

U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

GRAVITY AND MAGNETIC DATA OF FORTYMILE WASH,
NEVADA TEST SITE, NEVADA

By

D. A. Ponce, S. B. Kohn, and Sandra Waddell

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Menlo Park, California
1992

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D. A. Ponce¹, S. B. Kohn¹, and Sandra Waddell²

GEOLOGICAL SURVEY OPEN-FILE REPORT 92-343

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ABSTRACT

Gravity and ground magnetic data collected along six traverses across Fortymile Wash, in the southwest quadrant of the Nevada Test Site suggest that there are no significant vertical offsets below Fortymile Wash. The largest gravity and magnetic anomaly, in the vicinity of Fortymile Wash, is produced by the Paintbrush fault, on the west flank of Fran Ridge. Inferred vertical offset is about 250 ± 60 m (800 ± 200 ft). Geophysical data indicate that the fault is about 300 m (1,000 ft) east of its mapped, but concealed location. North of Busted Butte, near Fran Ridge, geophysical data do not preclude the existence of small vertical offsets bounding Fortymile Wash. However, gravity and magnetic profiles south of Busted Butte show little correlation to those to the north and suggest that vertical offsets, comparable in size to the Paintbrush fault, are not present. Density profiling, a technique used to determine the average density of small topographic features, suggests that the density of near-surface material in the vicinity of Fortymile Wash is 1.80 to 2.00 g/cm³.

INTRODUCTION

A gravity and magnetic investigation of Fortymile Wash was begun as part of an effort to help geologically characterize Yucca Mountain as a potential site for the storage of commercial spent nuclear fuel and high-level radioactive waste. Fortymile Wash (including Fortymile Canyon) is a linear feature that extends for about 65 km (40 mi), part of which occurs along the east side of Yucca Mountain. The study area is in the southwest quadrant of the Nevada Test Site (NTS) and is bounded by Yucca Mountain to the west, Timber Mountain area (Dome Mountain) to the north, Jackass Flats to the east, and the town of Amargosa Valley (formerly Lathrop Wells) to the south (fig. 1).

Fortymile Canyon, a part of the Amargosa River drainage system, begins in the southeastern part of Timber Mountain where it breached the Timber Mountain caldera rim at least 9 m.y. ago. Down-stream the canyon opens onto Jackass Flats and becomes Fortymile Wash, the largest incised channel (in alluvial-fan deposits) in the entire drainage system. The formation of incised washes marked a major change from alluvial-fan construction to fan-head erosion that probably reflected a climatic rather than tectonic change in the drainage system. (See Huber, 1987).

Because Lipman and McKay (1965) believed the wash to be fault controlled, electrical data were initially collected (Hoover and others, 1982) to better define the location of possible faults. Whether or not Fortymile Wash is a fault-controlled drainage area becomes important to the hydrology of the waste repository, as ground-water flow is a possible transport mechanism for allowing radionuclides to reach the surface.

ACKNOWLEDGMENTS

R. N. Harris of the U.S. Geological Survey (USGS) assisted in the gravity observations, elevation control, terrain corrections, and Bouguer density profiling; J. B. Spielman of the

USGS assisted in compilation and drafting of the gravity and magnetic data, and R. Lahoud of Fenix and Scisson, Inc., assisted in the gravity observations and elevation control.

GENERAL GEOLOGY

The general stratigraphy that underlies Fortymile Wash is composed 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 limestones and dolomites, with lesser amounts of argillite, quartzite, and marble. The Devils Gate Limestone, Nevada, and Eleana Formations are exposed in the northeastern part of the study area at Calico Hills. The Paleozoic Lone Mountain Dolomite and Roberts Mountain Formations were penetrated in drill-hole UE-25p#1 west of Fran Ridge (fig. 1, p-1), at a depth of 4,080 and 5,470 ft, respectively (Muller and Kibler, 1984).

Five major Cenozoic volcanic units occur; in ascending order these are: (1) older ash-flow tuffs, (2) Lithic Ridge Tuff, (3) Crater Flat Tuff, (4) tuffaceous beds of Calico Hills, and (5) Paintbrush Tuff. The Crater Flat Tuff is composed of the Tram, Bullfrog, and Prow Pass Members. The Paintbrush Tuff is composed of the Topopah Spring, Pah Canyon, Yucca Mountain, and Tiva Canyon Members. The entire volcanic section was observed in exploratory drill-hole USW G-1 (fig. 1, G-1) on the east flank of Yucca Mountain (Spengler and others, 1981). The stratigraphic section penetrated at well J-13, on the east side of Fortymile Wash is shown in table 1 (modified from Byers and Warren, 1983; and Thordarson, 1983). Well J-13 shows a similar sequence to USW G-1 but the absence of the Pah Canyon and Yucca Mountain Members of the Paintbrush Tuff reflects a general thinning of ash-flow tuffs from their sources in the northwest (Spengler and Rosenbaum, 1980, p. 20). Ash-flow tuffs in the area vary from densely welded to partially welded tuffs (table 1). Moderate to densely welded tuffs include the middle of the Bullfrog Member of the Crater Flat Tuff, and the Topopah Spring and Tiva Canyon Members of the Paintbrush Tuff. Otherwise, the majority of the tuffs are partially welded to non-welded.

TABLE 1.— *Generalized lithology penetrated by well J-13*
 [modified from Byers and Warren (1983) and Thordarson (1983)]

Unit	Depth (ft)	Thickness (ft)	Lithology
Alluvium	0	435	Sand and gravel; composed of tuff and basalt from 160–330 ft
Paintbrush Tuff			
Tiva Canyon	435	245	Ash-flow tuff, partly welded
Topopah Spring	680	795	Ash-flow tuff, moderately welded
Tuffaceous beds of Calico Hills	1,475	265	Zeolitized
Crater Flat Tuff			
Prow Pass	1,740	216	Ash-flow tuff, partly welded
Bedded tuff	1,956	59	Tuffaceous sandstone
Bullfrog	2,015	305	Ash-flow tuff, partly welded
Bedded tuff	2,320	30	Zeolitized
Tram unit	2,350	850	Ash-flow tuff, partly-welded, zeolitized
Bedded Tuff	3,200	20	Zeolitized
Tuff of Lithic Ridge	3,220	268	Ash-flow tuff

GRAVITY, DENSITY, AND MAGNETIC DATA

GRAVITY DATA

Detailed gravity data were collected along six profiles across Fortymile Wash (fig. 1) using LaCoste and Romberg gravity meters G177 and G17. Gravity meter performance and calibration factors were checked over the Charleston Peak gravity meter calibration loop near Las Vegas, Nev. (Ponce and Oliver, 1981). Gravity data (Jansma and others, 1982, p. 33-43) were reduced using the Geodetic Reference System of 1967 (International Union of Geodesy and Geophysics, 1971) and referenced to the International Gravity Standardization Net 1971 gravity datum (Morelli, 1974, p. 18) via base station MERC, at the USGS core library building at Mercury, Nev. (Ponce and Oliver, 1981, p. 13). Gravity data were reduced to complete Bouguer anomalies and include earth-tide, instrument drift, free-air, Bouguer, latitude, curvature, and terrain corrections. In general, observed gravity data are accurate to about 0.05 mGal, while Bouguer and isostatic anomalies are accurate to about 0.1 to 0.2 mGal.

Gravity stations were surveyed using a Hewlett-Packard electronic-distance-measurement instrument and station elevations are accurate to within about 0.1 m from a reference bench mark. Reference elevations were local U.S. Coast and Geodetic Survey and Nuclear Rocket Development Station bench marks. In general, gravity stations were spaced between 25 to 150 m (100 to 500 ft) apart depending on the proximity to Fortymile Wash.

Terrain corrections were computed to a radial distance of 167 km (103 mi) and involved a 3 part process: (1) Hayford-Bowie zones A and B with an outer radius of 68 m (223 ft)

were estimated in the field with the aid of tables and charts, or sketched and later calculated in the office, (2) Hayford-Bowie zones C and D with an outer radius of 590 m (1,936 ft) were calculated by averaging compartment elevations on a circular template based on Hayford's system of zones (Swick, 1942, p. 66), and (3) terrain corrections from a distance of 0.59 km (0.37 mi) to 167 km (103 mi) were calculated using a digital elevation model and a procedure by Plouff (1977).

DENSITY DATA

Sources of rock density information are from rock sampling, core sampling, and geophysical logs. Results of mean densities of more than 400 rock samples from the NTS were summarized by Ponce (1981, table 3). Grain densities of additional rock samples from within the study area are shown in table 2. Densities were determined by weighing the sample in air, then weighing the sample submerged in water using an electronic balance equipped with a stirrup and suspending the sample by a wire. Grain density was calculated from the difference of the two weighings, using Archimedes' principle:

$$\rho = \frac{W_a}{W_a - W_w},$$

where

ρ = grain density,

W_a = weight in air,

and

W_w = weight in water.

Dry-bulk, natural-state bulk, and calculated saturated bulk densities from units penetrated by drill hole J-13 are shown in table 3. Data are from Thordarson (1983) modified to show density variations between welded, partly-welded, and zeolitized tuffs. Density data indicate that there are significant density contrasts between alluvium, zeolitized tuffs, partly-welded tuffs, and welded tuffs that range from about 0.2 g/cm³ between zeolitized and partly-welded tuffs and up to about 0.6 g/cm³ between alluvium and welded tuffs.

TABLE 2.— Mean bulk densities of rock samples within the study area

Lithology	Number of samples	Mean bulk density (g/cm ³)	Range in density (g/cm ³)	Comments
Tuff	14	2.31	2.18–2.38	Crater Flat Tuff, Paintbrush Tuff, and Timber Mountain Tuff
Rhyolite	17	2.31	2.00–2.52	Dome Mtn.
Mafic lavas	3	2.41	2.26–2.53	Dome Mtn.

TABLE 3.- *Densities for rocks penetrated in well J-13*
 [modified from Thordarson (1983); sd, standard deviation]

Rock type	Number of samples	Dry-bulk density (g/cm ³)	sd	Natural-state bulk density	sd	Calculated saturated bulk density	sd
Welded tuff	10	2.22	.22	2.31	.09	2.33	.09
Partly-welded tuff	8	2.01	.19	2.20	.13	2.24	.13
Zeolitized tuff	7	1.70	.32	1.98	.28	2.03	.22

MAGNETIC DATA

Ground magnetic data with the sensor at 2.4 m (8 ft) above the surface were gathered along the six profiles across Fortymile Wash (fig. 1). A Geometrics portable proton precession magnetometer model G-816 and base station magnetometer G-826A were used to collect data. Because the anomalies of interest were believed to be small (20 to 50 nT) and the profile lines were long (about 3 km) a base station was required to make corrections for diurnal time variations of the Earth's magnetic field. The base station was located near well J-13 and readings were taken at 2-minute intervals or less. Magnetic observations are accurate to about 1 nT.

Magnetic data corrected for the observed diurnal variations were profiled and manually smoothed to remove short-wavelength, high-amplitude noise related to surface magnetization, near-surface material, instrument error, or operator error. Unsmoothed magnetic data, magnetic station locations, and diurnal drift for each traverse are shown in the appendix. High-amplitude magnetic anomalies were 'cutoff' or 'clipped' for ease of visual display. Maximum station spacing was 10 paces or about 9 m (30 ft) while minimum spacing was 1 pace or about 1 m (3 ft).

DENSITY PROFILING

Density profiling (Nettleton, 1976) is an interpretive technique used to determine the average density of small topographic features by selecting the density profile that exhibits the least correlation with topography. Because the gravity station spacing of the traverses across Fortymile Wash were closely spaced and five of the traverses cross topographic features of low relief, including Fortymile Wash, the data were well suited to the density profiling technique. Six Bouguer reduction densities, ranging from 1.60 to 2.67 g/cm³, were used to compute density profiles for each of the six lines across Fortymile Wash (Fig. 2a-f).

The density profile of line 1 (fig. 2a), which is oblique to Fortymile Canyon, indicates that the density of the two small hills (located by vertical dashed lines) is about 2.20 g/cm³. Both topographic features are composed of Tertiary volcanic rocks of a similar density. Density profiles for lines 2, 3, and 4 (figs. 2b-d) show the relationship between reduction density and topography best, primarily due to the sharper topographic expression of the wash as compared to lines 1, 5, or 6. As the topographic expression of the wash decreases

it becomes more difficult to distinguish which reduction density has the least correlation to topography (compare lines 4 and 5, figs. 2d and 2e). Finally, at line 6, which has virtually no topographic expression (fig. 2f) the density profiling technique is not applicable, but is shown for comparison. The combined results suggest that a density of about 1.80 to 2.00 g/cm³ produces a minimum correlation of the gravity anomaly data to topography and probably represents the average density of the near-surface layer in the vicinity of Fortymile Wash.

