# A prominent geophysical feature along the northern Nevada rift and its geologic implications, north-central Nevada

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## ABSTRACT

**We consider the origin and character of a prominent large-scale geophysical feature in north-central Nevada that is coincident with the western margin of the northern Nevada rift—a mid-Miocene rift that includes mafic dike swarms and associated volcanic rocks expressed by a NNW-striking magnetic anomaly. The geophysical feature also correlates with mid-Miocene epithermal gold deposits and is coincident with the central part of the Battle Mountain–Eureka mineral trend. The Reese River Valley, a 2-km-deep Cenozoic basin, is located along the western margin of this feature and is inferred from the inversion of gravity data to be influenced by, and perhaps in part structurally controlled by, the geophysical feature.**

**Geophysical modeling indicates that the source of the geophysical anomaly must extend to mid-crustal depths, perhaps reflecting a transition from Paleozoic crust in the southwest to Precambrian crust in the northeast, the presence of felsic intrusive rocks in the middle crust, or the edge of mid- to subcrustal mafic intrusions related to late Tertiary magmatic underplating associated with hotspot magmatism.**

**These cases offer very different possibilities for the age, depth, and origin of the source of the geophysical anomaly, and they present distinct implications for crustal evolution in the northern Great Basin. For example, if the anomaly is due to a pre-Cenozoic basement structure, then its coincidence with the mid-Miocene northern Nevada rift suggests that the trend of the rift was guided by the preexisting crustal structure. On the other hand, if the anomaly is related to Tertiary mafic intrusions, then the western limit of this magmatism may have been influenced by hotspot fracturing of the crust.**

**Keywords:** gravity and magnetic anomalies, northern Nevada rift, epithermal gold deposits, Battle Mountain–Eureka mineral trend, Basin and Range, Nevada.

## INTRODUCTION

Investigations of large-scale crustal geologic features in the Great Basin provide new insights into the metallogeny, tectonics, and magmatism of the region. Their potential influence on fluid flow and association with world-class gold deposits are of interest to worldwide mineral and water resource issues at both regional and local scales. Here, we investigate a large-scale geophysically inferred crustal feature in north-central Nevada, discuss its relation to adjacent geologic features and mineral deposit trends in north-central Nevada, and speculate on its origin and importance based on improved geophysical and physical property data.

Geophysical studies in northern Nevada have resulted in several models for the origin and significance of a series of prominent geophysical features known as the northern Nevada rifts (NNRe, NNRc, NNRw, Fig. 1) (Glen and Ponce, 2002; Ponce and Glen, 2002). The originally named northern Nevada rift (Zoback and Thompson, 1978; Zoback et al., 1994), expressed by a prominent aeromagnetic anomaly herein referred to as the *eastern* northern Nevada rift (Figs. 1 and 2), extends from at least the Nevada-Oregon border to southeast Nevada (Blakely, 1988; Blakely and Jachens, 1991). Moreover, recent studies along the eastern northern Nevada rift and associated features to the west (Fig. 1) (John et al., 2000; Glen and Ponce, 2002; Ponce and Glen, 2002) have indicated that the northern Nevada rift is a much wider feature than previously thought. These studies expand on its relationship to known and potential mineral resources along its trend, and they indicate that the feature extends northward well beyond the Nevada-Oregon border.

## PREVIOUS WORK

Previous studies along the northern Nevada rift include pioneering work in the middle to late 1960s by Mabey (1966), who first described a large magnetic high along the western edge of the Roberts Mountains, later termed the northern Nevada rift by Zoback and Thompson (1978). Robinson (1970) showed that the mafic source rocks of the northern Nevada rift may extend to 15 km below the surface based on two-dimensional magnetic modeling and that the northern Nevada rift is associated with an alignment of doming and mining districts described by Roberts (1960). Stewart et al. (1975) suggested that the magnetic feature is part of a 750-km-long lineament that extends into Oregon and may be a deep-seated fracture zone expressed by mid-Miocene volcanic rocks. Zoback's (1978) definitive work on the northern Nevada rift showed that a deep-seated mafic dike swarm, part of which is exposed in the Roberts Mountains (McKee, 1986), can account for the magnetic anomaly and that its trend reflects the mid-Miocene least principal stress direction. Based on an analysis of low-level (120 m above terrain) but widely spaced (~5 km) aeromagnetic data, Blakely and Jachens (1991) suggested that the northern Nevada rift extends much farther to the south and that the rift also follows a well-defined isostatic and basement gravity gradient. Zoback et al. (1994) reassessed the northern Nevada rift in light of more recent data and reaffirmed their earlier interpretations of the northern Nevada rift

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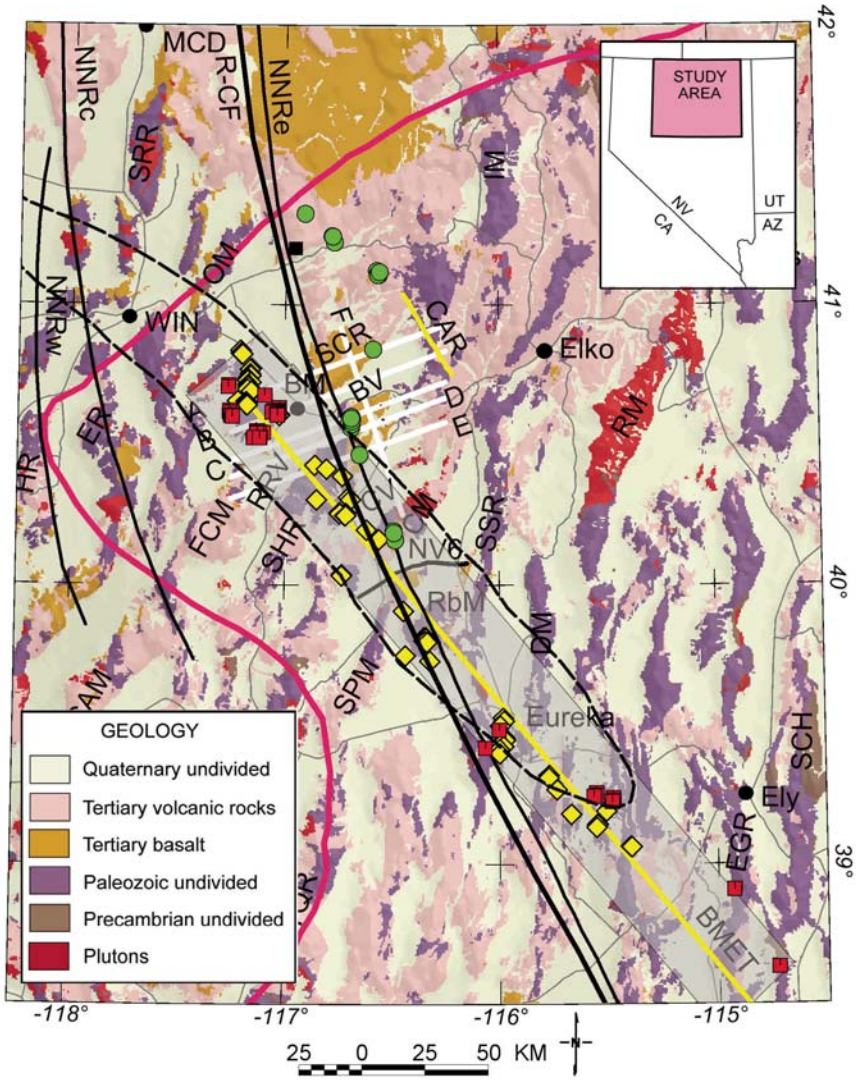


