REGIONAL ANALYSIS OF THE DISTRIBUTION OF GOLD DEPOSITS IN NORTHEAST NEVADA USING NURE ARSENIC DATA AND GEOPHYSICAL DATA

By Boris B. Kotlyar, Donald A. Singer, Robert C. Jachens, *and* Ted G. Theodore

ABSTRACT

Regional geochemical surveys, gravity surveys, and magnetic surveys examined by means of modern computer-contouring methods employing various normalization and filtering techniques provide additional insight into crustal processes of metallogenesis. Regional-scale distribution patterns of stream-sediment arsenic anomalies in northeast Nevada bear striking similarities to some important mineralized trends and to some isostatic residual gravity anomalies and their gradients. The gravity anomalies and their bounding gradients, which primarily result from density distributions in the pre-Cenozoic rocks of the middle and upper crust, and their coincidence with linear zones of apparently enriched arsenic suggests that arsenic, as well as precious metals, also may have been derived from the middle and upper crust. However, other broad areas of apparently elevated arsenic concentrations show no indication of the presence of metal deposits. In addition, a map of residual magnetic potential anomalies indicates that magnetic rocks in the middle and upper crust—most likely late Tertiary in age—also must play an important role in the eventual distribution of some hot-spring gold-silver deposits.

INTRODUCTION

Regional-scale geochemical surveys, which were completed by the National Uranium Resource Evaluation (NURE) Program in the 1970's in northeast Nevada, can provide valuable information to a number of earth-science disciplines. However, this information is most powerful when the data are treated by modern computer methodologies and compared with regional geophysical surveys. For example, these data in northeast Nevada can provide fundamental information about: (**1**) geochemical background metal content of soils and stream sediments prior to much of the widespread gold mining in this part of Nevada (useful for ongoing environmental investigations); (**2**) regional metal distributions requisite for site-specific and mining district-scale geochemical studies; (**3**) the regional extent of metallotects such as the Cortez trend (also termed the Battle Mountain-Eureka trend) of mineral deposits, and (**4**) linkages between deep-seated crustal structures and metals channeled along them. In this report, we focus on the last three.

Soil and stream-sediment geochemical data from the NURE program (Hoffman and Marsh, 1994), and a recently released digital version of the same data (Hoffman and Buttleman, 1994) is the multipurpose database examined herein. In spite of the recognized shortcomings of the geochemical data, including different sampling techniques, variability in density of sampling, different size fractions used for analysis, and different laboratories with different analytical sensitivities, the data can be a source of abundant information if treated properly (see also, McGuire and others, 1994; King, 1996; King and others, 1996).

For the present study, NURE data in northeast Nevada in the areas of the Carlin, Cortez, and Getchell gold trends were selected for study, including the McDermitt, Winnemucca, Millet, Wells, and Elko 1°X 2° quadrangles (fig. 1). From all elements analyzed in these areas, arsenic specifically was selected for our study, primarily because of: (**1**) its presence in a wide variety of minerals in many base- and precious-metal deposits in the region, and (**2**) the large number of samples in which arsenic contents were determined at acceptable lower determination levels. In the Ely 1°X 2° quadrangle, which is immediately south of the Elko quadrangle (fig. 1), samples were collected but not analyzed by the NURE Program. The NURE samples in the five selected quadrangles include three types of samples: wet stream-sediment samples, and dry stream-sediment samples, and soil samples.

From the original 4,758 samples with detectable arsenic in the five quadrangles, 4,256 samples were extracted and interpolated to a square grid by means of a routine based on the principal of minimum curvature (Briggs, 1974; see also, Kotlyar and others, 1995). However, the arsenic data from these quadrangles first were transformed. With trace-element geochemistry, small but important variations may be compressed into a relatively narrow range while other variation is spread out over a range wider than its importance justifies (Masters, 1993). Another reason to transform the data is that tests of significance of correlation coefficients are not valid for skewed distributions. For these reasons, we have used a logarithmic (base 10) transformation on the data (table 1*A*).

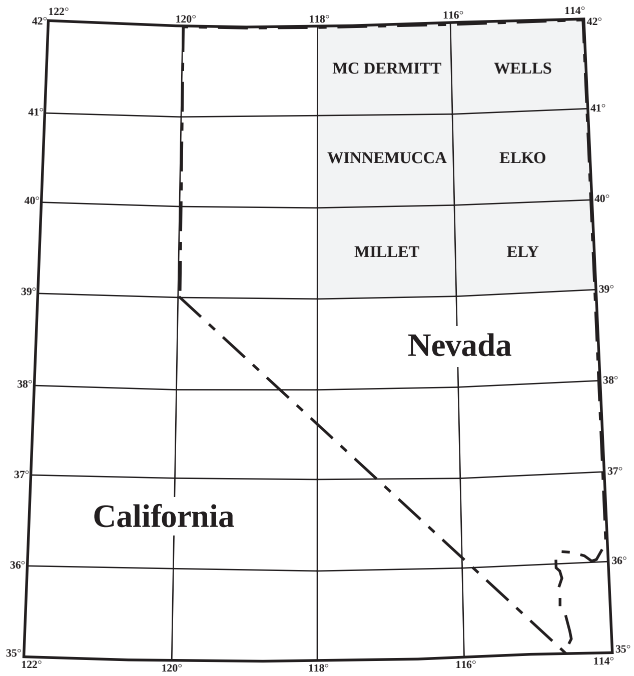

Figure 1. Index map showing location of six 1º X 2º quadrangles discussed in this report.

