CHAPTER 3

SHALLOW MAGNETIC LITHOLOGIES AS INTERPRETED FROM LOW-ALTITUDE AEROMAGNETIC DATA

Richard J. Blakely, Paul G. Schruben, and Barry C. Moring

INTRODUCTION

Mineralization is often associated with volcanic and plutonic rocks, and knowing where these rocks are located at exploration depths is of significance to any systematic mineral resource evaluation. Igneous rocks often contain magnetic iron oxides in sufficient concentrations to be detected as magnetic anomalies at low altitudes, and spatial patterns of aeromagnetic anomalies can be used to identify the location of these rock types beneath less magnetic cover. Moreover, because the shape of a magnetic anomaly depends in part on the depth to its source, aeromagnetic anomalies can also be used to infer the depth to magnetic lithologies.

Low-altitude aeromagnetic anomalies were used to derive the locations of shallow magnetic rocks throughout the state of Nevada. The regional aspects of this interpretation were discussed by Blakely and Jachens (1991). In particular, this analysis shows that over half of Nevada has magnetic sources, generally Mesozoic and Cenozoic igneous rocks, within 1 km of the topographic surface, a testimony to the widespread magmatic events that were a part of Nevada’s geologic history.

The interpretation of the distribution of shallow magnetic rocks was combined with a digital geologic database to provide a simplified interpretation of shallow magnetic lithology throughout Nevada. The results are shown as plate 3-1, which shows the state divided into five categories. These categories were derived by a two-step process. First, all exposures in the state were lumped into four rock types: sedimentary deposits younger than 17 Ma, sedimentary rocks older than 17 Ma, igneous rocks of Mesozoic and Cenozoic age, and all other lithologies. Second, each of these rock types was classified as either magnetic or nonmagnetic based on interpretation of low-altitude aeromagnetic data.

Several of the resulting categories are of particular interest to a regional mineral resource appraisal. For example, a large part of Nevada is covered by sedimentary deposits younger than 17 Ma that are underlain by shallow magnetic sources, probably volcanic and igneous rocks at less than 1 km depth. Hence, this category represents a vast area of Nevada that may have volcanic- or intrusive-related mineral deposits at exploration depths.

METHODOLOGY

Data Sources

The primary data used in this interpretation were compiled under contract to the U. S. Department of Energy as part of the National Uranium Resource Evaluation (NURE) program. The NURE survey includes the entire conterminous United States plus Alaska and varies widely in flight specifications. In Nevada (fig. 3-1), flightlines were spaced roughly 5 km apart, except in the Death Valley and part of the Kingman 1° by 2° Quadrangles where flightlines were spaced approximately 1.6 km apart. NURE profiles were measured approximately 120 m above terrain, and this low altitude provides a significant advantage in the detection of shallow magnetic sources.

A compilation of aeromagnetic data (fig. 3-2, on page 3-9) by Hildenbrand and Kucks (1988) was used to support interpretations based on NURE data. This compilation was based on 38 separate aeromagnetic surveys. Each survey was interpolated to a rectangular grid, analytically continued to a surface 305 m above terrain, and splined together. This compilation has proven to be a fruitful source of information about the mineral potential and regional tectonic framework of Nevada (Blakely, 1988; Grauch and others, 1988; chapter 7 in this report).

The geologic information used in plate 3-1 is from a statewide compilation at 1:500,000 scale by Stewart and Carlson (1978). This geologic map was electronically digitized thereby producing a digital database of geologic contacts suitable for geographic information system (GIS) analysis. These digital data are available on compact disk (Turner and Bawiec, 1991).

Analysis

Magnetic anomalies caused by shallow sources are higher in amplitude and shorter in dominant wavelength than anomalies caused by identical sources at greater depth. Generally speaking, deeper sources produce "smoother" anomalies. This well-known principle guided our identification of shallow-source anomalies.

The primary method of identification was qualitative in nature. NURE magnetic profiles were plotted along flightlines at 1:250,000 scale for each 1° by 2° quadrangle of the state. Boundaries between areas with and areas without shallow (<1 km depth) magnetic sources were sketched on each map based on inspection of slope and amplitude of anomalies along individual profiles. Specific anomalies were analyzed with the graphical method of Peters (1949) to verify estimates at discrete locations.

We also applied a computer-based method, modified from Blakely and Hassanzadeh (1981), to all NURE data from Nevada in order to aid and modify the above qualitative interpretation. Although the entire state was analyzed using this automatic method, the poor quality of the NURE data in many locations significantly reduced its applicability.

