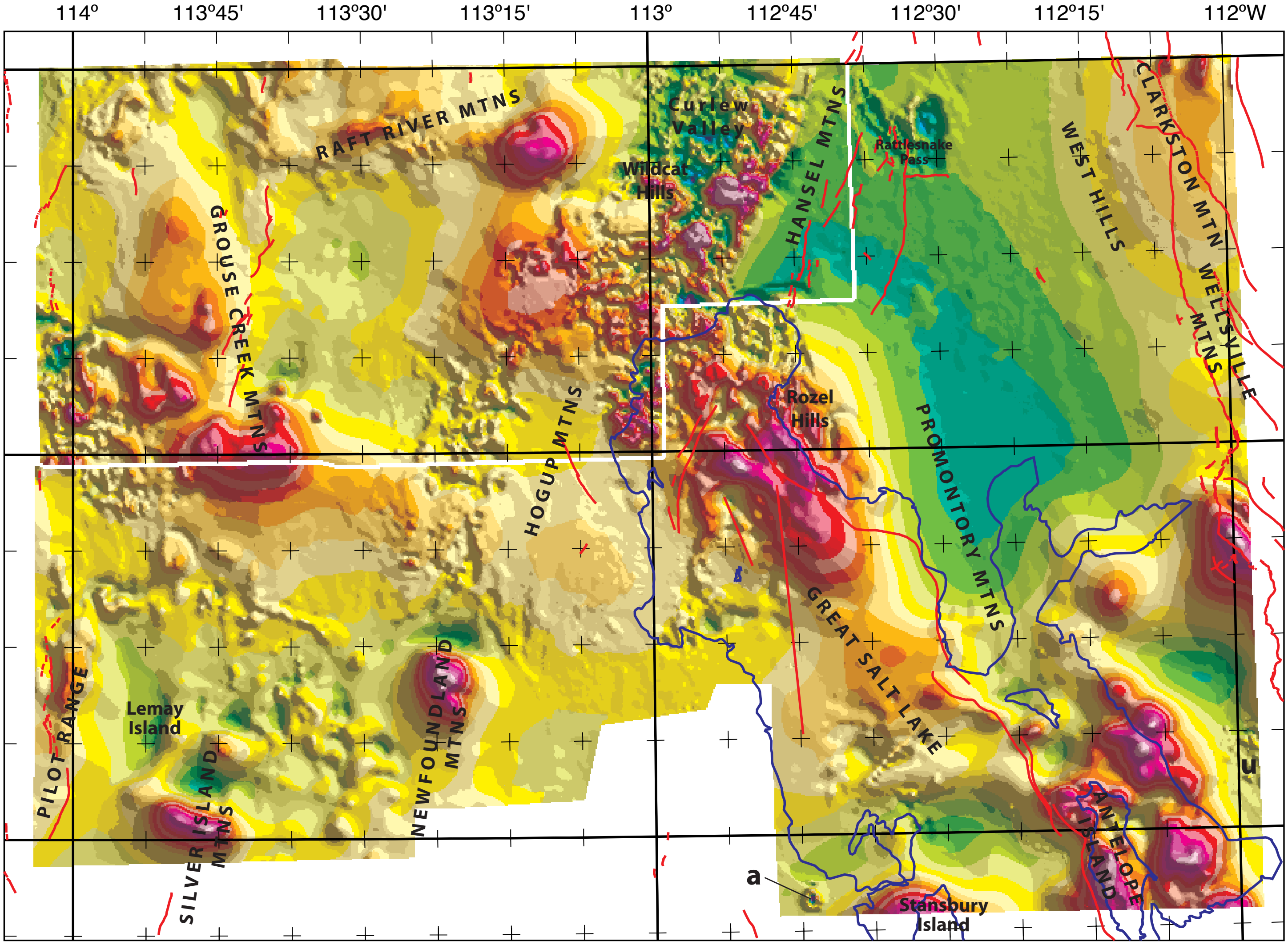
AEROMAGNETIC MAP OF NORTHWEST UTAH AND ADJACENT PARTS OF NEVADA AND IDAHO

by Victoria E. Langenheim



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CONTENTS

FIGURES

TABLE

PLATE

DATA FILES

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AEROMAGNETIC MAP OF NORTHWEST UTAH AND ADJACENT PARTS OF NEVADA AND IDAHO

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INTRODUCTION

Two aeromagnetic surveys were flown to promote further understanding of the geology and structure in northwest Utah and adjacent parts of Nevada and Idaho by serving as a basis for geophysical interpretations and by supporting geological mapping, water and mineral resource investigations, and other topical studies. Although this area is in general sparsely populated, (except for cities and towns along the Wasatch Front such as Ogden and Brigham City), it encompasses metamorphic core complexes in the Grouse Creek and Raft River Mountains (figure 1) of interest to earth scientists studying Cenozoic extension. The region was shaken in 1909 and 1934 by M6+ earthquakes east of the Hansel Mountains