Histograms of the log transformed data for arsenic typically show a spike on the left (fig. 2) representing values substituted by the analyst for lower limit of detection or censored data. If the number of cases affected by this substitution represents more than a few percent of the number of samples, this practice can introduce biases in contoured values. For this reason, we have removed all such values (502 samples) in the following transformations and in contouring.

For arsenic, the transformed values were standardized or normalized to a Z–score by subtracting the subset's mean and dividing by its standard deviation: $(X_C - X_{mean})/X_{standard\ deviation}$, where all values are logarithms and X_C is the concentration for arsenic in an analyzed sample. Various descriptive statistics in the transformed database used to generate the elemental distribution diagrams also are given in table 1. This process removes all effects of different means and measurement scales and facilitates the comparison of the spatial patterns of elements among the five quadrangles. Histograms of the normalized As data approximate lognormal distributions (fig. 2*B*). Kotlyar and others (1995) discuss the gridding procedures employed and the various filter parameters used.

A computer-contoured plot for arsenic shows that the above-described transformation technique results in a relatively even distribution of arsenic across all of the quadrangles investigated (fig. 3). Boundary effects are absent with the possible exception of the data from the Elko 1º X 2º quadrangle. Areas shown in white represent areas excluded from the contouring procedures because of an absence of samples.

DISCUSSION

Elevated concentrations of arsenic, where arsenic contents are greater than scaled values of 0.0, are present in the general area of known gold, mercury and antimony deposits of various types (figs. 3 and 4). However, the distribution of arsenic also forms individual anomalies and trends, which conform closely to the major known gold trends in the region, including the Carlin, Cortez, and Getchell trends. With the exception of a group of Comstock- and Sado-type deposits in the southwestern corner of the Millet quadrangle, hot-spring Au–Ag deposits at Buckskin, and distal-disseminated Ag–Au deposits in the northwest part of the Wells 1º X 2º quadrangle (fig. 3), all other gold deposits are in areas where regional stream-sediment arsenic contents are inferred to have values greater than scaled values of 0.0. Nonetheless, many areas have arsenic anomalies or trends wherein regional stream-sediment values are greater than scaled values of 0.0 (fig. 3). These areas include:

(**1**) to the south-east of the Dixie hot-spring gold deposit;
(**2**) to the north-northeast and south-southwest of the Austin sediment-hosted Au deposit in the Millet quadrangle;
(**3**) to the northwest of the Goldbanks hot spring gold deposit in the Winnemuca quadrangle;
(**4**) to the north and northeast of the Bald Mountain sediment-hosted gold deposit;
(**5**) to the north-northeast of the Gnome and Rain sediment-hosted gold deposits (fig. 4) in the Winnemuca and Elko quadrangles;
(**6**) to the north and northwest of the Kinsley sediment-hosted gold deposit near the southeast corner of the Elko quadrangle;
(**7**) to the east of Bootstrap and Dee sediment-hosted gold deposits (fig. 4) in the McDermitt quadrangle;
(**8**) to the east of the Getchell and Rabbit Creek sediment-hosted gold deposits in the McDermitt quadrangle, although a part of this anomaly may reflect wind-blown contamination from the dumps at Getchell.

Generalized arsenic anomalies and their trends at the regional scale apparently have mainly four orientations, including northwest (Cortez and Carlin), northeast (Gold Bar-Tonkin Springs and others), north-northeast (Getchell, Austin, and Independence Range), and east-northeast (to the east of Getchell). These arsenic trends also are characterized by relatively pronounced changes of orientation along an "arsenic boundary" present in the central part of the region (fig. 3). To the northwest of this boundary, many of the arsenic anomalies have a northwest orientation, whereas to the southeast of the boundary, many of the arsenic anomalies have a northeast orientation.

Table 1. Descriptive statistics of arsenic in NURE soil and stream-sediment samples in five 1º X 2º quadrangles in northeast Nevada. Data from Hoffman and Buttleman (1994). ***A***, logarithmic data (base 10); ***B***, Normalized Z–score data without censored values (see text).

A. Logarithmic data

Arsenic	McDermitt	Winnemucca	Millet	Wells	Elko
Mean	3.617	3.531	3.89	0.266	3.192
Std. Dev	0.226	1.25	0.692	0.309	1.019
Count	1383	692	793	58	1832
Minimum	3	1.544	1.845	0	-0.301
Maximum	4.643	5.769	5.75	1.079	4.544
Coef. Var.	0.062	0.354	0.178	1.164	0.319
Range	1.643	4.225	3.905	1.079	4.845
Sum Squares	18163.274	9708.826	12376.939	9.532	20561.296
Skewness	0.141	-0.711	-1.585	0.771	-2.727
Kurtosis	0.454	-1.121	2.643	-0.531	6.226
Median	3.602	4.085	4.005	0.151	3.477
Mode	3.602	1.544	1.845	0	3.477
10% Tr. Mean	3.612	3.599	4.008	0.231	3.447

