Gravity Data from Newark Valley, White Pine County, Nevada

By Edward A. Mankinen and Edwin H. McKee

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By Edward A. Mankinen and Edwin H. McKee[1]

Abstract

The Newark Valley area, eastern Nevada is one of thirteen major ground-water basins investigated by the BARCAS (Basin and Range Carbonate Aquifer Study) Project. Gravity data are being used to help characterize the geophysical framework of the region. Although gravity coverage was extensive over parts of the BARCAS study area, data were sparse for a number of the valleys, including the northern part of Newark Valley. We addressed this lack of data by establishing seventy new gravity stations in and around Newark Valley. All available gravity data were then evaluated to determine their reliability, prior to calculating an isostatic residual gravity map to be used for subsequent analyses. A gravity inversion method was used to calculate depths to pre-Cenozoic basement rock and estimates of maximum alluvial/volcanic fill. The enhanced gravity coverage and the incorporation of lithologic information from several deep oil and gas wells yields a view of subsurface shape of the basin and will provide information useful for the development of hydrogeologic models for the region.

Introduction

Enabling legislation and funding for the BARCAS study was through HR 4593, the "Lincoln County Conservation, Recreation, and Development Act of 2004." The specific language in the bill that relates to the study directs the Secretary of Interior, acting through the United States Geological Survey and the Desert Research Institute, and a designee from the State of Utah to conduct a study to investigate ground water quantity, quality, and flow characteristics in the deep carbonate and alluvial aquifers of Lincoln and White Pine Counties, Nevada and adjacent areas in Utah. A draft report of this study is currently available (Welch and Bright, 2007).

The Geophysical Unit of Menlo Park (GUMP) initiated a number of geophysical investigations within valleys encompassed by the BARCAS study where data were lacking. Surface geophysical techniques were applied to take advantage of characteristic density and magnetic properties of different rocks to provide insight into the subsurface geology and identify faults, subsurface structure, and the interconnectivity of adjacent basins. Geophysical results were summarized in a chapter of the BARCAS draft report (Sweetkind and others, 2007), but detailed interpretations and the physical data are appearing in separate releases (e.g., Watt and Ponce, 2007). This paper contains new gravity data from Newark Valley.

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[1] Menlo Park, Calif.

Geologic Setting

The main part of Newark Valley is bounded on the west by the Diamond Mountains, and Buck Mountain and other bedrock areas to the east (figure 1). At its southern end, Newark Valley is divided into two parts, separated by the Pancake Range. The area shown in figure 1, herein referred to as the study area, constitutes part of the Newark Valley ground-water system, one of thirty-nine regional flow systems of the Great Basin (Harrill and Prudic, 1998). The Newark Valley system covers an area of ~3,760 km^2 (1,450 mi^2) and receives ~27 $hectometers^3$ (22,000 acre-feet) of recharge per year (Harrill and Prudic, 1998).

The oldest rocks in the study area belong to the Lower Cambrian Prospect Mountain Quartzite exposed in the Diamond Mountains (Lehner and others, 1961; Hose and others, 1976). Where not greatly faulted and fractured, these rocks form effective barriers to ground-water flow especially where they are in contact with younger carbonate rocks, and they may form the base of the carbonate-rock aquifer in areas where circulation extends throughout the entire stratigraphic thickness (Plume, 1996; Harrill and Prudic, 1998). The carbonate-rock aquifer is a thick sequence of predominately carbonate formations overlying the quartzite and ranging in age from the Middle Cambrian to Lower Triassic (Hose and others, 1976; Plume, 1996). The total stratigraphic thickness of the carbonate sequence in the study area is ~4,000 meters (Plume, 1996).

Overlying the carbonate sequence in the study area is the Cretaceous Newark Canyon Formation (Lehner and others, 1961; Hose and others, 1976), a sequence of continental deposits exposed mainly in the Diamond Mountains and, perhaps, in the Pancake Range (Hose and others, 1976). Other rocks that we consider part of the pre-Cenozoic basement in the study area are a series of shallow intrusive rocks (Hose and others, 1976; Stewart and Carlson, 1978) ranging from Jurassic to Tertiary in age. All, regardless of age, are grouped with the basement rocks because their density is similar to most of the pre-Cenozoic rocks and differs strongly from that of the later eruptive and basin-fill rocks. Intrusive igneous rocks typically are barriers to ground-water flow (Plume, 1996) except in areas where extensively fractured.

Major extensional faulting began throughout the region at about 17 Ma (McKee, 1971; Christiansen and McKee, 1978; Stewart, 1978) and formed the horst-graben terrain that is typical of the Basin and Range Province. Clastic material derived from adjacent mountain ranges began filling the basins, including semi-consolidated to unconsolidated sand, gravel, silt, clay, and local evaporites with some interbedded volcanic units in many areas. None of the oil and gas wells drilled in Newark Valley differentiate between the various basin-fill units, so whether volcanic rocks occur is unknown. Existing aeromagnetic data for the study area (e.g., Hildenbrand and Kucks, 1988; Watt and Ponce, 2007) are generally of poor quality and insufficient for resolving shallow magnetic sources. The sand and gravel deposits form a major, shallow aquifer in the region where they are not clogged by clay or zeolitic intergranular materials. These aquifers are commonly exploited because groundwater in the valleys typically is within a few meters or tens of meters below the ground surface and easily reached by wells. During Pleistocene time, ancient Lake Newark filled the main part of Newark Valley and the area west of the Pancake Range to a shoreline altitude of 1847 meters (Reheis, 1999)—more than 70 meters above the current lake levels (figure 2).

