Gravity and Magnetic Data Along a Seismic Refraction-Reflection Line in Northwest Nevada and Northeast California

By Janet E. Tilden, David A. Ponce, Jonathan M.G. Glen, and Kathleen D. Gans

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Introduction

In September, 2004, the U.S. Geological Survey (USGS) collected 84 gravity stations and about 250 line-kilometers (150 line-miles) of truck-towed magnetometer data in northwest Nevada and northeast California (fig. 1) along a USArray seismic refraction-reflection line collected by Stanford University in September 2004. The seismic line (A-A') extends from about 50 km west of Alturas, Calif., through Vya, Nev., to the junction of Highways 395 and 140 about 50 km north of Winnemucca, Nev. (fig. 1). It crosses, from west to east, the Warner Mountains, Surprise Valley, Charles Sheldon Antelope Range, and the Black Rock Desert. Gravity and magnetic data were collected along the seismic transect to study regional crustal structures and geology. Although the study area is composed predominantly of Tertiary volcanic rocks of the Modoc Plateau, the region also includes upper Paleozoic siliceous and volcanic rocks, Triassic and Jurassic meta-sedimentary rocks, and Mesozoic and Tertiary intrusive rocks (Jenkins, 1958; Stewart and Carlson, 1978). These rock types create a distinguishable pattern of gravity and magnetic anomalies that reflect their physical properties.

Acknowledgments

We would like to thank Robert L. Morin and others of the U.S. Geological Survey for the development of the truck-towed magnetometer system used in this study.

Gravity and Magnetic Data

Gravity data collected during September of 2004 consist of 84 stations concentrated along the seismic refraction-reflection line, in areas of sparse control (fig. 2). All gravity data are tied to two primary base stations, WINNEMUCCA at the Winnemucca Airport, Nev. at 40° 54.23' N and 117° 48.27' W, with an observed gravity value of 979,810.48 milligals (mGal) and ALTURAS at the courthouse in Alturas, Cal. at 41° 28.99' N and 120° 32.46' W, with an observed gravity value of 979,874.30 mGal. New gravity stations were located between latitudes 41°20' and 40° 40' N and longitudes 117° 45' and 121° 0' W and are on the Alturas, Lovelock, and McDermitt 1 x 2 degree (1:250,000-scale) quadrangles. Principal facts of the gravity data are given in the appendix.

About 250 line-kilometers (150 line-miles) of truck-towed magnetometer data were collected along the seismic transect (fig. 1). Magnetic and GPS data were collected using a cesium vapor magnetometer attached to an aluminum carriage connected to the vehicle by aluminum

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tubing and towed about 9 m (30 ft) behind the vehicle. The height of the magnetometer above the ground surface was 2 m (7 ft). Magnetometer and Geographic Positioning System (GPS) data were collected simultaneously at one-second intervals. A portable proton-precession base station magnetometer was used to record diurnal variations of the Earth's magnetic field during the truck-towed magnetometer surveys.

Gravity Methods

All gravity data were reduced using standard gravity methods (Blakely, 1995) and include the following corrections: (a) the earth-tide correction, which corrects for tidal effects of the moon and sun; (b) instrument drift correction, which compensates for drift in the instrument's spring; (c) the latitude correction, which accounts for the variation of the Earth's gravity with latitude; (d) the free-air correction, which accounts for the variation in gravity due to elevation relative to sea level; (e) the Bouguer correction, which corrects for the attraction of material between the station and sea level; (f) the curvature correction, which corrects the Bouguer correction for the effect of the Earth's curvature; (g) the terrain correction, which removes the effect of topography to a radial distance of 167 km (104 mi) around the station; and (h) the isostatic correction, which removes long-wavelength variations in the gravity field related to topography.

