U.S. DEPARTMENT OF THE INTERIOR
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INTERPRETATION OF AN AEROMAGNETIC SURVEY OVER PART OF VIRGIN VALLEY, TULE DESERT, AND THE VALLEY SURROUNDING MEADOW VALLEY WASH, SOUTHEASTERN NEVADA

By

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ABSTRACT

A high-resolution aeromagnetic survey over Virgin Valley near Mesquite, Nevada, and over Tule Desert and the valley surrounding Meadow Valley Wash, Nevada, reveals geologic features of potential importance to understanding the geohydrology of the region. Local magnetic highs over Virgin Valley suggest the presence of isolated lava flows buried at depths of approximately 1500-2500 ft (500-800 m) and bounded by faults. The faults and the lava flows themselves could influence the movement of ground water beneath the valley. South of the Virgin River, magnetic data reveal buried channels and elongate alluvium lenses that could control the movement of ground water from the recharge area in the Virgin Mountains northward toward the Virgin River. North of the river, subtle linear magnetic anomalies may delineate ancient drainage systems that have subsequently been buried. Magnetic data over Tule Desert and the valley surrounding Meadow Valley Wash suggest the presence of a system of NW-trending faults in the shallowly buried bedrock, similar to faults that cut the volcanic rocks of the Caliente caldron complex to the north and northwest. In addition, the data suggest a major ENE-trending fault zone buried beneath Tule Desert, probably associated with the Tule Springs detachment fault.

INTRODUCTION

The U.S. Geological Survey, in cooperation with the Virgin Valley Water District, is conducting a study of the geological and structural framework of Virgin Valley and surrounding basins near Mesquite, Nevada, in an effort to better understand the geologic controls on the geohydrology and ground-water resources of the region. As part of this study, a high-resolution aeromagnetic survey was flown of Virgin Valley near Mesquite, Nevada, and two valleys to the north, Tule Desert and the valley that contains Meadow Valley Wash (fig. 1). The purpose of the survey was to search for shallow faults and other features such as localized rock masses or ancient drainage channels within the valley fill and underlying bedrock that might influence or control the movement of ground water. In this report, we present the aeromagnetic survey data and our interpretation of these data in terms of geologic features important to the regional geohydrology.

AEROMAGNETIC SURVEY

Data Collection and Reduction

Total-field magnetic data were collected with a fixed-wing aircraft along flightlines spaced 0.25 mi (400 m) apart at a nominal height of 500 ft (150 m) above the ground surface. Over the basin areas, the aircraft was able to closely maintain the 500 ft (150 m) clearance, but topographic relief over hills such as the Tule Springs Hills forced the pilot to fly closer to the ridge tops than to the bottoms of the narrow intervening valleys. Flightlines were oriented N. 70° W. for that part of the survey covering Virgin Valley and Tule Desert and were oriented N. 5° W. over the valley surrounding Meadow Valley Wash. Positioning was controlled by Global Positioning System navigation.

The raw data were corrected for diurnal fluctuations of the geomagnetic field, and the datum-levels of individual flightlines were adjusted relative to the entire survey by the use of tie-lines flown perpendicular to the flightlines. The International Geomagnetic Reference Field (see Blakely, 1995, p. 163-4 for a description and references to the IGRF), updated to the date of the survey, was subtracted from the reduced data, and the resulting residual magnetic field data were interpolated onto a square grid 328 ft (100 m) on a side by means of a procedure based on the principal of minimum curvature (Briggs, 1974). The residual magnetic field of the study area is shown in figure 2.

AEROMAGNETIC ANOMALIES AND GEOLOGY

Magnetic anomalies (local magnetic highs and lows) on an aeromagnetic map such as figure 2 typically reflect the distribution of magnetite or other magnetic minerals contained within the rocks and sediments of the study area. Many of the strongest magnetic highs (warmest colors) on figure 2 are produced by very old (Precambrian age) rocks exposed in the East Mormon Mountains and buried at depth beneath Virgin Valley (western edge and extreme southeastern corner of the survey area) and beneath the Tule Springs Hills and the adjacent area to the east. The strong magnetic anomalies around the north rim of Meadow Valley Wash and north of Tule Desert/Tule Springs Hills are caused mostly by volcanic rocks that make up the Clover Mountains and parts of the Meadow Valley Mountains. Although the large magnetic anomalies on figure 2 can be studied to help unravel the structure of the earth's crust and to understand the forces that have built the mountains in the region, some anomalies that reflect features important to understanding the movement of ground water in the region are much smaller than those discussed above, and further processing of the aeromagnetic data is necessary in order to emphasize these subtle anomalies.

Occasionally, man-made structures cause magnetic anomalies that are measurable during an aeromagnetic survey. The northeast-trending string of magnetic highs labeled 'power line' is caused by a direct-current transmission line that crosses the survey area-each individual high indicates the place where the aircraft crossed the transmission line. Even buildings such as those at the Virgin River Inn or the industrial park in the northern part of Mesquite cause magnetic anomalies that can be measured by survey aircraft, and some of these will be evident on the high-resolution magnetic maps presented later in this report.

High-Resolution Aeromagnetic Maps

Figures 3 and 4 show maps of the magnetic field of the study area in which the large, broad anomalies that dominate the map in figure 2 have been suppressed, consequently enhancing the smaller anomalies that reflect the features of interest to studies of ground water. These maps were produced from the original magnetic survey data by the procedure described in the Appendix. Note that the magnetic field shown in figures 3 and 4 are 60 and 30 times more detailed, respectively, than that shown in figure 2 (i.e. each color band in figure 2 represents 30 nanoTeslas (nT) whereas those in figures 3 and 4 represent 0.5 nT and 1.0 nT, respectively.