Procedures

Gravity data were obtained using LaCoste and Romberg meters (G17C and G8N) and observed gravity values were referenced to the base station at the Ely, Nevada airport (***ELYA***), at 39°17.59'N, -114°50.52'W. This station is tied to the International Gravity Standardization Net 1971 (ISGN 71) gravity datum (Morelli, 1974) and has an observed gravity value of 979,480.08 mGal. Locations of gravity stations were determined with a differential Global Positioning Satellite (GPS) system using differential corrections provided by Continually Operated Reference Station (CORS) satellites. Locations after post-acquisition processing are accurate to within 1 meter, both horizontally and vertically.

Gravity Data

Seventy new gravity stations were established in the area of Newark Valley during 2005 and 2006 (figure 3b). Observed gravity at each station was adjusted by assuming a time-dependent linear drift between readings of a base station at the start and finish of each daily survey. This adjustment compensates for drift in the instrument's spring. Observed gravity values are considered accurate to about 0.05 mGal based on repeat measurements over several mountain calibration loops (Barnes and others, 1969; Ponce and Oliver, 1981). Gravity data were reduced using standard gravity corrections (Blakely, 1995) and a reduction density of 2670 kg/m^3. Field terrain corrections (zones A and B of Hayford and Bowie, 1912) were carried out to 68 m using templates and charts (e.g., Plouff, 2000). Inner-zone terrain corrections for zones C and D (Hayford and Bowie, 1912), which are necessary to account for variations in topography near a gravity station, were obtained to a radial distance of 2 km using digitized topography in a digital elevation model (DEM) (D. Plouff, USGS, written communication, 2006). Outer terrain corrections, from 2 km to 167 km, are also calculated using digitized topography and a procedure by Plouff (1977). The resulting gravity anomaly is termed the complete Bouguer anomaly.

A regional isostatic field was calculated using an Airy-Heiskanen (Heiskanen and Vening Meinesz, 1958) model for local compensation of topographic loads (Jachens and Roberts, 1981; Simpson and others, 1986). This model assumes a crustal thickness of 25 km, a crustal density of 2670 kg/m^3, and a 400 kg/m^3 density contrast between the crust and mantle. This regional isostatic field was subtracted from the complete Bouguer anomaly, thus removing long-wavelength variations in the gravity field that are inversely related to topography. The resulting isostatic residual gravity anomaly, therefore, is a reflection of local density distributions within the middle to upper crust. Gravity data obtained during the course of this study, and their associated parameters, are given in table 1 and are available via download as an Excel spreadsheet.

Because prior gravity data (figure 3a) for the study area were made by many different observers at different times (see compilation of Ponce, 1997), we examined the dataset to remove duplicate and inconsistent entries. In order to reduce edge effects in the grids we will produce, the area examined is larger than the study area (figure 1) and extends from latitude
39°0' to 40°20' and from -115°10' to -116°10'.

After removing duplicate entries, we then compared reported station elevations with elevations interpolated from 10- and 30-meter DEMs using a procedure by D. Plouff (USGS, written communication, 2005). We flagged differences greater than 24 meters as indicating possible errors in station location or elevation, and each station identified was examined individually to confirm the discrepancy. Some of these errors occurred because of imprecise locations (i.e., lack of significant digits in published reports) and could be corrected with a high degree of confidence. Where the source of the discrepancy could not be determined and corrected (22 stations total), that station was omitted from the dataset. Observations from the revised dataset were then gridded at a spacing of 0.5 km using the minimum curvature algorithm of Webring (1981), and the resulting isostatic residual gravity field (fig. 4b) is considered reliable for subsequent analyses.

Gravity Inversion

To first order, the isostatic residual gravity field (fig. 4) reflects the pronounced contrast between dense (~2670 kg/m3) pre-Cenozoic basement rocks and the significantly less dense (generally < 2500 kg/m3) overlying volcanic and sedimentary basin-fill. Because of this relationship, the gravity inversion method (Jachens and Moring, 1990) can be used to separate the isostatic residual anomaly into pre-Cenozoic "basement" and Cenozoic "basin" fields, thus allowing an estimate of thickness of Cenozoic alluvial fill within the area. The accuracy of thickness estimates derived by the gravity inversion technique is dependent on the assumed density-depth relation of the Cenozoic rocks, and on the initial density assigned to the basement rocks. Density of basement rocks is generally assumed to be 2670 kg/m3 and this value is considered appropriate in this area where major exposures consist of late Precambrian through late Paleozoic marine carbonate and quartzose sedimentary rocks.

The density of basin-filling deposits generally increases with the degree of compaction and consolidation, and thus usually correlates with depth of burial, as well as with other factors such as increasing water content. The density-versus-depth relationship we use is given in table 2 and is the same used by Jachens and Moring (1990) to separate the isostatic residual anomaly into basement and basin fields. This density-depth distribution also is the same as used by Saltus and Jachens (1995) for their basin-depth map of the Basin and Range Province and similar to those shown to be widely applicable to other volcanic basin-fill deposits throughout Nevada (Blakely and others, 1998, 2000; Mankinen and others, 2003).

In the inversion process, the density of basement is allowed to vary horizontally but the density of basin-filling deposits is fixed using the density-depth distribution (table 2). In this iterative approach, a first approximation of the basement gravity field is derived from those gravity measurements made on exposed pre-Cenozoic rocks. A modified version of the inversion method used here (B.A. Chuchel, unpublished data, 2005) allows basement gravity values to be approximated by correcting the isostatic gravity anomaly at sites where depth to basement is known from deep boreholes (Garside and others, 1988; Hess, 2004). Information on oil and gas wells for Nevada is available on-line at http://www.nbmg.unr.edu/lists/oil/oil.htm. Wells providing constraints in the Newark Valley region are shown in figure 5. This basement gravity field ignores the gravity effects of nearby basins and is subtracted from the observed gravity, which provides the first approximation of the basin gravity field. Again using the selected density-depth relation, the thickness of the basin-filling deposits is calculated. The gravitational effect of this first approximation of the basin-filling layer is computed at each known basement station. This effect is, in turn, subtracted from the first approximation of the basement gravity field, and the process is repeated until successive iterations produce no substantial changes in the basement gravity field. Results of the inversion, shown in figure 6, were gridded at a spacing of 2.0 km using a minimum curvature algorithm Webring (1981).