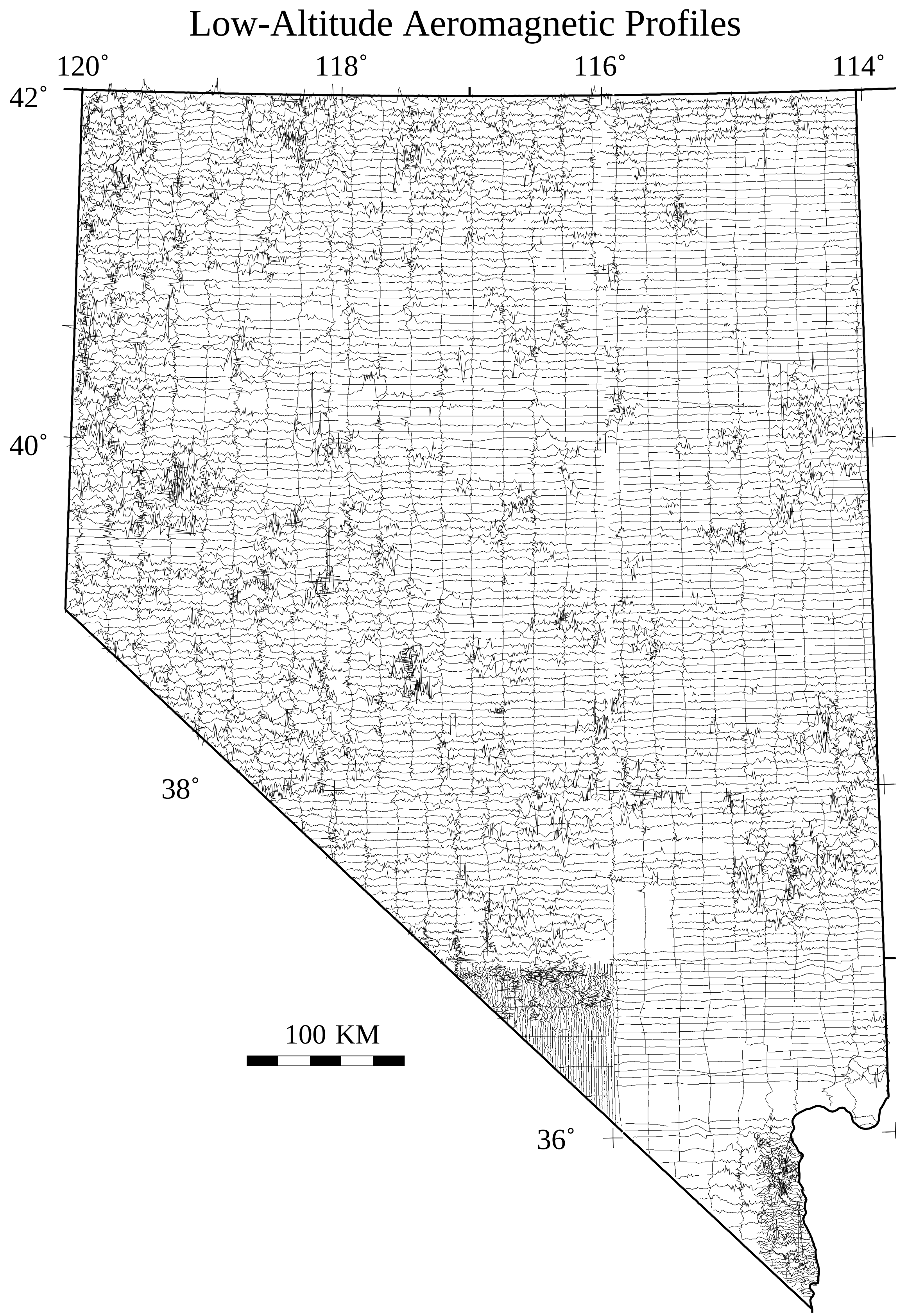

Figure 3-1. NURE magnetic profiles of Nevada plotted along flightlines (Blakely and Chuchel, 1990).

Consequently, depth determinations were developed primarily with the qualitative method described above, augmented in ambiguous places by results from the computer-based method. Limitations of NURE magnetic data are discussed in the next section.

Interpreted boundaries from the 1:250,000-scale maps were digitized and combined into a statewide database. The results are shown on figure 3-3, which identifies areas of Nevada with magnetic sources within 1 km of the topographic surface. Figure 3-3 shows the location of *shallow* magnetic sources only. Some anomalies in aeromagnetic compilations are caused by deep magnetic sources and are not expected to appear in figure 3-3. For example, the broad anomaly over the Spring Mountains (fig. 3-4) in southern Nevada is a significant feature of most aeromagnetic compilations (fig. 3-2), including low-altitude NURE profiles (fig. 3-1). The source of this anomaly, however, is buried several kilometers below the topographic surface (Blank, 1988) and, therefore, does not appear as a shallow magnetic feature in figure 3-3.

Using GIS techniques, units of the digital geologic map were lumped into four lithologic types: sedimentary deposits younger than 17 Ma, sedimentary rocks older than 17 Ma, igneous rocks of Mesozoic and Cenozoic age, and all other lithologies (metamorphic rocks and igneous rocks older than Triassic age). Each of these four lithologic categories then was subdivided into two parts based on the interpretation of low-altitude NURE profiles (fig. 3-3): those parts associated with shallow magnetic sources and those parts not associated with shallow magnetic sources. This resulted in eight distinct lithologies that were lumped into the following six subcategories.

1. Sedimentary deposits younger than 17 Ma
   a. *with shallow magnetic sources*. These young sedimentary deposits generally are not expected to be magnetic. The magnetic anomalies are interpreted to be caused by underlying magnetic rocks. This interpretation is discussed more fully under Interpretations.
   b. *with no shallow magnetic sources*. Underlying basement is interpreted to be composed of nonmagnetic rocks.
2. Mesozoic and Cenozoic igneous rocks
   a. *with shallow magnetic sources*. Most volcanic and many intrusive rocks are magnetic. Hence, the magnetic anomalies are probably caused by the igneous outcrops and their subsurface extensions.
   b. *with no shallow magnetic sources*. Exposed igneous rocks are nonmagnetic. This interpretation is discussed more fully under Interpretations.
3. Sedimentary rocks older than 17 Ma, metamorphic rocks, and pre-Mesozoic igneous rocks
   a. *with shallow magnetic sources*. Either these older rocks are magnetic, or they are underlain by younger magnetic intrusive or volcanic units. This interpretation is discussed more fully under Interpretations.
   b. *with no shallow magnetic sources*. These older rocks and related substrate are nonmagnetic.