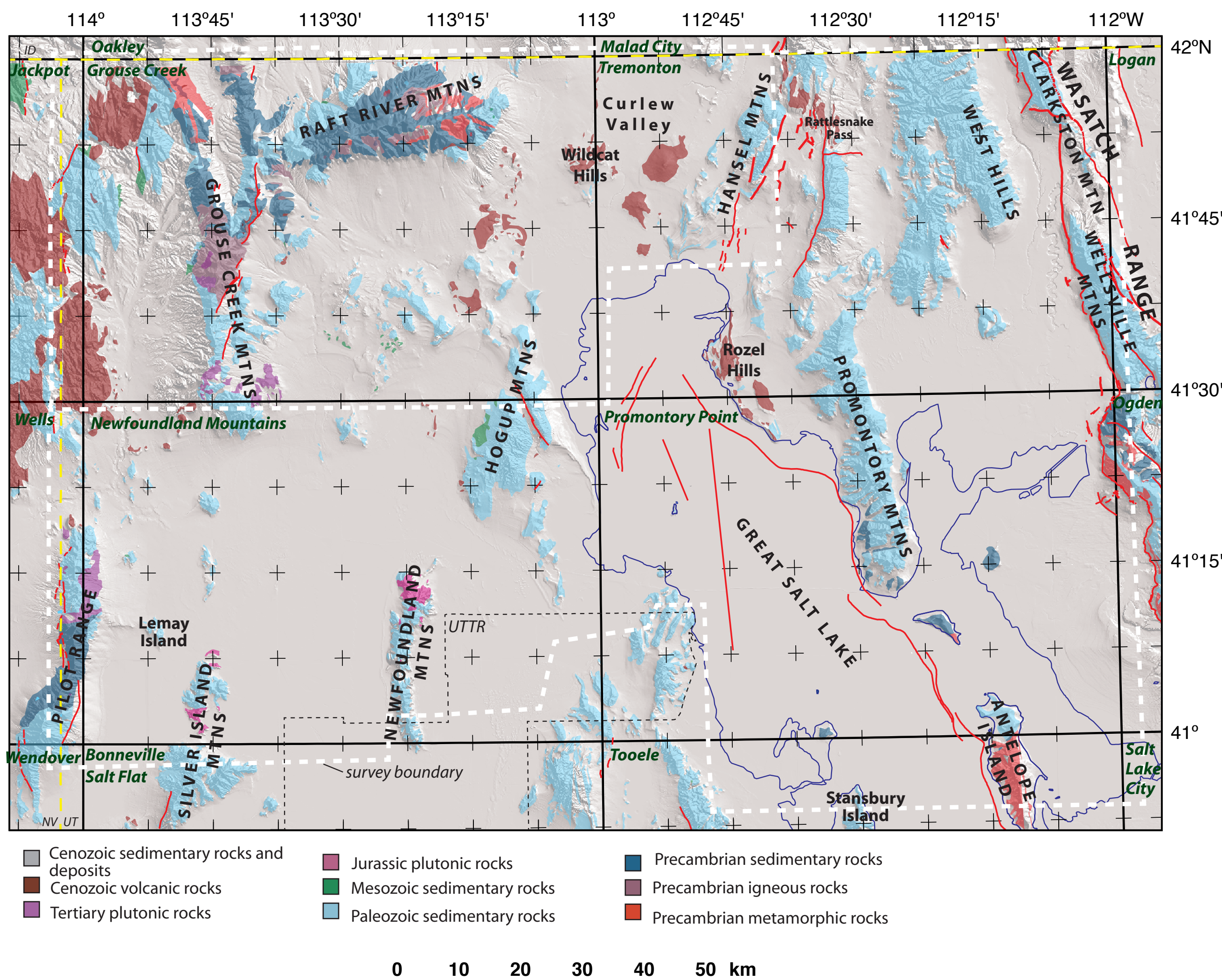

Figure 1. Simplified geologic map. Geology modified from Hintze (1980); red lines, faults from U.S. Geological Survey and Utah Geological Survey (2006). White dashed line, aeromagnetic survey boundary. Dark green italicized text refers to the names of the 1:100,000-scale quadrangles. Yellow dashed lines, state boundaries. UTTR, Utah Test and Training Range.

(Doser, 1989; Arabasz and others, 1994); damage from the 1934 earthquake occurred as far east as Logan, Utah (http://www.seis.utah.edu/lqthreat/nehrp_htm/1934hans/n1934ha1.shtml#urbse). The presence of Quaternary shield volcanoes and bimodal Pleistocene volcanism in Curlew Valley (Miller and others, 1995; Felger and others, 2016) as well as relatively high temperature gradients encountered in the Indian Cove drillhole in the north arm of Great Salt Lake (Blackett and others, 2014) may indicate some potential for geothermal energy development in the area (Miller and others, 1995). The area also hosts four significant mining districts, in the northern Pilot Range, the Goose Creek Mountains in the northwest corner of the map, the southern end of the Promontory Mountains, and the southwest part of the Raft River Mountains, although production notably waned after World War II (Doelling, 1980). Other prospects of interest include those in the southern Grouse Creek Mountains, Silver Island, and the northern Newfoundland Mountains.