**Figure 1. Shaded-relief and simplified geologic map (modified from Stewart and Carlson, 1978) of north-central Nevada showing the location of the geophysically inferred crustal feature in north-central Nevada (rift crustal feature [R-CF]). Lines and symbols: Yellow diamonds—sediment-hosted gold deposits (Wallace et al., 2004a); red squares—pluton-related gold deposits (Wallace et al., 2004a); green circles—epithermal gold deposits (modified from John et al., 2000; Wallace et al., 2004a); NNRe, NNRc, and NNRw—apex of magnetic anomaly associated with the eastern, central, and western northern Nevada rifts; yellow lines—Battle Mountain–Eureka mineral trend (BMET) and Carlin (CAR) mineral trend; semi-transparent rectangle—extent of Battle Mountain–Eureka mineral trend deposits; black dashed line—Battle Mountain–Eureka belt (from Roberts, 1966); NV6—COCORP deep seismic-reflection profile (from Allmendinger et al., 1987); white lines—locations of geophysical models (A–F, see Watt et al., 2007); magenta line—initial $^{87}Sr/^{86}Sr = 0.7060$ isopleth (from Tosdal et al., 2000); black square—Sawtooth dike; gray lines—major roads. Cities: BM—Battle Mountain; MCD—McDermitt; WIN—Winnemucca. Geography: BV—Boulder Valley; CAM—Clan Alpine Mountains; CM—Cortez Mountains; CV—Crescent Valley; DM—Diamond Mountains; EGR—Egan Range; ER—East Range; FCM—Fish Creek Mountains; GR—Grant Range; HR—Humboldt Range; IM—Independence Mountains; OM—Osgood Mountains; RM—Ruby Mountains; RRV—Reese River Valley; RbM—Roberts Mountains; SCH—Schell Creek Range; SCR—Sheep Creek Mountains; SHR—Shoshone Range; SPM—Simpson Park Mountains; SRR—Santa Rosa Range; SSR—Sulfur Springs Range; TR—Toiyabe Range; TQR—Toquima Range.**

as an indicator of the mid-Miocene stress direction. A study by John et al. (2000) have shown that the northern Nevada rift is prominently expressed in gravity, magnetic, and other derivative geophysical maps, that it is an arcuate and a much wider feature than previously thought, and that it correlates to known epithermal deposits. The eastern northern Nevada rift and related parallel magnetic anomalies to the west (NNRc, NNRw, Fig. 2) are associated with epithermal gold deposits in northern Nevada, extend well beyond the Nevada-Oregon border, and converge at a point along the Oregon-Idaho border at latitude 44°, which is interpreted to be the inception site of the Yellowstone hotspot (see Glen and Ponce, 2002; Ponce and Glen, 2002).

Grauch et al. (1995) were the first to suggest that the Battle Mountain–Eureka mineral trend, an alignment of a wide range of gold deposits including sediment-hosted and pluton-related gold deposits (Roberts, 1966), corresponds to a basement gravity gradient and that this boundary could be of Jurassic age or older because of an associated alignment of Jurassic plutons and possible folds. Grauch et al. (2003a, 2003b) presented additional evidence that the Battle Mountain–Eureka mineral trend correlates to a major crustal-scale fault zone primarily based on magnetotelluric and radiogenic isotope data (also see Tosdal et al., 2000; Crafford and Grauch, 2002; Rodriguez et al., 2007). Both the Battle Mountain–Eureka mineral trend and the northern Nevada rift occur in a transition zone between the craton to the east and oceanic crust to the west, where the intervening continental margin is defined by the initial $^{87}Sr/^{86}Sr = 0.7060$ isopleth (e.g., Tosdal et al., 2000) (Fig. 1). Ponce and Glen (2002) showed that the western edge of the northern Nevada rift also occurs along a large-scale crustal feature, part of which is coincident with the central part of the Battle Mountain–Eureka mineral trend (Figs. 2 and 3).

In the following discussion, the rift-related geologic feature that formed in the mid-Miocene, which includes mafic dike swarms and associated volcanic rocks, is referred to as the northern Nevada rift; the aeromagnetic expression of the northern Nevada rift, which can be used as a proxy to infer concealed portions of the rift or structures that led to its formation, is referred to as the eastern northern Nevada rift; the inferred crustal-scale geologic feature associated with the northern Nevada rift is referred to as the rift crustal feature; the mineral deposit trend itself is referred to as the Battle Mountain–Eureka mineral trend (from Wallace et al., 2004a); and the crustal fault zone along the Battle Mountain–Eureka mineral trend (Grauch et al., 2003a, 2003b) is referred to as the Battle Mountain–Eureka crustal fault zone.



