MAGNETIC AND GRAVIMETRIC EXPLORATION FOR BURIED FAULT SYSTEMS: AN EXPAMPLE FROM THE NORTHEAST BOISE GEOTHERMAL AREA, IDAHO

J. R. Pelton, C. K. Beagarie, L. I. Beem, S. M. Bunch, M. Caldwell, D. E. DeAvies, G. Eisele, M. N. Ellison, R. B. Howarth, D. P. Johnson, R. W. Krebs, M. L. Nimnicht, M. R. Sadrzadeh, S. Yahaya

Abstract

Total field ground magnetic data collected at approximately 1400 stations in a 9 square mile portion of the northeast Boise geothermal area outlines large amplitude (up to 2500 gammas) complex anomalies which correlate strongly with an irregular distribution of Tertiary volcanic rocks. A band of subdued anomalies trending northwest-southeast across the center of the survey area is interpreted to represent volcanic rocks underlying Idaho Group sediments. The southwest margin of this band of subdued anomalies could mark a major down to the southwest offset of the interpreted volcanic rocks. Gravimetric data collected on a short (4260 feet) N40E profile from Barber Dam to the mouth of Squaw Creek indicate two separated horizontal gradients of 3.4 and 7.1 mgal/mile (increasing to the northeast) which may represent faults with down to the southwest throw. An alternate interpretation relates the gradients to the unfaulted edges of two basalt flows. It is also possible that the steeper gradient is related to low density sediments associated with the present Boise River flood plain. Unfortunately, quantitative modeling is not warranted because the approximate termination points of the gradients are unknown.

Introduction

Detailed geologic mapping supplemented with well control and some geophysical data has helped define a late Cenozoic northwest-southeast trending range-front fault zone within the foothills of northeast Boise (Wood, 1982; Wood and Burnham, 1983; Burnham and Wood, 1985). A good understanding of this fault zone is desirable because it is an important factor in controling the depth to the Boise geothermal acquifer. At present, the faulting is best documented in the vicinity of the Old State Penitentiary and Quarry View Park (i.e., the Castle Rock area). Fault traces can be mapped there from mostly normal offsets in hillside exposures of Tertiary volcanic and sedimentary rocks. Moreover, several geothermal wells are deep enough to indicate the total offset of the oldest mapped unit across the boundary between the foothills and the flood plain north of the Boise River. In contrast, very little is known about the fault zone immediately to the southeast between the Old Penitentiary and Squaw Creek. Unpublished geologic mapping suggests that the faulting continues along a northwest-southeast trend, but surface evidence is discontinuous and often concealed by younger deposits (W. L. Burnham, personal communication, 1986). One well was drilled for geothermal purposes near Warm Springs Creek, but the well log data are not available in the public domain (S. H.

Wood, personal communication, 1986).

In an attempt to provide additional information on the fault zone between the Old Penitentiary and Squaw Creek, Boise State University geophysics students collected new magnetic and gravimetric data for that area. This paper presents the data in map and profile form and gives a qualitative interpretation of the results.

Magnetic Data

Total field magnetic data were gathered on a grid of approximately 1400 ground stations in a 9 square mile area: T3N, R3E, Sections 7, 8, 17, 18, 19, 20; T3N, R2E, Sections 12, 13, 24 (Figure 1). Roughly speaking, this is an area centered on Table Rock and extending south to the Boise River, north to Cottonwood Creek, west to Castle Rock, and east to the mouth of Squaw Creek. The station spacing for a substantial portion of the survey was approximately 250 feet, but in some areas station spacing was considerably larger (rarely up to 1800 feet). Station locations were determined in the field on USGS 7.5 minute topographic quadrangles using pace and compass techniques. The magnetometer was a Geometrics G-816 proton precession instrument with a +/-1 gamma repeatability under normal magnetic conditions. At each station the instrument was read at least three times to prevent blunders in recording. Return visits to base stations were made every two hours to ascertain drift. Each day's readings were drift-corrected back to the start of the day, but the readings were not drift-corrected back to the start of the survey. Daily readings made at a main base in Julia Davis Park showed that total field fluctuated by +/- 30 gammas about an average during the survey which took place between 17 July 1984 and 14 August 1984.

In addition to the magnetic contour map of Figure 1, two detailed total field magnetic profiles were run across Quarry View Park and up the hillslope above the Boise Warm Springs Water District wells in late December 1985 and early January 1986 (Figure 2). The magnetometer was the same as above and distances were measured by pacing. Drift was negligible (approximately 10 gammas). At each station the instrument was read at least twice and then two readings were made approximately 10 feet to the right of the station and two readings were made approximately 10 feet to the left. The purpose of the side readings was to obtain an estimate of the horizontal gradient of the magnetic field. We found that in the field area large horizontal gradients correspond to one of two situations: either the station is over an obvious volcanic outcrop or the station is near an obvious potential source of strong cultural magnetic fields. In the flood plain area the occurrence of volcanic outcrops can be ruled out. Thus on the flood plain the measurement of horizontal gradients was very useful for separating real anomalies (small gradients) from cultural anomalies (large gradients) when near a suspected source of cultural magnetic fields.

