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REGIONAL GRAVITY AND MAGNETIC ANONALIES IN THE NORTHERN BASIN AND RANGE PROVINCE

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Abstract

The distribution of gravity stations in the northern Basin and Range Province is adequate to define regional anomalies and the more important features of most of the major local anomalies. These gravity data have been combined with digital topographic data to produce complete Bouguer, free-air and Airy-type isostatic maps. The Bouguer anomaly maps are dominated by the inverse relation with regional topography and by local gravity lows produced by thick accumulations of low-density Cenozoic rocks. Filtered versions of the Bouguer anomaly data enhance both regional and local anomalies. Free air and isostatic anomalies indicate that the region is in approximate isostatic equilibrium. Most of the individual basins and ranges are not locally compensated, but regional topographic features a few tens of kilometers in extent appear to be compensated. Isostatic highs are associated with the Lake Bonneville basin and a zone across northern Nevada.

Aeromagnetic data from numerous surveys have been merged to produce a map of the magnetic field at 3810 m above sea level. The map shows that the major magnetic anomalies over the northern Basin and Range Province are associated with Phanerozoic igneous rocks and only in a few areas is there evidence of an older magnetic basement. Several zones of magnetic anomalies are apparent, such as those reflecting west-trending belts of igneous rocks in western Utah and the Tertiary rift in north-central Nevada. The magnetic data delineate large crustal units with contrasting magnetic signature.

The regional gravity data in the northern Basin and Range Province for the most part reflect the distribution of late Cenozoic masses in the upper crust and the state of isostatic equilibrium. Gravity data can be combined with the seismic refraction data to provide control on the nature of isostatic compensation. The magnetic anomalies provide information on the formation of the crust and on temperature variations within the lower crust. Together the data indicate that the crust of the region is thinner, hotter, more mobile and generally less complexly magnetized than the crust of the craton to the east.

Introduction

For over thirty years gravity and aeromagnetic surveys have been an important part of many geologic programs in the northern Basin and Range Province. In the last few years, gravity and magnetic data from many of these programs have been merged into digital data sets that provide good regional coverage over most of the province. With these data sets computers and plotters can be used to prepare maps and other presentations of the data in a variety of forms. These data combined with digital topography and other sets of digital geological and geophysical data are powerful tools for studying the geology and resources of the province. Gravity and magnetic methods are useful in exploration programs by contributing to the definition of the present geology and also by helping to understand the geologic development of the region. Much work remains to be done with these important data sets. This report describes the major gravity and magnetic anomalies and discusses the possible geologic significance of some of the more prominent features.

The geophysical data come from many sources. The basic gravity set is from the U.S. Geological Survey and Department of Defense files and includes the data from surveys by hundreds of individuals and groups (Oliver and others, 1982; Snyder and others, 1982). The magnetic data set is built around a compilation of Nevada data by Sweeney and others (1978). The present set was compiled by Hildenbrand and others (1983). Most of the magnetic data are from surveys done by or for the U.S. Geological Survey. The original data used to develop both the gravity and magnetic data sets are of varying quality. Many of the earlier surveys were made with instruments that were not well calibrated and the observations were not always referenced to an absolute datum. Much work was involved in merging the individual surveys into the regional data sets. We (the authors) have been involved in all phases of the work and are convinced that the accuracy of the data sets is consistent with the presentations and interpretations in this report.

Various aspects of the regional geology of the northern Basin and Range Province are described in other reports in this volume and will not be repeated here. Both the gravity and magnetic fields over the northern Basin and Range Province reflect geologic events that occurred from very early geologic time to the present. Most of the larger gravity anomalies reflect mass anomalies related directly to the extensional tectonics that has dominated the province in late Cenozoic time. In the central and eastern part of the province the leading cause of the magnetic anomalies is Cenozoic intrusive and extrusive rocks, but in the west the pattern of magnetic anomalies is more complex and reflects rocks and structures with a much wider range of ages.