B. Normalized Z–score data

Arsenic	McDermitt	Winnemucca	Millet	Wells	Elko
Mean	0	0	0	0	0
Std. Dev.	1	1	1	1	1
Count	1383	489	691	19	1674
Minimum	-2.73	-2.545	-1.547	-1.005	-1.98
Maximum	4.542	3.832	5.101	2.455	4.221
Range	7.272	6.377	6.647	3.46	6.201
Skewness	0.141	0.679	1.341	1.025	0.243
Kurtosis	0.454	0.746	2.741	0.485	0.928
Median	-0.066	-0.09	-0.208	-0.287	-0.064
10% Tr. Mean	-0.021	-0.063	-0.112	-0.085	-0.002

A number of earlier studies compared the distribution of mineral deposits in the region with geophysical fields, and showed that a correlation between gradients in gravity fields and some of the gold trends, in particular the Cortez trend (Grauch and others, 1995). In the remainder of this report, we will compare the regional distribution of arsenic anomalies and loci of mineral districts with regional gravity and magnetic patterns.

Figure 5 shows the gravity field of the study area, modified to emphasize those parts of the field most likely to be related to features in the middle and upper crust (see also, Saltus and Jachens, 1995). Two corrections were added to the standard Bouguer gravity to produce the map shown in figure 5. First, the strong regional gravity variations produced by deep-seated density distributions that isostatically support the topography were removed by direct calculation, assuming an Airy-Heiskanen model of isostatic compensation (Simpson and others, 1986). The resulting map (see map of isostatic residual gravity anomalies in Saltus and Jachens, 1995) emphasizes gravity anomalies from density distributions in the middle and upper crust. A second correction was added to the isostatic residual gravity, one designed to eliminate the pervasive pattern of gravity lows that are caused by the low-density deposits contained in the Cenozoic basins throughout the region. This correction was determined by iteratively partitioning the isostatic residual gravity field into a "basin" component and a "basement" component (Jachens and Moring, 1990). The "basement" gravity component, shown in figure 5, approximates the gravity field that would have been measured if the Cenozoic deposits did not exist, and thus reflects the density distributions in the pre-Cenozoic rocks of the middle and upper crust. Coincidence of arsenic anomalies and their

