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GRAVITY AND MAGNETIC EVIDENCE FOR A GRANITIC INTRUSION NEAR WAHMONIE SITE, NEVADA TEST SITE, NEVADA

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Abstract. Gravity and magnetic data outline a broad anomaly near Wahmonie Site, Nye County, Nevada. A positive 15-mGal gravity anomaly with a steep western gradient and a broad magnetic anomaly coincident with the gravity high characterize the area. Two-dimensional computer models of the gravity data were made using magnetic, seismic, and electric data as independent constraints. The models indicate the presence of a shallow, relatively high density body of 2.65 kg m^{-3} buried near Wahmonie Site. Aeromagnetic and ground magnetic data also indicate the presence of a large, shallow body. Two smaller local magnetic highs that occur along a magnetic prominence extending northward from the broad anomaly directly correlate to granodiorite outcrops. This indicates that the main anomaly is produced by a large shallow intrusion.

Introduction

Wahmonie Site is located on the Nevada Test Site (NTS) about 112 km northwest of Las Vegas, Nevada (Figure 1). The NTS is near the southern border of the Great Basin and lies near the thickest parts of the Paleozoic Cordilleran miogeosynclinal section. Outcrops in the Wahmonie Site are predominantly composed of Tertiary volcanic rocks. These volcanics consist of a series of ashfall and ash flow tuffs that are dominantly rhyolitic in composition and range in age from 26 to 7 Ma [Ekren, 1968]. The Wahmonie volcanic center (Figure 2) erupted andesite, dacite, latite, and tuff. Lower and upper parts of the Wahmonie Formation are dated at 12.9 and 12.5 Ma, respectively [Kistler, 1968, p. 255]. A conspicuous feature near Wahmonie Site is a horst trending north-northeast about 1.6 km wide and 4.8 km in length (Figure 2). The Wahmonie horst is predominantly composed of rhyodacite of the late Miocene Salyer Formation. Two small Tertiary granodiorite intrusive bodies crop out on the east marg n of the horst. The northern body is closely associated with and nearly encircles a small outcrop of the Eleana Formation of Carboniferous age. The Eleana outcrop consists of tan quartzite, calcareous sandstone, and conglomerate. Other, smaller intrusive bodies are present within the horst and are composed of andesite, rhyodacite, and intrusive breccia.

The chemical and mineralogic similarities of the Salyer and Wahmonie formations indicate they are comagmatic and probably are the extrusive equivalents of the granodiorite.

Previous geologic work was done by Ball [1907], Johnson and Hibbard [1957], Poole et al. [1965], Ekren and Sargent [1965], and Cornwall [1972]. Geophysical work includes regional gravity [Healey et al., 1980], detailed gravity [Ponce, 1981], aeromagnetic [Boynton and Vargo, 1963a, b; U.S. Geological Survey, 1979], ground magnetic [Bath, G. D., personal communication 1980], electrical [Smith et al., 1981; Hoover et al., 1982], and seismic [Pankratz, 1982]. These studies were initiated by the U.S. Geological Survey as part of an effort on behalf of the U.S. Department of Energy (Interagency Agreement DE-AI08-78ET44802) to characterize a possible nuclear waste repository in granitic rocks.

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Density Data

More than 250 density measurements of surface samples were used to compute the gravity models. In general, rock densities at the NTS fall into three broad groups: (1) Paleozoic, Mesozoic, and intrusive rocks, (2) Cenozoic volcanic rocks, and (3) ash flow tuff and alluvium. The three groups have approximate average dry bulk densities of 2.67, 2.40, and 2.00 kg m^{-3} respectively. Alluvial densities range from 1.30 to 2.12 kg m^{-3}, partly dependent on the lithology of the source rocks. Densities of rock types in the area are presented in Table 1.

Gravity Data and Regional Trend Separation

Standard gravity corrections were made on all the data and include (1) the earth tide correction, which removes the effect of the tidal attraction of the sun and moon, (2) the instrument drift correction, (3) the free-air correction, which accounts for the fact that each station is at a different elevation, (4) the simple Bouguer correction, which accounts for the attraction of rock material between the station and sea level, (5) the latitude correction, which takes into account the variation with latitude of the earth's gravity at sea-level, (6) the curvature correction, which corrects the Bouguer correction for the effect of the earth's curvature, and (7) the terrain correction, which removes the effect of topography to a radial distance of 166.7 km. Data were reduced using the Geodetic Reference System of 1967 [International Union of Geodesy and Geophysics, 1971] and referenced to the IGSN 1971 gravity datum [Morelli, 1974].

Two regional gravity gradients were removed from the gravity data at Wahmonie Site by determining residual and isostatic corrections. The residual gravity values were computer calculated by removing a planar regional gravity gradient from the complete Bouguer values. The gradient is based on data from gravity stations on pre-Tertiary rocks and was determined from Diment et al.'s [1961, Figure 2] regional gravity