The gravity and magnetic anomalies associat with Cenozoic events are superimposed on anomalies related to earlier events, and the older anomalies are often difficult to identify. Not only have the older anomalies been submerge in the Cenozoic anomalies, but some anomalies a destroyed or severely altered by geologic processes. For example, isostatic processes wo to reduce regional gravity anomalies, and heati of the lower crust above the Curie temperature magnetite eliminates most of the magnetic anomalies from this zone. Identifiable gravity and magnetic anomalies might be found that rela to any of the major events in the formation of the crust of the northern Basin and Range Province, particularly those that involved igneous events and those that juxtaposed rocks different density or magnetization. Also, gravity anomalies directly or indirectly reflecting the condition of the upper mantle should be discernible. However, such deep effects produce broad anomalies at the earth's surface that may be difficult to separate from those associated with isostasy.

Gravity Data

Gravity data from land areas are most commonly presented as simple or complete Bougue anomaly maps or profiles. The complete Bouguer anomaly map (Fig. 1) was prepared by reducing th gravity data to a sea-level datum assuming a density of 2.67 g/cm^3 for the material above the datum. The resulting anomalies reflect all mass anomalies below sea level and any departure from 2.67 g/cm^3 density above sea level. The dominant regional Bouguer anomalies in the northern Basin and Range Province have a pronounced inverse correlation with regional topography. This correlation reflects the general isostatic equilibrium of the region. Th mass anomalies reflected by the regional gravity anomalies include variations in crustal thicknes and variations in the density of the crust and upper mantle. Although the correlation between gravity anomalies and regional topography was recognized by the first interpreters of data fr the region, much work remains to be done before the full significance of this correlation is understood. The dominant local gravity anomalie are lows produced by thick accumulations of low-density Cenozoic rocks within the structural basins of the region and volcanotectonic depressions. In addition to providing a quick and relatively inexpensive technique for estimating the distribution and thickness of the Cenozoic rocks, gravity surveys provide importar information on the Cenozoic structures. More subtle gravity anomalies are produced by Cenozoi igneous rocks and by mass anomalies within the older rocks.

The gross symmetry of Bouguer anomaly and regional topography over the northern Basin and Range Province was discussed by Eaton and others (1978). The low gravity and high topography of the Sierra Nevada on the west and the Wasatch Range and Colorado Plateau on the east are