Figures 3 and 4 contain small '+' symbols (from now on called 'MaxSpots', short for maximum gradient spots) that indicate the edges of magnetic rock bodies, or abrupt lateral changes in the amount of magnetic minerals in the near-surface sediments. These locations were determined by an automatic analysis of the magnetic data that is described in the Appendix. Knowledge of such locations is useful for interpreting aeromagnetic maps in terms of geologic features that might be important for understanding ground-water movement because faults, buried channels, and edges of aquifers often coincide with abrupt lateral changes in the amount of magnetic minerals. For example, movements on faults commonly cause different kinds of rocks or sediments with different magnetic properties to be in contact across the fault plane. In such cases, a line of MaxSpots would mark the fault. Similarly, a former drainage channel that was subsequently filled and buried might be filled with material having different magnetic properties than its surroundings. In this case, the edges of the buried channel would be marked by lines of MaxSpots.

INTERPRETATION

The magnetic boundaries indicated by the MaxSpots on figures 3 and 4 will be used extensively in the following interpretation. For convenience, the interpretation will be discussed in three separate areas: 1) Virgin Valley, including the area east of the Tule Springs Hills (figs. 1 and 3); 2) Tule Desert (figs. 1 and 3); and 3) the valley surrounding Meadow Valley Wash (figs. 1 and 4)

Virgin Valley

Volcanic Flows

Magnetic anomalies labeled A1-A5 on figure 3 are unusual because their shapes and amplitudes indicate that they are caused by strongly magnetic rocks buried at most a few thousand feet beneath the surface, in areas where weakly magnetic sedimentary rocks are many thousands of feet thick (Bohannon and others, 1993). In addition, anomaly A5 has an unusually strong magnetic low near its center, suggesting that its source body acquired its magnetization at a time when the geomagnetic field was reversed. Based on these magnetic anomaly characteristics, we interpret these anomalies to be caused by shallowly buried volcanic rocks. Volcanic rocks are known to occur within, and at the base of the sedimentary deposits of the Muddy Creek formation (Longwell and others, 1965; Tschanz and Pampeyan, 1970), the formation that makes up most of the upper few thousand feet of fill in Virgin Valley. Seismic reflection profiles cross the sources of anomalies A3 and A5 (Bohannon and others, 1993), and reveal flat-lying reflecting source bodies with tops at about 2500 ft (800 m) and 1500 ft (500 m), respectively. Bohannon and others (1993) interpreted these bodies as composed of gypsum. However, we interpret them to be composed of volcanic rocks, possibly parts of lava flows, because

- gypsum is not magnetic,
- the edges of the reflecting bodies coincide with the edges of the magnetic source bodies A3 and A5, and
- these bodies lie at depths consistent with the sources of the magnetic anomalies.

The edges of the inferred magnetic volcanic rock bodies as defined primarily by the MaxSpots are shown in light blue (fig. 3).

These inferred volcanic rock bodies may be important to the flow of ground water in Virgin Valley. Lava flows often develop fractures as they cool, and such fractured flows can provide convenient paths for ground-water movement. Also, the porosity and permeability of a volcanic rock is likely to be much different from the porosity and permeability of the surrounding Muddy Creek deposits, with the volcanic rocks possibly constituting a better aquifer. The sources of anomalies A1-A4 may be parts of an original single lava flow, subsequently dismembered by faulting or isolated by previous erosion However, based on the magnetic anomalies we cannot rule out the possibility that they still are connected at depth. The eastern and western edges of the sources of anomalies A1-A5 may be faults (as interpreted by Bohannon and others (1993) for the edges of the sources of anomalies A3 and A5), and as such, could act as conduits for the local movement of ground water or as barriers to cross-fault ground-water flow. Although these inferred volcanic rocks may be good aquifers, they lie at depths with high concentrations of gypsum (as interpreted by Bohannon and others, 1993), and water quality may be a problem.

Channels South of the Virgin River

The high-resolution magnetic field over the alluvial fan between the Virgin Mountains and the Virgin River (fig. 3) is characterized by numerous NNW oriented narrow highs and lows, a pattern reinforced by the NNW-trending linear alignments of MaxSpots representing the edges of magnetic deposits. The near-surface deposits causing the magnetic anomalies over this alluvial fan are derived from erosion of the very old crystalline and sedimentary rocks that make up the Virgin Mountains to the south. Some of the narrow magnetic anomalies and their associated MaxSpots (shown in magenta) are caused by existing gullies and channels as identified by comparing the local magnetic anomalies with the record of the radar altimeter carried by the survey aircraft. The difference in magnetic properties between air, which fills the gullies and channels, and surrounding deposits produces linear magnetic lows over the gullies and channels. Many other narrow, NNW-trending anomalies are not associated with existing gullies or channels (MaxSpots shown in black) and these we interpret to be older filled channels or elongate depositional lenses made up of material eroded from the Virgin Mountains. Because the rocks that make up the Virgin Mountains range in magnetic properties from non-magnetic to very-strongly- magnetic, the magnetic properties of the sediments deposited in any given channel or lens of the alluvial fan depend on what rocks were being eroded at that time. For example, long, narrow magnetic highs probably define the drainage pattern when magnetic rocks were being eroded.