Another advantage of having closely-spaced gravity stations is the ability to locate small errors in the gravity anomaly data. This is particularly evident in line 2 (fig. 2b), at the west edge of the Wash. Other small amplitude errors in some of the profiles may be related to small errors in the terrain corrections.

SUMMARY OF ELECTRICAL STUDY

Four E-field ratio telluric traverses were collected across Fortymile Wash, to help better define faults that might be controlling the wash's location. E-field ratio tellurics is a resistivity method using an array of three in-line electrodes which form two dipoles with the center electrode in common. The electrodes are leap-frogged along the traverse one-dipole length at a time, such that the lead electrode becomes the center electrode for the next station's measurement. The potential difference across each dipole is proportional to the telluric field. (See Hoover and others, 1982). Data for two of the telluric traverses are nearly coincident to gravity and magnetic lines 2 and 3, and reveal four areas of low resistivity, two on either side of Fortymile Wash which were interpreted as fault zones (see TF1 to TF4, fig. 1). The westernmost inferred fault based on telluric data ('telluric fault') is the most prominent and correlates to the Paintbrush fault. The fault at TF1 has a larger telluric voltage amplitude than inferred faults at TF2 to TF4 (fig. 1), which may be caused by thin alluvial cover at TF1 (Hoover and others, 1982, p. 5).

INTERPRETATION

The largest gravity and magnetic anomaly in the vicinity of Fortymile Wash is the Paintbrush fault, on the west side of Fran Ridge (fig. 3b). Because the gravity data are more closely spaced than the electrical data, they provide a more accurate location of the fault, which is about 300 m (1,000 ft) east of its mapped location, although concealed under alluvium, shown on the geologic map of Lipman and McKay (1965). Since publication of Lipman and McKay's map, a detailed geologic map utilizing geophysical evidence shows the fault in the revised location (Scott and Bonk, 1984). The amplitude of the gravity anomaly associated with the Paintbrush fault is about 2 mGal and using as a model the maximum effect of a vertical fault (Nettleton, 1976, p. 193-195) and a density contrast of 0.25 to 0.33 g/cm³ infers an offset of about 180 to 240 m (600 to 800 ft).

Gravity anomalies along line 2 (fig. ^{3b}~~3-5~~) correlate well to faults inferred from electrical data, especially at the Paintbrush fault and suggest that vertical offset along faults, if present, on the east side of Fortymile Wash are small compared to the offset at the Paintbrush fault. In contrast, gravity anomalies along line 3 (fig. ^{3c}~~3-5~~) do not correlate very well to faults

inferred from electrical data, especially on the east side of the wash. In addition, gravity anomalies along profiles south of line 3 and Busted Butte (Fig. 3-4, lines 4, 5, and 6) are of lower amplitude than those near Fran Ridge and are probably not related to large vertical offsets. Because of their short-wavelength, gravity anomalies south of Busted Butte, but near Fortymile Wash, could be related to variations in density within the underlying alluvium or volcanic rocks. 3d-f

Gravity data along line 2, between about -2,700 to -2400 m (-9,000 to -8,000ft), show the presence of a gravity anomaly (fig. 3b) that is located near a mapped, although concealed, fault of Lipman and McKay (1965). This anomaly has an amplitude of about 0.5 mGal, is continuous to the south for about 2,000 m (6,500 ft), and probably represents a fault. A subsequent seismic refraction profile (H. D. Ackerman, written commun., 1984) indicated a low velocity zone at depth and electromagnetic soundings by Frischknecht and Raab (1984) indicated a major lateral discontinuity at this location. However, according to G.D. Bath (oral commun., 1984), the absence of an associated aeromagnetic anomaly probably precludes the existence of large vertical offsets in the underlying magnetic units. Additional data, especially ground magnetic data, are required to determine the exact nature of this anomaly.

A shallow-source, small-amplitude magnetic anomaly occurs directly over the edges of Fortymile Wash (figs. 3b-f and 4c). This feature is observed on lines 2 through 6 and helps define the edges of the wash, especially for line 6, where the wash topography is too slight to locate the edges from a topographic map or the detailed elevation survey. This magnetic signature over the edges of the wash probably reflects a continuous feature along the edges of the wash which does not appear to be related to topographic or magnetic terrain effects. The causative feature may be fluvial deposits carried downstream from the basalt flows at Dome Mountain (fig. 1) (D.L. Hoover, oral commun., 1985).

Because these gravity and magnetic studies were intended to determine whether or not Fortymile Wash was in itself a fault, detailed gravity data were not extended more than about 2 mi beyond the edge of the wash. Thus, the southernmost detailed profiles do not extend across major regional gravity anomaly features (Healey and others, 1980; Healey and others, 1987; Ponce and others, 1988) that probably reflect major faulting on either side of Fortymile Wash. Healey and Miller (1971) also recognized these gravity features and electrical data (Hoover and others, 1982a) and seismic refraction data (W.D. Mooney and S.G. Schapper, written commun., 1989) support the location of a major fault along the eastern edge of northern Amargosa Valley. In order to determine the exact nature of faulting, if present, in the immediate vicinity of Fortymile Wash several profiles need to be extended and additional detailed gravity, magnetic, and especially electrical data must be collected between the present profiles. These data would help determine the relationship between faults inferred from geologic and electrical data in the immediate vicinity of Fortymile Wash (figs. 3-4 and 4-5) and the major faults on either side of the wash in the northern part of the Amargosa Valley. 3b and 3c

SUMMARY

Geophysical data across Fortymile Wash suggests that there are no significant vertical offsets of geologic units directly below Fortymile Wash. Although electrical data indicate the presence of faults on either side of Fortymile Wash in the vicinity of Fran Ridge and Busted Butte, gravity and magnetic data indicate that any offsets are probably small compared to the offset at the Paintbrush Fault. South of Busted Butte, geophysical data indicate that faults are not present in the vicinity of Fortymile Wash, within the limits of the profiles. However, gravity and magnetic contour maps show steep gradients on either side of Fortymile Wash, but beyond the limits of the detailed profiles, that are probably related to normal faulting. To better define the continuity of faulting adjacent to Fortymile Wash, existing profiles need to be extended beyond their present limits and additional coincident gravity, magnetic, and electric profiles should be collected.

Gravity, magnetic, and electrical studies show that they are useful for delineating major faults at Yucca Mountain, such as the Paintbrush Fault. Additional detailed gravity, magnetic, and electrical data could provide an effective means to better define the location of known or suspected faults and to locate completely unknown faults, especially those concealed by alluvium.

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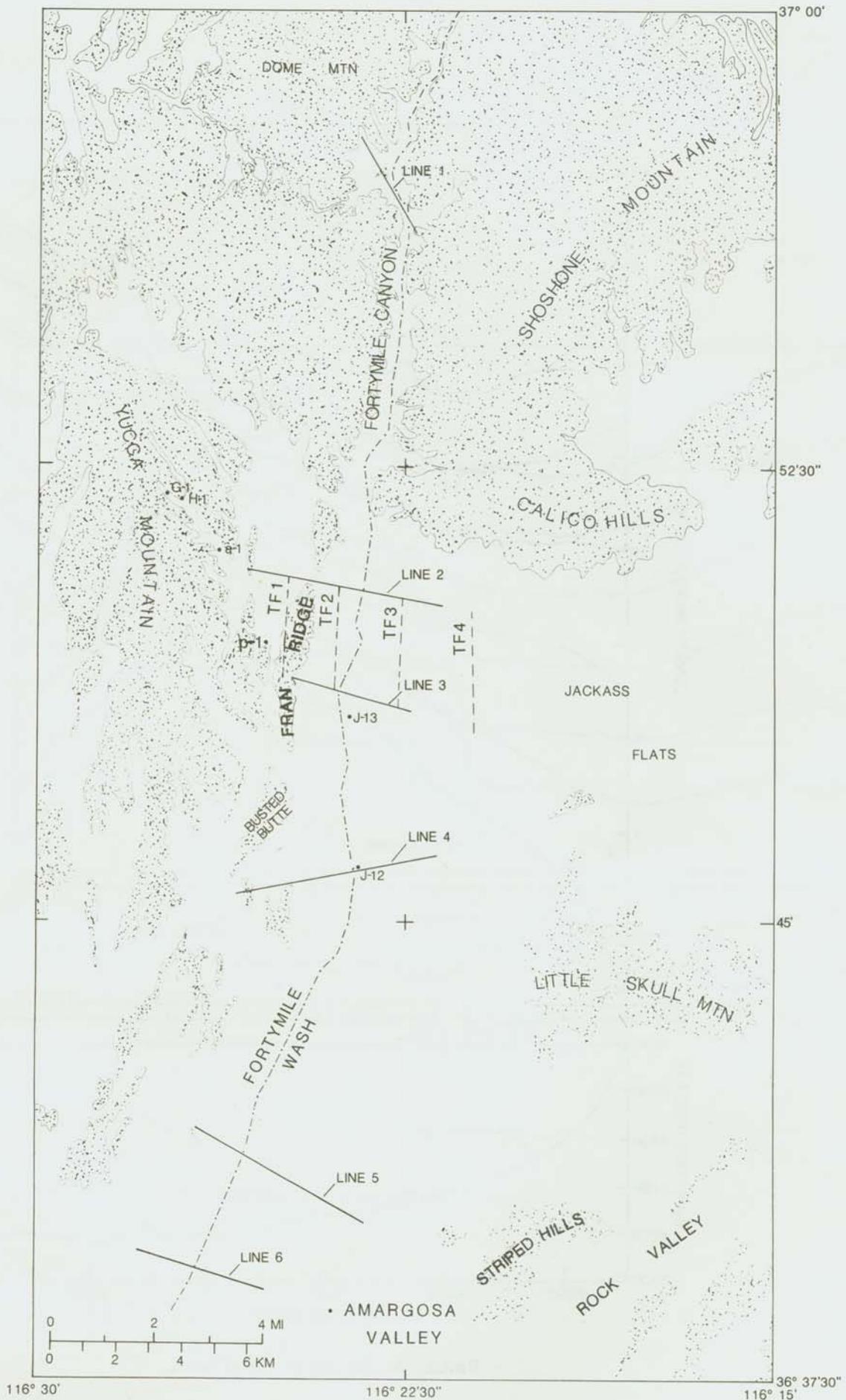


FIGURE 1.—Index map of the Fortymile Wash Study Area. Stippled area denotes exposed rocks.