Subcategories 1b and 3b were lumped together, and the resulting five subcategories are shown on plate 3-1.

Limitations

NURE magnetic data are suitable for analysis as individual profiles, but the low altitude relative to the wide spacing of flightlines precludes two-dimensional processing, such as gridding and contouring, in many parts of Nevada. It is relatively straightforward to locate shallow magnetic sources along individual profiles, but connecting shallow-source regions across the gaps between profiles is a much more subjective process. Simplicity was the guiding principle in construction of plate 3-1; boundaries were sketched as smoothly as possible while maintaining consistency from profile to profile. It should be recognized that the interpretations of plate 3-1 are most reliable along flightlines and less reliable in the intervening spaces. Moreover, NURE magnetic profiles often include significant errors. Navigational errors are apparent in some locations, and high-frequency noise, probably caused by the magnetic field of the aircraft itself, is sometimes prevalent. Individual profiles were examined carefully with respect to local geology to distinguish "anomalies" caused by errors from anomalies caused by crustal magnetic sources, and these artifacts were not included in the interpretation.

The distinction between a "magnetic" and "nonmagnetic" region is also subjective. Indeed, no material is completely nonmagnetic. In making this distinction, the wavelengths of anomalies were considered more important than amplitudes. Very magnetic units, like Tertiary basaltic flows, were treated the same as very weakly magnetic units, such as certain Jurassic plutons; consequently the two outcrops are identically classified on plate 3-1.

The interpretation described by plate 3-1 faced geologic limitations as well. Plate 3-1 shows the complex geologic map of Stewart and Carlson (1978) lumped into four lithologic categories. Choosing the appropriate category was straightforward for most units of the geology map, but a few units presented problems. Volcanic material deposited in sedimentary environments, for example, could be classified as either igneous or sedimentary. On plate 3-1, "igneous rocks" includes all rocks exposed as flows and as welded and nonwelded ash-flow tuffs, but excludes tuffaceous sedimentary rocks. Similarly, we have categorized the Koipato Group as volcanic, even though it is composed partly of clastic rocks and fanglomerate deposits (Stewart, 1980). Moreover, the geologic map of Stewart and Carlson (1978) is generalized in some areas and out of date in other areas.

INTERPRETATIONS

Magnetic Rocks beneath Sedimentary Cover

Table 3-1 shows the spatial coverage of the five classifications on plate 3-1. It indicates that 53% of Nevada has magnetic sources within 1 km of the topographic surface. Forty percent of those shallow magnetic sources are covered by sedimentary deposits younger than 17 Ma, an area greater than 61,000 km^2. These shallowly buried rocks are most

