U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

MAGNETIC INVESTIGATIONS ALONG SELECTED HIGH-RESOLUTION SEISMIC TRAVERSES IN THE CENTRAL BLOCK OF YUCCA MOUNTAIN, NEVADA

By

D.A. Ponce, R.F. Sikora, C.W. Roberts, R.L. Morin, and P.F. Halvorson

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D.A. Ponce, R.F. Sikora, C.W. Roberts, R.L. Morin, and P.F. Halvorson [1]

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[1] All at U.S. Geological Survey, Menlo Park, CA

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ABSTRACT

Ground magnetic data collected along several traverses across the central block of Yucca Mountain in southwest Nevada are interpreted. These data were collected as part of an effort to evaluate faulting in the vicinity of a potential nuclear waste repository at Yucca Mountain. Magnetic data and models along traverses across the central block of Yucca Mountain reveal anomalies associated with known faults and indicate a number of possible concealed faults beneath the eastern flank of Yucca Mountain. The central part of the eastern flank of Yucca Mountain is characterized by numerous small-amplitude anomalies that probably reflect small-scale faulting. Magnetic modeling of the terrain along the eastern flank of Yucca Mountain indicates that terrain-induced magnetic anomalies of about 100 to 150 nT are present along some profiles where steep terrain exists above the magnetometer.

INTRODUCTION

Magnetic investigations of the central block of Yucca Mountain were begun as part of an effort to help characterize faulting near a potential nuclear waste repository at Yucca Mountain. The study area is about 80 mi northwest of Las Vegas in the southwest quadrant of the Nevada Test Site (NTS) and is bounded by Crater Flat to the west, Yucca Wash to the north, Midway Valley to the east, and Amargosa Valley to the south (fig. 1). Magnetic data and interpretations are reported along selected lines coincident with high-resolution seismic traverses (E. Majer and others, Lawrence Berkeley Laboratory, written commun., 1995).

GENERAL GEOLOGY

The geologic units that underlie the study area are listed in table 1 and consist of Precambrian and Paleozoic rocks, a series of Miocene ash-flow tuffs interbedded with relatively thin ash-fall and re-worked tuffs, and late Tertiary and Quaternary surficial deposits. Pre-Cenozoic sedimentary and metamorphic rocks in the study area are predominantly limestone and dolomite, with lesser amounts of argillite, quartzite, and marble (U.S. Geological Survey, 1984). Paleozoic rocks are exposed in the northeastern part of the study area at Calico Hills (Frizzell and Shulters, 1990). The Lone Mountain Dolomite and the Roberts Mountain Formation were penetrated in drill-hole UE-25p#1 (Carr and others, 1986) (fig. 1) at depths of 1,244 and 1,667 m, respectively (Muller and Kibler, 1984).

In ascending order the Cenozoic volcanic units at Yucca Mountain include: (1) older ash-flow tuffs, (2) Lithic Ridge Tuff, (3) Crater Flat Group, (4) Calico Hills Formation, (5) Paintbrush Group, and (6) Timber Mountain Group (Sawyer and others, 1994). The Crater Flat Group is composed of the Tram, Bullfrog, and Prow Pass Tuffs; the Paintbrush

Group is composed of the Topopah Spring, Pah Canyon, Yucca Mountain, and Tiva Canyon Tuffs; and the Timber Mountain Group is composed of the Rainier Mesa and Ammonia Tanks Tuffs. The Volcanics of Fortymile Canyon, which are younger than the tuff sequence exposed at Yucca Mountain, occur northeast of Yucca Wash. Ash-flow tuffs in the area vary from densely welded to partially welded tuffs. Moderately to densely welded tuffs include the Topopah Spring and Tiva Canyon Tuffs of the Paintbrush Group. Otherwise, the majority of the tuffs are partially welded to non-welded.

MAGNETIC PROPERTIES

Magnetic properties of various volcanic rocks were described by Bath (1968), Bath and Jahren (1984), and Rosenbaum and Snyder (1985). A summary of the physical properties used in the magnetic models is shown in table 2. Previous studies have shown that remanent magnetization is responsible for causing most of the magnetic anomalies present within the Nevada Test Site and vicinity (Bath, 1968; Bath and Jahren, 1984). In particular, many of the north-trending linear magnetic anomalies are caused by vertical offset of the moderately to highly magnetic Topopah Spring Tuff (Bath and Jahren, 1984). In general, magnetic highs occur over the upthrown block. The averaged values listed in table 2 do not take into account the widely varying magnetization of some units.

MAGNETIC DATA

Detailed magnetic data are reported along six profiles across the central block of Yucca Mountain (fig. 1). Ground magnetic data were collected with the sensor at 2.4 m above the surface with a nominal spacing of about 16 paces or about 12 m. The maximum station spacing was about 20 paces or about 18 m while minimum spacing was 1 pace or about 1 m. Locations of magnetic stations between surveyed points were determined by interpolation using the number of paces and the distance between surveyed points.

Geometrics proton precession magnetometers were used to collect the data. Because the anomalies of interest were believed to be small (20 to 50 nT) and the profile lines were long, a base-station magnetometer was used, or a temporary base along the traverse was periodically re-occupied during the survey to make corrections for diurnal variations of the Earth's magnetic field. The base-station magnetometer was located near the center of the study area in the southern part of Midway Valley and readings were typically recorded at about 1-minute intervals. Magnetic observations are accurate to about 1 nT (nanotesla).

Magnetic station locations were surveyed by Raytheon Services Nevada at a 12-m interval for lines 2 through 9 and at about a 50-m interval for line 10. Survey data for lines 2 through 9 were available in both geographic and Nevada State Plane coordinates, whereas line 10 was available only in geographic coordinates. Distances between surveyed stations along line 10 were determined by projecting the data to a Cartesian coordinate system using a Transverse Mercator projection.

METHODOLOGY

Because detailed interpretations of geophysical data can be somewhat subjective, we present an account of the methodology used to infer faulting and the inherent limitations of geophysical modeling. Observed detailed gravity and magnetic profiles were compared to geologic and structural information, primarily displayed on the geologic map of Yucca Mountain by Scott and Bonk (1984). This comparison yields information on the geophysical signature of known faults, fractures, structures, and of the various volcanic formations at Yucca Mountain. The geophysical signatures of known features combined with theoretical signatures or modeling can then be used to infer the location of unknown or concealed features.

An aeromagnetic anomaly map of the study area (fig. 2) is also shown to provide the regional magnetic framework of the detailed profiles across the central block of Yucca Mountain. The aeromagnetic map was derived from the Timber Mountain aeromagnetic survey (U.S. Geological Survey, 1979). Previous studies have shown that north-trending en echelon magnetic anomalies correlate to major down-to-the-west normal faults at Yucca Mountain (Kane and Bracken, 1983) including the Solitario Canyon and Bow Ridge faults (fig. 1). Major anomalies in the northeast part of the study area correlate to outcrops of the Topopah Spring Tuff, the major anomaly-producing unit in Yucca Mountain and vicinity. In addition, Bath and Jahren (1984) suggested that an east-trending magnetic anomaly across Yucca Mountain may be related to altered argillite at depth.