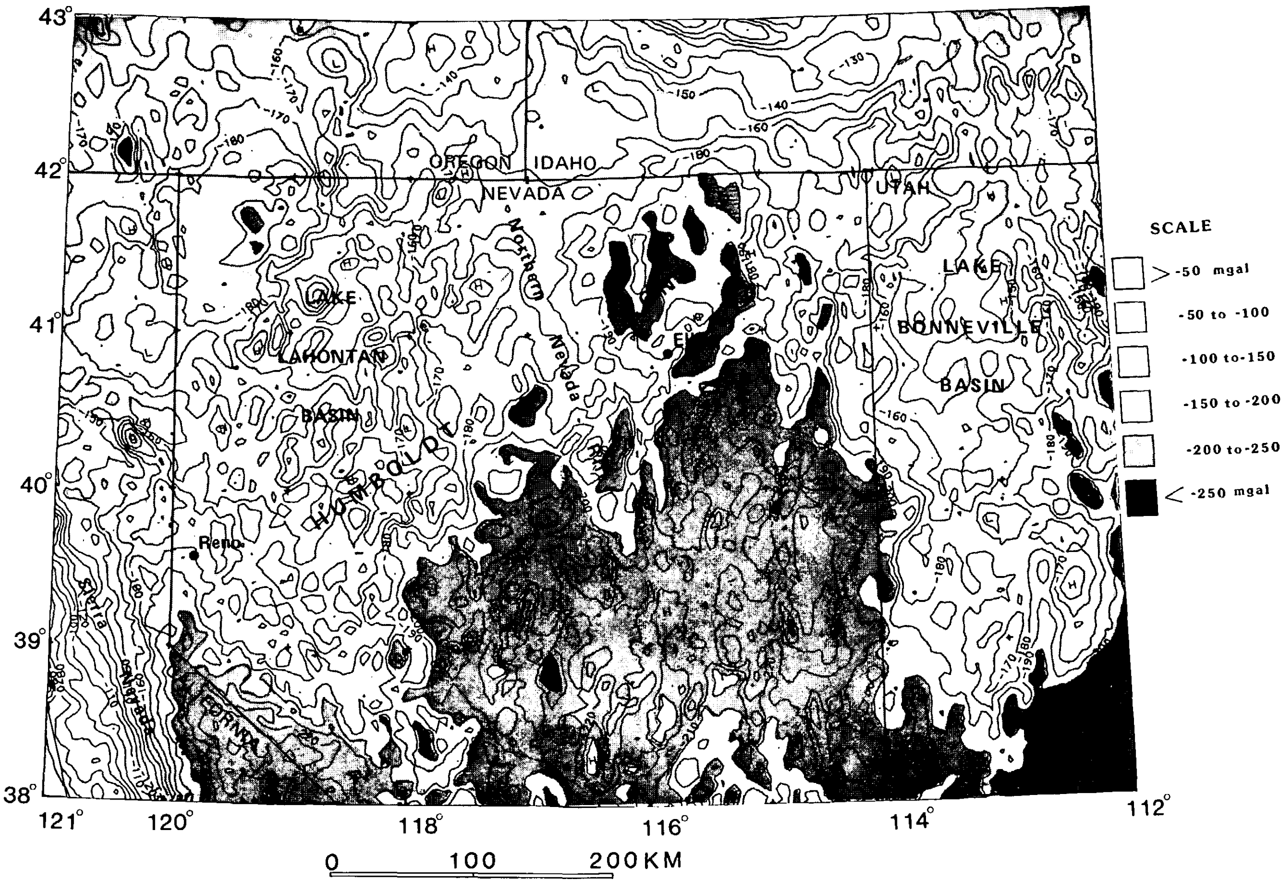

Figure 1. Complete Bouguer gravity anomaly of the northern Basin and Range Province - reduction density 2.67 g/cm^3

bordered by the high gravity and low elevations of the Lake Lahontan and Lake Bonneville basins. The symmetry is best developed in the south-central part of the northern Basin and Range Province where the regional topographic high and gravity low are divided by the north-trending axis of symmetry. To the north, this pattern is less well developed and subject to conflicting descriptions. Eaton and others (1978) proposed an eastward offset of the axis of symmetry in the north and a possible extension into central Idaho. However, the symmetry is severely disrupted by the northeast-trending Humboldt Zone and any extension to the north is poorly defined. Wave-length filtering of the Bouguer anomaly can be used to emphasize anomalies of different extent (Hildenbrand and others, 1982). A long-wavelength anomaly map emphasizes the north- and north-northwest-trending anomalies involved in the symmetrical pattern, and the complementary short-wavelength anomaly map emphasizes the trends of the local anomalies produced by the Basin and Range structures and some of the mass anomalies in the pre-Tertiary rocks.

Isostatic anomalies are computed by removing a calculated gravity effect related to the regional topography. This can be done either by assuming a direct correlation between the regional topography and the measured Bouguer anomaly or by assuming a model for isostatic compensation and using the model to compute the gravity effect of isostatic compensation for the regional topography. An isostatic anomaly map shows the gravity effect of uncompensated masses and departures from the model assumed in computing the anomaly and helps to isolate small but broad intracrustal gravity anomalies that tend to be lost in the larger effects of isostasy. Recent studies in California have shown that the isostatic anomaly map reveals anomalies that are not apparent on the Bouguer anomaly map (Oliver and Robbins, 1982, fig. 2; Jachens and Griscom, 1982) and provides a basis for comparing anomalies that occur in widely differing topographic regimes (Oliver and others, 1982, table 1).