Therefore, the present high-resolution magnetic anomaly pattern over the alluvial fan located between the Virgin Mountains and the Virgin River (fig. 3) defines not only the present day drainage pattern, but also the earlier drainage patterns. These earlier, now buried, drainage features may well control or influence the present day movement of water from rainfall or snow-melt in the Virgin Mountains toward groundwater recharge areas between the mountains and the Virgin River to the north. If so, the MaxSpots shown in black would be likely locations of the edges of buried channels or depositional lenses, places where hydrologic properties might change laterally.

Channels North of the Virgin River

Many of the major washes north of the Virgin River, including those east of the Tule Springs Hills, are clearly indicated by anomalies and alignments of MaxSpots on the high-resolution magnetic map (fig. 3). Some of the more obvious ones are Beaver Dam Wash, Bull Valley Wash, and Snow Spring Wash. Many less prominent present-day washes and gullies (again defined by examination of the radar altimeter record) also produce anomalies and associated curvilinear MaxSpot distributions, shown in magenta on figure 3. As was found in the high-resolution magnetic field over the alluvial fan south of the river, the area to the north also contains narrow, curvilinear magnetic anomalies and associated MaxSpots (shown in black on figure 3) that cannot be accounted for by the present day drainage system. Here we also interpret these to indicate mostly buried channels and gullies of earlier drainage systems, although some of them could be caused by faults that break the Muddy Creek formation and its overlying deposits. There also are many MaxSpots that do not form long curvilinear patterns, and probably do not reflect the earlier drainage systems. Some undoubtedly are caused simply by random variations of magnetization within the Muddy Creek deposits and overlying alluvium.

If the curvilinear MaxSpot patterns shown in black north of the Virgin River indicate buried drainage systems or faults, then these features should act as important controls on the movement of ground water in this region. Assuming that our interpretation is correct, we have identified coherent patterns of magnetic anomalies that may indicate the general direction of ground-water movement controlled by these features (shown by large arrows on figure 5). Individual features contributing to the general patterns are delineated by the MaxSpots on figure 3. It should be noted that none of these MaxSpot locations have been field-checked, so that additional verification is recommended before using this interpretation as a basis for planning.

Tule Desert

Geologic interpretations (Axen and others, 1990) and the lack of a significant gravity low over Tule Desert (Healey and others, 1981) indicate that Tule Desert is a shallow basin. Even at its deepest point, it probably contains no more than a few thousand feet of alluvium overlying volcanic rocks , such as those exposed in the Clover Mountains to the north, and older rocks such as those exposed in the Tule Springs Hills to the east. The high-resolution magnetic field (fig. 3) likely reflects features in these rocks concealed beneath the alluvium.

Two prominent features of the high-resolution magnetic field over Tule Desert are 1) a broad NNE-trending zone of NNE-trending MaxSpot alignments (anomaly A6), and 2) a set of NW-trending anomalies and associated alignments of MaxSpots (anomaly A7). Neither anomaly set coincides with the present day drainage system. The location, trend, and change in the magnetic field across anomaly A6 suggests that it is a major tectonic boundary, most likely the buried tip of the westward-dipping Tule Springs detachment fault (Axen and others, 1990). The causes of the NW-trending set of anomalies and MaxSpots (A7) are hidden beneath the alluvium, but their parallelism with the trends of a network of faults that cut the Caliente caldron complex a few tens of miles to the north and northwest (Ekren and others, 1977; Michel-Noel and others, 1990) suggests that the individual elements of anomaly A7 (i.e. the MaxSpot alignments) also are faults.

We interpret the high-resolution magnetic data over Tule Desert in terms of two intersecting fault sets in the bedrock beneath the alluvium: a NNE-trending fault zone associated with the Tule Springs detachment fault; and NW-trending set of steeply-dipping faults concentrated in the southern part of the valley. Because both sets of faults cut the bedrock beneath the alluvium, both might act as conduits for ground-water movement within the bedrock and might act as barriers to the movement of ground water across them. We cannot tell from the magnetic data whether these faults extend up into the alluvium, but such a possibility must be considered when attempting to predict the movement of ground water beneath Tule Desert. In addition, some of the linear magnetic anomalies could indicate buried channels within the alluvium, similar to those we have interpreted for the area south of the Virgin River.

Meadow Valley Wash and Vicinity

The valley containing Meadow Valley Wash, like Tule Desert, is a shallow basin containing at most a few thousand feet of alluvium overlying bedrock composed mainly of volcanic rocks (Axen and others, 1990; Ekren and others, 1977; Healey and others, 1981). The magnetic anomaly pattern on the high-resolution magnetic map (fig. 4) is extremely complex, typical of the magnetic field over volcanic terranes throughout Nevada. The complexity typically arises from the combined effects of random amounts of magnetic minerals in the various volcanic units, juxtaposition of normally and reversely magnetized units, and subsequent dismemberment by faulting. Despite the complexity, two consistent trends of magnetic anomalies and MaxSpots can be seen on figure 4; a NE-trending set mostly confined to the eastern half of the valley , and a less pronounced NW-trending set with a trend similar to that seen in Tule Desert (fig. 3). Most (but not all) of the NE-trending anomalies and MaxSpots are caused by topography of the present-day drainage system in the valley (see MaxSpots in magenta on fig. 4). In contrast, few of the NW-trending features are related to local topography.

As in the case of Tule Desert, the sources of the NW-trending magnetic anomalies and MaxSpot alignments on figure 4 are not caused by the present-day drainage system. However, the similarity in trend with the NW-trending fault system that cuts the volcanic rocks of the Caliente caldron complex a few tens of miles to the north and northwest (Ekren and others, 1977; Michel-Noel and others, 1990) strongly suggests that the NW trending features on figure 4 also are caused by faults in the bedrock volcanic units, possibly extending up into the alluvium. The causes of the NE-trending anomalies and MaxSpot alignments not related to the present-day drainage system are more uncertain, but they could be related to a complementary fault or joint system in the volcanic rocks. If so, the fact that the NE trend is so strongly present in the existing drainage system might mean that the faults also cut the alluvium. This last conclusion is highly speculative and requires verification in the field before it can be accepted.