The magnetic effect of a fault is complex due to the inherent directional nature of rock magnetism and the fact that total magnetization is composed of induced and remanent effects. The induced magnetization is in the direction of the Earth's present magnetic field, whereas the remanent magnetization can be in a completely different direction. The magnetic effect of down-to-the-west and down-to-the-north vertical faults with infinite offset was illustrated by Bath and Jahren (1984) by modeling the four main anomaly-producing units that occur at Yucca Mountain (fig. 3). Bath and Jahren (1984) modeled the effect of these units for both east- and north-striking faults. The four units in the model are the Tiva Canyon Tuff, Topopah Spring Tuff, Bullfrog Tuff, and Tram Tuff, and their physical properties are described in table 2. The model is based on the magnetic properties and thickness of the tuff units penetrated in drill hole USW G-1 (Spengler and others, 1981; Rosenbaum and Snyder, 1985). The shape and amplitude of the anomalies are also applicable for down-to-the-east or down-to-the-south faults by simple rotation of 180° about the zero point of the horizontal axis. An important result of these models is that the overriding or dominant magnetic signature of a normal fault at Yucca Mountain and vicinity is caused by the Topopah Spring Tuff.

In summary, two geophysical fault models have been used to infer faulting on the eastern flank of Yucca Mountain: a down-to-the-west (or north) fault model and a fault-zone model. For north-south trending faults along east-west profiles, the down-to-the-west fault model is characterized by a magnetic low on the down-thrown block and a magnetic high on the upthrown block as shown in figure 3a. Although not shown, gravity data across north-trending faults along east-west profiles are characterized by a gravity low on the west or downthrown block and a gravity high on the east or upthrown block. Similarly, for east-trending faults along north-south profiles, the down-to-the-north fault model is characterized by a magnetic low of higher amplitude on the downthrown block and a magnetic high of lower amplitude on the upthrown block (fig. 3b) as compared to north-trending faults.

The fault-zone model is characterized by both gravity and magnetic lows, exemplified by the gravity and magnetic signatures over the Ghost Dance fault along Antler and Live Yucca Ridges described by Ponce and Langenheim (1995, figs. 3b and 3d). The gravity low results from a decrease in density caused by brecciation along the fault zone, and the magnetic low results from a loss of magnetization caused by alteration. Although the authors recognize that other fault types may be present along the eastern flank of Yucca Mountain, such as down-to-the-east and strike-slip faults, these faults have not been inferred because most geophysical and geologic data indicate that most faults are north-trending and down-to-the-west.

As an aid to the reader, three levels of confidence for interpretation of possible faulting are indicated by bold-, medium-, and fine-width lines that denote high-, medium-, and low-confidence levels, respectively. High-confidence faults are those that correlate to three or more lines of evidence such as magnetic, gravity, or geologic information. Medium-confidence faults are those that correlate to two of the following lines of evidence: magnetic, gravity, or geologic information. Finally, low-confidence faults correlate to only one of the lines of evidence. In a few cases, the confidence level of a possible fault was increased if the geophysical signature was prominent.

In order to isolate anomalies of interest and to smooth the raw magnetic data, a simple filtering or smoothing technique was used to facilitate interpretation of the data. Extremely short-wavelength anomalies, shorter than those of interest, were suppressed by applying a five-point weighted running average to the data. In general, the short-wavelength anomalies are probably related to lateral changes in magnetization or to randomly oriented near-surface rocks. More sophisticated filtering techniques to suppress short-wavelength anomalies such as bandpass filtering or upward continuation could also be applied to the data. However, tests show that the five-point weighted average give results very similar to these techniques.

INTERPRETATION

EAST-WEST PROFILES 3, 4, AND 9

Profile 3 (fig. 1) is about 3.8 km in length, extends eastward from the crest of Yucca Mountain, along the south-facing slope of an unnamed ridge immediately south of Antler Ridge, then along a south-southeast-trending unnamed wash, and ends on the east side of an extension of Bow Ridge called Muck Pile Hill. Magnetic data along the eastern part of line 3 (fig. 4) reveal a 150-nT anomaly centered about 120 m west of the mapped location of the Bow Ridge fault (Scott and Bonk, 1984). The location of the magnetic anomaly is similar to that previously shown by Ponce and others (1994, figs. 2c and 2d) where a 180- to 250-nT anomaly is centered about 100 m west of the mapped location of the Bow Ridge fault. This anomaly probably reflects the position of the top of the Topopah Spring Tuff, the major magnetic anomaly-producing unit at Yucca Mountain, in the downdropped block. Alternatively, this may be an indication of reversely magnetized Rainier Mesa Tuff in the downdropped block. Gravity data across the Bow Ridge Fault along line 3 reduced by V.E. Langenheim (U.S. Geological Survey, written commun., 1995) are also similar to data collected along other traverses across the Bow Ridge fault and yield a fault location that is coincident with the mapped location of the Bow Ridge fault (Scott and Bonk, 1984). The western part of profile 3, along the south slope of an unnamed ridge from about station 3-101 to 3-181 (distance from 0 to 950 m), is difficult to interpret because of possible magnetic terrain effects. The profile section along a wash from about 3-181 to 3-221 (distances from 950 to 1,400 m) also includes magnetic terrain effects caused by reversely magnetized rocks along ridges above the sensor. However, within this section a magnetic signature across the Ghost Dance fault can be identified with the aid of its mapped location (Scott and Bonk, 1984). The observed magnetic low across the Ghost Dance fault (Spengler and others, 1993) is similar to and characteristic of previously collected profiles along the fault (Ponce and Langenheim, 1994). Geophysical modeling across the Ghost Dance fault along Antler Ridge indicate vertical offsets of the volcanic section of about 50 m (Ponce and Langenheim, 1995). Magnetic data reveal the presence of other magnetic anomalies that are related to possible small-scale faulting or changes in magnetic properties, most of which correlate to mapped faults (Scott and Bonk, 1984).

Traverse 4 (fig. 1) is about 4.0 km in length and is about 1.2 km north of and parallel to line 3. Line 4 extends eastward from the crest of Yucca Mountain, along the north-facing slope of an unnamed ridge immediately south of Live Yucca Ridge, then south-southeast along Split Wash, and ends in the southern part of Midway Valley. The magnetic expression of the Bow Ridge fault (fig. 5) is nearly identical to that of line 3. The magnetic signature of the Ghost Dance fault along line 4 is obscured by a broad magnetic high mostly to the west of the fault that is related to magnetic terrain effects caused by reversely magnetized volcanic rocks above the sensor. In addition, the mapped location of the north-northwest-trending

Sundance fault (R. Spengler, U.S. Geological Survey, written commun., 1995) intersects line 4 at the same location as does the Ghost Dance fault and may contribute to masking the magnetic effect of the Ghost Dance fault. A number of other magnetic anomalies may indicate the presence of small-scale faulting, alteration, or lateral changes in magnetic properties.

Using the properties of the Tiva Canyon Tuff (table 2) to create a magnetic terrain model along the entire east flank of Yucca Mountain we can estimate the magnetic effect of the terrain above the magnetic observations. Along lines 3 and 4 (fig. 1), modeling reveals that the magnetic terrain above the sensor produces a 100- to 150-nT high along parts of the profile. The effect is most pronounced in the central part of these traverses where the magnetometer was below steep canyon walls. These terrain-induced anomalies are of the same order of magnitude as the observed 150- to 200-nT high thought to be related to terrain effects located just east of the Ghost Dance fault on line 3 (fig. 4) and west of and including the Ghost Dance Fault on line 4 (fig. 5).