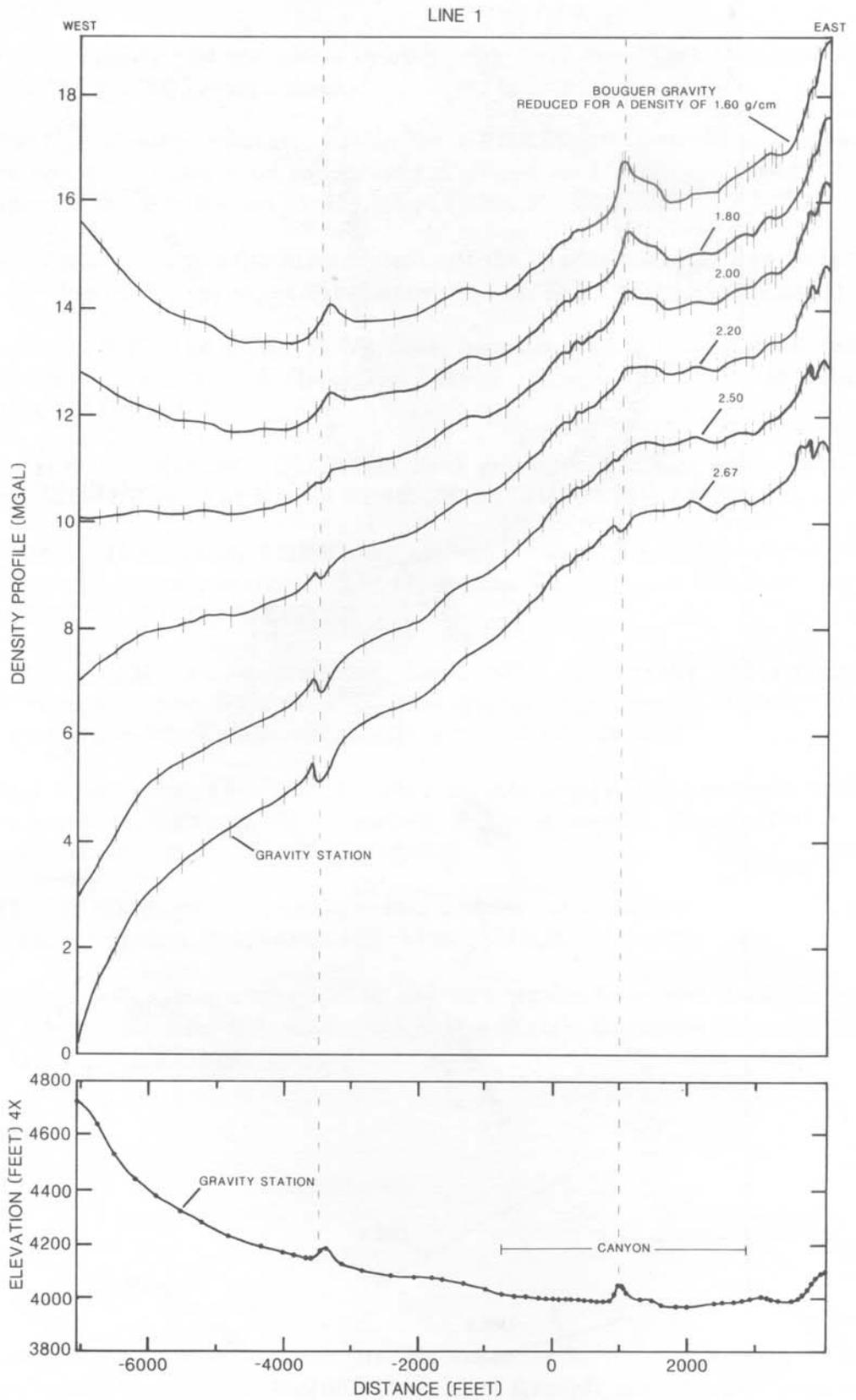


FIGURE 2a.—Density profile of line 1.

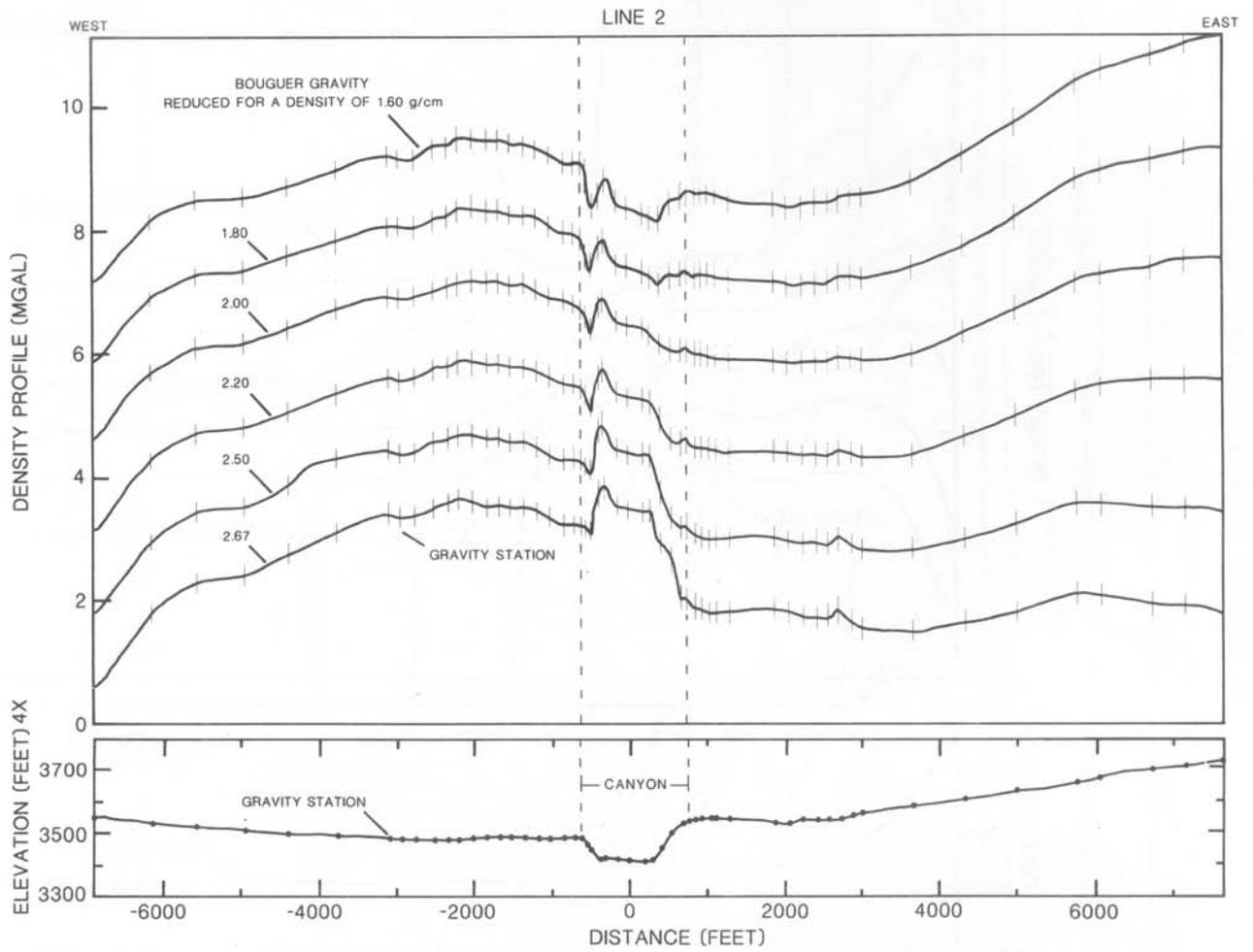


FIGURE 2b.—Density profile of line 2.

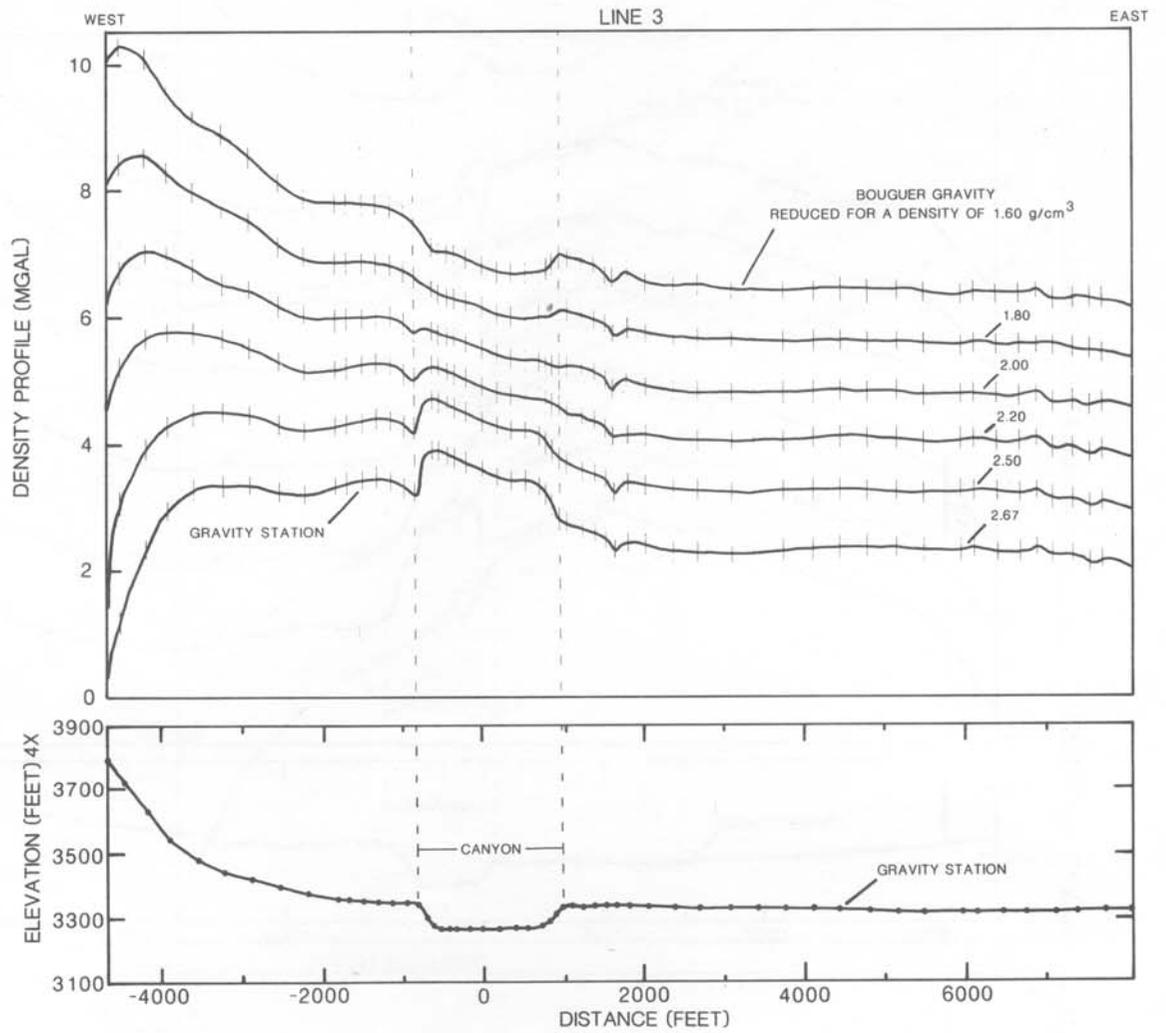


FIGURE 2c.—Density profile of line 3.

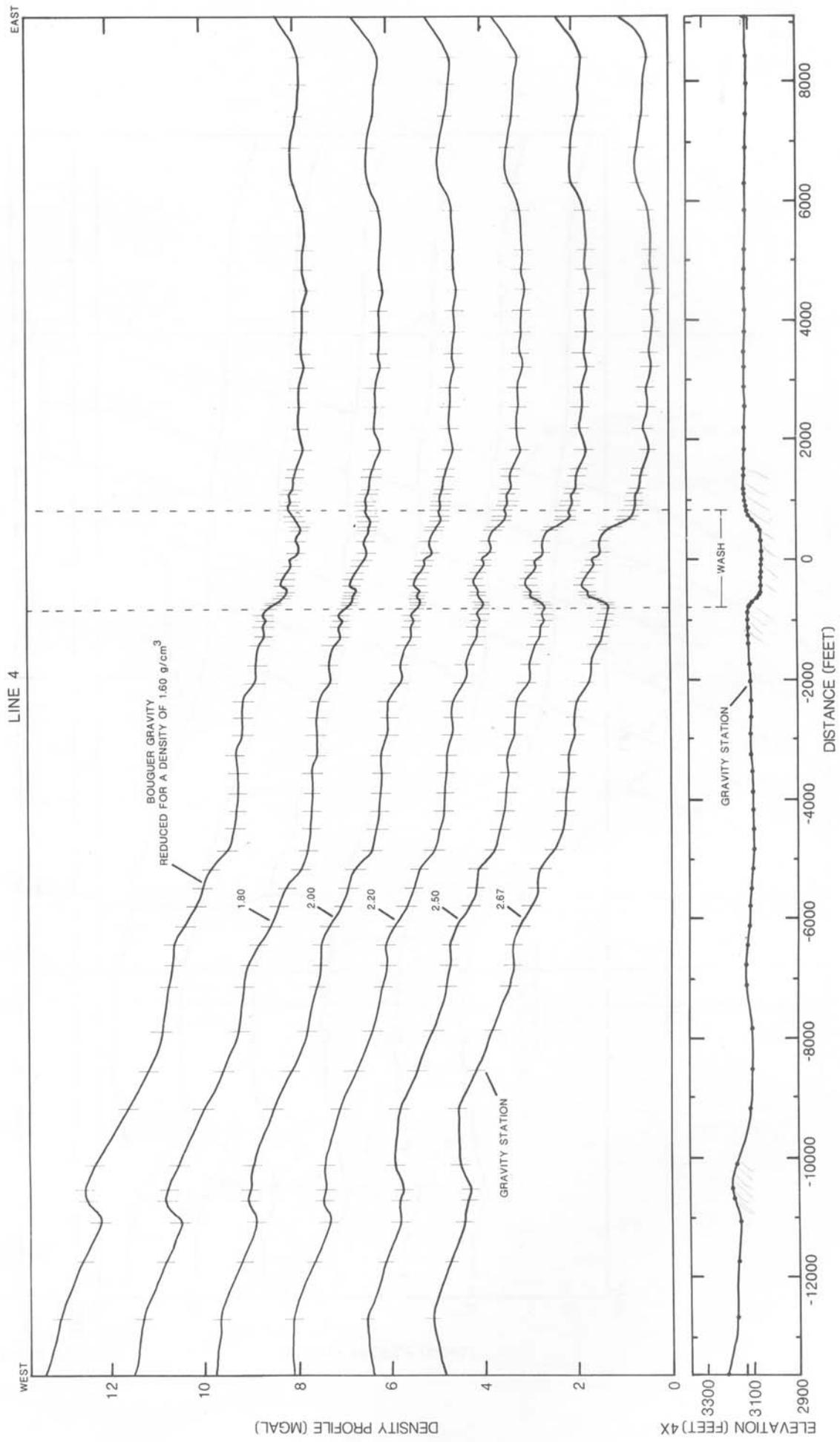


FIGURE 2d.—Density profile of line 4.