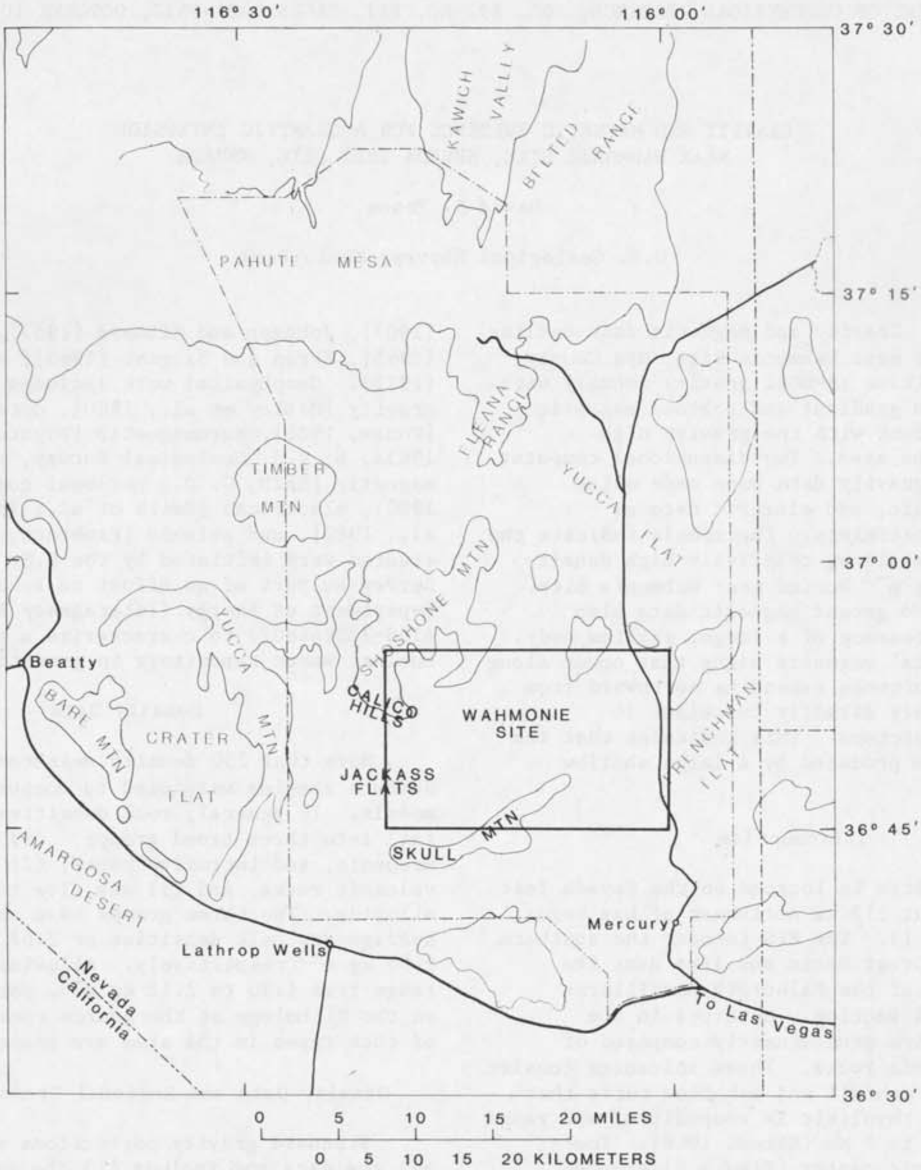

Fig. 1. Index map of part of southern Nevada. Outlined area indicates location of study area shown in Figures 2-5.

TABLE 1. Mean Dry Bulk Density of Surface Rock Samples

Lithology	Number of Samples	Mean Bulk Density, kg m^{-3}	Range of Density, kg m^{-3}	Remarks/Source
		Tertiary		
Tuff	31	2.18	n.a.	Keller [1959]
Volcanic rocks	77	2.22	1.55-2.71	W. J. Carr et al. (personal communication, 1975)
Dacite porphyry	76	2.27	1.81-2.43	Johnson and Ege [1964]
Volcanic rocks	6	2.29	2.18-2.35	
Rhyolite	17	2.31	2.00-2.52	
Altered breccia flow	6	2.31	2.21-2.49	Wahmonie Site area
Hydrothermally altered rock	18	2.36	2.17-2.50	Wahmonie Site area
Mafic lavas	3	2.41	2.26-2.53	
Intrusive rhyolite	9	2.57	2.52-2.63	Wahmonie horst
Breccia flow	6	2.58	2.54-2.60	Wahmonie Site area
Rhyodacite	27	2.58	2.53-2.65	Wahmonie horst
Granodiorite	23	2.65	2.60-2.69	Wahmonie horst
Andesite	8	2.66	2.62-2.70	Wahmonie horst
		Paleozoic		
Quartzite	2	2.61	2.58-2.63	Wahmonie horst
Limestone	3	2.63	2.62-2.65	Harley Barnes, (personal communication, 1967)
Meta-sediment	7	3.12	2.98-3.18	Wahmonie horst