DISCUSSION AND RECOMMENDATIONS

In the previous sections, we interpreted the high-resolution aeromagnetic data in terms of geologic features and structures that might be important for understanding the movement of ground water within the basin fill and underlying shallow bedrock. In doing so, we presented some interpretations of which we are quite confident, and some speculative interpretations that may not prove to be correct upon further study. The interpretations concerning the volcanic flows buried beneath Virgin Valley and the buried channels and alluvial lenses south of the Virgin River are well supported, whereas the identification of concealed faults beneath Tule Desert and the area around Meadow Valley Wash are more speculative. The identification of possible ancient drainage systems north of the Virgin River and east of the Tule Springs Hills is the most speculative of our interpretations. We deliberately presented all of these interpretations in the belief that future studies of the ground-water regime in this region will benefit most from the aeromagnetic data if we include all of our thoughts concerning the meaning of these data. Because of this, we strongly recommend that field-checking of our interpretations be an integral part of any future study of the ground-water regime of this region.

The geologic and structural framework interpretations presented in this report provide only part of the information needed to understand the groundwater regime of the valleys surrounding Mesquite, NV, and to plan for the future development of their ground-water resources. The information in these interpretations should be integrated with the results of detailed geologic mapping, other geophysical investigations, ground-water geochemical analyses, and ground-water hydrology studies to produce a ground-water flow model of the region. To best accomplish this goal, ground-water specialists should work directly with the geologists and geophysicists familiar with the area to develop a coherent model that includes all the available information.

Many geologic features potentially important to understanding the ground-water regime (inferred faults, ancient stream channel boundaries, edges of the lava flows) are delineated by the MaxSpots derived from the magnetic data. Because the aircraft from which the magnetic field was measured was nominally 500 ft (152 m) above the ground surface, there is some uncertainty in the location of the MaxSpots relative to the actual location of the feature they delineate. Based on comparisons between MaxSpot locations and features that we know are the cause of the magnetic anomaly (e.g. edges of present-day channels, buildings, bridges, etc.) we estimate that the MaxSpots typically lie within 150-300 ft (50-100 m) of the features they reflect. Possible positional uncertainties of this magnitude should be kept in mind when field-checking the interpretations presented in this report.

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APPENDIX

High-Resolution Processing

The high-resolution aeromagnetic maps shown in figures 3 and 4 were produced in the following way. First, a digital filter that eliminates slight differences in average measured magnetic field between adjacent flightlines was applied to the gridded data. Second, a digital filter that transforms the magnetic field measured at one height to the magnetic field that would have been measured at a different height was applied to the gridded data to produce the magnetic field 328 ft (100 m) higher than the measured survey. All magnetic anomalies decrease in amplitude as the distance between the magnetic source and the magnetic sensor increases, so the anomalies on the filtered magnetic map (field higher above the ground than the measured map) will be smaller than those on the measured map. Narrow anomalies from sources close to the sensor (i.e. sources near the surface) will decrease in amplitude much faster with distance from the source than broad anomalies from deep sources. Therefore, a new magnetic map produced by subtracting the field 328 ft (100 m) above the measurement surface from the measured field will emphasize the magnetic anomalies from shallow sources (those of most interest in ground-water studies) at the expense of those from deeper sources. Such maps are shown in figures 3 and 4. Note that the magnetic field shown in figures 3 and 4 are 60 and 30 times more detailed, respectively, than that shown in figure 2 (i.e. each color band in figure 2 represents 30 nanoTeslas (nT) whereas those in figures 3 and 4 represent 0.5 nT and 1.0 nT, respectively

Figures 3 and 4 also contain "+" symbols that mark the edges of magnetic bodies. These locations (referred to as 'MaxSpots' in the text) were determined by means of a numerical technique applied to the magnetic data that is a slight modification of a technique proposed by Cordell and Grauch (1985) and implemented by Blakely and Simpson (1986). The original technique is a process for locating the edges of magnetic bodies which makes use of a linear filter, the pseudogravity transform (Baranov, 1957), which converts a magnetic anomaly to an equivalent gravity anomaly (called the pseudogravity anomaly). In the same way that the maximum horizontal gradients of a gravity anomaly produced by a shallowly buried body lie nearly over the edges of the body, especially if the sides dip steeply, the maximum horizontal gradients of a pseudogravity anomaly define the edges of the magnetic body that cause the magnetic anomaly. For the present study, we modified the edge-locating procedure slightly by applying the technique, not to the simple pseudogravity transformation of the magnetic data, but rather to the difference between the transformed magnetic data and those same data upward continued 100 m. In the same way as described for the magnetic data in the previous paragraph, applying the edge-locating technique to the difference focuses on the shallowest parts of the magnetic bodies, the top edges and those closest to the surface

In order to identify those MaxSpots based on the high-resolution aeromagnetic data that are caused by the present-day distribution of channels and gullies, or other sharp breaks in the topographic surface, the radar altimeter data collected by the survey aircraft concurrent with the magnetic data were analyzed in the following manner. First, the radar altimeter readings (distance of the ground surface below the aircraft) were gridded and contoured in the same manner as the magnetic data. Second, a digital filter that eliminates slight differences in the average measured radar altimeter data between adjacent flightlines was applied to the gridded data (this is the same filter used for a similar purpose on the gridded magnetic data). The resulting map is proportional, to first approximation, to the pseudogravity field that would have been derived from a magnetic survey collected by an aircraft that just cleared the locally highest points of the ground surface (assumed to be uniformly magnetized), provided that the local topography is not severe. Third, a digital filter that approximates the pseudogravity field at an elevation higher than measured was used to calculate the "topographic pseudogravity" field at a height of 500 ft (152 m) above the ground, the height of the survey aircraft. Finally, this upward continued "topographic pseudogravity" field was analyzed by the MaxSpot technique described in the previous paragraph, and the resulting MaxSpots were compared to those derived from the magnetic data to identify those magnetic MaxSpots caused by the present-day drainage systems.