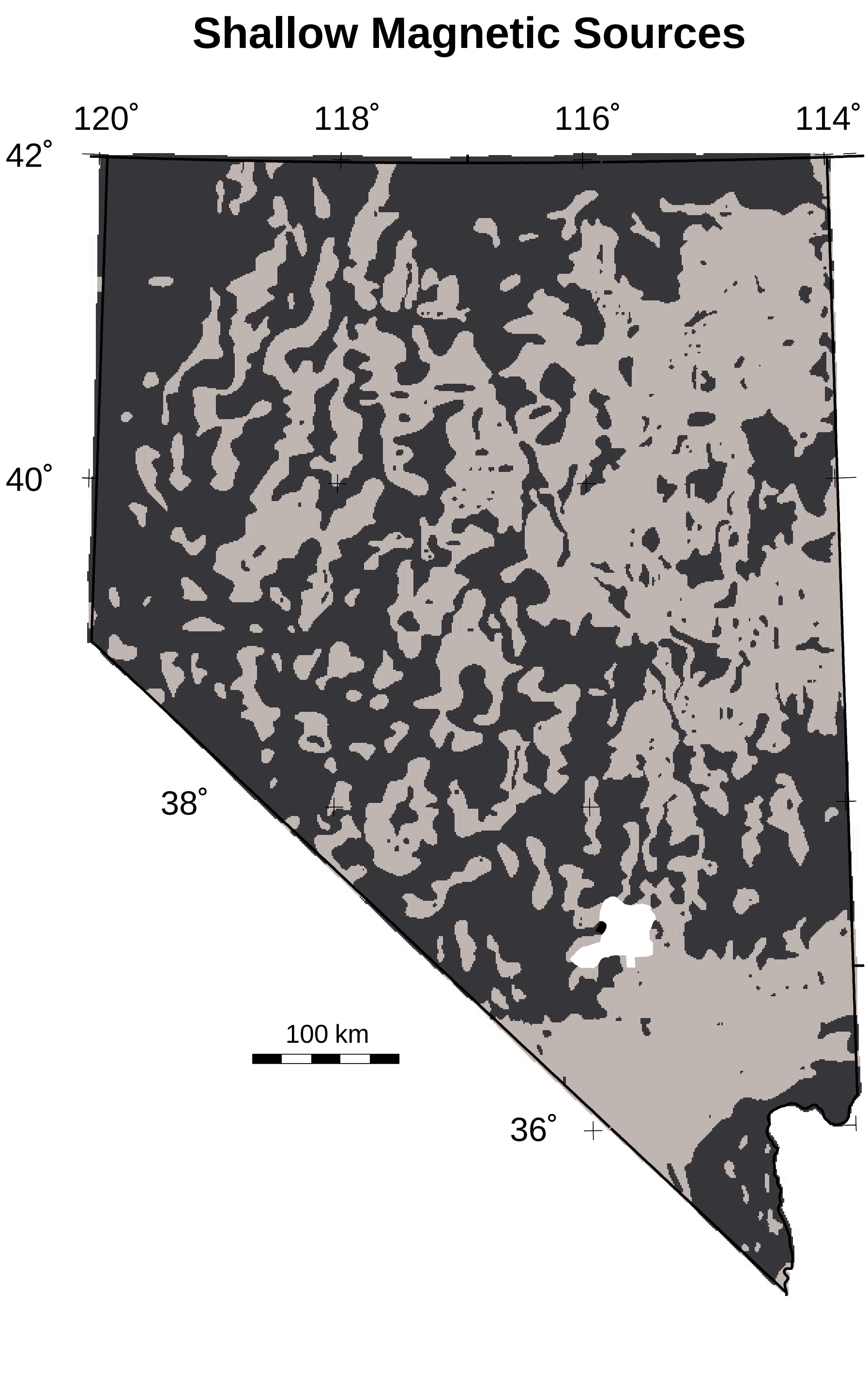

Figure 3-3. Location of shallow magnetic sources in Nevada as interpreted from NURE magnetic profiles. Areas with magnetic sources within 1 km of the topographic surface are shown in black; areas without magnetic sources within 1 km of the surface are shown in gray. Anomalies caused by deep sources evident on aeromagnetic maps (fig 3-2) will not appear on this map. Likewise, some shallow sources shown on this map may not be obvious on aeromagnetic compilations (fig. 3-2). Blank area indicates insufficient data to make a reliable interpretation.

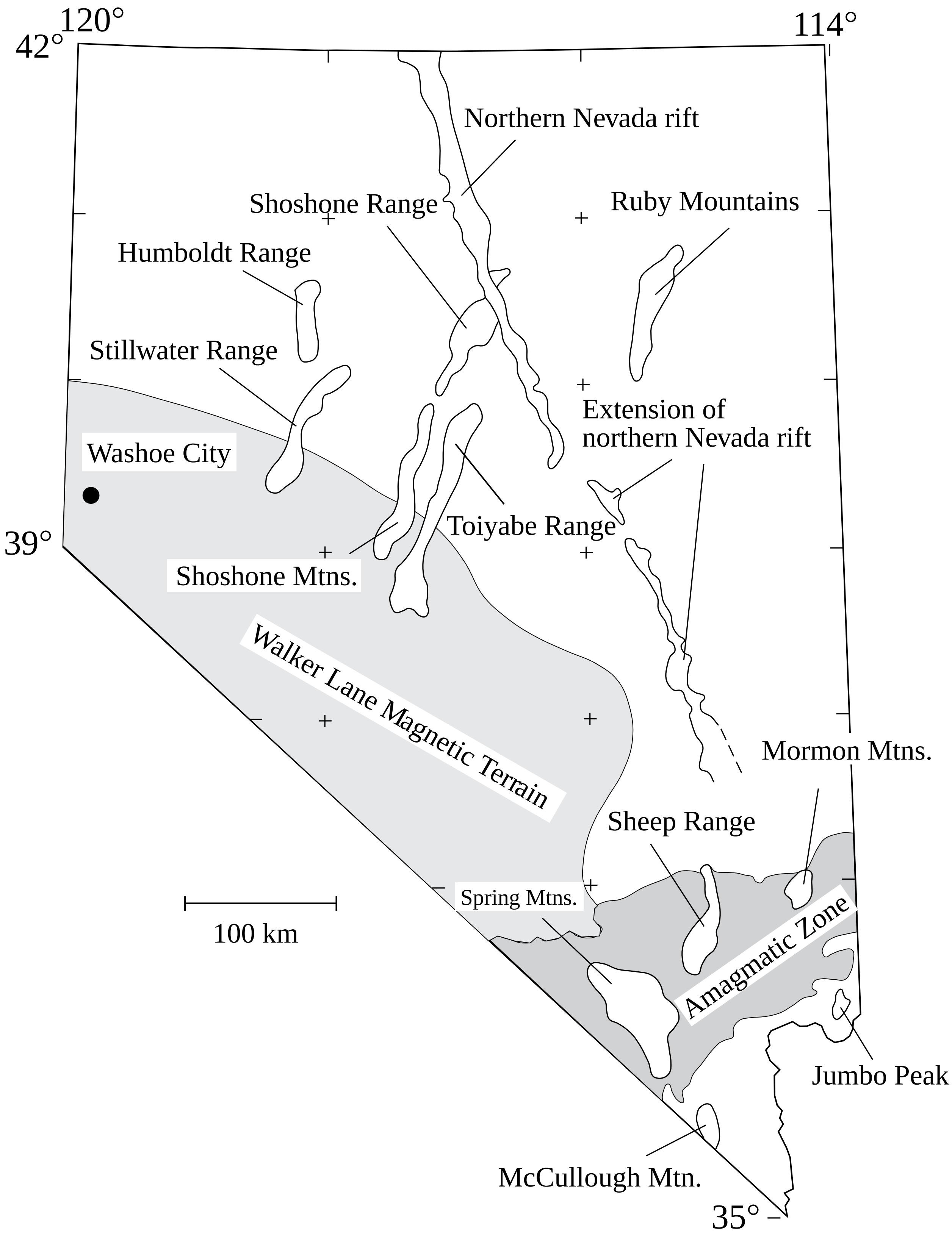

Figure 3-4. Location map of physiographic and magnetic features discussed in the text.

likely igneous; of the shallow-source regions not covered by young deposits, igneous outcrops are 5.4 times more abundant than all other rock types. It seems reasonable, therefore, that volcanic and intrusive rocks are the dominant magnetic sources beneath the young deposits. This conclusion is of interest to mineral exploration insofar as igneous rocks may be associated with mineralization; it indicates a vast potential target area at relatively shallow, accessible depths.