Figure 1 shows a strong correlation of large amplitude (up to 2500 gammas) complex magnetic anomalies with Tertiary volcanic rocks mapped most recently by Burnham and Wood (1985) and Burnham (unpublished map). The same correlation holds for the more detailed magnetic profiles (Figures 3 and 4). Thus the volcanic rocks are acting as sources and the associated anomalies must weaken and become less complex when the separation between magnetometer and source is increased. With this in mind, we suggest that the northwest-southeast trending band of subdued anomalies in the center of the map may be underlain at depth by rocks similar to the rhyolitic and basaltic rocks outcropping in the northwest quarter of Figure 1. If volcanic rocks do underly the band of subdued anomalies, then the subdued character would be a result of burial of the source rocks under Idaho Group sediments which outcrop over the central part of the map. The sediment thickness would be as much as 700 feet if the volcanic rocks are at the same elevation as those in the Castle Rock area, but even small dip could change this estimate considerably.

Two heavy solid lines are shown in Figure 1. The longer of the two lines marks the boundary between the band of subdued anomalies crossing the center of the map and the relatively simple magnetic pattern to the southwest. We suggest that this line marks a major offset between relatively shallow volcanic rocks (northeast) and deeper volcanic rocks (southwest). We visualize the relatively shallow volcanic rocks to be similar to those mapped near Castle Rock: an assemblage of rhyolites and basalts of differing magnetizations with structural relationships complicated by faulting. The line is drawn so that on the east side of the map it passes between the Castle Rock rhyolite and a well in Quarry View Park which encounters the same rhyolite at a depth of 850 feet beneath the surface (Burnham and Wood, 1985). The line also passes between the Castle Rock rhyolite and the Kanta well where the vertical offset of the rhyolite is documented at approximately 1000 feet (Wood and Burnham, 1983). Beyond this point to the southeast, the line is drawn on the basis of the magnetic data only. In the western third of the map, very large anomalies dominate the magnetic field; these anomalies are associated with exposures of basaltic tuff in the Warm Springs drainage and prevent further tracing of the line to the southeast. The short solid line separates a northwest-southeast trending high from a low of the same trend and may also represent a fault.

A few minor points concerning the magnetic map in Figure 1 should also be discussed. The two small closed lows near map coordinates 2000E and 16000N are probably the result of cultural magnetic fields and should be ignored. The original field crew took these measurements along roads that run just behind the complex of state buildings south of Quarry View Park and behind the Old State Penitentiary. Checks show large horizontal gradients in these areas which suggest the influence of cultural magnetic fields. On another subject, the tendency of anomalies to line up along east-west profiles is a result of the spatial sampling rate being greater in an east-west direction as compared to a north-south direction. Thus the contouring algorithm is able to interpolate higher east-west spatial frequencies during the digital to analog conversion.

The detailed magnetic profiles shown in Figures 3 and 4 were undertaken to investigate the magnetic signature of the known fault offset between Castle Rock and the well in Quarry View Park. Both profiles show that except for cultural disturbances, the magnetic field is flat on the flood plain north of the Boise River. This suggests that the magnetic rocks are either deep or reasonably uniform in their lateral distribution, or both. The profiles are also consistent with a small magnetic low at the first break in slope followed by increasing field strength and erratic behavior near volcanic outcrops on the footwall side of the fault. In Figure 3, large horizontal gradients and large anomalies are associated with: (i) the complex of state buildings south of Quarry View Park and cultural features within Quarry View Park; (ii) the basalt quarry on the hillslope east of Castle Rock. In Figure 4, strong horizontal gradients are associated with: (i) a very sharp anomaly on the flood plain near the begining of the profile (obviously shallow, possibly a pipe), (ii) a trash dump about 200 feet west of the Boise Warm Springs Water District pumphouse near the first break in slope, and (iii) basalt exposures on the hillslope.

<u>Gravimetric Data</u>

A relatively short (4260 feet) gravimetric profile was run across the Boise River flood plain from Barber Dam to the mouth of Squaw Creek in Sections 28 and 29 of T3N, R3E (Figure 2). The line consists of two halves separated by a 1000 foot left-stepping offset along state highway Idaho 21 (Warm Springs Avenue). The azimuth of both halves is N40E, and the station spacing for both halves was 200 feet (except for one interval of 190 feet between the last two stations at the mouth of Squaw Creek). Station intervals were taped; the total number of stations is 23. The gravimeter was Worden Prospector No. 608 with scale constant 0.0756(2) mgal/scale division and a repeatability under good observing conditions of +/-0.1 scale divisions (+/-0.01 magal). Field measurements were made on 5 October 1985 with brief followup measurements on 10 October 1985. Station B on Figure 5 was used as a base for repeat measurements to determine drift on 5 October; repeat measurements were made approximately every hour. Drift rates were on the order of 0.1 mgal/hr and showed a smooth curve peaking in the late afternoon of 5 October. Elevations relative to station B were determined by spirit leveling using an automatic level and a Philadelphia rod read to the nearest 0.01 foot; each section between stations was run forward and backward and three-wire techniques were used. We feel confident that relative elevation differences were determined with +/-0.1 foot precision.