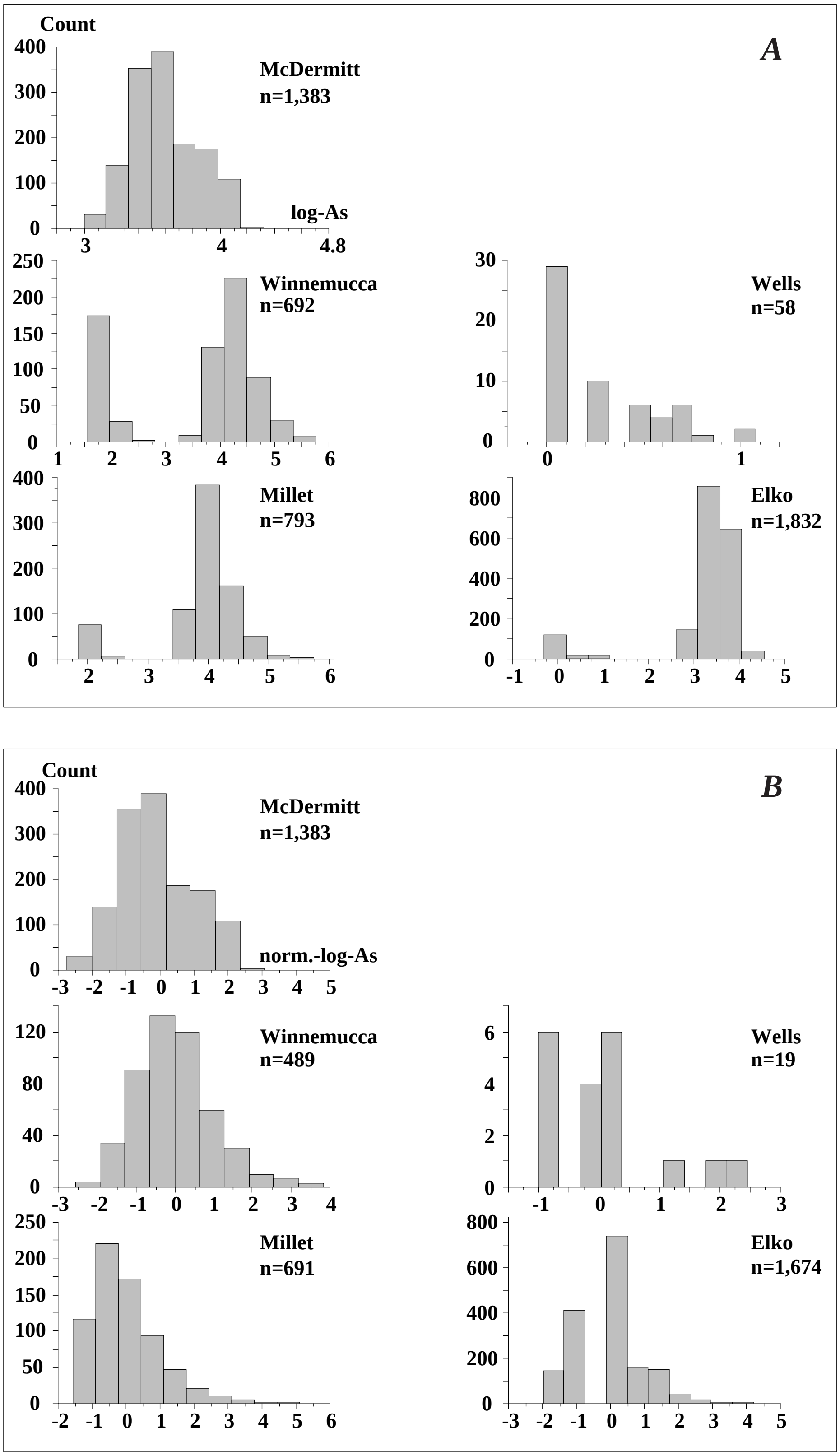

Figure 2. Frequency distributions of (***A***) logs (base 10) of arsenic contents (ppm) and (***B***) normalized logs of arsenic contents (see text), with censored data removed in sediment samples in McDermitt, Wells, Winnemucca, Elko, and Millet 1º X 2º quadrangles, Nevada.

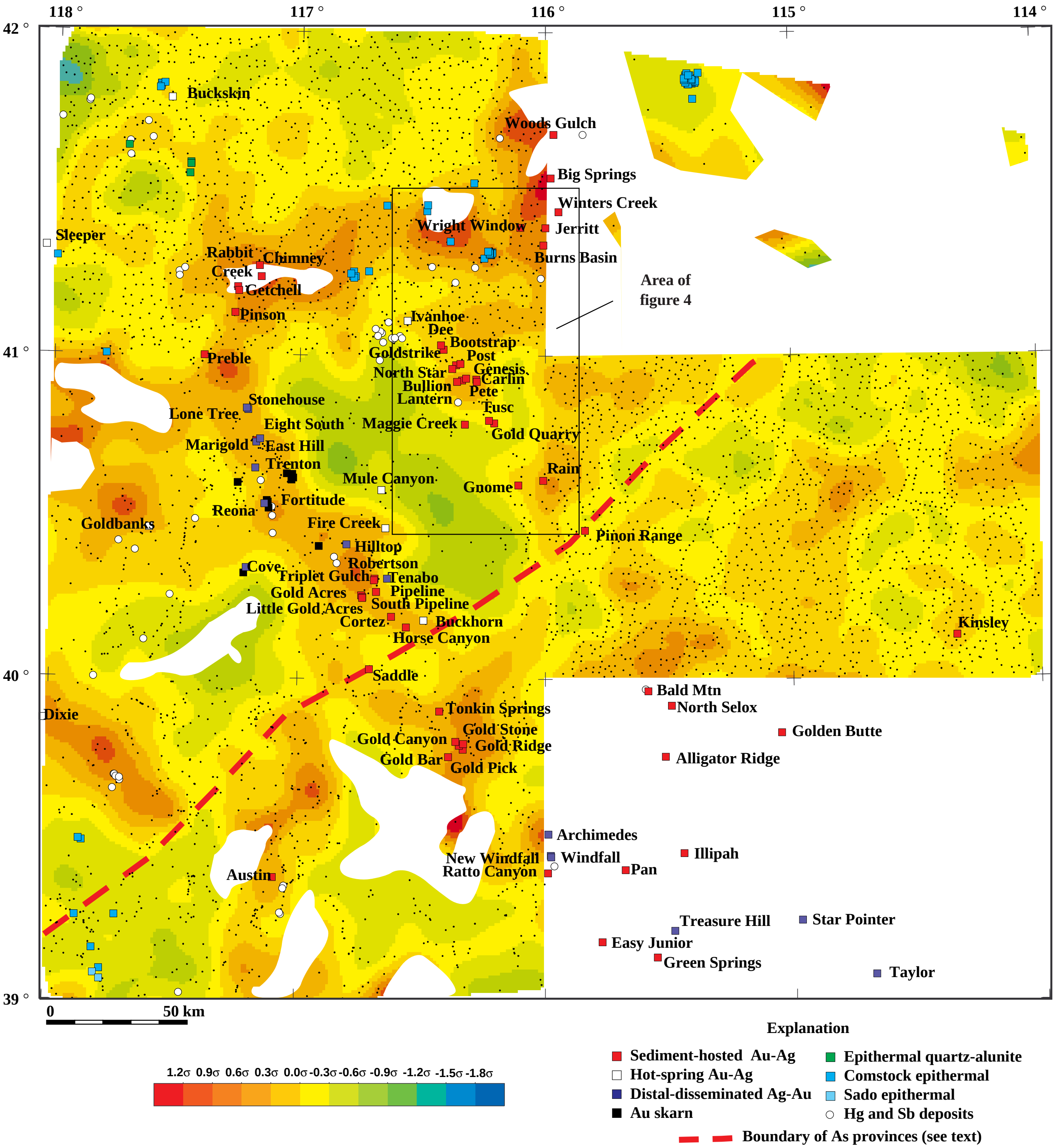

Figure 3. Distribution of normalized logs for arsenic contents in sediment samples, northeast Nevada. Dots are sample locations of analyzed samples. Reported arsenic contents gridded (1,000–m-wide cells) and filtered (*z* = 5,000 m) (see Kotlyar and others, 1995), resulting in contours showing standard deviations (s) of log-transformed metal concentrations from the mean. Unpatterned, areas without analyzed samples. Deposit types from U.S. Geological Survey Mineral Resource Data System (MRDS) (see also Sherlock, and others, 1996). Aresenic data modified from Hoffman and Buttleman (1994).