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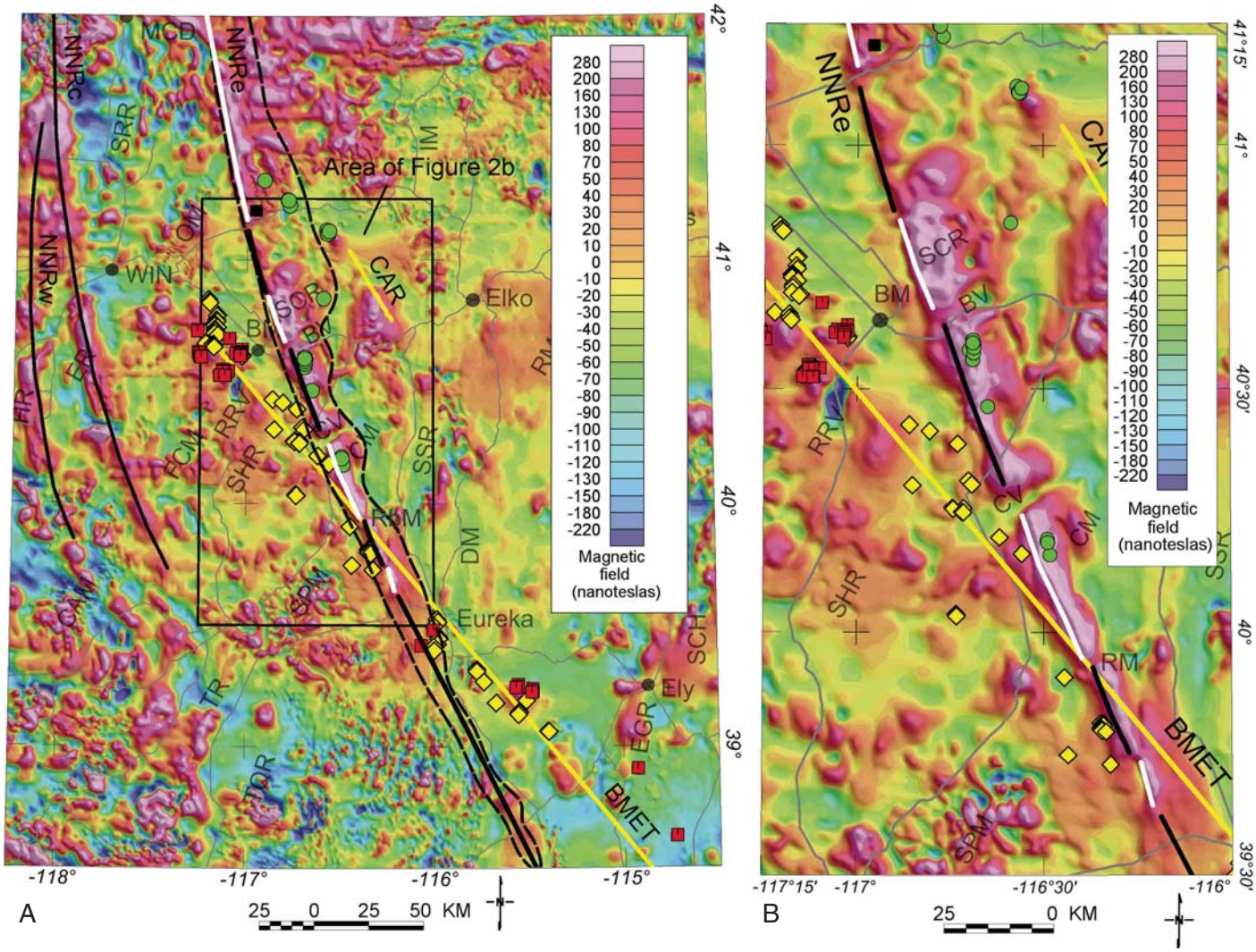


**Figure 2. (A) Aeromagnetic map of north-central Nevada. Inset box shows area of part B. (B) Aeromagnetic map emphasizing the central part of the eastern northern Nevada rift and its segments. Alternating black and white dashed lines—segments; black dashed line—extent of the eastern northern Nevada rift zone (modified after John et al., 2000). See Figure 1 for additional explanation.**

## GEOPHYSICAL DATA AND METHODOLOGY

### Magnetic and Gravity Data

A residual total intensity aeromagnetic map of the study area (Fig. 2) was derived from a new statewide compilation of Nevada (Kucks et al., 2006). Aeromagnetic surveys were flown at various flight-line spacings and altitudes. In general, the aeromagnetic coverage of the study area is fair. Most of the study area was flown at a flight-line spacing of 1.6–3.2 km (1–2 mi) at various flight-line altitudes up to 2.7 km (9000 ft) (Kucks et al., 2006). Aeromagnetic data were corrected by Kucks et al. (2006) for diurnal variations of Earth's magnetic field, either upward or downward continued, if necessary, to a flight-line elevation of 305 m (1000 ft) above the ground, adjusted to a common datum, and merged to produce a uniform map that allows interpretations across survey boundaries (Hildenbrand and Kucks 1988; Kucks et al., 2006). Although the coarse flight-line spacing and, in general, high flight-line elevation of the original surveys may not resolve some magnetic sources lying at shallow depths beneath the surface, there is little impact on the regional nature of our investigations.

An isostatic gravity map of the region (Fig. 3) was derived from a statewide gravity data compilation of Nevada (Ponce, 1997) and augmented with over 2000 new gravity stations collected throughout northern Nevada (e.g., Jewel et al., 2000; Sanger and Ponce, 2003; Scheirer, 2005; Tilden et al., 2005, 2006; Mankinen et al., 2006). All gravity data were reduced using standard gravity methods (e.g., Dobrin and Savit, 1988; Blakely, 1995) to yield isostatic gravity anomalies that emphasize features in the middle to upper crust, having removed long-wavelength variations in the gravity field related to topography (e.g., Jachens and Roberts, 1981; Simpson et al., 1986).

### Gravity Inversion and Basement Gravity

The isostatic gravity map of northern Nevada (Fig. 3) is dominated by anomalies related to low-density basin-filling materials. It is therefore desirable to remove these effects to highlight gravity anomalies associated with pre-Cenozoic basement rocks. This was achieved by using an iterative gravity inversion technique



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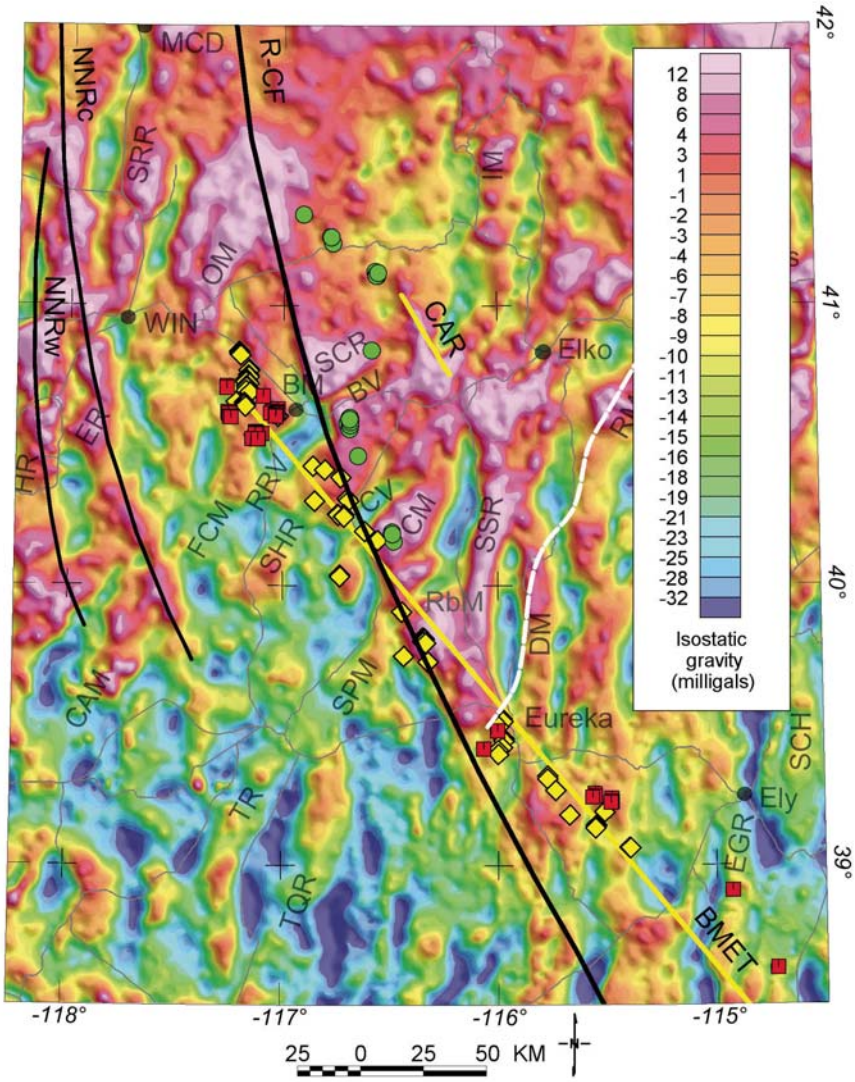