Conversion of meter readings to gravity units was made using factory calibration constants as well as a secondary calibration factor determined by multiple gravity readings over the Mt. Hamilton calibration loop east of San Jose, California (Barnes and others, 1969). LaCoste and Romberg gravity meter G614 was used in this survey, with a secondary calibration factor of 1.00036. Observed gravity values were based on a time-dependent linear drift between successive base readings and were referenced to the International Gravity Standardization Net 1971 (IGSN 71) gravity datum (Morelli, 1974, p. 18). Free-air gravity anomalies were calculated using the Geodetic Reference System 1967 formula for theoretical gravity on the ellipsoid (International Union of Geodesy and Geophysics, 1971, p. 60) and Swick's formula (1942, p. 65) for the free-air correction. Bouguer, curvature, and terrain corrections were added to the free-air anomaly to determine the complete Bouguer anomaly at a standard reduction density of 2.67 g/cm^3 . Finally, a regional isostatic gravity field was removed from the Bouguer field assuming an Airy-Heiskanen model for isostatic compensation of topographic loads (Jachens and Roberts, 1981) with an assumed crustal thickness of 25 km (16 mi), a crustal density of 2.67 g/cm^3 , and a density contrast across the base of the model of 0.4 g/cm^3 . Gravity values are expressed in mGal, a unit of acceleration or gravitational force per mass equal to 10^{-5} m/s^2 .

Station locations and elevations were obtained using two Trimble® differential Global Positioning Systems (DGPS); 1) GeoExplorer CE hand-held receiver and 2) Ag132 pole-mounted receiver. The GeoExplorer CE receiver uses the Wide Area Augmentation System (WAAS) correction signal, which combined with base station post-processing results in sub-meter vertical accuracy. The Ag132 receiver has real-time differential correction capabilities using an Omnistar satellite system, resulting in sub-meter horizontal accuracy and approximately 1-2 m (3-7 ft) vertical accuracy.

Terrain corrections, which account for the variation of topography near a gravity station, were computed using a combination of manual and digital methods. Terrain corrections consist of a three-part process: the innermost or field terrain correction, inner-zone terrain correction, and outer-zone terrain correction. The innermost terrain corrections were estimated in the field and extend from the station to a radial distance of 68 m (223 ft), equivalent to Hayford and Bowie (1912) zone B. Inner-zone terrain corrections were estimated from Digital Elevation Models

(DEMs) with 10-m or 30-m resolutions derived from USGS 7.5' topographic maps and extend from 68 m (223 ft) to a radial distance of 2 km (1.25 mi) (D. Plouff, USGS, unpublished software). Outer-zone terrain corrections, from 2.0 km to a radial distance of 167 km (104 mi), were computed using a DEM derived from USGS 1:250,000-scale topographic maps and an automated procedure based on geographic coordinates (Plouff, 1966; Plouff, 1977; Godson and Plouff, 1988). Digital terrain corrections are calculated by computing the gravity effect of each grid cell using the distance and difference in elevation of each grid cell from the gravity station.

Gravity data described in this report were combined with pre-existing gravity data from the surrounding areas in Nevada and California (Ponce, 1997; Snyder et al., 1981). Gravity data were gridded at an interval of 400 m (1/4 mi) using a computer program (Webring, 1981) based on a minimum curvature algorithm by Briggs (1974) and displayed as a color-contoured map (fig. 3).

Magnetic Methods

During field operations, magnetic data were recorded and viewed in real-time using Geometrics[®] MagLog software. Raw magnetic data were downloaded and processed using MagMap2000 software, where magnetometer and GPS data were merged. The location of the magnetometer was recorded using the Trimble[®] non-magnetic Ag132 GPS receiver (described above) mounted on an aluminum frame attached to the magnetometer. Diurnal variations recorded by the base station magnetometer were removed from the dataset and although individual lines have not been leveled with one another, the magnetic data were filtered to remove cultural “noise” such as passing cars, culverts, fences, and power lines.

Truck-towed magnetometer data were gridded and displayed as a color-contoured map overlying topography (fig. 4A) and overlying pre-existing regional aeromagnetic data of Nevada and California (Hildenbrand and Kucks, 1988; Roberts and Jachens, 1999) (fig. 4B). Gravity, regional magnetic, ground magnetic, and topographic profiles along the seismic line (A-A') are shown in figure 5.