Conclusions

New gravity data collected during the course of this study allows a much improved definition of the Newark Valley basin. A comparison of the gravity anomaly field before and after the current study (figure 4) shows that the low-density, basin-fill is much more continuous through the main part of Newark Valley and into Huntington Valley than previously known. The main part of Newark Valley is separated from the area southwest of the Pancake Range by a bedrock sill near Pancake summit (figure 7). Another bedrock sill separates Newark Valley from Huntington Valley near the topographic rise between the two valleys. Two oil and gas wells in this vicinity (figure 4) encountered bedrock at depths of 150 and 330 meters below the surface. Thickness of fill throughout much of Newark Valley is generally between 1 and 2 km (figure 7), with a maximum approaching 4 km in limited areas. It is possible, however, that the apparent rise in the basement surface near the center of the valley may not be as pronounced as shown because there is a lack of gravity observations due to present-day Newark Lake.

Acknowledgments

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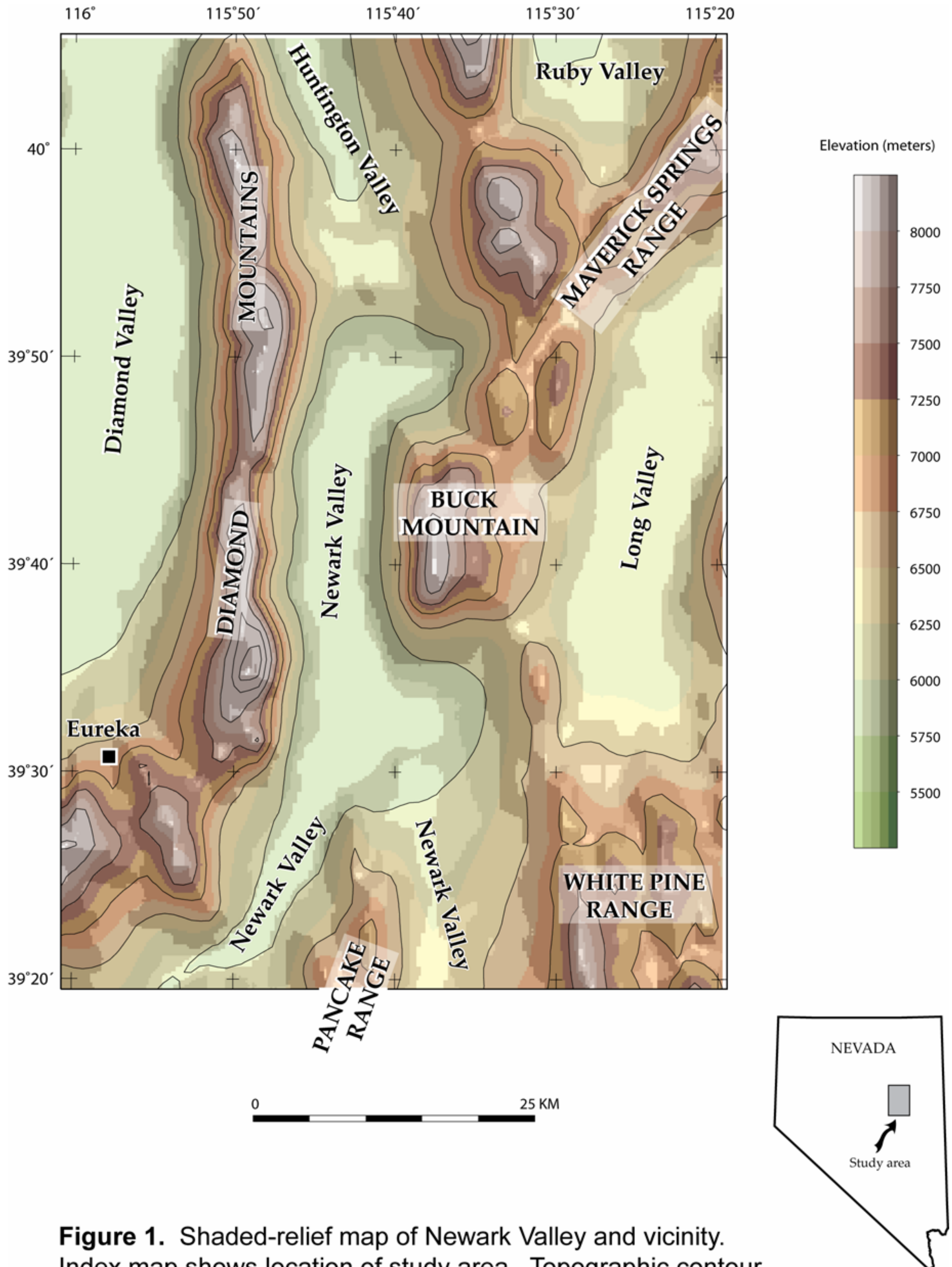

Figure 1. Shaded-relief map of Newark Valley and vicinity. Index map shows location of study area. Topographic contour interval = 500m.

Figure 2. Remnant of ancient Lake Newark shoreline. View looking west toward the Diamond Mountains. Present-day lake surface represented by the playa seen in the middle distance.