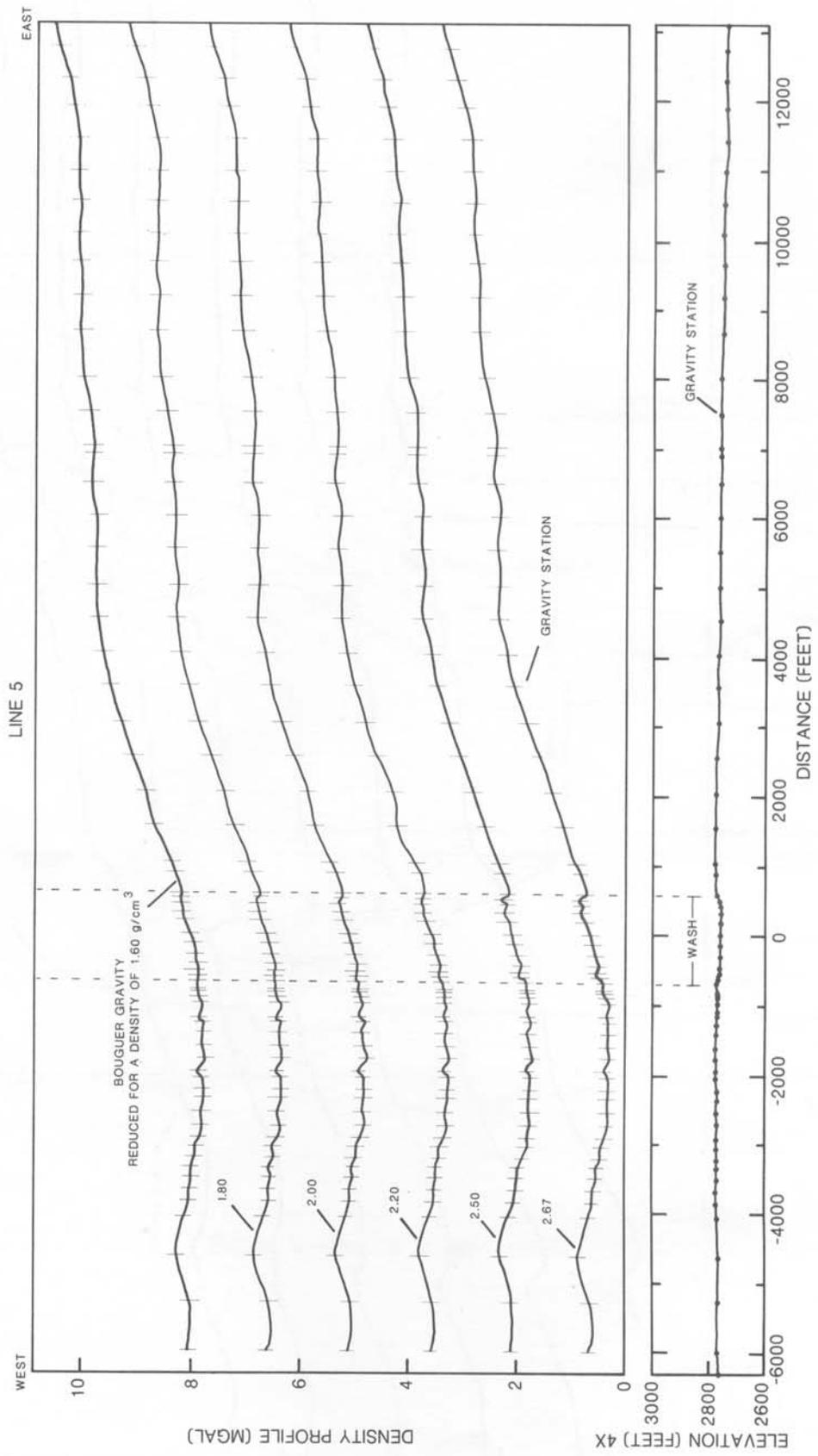


FIGURE 2e.-Density profile of line 5.

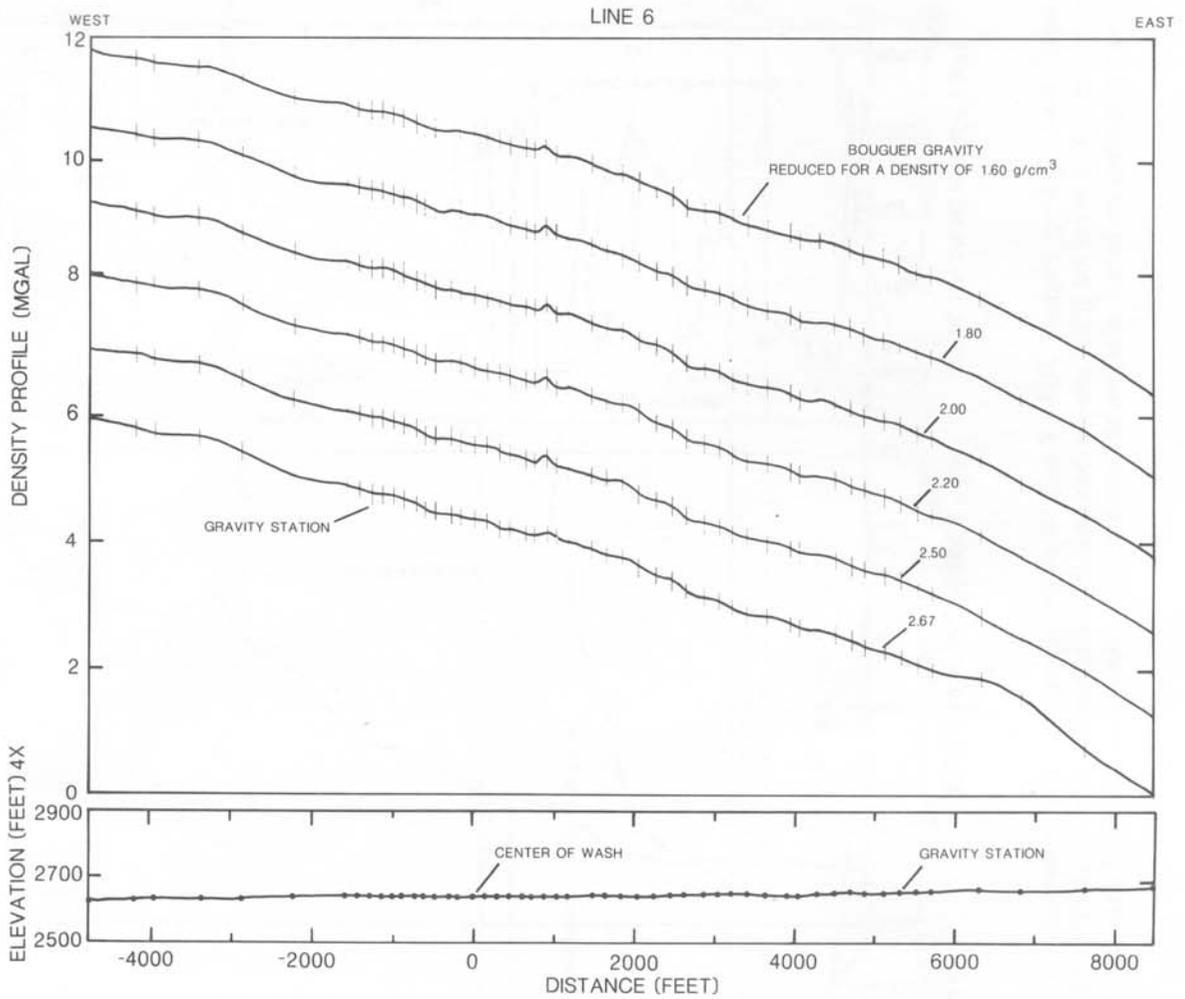


FIGURE 2f.—Density profile of line 6.

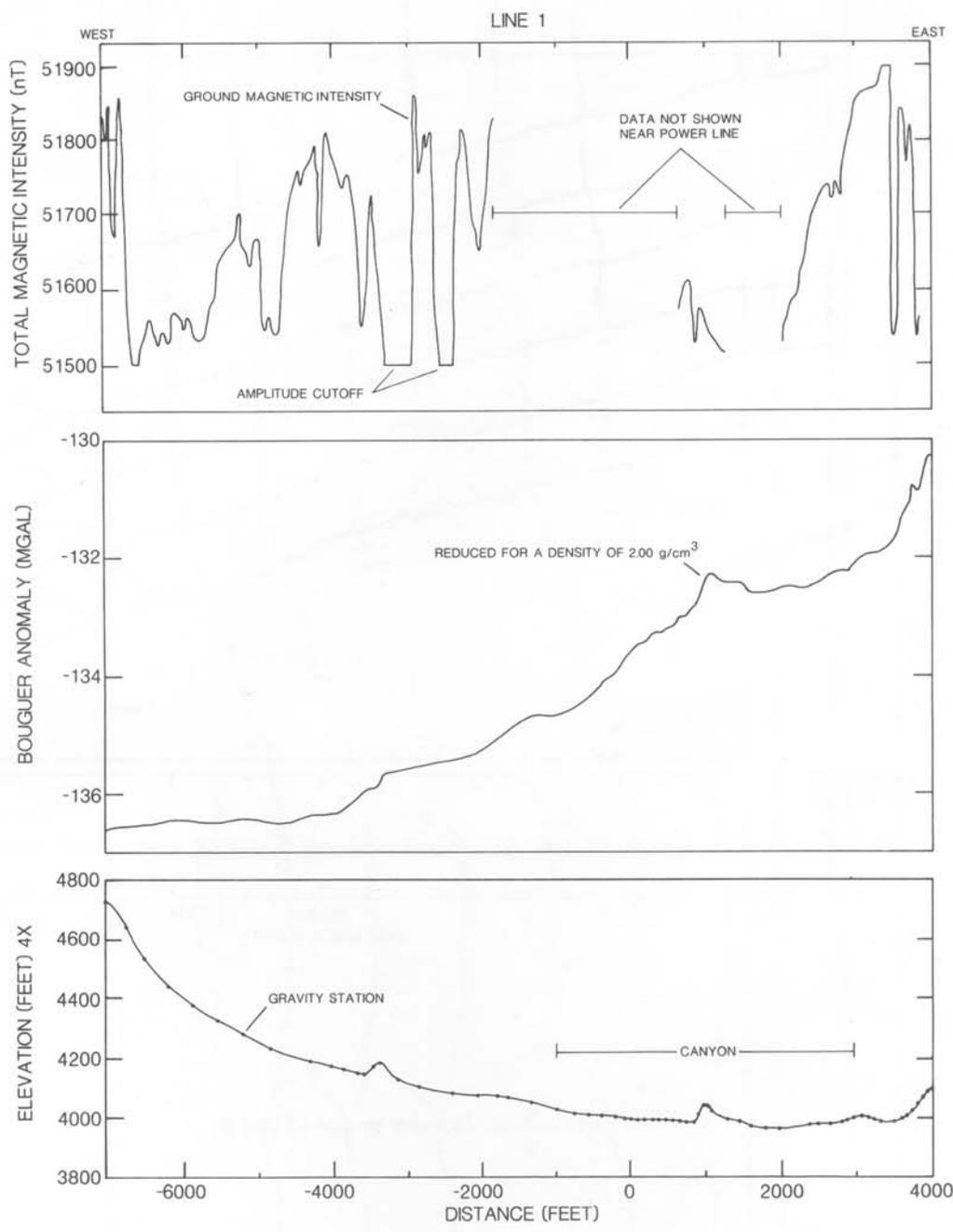


FIGURE 3a.—Gravity, magnetic, and topography profile of line 1.