Table 3-1. Areal extent and relative abundance of the six categories shown on plate 3-1.

Category	Area, km^2	Percent
Sedimentary rocks younger than 17 Ma underlain by shallow magnetic sources	61,071	21
Sedimentary rocks older than 17 Ma, metamorphic rocks, and pre-Mesozoic igneous rocks associated with shallow magnetic sources	12,927	5
Sedimentary, metamorphic, and pre-Mesozoic igneous rocks with no shallow magnetic sources	124,336	44
Magnetic Mesozoic and Cenozoic igneous rocks	77,140	27
Nonmagnetic Mesozoic and Cenozoic igneous rocks	7,476	3
Water	537	<<1

The distribution of shallow magnetic sources in Nevada is far from uniform. For example, the roughly east-west zone between lat 36°N and lat 37°N (figs. 3-3 and 3-4) is characterized by virtually no magnetic sources within 1 km of the surface. As shown by geologic mapping (Stewart and Carlson, 1978), igneous rocks are essentially nonexistent in this region. This part of Nevada apparently was unaffected by the widespread magmatism that occurred in surrounding areas prior to 17 Ma. The amagmatic zone also corresponds approximately to a region of anomalously high basement gravity (chapter 2). The increase in basement gravity from north to south at about lat 37°N apparently indicates the southern extent of silicic intrusions within the midcrust, presumably the intrusive counterparts of the volcanic rocks older than 17 Ma north of the amagmatic zone (chapter 2).

Aeromagnetic maps, such as figure 3-2, show only a subdued pattern of magnetic anomalies in the amagmatic zone, suggesting that the zone continues to significant depths. Several notable exceptions may exist, however, such as the sources of anomalies located beneath the Spring Mountains (figs. 3-2 and 3-4, lat 36°15'N, long 115°30'W) and the Mormon Mountains (figs. 3-2 and 3-4, lat 37°00'N, long 114°30'W). Blank (1988) interpreted these anomalies to be caused by topographic relief on a magnetic basement and by Tertiary magnetic plutons. In any case, the magnetic sources lie deeper than about 4 km (Blank, 1988), consistent with our interpretation that virtually no significant magnetic sources lie at shallow depth in the amagmatic zone.

A narrow, linear magnetic anomaly with north-northwest trend is apparent in figure 3-2 and other aeromagnetic surveys of north-central Nevada. It extends from lat 42°N, long 117°15'W to about lat 39°15'N, long 116°W (fig. 3-4). The association of this anomaly with basaltic and andesitic rocks (Mabey, 1966) dated at 15-17 Ma (McKee and Noble, 1986) suggests that the anomaly is caused by a rift zone, the northern Nevada rift, active during the middle Miocene (Stewart and others, 1975; Zoback and Thompson, 1978; Zoback and others, 1994). Aeromagnetic compilations like figure 3-2 show that the northern Nevada rift extends south only to about lat 39°15'N, but figure 3-3 and plate 3-1 suggest that the rift extends farther south approximately on strike to at least lat 38°N, a distance of nearly 500 km. As shown by plate 3-1, magnetic rocks of the rift are unexposed along most of its length, but these rocks lie at shallow (<1 km) depth. Three volcanic-hosted epithermal deposits (Mule Canyon, Fire Creek, and Buckhorn) are associated with volcanic rocks of the northern Nevada rift (Seedorff, 1991), and by analogy the entire narrow feature, from the northern border of Nevada to the amagmatic zone, may be a target for hot-spring gold and mercury deposits.

The Walker Lane belt of southwestern Nevada (Albers, 1967; Stewart and others, 1968; Stewart, 1988) is represented in aeromagnetic compilations (fig. 3-2) by arcuate, northwesterly trending anomalies generally parallel to the Walker Lane, but the width of this magnetic terrane (fig. 3-4) is considerably wider than the belt described by Albers (1967) and Stewart and others (1968), extending in some places over 150 km north-northeast of the Walker Lane (Blakely, 1988). The Walker Lane belt has abundant shallow magnetic sources (fig. 3-3 and plate 3-1), many of them lying beneath sedimentary deposits younger than 17 Ma. Cox and others (1991) noted that all of the volcanic-hosted epithermal deposits in southwestern Nevada are located within the Walker Lane magnetic terrane, whereas pluton-related deposits and most sediment-hosted gold deposits are absent from this magnetic zone. Covered areas within the Walker Lane magnetic terrane presumably have similar potential for volcanic-hosted epithermal deposits.

Magnetic and Nonmagnetic Igneous Rocks

Most volcanic and intrusive rocks of Nevada are sufficiently magnetic to be detected by low-altitude aeromagnetic surveys. Indeed, the analysis shown on plate 3-1 indicates that about 10% of exposed igneous rocks are insufficiently magnetic to be detected at the altitude of NURE profiles. Nonmagnetic igneous rocks can be explained in several ways.