Large areas of northwest Utah are covered by young, surficial deposits or by Great Salt Lake or are down-dropped into deep Cenozoic basins, making extrapolation of bedrock geology from widely spaced exposures difficult or tenuous (figure 1). Local spatial variations in the Earth's magnetic field (evident as anomalies on aeromagnetic maps) reflect the distribution of magnetic minerals, primarily magnetite, in the underlying rocks. In many cases the volume content of magnetic minerals can be related to rock type, and abrupt spatial changes in the amount of magnetic minerals commonly mark lithologic or structural boundaries. Magnetic data reflect magnetization variations within the crust and are well suited for mapping the distribution of mafic igneous rocks, although felsic igneous rocks, some mineralized zones, and other rock types also can produce measurable magnetic anomalies. For these reasons, the U.S. Geological Survey (USGS) and Utah Geological Survey (UGS) contracted for the collection of aeromagnetic data in this area.

DATA

The aeromagnetic surveys were flown over the entire Grouse Creek and Tremonton 1:100,000-scale quadrangles, most of the Newfoundland Mountains and Promontory Point 1:100,000-scale quadrangles (except those areas restricted by the military), and small areas of the Bonneville Salt Flat, Tooele, Logan, Ogden, Jackpot, Wells, and Wendover 1:100,000-scale quadrangles, totaling an area of approximately 20,000 square kilometers (7722 mi^2) (white dashed lines in figure 1). Total-field aeromagnetic data were collected along east-west flight lines spaced 800 m (0.5 mi) apart in 2010 and 2011 (table 1). Distance between measurements along a flightline was about 6.5 m. Tie lines were flown north-south 8000 m (5 mi) apart. Although the surveys were flown at a nominal terrain clearance of 305 m (1000 ft), the average height of the aircraft above terrain varied due to safety considerations (figure 2). In areas of low topographic relief, such as Curlew Valley, Great Salt Lake, and the area between the Newfoundland Mountains and the Silver Island Mountains, the plane was less than 320 m (1050 ft) above ground and lake (figure 2). In areas of higher relief, the aircraft was as much as 1900 m (6200 ft) above the valley between the Silver Island Mountains and the Pilot Range and as much as 1500 to 1600 m (4900–5250 ft) above the valley floor immediately west of the Wellsville Mountains (figure 2). Note that short-wavelength anomalies, if present, are smoothed and attenuated in these areas.

The aeromagnetic measurements were collected using a cesium vapor magnetometer (Geometrics G-822A) mounted in the tail boom of the aircraft. Measurements were corrected for the effect of the airplane using a tri-axial fluxgate magnetometer. The measurements were adjusted so that the resulting magnetic field shown in the map and in figure 3 is relatively free of artifacts. Data were adjusted for tail sensor lag and diurnal field variations. The base magnetometer used to correct the diurnal field variations was a GEM GSM-19W Overhauser magnetometer located in a magnetically quiet area at the Brigham City airport (41°32'55"N; 112°03'54"W). Further processing included micro-leveling using the tie lines

Table 1. *Aeromagnetic survey specifications.*

Survey name	Date flown	Flight-line spacing	Flight-line direction	Target flight height above average terrain	IGRF removed	Operator
Grouse Creek	04/22–5/19/2010	800 m	east-west	305 m	2010 updated to date of flight	Firefly Aviation
Tremonton	8/15–10/6/2011	800 m	east-west	305 m	2010 updated to date of flight	Firefly Aviation

(See area of survey in figure 2. IGRF, International Geomagnetic Reference Field)