**Figure 3. Isostatic gravity map of north-central Nevada. See Figure 1 for explanation.**

originally developed by Jachens and Moring (1990) and discussed in more detail by them and others (e.g., Blakely and Jachens, 1991; Saltus and Jachens, 1995; Jachens et al., 1996). The inversion process essentially separates the isostatic gravity field into two components: the gravity field generated by less-dense overlying Cenozoic deposits and the gravity field generated by intrusions and pre-Cenozoic basement rocks. The resulting basin gravity field can be used to determine the thickness of Cenozoic deposits in the study area (Fig. 4), and the basement gravity field can be used to identify geophysical features within the basement rocks (Fig. 5). The gravity inversion was constrained by simplified geologic data (Stewart and Carlson, 1978), a density-depth function for Cenozoic deposits (e.g., Jachens and Moring, 1990; Saltus and Jachens, 1995; Jachens et al., 1996); drill-hole information (e.g., Ponce and Moring, 1998; Hess, 2004), and other geophysical constraints (e.g., magnetotelluric data; Rodriguez and Williams, 2002).

### Boundary Analysis

Maximum horizontal gradients of both gravity and magnetic data were generated as an aid to define the edges or boundaries of geophysical sources (Fig. 6). A technique (R.W. Simpson, 2006, oral commun.) similar to that described by Cordell and Grauch (1985) and Blakely and Simpson (1986) was used to calculate locations of maximum horizontal gradients, which reflect abrupt lateral changes in the density or magnetization of the underlying geology. Because the regional magnetic field and the direction of magnetizations are seldom vertical, magnetic anomalies are commonly laterally displaced from their sources, and they often have a more complex form than gravity anomalies, magnetic data were first reduced-to-the-pole and then transformed to their magnetic potential (or pseudogravity) (e.g., Baranov, 1957; Baranov and Naudy, 1964) prior to boundary analysis. The steepest gradients in gravity and magnetic potential-field anomalies typically occur approximately over the edges of their causative sources, especially for shallow sources (e.g., Cordell and Grauch, 1985; Blakely and Simpson, 1986; Grauch and Cordell, 1987; Blakely, 1995); thus, alignments of maximum horizontal gradient locations can be used as an aid to define lineaments, faults, boundaries of geologic features, and geophysical terranes.

### Filtering

Aeromagnetic, isostatic gravity, and basement gravity fields were filtered using a matched band-pass filter (e.g., Syberg, 1972; Phillips, 2001) to separate anomalies produced by the deepest equivalent layer, a gravity or magnetic half space, at depths of 13.5, 4.5, and 13.5 km, respectively. These depths represent the approximate maximum average depth to the top of the sources within each layer (Phillips, 2001). Data were first Fourier transformed and then band-pass filtered by matching the average radially symmetric part of the power spectrum. The data were matched by a three-layer equivalent model that consisted of a shallow layer, an intermediate layer, and a deeper half-space. Note that wavelength separation is not complete, and some long-wavelength components of broad, relatively high-amplitude shallow sources may be present (e.g., Hildenbrand et al., 2000; Phillips, 2001).

## GEOPHYSICAL EXPRESSION

The most conspicuous aeromagnetic anomaly in Nevada is associated with the northern Nevada rift, and the most prominent part of this anomaly occurs between the Nevada-Oregon border and Eureka, Nevada (Fig. 2). Additional studies using profiles of low-level flight-line aeromagnetic data show that the anomaly traverses nearly across the entire state of Nevada (Blakely and Jachens, 1991), and highly processed (filtered) magnetic data indicate that the anomaly extends well into Oregon and Idaho (Glen and Ponce, 2002). Accordingly, the total length of the anomaly is on the order of ~1000 km. The source of the magnetic anomaly is essentially vertical, and the longer wavelengths (Fig. 6A) or deeper parts indicate that the main part of the anomaly is, in general, ~12–15 km



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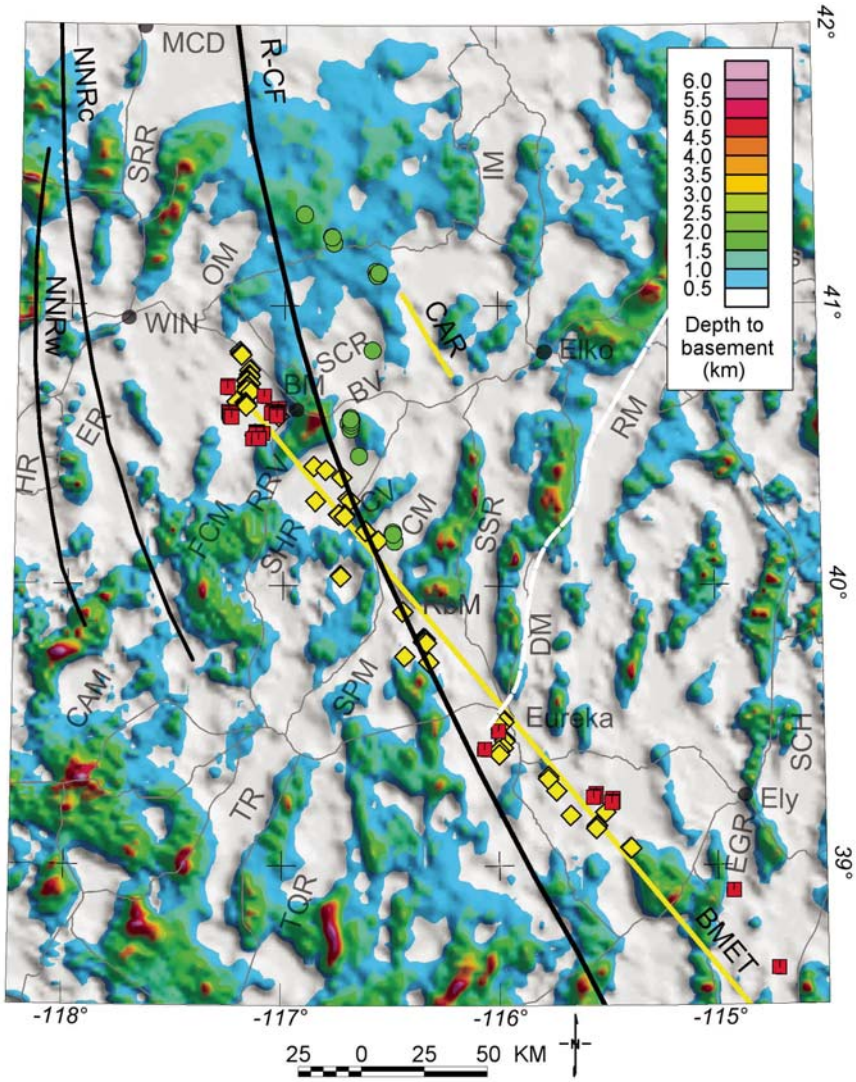