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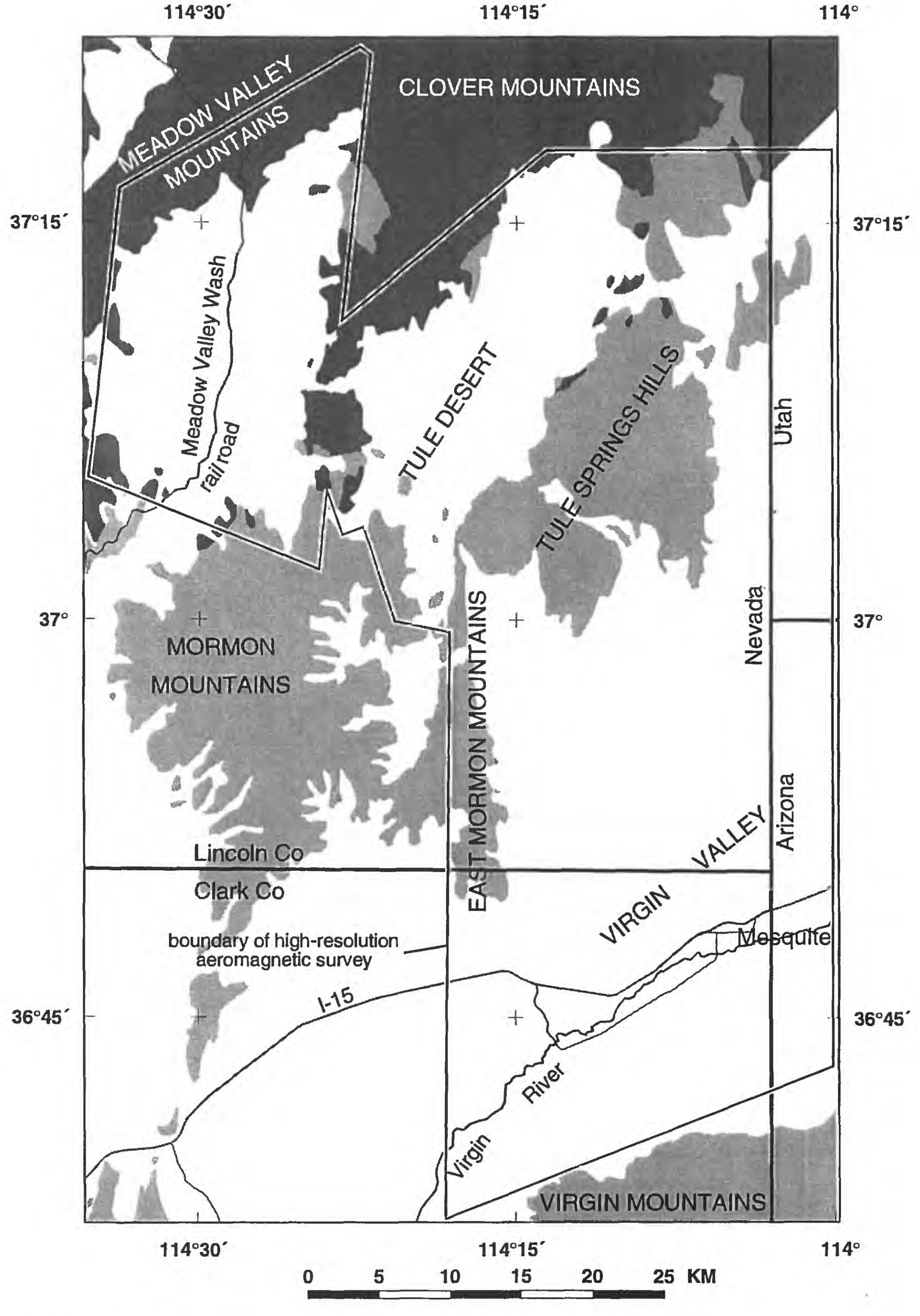

Figure 1. Map showing location of study area, outline of the high-resolution aeromagnetic survey on which this report is based, and the simplified geology of the area. Geologic units—light grey, pre-Tertiary basement rocks exposed in the mountain ranges: dark grey, Tertiary volcanic rocks: white, valley fill deposits, including alluvium and deposits of the Muddy Creek formation.