General Discussion

In general In general, isostatic gravity anomalies reflect lateral (horizontal) density variations in the middle to upper crust. Thus, gravity anomalies can be used to infer the subsurface structure of known or unknown geologic features. Gravity anomalies often reveal features such as carbonate rocks, calderas, deep sedimentary basins, and faults that may play a role in defining the geologic framework of the area.

Along the seismic refraction-reflection line, prominent gravity highs occur over the Warner Mountains, Hays Canyon Range, parts of the Black Rock Range, Pine Forest Range, Bilk Creek Mountains, Montana Mountains, Slumbering Hills, and Santa Rosa Range (fig. 3). Gravity highs in the northern part of the Warner Range are associated with Tertiary intrusive rocks (Chapman and Bishop, 1968). Prominent gravity lows occur over Surprise Valley, Long Valley, Charles Sheldon Antelope Range, Black Rock Desert, Desert Valley, Silver State Valley, and Quinn River Valley. In general, these lows reflect sedimentary basins filled with lower density alluvial and volcanic deposits. Isostatic gravity data indicate the central part of Surprise Valley may correspond to a 30-mGal gravity low, and assuming a density contrast of 0.4 g/cm³, an infinite slab approximation yields a basin depth of approximately 2.3 km (7,500 ft).

Magnetic anomalies reflect changes in the Earth's magnetic field and are generally used to infer lateral variations in the magnetization of rocks. These anomalies can be explained by the

variations in rock type across the region. Often, short-wavelength and high-amplitude magnetic highs are caused by volcanic rocks that are moderately to strongly magnetic. Due to the dipolar nature of magnetic sources, these magnetic highs are typically accompanied by an associated magnetic low. Isolated magnetic lows, however, are often associated with weakly magnetic silicic and sedimentary rocks (fig. 4).

Magnetic highs occur in the study area over the hills north and west of Alturas, portions of the Warner Mountains, the Hays Canyon Range, the southwestern section of the Charles Sheldon Antelope Range, and the southern Montana Mountains (fig. 4). For the most part, magnetic highs are associated with Tertiary and Quaternary volcanic rocks. The magnetic high in the southern Montana Mountains likely reflects magnetic volcanic rocks at depth, because less magnetic silicic ash-flow tuffs are exposed at the surface. Areas where the magnetic field is lower include the valley west of Alturas, Surprise Valley, western Long Valley, portions of the Charles Sheldon Antelope Range, the Black Rock Desert, Silver State Valley and Quinn River Valley. Overall, these magnetic lows reflect less magnetic Tertiary and Quaternary sedimentary rocks in the valleys. The magnetic lows within the Charles Sheldon Antelope Range likely reflect less magnetic Tertiary ash-flow tuffs.

The diverse physical properties of the rocks that underlie this region are well suited to geophysical investigations. The contrast in density and magnetic properties between pre-Cenozoic crystalline basement and the overlying Tertiary volcanic rocks and unconsolidated alluvium, for example, produce a distinctive pattern of gravity and magnetic anomalies that can be used to infer subsurface geologic structure.

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Figure 1 . Shaded relief index map of northeast California and northwest Nevada showing location of USArray seismic line (A-A') (black line) Winnemucca is located just southeast of the study area (yellow star). The topographic grey-line contour interval is 50 m.

Figure 2. Index map showing location of gravity stations. Yellow, existing stations; red, new gravity stations.

Figure 4. A, Ground magnetic data superimposed on a shaded relief topographic map of the study area. B, Ground magnetic data superimposed on the regional aeromagnetic map of the study area.

Figure 5. Gravity, ground magnetic, aeromagnetic, and topographic profiles interpolated at ground magnetometer stations. Gaps in the data along all the profiles correspond to data gaps in the ground magnetics. The gravity profile was derived from gridded data displayed in figure 3. Aeromagnetic data were interpolated from gridded data displayed in figure 4. The topographic profile was interpolated from gridded data displayed in figure 1 and derived from USGS 30-m digital elevation models.