The isostatic map included here (Fig. 2) is based on the Airy model assuming a crustal thickness of 25 km at sea level and a density contrast of 0.4 g/cm^3 between the crust and upper mantle. Varying these assumptions produces significant changes in the isostatic anomalies in the northern Basin and Range Province, although local gravity differences are insensitive to the assumed parameters. Free-air anomalies can also be used to investigate isostatic phenomena and may be thought of as isostatic anomalies with a sea-level depth of compensation. In the Basin and Range Province, however, the free-air anomaly is strongly dependent on the elevation of the gravity station, and regional free-air anomalies must be used with care to be certain that the observations provide a representative sample. Adjusting the free-air anomaly for the differenc between the station elevation and the regional elevation results in a kind of isostatic anomaly (Mabey, 1966a).

The isostatic anomaly map shows most of the regional and local anomalies apparent on the Bouguer anomaly map, but the amplitudes of the regional anomalies are greatly reduced. Important features to note on the isostatic map are the prominent high over the Lake Bonneville basin, the high along the axis of symmetry and its extension to the north, and the generally high zone across northern Nevada excluding the northwest corner.

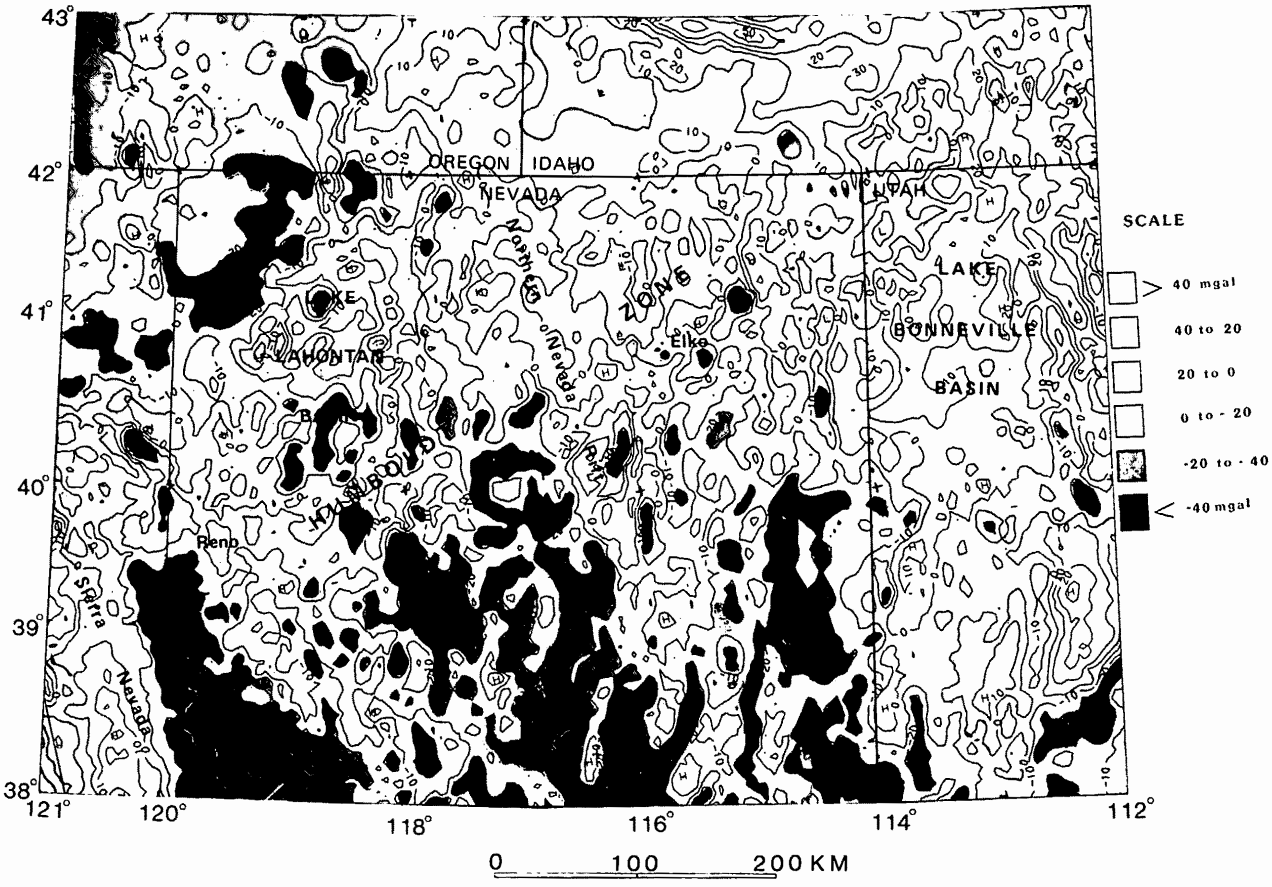

Figure 2. Isostatic anomaly map of the northern Basin and Range Province. Based on an airy model with reduction density of 2.67 g/cm^3, 25 km crust at sea level and a 0.4 g/cm^3 density contrast at the base of the crust.

Magnetic Data

The residual magnetic anomaly map (Fig. 3) portrays the total magnetic intensity at 3810 m above sea level with a reference field removed. Figure 3 at top of next page. This level is about 2000 m above the general land surface; thus, many of the local near-surface anomalies are effectively filtered out of the map. The