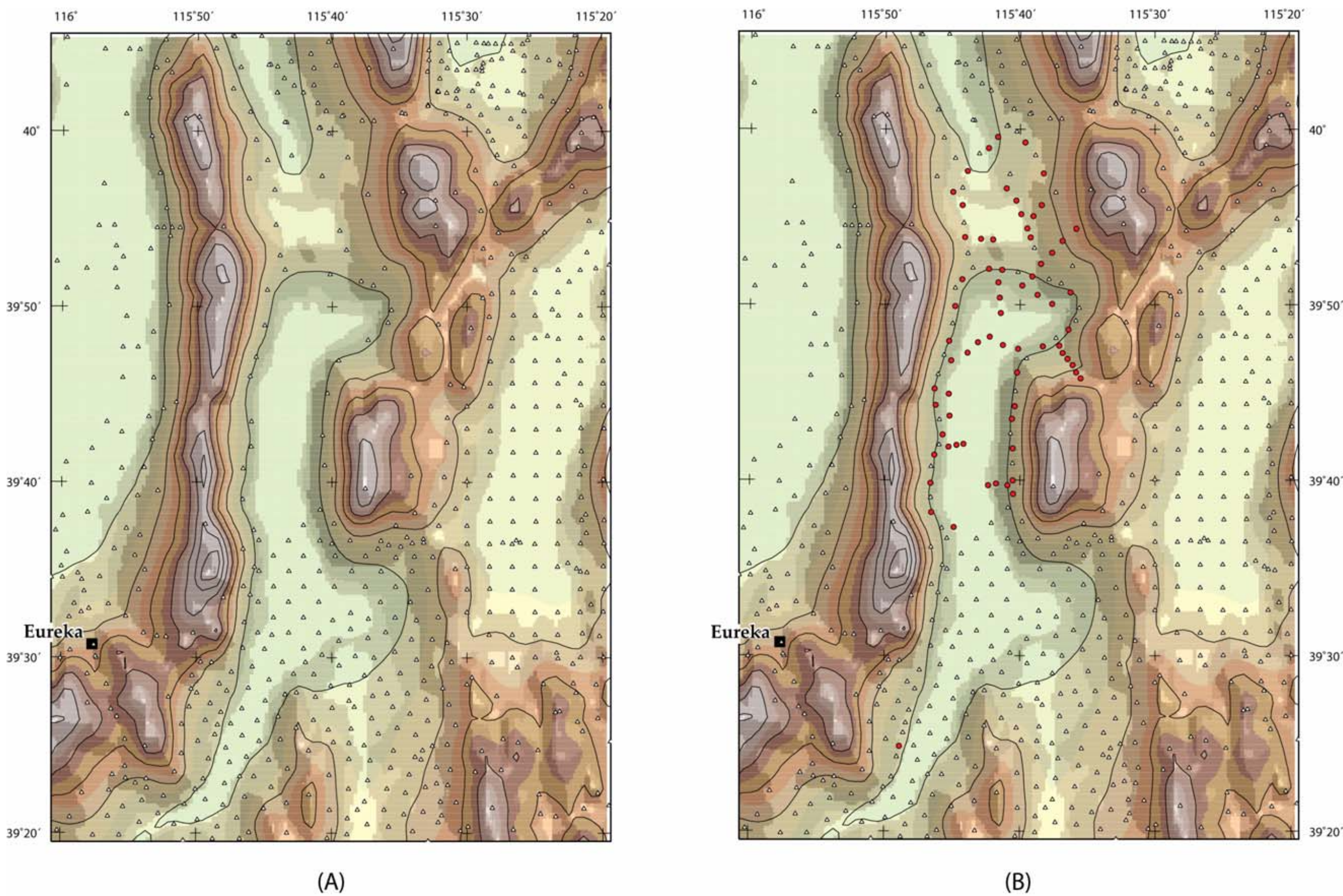

Figure 3. Locations of gravity stations in the study area. (A) Triangles, previously available stations; (B) Red dots, stations added during the current study.

