GQ-214.

Bhattacharyya, B. K., and Leu, Lei-Kuang, 1975, Analysis of magnetic anomalies over Yellowstone National Park--Mapping of Curie Point isothermal surface for geothermal reconnaissance: Jour. Geophys. Research, v. 80, no. 32, p. 4461-4465.

Boynton, G. R., Meuschke, J. L., and Vargo, J. L., 1963a, Aeromagnetic map of the Tippipah Spring quadrangle and parts of the Papoose Lake and Wheelbarrow Peak quadrangles, Nye County, Nevada; U.S. Geol. Survey Geophys. Inv. Map GP-441.

______1963b, Aeromagnetic map of the Timber Mountain quadrangle and part of the Silent Canyon quadrangle, Nye County, Nevada: U.S. Geol. Survey Geophys. Inv. Map GP-443.

Boynton, G. R., and Vargo, J. L., 1963a, Aeromagnetic map of the Topopah Spring quadrangle and part of the Bare Mountain quadrangle, Nye County, Nevada: U.S. Geol. Survey Geophys. Inv. Map GP-440.

______1963b, Aeromagnetic map of the Cane Spring quadrangle and parts of the Frenchman Lake, Specter Range, and Mercury quadrangles, Nye County, Nevada: U.S. Geol. Survey Geophys. Inv. Map GP-442.

Bullard, E. C., 1967, The removal of trend from magnetic surveys: Earth and Planetary Sci. Letters 2 (Amsterdam, North-Holland Publishing Co.), p. 293-300.

Byers, F. M., Jr., and Barnes, Harley, 1967, Geologic map of the Paiute Redge quadrangle, Nye and Lincoln Counties, Nevada: U.S. Geol. Survey Geol. Quad. Map GQ-577.

Colton, R. B., and McKay, E. J., 1966, Geologic map of the Yucca Flat quadrangle, Nye and Lincoln Counties, Nevada; U.S. Geol. Survey Geol. Quad. Map GQ-582.

Cox, Allan, 1961, Anomalous magnetization of basalt: U.S. Geol. Survey Bull. 1083-E, p. 151-160.

Dane, C. H., and Bachman, G. O., 1965, Geologic map of New Mexico; Washington, D. C., U.S. Geological Survey, 2 sheets, scale 1:500,000.

Doell, R. R., and Cox, Allan, 1962, Determination of the magnetic polarity of rock samples in the field, in Short papers in geology, hydrology, and topography: U.S. Geol. Survey Prof. Paper 450-D, p. D105-D108.

_____ 1967, Magnetization of rocks, in Theory, Volume 2 of Mining Geophysics: Tulsa, Okla., Soc. Explor. Geophysicists, p. 446-453.

Ekren, E. B., Bath, G. D., Dixon, G. L., Healey, D. L., and Quinlivan, W. D., 1974, Tertiary history of Little Fish Lake Valley, Nye County, Nevada, and implications as to the origin of the Great Basin: U.S. Geol. Survey Jour. Research, v. 2, no. 1, p. 105-118.

Fabiano, E. B., and Peddie, N. W., 1969, Grid values of total magnetic intensity IGRF-1965: U.S. Dept. Commerce ESSA Tech. Rept. C&GS-38.

Filatov, V. A., 1969, Calculation of the magnetic field of a two-dimensional body of arbitrary cross section: Akad. Nauk SSR, Ser. Fizika Zemli, no. 2, p. 82-91.

Gibbons, A. B., Hinrichs, E. N., Hansen, W. R., and Lemke, R. W., 1963, Geologic map of the Rainier Mesa quadrangle, Nye County, Nevada: U.S. Geol. Survey Geol. Quad. Map GQ-215

Grant, F. S., 1972, Review of data processing and interpretation methods in gravity and magnetics, 1964-71: Geophysics, v. 37, p. 647-661.

Grant, F. S., and Martin, L., 1966, Interpretation of aeromagnetic anomalies by the use of characteristic curves: Geophysics, v. 31, p. 135-148.

Grant, F. S., and West, G. F., 1965, Interpretation theory in applied geophysics: New York, McGraw-Hill Book Co., 583 p.

Healey, D. L., 1976, Interpretation of gravity surveys in intermontane valleys of Nevada and New Mexico: Air Force Weapons Laboratory report (in preparation).

Irving, E., 1964, Paleomagnetism: New York, John Wiley and Sons, 399 p.

Jahren, E. E., and Bath G. D., 1967, Rapid estimation of induced and remanent magnetization of rock samples, Nevada Test Site: U.S. Geol. Survey open-file report, 29 p.

Johnson, W. W., 1969, A least-squares method of interpreting magnetic anomalies caused by two-dimensional structures: Geophysics, v. 34, no. 1, p. 65-74.

Koulomzine, Th., Lamontagne, Y., and Nadeau, A., 1970, New methods for the direct interpretation of magnetic anomalies caused by inclined dikes of infinite length: Geophysics, v. 35, p. 812-830.

Mattick, F. H., Olmstead, F. H., and Zohdy, A. A. R., 1973, Geophysical studies in the Yuma area, Arizona and California: U.S. Geol. Survey Prof. Paper 726-D, 36 p.

McGrath, P. H., and Hood, P. J., 1970, The dipping dike case--A computer curve-matching method of magnetic interpretation: Geophysics, v. 34, p. 831-848.

Naudy, Henri, 1970, Une methods d'analyse fine des profils aeromagnètiques (A method of the analysis of aeromagnetic profiles): Geophys. Prosp. (Netherlands), v. 18, no. 1, p. 56-63.

Orkild, P. P., 1963, Geologic map of the Tippipah Spring quadrangle, Nye County, Nevada: U.S. Geol. Survey Geol. Quad. Map GQ-213.

Powell, D. W., 1967, Fitting observed profiles to a magnetized dike or fault-step model: Geophys. Prospect, V. 15, p. 208-220.

Richards, M. L., Vacquier, Victor, and Van Voorhis, G. D., 1967, Calculation of the magnetization of uplifts from combining topographic and magnetic surveys: Geophysics, v. 32, no. 4, p. 678-707.

Sauck, W. A., and Sumner, J. S., 1970, Residual aeromagnetic map of Arizona: Tucson, Ariz., Univ. Arizona, Dept. Geosciences, scale 1:1,000,000 (1971).

Talwani, M., 1965, Computation with the help of a digital computer of magnetic anomalies caused by bodies of arbitrary shape: Geophysics, v. 30, p. 797-817.

U.S. Geological Survey, 1968, Aeromagnetic map of the Hot Creek Range region south-central Nevada: U.S. Geol. Survey Geophys. Inv. Map GP-637.

Vacquier, Victor, Steenland, N. C., Henderson, R. G., and Zietz, Isidore, 1951, Interpretation of aeromagnetic maps: Geol. Soc. America Mem. 47, 151 p.