Data reduction followed standard procedures with the datum chosen at the elevation of B and a Bouguer density of 2.0 g/cc to reflect the expected density of the alluvium above the datum. Terrain corrections were carried out to zone K of Hammer (1939) for the four stations at the endpoints of the two profile halves; a density of 2.67 g/cc was used to represent the bulk of the terrain which was to the north of the line in the Boise foothills. The zone K terrain corrections for the four endpoints lie within a 0.03 mgal interval indicating that zone K effectively treats the entire profile as the same station. Corrections beyond zone K are therefore unnecessary because they would add the same constant to the anomaly value for each station (zone K has an outer radius of 32490 feet). Terrain corrections at stations between the endpoints of each profile half were linearly interpolated. This procedure is justified on the basis of the nearly linear increase of the four calculated terrain corrections as the Boise foothills are approached along the profile.

The complete Bouguer anomaly and residual complete Bouguer anomaly are shown in Figure 5. The residual was computed by removing a regional gradient of -1.723 mgal/mile in the N40E azimuth. This gradient reflects the deep lateral density changes associated with isostatic equilibrium of the Snake River Plain and the Idaho batholith (Mabey, 1976; Mabey, 1985). It was measured from a regional gravity map computed by Mabey (1985) by applying a 64 km lowpass filter to a complete Bouguer anomaly map for Idaho. Because of the 1000 foot left-stepping offset in the profile along Idaho 21, we have not connected the two profile halves in rigorous fashion. The 0.18 mgal discontinuity in the anomaly curves precisely at the Idaho 21 offset suggests that two-dimensional subsurface geometry striking perpendicular to the profile is not a perfectly valid assumption, although it may be a useful hypothesis as a first approximation. In our judgment, it is reasonable to assume that the 0.18 mgal discontinuity is the result of lateral variations in gravity perpendicular to the profile, and had the profile been continuous to the northeast, the residual probably would have followed the solid curve without marker symbols (Figure 5).

The residual contains two horizontal gradients of 3.4 and 7.1 mgal/mile separated by a relatively flat section (ignoring the discontinuity in the curve at the Idaho 21 offset). A simple interpretation would be to assume that these gradients result from variations in alluvial thickness above bedrock. Thus alluvial thickness increases from the mouth of Squaw Creek to the southwest towards Idaho 21, somewhere in the middle of the profile the alluvial thickness stabilizes, and then alluvial thickness increases again towards the Boise River. Comparison of the two gravity gradients implies that the slope of the bedrock surface is more gradual on the northeast side of the profile relative to the slope in the vicinity of the Boise River; the differences in bedrock slope must be rather large to more than offset the gravitational effect of the the differences in depth at which the slopes presumably occur. If the increases in alluvial thickness are the result of down to the southwest normal faulting, then the fault plane under the southwest side of the profile is more steeply dipping and/or involves more offset than the fault plane beneath the northeast side of the profile. Equivalently, the initial increase in alluvial thickness at the range front may be the result of stair-step faulting, while the more sudden increase near the Boise River may be the result of large offset along a major fault. A hypothesis which does not require faulting would account for the gradients with the distal edges of two basalt flows.

The terrain effect of the dike which parallels the southwestern stations

(Figure 2) has not been removed from the data of Figure 5. We estimate that the dike has a maximum terrain effect of approximately 0.1 mgal and the effect generally decreases to the northeast because the height of the dike diminishes in that direction. Thus the dike may be partially responsible for the large gravity gradient in the vicinity of the Boise River, but the contribution of the dike is probably not substantial. Another factor that may be partially responsible for the large gradient is a shallow boundary marking a decrease in sediment density associated with the present flood plain. Order of magnitude calcualtions which test this hypothesis are inconclusive because the data are insufficient to determine the depth to top, depth to bottom, and angle of dip of the hypothetical shallow boundary. In fact, all numerical modeling of this data will be hampered until we can extend the line to the northeast and southwest to find the likely termination points of the observed gravity gradients. For example, the estimation of depth to top and bottom of a vertical offset requires a knowledge of the total amplitude of the anomaly as well as the horizontal gradient.

Conclusions

(1)Well log data analyzed by others tells us that a major fault is located between the outcrops of volcanics on the Castle Rock hillside and a well drilled approximately 700 feet to the southwest in Quarry View Park. The fault throw is down to the southwest with an 850 foot offset of the Castle Rock rhyolite, one of the oldest volcanic units in the Boise foothills (Burnham and Wood, 1985). We also know from detailed magnetic profiles that the magnetic field is essentially flat on the downthrown side of the fault except for cultural disturbances; on the upthrown side the field is complicated by near-surface and non-uniform distributions of volcanic rocks (Figures 3, 4). Thus the position of the major fault may be approximately identified on the profiles by the boundary between a relatively flat anomaly curve on the downthrown side and a more complex anomaly curve on the upthrown side. This result is referred to in the next conclusion.