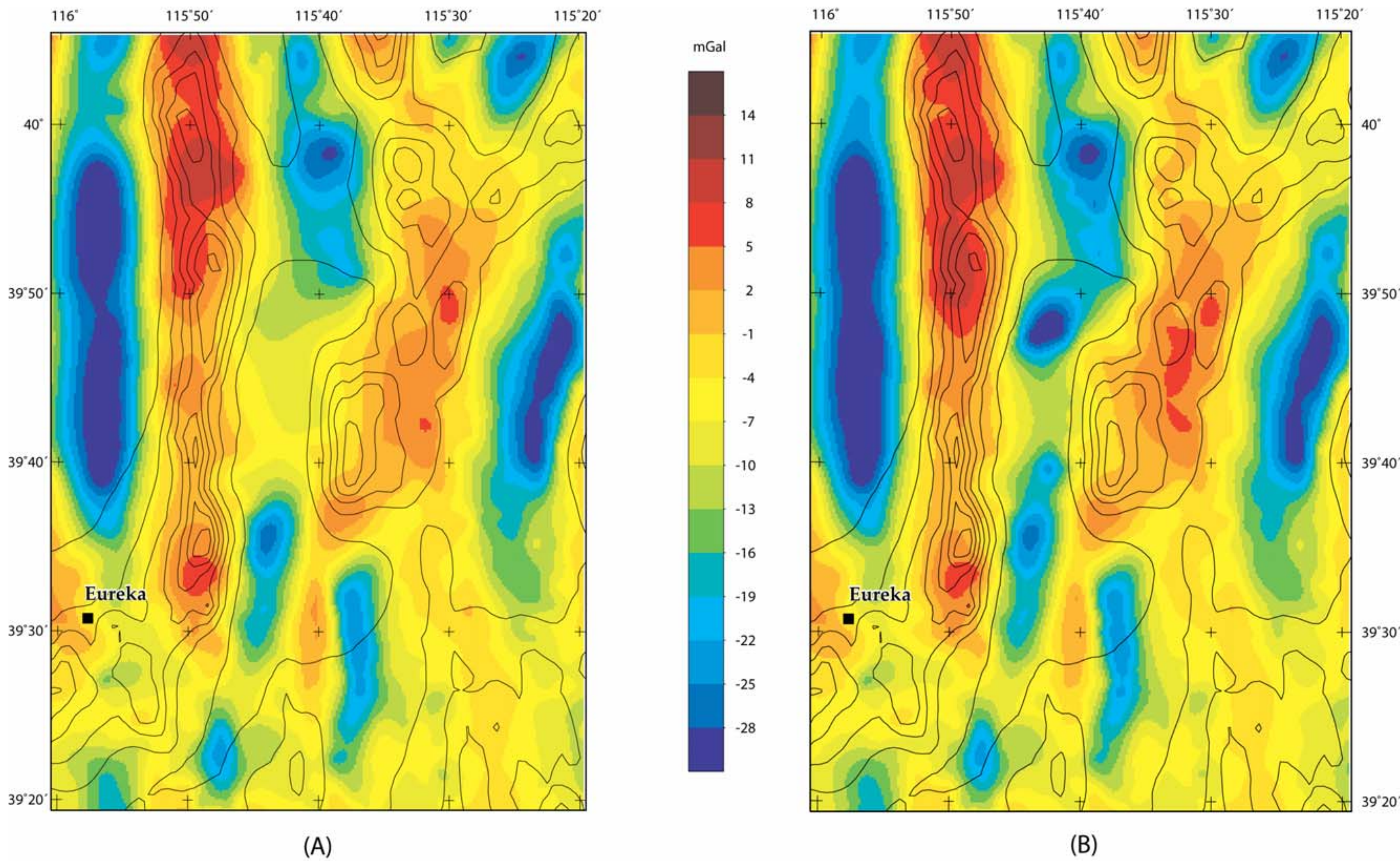

Figure 4. Isostatic gravity field of the study area. Calculated (A) using previously available gravity stations, and (B) using gravity stations added during the current study.

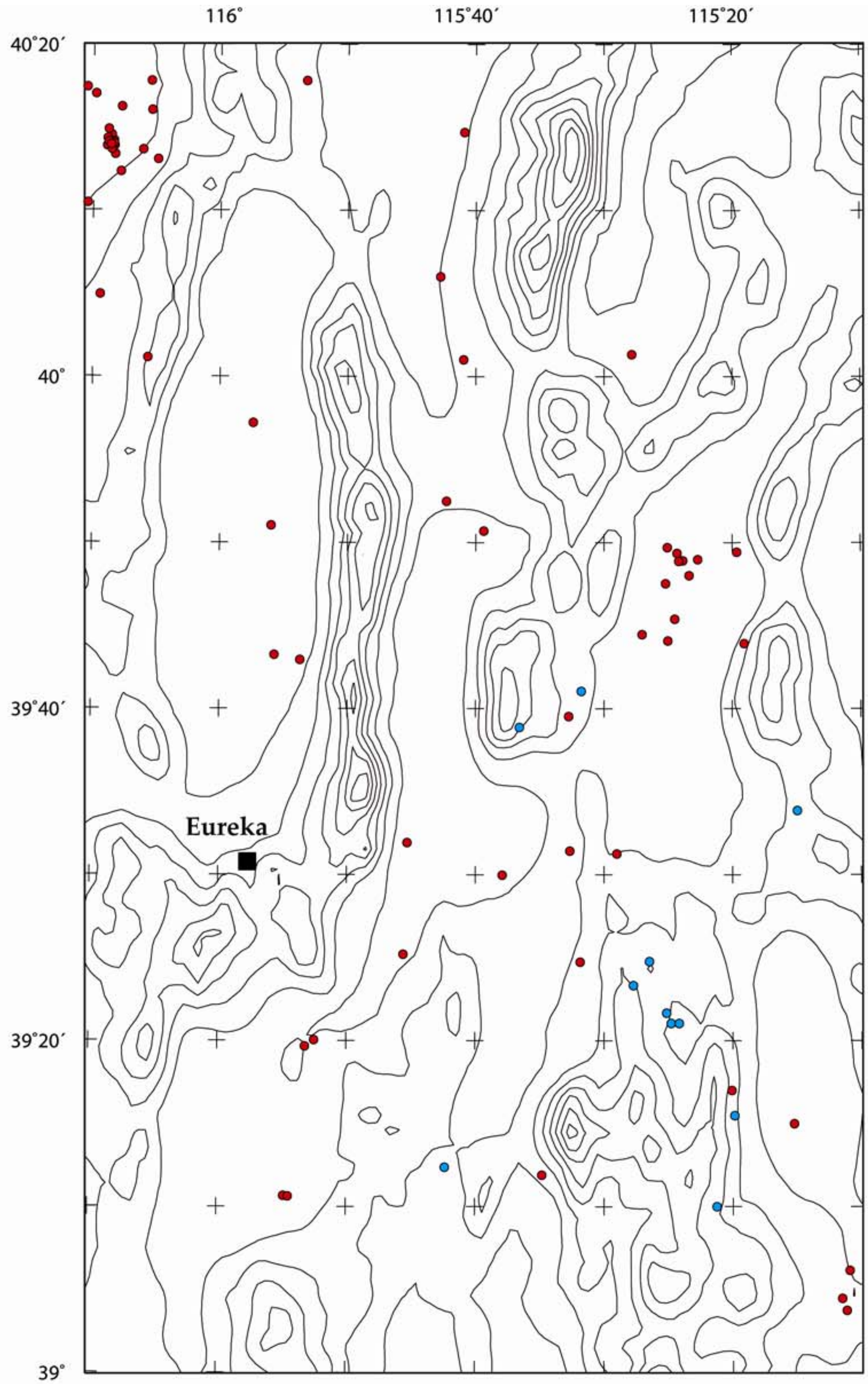

Figure 5. Deep oil and gas wells that are used as constraints in the calculation of the basement surface. Red dots, wells encountering pre-Cenozoic basement; Blue dots, wells spudded in pre-Cenozoic rocks.