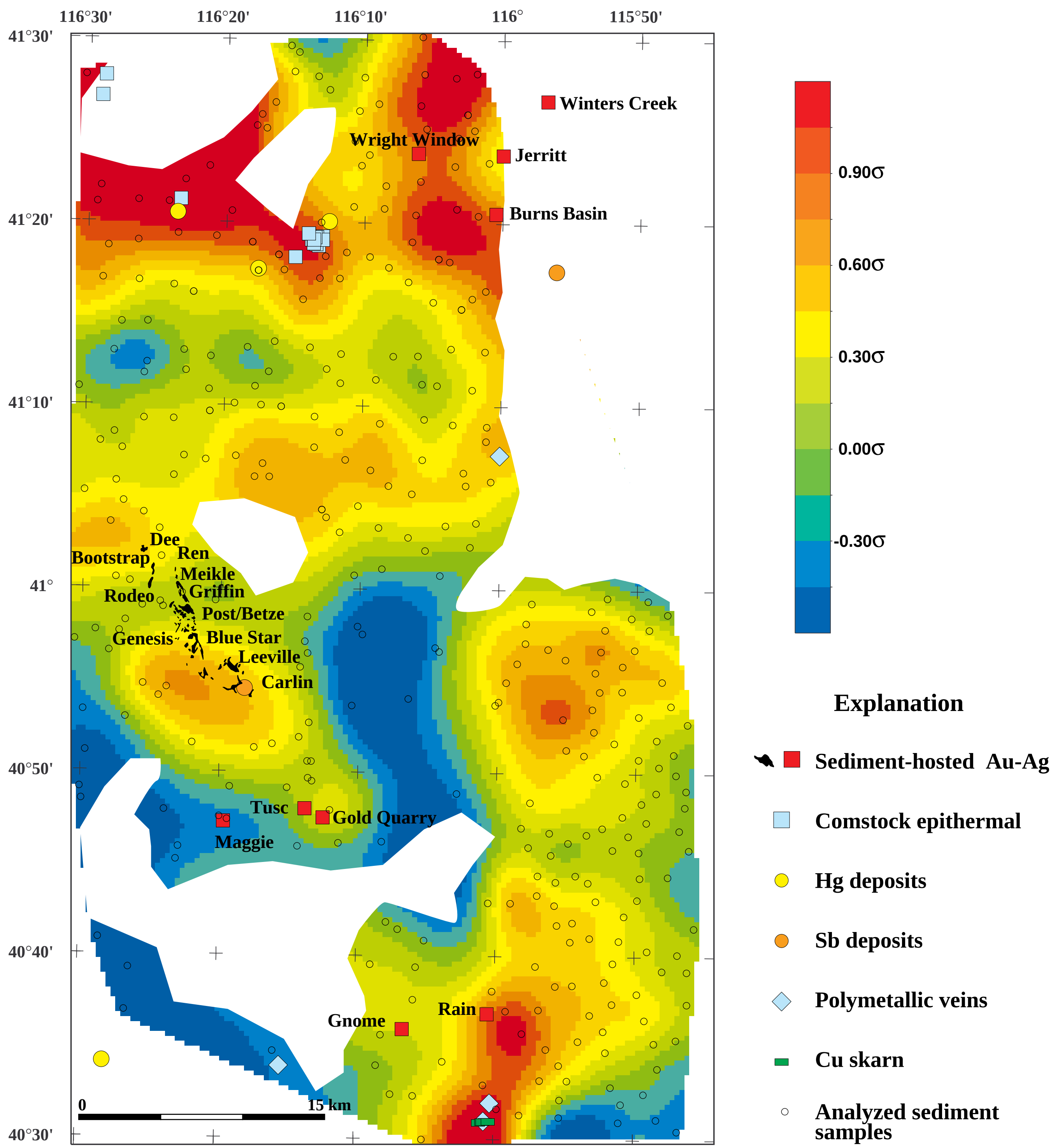

Figure 4. Distribution of normalized logs for arsenic contents in sediment samples near Carlin trend and surrounding area, Nevada (500–m-wide cells gridding, and *z* = 3,000 m), (see Kotlyar and others, 1995). Surface projection of sediment-hosted Au–Ag orebodies from S. G. Peters (written, commun., 1997). Deposit type and source of geochemical data same as figure 3.