Line 9 (fig. 1) is about 1.2 km in length and entirely within Drill Hole Wash in the northern part of Yucca Mountain. The position of the profile within the wash and away from nearby terrain minimizes the difficulty of interpreting magnetic data that contain terrain effects. Two magnetic spikes (fig. 6) at stations 9-198 and 9-170 at distances of 25 and 400 m are caused by proximity of the traverse to metal casing in drill holes USW UZ-14 and USW G-1, respectively. A prominent magnetic anomaly is associated with a mapped fault (Scott and Bonk, 1984) near station 9-145 at a distance of about 700 m. A preferred location of the fault based on the magnetic effect of a down-to-the-west fault model (fig. 3a) is at the inflection of the magnetic profile near station 9-137 at a distance of about 800 m along the profile. Other mapped faults are shown along the profile as are faults or changes in magnetic properties inferred from the magnetic data.

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NORTH-SOUTH PROFILES 5, 10, AND 2

In general, north-trending profiles yield less geologic information than east-trending profiles because they parallel most geologic features or structures at Yucca Mountain. However, there may be a number of northwest-trending geologic features associated with some of the major washes at Yucca Mountain, such as Yucca Wash and Drill Hole Wash in the northern part of the study area. This suggests the possibility that other washes may be controlled by geologic features. In addition, some north-northeast- or north-northwest-trending segments of generally north-trending faults may obliquely intersect the north-south profiles.

Profile 5 (fig. 1) is about 4.6 km in length and extends along most of Yucca Mountain Crest from just north of drill hole USW H-3 to Little Prow. Magnetic data along line 5 (fig. 7) primarily reflect a long-wavelength feature from station 5-117 to 5-401 whose source is at intermediate depths of about 1.5 to 2 km below the surface. This regional anomaly is present in an aeromagnetic map of the study area (fig. 2) and was previously discussed by Kane and Bracken (1983) and Bath and Jahren (1984, 1985). The regional aeromagnetic anomaly trends nearly east-west and may mark the southern extent of an inferred magnetic argillite of the Eleana Formation of Mississippian age, similar to that exposed at Calico Hills.

Line 5 is nearly coincident with a traverse collected by Bath and Jahren (1985, A82, fig. 4) and is nearly identical to it. Bath and Jahren (1985) indicated that a lateral change from weak to moderate magnetization is revealed for the Tiva Canyon Tuff by abrupt changes in the magnetic anomalies. However, we suggest that the change in magnetic character north of drill hole USW H-5 at a distance of about 3,100 m is probably caused by a facies change in the uppermost part of the Tiva Canyon Tuff rather than a change in the magnetic properties of any particular tuffaceous unit. This is supported by geologic data that show that volcanic rock units are downdropped by faulting in the northern part of the crest of Yucca Mountain revealing a cap rock unit of the Tiva Canyon Tuff exposed at the surface (R. Spengler, U.S. Geological Survey, oral commun., 1995). The cap rock is probably moderately magnetic and the cause of the change in magnetic character along the profile.

Traverse 10 (fig. 1) is about 4.2 km in length, extends nearly due north from Abandoned Wash, across a number of ridges and washes, and ends in Split Wash at drill hole USW H-1. Line 10 strikes along the central part of the eastern flank of Yucca Mountain and has, by far, the greatest topographic relief of any of the lines presented here. Once again, line 10 is difficult to interpret because of severe magnetic terrain effects. However, line 10 is an important traverse because it transects a number of the central block lines and could be used to level all the ground magnetic data to a common datum. The correlation of magnetic anomalies to mapped faults by Scott and Bonk (1984) is shown in figure 8.

Line 2 (fig. 1) is about 3.2 km in length, extends north-northeast from west of Bow Ridge to just south of Exile Hill, then bends due north to just west of the northern part of Exile Hill. Because most of line 2 is positioned over alluvium in an area of low relief, there are few magnetic terrain effects. Several mapped faults (Scott and Bonk, 1984) correlate with observed magnetic anomalies (fig. 9), especially at distances of about 200, 550, and 2,000 m. The magnetic feature between distances of about 2,000 to 2,400 m is actually caused by a single fault that crosses the profile twice due to a bend in the profile. Magnetic anomalies reveal the presence of of other possible small-scale faults, alteration, or lateral changes in the physical properties of rock units.

CONCLUSIONS

Magnetic data and models along traverses across the central block of Yucca Mountain reveal anomalies associated with known faults and indicate a number of possible concealed faults beneath the eastern flank of Yucca Mountain. The central part of the eastern flank of Yucca Mountain is characterized by numerous small-amplitude anomalies that probably reflect small-scale faulting. Because of the location of some of the profiles in washes with steep sides or along the flanks of ridges, magnetic terrain effects are present in the observed data, and caution should be used in any detailed interpretations.

These magnetic studies show that they are useful for delineating major faults at Yucca Mountain such as the Bow Ridge fault, intermediate faults such as the Ghost Dance fault, and minor faults such as those along the eastern flank of Yucca Mountain. Additional detailed magnetic data could provide an effective means to better define the location of known or suspected faults and to locate concealed or unknown faults.

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TABLE 1.—*Geologic names and symbols. Modified from Sawyer and others (1994)*

Name of Unit	Symbol
Quaternary	
Alluvium and colluvium	Qac
Miocene[1]	
Volcanics of Fortymile Canyon	Tfc
Timber Mountain Group	
Ammonia Tanks Tuff	Tma
Rainier Mesa Tuff	Tmr
tuff unit "X"	Tmx
Paintbrush Group	
Tiva Canyon Tuff	Tpc
Yucca Mountain Tuff	Tpy
Pah Canyon Tuff	Tpp
Topopah Spring Tuff	Tpt
Calico Hills Formation	Tht
Crater Flat Group	
Prow Pass Tuff	Tcp
Bullfrog Tuff	Tcb
Tram Tuff	Tct
Lavas and Flow Breccias	Tll
Lithic Ridge Tuff	Tlr
Older Tuffs	Tt
Paleozoic	
Paleozoic rocks, undifferentiated	Pz

[1] Includes bedded tuff at base of most units

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TABLE 2.–*Physical properties of rock units used in the theoretical fault model. Values were derived from core samples in drill-hole G-1.*[1]

Unit	Declination[2] deg	Inclination[2] deg	Magnetization[2] A/m
Tpc	167	-38	1.1
Tpt	326	62	1.3
Tcb	13	49	1.0
Tct	141	-42	1.2

[1] Data from Bath and Jahren (1984)