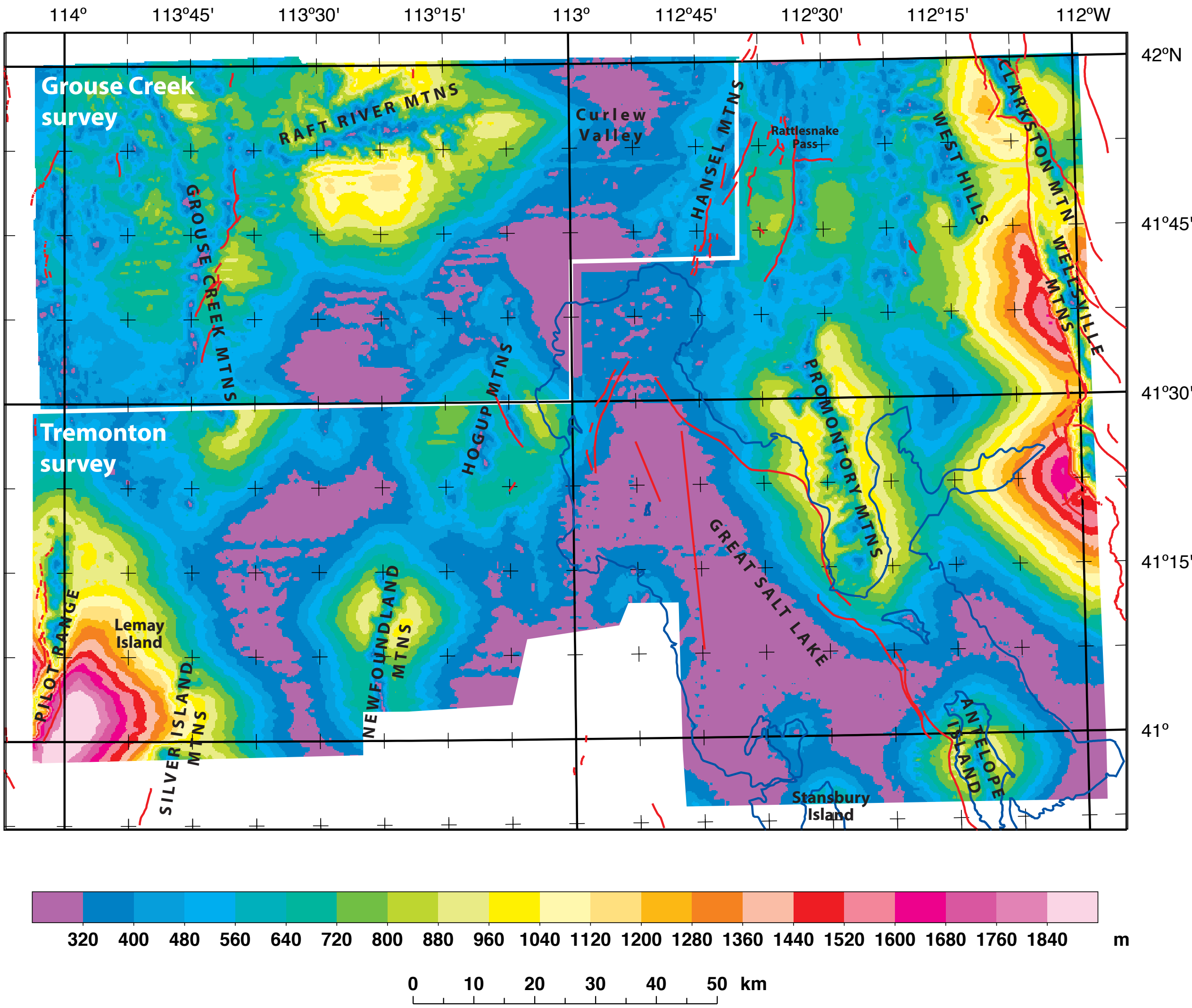

Figure 2. *Map of the height of the magnetic sensor above ground surface measured by radar altimetry. Dark blue line, Great Salt Lake; red lines, faults from U.S. Geological Survey and Utah Geological Survey (2006).*

and correction for the Earth's main magnetic field (International Geomagnetic Reference Field [Langel, 1992] defined in 2010) updated to the time period during which the data were collected (table 1).

The resulting data from the two surveys were transformed to a Universal Transverse Mercator Projection (base latitude 0°, central meridian -114° W) and interpolated to a square grid with a grid interval of 200 m (656 ft) using the principle of minimum curvature (Briggs, 1974). The magnetic base levels of the surveys were then adjusted slightly by subtracting their respective means to bring them onto a common magnetic datum. Accuracy of these survey data is 1 nanotesla (nT) or better.

The new data provide a considerable improvement on pre-existing data (figure 3A), which consisted of profiles flown 5 to 10 km (3–6 mi) apart at a height of only 120 m (400 ft) as part of the National Uranium Resource Evaluation (NURE) (Geodata International, Inc. 1979; EG&G Geometrics, Inc., 1980) or along profiles 10 km (6 mi) apart at a constant barometric elevation of 3350 to 4000 m (11,000–13,000 ft) (Zietz and others, 1976). The latter data set was flown too high over valley areas to measure short-wavelength anomalies associated with near-surface or exposed sources and the NURE surveys were flown too far apart to effectively map the magnetic field between the lines. The new map (plate 1; figure 3B) in particular reveals short-wavelength magnetic anomalies associated with Cenozoic volcanic rocks.

FILTERING AND MAGNETIZATION BOUNDARIES

To help delineate structural trends and gradients expressed in the magnetic fields, a computer algorithm was used to locate the maximum horizontal gradient (Cordell and Grauch, 1985;