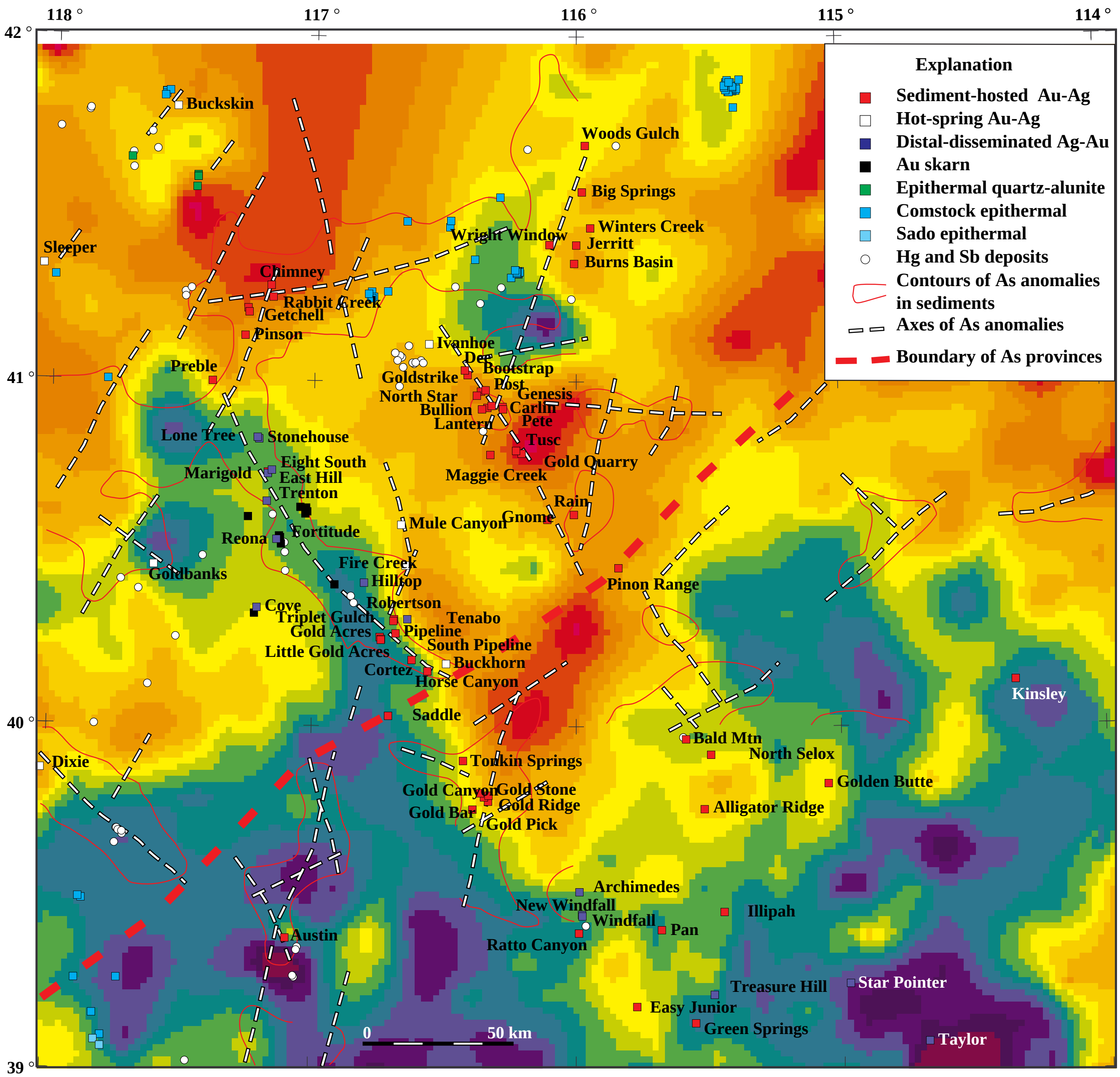

Figure 5. Map showing isostatic residual gravity of the pre-Cenozoic basement rocks of northern Nevada (after Saltus and Jachens, 1995), gold, mercury and antimony deposits, as well as contours and axes of arsenic anomalies from soil and stream sediment samples. Warm colors mark areas with rock in the middle and upper crust that are denser than those in areas marked by cool colors.

trends with linear trends defined by precious-metal deposits as well as density distributions in the middle and upper crust suggests derivation of arsenic and precious metals from these crustal levels.

In general, gravity anomalies and their gradients are characterized by three major trends, including northwest, northeast, and east-northeast, which orientations are similar to the known gold trends in northeast Nevada, as well as the orientations of the patterns of the regional arsenic anomalies (fig. 5). Comparison of gravity data and distribution of gold deposits and arsenic anomalies shows that:

(**1**) the southern part of the Cortez trend, which is comprised mostly of sediment-hosted gold deposits, coincides with a well-developed gravity gradient (fig. 5; see also, Grauch and others, 1995). Farther to the northwest along the Cortez trend, however, the bulk of the mineral deposits diverge away from the gravity gradient, and are situated in areas that have a negative gravity anomaly.

(**2**) sediment-hosted gold deposits in the southern part of the Getchell trend correlate with the same gravity gradient,