AEROMAGNETIC FIELD

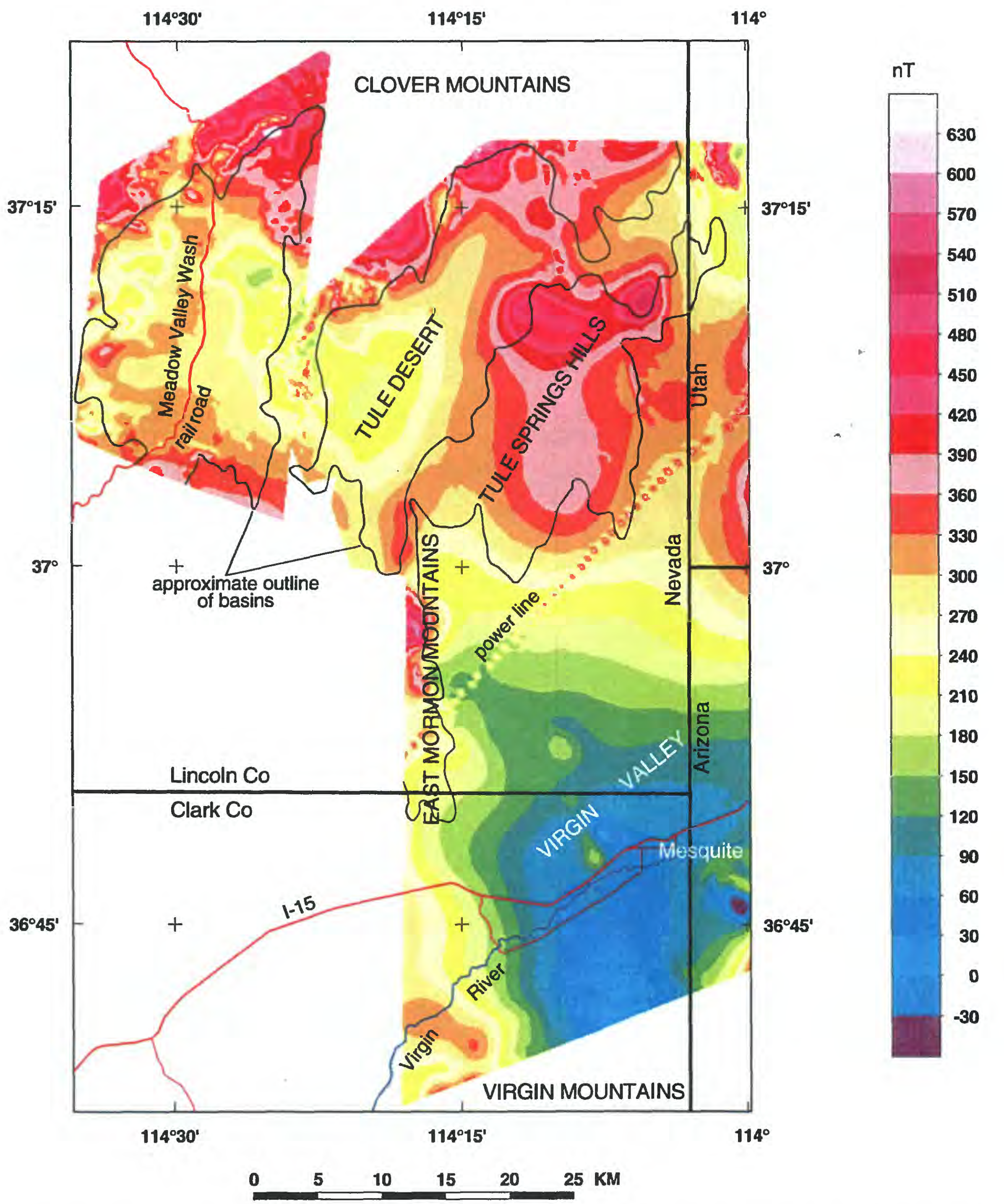

Figure 2. Map showing the magnetic field of the study area. Warm colors indicate locations of magnetic rocks. Color contour interval-30 nanoTeslas (nT).