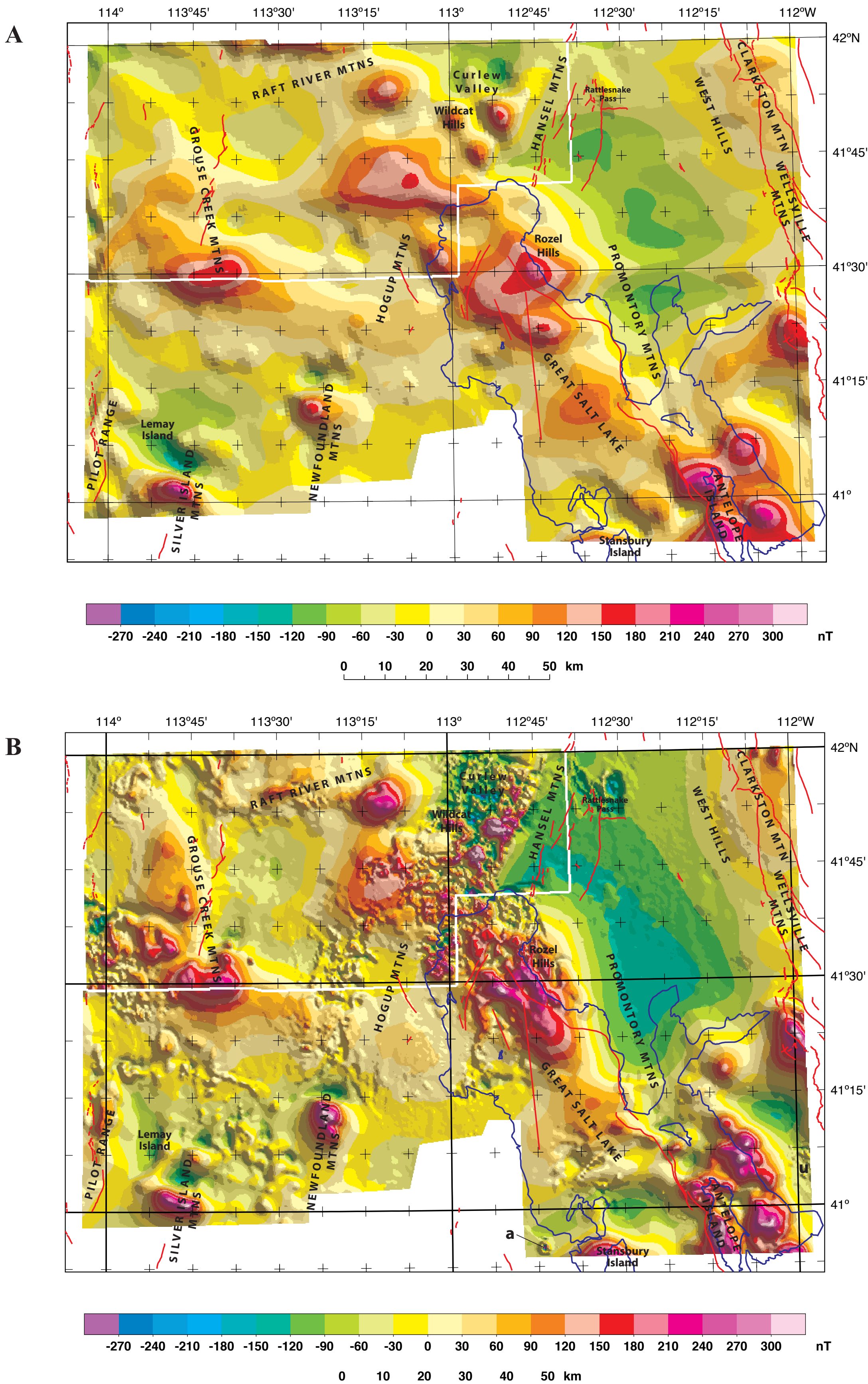

Figure 3. ***(A)*** *Color shaded-relief aeromagnetic data based on previous surveys (North American Magnetic Anomaly Group, 2002).* ***(B)*** *Color shaded-relief aeromagnetic map based on new data. Dark blue line, Great Salt Lake; red lines, faults from U.S. Geological Survey and Utah Geological Survey (2006). "a" denotes anomaly caused by a facility that produces magnesium, and "u" denotes the area marked by short-wavelength, low-amplitude anomalies coincident with urbanization. Data shown in nanoteslas.*

Blakely and Simpson, 1986). Concealed basin faults beneath the valley areas can be mapped using horizontal gradients in the magnetic fields, particularly where Cenozoic volcanic rocks are offset by faults. We calculated magnetization boundaries, shown as red circles on the map, on a filtered version of the magnetic field to isolate anomalies caused by shallow sources (Blakely, 1995). First, the magnetic field was upward-continued 100 m (305 ft) and subtracted from the original magnetic field. This procedure emphasizes those components of the magnetic field that are caused by the shallow parts of the magnetic bodies, which are most closely related to the mapped geology. This residual magnetic field emphasizes more subtle features, such as those shown in figure 4, which may not be readily apparent in the unfiltered aeromagnetic map. Second, the resulting residual aeromagnetic field was mathematically transformed into magnetic potential anomalies (Baranov, 1957); this procedure effectively converts the magnetic field to the equivalent "gravity" field that would be produced if all magnetic material were replaced by proportionately dense material. This procedure also removes the dipolar effect of the Earth's magnetic field and shifts the anomalies over their sources using an inclination and declination of the main magnetic field of 67° and 14°, respectively. The horizontal gradient of the magnetic potential field was then calculated everywhere by numerical differentiation. The locations of locally steepest horizontal gradient (red circles in plate 1) were determined by numerically searching for maxima in the horizontal gradient grid (Blakely and Simpson, 1986). Gradient maxima occur approximately over steeply dipping contacts that separate rocks of contrasting magnetizations. For moderate to steep dips (45° to vertical), the horizontal displacement of a gradient maximum from the top edge of an offset horizontal layer is always less than or equal to the depth to the top of the source (Grauch and Cordell, 1987).