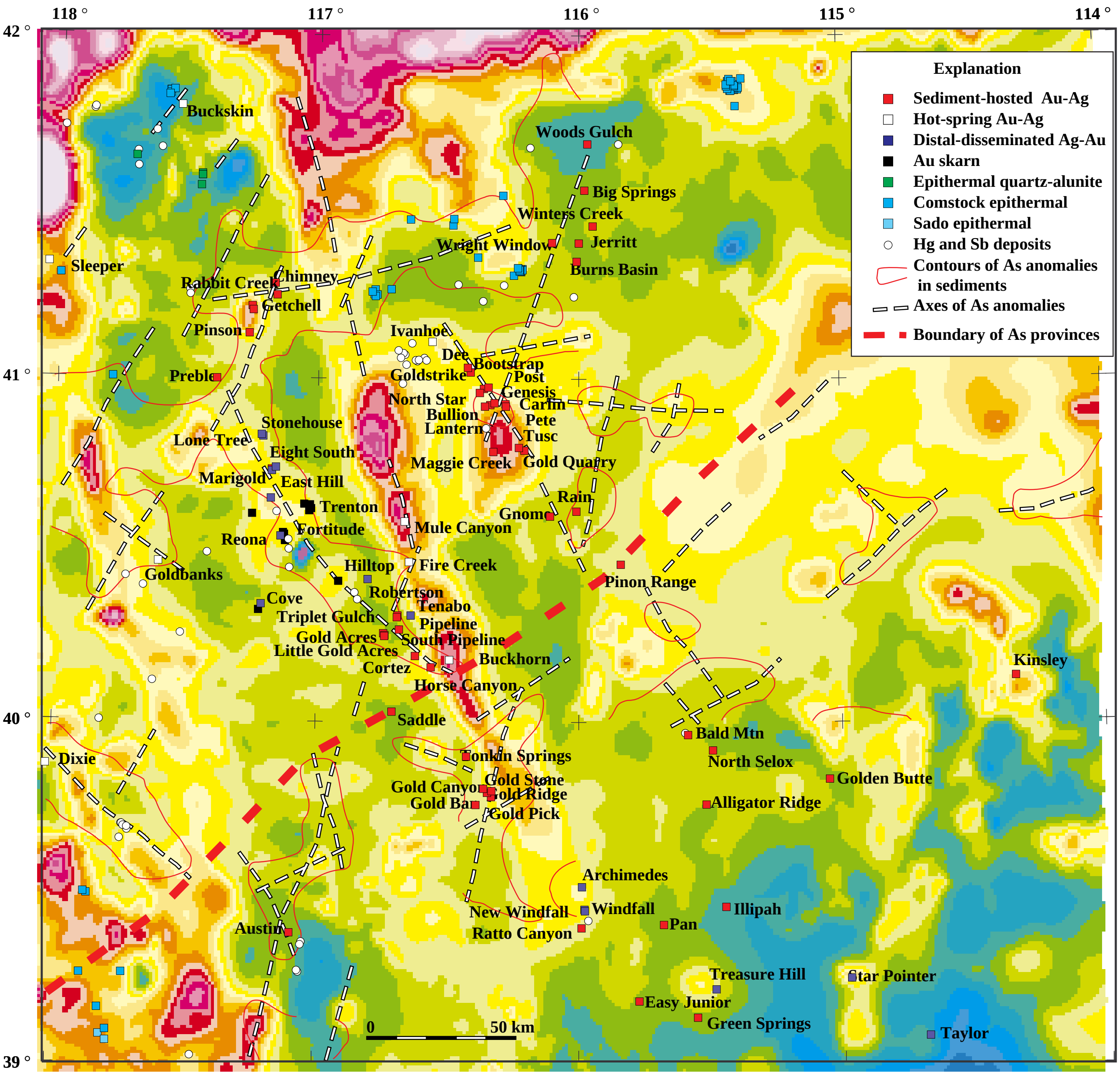

Figure 6. Map showing residual magnetic potential (pseudogravity) anomalies of northern Nevada, and gold, mercury and antimony deposits, as well as contours and axes of arsenic anomalies from soil and stream sediment samples. Warm colors mark areas with rock in the middle and upper crust that are more magnetic than those in areas marked by cool colors.

but they extend to the northeast at high angles to the gravity gradient and well away from the trace of the gravity gradient (fig. 5). A generalized axis of anomalous arsenic roughly correlates with the deposits along the Getchell trend, however. Similar relations are present near the sediment-hosted gold-silver deposits (including Burns Basin, Jerritt, Big Springs) in the northern Independence Mountains (fig. 5).

(**3**) gold deposits along the Carlin trend occur in areas where regional stream-sediment arsenic anomalies are present and they also are in an area of elevated gravity.

Figure 6 shows a map that reflects the regional distribution of magnetic rocks within the study area. It was derived from the magnetic map of Nevada (Hildenbrand and Kucks, 1988) by a procedure meant to emphasize the volume distribution of magnetization in the middle and upper crust. First, the map of magnetic anomalies was transformed to a map of magnetic potential anomalies (pseudogravity anomalies of Baranov, 1957), both to eliminate asymmetry of the anomalies caused by the inclination of the main geomagnetic field, and to emphasize the parts of the anomalies produced by the deeper parts of the magnetic bodies. Second, the longest wavelengths of the magnetic potential anomalies (MPA) were suppressed in order to focus more closely on anomalies from sources in the middle and upper crust. This was accomplished by applying the following numerical filter: Residual MPA=MPA–MPA (upward continued 15 km).

The process of upward continuation 15-km selectively suppresses anomalies with wavelengths shorter than 100 km, anomalies that mostly are produced by sources in the middle and upper crust. By subtracting the upward continued magnetic potential anomalies from the original magnetic potential anomalies, the map of residual magnetic potential anomalies shown in figure 6 focuses on the distribution of magnetic rocks in the middle and upper crust.