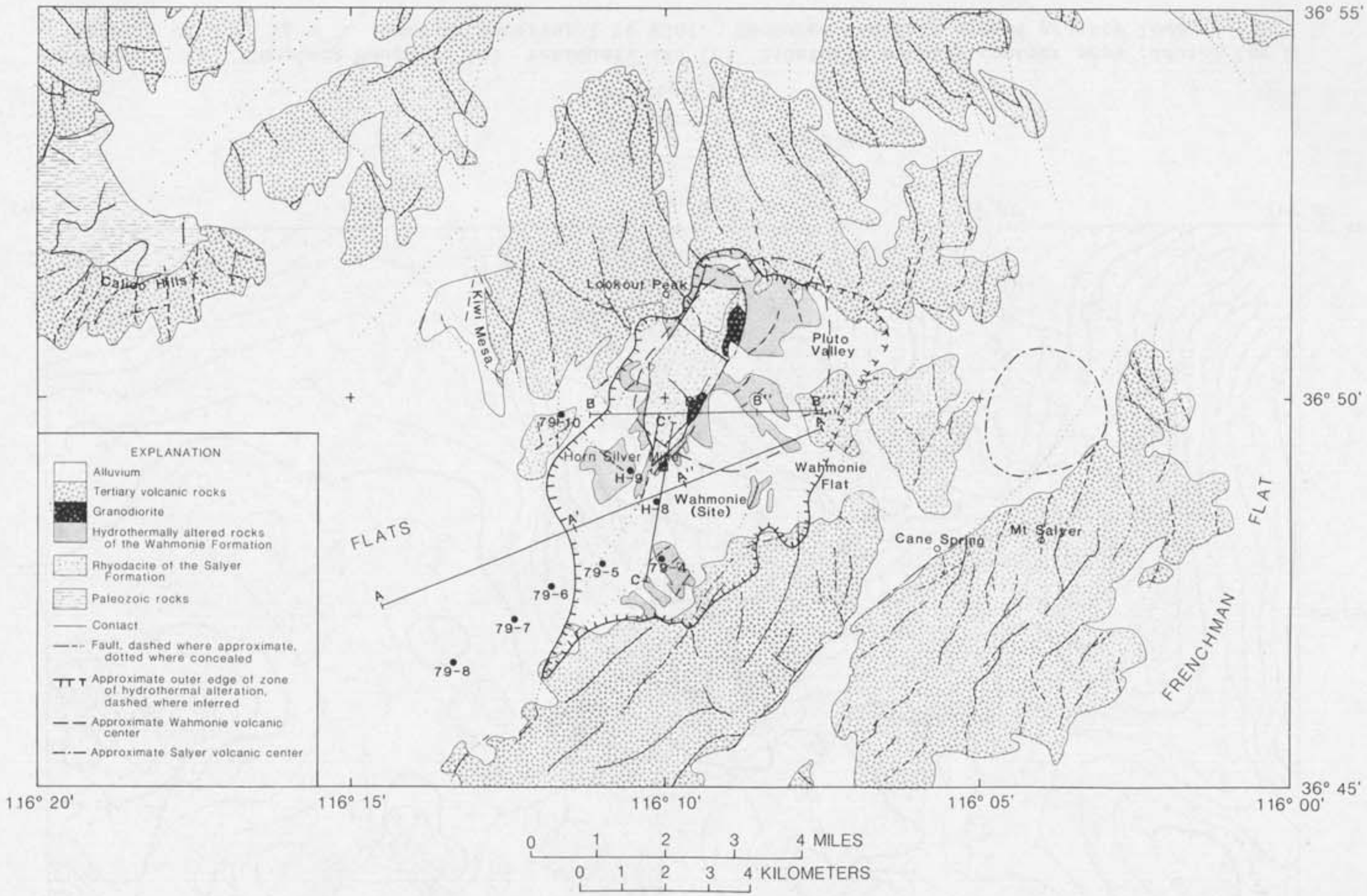

Fig. 2. Generalized geologic map of Wahmonie Site (modified from Ekren and Sargent [1963]) Showing gravity profiles AA''' and BB''', magnetic profile CC', seismic profiles A'A" and B'B", and vertical electrical soundings (79-5).

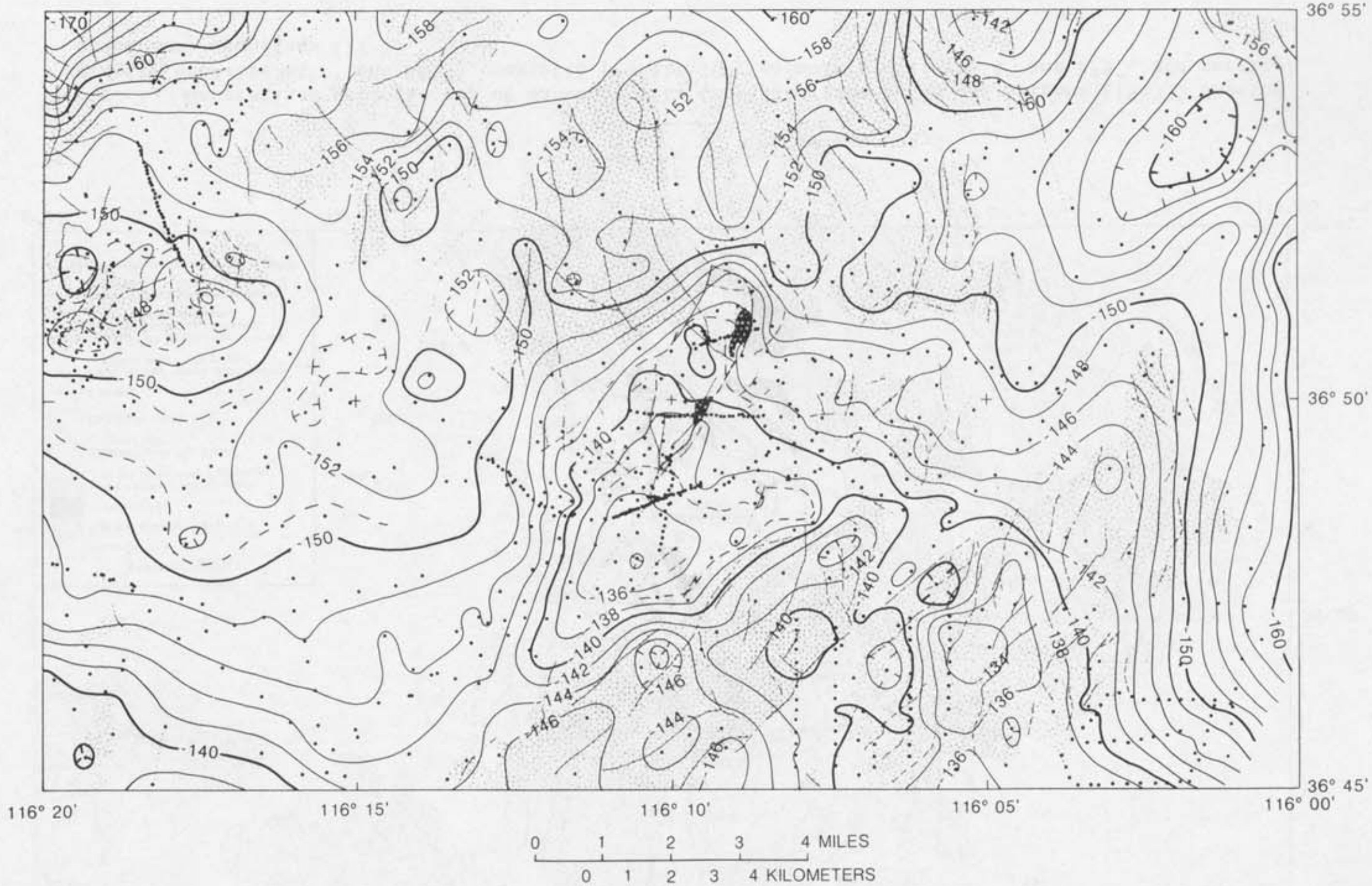

Fig. 3a.

Fig. 3. (a) Complete Bouguer, (b) residual, and (c) isostatic anomaly contour maps reduced for a density of 2.67 kg m^{-3}. Contour interval 2 is mGal. Hachures indicate closed gravity lows.