(2)A total field ground magnetic anomaly map for a nine square mile area centered on Table Rock shows a strong correlation of Tertiary volcanic rocks with complex and large amplitude magnetic anomalies (Figure 1). This correlation is also found on the detailed magnetic profiles in the Castle Rock area (Figures 3 and 4) and implies that the volcanic rocks are acting as the principal natural sources of disturbances in the magnetic field. A northwest-southeast trending band of subdued anomalies crossing the center of the map does not correlate with any mapped volcanic rocks, but may represent volcanic rocks underlying Idaho Group sediments. If volcanic rocks are producing the subdued anomalies, then it is possible that these volcanic rocks are correlative with rhyolites and basalts mapped northwest of the Table Rock area, including the Castle Rock rhyolite. As indicated earlier, the entire survey area is crossed by a northwest-southeast trending late Cenozoic fault zone with offset generally down to the southwest. Thus we would expect any volcanic unit lying southeast of Castle Rock and of the same age to also have undergone a major down to the southwest offset along one of the late Cenozoic faults. Since the detailed magnetic profiles in the vicinity of Castle Rock indicate that a known major offset of this type is marked approximately by the boundary between a flat magnetic field on the downthrown side and a more complicated magnetic field on the upthrown side, we are led to speculate as follows: the heavy line in Figure 1 which marks the northwest-southeast trending boundary between relatively flat anomaly patterns to the southwest and more complex anomaly patterns to the northeast represents major down to the southwest offset of volcanic rocks which underly Idaho Group sediments. Major offset in the overlying Idaho Group sediments has not been proven conclusively, requiring the interpreted fault to be older than the sediments.

(3)A short (4260 feet) N40E gravimetric profile from Barber Dam northeast to the mouth of Squaw Creek contains two separated horizontal gradients of 3.4 and 7.1 mgal/mile which may represent two subsurface faults: one near the mouth of Squaw Creek, the other near the Boise River. Offset on both faults would be down to the southwest. The relative sizes and positions of the two gradients suggests that the fault near the Boise River has more offset and/or is more steeply dipping than the fault near the mouth of Squaw Creek. An alternate interpretation that does not require faulting would attribute the gradients to the distal edges of two basalt flows buried by flood plain deposits. The steeper gradient might also be related to low density sediments associated with the present Boise River flood plain. Quantitative modeling of the profile is not warranted because the termination points of the gradients are unknown. For this reason the line should be extended to the northeast and southwest.

The authors are all associated with the Department of Geology and Geophysics, Boise State University, Boise, Idaho 83725.

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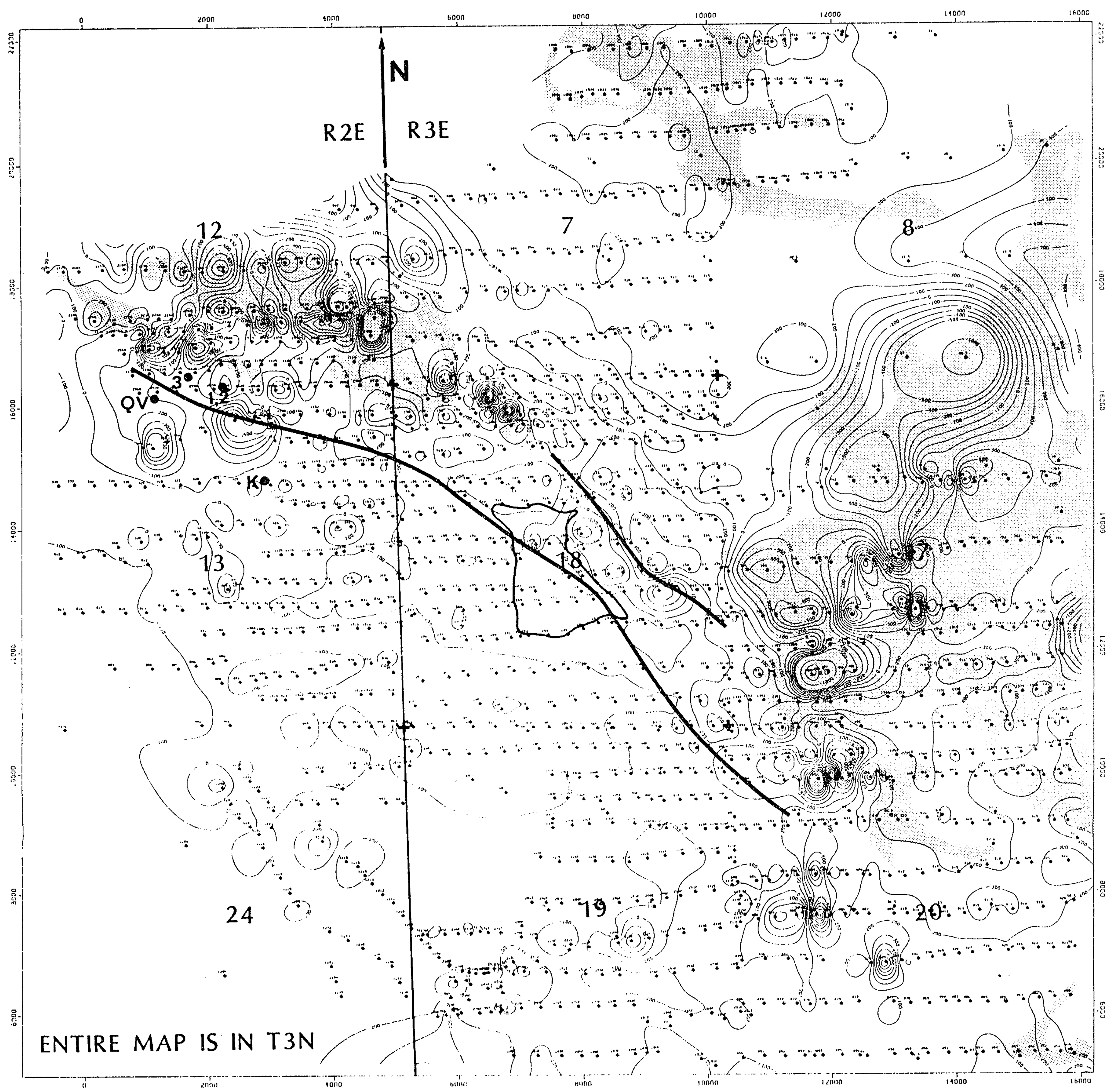