Comparison of these magnetic data (fig. 6) with distributions of gold deposits and patterns of arsenic anomalies shows that there are at least two types of relations. First, strong elongate north-northwest magnetic anomalies correspond with mafic volcanic rocks of Tertiary age. Miocene hot-spring deposits are present along the northern Nevada rift, and these deposits include Buckhorn, Fire Creek, and Mule Canyon. In addition, much of the northern Nevada rift also coincides with the axis of an arsenic anomaly (fig. 6). Second, local magnetic highs coincide with a number of Mesozoic plutons and nearby sediment-hosted gold deposits, as well as some of distal-disseminated Ag-Au deposits in the northern part of the Cortez trend. However, a significant number of the gold deposits in the region, including those in the northern Independence Range, southern part of the Cortez trend, Austin, and sediment-hosted Au-Ag deposits in the Ely 1º X 2º quadrangle are located in areas that have regionally extensive negative magnetic anomalies.

CONCLUSIONS

Regional geochemical surveys, gravity surveys, and magnetic surveys examined by means of modern computer-contouring methods employing various normalization and filtering techniques provide additional insight into crustal processes of metallogenesis. Regional-scale distribution patterns of arsenic anomalies in northeast Nevada bear striking similarities to many important mineralized trends and to some isostatic residual gravity anomalies and their gradients. The gravity anomalies and their gradients primarily result from density distributions in the middle and upper crust and their coincidence with linear zones of apparently enriched arsenic suggests that arsenic, as well as precious metals, also may have been derived from the middle and upper crust. However, broad areas of apparently elevated arsenic concentrations also show no indication of metal deposits. In addition, a map of residual magnetic potential anomalies indicates that magnetic rocks in the middle and upper crust—most likely late Tertiary in age—also must play an important role in the eventual distribution of some hot spring Au–Ag deposits.

REFERENCES CITED

Baranov, V., 1957, A new method for interpretation of aeromagnetic maps: Geophysics, v. 22, p. 359-383.

Hildenbrand, T.G., and Kucks, R.P., 1988, Total intensity magnetic anomaly map of Nevada: Nevada Bureau of Mines and Geology Map Series 93A, scale 1:1,000,000.

Hoffman, J.D., and Buttleman, Kim, 1994, National geochemical data base: National uranium resource evaluation for the conterminous United States: U.S. Geological Survey Digital Data Series DDS–18–A, 1 CD.

Hoffman, J.D., and Marsh, S.P., 1994, National geochemical data base, *in* Carter, L.M., Toth, M.,I. and Day, W., eds., USGS research on mineral exploration, 1994; Part A, Program and abstracts, p. 62–64.

Jachens, R.C., and Moring, B.C., 1990, Maps of the thickness of Cenozoic deposits and the isostatic residual gravity over basement for Nevada: U.S. Geological Survey Open-File Report 90-404, 15 p., 2 sheets, scale 1:1,000,000.

Jachens, R.C., Moring, B.C., and Schruben, P.G., 1996, Thickness of Cenozoic deposits and isostatic residual gravity over basement, *in* Singer, D.A., ed., An analysis of Nevada's metal-bearing mineral resources: Nevada Bureau of Mines and Geology Open-File Report 96–2, p. 2–1 to 2–10.

King, H.D., 1996, Interpretation of reconnaissance geochemical data from the Bureau of Land Management's Winnemucca District and Surprise Resource Area, northwest Nevada and northeast California: U.S. Geological Survey Open-File Report 96–533, 36 p.

King, H.D., Fey, D.L., Motooka, J.M., Roushey, B.H., and McGuire, D.J., 1996, Analytical data and sample locality map of stream-sediment and soil samples from the Winnemucca-Surprise Resource Assessment Area, northwest Nevada and northeast California: U.S. Geological Survey Open-File Report 96–062A, paper version, 341 p.; 96–062B, Diskette version.

Kotlyar, B.B., Theodore, T.G., and Jachens, R.C., 1995, Re-examination of rock geochemistry in the Copper Canyon area, Lander County, Nevada: U.S. Geological Survey Open-File Report 95–816, 47 p.

Masters, T., 1993, Practical neural network recipes in C++: San Diego, California, Academic Press, Inc., 493 p.

McGuire, D.J., and Albino, G.V., 1994, Arsenic and antimony anomalies in NURE sediments show mineralized areas in northwestern Nevada, *in* Carter, L.M., Toth, M., I. and Day, W., eds., USGS research on mineral resources—1994; Part A, Program and abstracts, p. 62–64.

Saltus, R.W., and Jachens, R.C., 1995, Gravity and basin-depth maps of the Basin and Range province, western United States: U.S. Geological Survey Geophysical Inverstigations Map GP–1012, scale 1:2,500,000.

Sherlock, M.G., Cox, D. P., and Huber, D.F., 1996, Known mineral depositsin Nevada, *in* Singer, D.A., ed., An analysis of Nevada's metal-bearing mineral resources: Nevada Bureau of Mines and Geology Open-File Report 96-2, Chapter 10, p.10.1–10.38, 2 sheets, scale 1:1,000,000. (Also available at: www.nbmg.unr.edu/ofr962.)

Simpson, R.W., Jachens, R.C., Blakely, R.J., and Saltus, R.W., 1986, A new isostatic residual gravity map of the conterminous United States with a discussion on the significance of isostatic residual anomalies: Journal of Geophysical Research, v. 91, p. 8,348–8,372.