Appendix

Table A1. Principal facts of gravity stations along the USArray seismic line [Latitudes (north) and longitudes (west) are on the North American Datum 1927 (NAD27). Elevations are on the North American Vertical Datum 1929 (NAVD29). CBA, complete Bouguer anomaly; FAA, free-air anomaly; ISO, isostatic anomaly; ITC, inner terrain correction; OG, observed gravity; SBA, simple Bouguer anomaly; TTC, total terrain correction.]

Station	Latitude		Longitude		Elevation	OG	FAA	SBA	ITC	TTC	CBA	ISO
	deg	min	deg	min	ft	mGal	mGal	mGal	mGal	mGal	mGal	mGal
04USA001	41	23.76	117	46.97	4647.5	979854.10	-2.73	-161.23	0.15	1.54	-161.06	1.17
04USA002	41	23.78	117	47.54	4532.7	979861.02	-6.63	-161.22	0.16	1.32	-161.24	0.87
04USA003	41	23.85	117	48.60	4306.7	979873.46	-15.53	-162.42	0.10	1.02	-162.71	-0.87
04USA004	41	23.92	117	49.75	4208.9	979877.43	-20.86	-164.41	0.02	0.65	-165.05	-3.51
04USA005	41	23.99	117	50.95	4172.5	979872.09	-29.73	-172.04	0.01	0.40	-172.92	-11.69
04USA006	41	24.06	117	52.08	4147.3	979869.06	-35.23	-176.68	0.00	0.25	-177.71	-16.82
04USA007	41	24.13	117	53.25	4138.6	979868.29	-36.92	-178.08	0.00	0.17	-179.19	-18.61
04USA008	41	24.20	117	54.43	4133.8	979871.39	-34.38	-175.37	0.00	0.10	-176.55	-16.24
04USA009	41	24.27	117	55.59	4134.9	979876.30	-29.47	-170.50	0.01	0.07	-171.71	-11.72
04USA010	41	24.35	117	56.82	4130.4	979883.35	-22.96	-163.84	0.00	0.04	-165.08	-5.37
04USA011	41	24.49	117	59.07	4128.8	979894.69	-11.98	-152.80	0.00	0.02	-154.06	5.10
04USA012	41	24.55	118	0.11	4134.0	979898.98	-7.29	-148.29	0.01	0.02	-149.55	9.42
04USA013	41	25.17	118	4.79	4128.3	979893.94	-13.80	-154.60	0.01	-0.04	-155.93	2.23
04USA014	41	25.45	118	6.03	4132.5	979888.61	-19.15	-160.10	0.01	-0.05	-161.44	-3.39
04USA015	41	25.68	118	7.09	4121.1	979886.26	-22.92	-163.47	0.00	-0.07	-164.83	-6.86
04USA016	41	25.93	118	8.22	4123.6	979888.37	-20.95	-161.59	0.00	-0.08	-162.95	-5.05
04USA017	41	26.46	118	10.62	4117.5	979882.51	-28.17	-168.61	0.00	-0.07	-169.96	-12.17