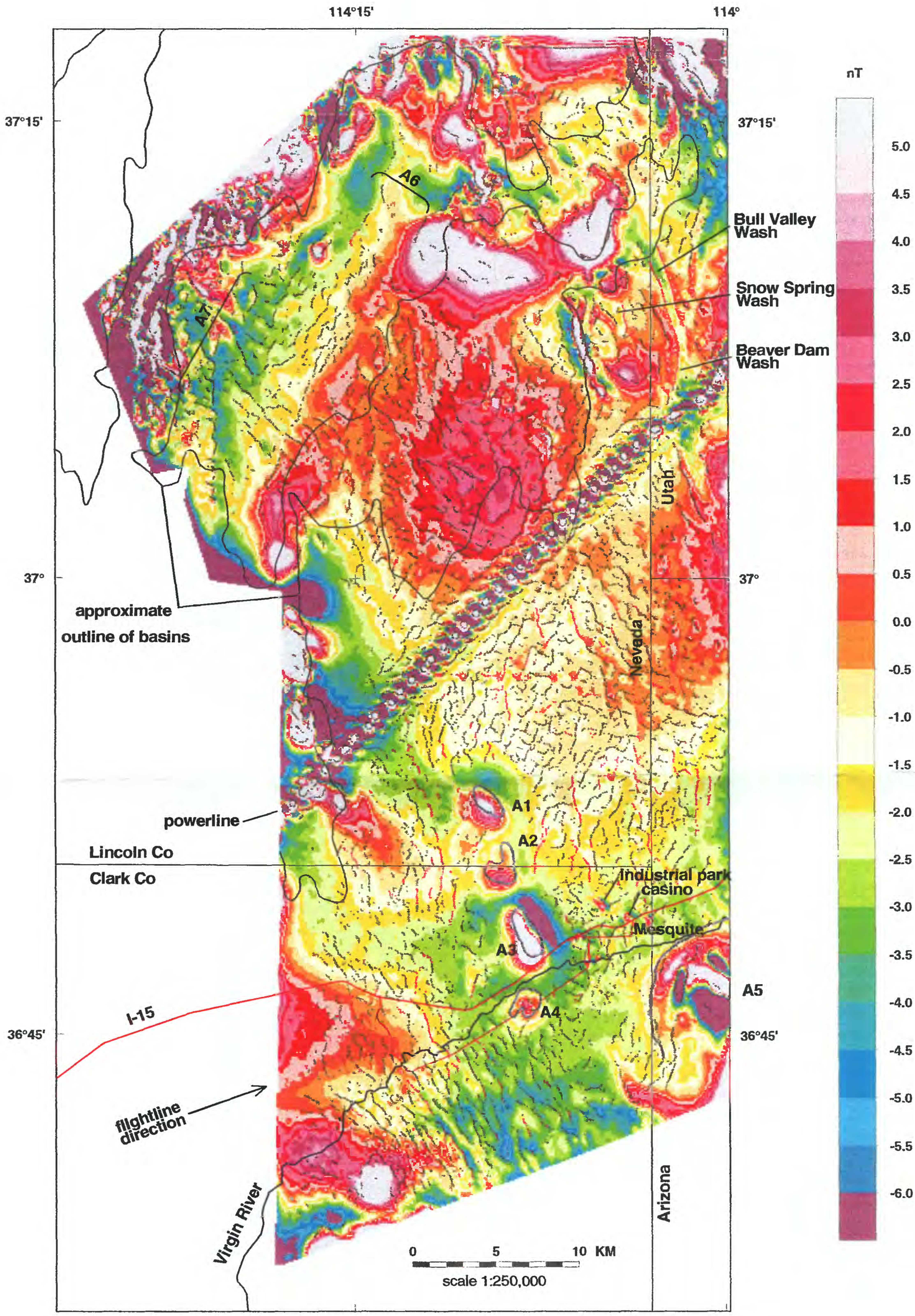

Figure 3. Map showing high-resolution magnetic field of Virgin Valley, Tule Desert, Tule Springs Hills, and vicinity. This map was computed from the data shown in figure 2 using methods described in the Appendix. Warm colors indicate magnetic highs. Color contour interval-0.5 nT. Small black and magenta spots (actually small '+' signs) indicate locations of boundaries of magnetic rock bodies or abrupt lateral changes in magnetic properties in the underlying deposits Magenta spots indicate those boundaries that reflect present-day topography of the basin filling deposits (e.g. channels, gullies, cliffs, etc.). Black spots indicate those boundaries that are likely concealed beneath the surface, although probably only at shallow depth. Scale 1:250,000.