residual anomaly map reflects large masses of contrasting magnetization lying above the Curie isothermal surface for magnetite. The Curie temperature of magnetite may range from 350°C to 580°C depending on the amount of titanium in the spinel structure (Nagata, 1961, fig. 3-10; Ade-Hall, 1964). The magnetic anomalies as they appear on the residual anomaly map and defined in the digital data do not reflect an internally consistent measure of the magnetic field. Differences in flight level and line spacing of the numerous surveys involved, the digitization and the projection of the data to a common plane produce systematic variations in the data that do not reflect geologic anomalies. Any operation on the data set or the map, such as filtering or quantitative analysis, must take this into account.

Over the northern Basin and Range Province magnetic anomalies reflecting the Precambrian crystalline basement are much less apparent than over the craton to the east of the province. This dearth of anomalies can be attributed to three factors: (1) The generally great depth of burial of the basement in the northern Basin and Range Province and the high level of projection (3810 m above sea level) combine to reduce the apparent magnetic effect of basement features. (2) Much of the basement underlying the province is younger and less complexly magnetized than the area to the east of the province. (3) High heat flow over most of the province has elevated the Curie isothermal surface and thinned the magnetized crust.

Most of the individual magnetic anomalies in the northern Basin and Range Province except in northwestern Utah are produced by Phanerozoic igneous rocks; at the level of the residual map, intrusive rocks are the dominant source. In northwest Utah several magnetic highs appear to reflect Precambrian basement rock. South of this zone of Precambrian anomalies the most prominent magnetic features are west-trending zones of magnetic anomalies (MB, fig. 3) produced by