04USA018	41	27.20	118	14.00	4120.4	979887.05	-24.47	-165.00	0.00	-0.01	-166.29	-8.50
04USA019	41	27.47	118	15.19	4121.9	979892.17	-19.61	-160.19	0.00	0.01	-161.46	-3.60
04USA020	41	27.92	118	17.23	4111.4	979899.88	-13.56	-153.79	0.02	0.10	-154.96	2.98
04USA021	41	28.92	118	18.65	4117.3	979906.78	-7.60	-148.03	0.01	0.12	-149.19	8.99
04USA022	41	29.62	118	19.41	4116.2	979907.56	-7.97	-148.36	0.02	0.14	-149.50	8.88
04USA023	41	30.30	118	20.15	4114.9	979903.02	-13.65	-154.00	0.01	0.15	-155.13	3.44
04USA024	41	32.05	118	22.04	4116.6	979895.07	-24.06	-164.47	0.01	0.15	-165.60	-6.45
04USA025	41	32.98	118	23.06	4111.3	979894.51	-26.51	-166.73	0.00	0.13	-167.88	-8.42
04USA026	41	35.07	118	25.31	4117.8	979906.78	-16.76	-157.20	0.01	0.17	-158.31	1.93
04USA027	41	35.47	118	25.78	4119.0	979912.67	-11.36	-151.84	0.01	0.19	-152.93	7.50
04USA028	41	35.04	118	26.45	4089.3	979910.07	-16.11	-155.58	0.00	0.18	-156.67	3.68
04USA029	41	34.45	118	27.27	4093.6	979905.47	-19.42	-159.04	0.01	0.19	-160.12	0.10
04USA030	41	34.02	118	28.11	4083.0	979907.34	-17.90	-157.16	0.00	0.21	-158.22	1.95
04USA031	41	33.67	118	29.14	4085.0	979906.96	-17.57	-156.89	0.01	0.27	-157.90	2.28
04USA032	41	33.42	118	30.20	4077.4	979905.38	-19.49	-158.55	0.00	0.34	-159.48	0.78
04USA033	41	33.39	118	31.39	4077.5	979901.66	-23.15	-162.22	0.00	0.52	-162.97	-2.59
04USA034	41	33.32	118	32.49	4073.5	979902.66	-22.43	-161.36	0.01	0.90	-161.73	-1.20
04USA035	41	30.53	118	44.44	4191.3	979890.32	-19.52	-162.47	0.09	1.37	-162.39	-0.41
04USA036	41	30.11	118	45.56	4138.3	979890.43	-23.76	-164.90	0.05	1.36	-164.82	-2.69
04USA037	41	30.68	118	47.54	4438.0	979889.41	2.54	-148.83	1.36	2.96	-147.20	15.58
04USA038	41	31.84	118	49.77	5016.7	979845.47	11.25	-159.85	1.40	3.24	-158.01	5.58
04USA039	41	30.87	118	50.68	5129.8	979832.38	10.25	-164.71	2.12	3.86	-162.28	1.22
04USA040	41	30.46	118	52.02	5140.5	979822.35	1.83	-173.49	2.08	4.69	-170.22	-6.50