Figure 1

Figure 1
Total field ground magnetic anomaly map. Stations are circles with small crosses; station number shown illegibly at this scale. Contour values relative to 55000 gammas. Contour interval 100 gammas for contour values greater than -500 gammas, contour interval 500 gammas for contour values less than -500 gammas. Black dots are wells: QV - Quarry View; 3 - Boise Warm Springs Water District #3; 1,2 - Boise Warm Springs Water District #1, #2; K - Kanta. Straight medium-weight line separates R2E and R3E, North is along this line towards the binding. Heavy crosses are section corners for T3N, R3E, Section 18. Closed medium-weight curve in center is 3600 foot contour outlining Table Rock. Curved heavy-weight lines are interpreted faults (see text). Shaded areas show volcanic rocks from detailed geologic mapping (Burnham and Wood, 1985; Burnham, unpublished map). Tick marks on margins are at 2000 foot intervals. The 10% (approximate) discrepancy between north-south and east-west section line lengths and between north-south section line lengths and marginal tick mark intervals was caused by distortions in the enlargement of the original base map.

FIGURE CAPTIONS

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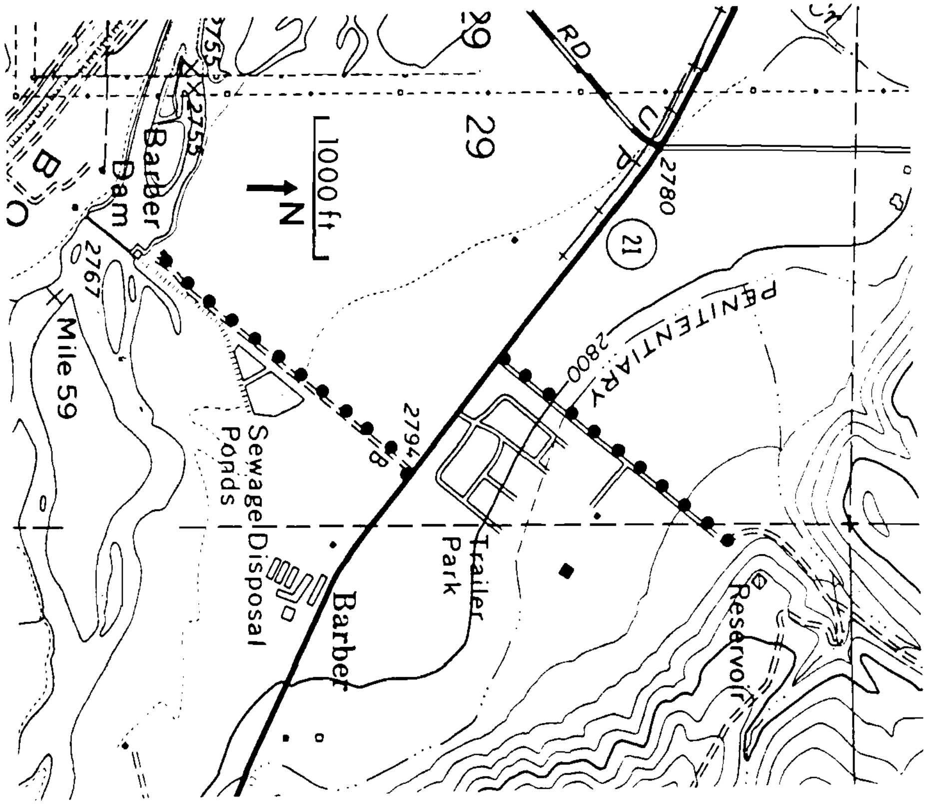
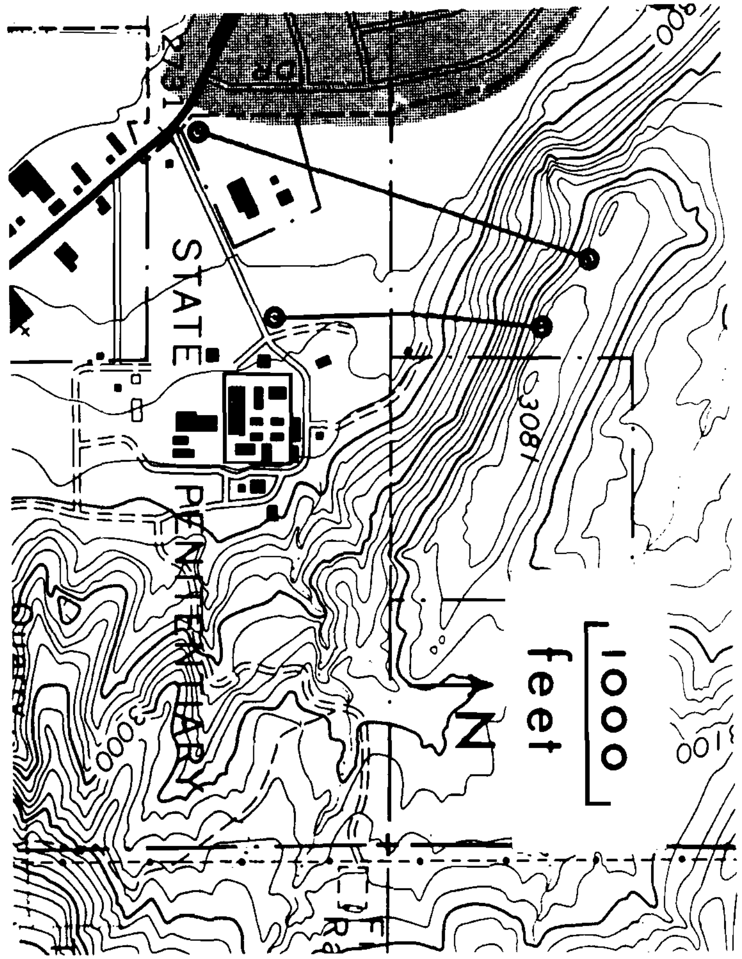
Figure 2
Location maps of detailed magnetic profiles (upper) and gravimetric profile (lower). Magnetic profiles shown by medium-weight lines with circled endpoints; gravity stations shown by black dots. From U. S. Geological Survey 7.5 minute 1972 Boise South quadrangle (upper) and U. S. Geological Survey 7.5 minute 1972 Lucky Peak, Idaho quadrangle (lower). Gravity station labeled B is the base station.

Figure 3
Detailed magnetic profile (western profile in Figure 2, top). Station spacing 10 paces = 28 feet approximately. Arrow indicates location of first break in slope. Symbols TEN CTS and PAV mean tennis courts and pavillion, respectively; B indicates station over basalt outcrop on upthrown side of fault. Vertical bars indicate minimum and maximum of: station reading, right lateral reading, left lateral reading; used to check horizontal gradient (see text).

Figure 4
Detailed magnetic profile (eastern profile in Figure 2, top). Station spacing, arrow, B, and vertical bars same as in Figure 3.

Figure 5
Gravimetric profile (for location see Figure 2, bottom). Symbols CBA and B indicate complete Bouguer anomaly and base station, respectively. See text for description of anomaly curves.