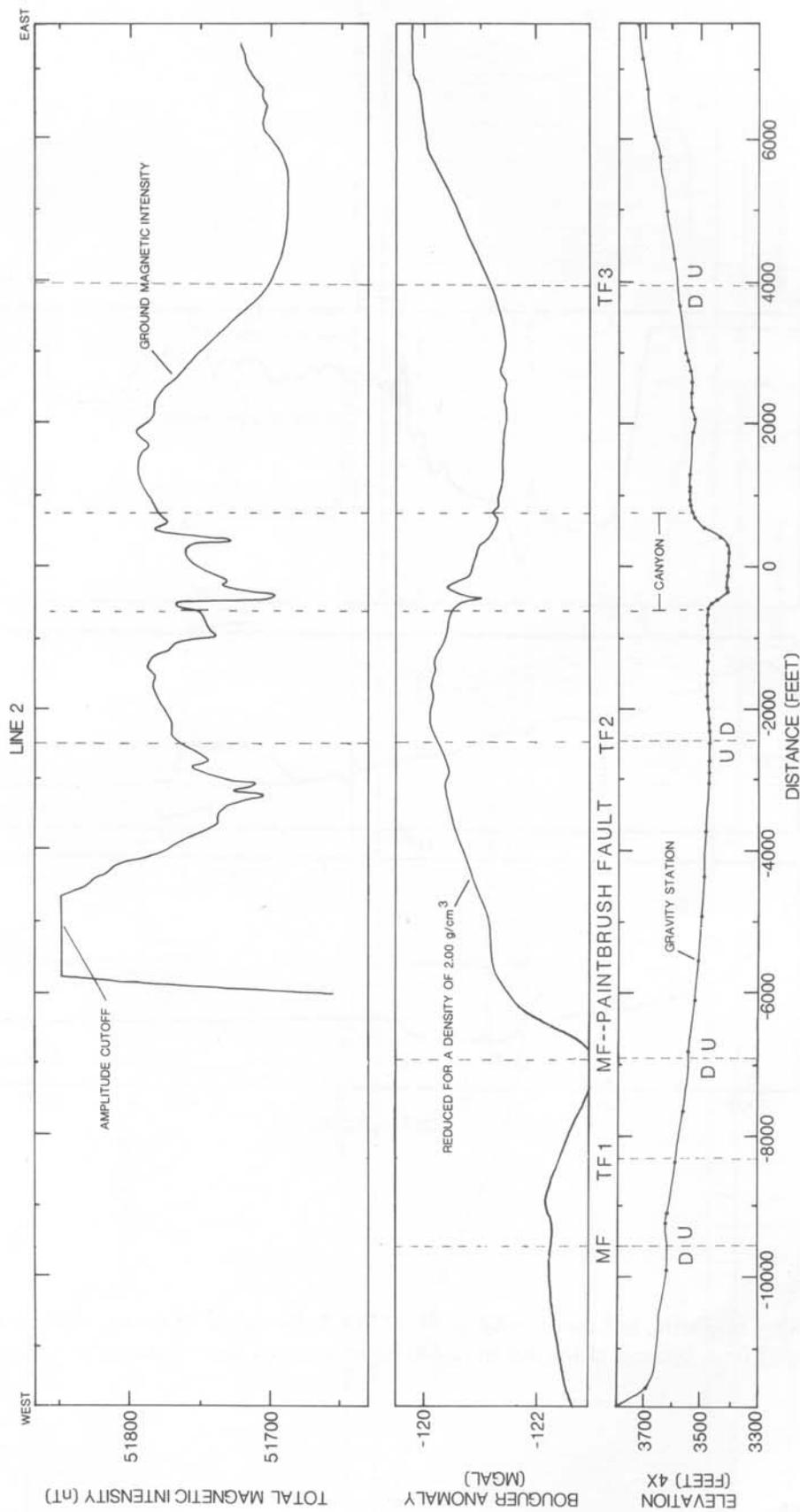


FIGURE 3b.—Gravity, magnetic, and topography profile of line 2. MF, mapped geologic fault (Lipman and McKay, 1965). TF1 to TF3, inferred telluric faults (Hoover and others, 1982) accurate to within 500 m (1,600 ft). TF1 is the Paintbrush Fault. U, upthrown, side, D, down thrown side, based on geologic or geophysical data.

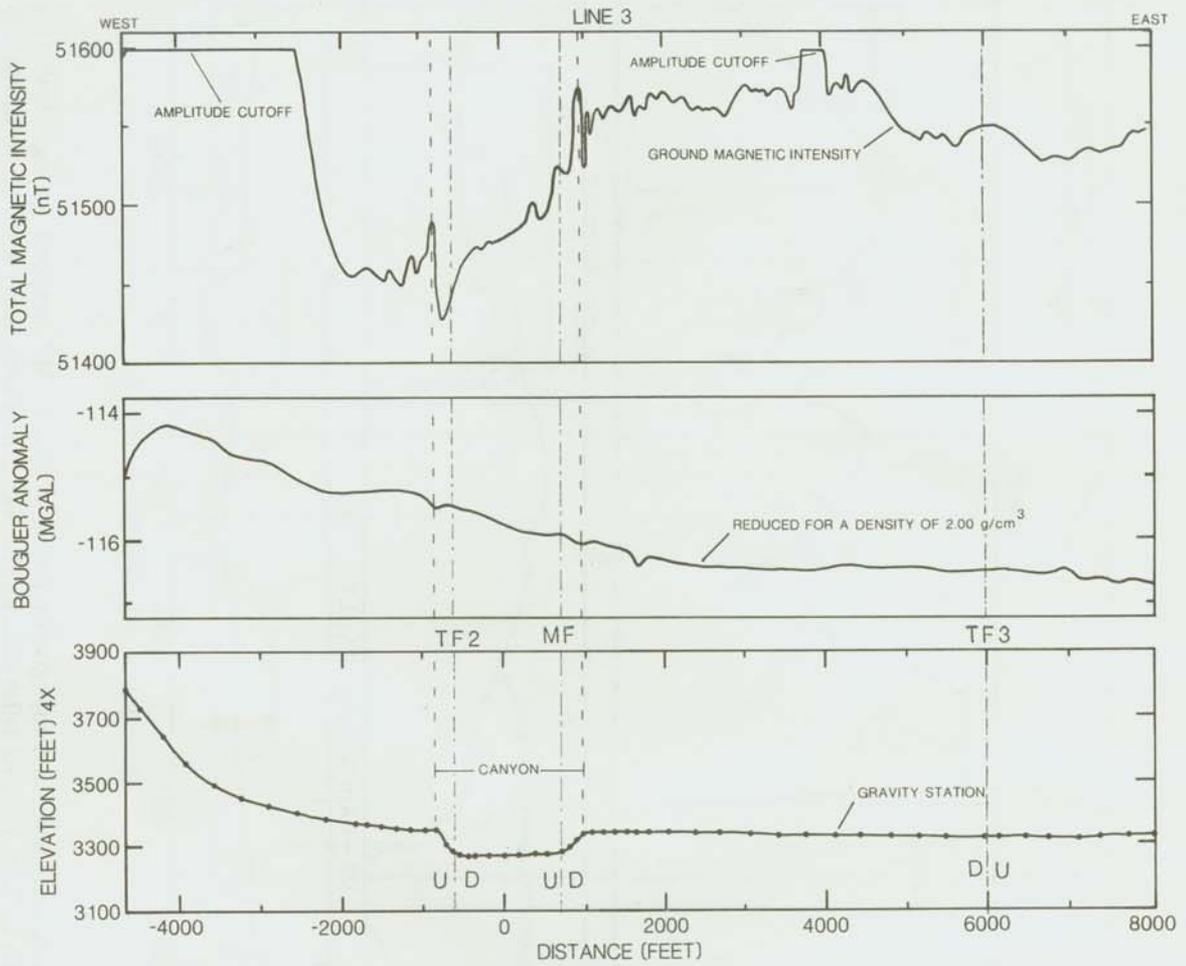


FIGURE 3c.—Gravity, magnetic, and topography profile of line 3. See figure 3b for explanation of symbols. TF2 may be the mapped fault because of the 500 m (1,600 ft) accuracy of the telluric data.

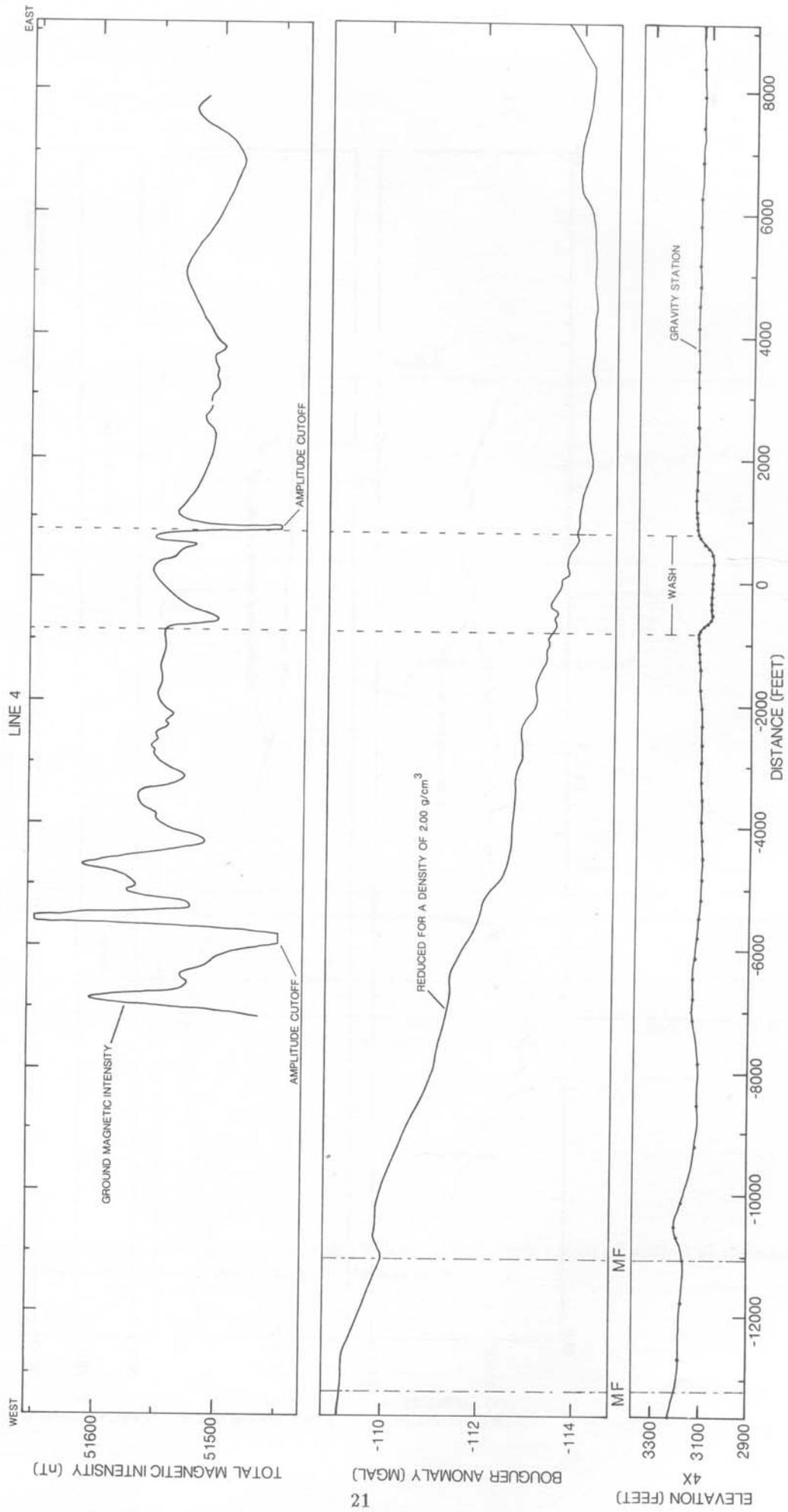


FIGURE 3d.-Gravity, magnetic, and topography profile of line 4.