**Figure 4. Depth-to-basement map of north-central Nevada. See Figure 1 for explanation.**

wide in north-central Nevada. Alongside and parallel to the anomaly, magnetic data (Fig. 2) indicate additional magnetic sources associated with the northern Nevada rift. This is particularly evident along the east side of the northern Shoshone Range, as revealed by two- and three-dimensional modeling (Watt et al., 2007). These modeling studies indicate that the eastern northern Nevada rift reflects a major crustal feature that extends to at least mid-crustal depths, and, combined with geologic data, they indicate that the northern Nevada rift and vicinity is characterized by complex structures that could play an important role in localizing fluid flow and mineralization.

The central part of the eastern northern Nevada rift is also characterized by a series of left-stepping segmented magnetic anomalies (Fig. 2A). These segments may reflect later, perhaps Late Miocene, offsets along NE-striking left-lateral cross faults (e.g., Mabey, 1966; Zoback et al., 1994; John et al., 2000). Lateral offsets along four main cross faults range from 1.6 to 3.4 km (Zoback et al., 1994). These segments, of which there may be six or more (Figs. 2A and 2B), vary in length from ~11 to 41 km, and average ~27 km. The largest intervening gaps or distances along strike between these segments occur in Boulder Valley, with a length of ~4 km, and in Crescent Valley, with a length of ~7 km (BV and CV, black and white lines in Fig. 2B).

Although a prominent aeromagnetic anomaly delineates (and defines) the northern Nevada rift, the rift is also expressed in gravity and other derivative gravity maps (e.g., Eaton et al., 1978; Mabey et al., 1983; Blakely, 1988; Saltus, 1988; Blakely and Jachens, 1991; Grauch et al., 1995; Ponce and Glen, 2002). An improved isostatic gravity map (Fig. 3), which includes ~2000 recently collected gravity stations in northern Nevada, highlights the steep gravity gradient in central Nevada that is coincident with the western margin of the northern Nevada rift.

## ASSOCIATED MINERAL DEPOSITS

An alignment of mid-Miocene volcanic rocks, intrusive rocks, and known epithermal gold-silver resources coincides with the trend of the eastern northern Nevada rift (Fig. 1) (e.g., Blakely and Jachens, 1991; Wallace and John, 1998; John et al., 2000; John and Wallace, 2000; Ponce and Glen, 2002). Epithermal gold deposits in the Shoshone Range occur mainly along the apex of the magnetic anomaly (Figs. 2 and 6). Although other epithermal gold deposits are farther away from the apex of the magnetic anomaly, they too essentially lie within the eastern northern Nevada rift zone (Figs. 2 and 6). The deposits in the Shoshone Range formed as the result of hydrothermal activity along the rift during mid-Miocene volcanism over a short time period and are associated with NNW-striking high-angle faults (John et al., 1999, 2003; John and Wallace, 2000). Ore formation took place at or slightly after the end of an early mafic phase of volcanism, and units that formed after this event are unmineralized (John et al., 2000). Because known epithermal gold-silver mineral deposits are spatially and temporally associated with the eastern northern Nevada rift, undiscovered deposits may occur along the extension of the eastern northern Nevada rift into Oregon and along the similar and parallel magnetic anomalies to the west (NNRw, NNRc, Fig. 2). In fact, several middle Miocene epithermal gold-silver deposits occur along the western two magnetic anomalies as well (Ponce and Glen, 2002; Wallace et al., 2004b). Some of these undiscovered deposits might be present beneath younger sedimentary or volcanic cover.

The prominent crustal feature along the northern Nevada rift (R-CF, Fig. 1) is also adjacent to the Battle Mountain–Eureka mineral trend, a Late Cretaceous to Tertiary mineral trend that contains a wide range of mineral deposits, including sediment-hosted as well as pluton-related gold deposits (Roberts, 1966). The Battle Mountain–Eureka mineral trend includes deposits in Buffalo Valley, Battle Mountain, Cortez-Pipeline, Eureka, and White Pine mining districts (e.g., Wallace et al., 2004a). Deposits along the Battle Mountain–Eureka mineral trend were used to define a least-squares regression line (yellow line, Fig. 1) as well as a rectangular area depicting their horizontal extent (transparent rectangle, Fig. 1). Not surprisingly,



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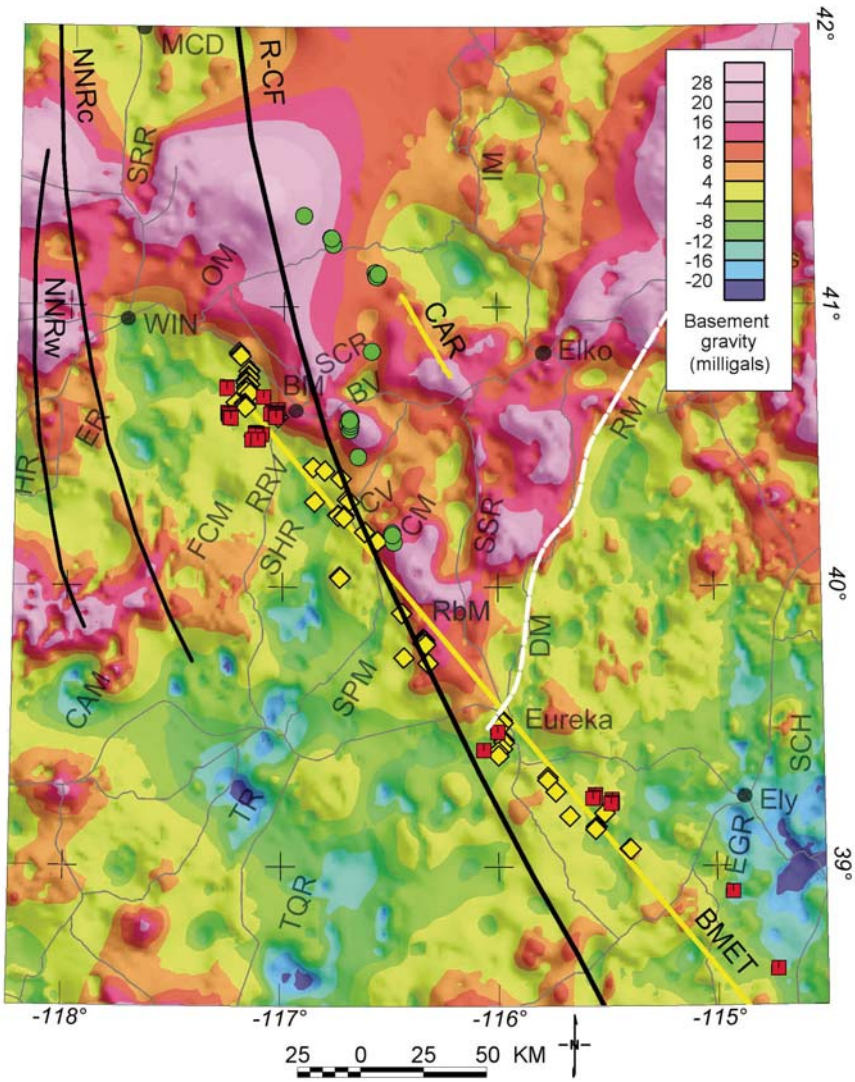