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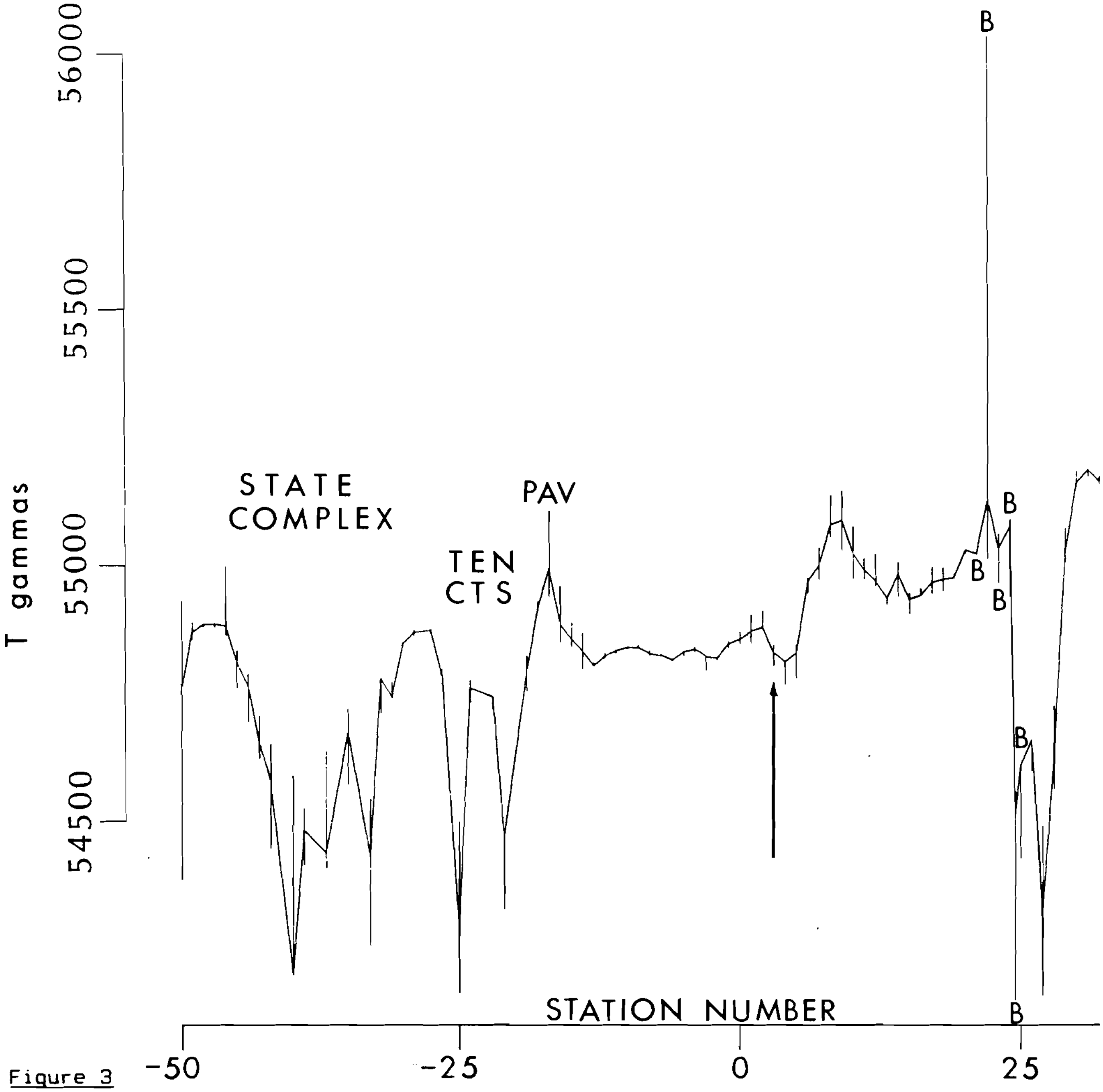