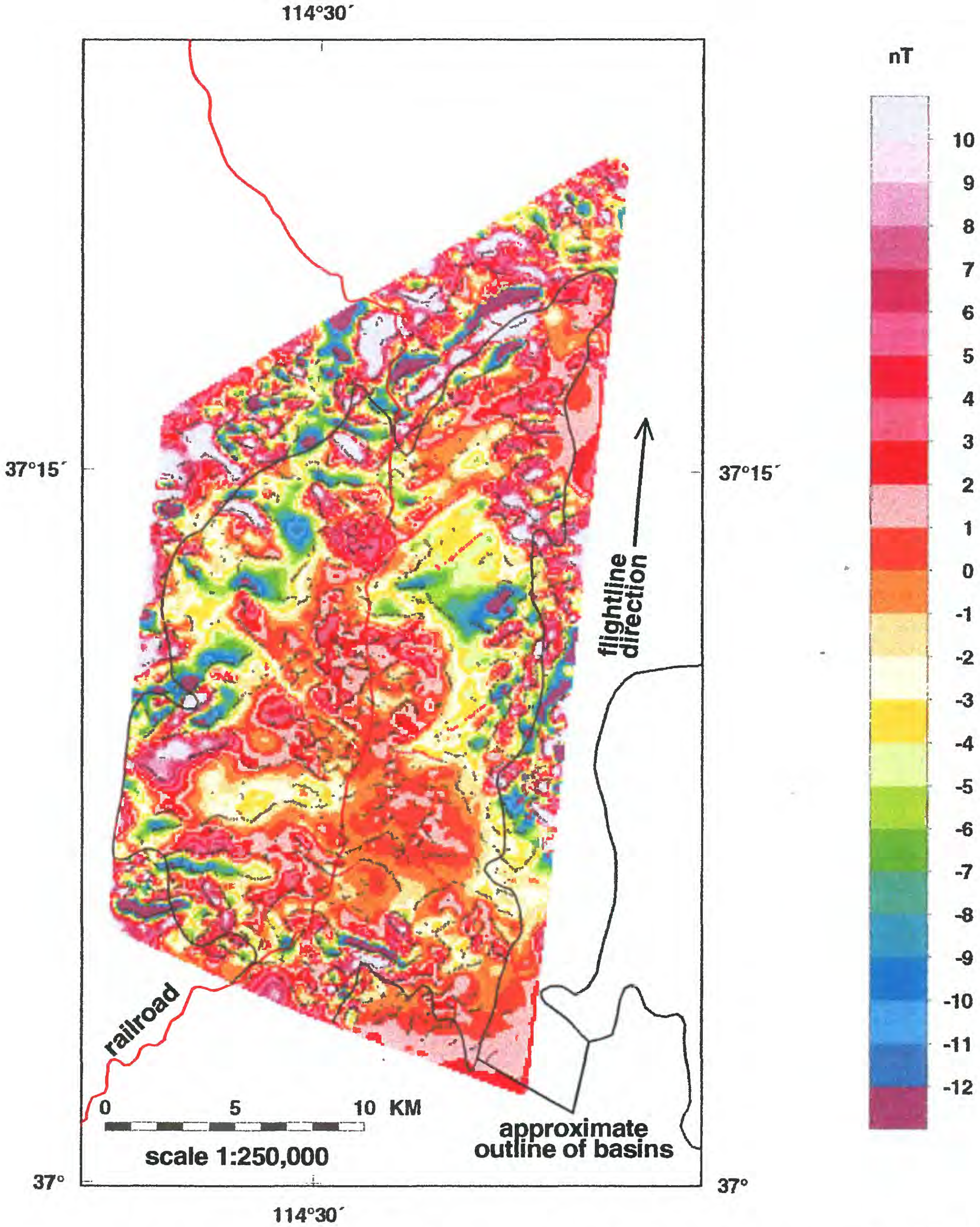

Figure 4. Map showing high-resolution magnetic field of the valley surrounding Meadow Valley Wash. This map was computed from the data shown in figure 2 using methods described in the Appendix. Warm colors indicate magnetic highs. Color contour interval-0.5 nT. Small black and magenta spots (actually small '+' signs) indicate locations of boundaries of magnetic rock bodies or abrupt lateral changes in magnetic properties in the underlying deposits Magenta spots indicate those boundaries that reflect present-day topography of the basin filling deposits and the surrounding volcanic rocks (e.g. channels, gullies, cliffs, etc.). Black spots indicate those boundaries that are likely concealed beneath the surface, although probably only at shallow depth. Scale 1:250,000.

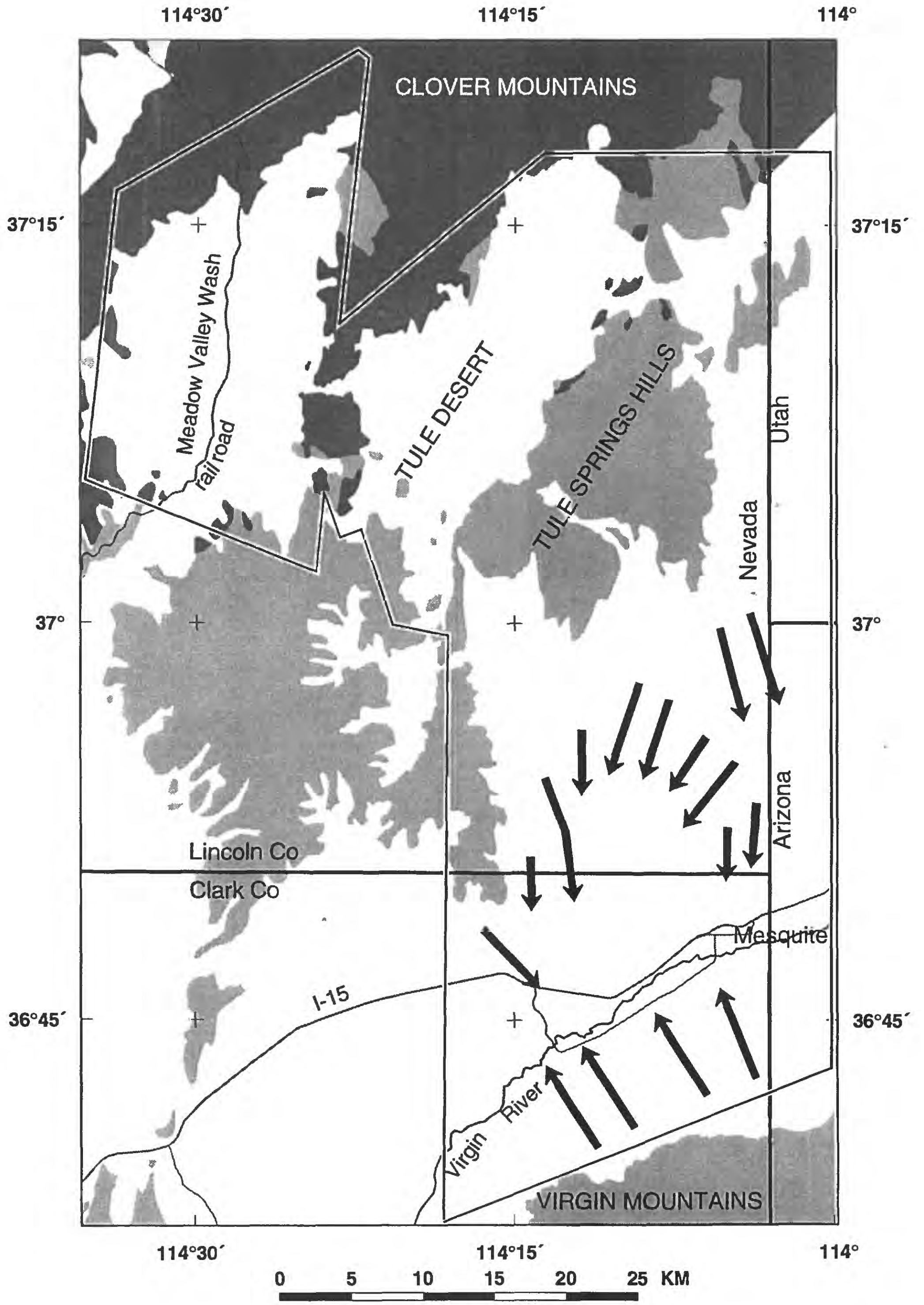

Figure 5. Map showing suggested ground water flow directions (large arrows) within the upper few thousand feet of Virgin Valley. These arrows are based on the interpretation that the coherent patterns of aligned MaxSpots show on figure 3 indicate young faults or buried former drainage systems that today can influence the movement of ground water.