First, igneous outcrops may be relatively nonmagnetic because they are particularly silicic in composition or because iron is contained in essentially nonmagnetic ilmenite rather than magnetite. The Ruby Mountains (fig. 3-4) are the most apparent examples on plate 3-1. As summarized by Stewart (1980), the Ruby Mountains area is underlain by a metamorphic core complex consisting of a Mesozoic igneous complex intruding metamorphosed strata of latest

Precambrian and Paleozoic age. A long-wavelength anomaly overlies the Ruby Mountains (fig. 3-2), and the broad gradients of this anomaly indicate a deep-seated source (Blakely, 1988). Grauch and others (1988) suggested that the anomaly is caused by buried plutonic rocks, but this is no doubt an oversimplification (chapter 7). The analysis of NURE profiles indicates that the shallow parts of the core complex are essentially nonmagnetic. The Tertiary granitic intrusion that bounds the core complex to the south is also nonmagnetic. Exposures of granitic rocks in this area contain very low percentages of magnetic minerals, apparently too low to produce aeromagnetic anomalies (R. Kistler, oral commun., 1991). Similarly, some of the nonmagnetic regions on plate 3-1 are associated with rhyolitic domes and are insufficiently magnetic to produce aeromagnetic anomalies. The nonmagnetic regions in the southern Shoshone Mountains (fig. 3-4, plate 3-1, lat 39°10’ N, long 117°30’ W), for example, may reflect ash flow tuffs that are too silicic in composition to be detected at the altitude of NURE profiles (E. H. McKee, oral commun., 1991).

Second, igneous rocks may be less magnetic because of hydrothermal alteration of magnetic minerals. Nonmagnetic ash flow tuffs exposed in the southern Shoshone Range (fig. 3-4, plate 3-1, lat 40°10’N, long 117°00’W) and in the Toiyabe Range (fig. 3-4, plate 3-1, 39°05’ N, long 117°18’ W) are extensively altered (E. H. McKee, oral commun., 1991) so that magnetite may be significantly depleted in these areas. The small nonmagnetic region (plate 3-1, lat 39°50’N, long 118°5’W) along the east flank of the Stillwater Range (fig. 3-4) is less than 3 km from Dixie Hot Springs, a known geothermal resource. These nonmagnetic rocks are part of a gabbroic complex of Jurassic age (Stewart and Carlson, 1978) that may be altered; similar rocks in the Stillwater Range farther from the hot springs are magnetic. Similarly, the small nonmagnetic region (plate 3-1, lat 39°15’N, long 119°50’W) near Washoe City (fig. 3-4) is approximately 8 km southwest of Steamboat Springs, another known geothermal area. These regions may be nonmagnetic because their magnetic minerals have been hydrothermally altered due to their proximity to active geothermal systems.

Exposed Sedimentary and Metamorphic Rocks Associated with Magnetic Sources

As a general rule, most sedimentary and metamorphic rocks are relatively nonmagnetic compared to igneous rocks. This is demonstrated by plate 3-1, which shows that 84% of all magnetic regions not covered by sedimentary deposits younger than 17 Ma are igneous. Much of the remaining area (16%) may be magnetic due to the presence of igneous rocks at shallow depth.

Many tuffaceous sedimentary rocks of Tertiary age in northwestern Nevada are associated with shallow magnetic sources. Although these deposits may be the direct sources of the anomalies, these sediments often overlie basaltic and andesitic flows, and these underlying volcanic rocks may contribute to the low-altitude magnetic anomalies.

The Humboldt Range (fig. 3-4, plate 3-1, lat 40°30’ N, long 118°10’ W) is shown on plate 3-1 as being associated with shallow magnetic sources. The Humboldt Range is underlain by Jurassic and Triassic volcanic and sedimentary rocks, primarily Triassic rocks of the Koipato Group (Stewart and Carlson, 1978). The Koipato Group consists largely of volcanic rocks and coeval leocogranite and rhyolite porphyry. Although described as altered, these Mesozoic volcanic rocks may be sufficiently magnetic near the surface to cause magnetic anomalies at NURE altitudes. This conclusion is supported by other exposures of the Koipato Group that appear magnetic, such as in the East Range 20 km northeast of the Humboldt Range. Alternatively, the Humboldt Range may be intruded by plutonic rocks. A magnetic granitic pluton of Cretaceous age crops out along the western flank of the Humboldt Range (Stewart and Carlson, 1978) and may be more widespread at depth beneath the range, as proposed by Grauch and others (1988).

Precambrian granitic and metamorphic rocks in southernmost Nevada are identified on plate 3-1 as being associated with shallow magnetic sources. Notable examples include outcrops of Precambrian metamorphic rocks in the areas of McCullough Mountain (fig. 3-4, plate 3-1, lat 35°35’ N, long 115°11’ W) and Jumbo Peak (fig. 3-4, plate 3-1, lat 36°13’ N, long 114°11’ W). Blank and Kucks (1989, 1990) interpreted long-wavelength magnetic anomalies in southern Nevada as due in part to a crystalline basement, presumably Proterozoic in age, and Precambrian outcrops are probably causing many of the magnetic anomalies in NURE profiles from southern Nevada. However, Greene and others (1989) concluded that magnetic anomalies 20 km south of Lake Mead, although located over Precambrian exposures, are actually caused by Tertiary intrusions located at shallow depth beneath the Precambrian rocks. Granitic rocks of Tertiary age are abundant in this part of Nevada (Larsen and Smith, 1990), and similar rocks are also candidates for these shallow-depth anomalies.