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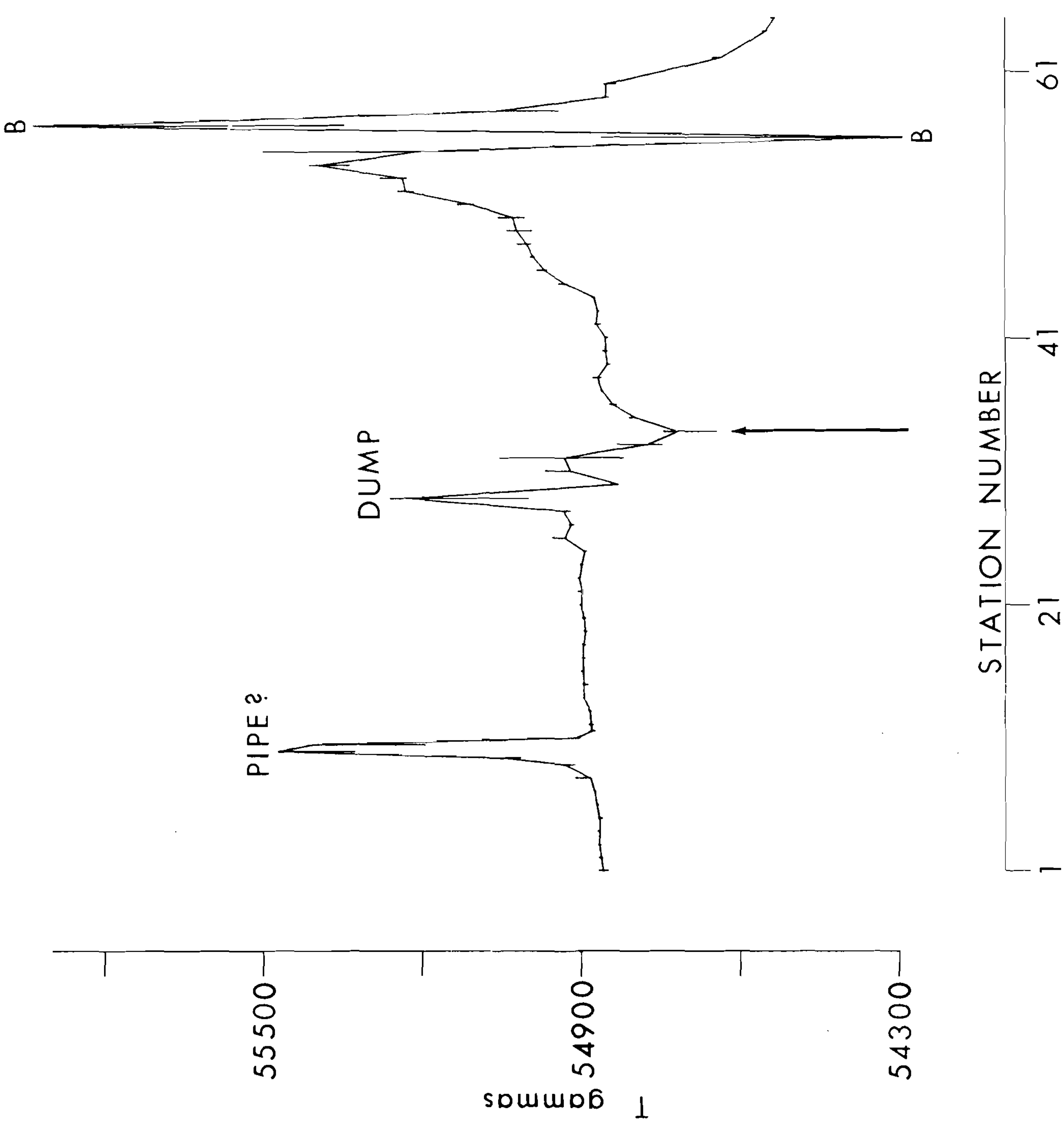