[2] Total declination, inclination, and magnetization

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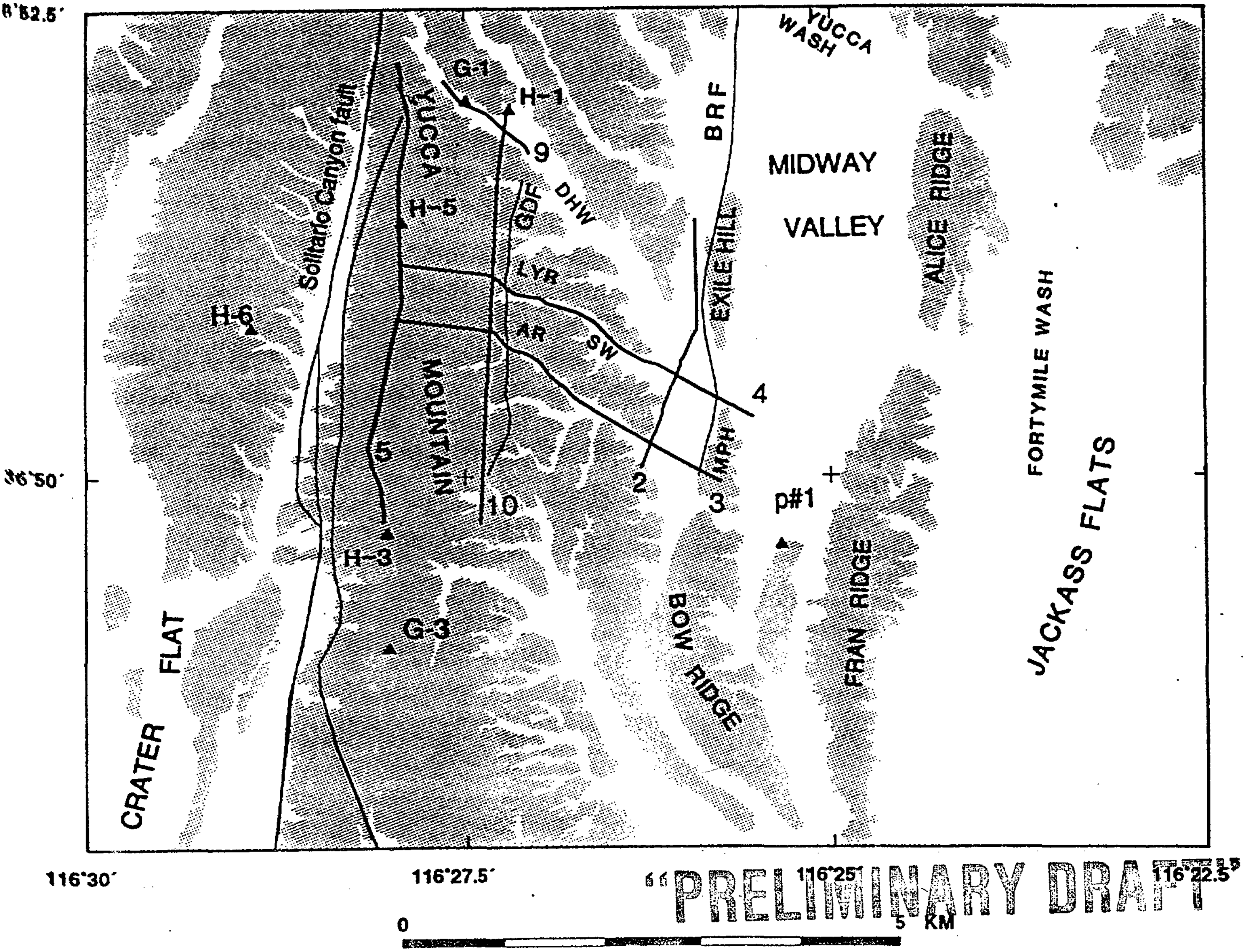

FIGURE 1.–Index map of the study area showing locations of magnetic profiles across the central block of Yucca Mountain. White area, Quaternary alluvium and colluvium; Shaded area, Tertiary volcanic rocks; Triangle, drill hole; AR, Antler Ridge; BRF, Bow Ridge fault; DHW, Drill Hole Wash; GDF, Ghost Dance fault; LYR, Live Yucca Ridge; MPH, Muck Pile Hill; SW, Split Wash. Geology modified from Frizzell and Shulters (1990).

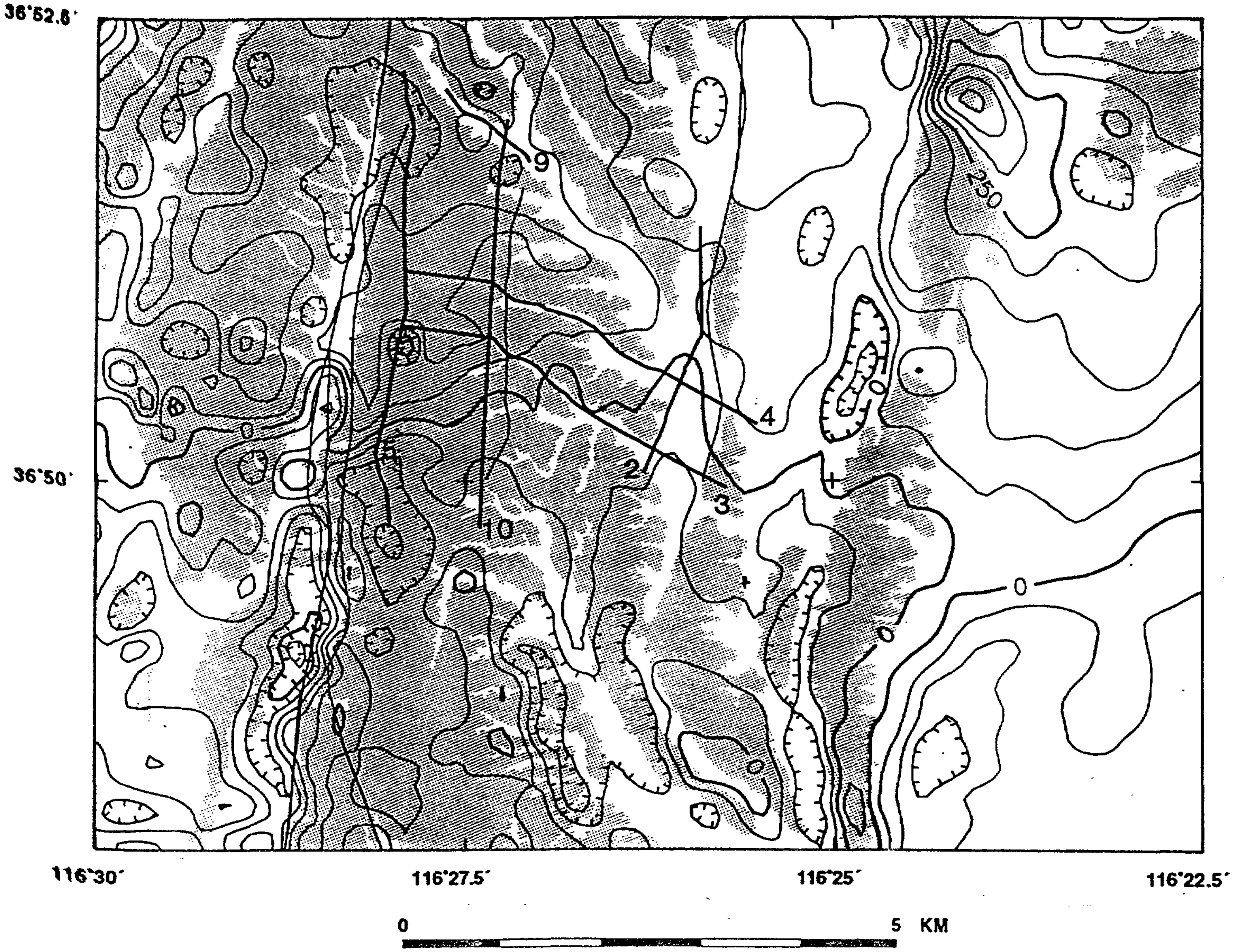

FIGURE 2.–Aeromagnetic anomaly map of the study area showing locations of magnetic profiles across the central block of Yucca Mountain. Magnetic contour interval 50 and 250 nT. See figure 1 for explanation.