PRELIMINARY RESULTS

Magnetic anomalies are generally caused by magnetite-bearing rocks, which are often igneous. Sedimentary rocks of Proterozoic to Quaternary age are weakly magnetic and are reflected by the smooth, relatively flat magnetic field over areas of extensive sedimentary cover, such as Paleozoic rocks exposed in the West Hills and Hogup, Promontory, and Hansel Mountains. In contrast, many Cenozoic volcanic rocks coincide with prominent, short-wavelength magnetic anomalies; examples include Curlew Valley, the northwest corner of the study area, Rozel Hills, and along the Nevada-Utah border west of the Grouse Creek Mountains (figure 4). These anomalies are enhanced by strong magnetization boundaries that form a characteristic "worm-like" pattern in plate 1 and rumpled magnetic grain in the grayshade residual map (figure 4). Using this pattern as a guide, one can map the extent of magnetic rocks beneath surficial cover. The magnetic data thus predict a significant amount of volcanic rocks that are concealed beneath much of Curlew Valley south to northern Great Salt Lake, as well as west of the Hogup Mountains and north of the Newfoundland Mountains, in southern Grouse Creek Valley, and east of the Hansel Mountains. Concealed volcanic rocks have been corroborated by oil wells that penetrated Pliocene basalt flows, as much as 335 m (1100 ft) thick, beneath northern Great Salt Lake west of the Rozel Hills (Bortz, 1987). Furthermore, magnetic anomalies associated with the volcanic rocks can also provide information on the polarity of the magnetization, and help confirm independently and refine the ages of some of the volcanic units, such as those exposed in the Wildcat Hills (Felger and others, 2016). Positive anomalies (highs) associated with a volcanic unit indicate that the unit erupted during a normal polarity event, while negative anomalies (lows) indicate that the unit erupted during a reversed polarity event. For example, the magnetic lows northwest of Rattlesnake Pass coincide with Miocene basalt that must have been erupted during a time when the magnetic field pointed south; furthermore, the easternmost low is mostly concealed beneath younger sediments. The anomaly pattern is not as complex as those associated with volcanic rocks in Curlew Valley, perhaps reflecting a slightly higher survey altitude, more consistent magnetizations due to age, or simpler stratigraphy. The broad low near Lemay Island could conceivably be related to volcanic rocks, but difficult to isolate the substantial smoothing from the elevation of the sensor in this part of the survey.

Other magnetic anomaly producers include plutons of various ages that range from Jurassic to Tertiary. These anomalies tend to be broader and smoother than those caused by Cenozoic volcanic rocks. A magnetic high at the southern end of the Grouse Creek Mountains coincides with exposures of the Emigrant Pass pluton of Tertiary age (Egger and others, 2003). The high extends beyond the outcrops of the pluton over weakly magnetic Paleozoic sedimentary rocks and could be interpreted as a greater lateral extent of Emigrant Pass granite or possibly as a completely buried unit within the Archean basement. The magnetic high in the northern Pilot Range coincides with exposures of the Tertiary McGinty pluton (Miller and others, 1987). Jurassic plutons, such as those exposed at the northern end of the Newfoundland Mountains and in the Silver Island Mountains, also coincide with prominent magnetic highs (Miller and others, 1990). The prominent lows to the north of these highs reflect the inclination of the Earth's magnetic field, not a separate, negative or reversely polarized body. A large semicircular magnetic high located at the eastern end of the Raft Rivers may also reflect a concealed pluton; the wavelength of the anomaly suggests that the source resides in the footwall of the Raft River detachment fault (Langenheim and others, 2011).

Magnetic highs southeast of Brigham City and on Antelope Island correspond with exposures of gneiss and amphibolite of the Farmington Canyon Complex (Crittenden and Sorensen, 1985; Doelling and others, 1990). Because of its wavelength, the broad magnetic high that extends north-northwest and lies west of the Promontory Mountains likely is caused by units in the crystalline basement and could be related to magnetic rock