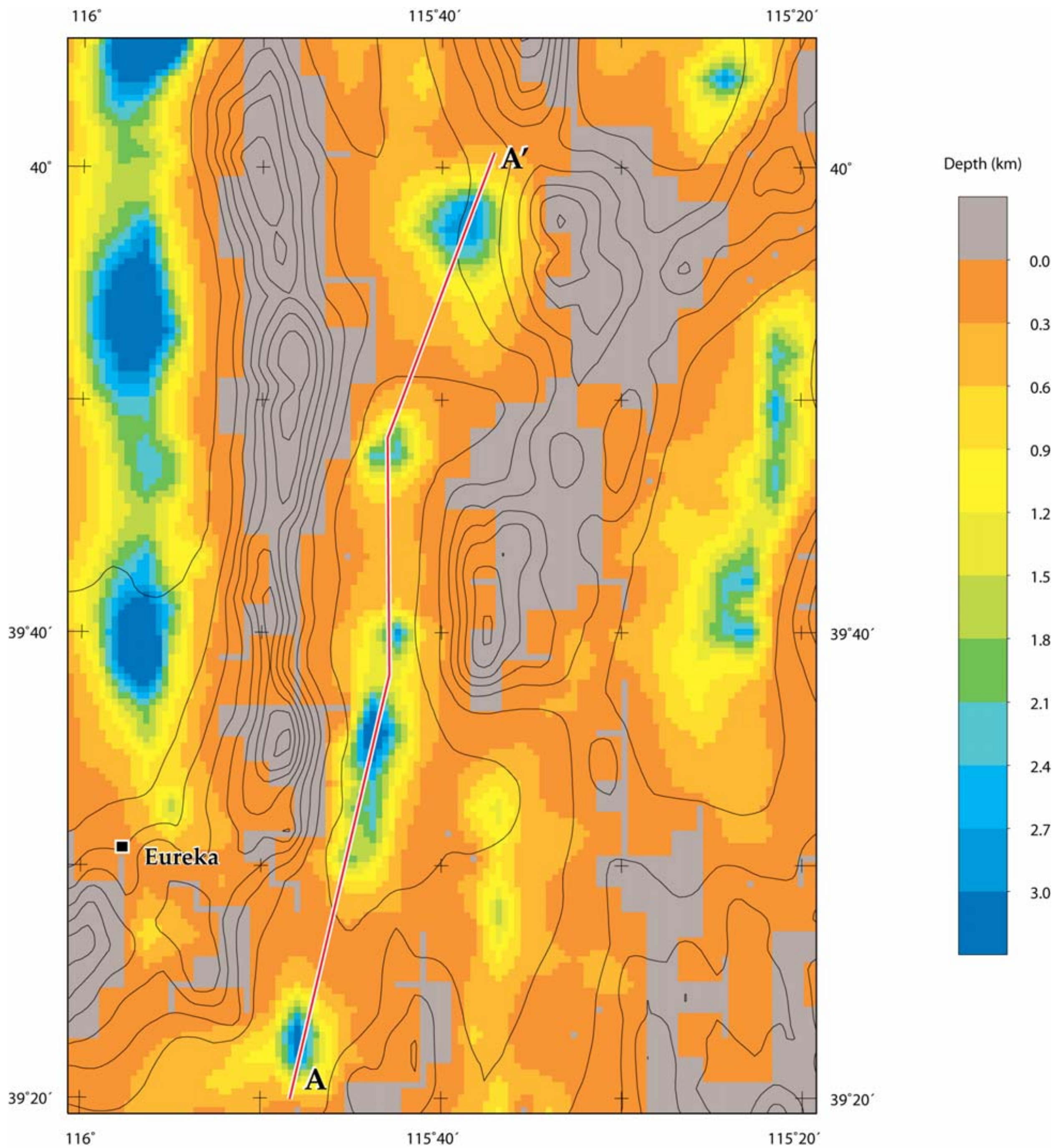

Figure 6. Depth to pre-Cenozoic basement calculated using the gravity inversion method of Jachens and Moring (1990) and incorporating the drill-hole constraints shown in Figure 4. Red line shows location of cross-section shown in Figure 7.