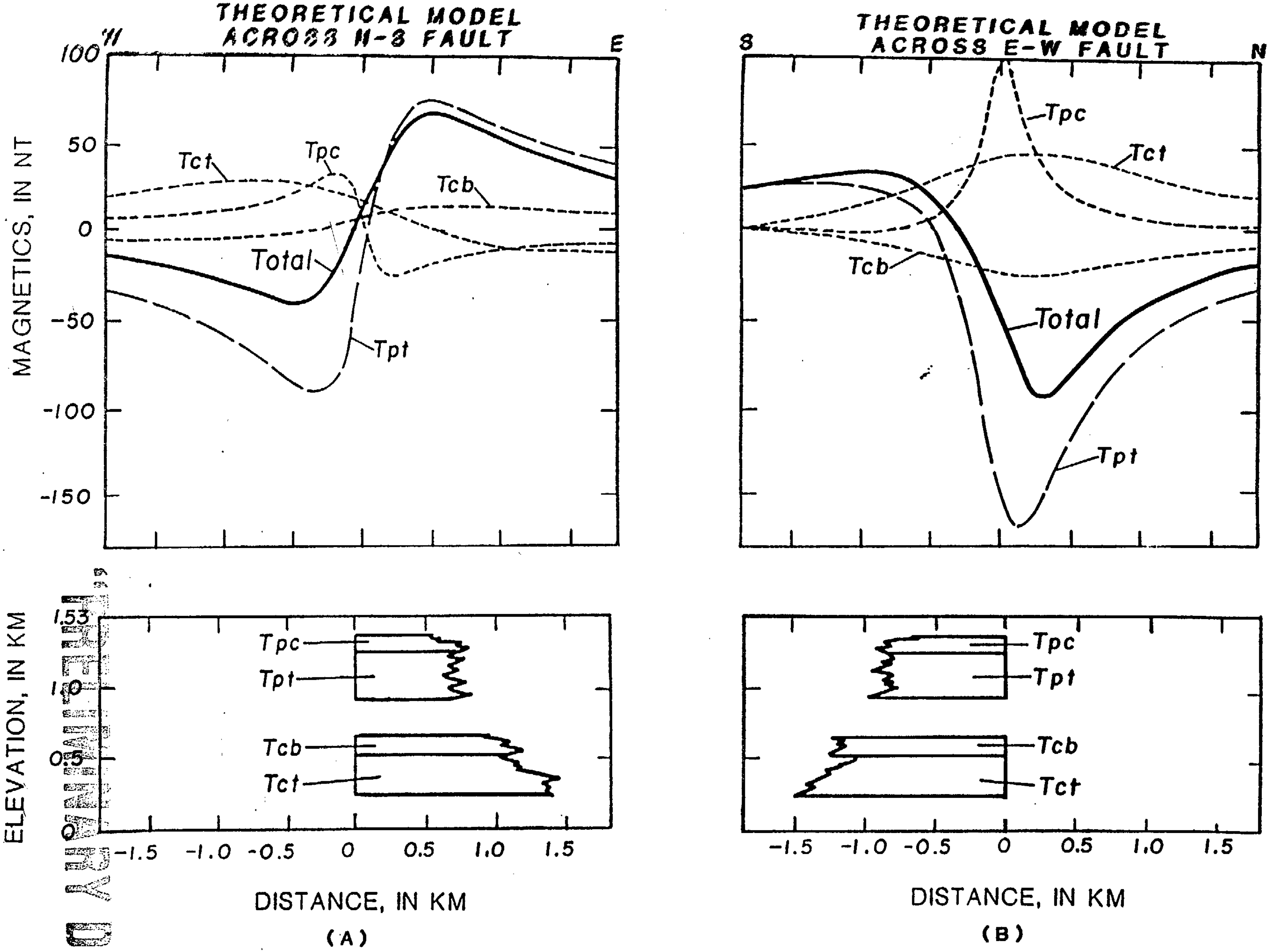

Figure 3.–Theoretical magnetic model across (a) north-south trending faults and (b) east-west trending faults modified from Bath and Jahren (1984). Geologic units and their modeled properties are described in tables 1 and 3, respectively.