CONCLUSIONS

Plate 3-1 is of necessity a regional-scale interpretation. It is based on a 1:500,000-scale geologic compilation and on magnetic profiles generally spaced 5 km apart. Nevertheless, it presents the first attempt at a statewide interpretation of shallow magnetic sources. It is hoped that the regional picture provided by this map will encourage closer inspection of key areas for purposes of tectonic, rock magnetic, and mineral resource investigations. For example, this study indicates that 21% of Nevada consists of sedimentary deposits younger than 17 Ma that conceal magnetic rocks less than 1 km deep. These magnetic rocks are probably volcanic or intrusive in nature and thus comprise a vast region of Nevada with the potential for volcanic- or intrusive-related mineralization at exploration depths.

ACKNOWLEDGMENTS

We are grateful for many discussions with other authors of this report, especially Robert Jachens, Dennis Cox, Edwin McKee, Donald Singer, V.J.S. Grauch, and Steve Ludington. The text also benefitted from reviews by V.J.S. Grauch and H.R. Blank.

REFERENCES

Albers, J.P., 1967, Belt of sigmoidal bending and right-lateral faulting in the western Great Basin: Geological Society of America Bulletin, v. 78, p. 143-156.

Blakely, R.J., 1988, Curie temperature isotherm analysis and tectonic implications of aeromagnetic data from Nevada: Journal of Geophysical Research, v. 93, p. 11,817-11,832.

Blakely, R.J., and Hassanzadeh, Siamak, 1981, Estimation of depth to magnetic source using maximum entropy power spectra, *in* Crustal formation and Andean convergence: Geological Society of America Memoir 154, p. 667-682.

Blakely, R.J., and Jachens, R.W., 1991, Regional study of mineral resources in Nevada: insights from three-dimensional analysis of gravity and magnetic anomalies: Geological Society of America Bulletin, v. 103, p. 795-803.

Blank, H.R., 1988, Basement structure in the Las Vegas region from potential-field data [abs.]: Abstracts with Programs, 84th Annual Meeting, Cordilleran Section, Geological Society of America, v. 20, p. 144.

Blank, H.R., and Kucks, R.P., 1989, Preliminary aeromagnetic, gravity, and generalized geologic maps of the USGS Basin and Range°Colorado Plateau transition zone study area in southwestern Utah, southeastern Nevada, and northwestern Arizona (the "BARCO" project): U.S. Geological Survey Open-File Report 89-432, 16 p. text, 3 plates, 1:250,000 scale.

Blank, H.R., and Kucks, R.P., 1990, Regional gravity and aeromagnetic anomalies in southwestern Utah, southeastern Nevada, and northwestern Arizona: Geological Society of America Cordilleran Section Annual Meeting, Abstracts with Programs, Tucson, Arizona, v. 22, p. 9.

Cox, D.P., Ludington, Steve, Sherlock, M.G., Singer, D.A., Berger, B.R., and Tingley, J.V., 1991, Mineralization patterns in time and space in the Great Basin of Nevada, *in* Raines, G.L., Lisle, R.E., Schafer, R.W., and Wilkinson, W.H., editors: Geology and Ore Deposits of the Great Basin Proceedings, v. 1, p. 193-198, Geological Society of Nevada, Reno.

Grauch, V.J.S., Blakely, R.J., Blank, H.R., Oliver, H.W., Plouff, Donald, and Ponce, D.A., 1988, Geophysical delineation of granitic plutons in Nevada: U.S. Geological Survey Open-File Report 88-11, 7 p., 2 plates, scale 1:1,000,000.

Greene, R.C., Eppinger, R.G., Hassemer, J.R., Jachens, R.C., Lawson, W.A., and Ryan, G.S., 1989, Mineral resources of the Mount Wilson Wilderness Study Area, Mohave County, Arizona: U.S. Geological Survey Bulletin 1737, 18 p.

Hildenbrand, T.G., and Kucks, R.P., 1988, Filtered magnetic anomaly maps of Nevada: Nevada Bureau of Mines and Geology Map 93B, scale 1:1,000,000 (4 sheets) and 1:2,000,000 (1 sheet).

Kucks, R.P., and Hildenbrand, T.G., 1987, Description of magnetic tape containing Nevada state magnetic anomaly data: U.S. Geological Survey EROS Data Center, Sioux Falls, Report D87-0270, tape and documentation.

Larsen, L.L., and Smith, E.I., 1990, Mafic enclaves in the Wilson Ridge pluton, northwestern Arizona: implications for the generation of a calc-alkaline intermediate pluton in an extensional environment: Journal of Geophysical Research, v. 95, p. 176,693-17,716.

Mabey, D.R., 1966, Regional gravity and magnetic anomalies in part of Eureka County, Nevada, *in* Mining Geophysics, v. 1, p. 77-83: Society of Exploration Geophysicists, Tulsa, Oklahoma.

McKee, E.H., and Noble, D.C., 1986, Tectonic and magmatic development of the Great Basin of western United States during late Cenozoic time: Modern Geology, v. 10, p. 39-49.

Peters, L.J., 1949, The direct approach to magnetic interpretation and its practical applications: Geophysics, v. 14, p. 290-320.

Seedorff, Eric, 1991, Magmatism, extension, and ore deposits of Eocene to Holocene age in the Great Basin—mutual effects and preliminary proposed genetic relationships, *in* Raines, G.L., Lisle, R.E., Schafer, R.W., and Wilkinson, W.H., Geology and Ore Deposits of the Great Basin, Symposium Proceedings: Geological Society of Nevada, Reno, Nevada, p. 133-178.

Stewart, J.H., 1980, Geology of Nevada, a discussion to accompany the Geologic Map of Nevada: Nevada Bureau of Mines and Geology Special Publication 4, 136 p.