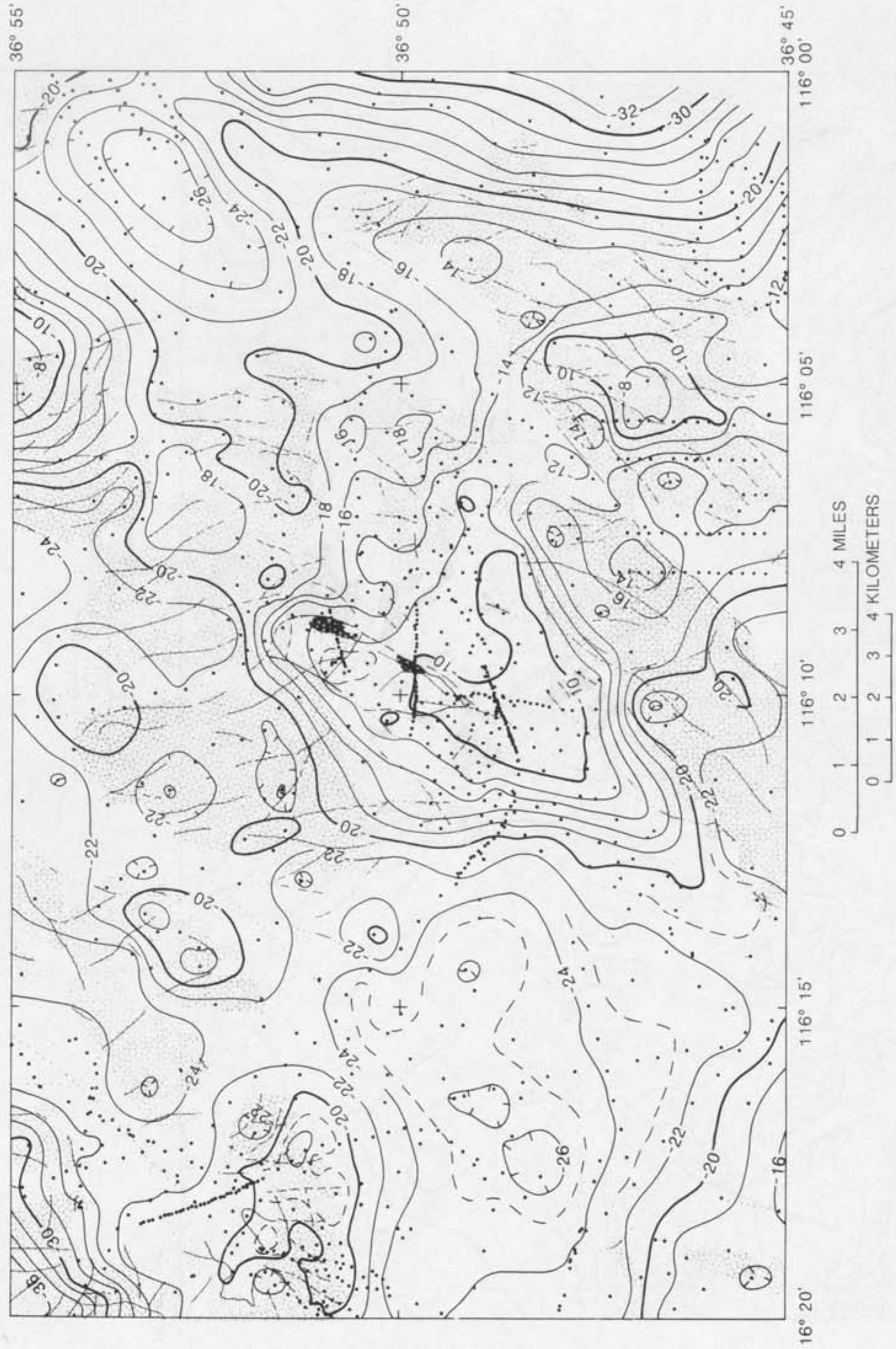
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Fig. 3b.

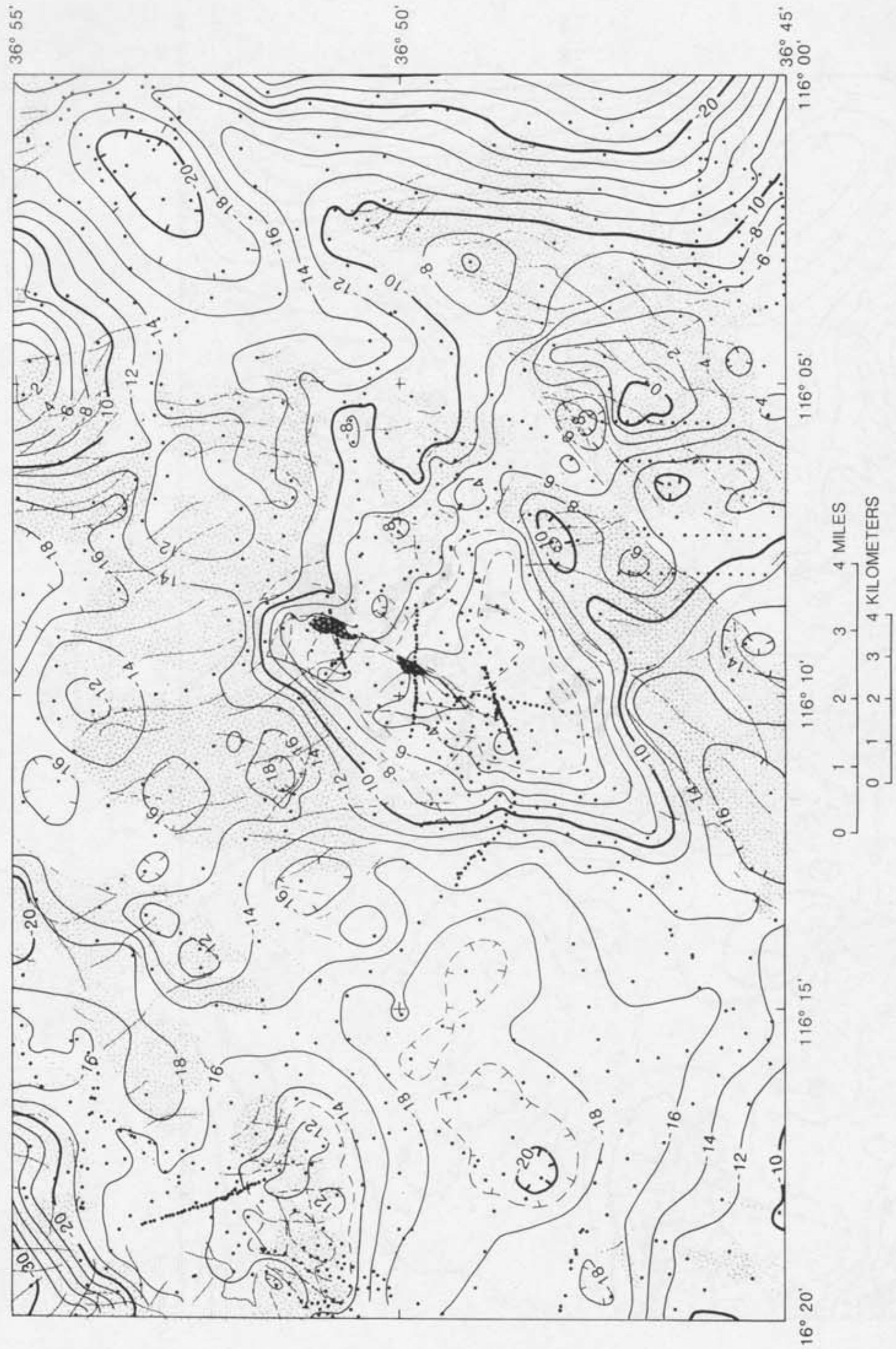
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Fig. 3c.