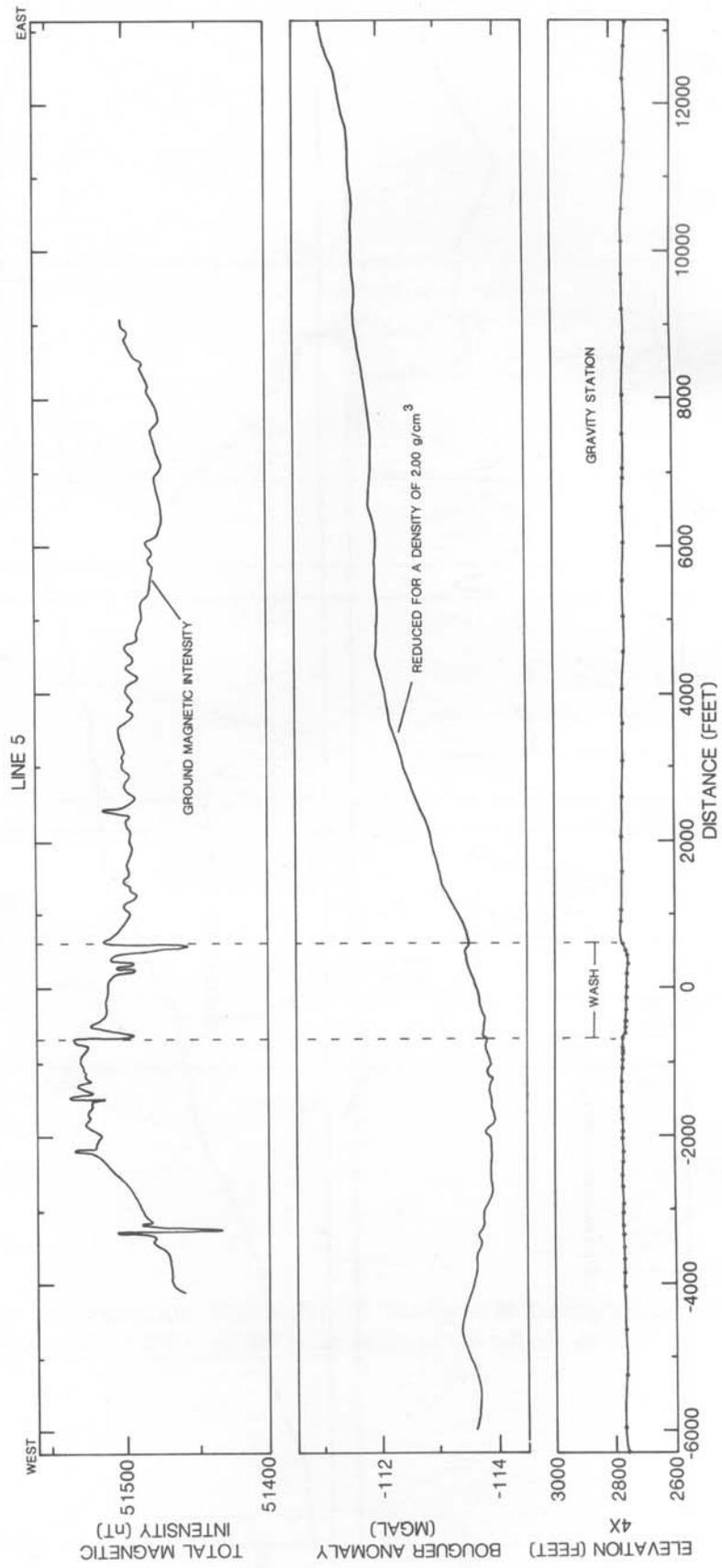


FIGURE 3e.—Gravity, magnetic, and topography profile of line 5.

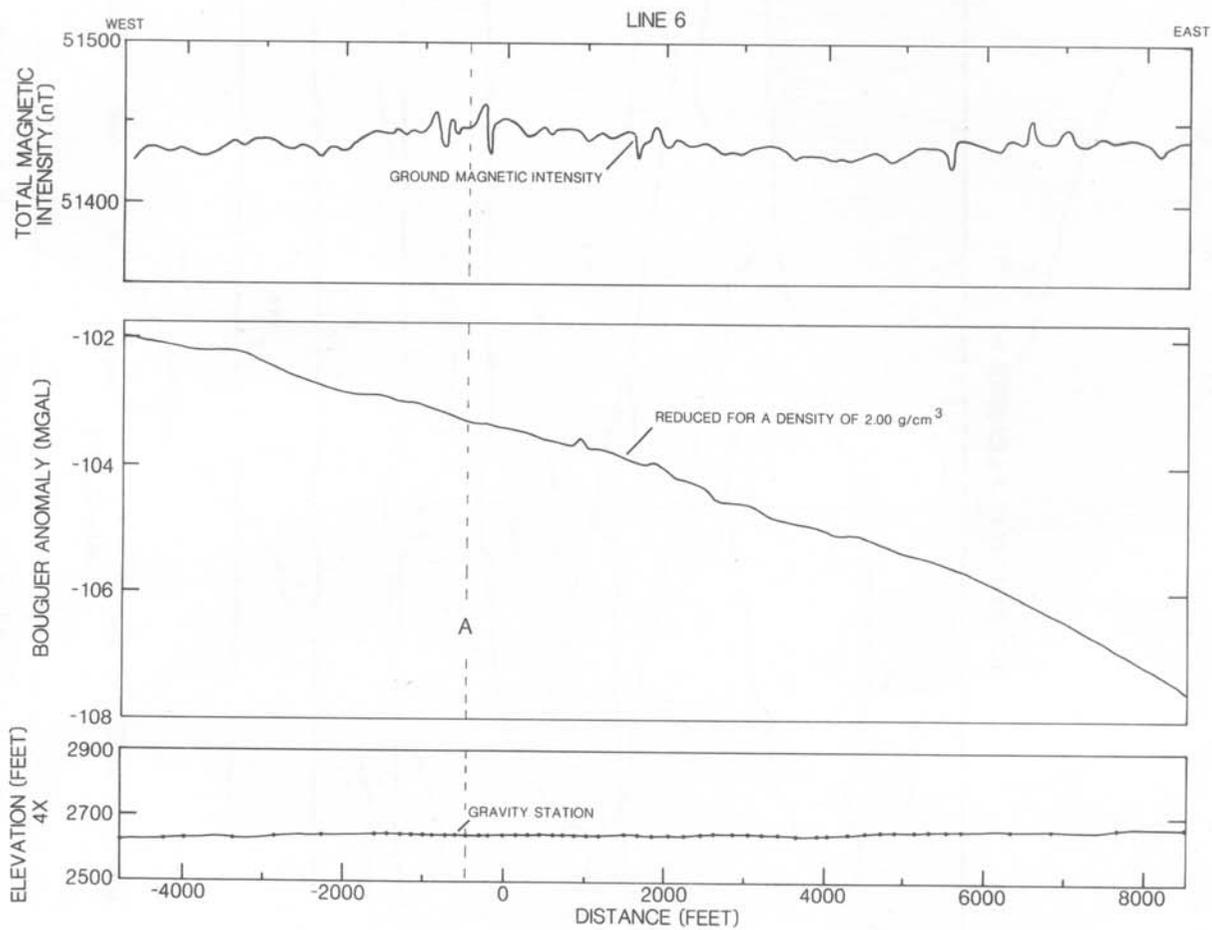


FIGURE 3f.-Gravity, magnetic, and topography profile of line 6. 'Indicated' center of wash is at distance 0.0 ft. Inferred center of wash determined from magnetic data is at 'A'.

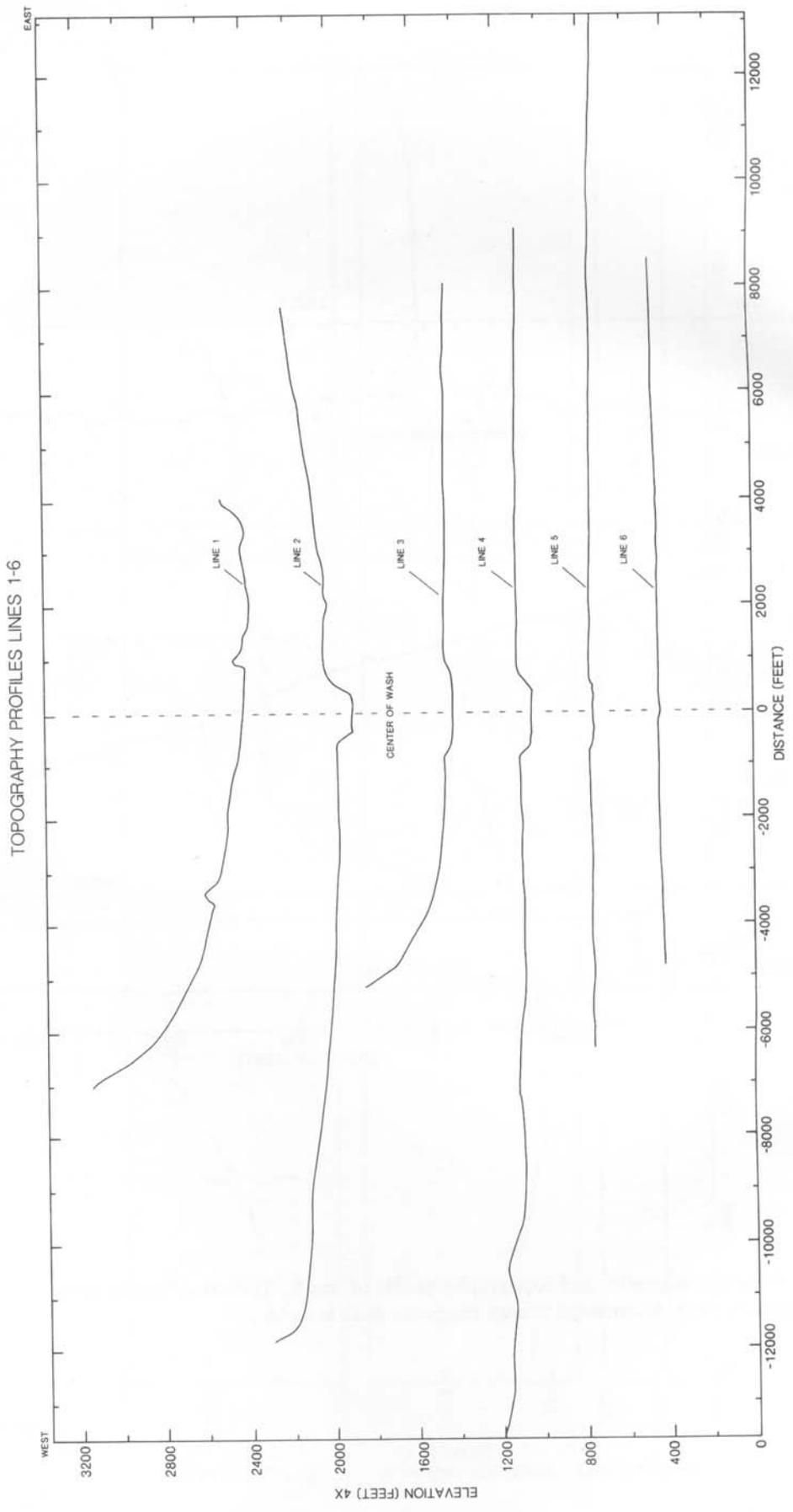


FIGURE 4a.-Composite profile of topography for six lines across Fortymile Wash.