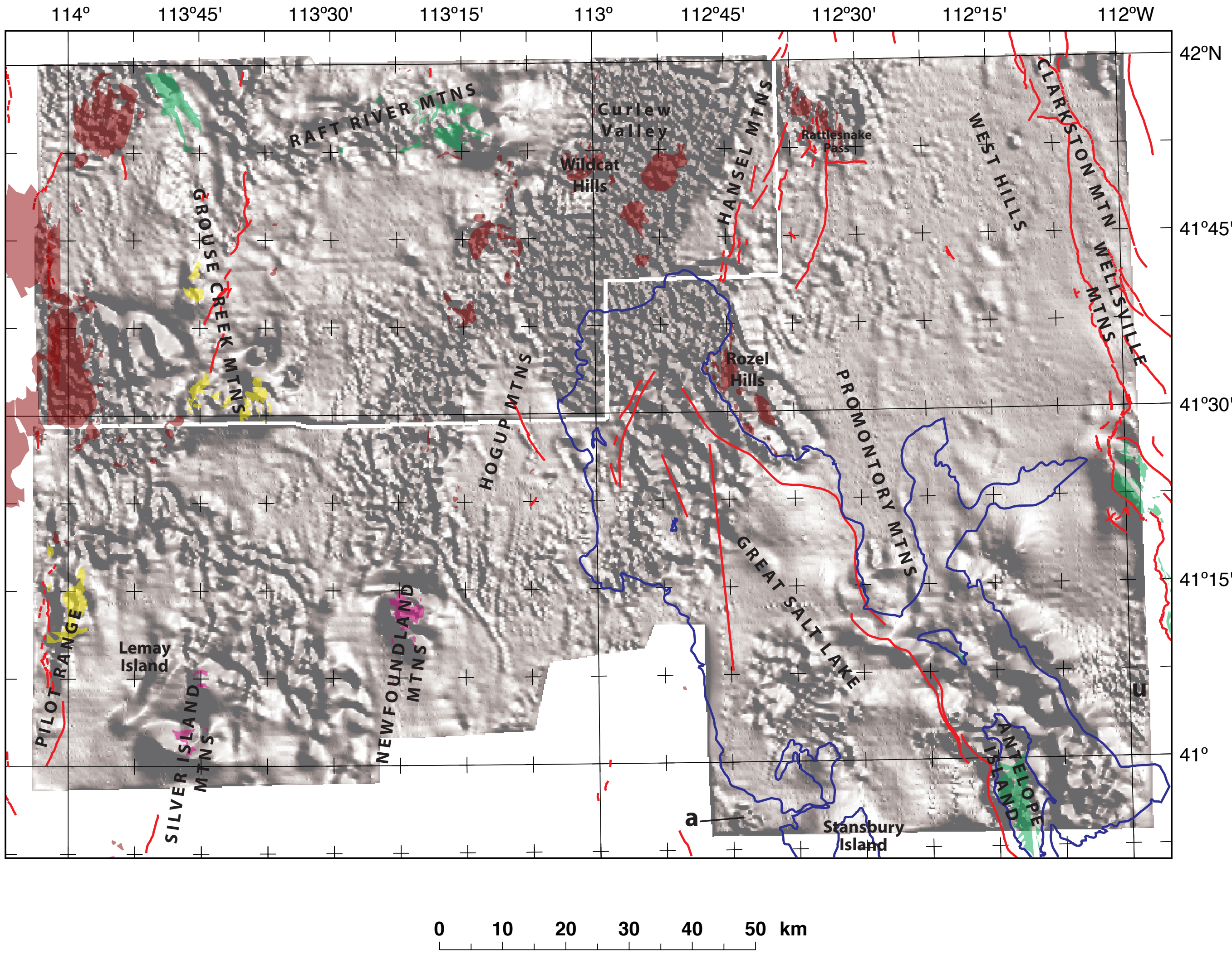

__Figure 4.__ Shaded-relief map of the residual aeromagnetic field. Dark blue line, Great Salt Lake; red lines, faults from U.S. Geological Survey and Utah Geological Survey (2006). Brown polygons, Cenozoic volcanic rocks; yellow polygons, Cenozoic plutons; magenta polygons, Jurassic plutons; green polygons, Precambrian metamorphic rocks. "a" denotes anomaly caused by a facility that produces magnesium, and "u" denotes the area marked by short-wavelength, low-amplitude anomalies coincident with urbanization.

types of the Farmington Canyon Complex. The northern part of another prominent, broad high is located 30 km (19 mi) to the west over Stansbury Island; the exposed rocks are Precambrian quartzite and phyllite in fault contact with a Paleozoic sedimentary sequence (Moore and Sorensen, 1979), weakly magnetic rock types that, in conjunction with the wavelength of the anomaly, indicate that the source is concealed and resides within the crystalline basement. Similarly, the sources of two prominent magnetic highs in the northeast corner of the map is not readily explained by the exposed geology, which consists of Miocene Salt Lake Formation and younger deposits. The apparent southward truncation of the anomalies likely results from the smoothing caused by the increased height of the magnetometer above the ground in this area. The source could be volcanic or intrusive rocks within the Salt Lake Formation or unknown sources in the basement.

Although sedimentary rocks are weakly magnetic (especially when compared to young volcanic rocks), filtering of the magnetic data to enhance those anomalies caused by shallow sources reveals subtle gradients in areas where these rocks are exposed. For example, north- to northwest-trending gradients are present over weakly magnetic Paleozoic sedimentary rocks northwest of the town of Grouse Creek. These gradients are parallel to mapped faults and provide a means to map structural grain elsewhere in the quadrangle. Additional north- to northwest-trending gradients may highlight structural grain east of the Newfoundland Mountains and between the Hansel Mountains and Clarkston Mountain. East-west features in figure 4, such as those east of the Grouse Creek Mountains, likely result from incomplete removal of flight line artifacts.

Because of the generally rural population of this region, anthropogenic artifacts are uncommon. One obvious anthropogenic source is the small, high-amplitude round anomaly located at latitude 40°53'N and longitude 112°45'W ("a" in figures 3B, 4), that coincides with a large facility that produces magnesium. Another exception is the very short-wavelength, relatively small-amplitude anomaly pattern present over the city of Ogden in the southeast corner of the map ("u" in figures 3B, 4).