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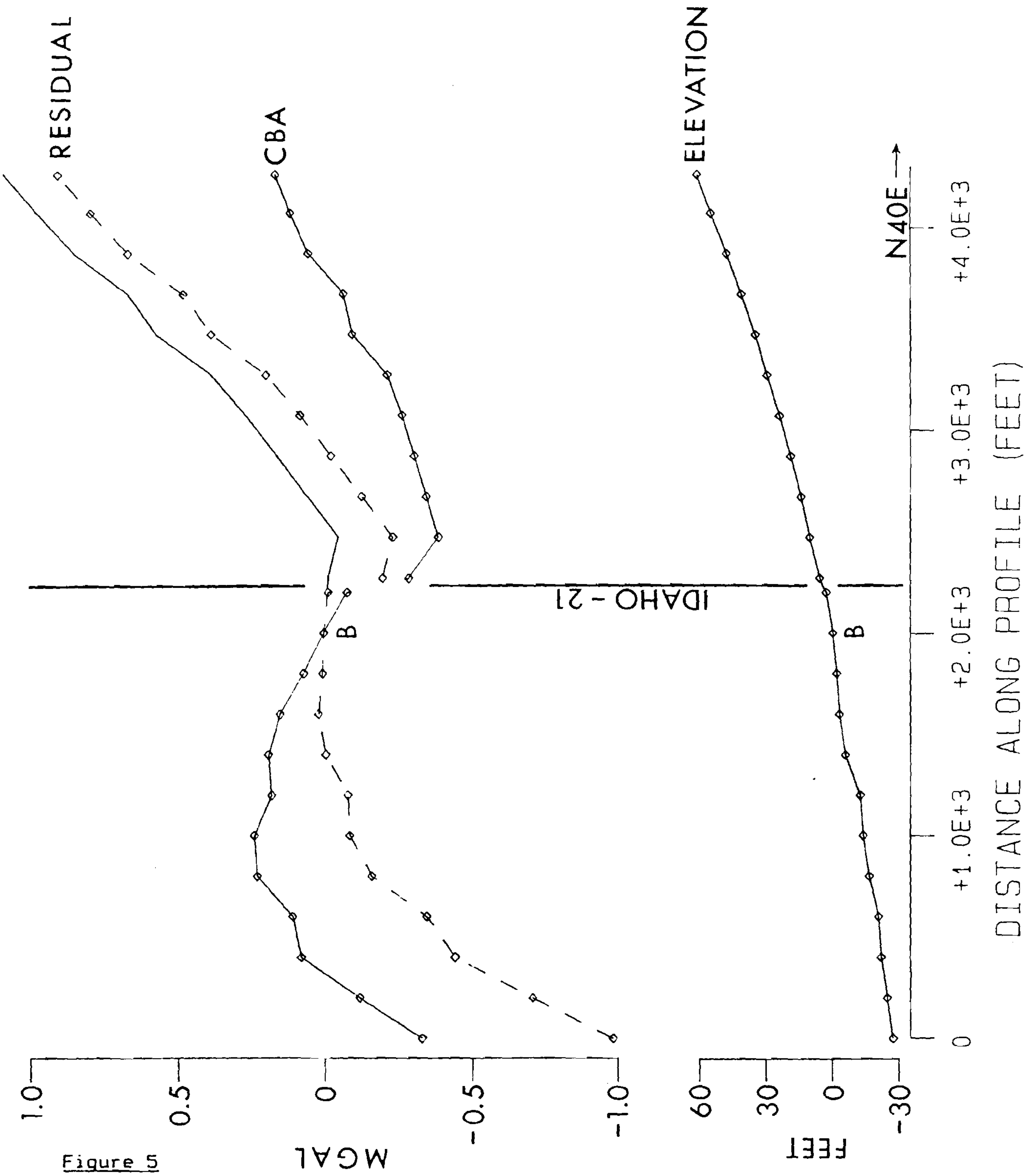

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