**Figure 5. Basement gravity map of north-central Nevada. White bold dashed line—crustal boundary on east side of V-shaped basement gravity high (e.g., Ponce and Glen, 2002; Grauch et al., 2003a; Ponce, 2004). See Figure 1 for additional explanation.**

the horizontal extent of the Battle Mountain–Eureka mineral trend thus defined is very similar to that originally shown by Roberts (1966) from Battle Mountain to southeast of Eureka, Nevada (dashed line, Fig. 1). The rift crustal feature is especially coincident with the central part of the Battle Mountain–Eureka mineral trend, in between but exclusive of Battle Mountain and Eureka. South of Eureka, the rift crustal feature diverges from the Battle Mountain–Eureka mineral trend, based on mineral deposit locations considered part of the trend (e.g., Wallace et al., 2004a). An associated belt of high arsenic values along the Battle Mountain–Eureka mineral trend, which probably reflects the mobilization of arsenic by hydrothermal fluids from associated plutons, faulting, and mineral deposits (Ludington et al., 2006), also indicates that the Battle Mountain–Eureka mineral trend and the rift crustal feature are separate features south of Eureka. Interestingly, the northern Nevada rift itself is not associated with an arsenic anomaly, even though it is associated with arsenic-rich epithermal gold deposits and reflects a zone of crustal rifting (Ludington et al., 2006).

## DISCUSSION

Combined magnetic, gravity, and basement gravity anomalies in north-central Nevada coincide with the location of the northern Nevada rift (Figs. 2, 3, and 5). Boundary analysis of these geophysical data (Fig. 6) and geophysical modeling indicate that this feature is unusually abrupt and represents a near-vertical crustal-scale structure or fault. Two-dimensional geophysical modeling (Watt et al., 2007) indicates that the northern Nevada rift can be exclusively modeled by upper- and mid-crustal sources that are more extensive than just the northern Nevada rift and associated intrusions, and it cannot be solely accounted for by lower-crustal sources. Geophysical modeling is consistent with the possibility that the northern Nevada rift is contemporaneous with mafic intrusions and perhaps underplating and represents a major lithologic boundary, or both. This crustal boundary appears to be long-lived and related to older Precambrian features or rifting (e.g., Blakely, 1988; Blakely and Jachens, 1991; Grauch et al., 1995; Tosdal et al., 2000; Crafford and Grauch, 2002; Grauch et al., 2003a, 2003b; Sims et al., 2005). Here, we propose that cratonic rocks, mafic intrusions, underplating, or a combination of these, influenced the location of the rift crustal feature in northern Nevada and that the northern Nevada rift, the most prominent of the pervasive rifts associated with the inception of the Yellowstone hotspot, partly followed the margin of this tectonic and structural weak spot. COCORP seismic-reflection data across the northern Nevada rift (Fig. 1, line NV6) indicate that the eastern margin of a broad deep-crustal subhorizontal layered fabric, which may represent mid- to lower-crustal intrusions, coincides with the northern Nevada rift, and that an inclined mid-crustal reflector, which could represent a magma feeder, is also associated with the northern Nevada rift (Potter et al., 1987).

The rift crustal feature appears to be subparallel to and partially coincident with the inferred Battle Mountain–Eureka crustal fault zone (Grauch et al., 1995, 2003a). This is particularly evident along the central part of the Battle Mountain–Eureka mineral trend, southeast of Battle Mountain and northwest of Eureka, Nevada. The association of the northern Nevada rift and the central part of the Battle Mountain–Eureka crustal fault zone suggests that the northern Nevada rift, at least in part, preferentially followed a pre-existing structure. If so, this could bring into question whether or not the northern Nevada rift reflects the mid-Miocene direction of least principal stress (Zoback and Thompson, 1978; Zoback et al., 1994; Glen and Ponce, 2002). On the other hand, the curvilinear pattern of the eastern northern Nevada rift and the parallel features to the west (NNRw, NNRc, Figs. 1 and 2), combined with the results of a superimposed simple model of hotspot and regional stress fields (Glen and Ponce, 2002), which yield a radiating stress pattern near the hotspot that spirals into the regional stress field at distance, indicate that the northern Nevada



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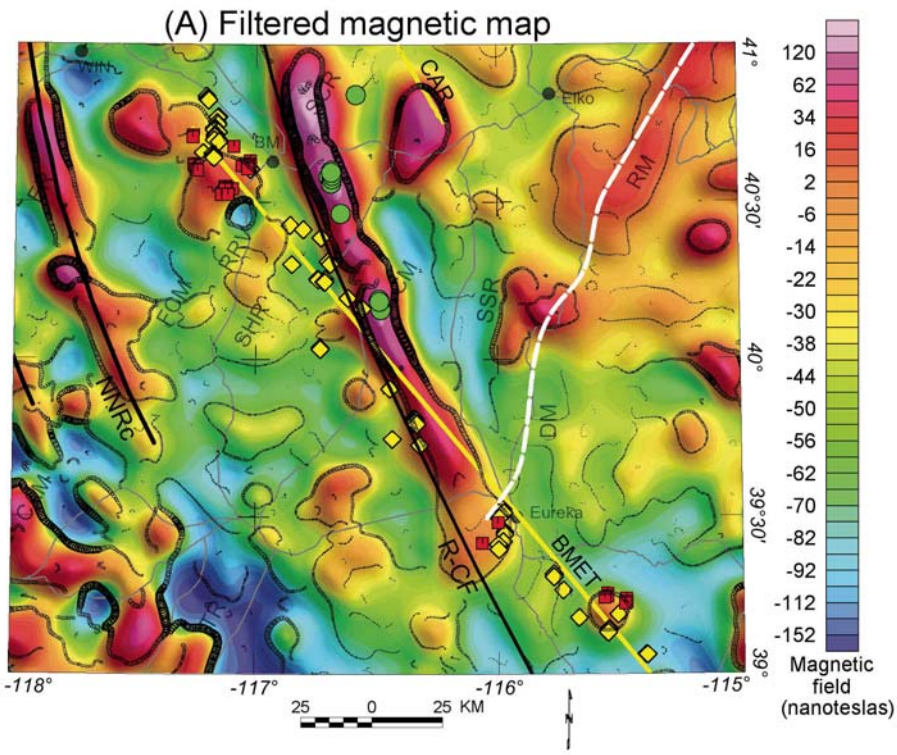