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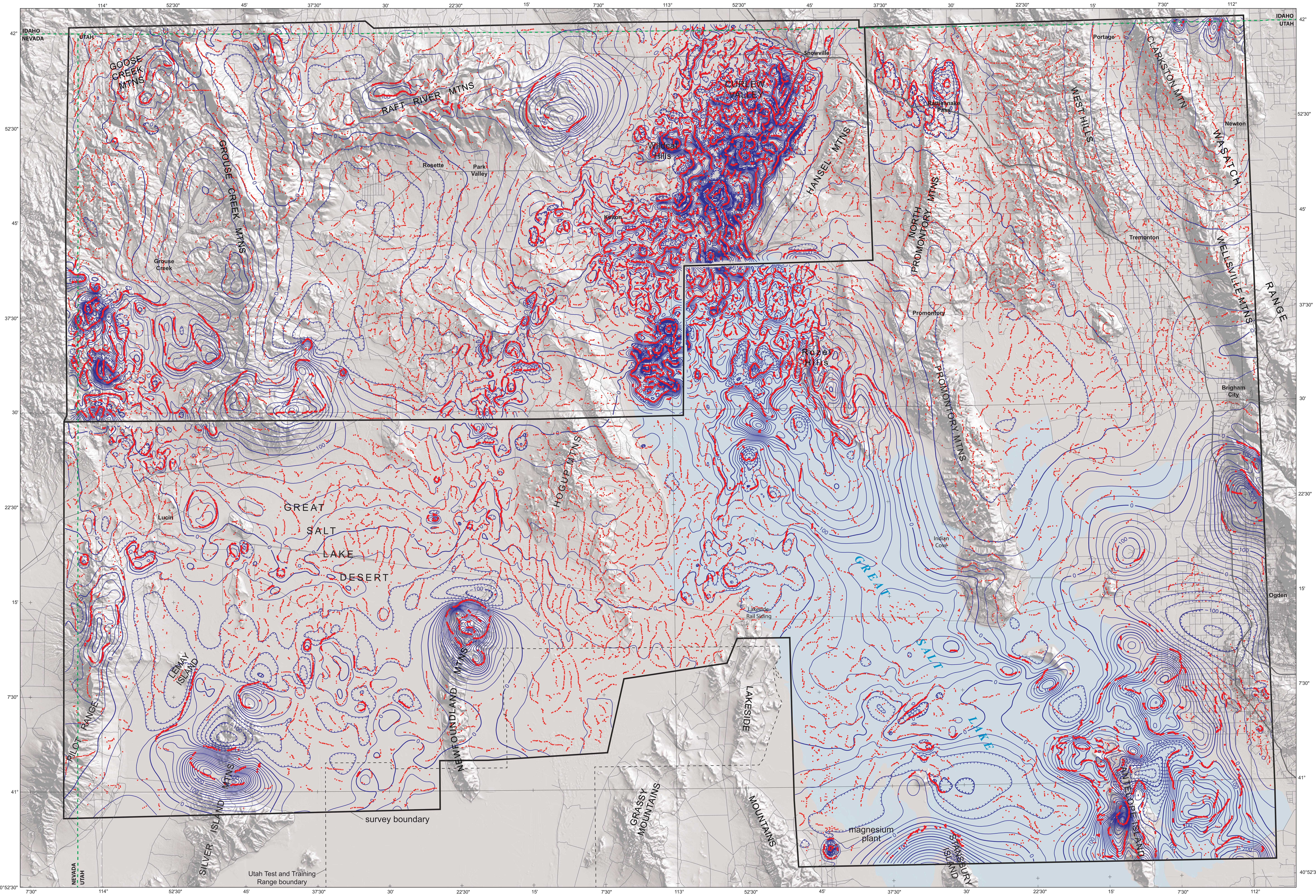

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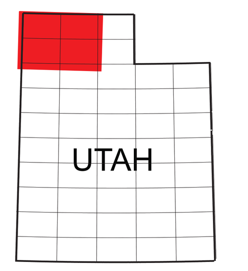

30' x 60' QUADRANGLES INDEX MAP

SCALE 1:200,000

2 0 2 4 6 miles

2 0 2 4 6 Kilometers

APPROXIMATE MEAN DECLINATION, 2016

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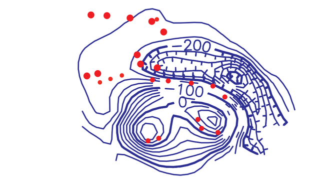
by

Victoria E. Langenheim
U.S. Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025-0046

2016

Base map from 30-m digital elevation data.
Shaded relief derived from digital elevation data.
Road network from USGS national transportation data set.
Projection, Universal Transverse Mercator. 1927 North American Datum.



Contours of total magnetic field intensity relative to the International Geomagnetic Reference Field. Contour interval is 20 nanoteslas. Hachures indicate closed magnetic lows. Red circles indicate locations of maximum horizontal gradient in the filtered residual field that separate regions of different magnetizations (see accompanying text for explanation): larger circles denote gradient amplitudes greater than the mean for the study area and smaller circles denote amplitudes less than the mean (0.025, minimum of 0.001, maximum of 1.17).

Road — Highway — Interstate — State Boundary