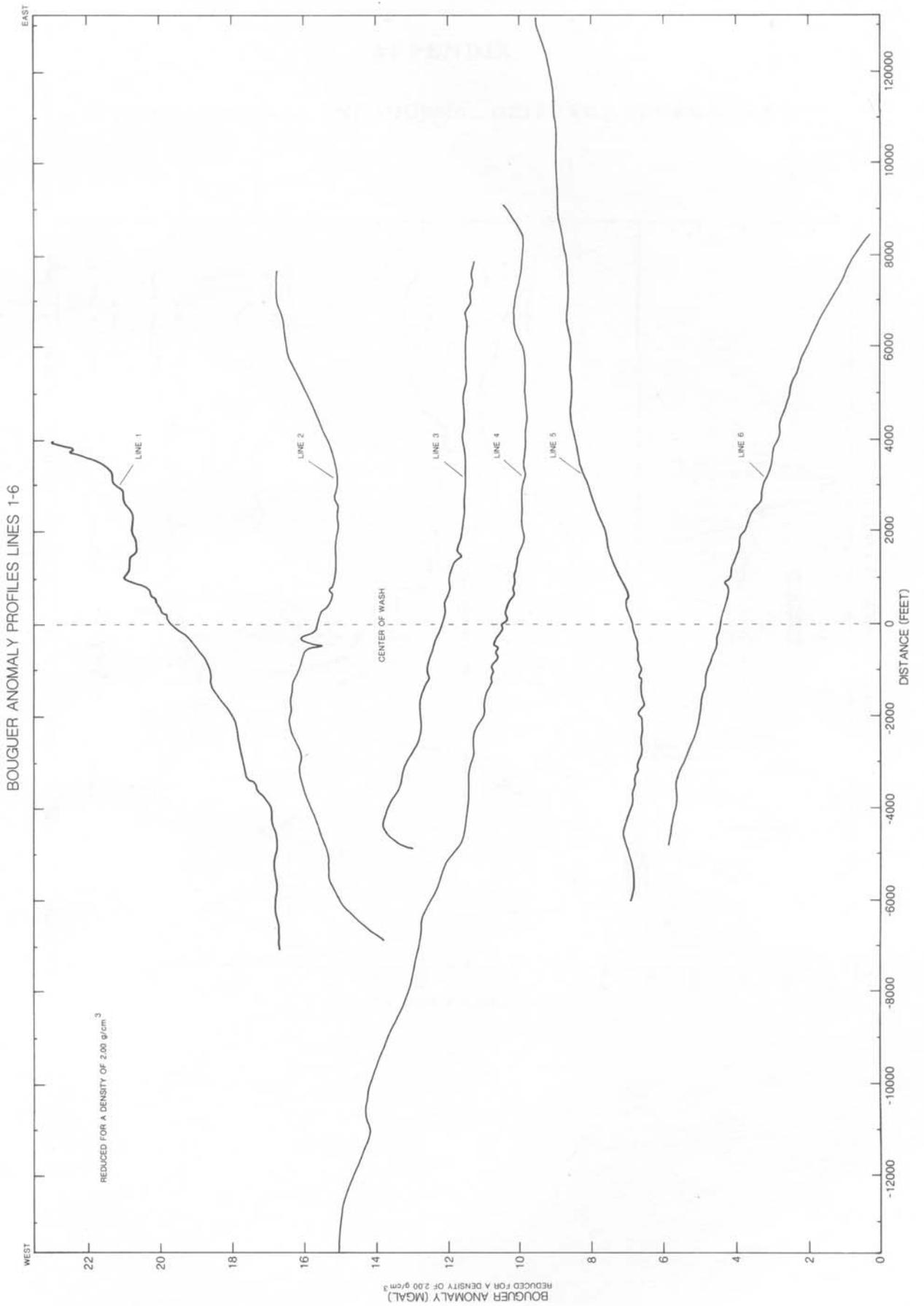


FIGURE 4b.—Composite profile of Bouguer gravity for six lines across Fortymile Wash, reduced for a density of 2.00 g/cm³.

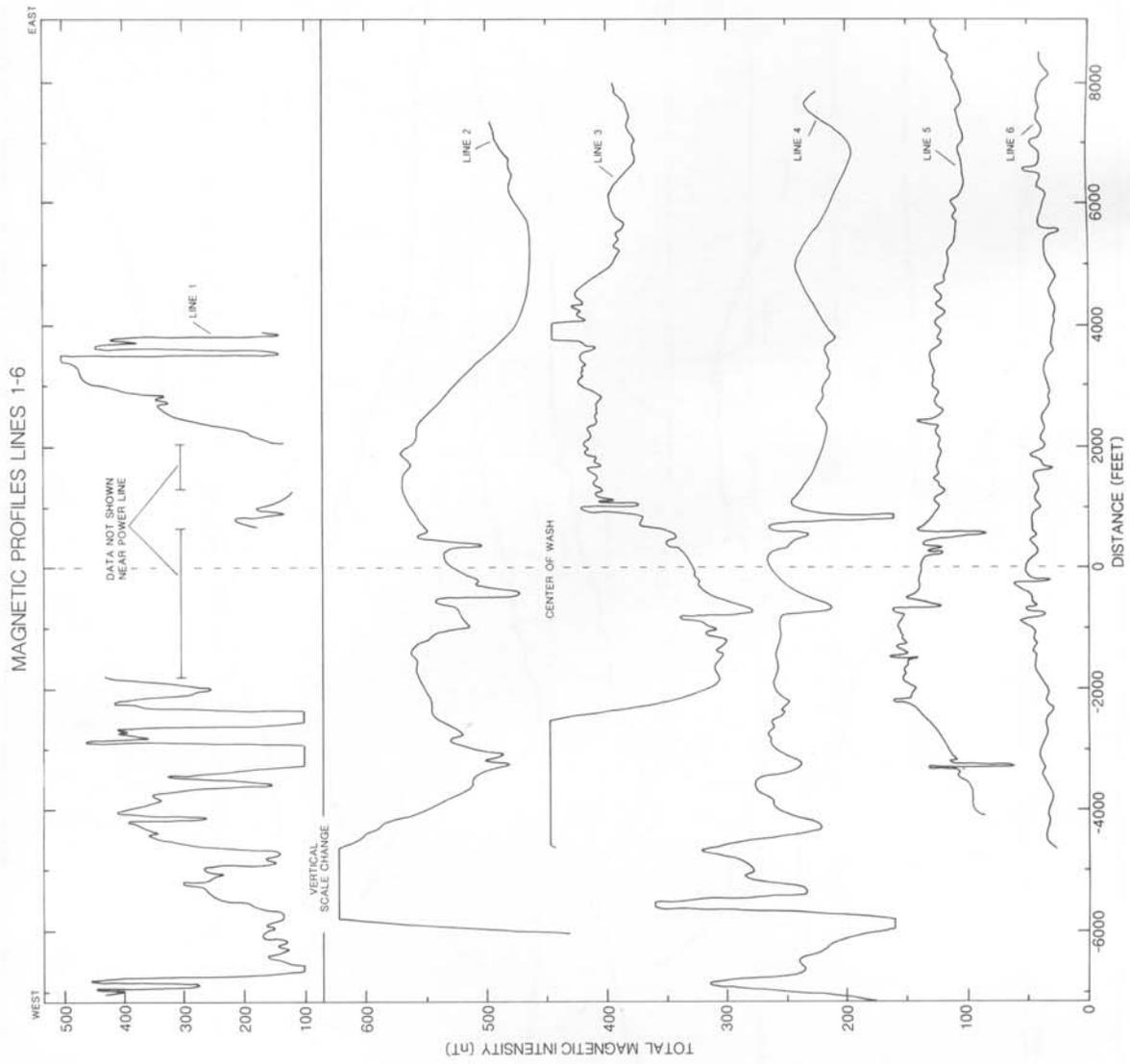
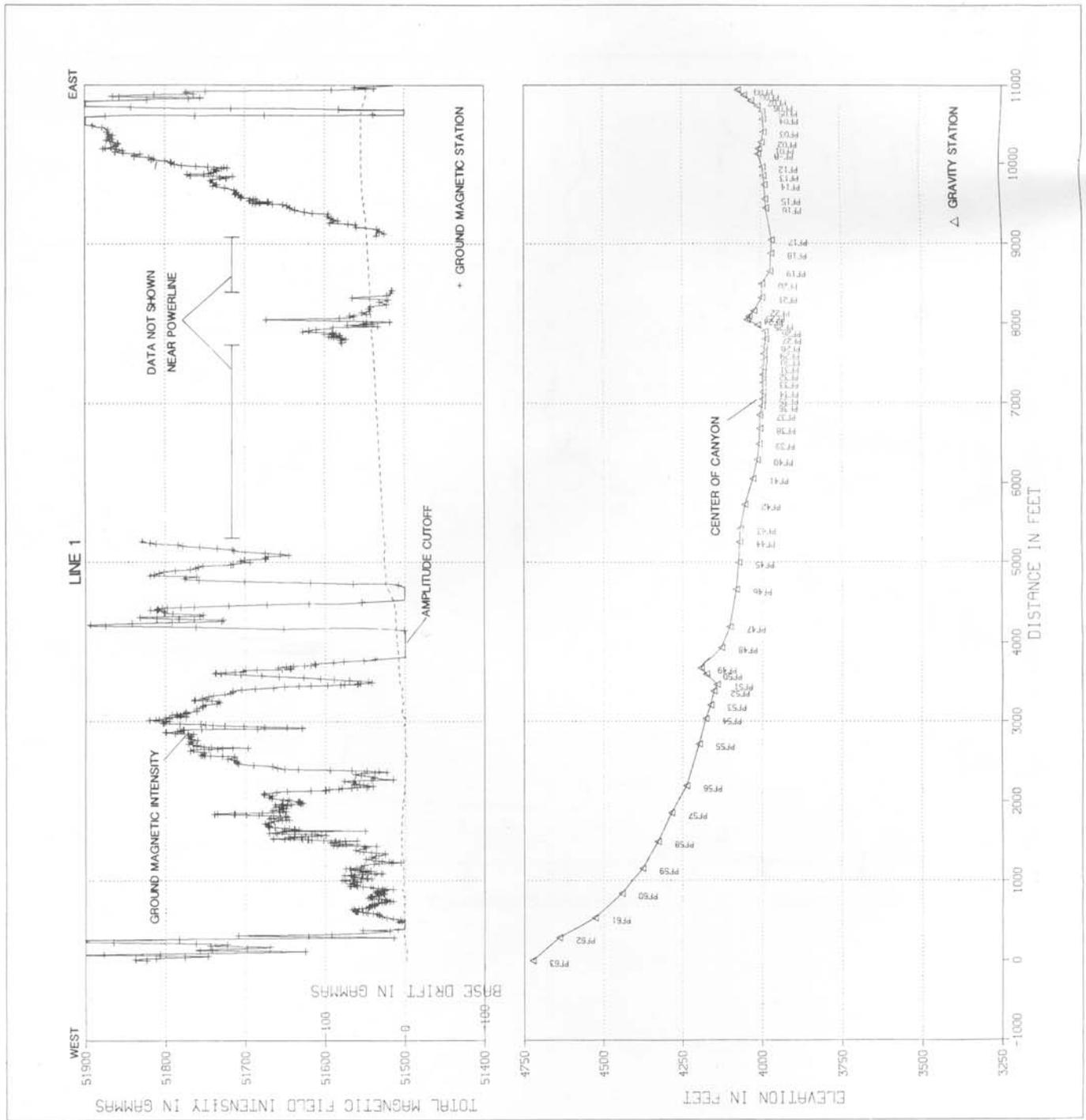
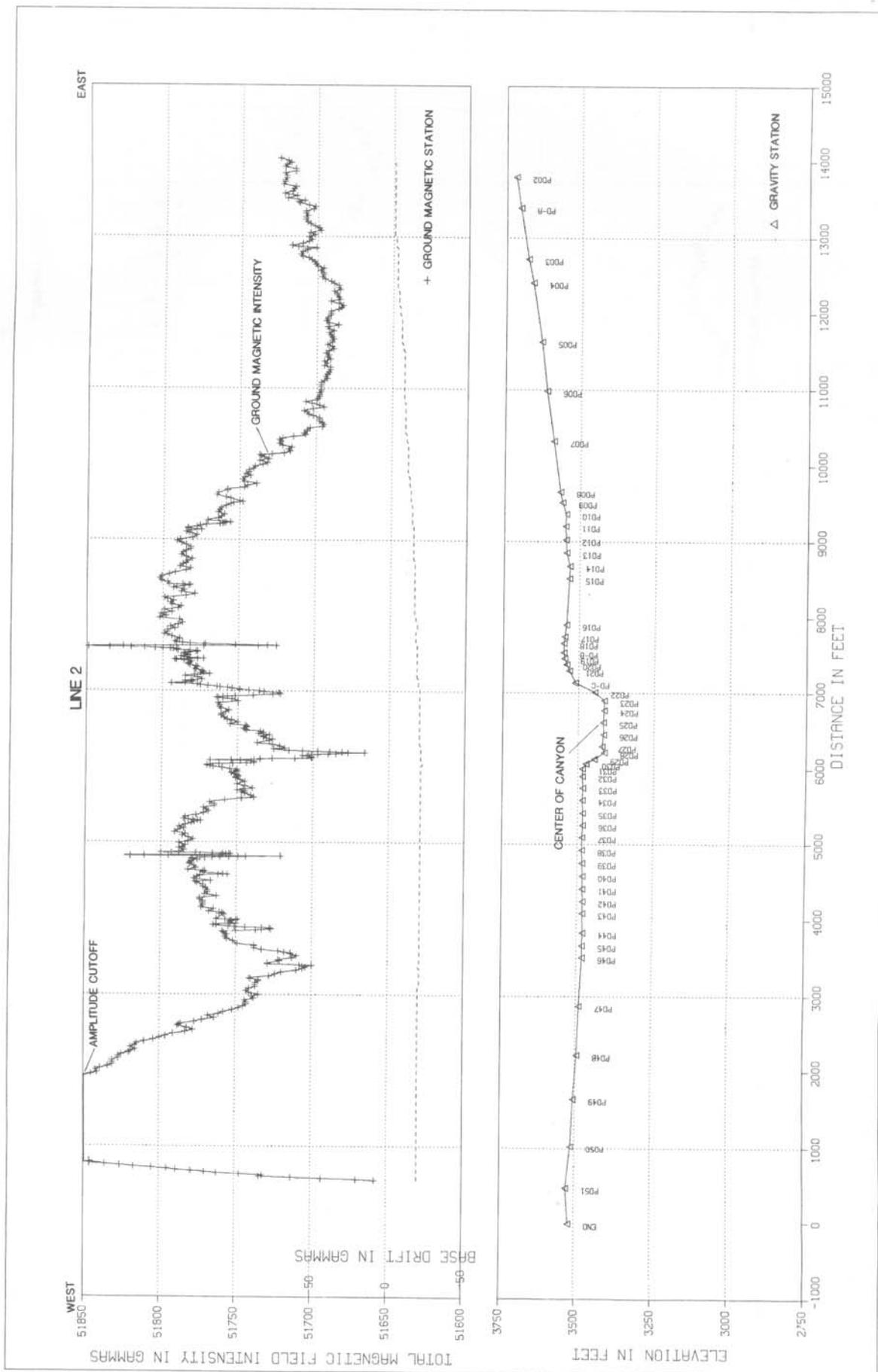