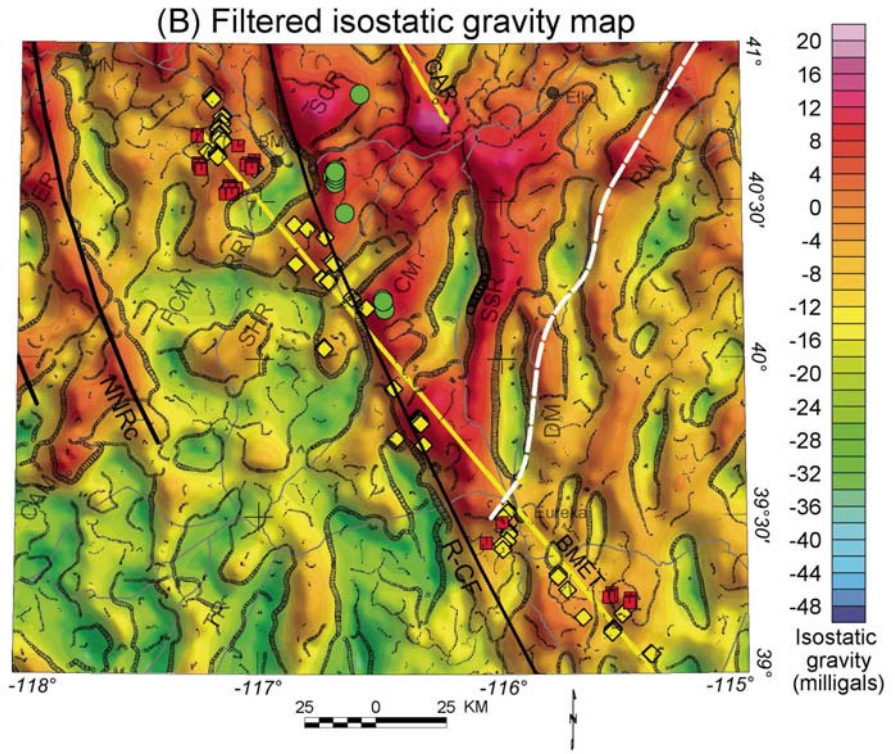


**Figure 6** ***(on this and following page)*****. Filtered (A) magnetic, (B) gravity, and (C) basement gravity maps. Black circles—maximum directional derivatives (size is proportional to magnitude); white bold dashed line—crustal boundary on southeast side of V-shaped basement gravity high (Ponce and Glen, 2002; Grauch et al., 2003b; Ponce, 2004). See Figure 1 for additional explanation.**



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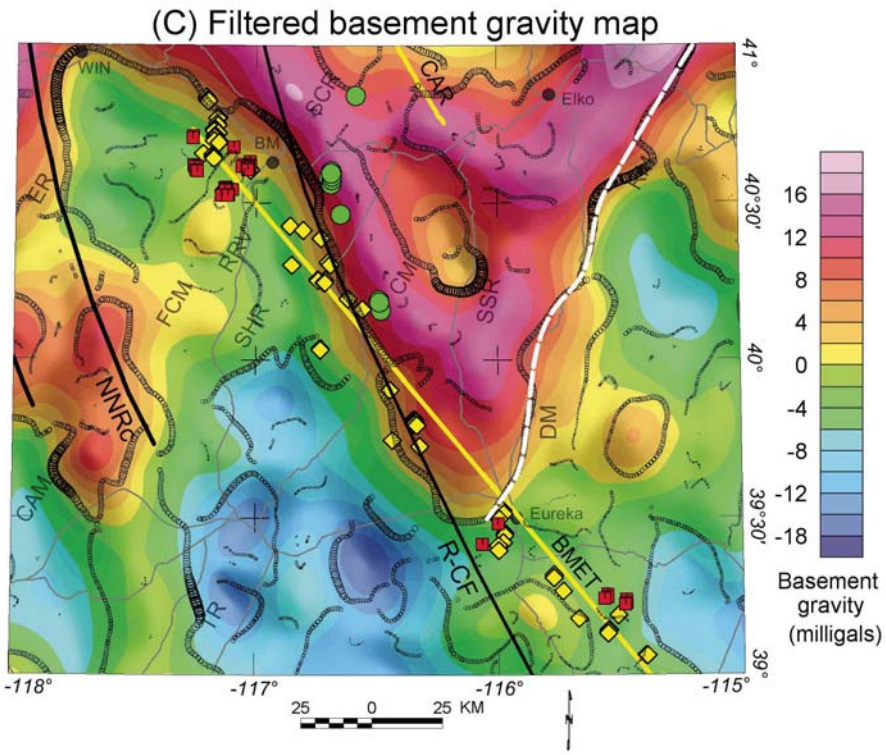


**Figure 6 (*continued*).**

rift likely reflects the mid-Miocene least principal stress direction in north-central Nevada, as first suggested by Zoback (1978), and that it only exploited the Battle Mountain–Eureka crustal fault zone where the two are coincident. During mid-Miocene time, the least principal stress direction was N65°–70°E, essentially perpendicular to the trend of the eastern northern Nevada rift (N22°W) in north-central Nevada, and between ca. 10 and 6 Ma, the least principal stress direction changed to about N60°–70°W, consistent with younger NNE-striking fault offsets along the northern Nevada rift (e.g., Zoback, 1978; Zoback et al., 1994).