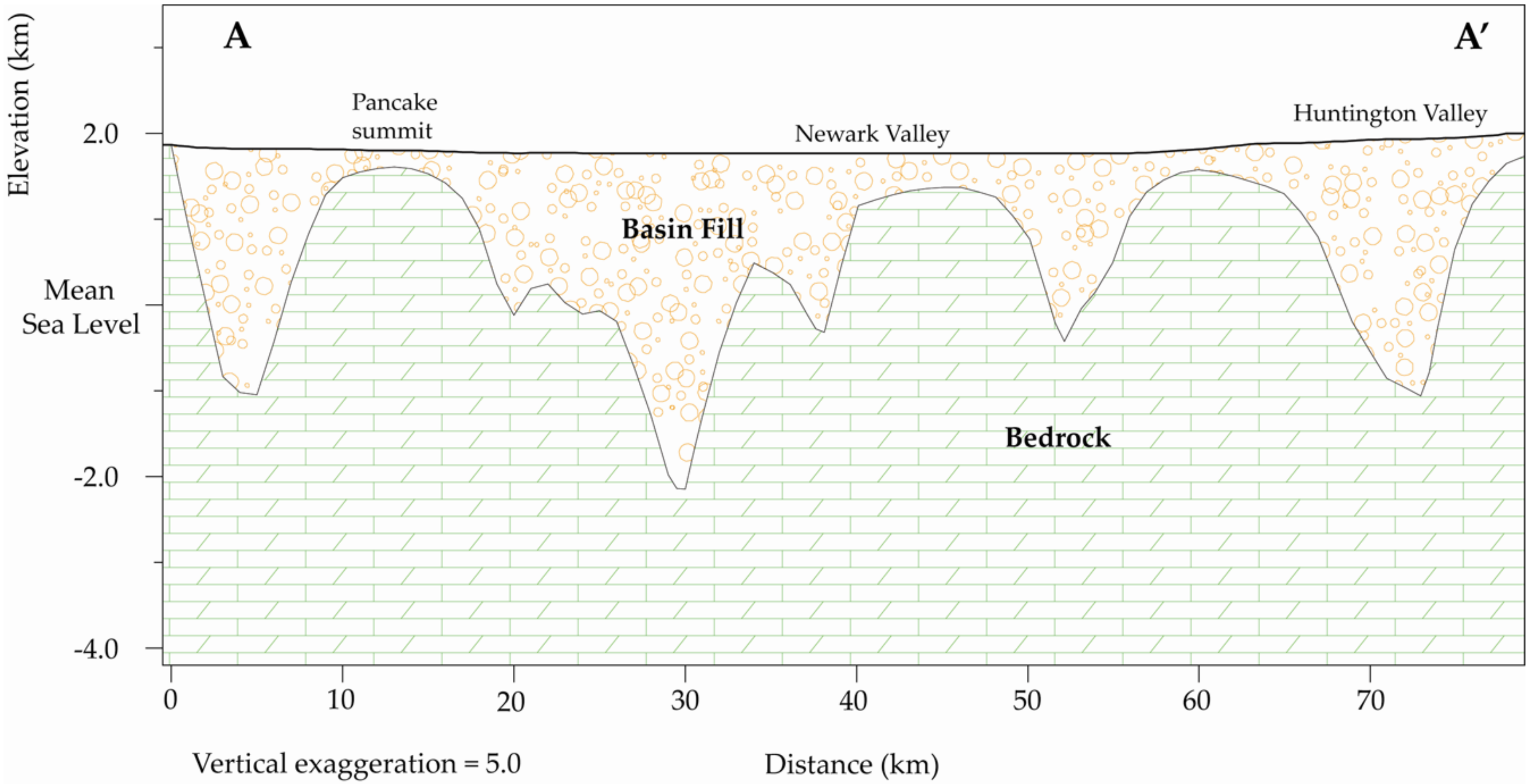

Figure 7. Cross-section along the profile A-A’ shown in figure 6 using depths to pre-Cenozoic basement as determined by the gravity inversion method.

Table 1. Principal facts of new gravity stations from Newark Valley, NV

[Station coordinates, NAD27; elevations, NAVD29; Bouguer anomaly calculated using a reduction density of 2670 kg/m³; terrain corrections calculated out to 166.7 km]

Station ID	Long. (°W)	Lat. (°N)	Elev. (meters)	Obs. Gravity (mGal)	Free Air Anomaly (mGal)	Total TC (mGal)	Bouguer Anomaly (mGal)	Isostatic Anomaly (mGal)
5NWV001	-115.8147	39.4140	1823.0	979545.93	-8.59	0.68	-213.39	-7.71
5NWV002	-115.7758	39.6363	1801.8	979570.42	-10.42	2.84	-210.68	-6.34
5NWV003	-115.7770	39.6642	1794.8	979576.46	-8.98	2.53	-208.78	-4.63
5NWV004	-115.7723	39.6908	1799.2	979581.19	-5.29	1.95	-206.15	-2.20
5NWV005	-115.7622	39.7098	1789.4	979583.08	-8.11	1.37	-208.44	-4.57
5NWV006	-115.7708	39.7380	1793.9	979586.81	-5.48	1.84	-205.87	-2.30
5NWV007	-115.7722	39.7537	1795.7	979586.28	-6.86	2.38	-206.90	-3.45
5NWV008	-115.7518	39.7803	1782.7	979579.86	-19.65	1.71	-218.90	-15.45
5NWV009	-115.7542	39.7988	1808.8	979582.47	-10.65	2.22	-212.32	-9.05
5NWV010	-115.7470	39.8320	1816.2	979584.45	-9.35	2.58	-211.48	-8.42
5NWV011	-115.7382	39.8573	1831.5	979585.87	-5.44	1.85	-210.02	-7.09
5NWV012	-115.7053	39.8673	1818.0	979586.62	-9.74	0.66	-214.01	-10.80
5NWV013	-115.6892	39.8665	1818.3	979582.73	-13.46	0.52	-217.91	-14.53
5NWV014	-115.6515	39.8603	1822.8	979577.53	-16.74	0.46	-221.74	-17.92
5NWV015	-115.6043	39.8450	1815.7	979582.83	-12.26	0.83	-216.09	-11.70
5NWV016	-115.6072	39.8098	1809.6	979588.77	-5.07	1.27	-207.78	-3.20
5NWV017	-115.6387	39.7937	1810.5	979585.45	-6.69	0.72	-210.05	-5.69