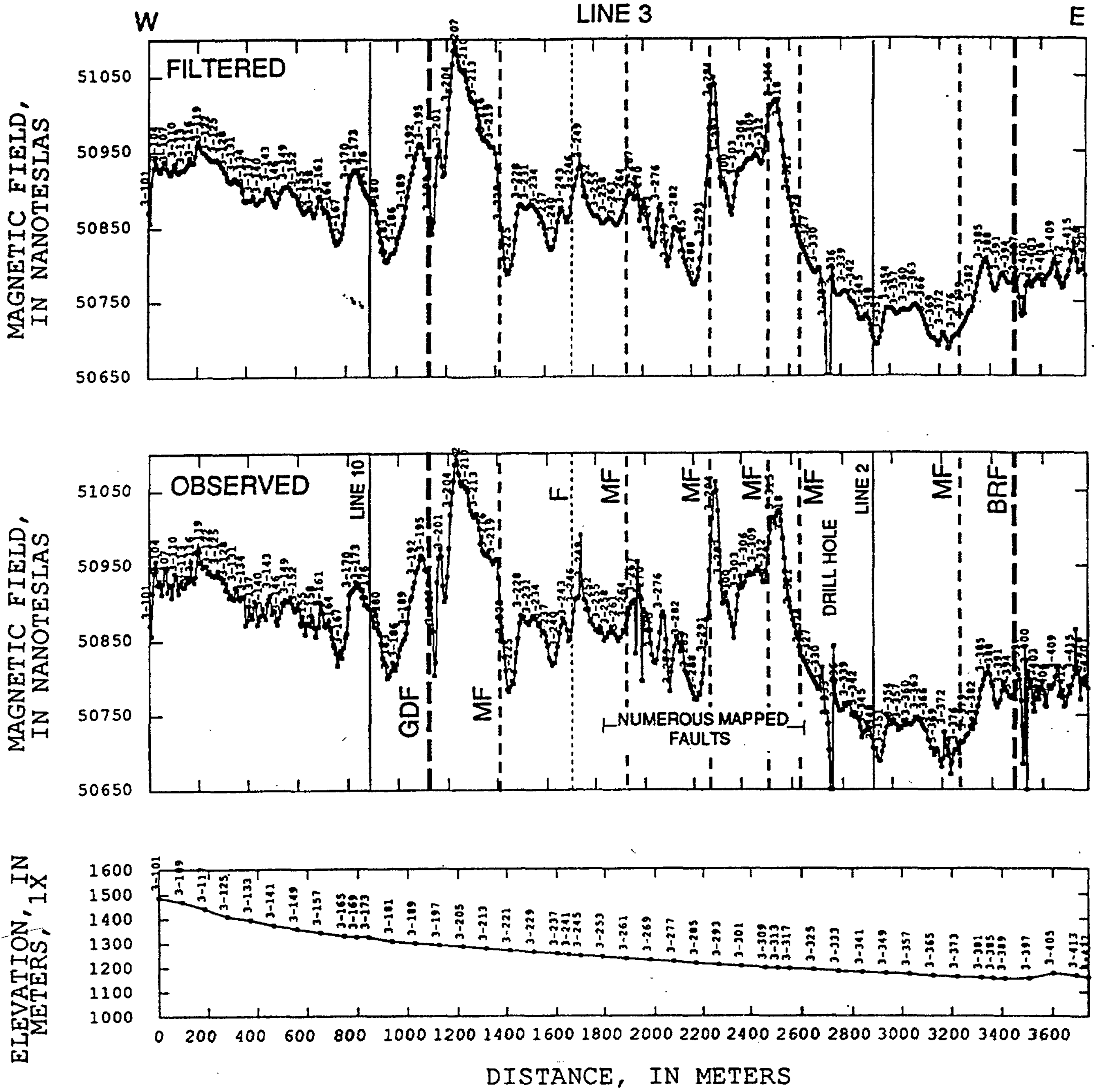

FIGURE 4.–Observed and filtered magnetic profile of line 3. BRF, mapped location of the Bow Ridge fault; GDF, mapped location of the Ghost Dance fault; F, possible fault or change in physical properties inferred from magnetic data; MF, mapped fault or fracture across or near traverse from Scott and Bonk (1984). Different dashed-line widths are used to denote confidence levels of possible faulting: Bold, high confidence; Medium, medium confidence; and Fine, low confidence.

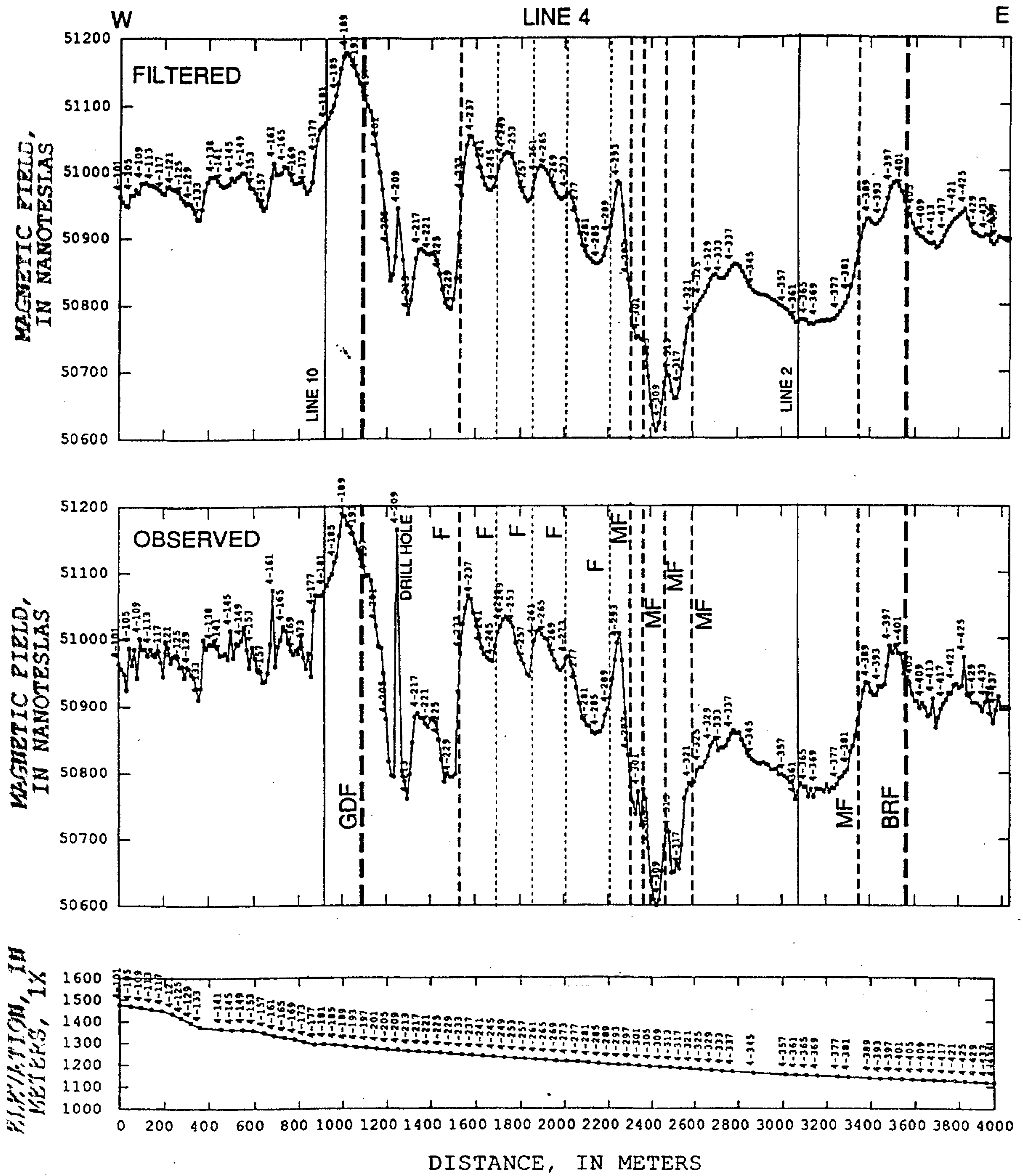

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FIGURE 5.–Observed and filtered magnetic profile of line 4. See figure 4 for explanation.

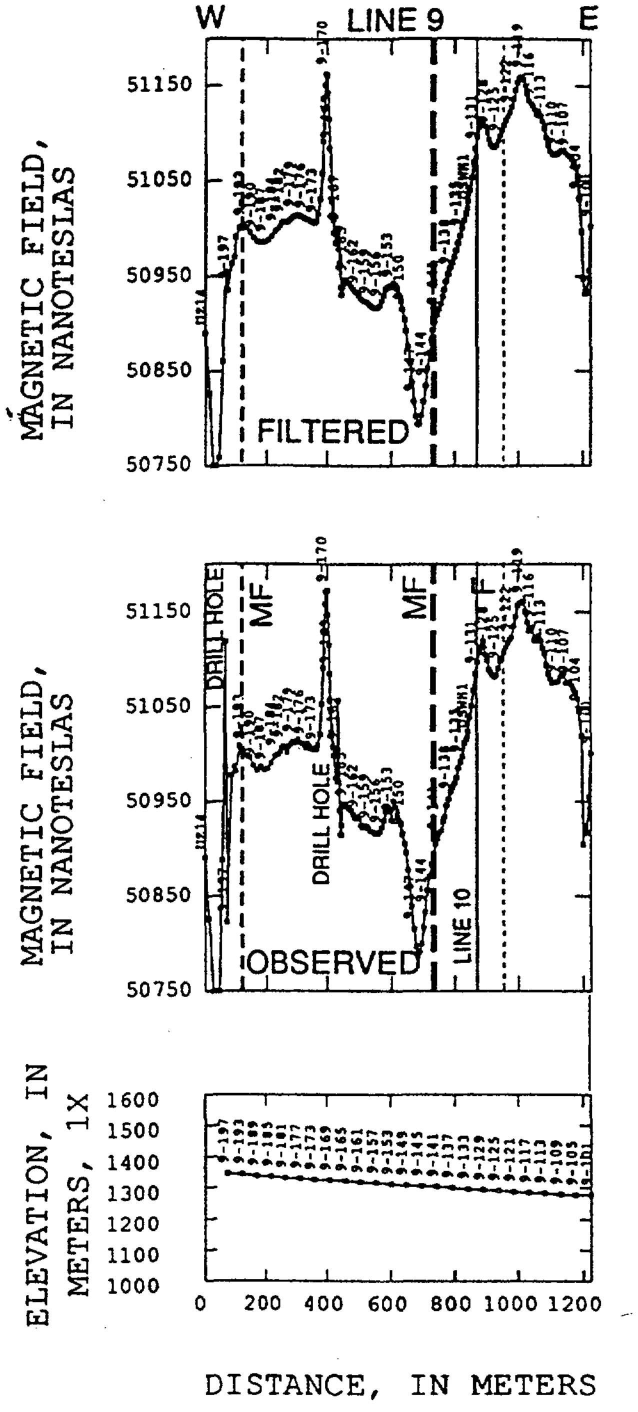


FIGURE 6.–Observed and filtered magnetic profile of line 9. See figure 4 for explanation.