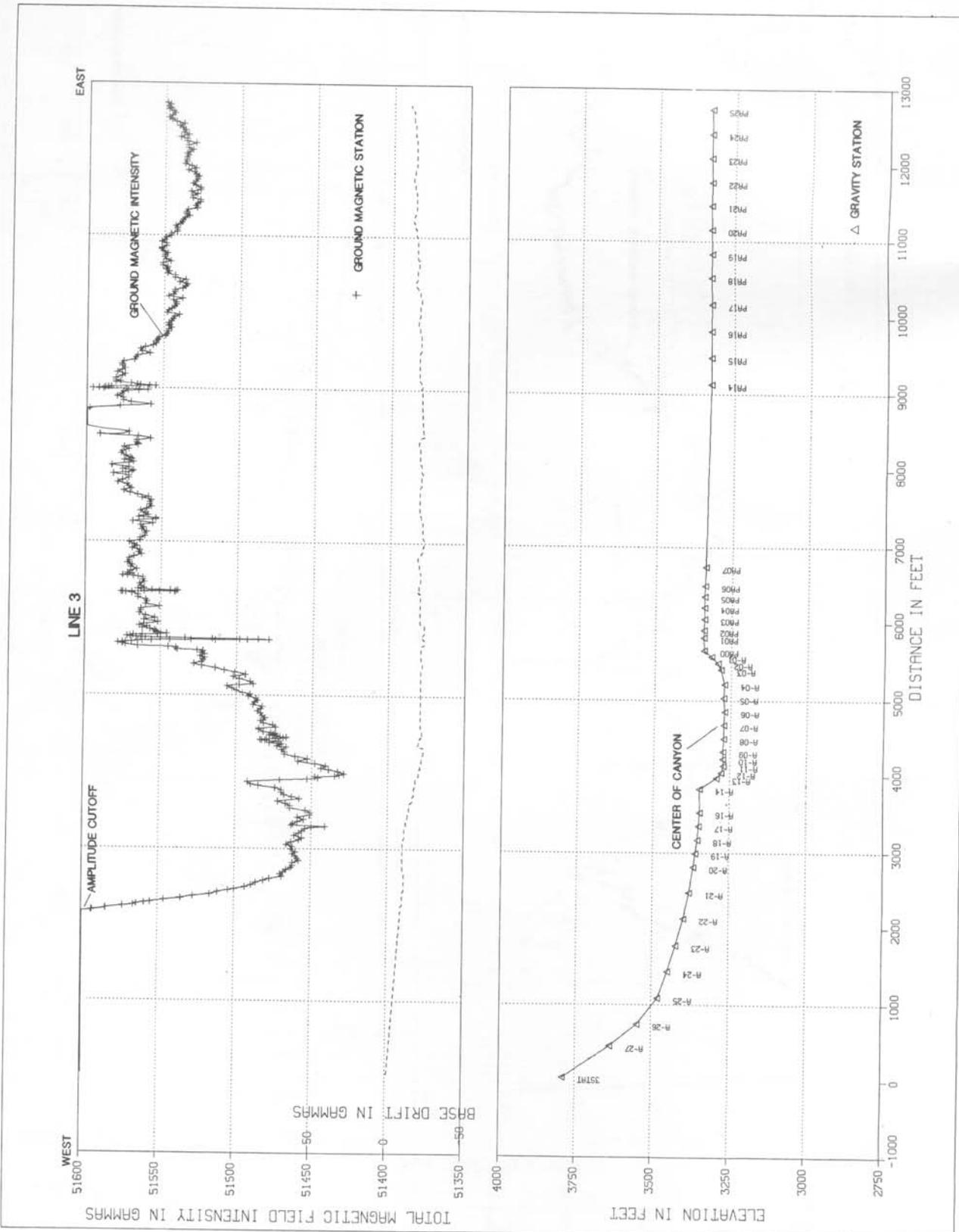
FIGURE 4c.-Composite profile of ground magnetic intensity for six lines across Fortymile Wash.

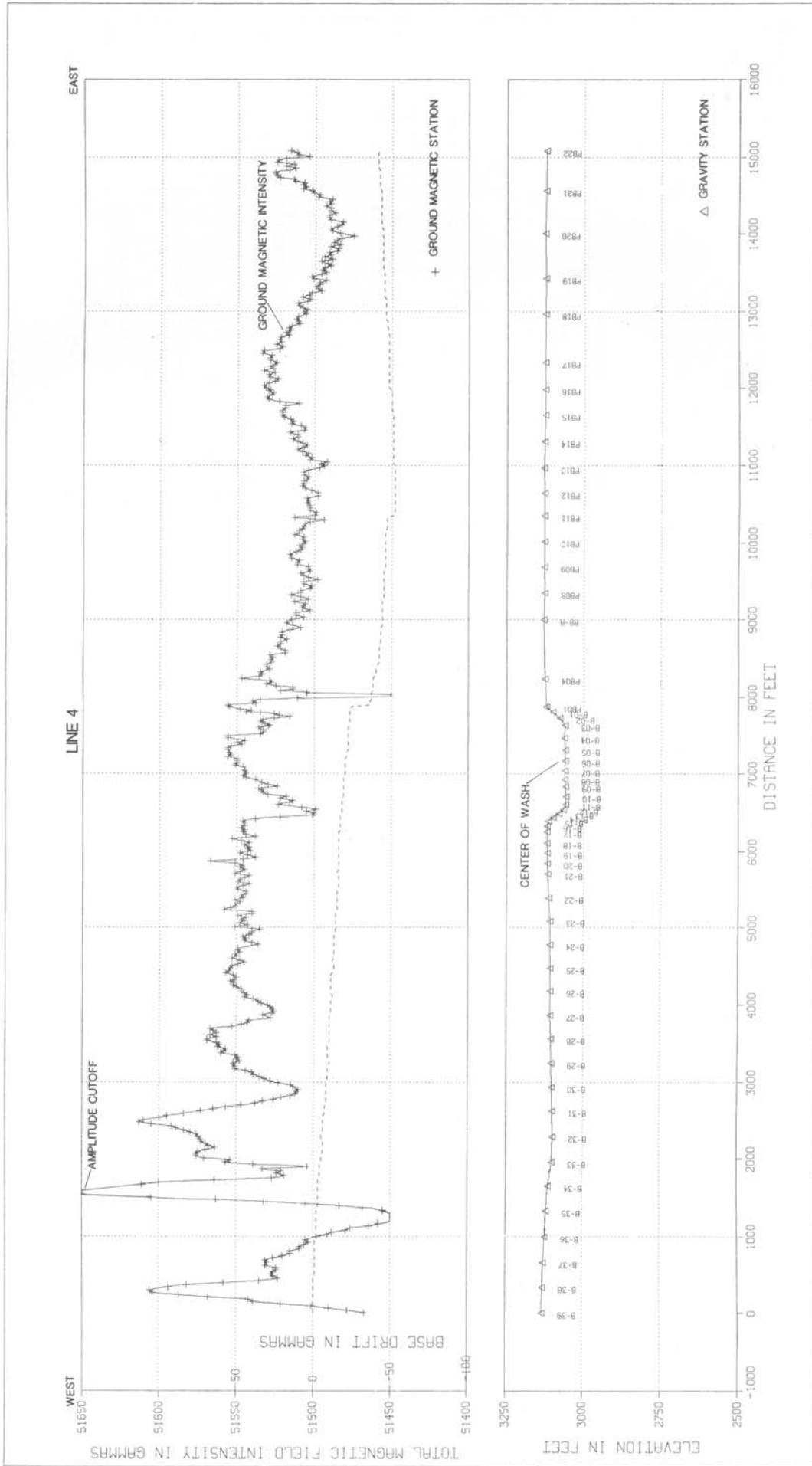
APPENDIX

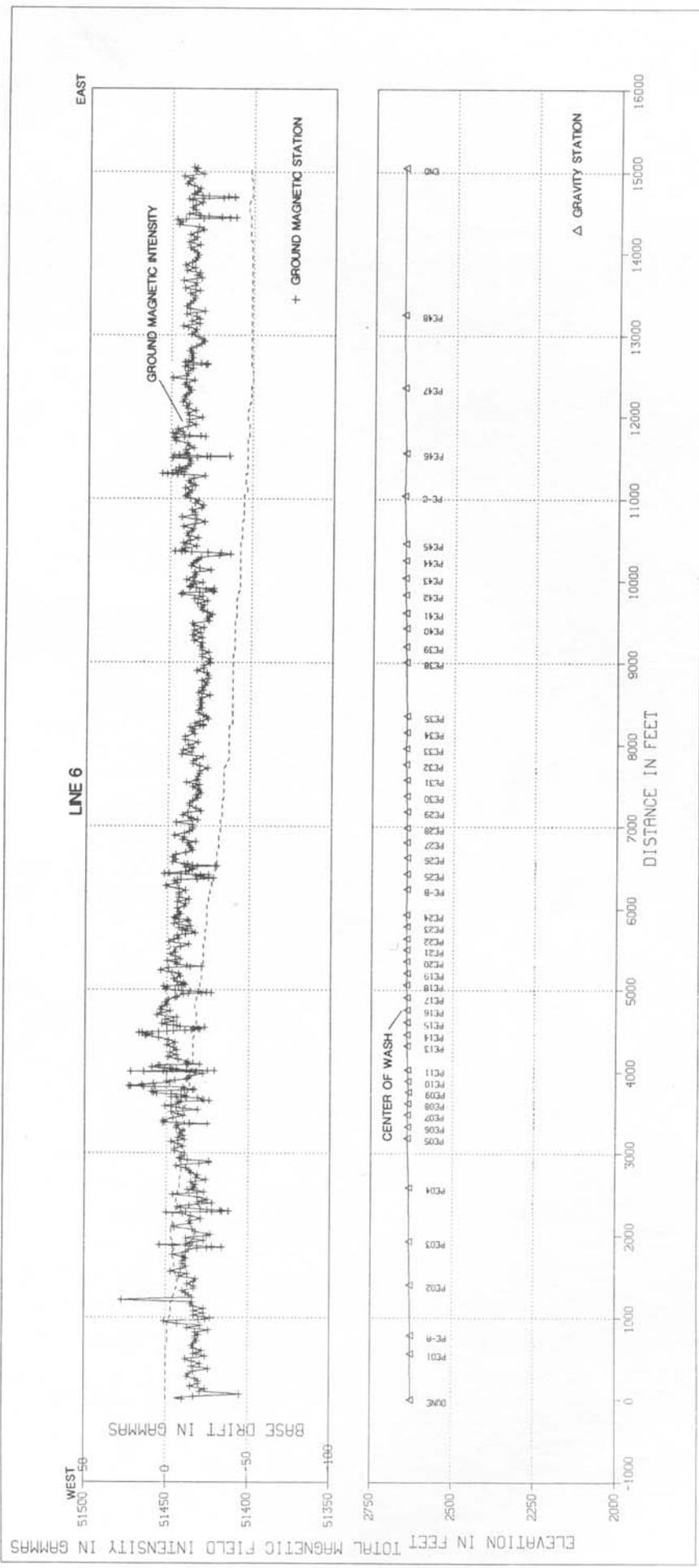
MAGNETIC DATA AND DIURNAL DRIFT FOR PROFILES 1-6











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