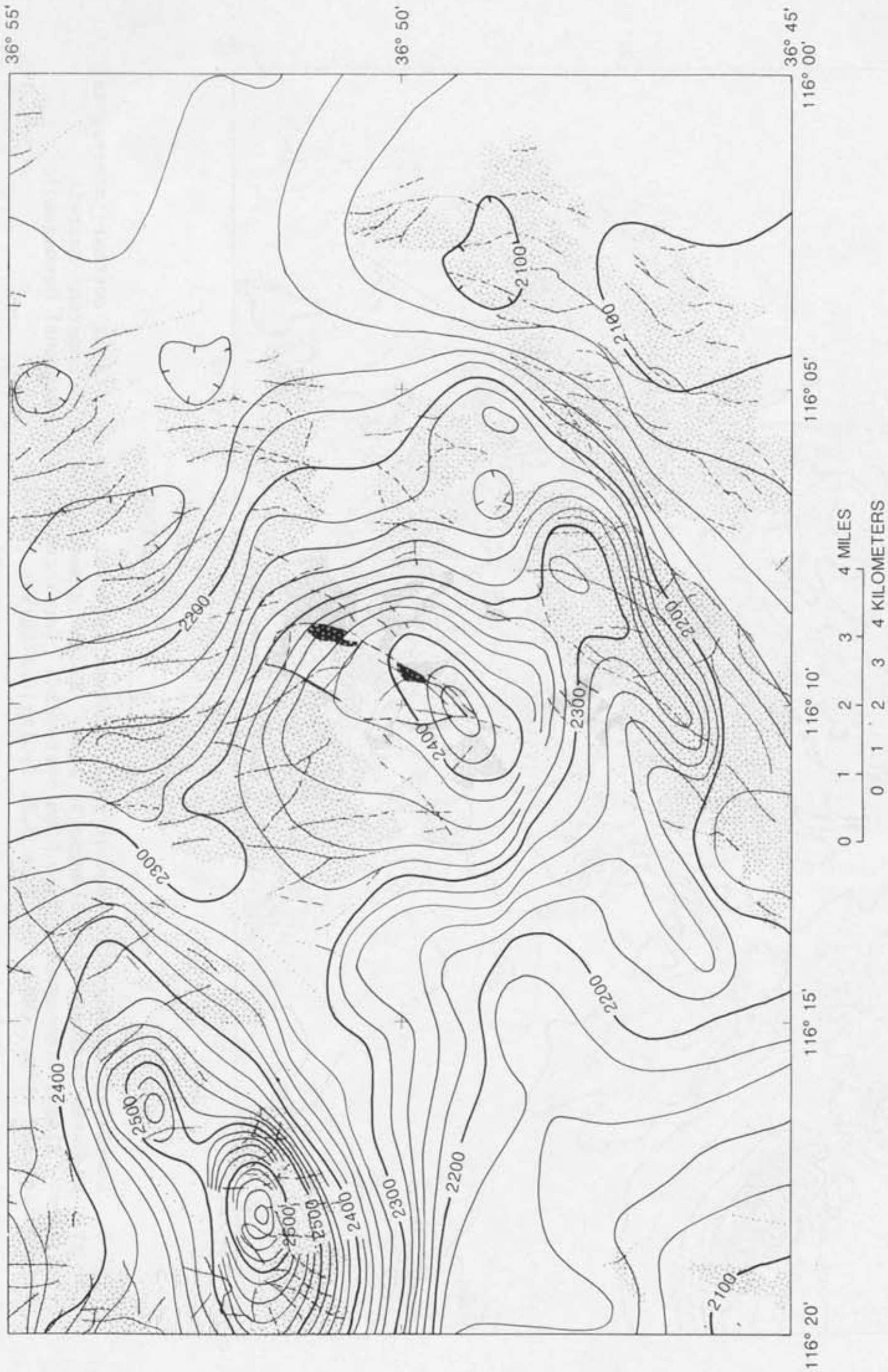

Fig. 4. High-level aeromagnetic contour map. Contour interval is 20 nT. Hachures indicate closed magnetic lows. Flight elevation is 2,400 m barometric. Flight line spacing is 800 m east-west. (Modified from Boynton and Vargo [1963a, b].)