Stewart, J.H., 1988, Tectonics of the Walker Lane belt, western Great Basin—Mesozoic and Cenozoic deformation in a zone of shear, *in* Metamorphism and crustal evolution of the western United States, Rubey volume VII: Englewood Cliffs, New Jersey, Prentice Hall, p. 683-713.

Stewart, J.H., Albers, J.P., and Poole, F.G., 1968, Summary of regional evidence for right-lateral displacement in the western Great Basin: Geological Society of America Bulletin, v. 79, p. 1407-1413.

Stewart, J.H., and Carlson, J.E., 1978, Geologic Map of Nevada: U.S. Geological Survey, scale 1:500,000.

Stewart, J.H., Walker, G.W., and Kleinhampl, F.J., 1975, Oregon-Nevada lineament: Geology, v. 3, p. 265-268.

Turner, R.M., and Bawiec, W.J., 1991, Digital geologic coverage of Nevada, 1978: U.S. Geological Survey Digital Data Series DDS-2.

Zoback, M.L., McKee, E.H., Blakely, R.J., and Thompson, G.A., 1994, The northern Nevada rift: Regional tectono-magmatic relations and Miocene stress direction: Geological Society of America Bulletin, v. 106, p. 37-382.

Zoback, M.L., and Thompson, G.A., 1978, Basin and Range rifting in northern Nevada: Clues from a mid-Miocene rift and its subsequent offsets: Geology, v. 6, p. 111-116.

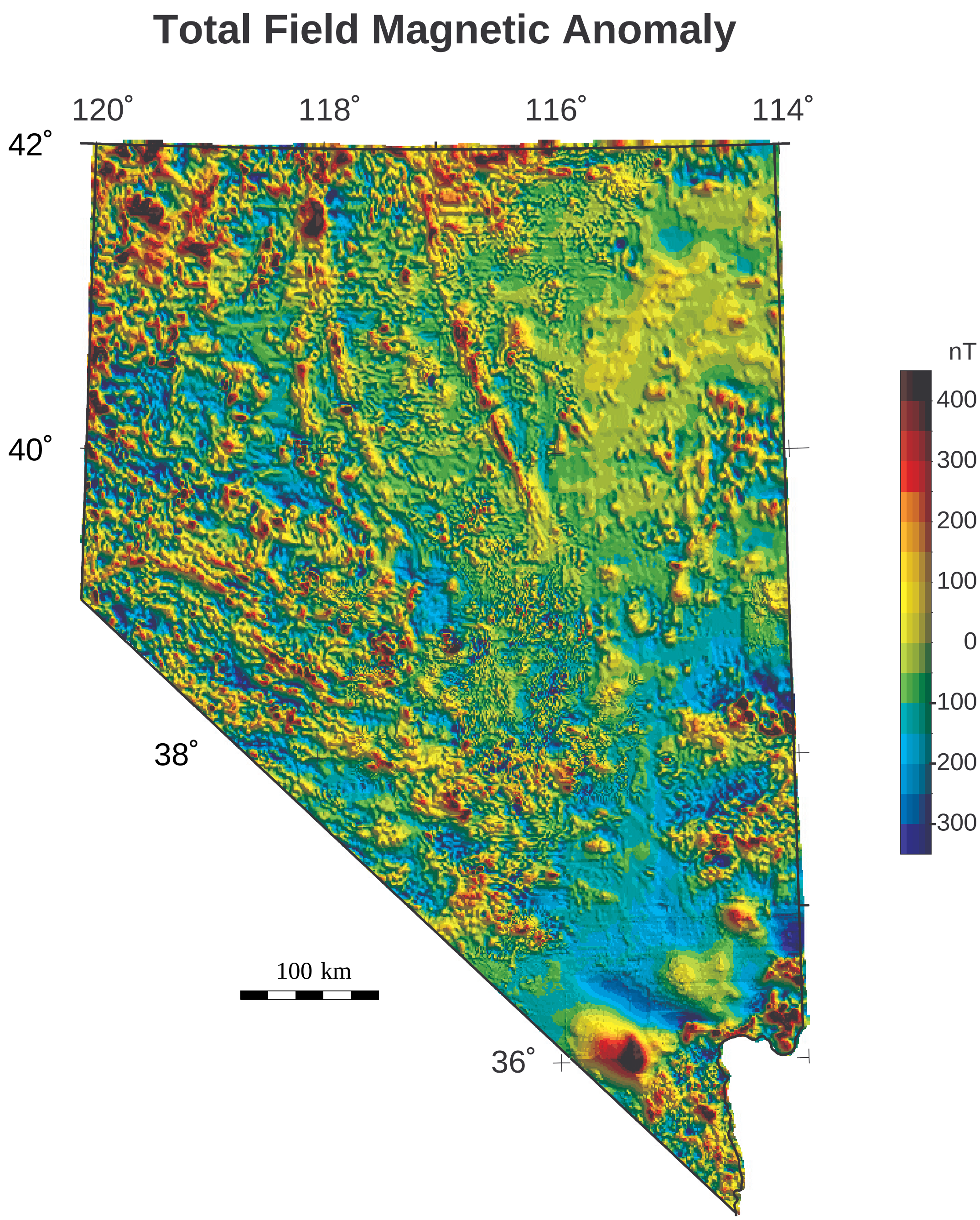

Figure 3-2. Aeromagnetic anomaly map of Nevada. Total field anomalies from Nevada analytically continued to 305 m above terrain. Color, shaded-relief presentation with illumination from northeast and color-contour interval 50 nT. From the compilation of kucks and Hildenbrand (1987).