04USA041	41	31.06	118	52.84	5572.5	979794.21	13.40	-176.66	0.64	3.06	-175.06	-11.05
04USA042	41	31.83	118	53.37	5979.3	979764.05	20.31	-183.62	1.20	3.40	-181.70	-17.42
04USA043	41	31.88	118	54.32	6326.1	979734.66	23.44	-192.32	1.34	3.91	-189.91	-25.46
04USA044	41	31.88	118	55.13	6809.3	979704.65	38.83	-193.41	1.28	4.48	-190.44	-25.93
04USA045	41	31.51	118	56.29	7182.5	979677.81	47.61	-197.35	0.47	4.24	-194.62	-30.03
04USA046	41	32.44	118	56.81	7117.4	979684.42	46.71	-196.03	0.19	3.52	-194.02	-29.00
04USA047	41	32.65	118	58.07	7056.6	979688.14	44.41	-196.27	0.45	3.40	-194.38	-28.93
04USA048	41	32.42	118	59.34	6440.1	979730.37	29.05	-190.59	0.52	2.43	-189.67	-23.72
04USA049	41	32.76	119	0.97	6043.8	979756.58	17.51	-188.62	0.40	1.84	-188.27	-21.68
04USA050	41	28.73	120	57.36	4622.6	979863.41	-3.19	-160.85	0.73	0.97	-161.24	-13.78
04USA051	41	28.35	120	56.31	4502.4	979869.96	-7.37	-160.93	1.64	1.96	-160.31	-12.44
04USA052	41	26.66	120	53.19	4335.7	979879.44	-11.03	-158.91	0.01	0.24	-159.98	-10.90
04USA053	41	27.67	120	46.30	4339.3	979879.07	-12.57	-160.57	0.02	0.13	-161.76	-10.07
04USA054	41	27.92	120	45.31	4333.7	979881.51	-11.04	-158.84	0.03	0.16	-160.00	-7.90
04USA055	41	28.66	120	43.75	4398.0	979885.44	-2.17	-152.17	0.10	0.27	-153.22	-0.62
04USA056	41	29.51	120	40.94	4392.4	979898.44	9.03	-140.78	0.32	0.60	-141.50	12.17
04USA057	41	29.39	120	37.29	4363.1	979892.44	0.46	-148.35	0.20	0.39	-149.27	5.72
04USA058	41	29.78	120	36.42	4356.4	979890.94	-2.26	-150.84	0.16	0.39	-151.77	3.57
04USA059	41	29.69	120	34.42	4399.2	979881.28	-7.76	-157.80	0.01	0.14	-158.98	-2.91
04USA060	41	30.26	120	31.19	4403.2	979874.48	-15.03	-165.21	0.04	0.23	-166.31	-9.03
04USA061	41	30.88	120	28.90	4437.5	979880.06	-7.16	-158.51	0.08	0.36	-159.48	-1.39
04USA062	41	32.56	120	26.59	4607.1	979882.56	8.77	-148.36	0.17	0.55	-149.17	9.69
04USA063	41	33.60	120	24.77	4944.1	979875.03	31.36	-137.27	0.14	0.65	-138.02	21.39
04USA064	41	33.73	120	22.83	5124.3	979864.85	37.92	-136.85	0.12	0.92	-137.35	22.66
04USA065	41	33.32	120	20.85	5241.9	979847.53	32.26	-146.52	0.41	1.85	-146.10	14.61
04USA066	41	33.63	120	17.49	5888.1	979791.40	36.40	-164.42	2.19	4.29	-161.61	-0.04
04USA067	41	33.15	119	5.00	5853.0	979771.07	13.49	-186.13	0.05	0.80	-186.81	-19.10
04USA068	41	34.03	119	5.60	5843.8	979775.77	16.01	-183.30	0.02	0.74	-184.05	-15.99
04USA069	41	34.80	119	6.08	5843.6	979776.53	15.60	-183.71	0.10	0.83	-184.36	-16.04
04USA070	41	35.28	119	7.06	5923.6	979772.05	17.92	-184.12	0.10	0.77	-184.83	-16.23
04USA071	41	35.53	119	8.21	5946.3	979770.84	18.46	-184.34	0.12	0.75	-185.08	-16.22
04USA072	41	36.36	119	9.34	5696.8	979782.17	5.10	-189.19	0.29	1.06	-189.61	-20.31
04USA073	41	36.88	119	10.08	5855.6	979771.35	8.43	-191.28	0.28	0.94	-191.83	-22.40
04USA074	41	36.51	119	11.14	5903.9	979766.40	8.57	-192.79	0.27	0.98	-193.30	-23.79
04USA075	41	35.97	119	12.76	6437.8	979732.85	26.00	-193.57	0.35	1.36	-193.71	-24.23
04USA076	41	36.22	119	13.75	6344.3	979737.34	21.33	-195.05	0.62	1.44	-195.11	-25.43
04USA077	41	37.89	119	30.00	5960.2	979773.22	18.62	-184.66	0.15	0.61	-185.54	-14.79
04USA078	41	36.86	119	31.12	5886.1	979778.95	18.93	-181.83	0.21	0.67	-182.64	-11.99
04USA079	41	35.98	119	33.00	5792.9	979782.25	14.78	-182.79	0.04	0.46	-183.80	-13.24
04USA080	41	34.92	119	43.50	5581.4	979796.11	10.36	-180.00	0.01	0.33	-181.14	-11.68
04USA081	41	34.98	119	48.20	5540.4	979796.18	6.48	-182.48	0.00	0.35	-183.59	-14.90
04USA082	41	34.32	119	59.18	5184.1	979816.09	-6.11	-182.92	0.19	1.25	-183.09	-16.68
04USA083	41	32.89	120	2.28	4540.3	979852.18	-28.38	-183.24	0.01	0.70	-183.88	-17.94
04USA084	41	32.02	120	12.68	5078.9	979843.01	14.37	-158.85	3.94	5.82	-154.45	8.82