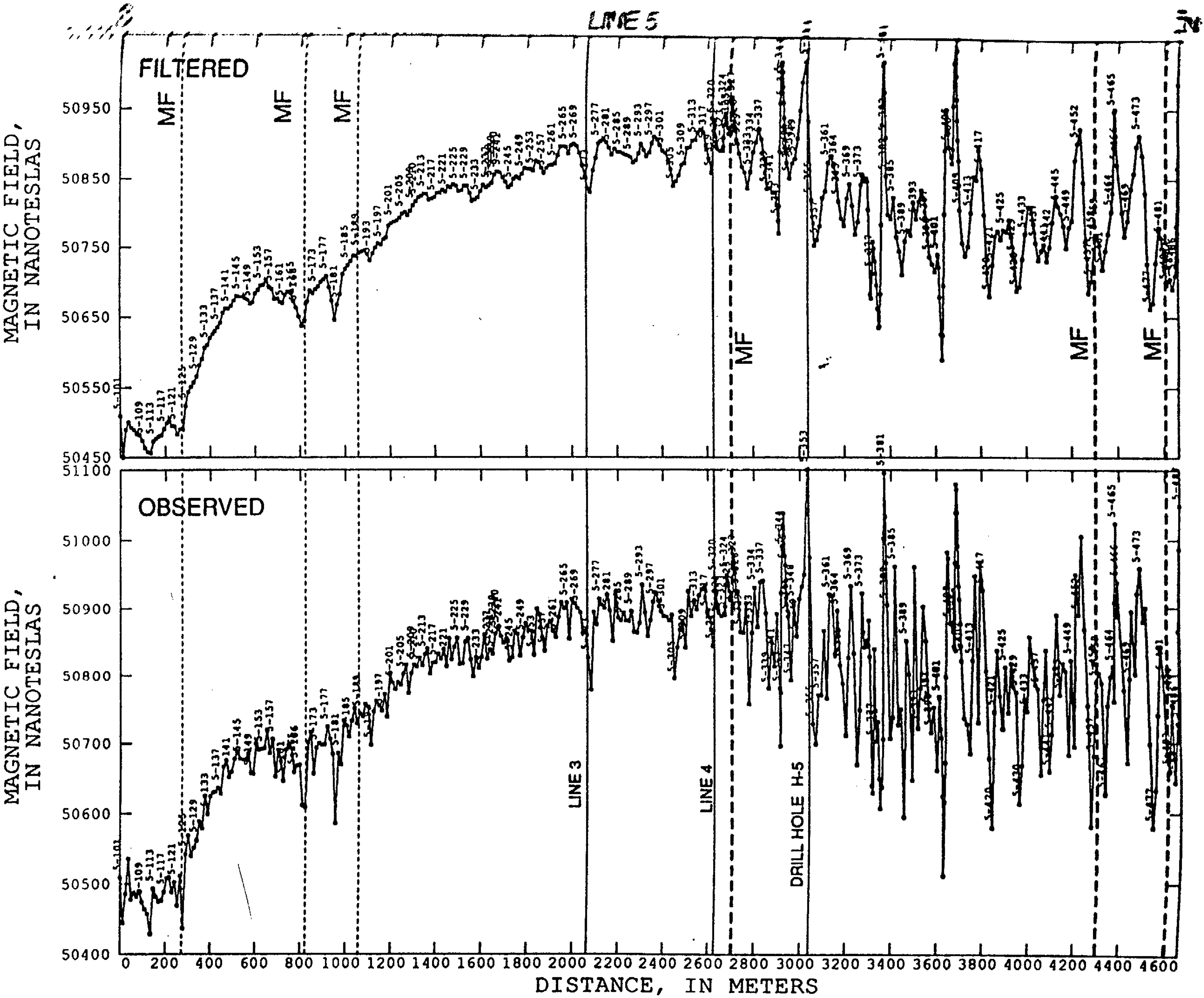


Figure 7.–Observed and filtered magnetic profile of line 5. See figure 4 for explanation.