The rift crustal feature and the Battle Mountain–Eureka mineral trend clearly deviate from one another only at Battle Mountain and southeast of and including Eureka. Near Battle Mountain, the Battle Mountain–Eureka mineral trend is offset by ~15 km and skewed by ~15–20°W (counterclockwise) from the N22°W trend of the northern Nevada rift. However, if the rift crustal feature and the central part of the Battle Mountain–Eureka crustal fault zone are in fact the same feature, increasing left-lateral offsets on range-bounding cross faults along the rift combined with the opening of Reese River Valley, a prominent depocenter more than 2 km thick (Fig. 5) that occurs between the northern Nevada rift and the Battle Mountain–Eureka mineral trend, could help to explain the divergence of the deposits at Battle Mountain from the rift crustal feature. This is supported by large-scale extension to the west (Wallace, 1991) and southwest (Colgan et al., 2008) of the northern Nevada rift in this area. The magnetic anomaly along the northern Nevada rift appears to be segmented (Fig. 2), and left-lateral offsets (up to several kilometers) by northeast-striking cross faults are exhibited (e.g., Mabey, 1966; Muffler, 1964; Mabey et al., 1978; Zoback, 1978; Zoback et al., 1994). Zoback (1978) estimated that extension may be up to 12 km (or ~20%) in the vicinity of the northern Nevada rift. In addition, the Reese River Valley is one of several basins in central Nevada obviously influenced by the rift crustal feature (Fig. 4), as first noted by Blakely and Jachens (1991), suggesting that the northern Nevada rift affected basin development. If so, the northern Nevada rift likely impacts water resources as well as mineral resources in north-central Nevada.

Alternatively, the left-stepping segmented pattern of magnetic anomalies along the eastern northern Nevada rift (black and white lines, Fig. 2), which is particularly noticeable between the Sheep Creek Range and Eureka, may reflect primary en echelon emplacement of the northern Nevada rift—i.e., originating at the time of intrusion. The left-stepping mid-Miocene Sawtooth dike (black rectangle, Fig. 2), which is within the magnetic anomaly associated with the northern Nevada rift, is suggestive of this, since it is considered to be the result of transform rather than left-lateral fault motion (Zoback and Thompson, 1978; Zoback et al., 1979). If so, this would imply that the northern Nevada rift and its associated mafic intrusions have been virtually unaffected by Basin and Range extension. Conversely, Livaccari (in Zoback et al., 1979) and Wallace (2000) have pointed out that this offset of the Sawtooth dike may be related to minor left-lateral movements along an ENE-striking fault, where the ends of the dike are faulted and dragged after emplacement, and where a small piece of the dike in the fault zone exhibits counterclockwise rotation consistent with left-lateral motion. In any case, the northern Nevada rift and associated basement structure probably act like a rigid keel in the crust, prohibiting extension across it and influencing subsequent Basin and Range development. Colgan et al. (2008) indicate that the basement gravity high in north-central Nevada, northeast of the northern Nevada rift (Fig. 5), partly correlates to an unextended mid-Miocene terrane that has acted as a rigid block and resisted extension. The faulting that possibly controlled the present location of the Battle Mountain deposits would then be necessarily



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restricted westward of the northern Nevada rift in a highly extended area.

At Eureka, deposits along the Battle Mountain–Eureka mineral trend are clearly on the east side of the rift crustal feature south of about latitude 39.5°N, a location that also marks a dramatic change in the character of the associated magnetic and basement gravity anomalies (Figs. 2 and 5) (e.g., Blakely, 1988; Blakely and Jachens, 1991; Zoback et al., 1994). Here, deposits along the Battle Mountain–Eureka mineral trend may, in part, be a local phenomena related to the intersection of the NW-trending rift crustal feature and a NE-trending basement gravity feature (V-shaped anomaly, Fig. 6C). Interestingly, there is a difference in the ages of pluton-related deposits along the Battle Mountain–Eureka mineral trend: deposits at Eureka are predominantly Cretaceous, whereas those near Battle Mountain are predominantly Eocene (e.g., Table 7-1, *in* Theodore et al., 2004). Ages of Carlin-type (sediment-hosted) deposits associated with the Battle Mountain–Eureka mineral trend are difficult to determine but, in general are similar in age and range from 42 to 30 Ma for the Great Basin (Hofstra et al., 1999; Arehart et al., 2003). For example, Yigit et al. (2003) indicated that mineralization at the Gold Bar deposit along the Battle Mountain–Eureka mineral trend in the Roberts Mountains (Fig. 1), is between 37.5 and 24 Ma. Deposits farther southeast of Eureka are not strongly associated with a prominent geophysical feature and may be unrelated to the rift crustal feature, Battle Mountain–Eureka mineral trend, or Battle Mountain–Eureka crustal fault zone.

Although the broad basement gravity feature that extends across northern Nevada (V-shaped anomaly, Figs. 5 and 6C) may be related to a pre-Cenozoic geologic structure (e.g., Grauch et al., 1995, 2003a; Tosdal et al., 2000), it is also continuous with the gravity expression of the Snake River Plain apron of volcanic rocks (Glen et al., 2004) and with the NE extension of the Battle Mountain heat-flow high (e.g., Lachenbruch and Sass, 1978; Sass et al., 1981; Blakely, 1988), which suggest that the source of the basement gravity anomaly is hotspot-related, mid- to subcrustal mafic intrusions and underplating. Either way, the basement crustal boundary probably played a major role in controlling and influencing subsequent mineralization and tectonic events in north-central Nevada (e.g., Grauch et al., 1995, 2003a; Hildenbrand et al., 2000; Tosdal et al., 2000; Crafford and Grauch, 2002).

## CONCLUSIONS

A prominent combined magnetic, gravity, and basement gravity feature in north-central Nevada is coincident with the western margin of the eastern northern Nevada rift, a long arcuate magnetic anomaly associated with a mid-Miocene mafic dike swarm. Geophysical modeling and boundary analysis indicate that this feature is an abrupt, near-vertical crustal-scale structure. Part of this geophysical feature also appears to be subparallel to and partially coincident with an inferred crustal fault zone along the central part of the Battle Mountain–Eureka mineral trend in between but exclusive of Battle Mountain and Eureka.

At Battle Mountain and southeast of and including Eureka, the geophysical feature and the Battle Mountain–Eureka mineral trend clearly deviate from one another. If the crustal faults along the mid-Miocene northern Nevada rift and the central part of the Eocene and older Battle Mountain–Eureka mineral trend are in fact the same feature, deposits at a greater distance from the crustal feature associated with the northern Nevada rift at Battle Mountain could be explained by postemplacement tectonic events. However, those deposits near Eureka may be related to the intersection of two crustal-scale faults. The association of the northern Nevada rift and the central part of the crustal fault zone along the Battle Mountain–Eureka mineral trend suggests that the location of the northern Nevada rift was at least in part preferentially influenced by a pre-existing structure.

Although the broad basement gravity feature in northern Nevada is likely related to a pre-Cenozoic geologic structure, its continuity with a broad gravity high extending from the Snake River Plain suggests that the source of the anomaly is, in part, related to hotspot magmatism. This implies that the extent of underplating was either limited by northern Nevada rift diking that tapped subcrustal magmas or that hotspot magmatism was guided and influenced by pre-existing structures. In any case, these large-scale crustal features are important to understanding the metallogeny, tectonics, and magmatism of the Great Basin, as well as water and environmental issues.

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