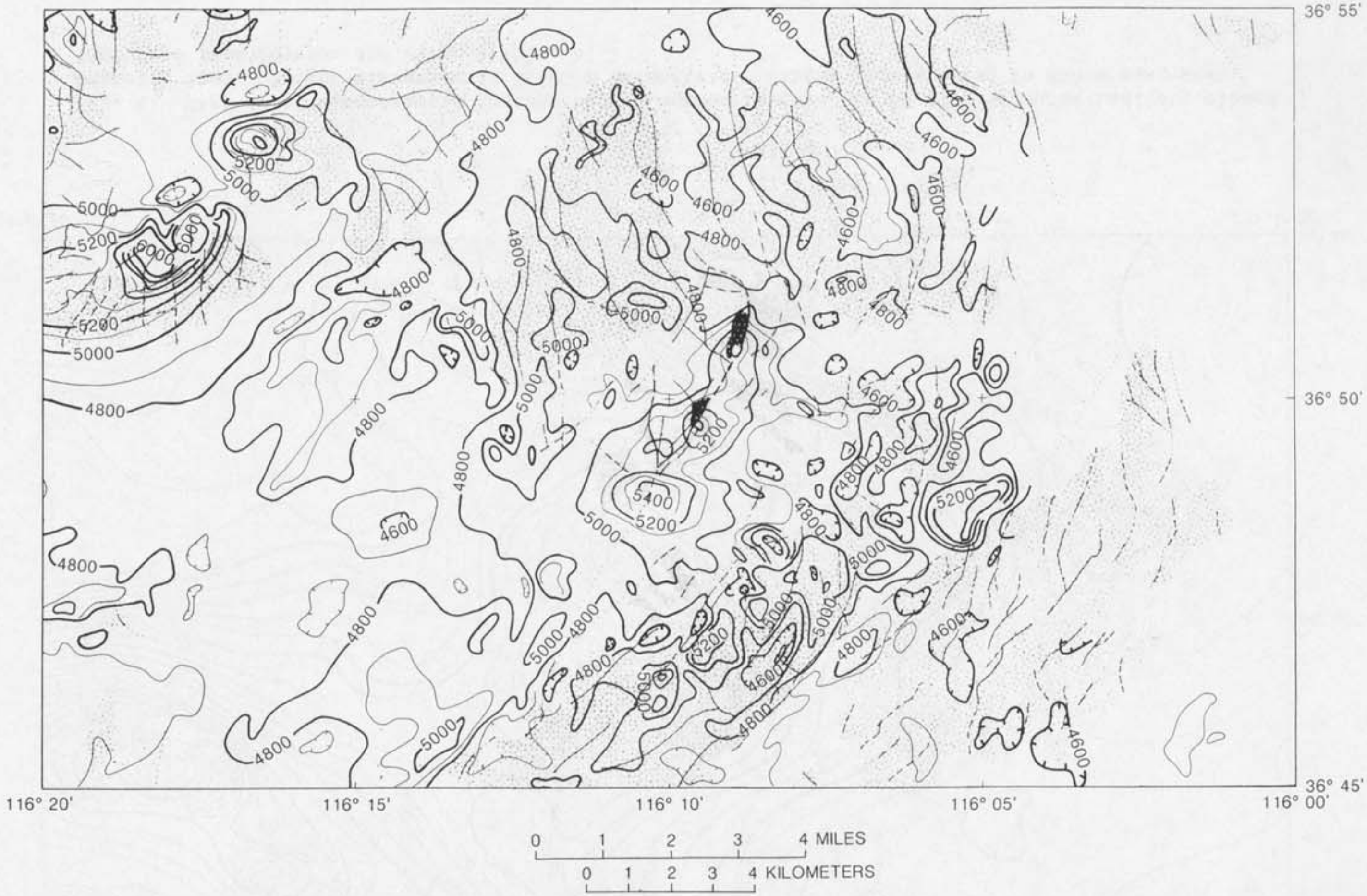

Fig. 5. Low-level aeromagnetic contour map. Contour interval is 200 nT. Light contour interval is 100 nT. Hachures indicate closed magnetic lows. Flight elevation is 120 m constant terrain clearance. Flight line spacing is 0.4 km east-west. Corrected for International Geomagnetic Reference Field 1975. (Modified from U.S. Geological Survey [1979].)

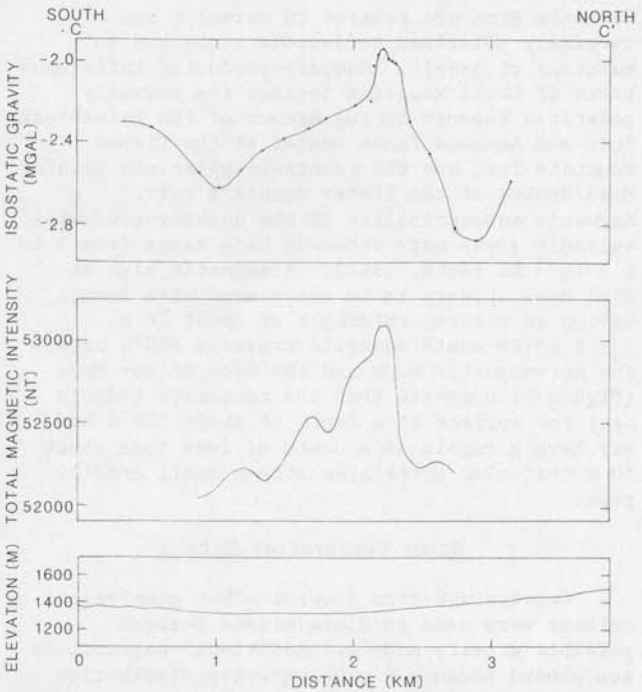

Fig. 6. North-south ground magnetic traverse CC' with isostatic anomaly profile reduced for a density of 2.67 kg m^{-3}. Circles indicate gravity stations.

map of Nevada. Their map is inferred to reflect density contrasts solely within the basement rocks and excludes anomalies caused by near-surface low-density rocks.

Isostatic anomalies were computed to remove long-wavelength variations of the gravity field in the shallow crust. The isostatic correction is based on complete Airy-Heiskanen isostatic compensation [Heiskanen and Vening Meinesz, 1958, pp. 135-137] using a program by Jachens and Roberts [1981] with an assumed upper crustal density of 2.67 kg m^{-3}, a crustal thickness at sea level of 25 km, and a density contrast between the lower crust and upper mantle of 0.40 kg m^{-3}.

The similarity of complete Bouguer, residual, and isostatic anomaly maps (Figure 3) suggests that the gravity anomaly near Wahmonie Site is produced primarily by near-surface structures and is minimally related to regional or isostatic effects. The gravity models presented were derived from the isostatic anomaly values.

Magnetic Data and Interpretation

Magnetic data in the vicinity of Wahmonie Site include two aeromagnetic surveys, a high level and a low level, and a ground magnetic traverse. A high-level aeromagnetic survey at a constant barometric elevation of 2400 m shows that a magnetic high at Wahmonie site is located at the easternmost edge of a magnetic ridge extending from Yucca Mountain, across Calico Hills to Wahmonie Site (Figure 4). This east trending aeromagnetic anomaly may be part of a large, deep, and intrusive complex beneath south west NTS. However, the only exposures of granitic rocks associated with this anomaly are on the east edge of the Wahmonie horst.

A low-level aeromagnetic survey at a constant terrain clearance (drape) of 120 m (Figure 5) shows that the high-level survey includes discrete near-surface components particularly at

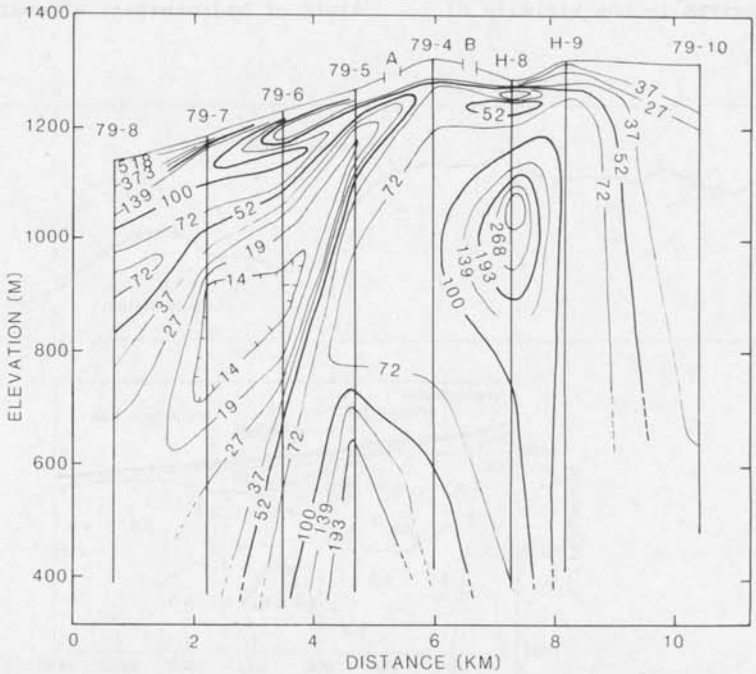

Fig. 7. Vertical electrical sounding geoelectric cross section. Contour interval is logarithmic. Resistivity is in ohm meters. (Modified from Hoover et al. [1982, Figure 5]). Station locations are shown in Figure 2. Major bends in the section are labeled A and B.