5NWV018	-115.6688	39.7913	1782.9	979584.34	-16.09	0.61	-216.46	-12.34
5NWV019	-115.6878	39.7950	1781.1	979569.90	-31.42	0.51	-231.69	-27.76
5NWV020	-115.7043	39.8030	1781.3	979565.29	-36.66	0.58	-236.90	-33.17
5NWV021	-115.7188	39.7977	1782.9	979566.42	-34.57	0.70	-234.86	-31.24
5NWV022	-115.7313	39.7877	1784.1	979567.42	-32.33	0.85	-232.60	-29.03
5NWV023	-115.6705	39.7690	1798.1	979584.87	-8.89	1.41	-210.17	-5.97
5NWV024	-115.6732	39.7370	1825.0	979573.40	-9.23	1.98	-212.95	-8.60
5NWV025	-115.6768	39.7250	1813.4	979573.05	-12.09	2.03	-214.46	-10.07
5NWV026	-115.6758	39.6968	1845.3	979564.45	-8.34	2.32	-214.00	-9.41
5NWV027	-115.6755	39.6665	1854.0	979560.98	-6.42	2.02	-213.35	-8.59
5NWV028	-115.6820	39.6618	1812.2	979564.67	-15.21	1.65	-217.83	-13.04
5NWV029	-115.6960	39.6635	1793.4	979563.10	-22.75	1.03	-223.88	-19.14
5NWV030	-115.7060	39.6618	1784.0	979560.26	-28.32	0.84	-228.58	-23.90
5NWV031	-115.6750	39.6537	1855.5	979560.02	-5.80	2.02	-212.90	-8.05
5NWV032	-115.6183	39.7943	1835.2	979580.13	-4.45	0.92	-210.37	-5.87
5NWV033	-115.6143	39.7877	1860.3	979575.29	-0.97	1.03	-209.59	-5.04
5NWV034	-115.6082	39.7818	1889.1	979570.58	3.72	1.21	-207.95	-3.35
5NWV035	-115.6018	39.7760	1926.0	979565.81	10.85	1.38	-204.78	-0.16
5NWV036	-115.5975	39.7692	1967.8	979557.56	16.10	1.67	-203.93	0.73
5NWV037	-115.5918	39.7635	2028.2	979546.30	23.98	2.08	-202.40	2.27
5NWV038	-115.6410	39.8722	1864.0	979565.73	-16.89	0.53	-226.43	-22.67
5NWV039	-115.6505	39.9175	1917.9	979557.19	-12.85	0.55	-228.42	-25.10
5NWV040	-115.6657	39.9193	1896.3	979567.36	-9.49	0.45	-222.74	-19.59
5NWV041	-115.6717	39.9322	1881.9	979568.20	-14.26	0.48	-225.85	-22.83
5NWV042	-115.6833	39.9437	1852.7	979579.13	-13.33	0.49	-221.65	-18.79
6NWV043	-115.7482	39.6220	1777.5	979561.09	-25.96	1.34	-225.00	-20.34
6NWV044	-115.7367	39.7012	1779.5	979574.18	-19.29	0.79	-219.10	-14.91
6NWV045	-115.7450	39.7000	1782.4	979577.06	-15.39	0.84	-215.49	-11.39

6NWV046	-115.7550	39.6983	1784.1	979580.60	-11.20	1.03	-211.29	-7.25
6NWV047	-115.7535	39.7277	1778.5	979579.79	-16.33	1.00	-215.82	-11.98
6NWV048	-115.7547	39.7487	1781.5	979582.31	-14.76	1.26	-214.33	-10.65
6NWV049	-115.6935	39.8545	1801.7	979585.05	-15.21	0.54	-217.76	-14.31
6NWV050	-115.6920	39.8400	1788.5	979581.79	-21.24	0.52	-222.33	-18.73
6NWV051	-115.6907	39.8255	1783.3	979574.88	-28.47	0.50	-229.01	-25.34
6NWV052	-115.6642	39.8517	1804.0	979588.28	-11.01	0.43	-213.94	-10.16
6NWV053	-115.6453	39.8427	1795.9	979581.73	-19.25	0.48	-221.21	-17.17
6NWV054	-115.6273	39.8340	1792.8	979578.97	-22.22	0.58	-223.73	-19.52
6NWV055	-115.7153	39.8958	1884.8	979578.53	0.20	0.60	-211.60	-8.79
6NWV056	-115.7002	39.8953	1895.7	979576.00	1.08	0.60	-211.94	-8.92
6NWV057	-115.7350	39.8973	1909.5	979575.81	4.96	0.87	-209.34	-6.78
6NWV058	-115.7380	39.9277	1888.6	979583.33	3.35	0.67	-208.81	-6.51
6NWV059	-115.7495	39.9403	1863.7	979591.40	2.62	0.89	-206.53	-4.42
6NWV060	-115.7318	39.9603	1832.4	979594.68	-5.55	0.62	-211.46	-9.31
6NWV061	-115.7055	39.9822	1816.7	979587.84	-19.17	0.48	-223.46	-21.15
6NWV062	-115.6945	39.9927	1831.0	979581.82	-21.72	0.49	-227.60	-25.23
6NWV063	-115.6607	39.9875	1882.3	979569.56	-17.68	0.57	-229.24	-26.49
6NWV064	-115.6378	39.9582	1960.6	979546.73	-13.75	0.72	-233.93	-30.79
6NWV065	-115.6403	39.9280	1957.1	979547.46	-11.43	0.66	-231.27	-27.95
6NWV066	-115.6580	39.9058	1886.7	979569.36	-9.25	0.46	-221.41	-18.04
6NWV067	-115.6537	39.8972	1873.3	979570.00	-11.97	0.52	-222.57	-19.06
6NWV068	-115.6272	39.8828	1923.5	979553.56	-11.67	0.68	-227.72	-23.96
6NWV069	-115.6145	39.8940	1993.4	979545.51	0.85	0.96	-222.77	-19.01
6NWV070	-115.5972	39.9057	2056.2	979545.11	18.76	2.07	-210.76	-6.96

Table 2. Cenozoic density-depth function for the Newark Valley study area.

Depth Range (km)	**Sedimentary rocks (kg/m^3)**	**Volcanic rocks (kg/m^3)**
0 to 0.2	2020	2220
0.2 to 0.6	2120	2270
0.6 to 1.2	2320	2320
> 1.2	2420	2420