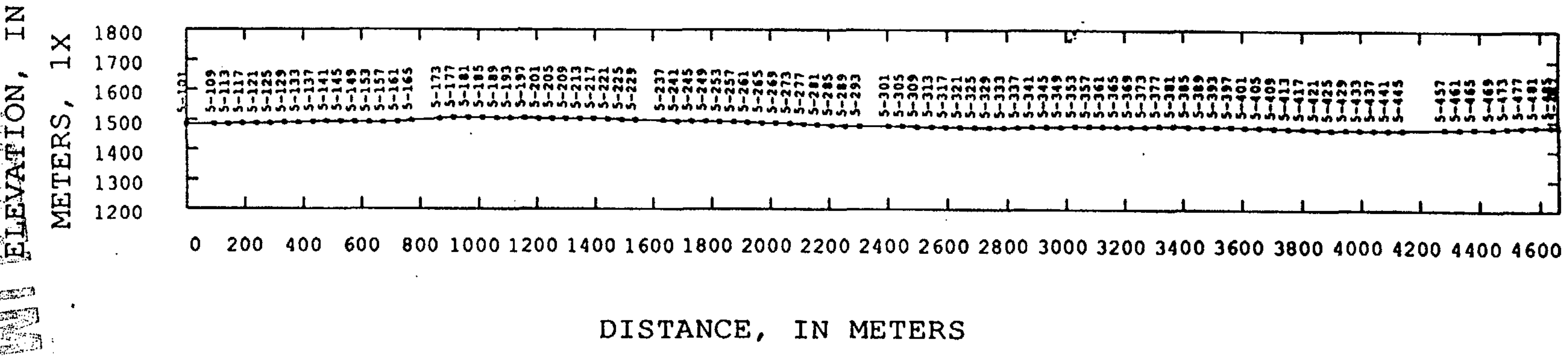
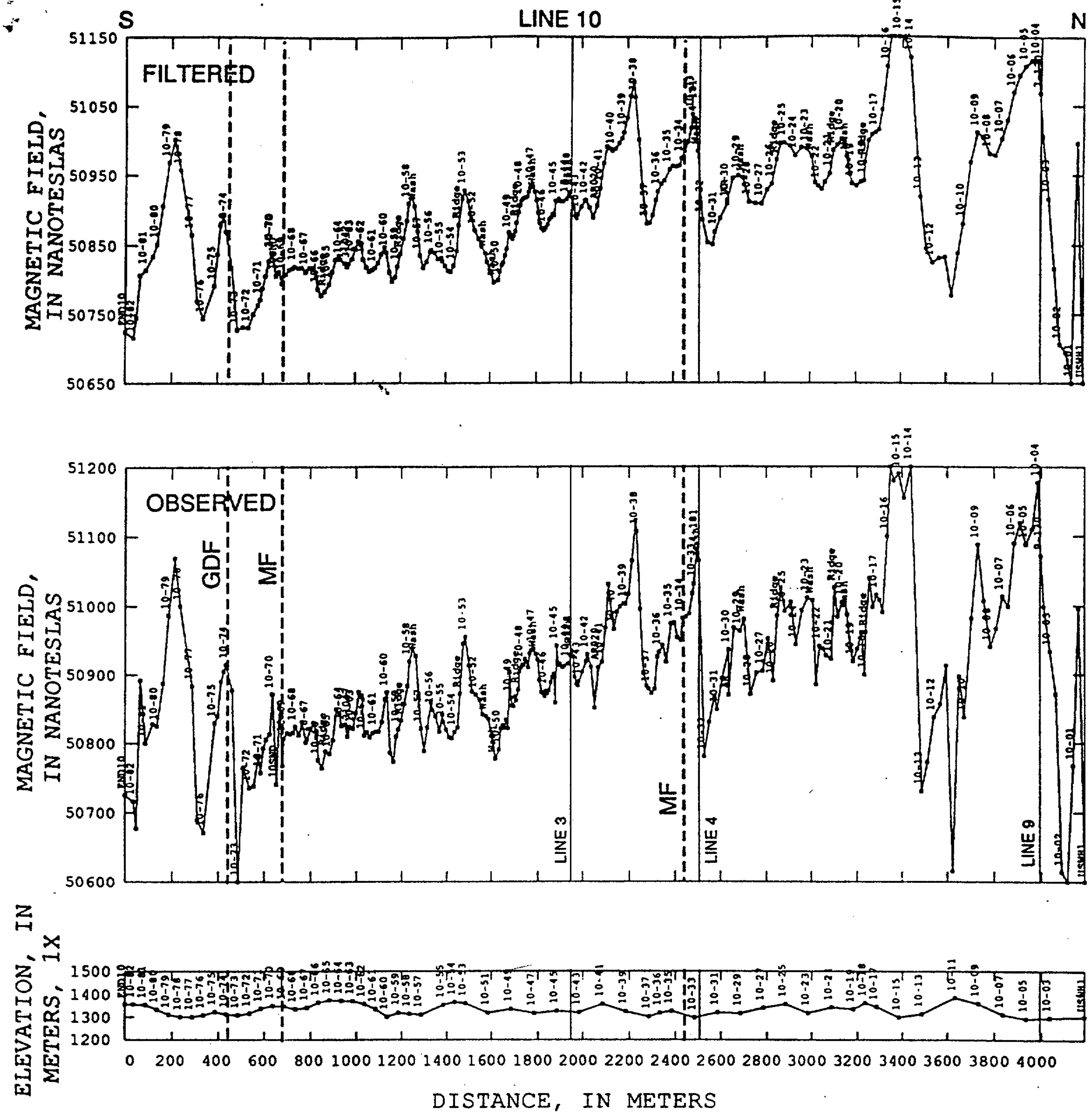


FIGURE 7.–Observed and filtered magnetic profile of line 5. See figure 4 for explanation.–Continued



"PRELIMINARY DRAFT"

FIGURE 8.–Observed and filtered magnetic profile of line 10. See figure 4 for explanation.

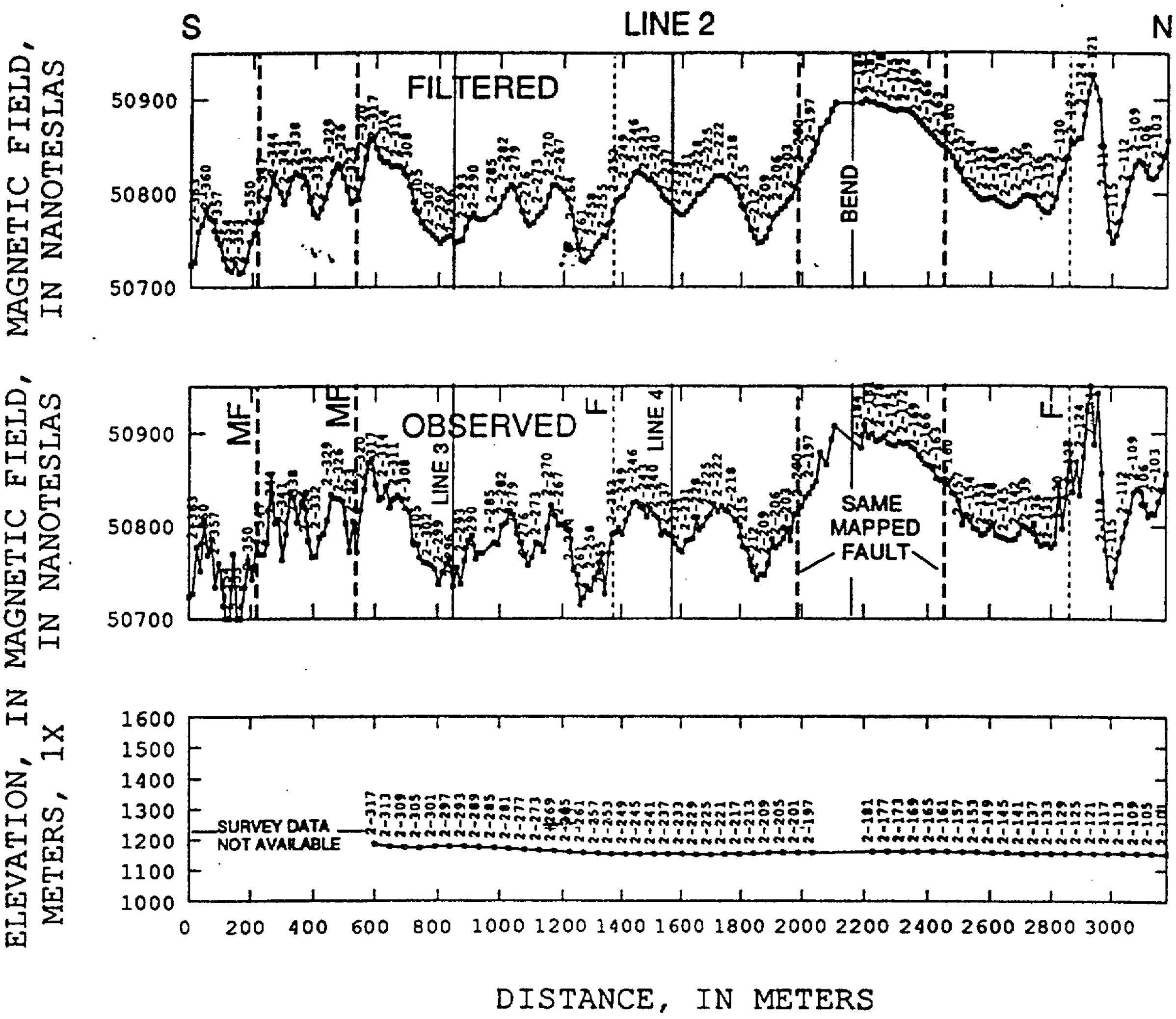


FIGURE 9.–Observed and filtered magnetic profile of line 2. See figure 4 for explanation.