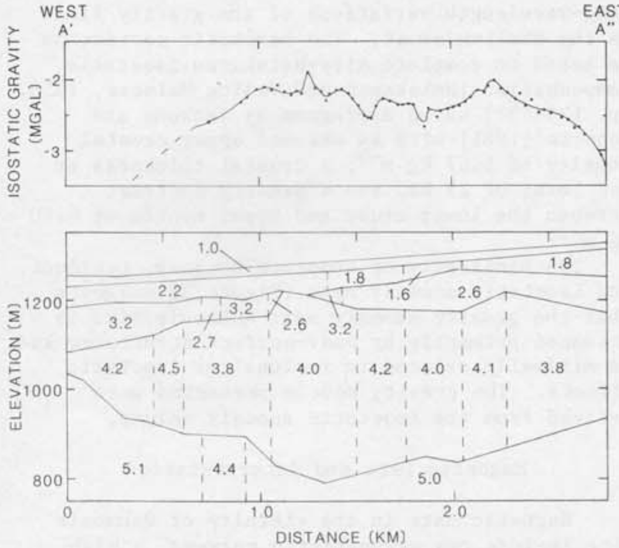

Fig. 8. Seismic refraction model (Modified from Pankratz [1982, Figure 7]) along profile A with isostatic anomaly data reduced for a density of 2.67 kg m^{-3}. Velocity in kilometers per second. Gravity stations are represented by circles.

Wahmonie Site and Calico Hills. The low-level data show a 400-nT high outlined by the 5000-nT contour at Wahmonie Site near the Horn Silver Mine that extends northeast along the eastern margin of the Wahmonie horst. The two smaller magnetic highs that occur at the eastern edge of the horst directly correlate to two small granodiorite outcrops. This correlation to granitic rocks suggests that the larger anomaly to the south may be associated with a large granitic mass at depth.

Other magnetic anomalies in the vicinity of Wahmonie Site are related to normally and reversely polarized tuffaceous rocks and to outcrops of basalt. Anomaly-producing tuffaceous rocks of Skull Mountain include the normally polarized Topopah Spring Member of the Paintbrush Tuff and Ammonia Tanks Member of the Timber Mountain Tuff and the reversely polarized Rainier Mesa Member of the Timber Mountain Tuff. Magnetic susceptibility of the anomaly-producing volcanic rocks near Wahmonie Site range from 3 to 9×10^{-3} SI [Bath, 1968]. A magnetic high at Kiwi Mesa appears to be associated with basalt having an outcrop thickness of about 76 m.

A north-south magnetic traverse (CC') across the aeromagnetic high and the Horn Silver Mine (Figure 6) suggests that the causative body is near the surface at a depth of about 100 m and may have a cupola at a depth of less than about 50 m that also correlates with a small gravity peak.

Other Geophysical Data

Constraints from several other geophysical methods were used to discriminate between possible gravity models. Additional constraints are needed because a given gravity distibution can be produced by many mass or density distributions.

There are several Schlumberger vertical electrical soundings (VES) and two induced polarization traverses at Wahmonie Site [Hoover et al., 1982]. Hoover's geoelectric cross section of the VES data interpreted from inverted sounding curves is shown in Figure 7. One-dimensional inversion of the VES data was done using programs of Zohdy [1974, 1975]. The geoelectric cross section shows a major resistivity boundary between soundings 79-6 and 79-5. This boundary coincides with the outer limit of hydrothermal alteration surrounding

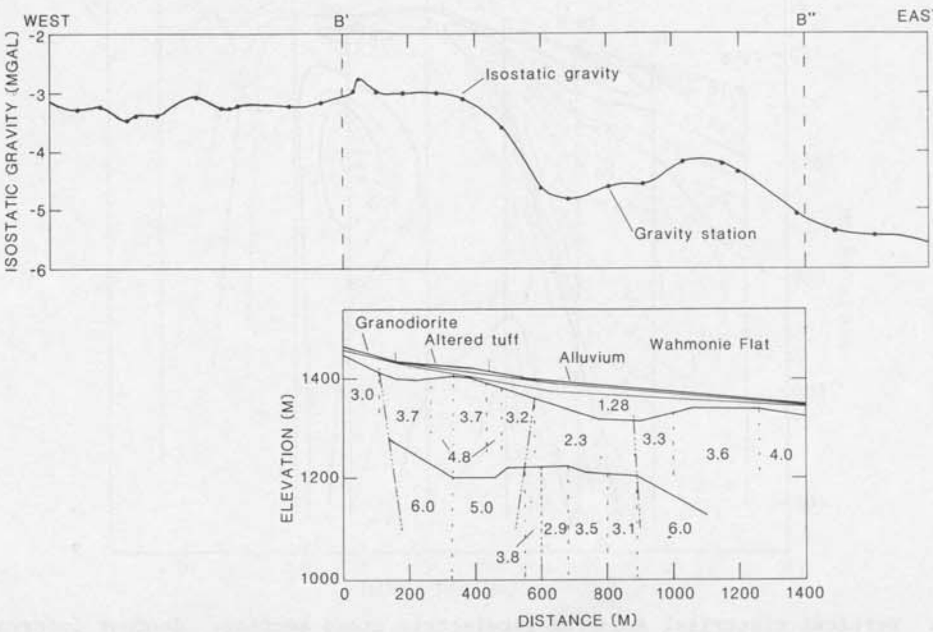

Fig. 9. Seismic refraction model (Modified from Pankratz [1982, Figure 6]) along profile B with isostatic anomaly data reduced for a density of 2.67 kg m^{-3}. Velocity is in kilometers per second.

TABLE 2. Comparison of Seismic Velocity and Density to Lithology

Layer Lithology	Seismic Velocity, km/s Profile A	Profile B	Modeled Density, kg m^{-3}, for Profiles A and B
Alluvium	1.0-2.2	1.0-1.28	1.90-2.10
Tuff	2.6-3.2	2.3-4.8	2.20-2.40
Fractured granite or rhyodacite	3.8-4.5	---	2.55
Granitic rocks	5.0	5.0-6.0	2.65

Wahmonie Site. Sounding 79-6 is outside this zone, while 79-5 is inside this zone and probably overlies the inferred intrusive (Figure 2). At VES 79-5 the presence of an intrusive body is suggested where the resistivity begins to increase with depth, at about 150 m below the surface. The absence of a sharp gradient suggests that the upper part of the intrusive is altered or fractured, which reduces its resistivity. The section below VES H-8, nearer the center of the gravity and magnetic highs, shows a resistive body of 268 to 373 ohm m at depths of 200 to 350 m. According to Hoover et al. [1982] this higher-resistive body may represent a less altered or fractured part of the intrusive body. Also, their two induced polarization dipole-dipole lines at Wahmonie Site support the VES data and give evidence for disseminated sulfide mineralization at depth.

There are two seismic refraction spreads in the vicinity of Wahmonie Site, A'A" and B'B" (Figure 2), with the resulting two-dimensional models by Pankratz [1982] shown in Figures 8 and 9. The velocities and layer configurations were derived from an inversion program of Ackermann [1979].

The two seismic lines provide near-surface control for the gravity modeling. At least four seismic refraction layers can be correlated to lithologic units in the study area. Densities were determined for each layer based on surface rock sampling, inferred rock type, and conversions of seismic velocity to density based on the empirical values of Nafe and Drake [1963, p. 807]. Table 2 shows the association of seismic velocity to density based on the empirical values for profiles A and B (Figures 8 and 9).

Gravity Modeling

Seismic and gravity models along profiles A and B (Figure 2) show a moderately dense (2.65 kg m^{-3}) body near the surface in the vicinity of Wahmonie Site. Estimation and modification of mass distributions were based on geologic and geophysical information. Computation of gravity effects, comparisons of the calculated and observed gravity anomalies, and the subsequent modification of the mass distributions until a satisfactory fit was achieved were facilitated by the use of a version of Talwani et al.'s [1959] two-dimensional computer modeling program. Gravity models were predominantly based on geology and seismic refraction control.

A two-dimensional gravity model of profile A (Figure 10) shows that a near-vertical contact or fault is necessary to produce the observed gradient at the western edge of the inferred intrusive. The gradient also coincides with the western edge of the hydrothermal alteration zone surrounding the intrusion. The model indicates the presence of a relatively high density body of 2.65 kg m^{-3} buried near the surface at Wahmonie Site.

The gravity model representing data along

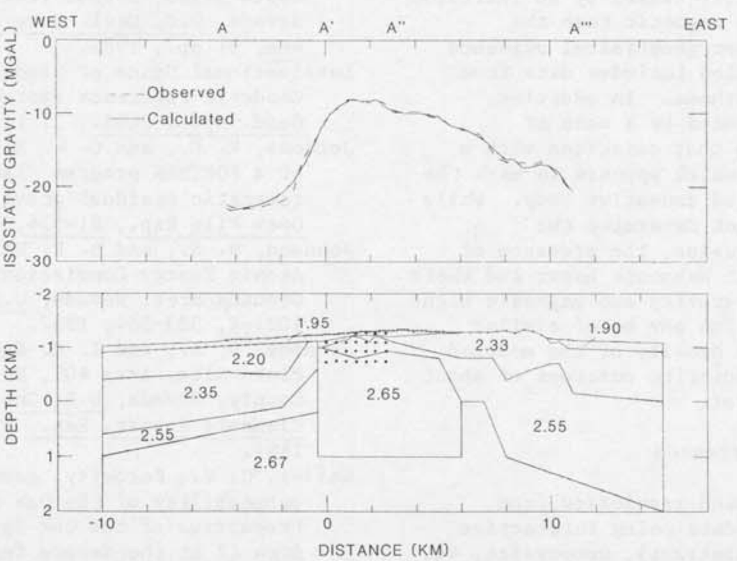

Fig. 10. Isostatic anomaly gravity model along profile A. Densities are in kilograms per cubic meters. Seismic refraction control is shown as stippled area.

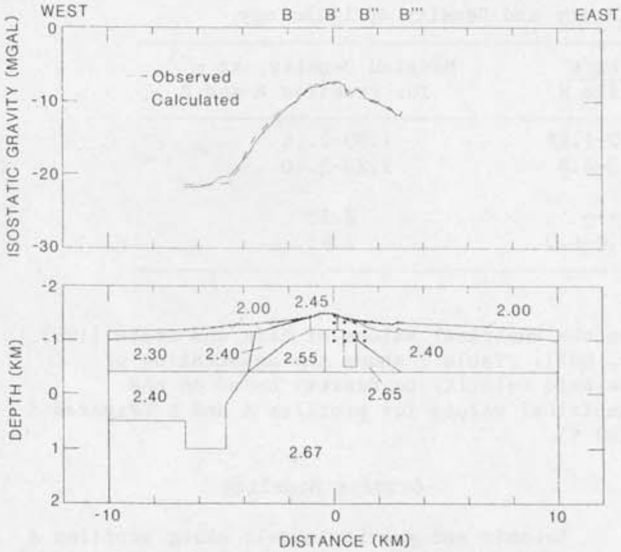

Fig. 11. Isostatic anomaly gravity model along profile B. Densities are in kilograms per cubic meters. Seismic refraction control is shown as stippled area.

profile B (Figure 11) also suggests the presence of a denser body near the surface. Although high seismic velocities greater than 5.0 km/s, characteristic of an igneous intrusive were not detected near the granodiorite outcrops of the Wahmonie horst, gravity data indicate the presence of a relatively dense body. This discrepancy between the seismic and gravity data may be due to starting the seismic spread too close to the edge of the granodiorite body or to weathering [Pankratz, 1982]. Both the gravity model and the seismic section (Figure 9) show a body with a density of 2.65 kg m^{-3} extending east of the Wahmonie horst about 200 m below the surface for about 1 km.

Interpretation

The anomalous gravity and magnetic highs at Wahmonie Site are probably caused by an intrusion that is denser and more magnetic than the surrounding rocks. Other geophysical evidence that supports an intrusion includes data from electric and seismic methods. In addition, Wahmonie Site is surrounded by a zone of hydrothermal alteration that coincides with a steep gravity gradient which appears to mark the outer limit of the buried causative body. While gravity data alone cannot determine the composition of the intrusion, the presence of granodiorite outcrops at Wahmonie horst and their association with local gravity and magnetic highs suggest that the intrusion may be of similar composition. Also, the density of the modeled intrusive and the granodiorite outcrops of about 2.65 kg m^{-3} is consistent.

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