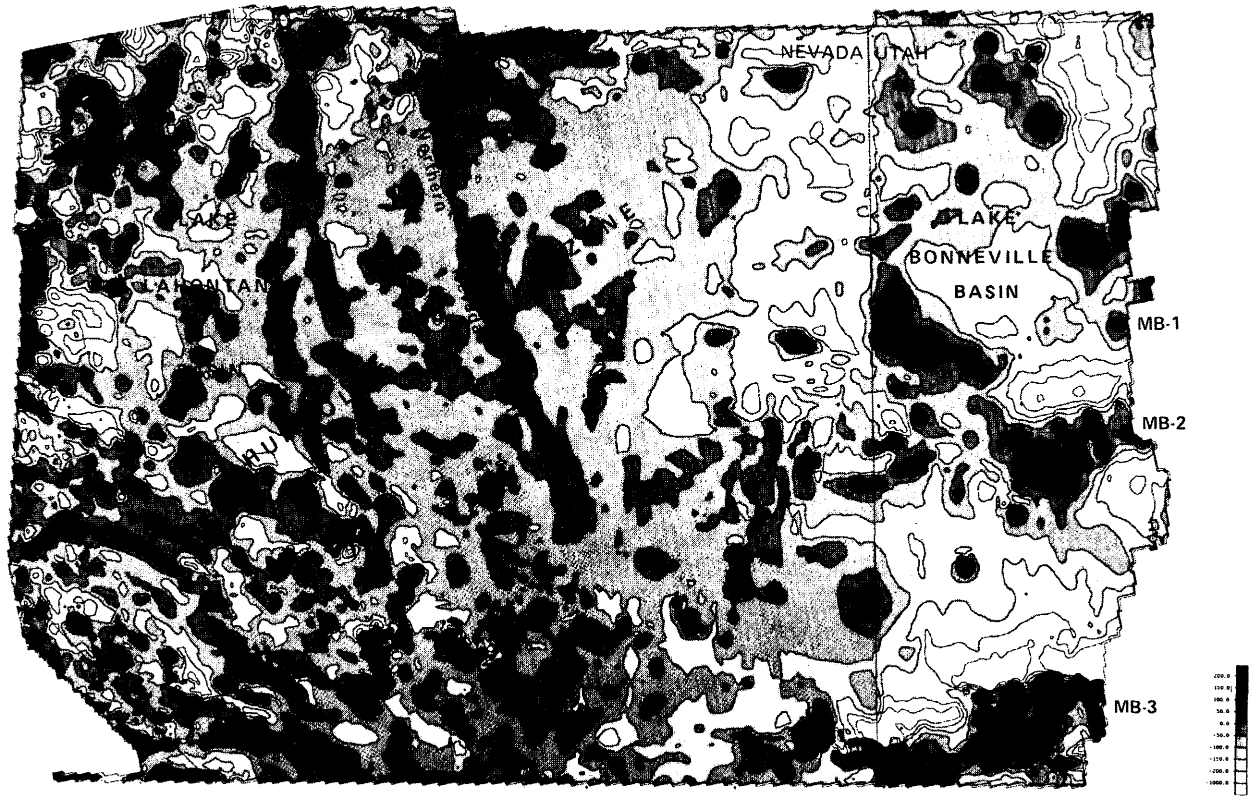

Figure 3. Residual aeromagnetic map of northern Nevada and northwest Utah. Based on numerous surveys merged to a common datum and projected to 3810 meters above sea level.

Tertiary intrusive rocks in major mineral belts. West of these anomalies is the "quiet zone" of Stewart and others (1977, fig. 5) with few large anomalies. One of the most prominent magnetic features is produced by a north-northwest- trending Tertiary rift in north-central Nevada. In the western part of the province the magnetic anomalies are produced by rocks with a wide range of ages, but the trend of many of the anomalies reflects, in large part, Cenozoic structures. (For discussions of the correlation of magnetic anomalies in this region to geology see Stewart and others, 1977, and Mabey and others, 1978).

Interpretation

The eastern margin of the northern Basin and Range Province is approximately coincident with the Cordilleran hingeline. The Cordilleran hingeline, Wasatch line, and hingeline are different terms referring to the zone that formed the eastern margin of the Cordilleran geosyncline and has persisted as a major geologic boundary (Stokes, 1976). The hingeline is expressed in a number of ways throughout Phanerozoic time, and although geologic evidence for a major structure at this location in Precambrian time is not compelling, the structure was well developed in Cambrian time and likely began to develop earlier. The hingeline and the province boundary are marked by a large eastward decrease in Bouguer anomaly values and a rise in regional elevation. Both primarily reflect an eastward thickening of the crust (Thompson and Zoback, 1979). East of the hingeline are large regional magnetic anomalies produced by the Precambrian basement rocks of the North American craton. This contrast suggests a fundamental difference in the basement across the hingeline. A notable exception is in northwest Utah where a band of moderately magnetized Archean rocks extends into the Basin and Range Province. Strontium-isotope ratios indicate that the western edge of the sialic Precambrian basement lies near the center of the province (see Kistler and others, this volume); however, the magnetic data indicate that the crust lying between the hingeline and the edge indicated by the isotopic data has had a different magnetic history from the area to the east.

The western edge of the sialic Precambrian crust indicated by the isotopic data is approximately coincident with the western edge of the quiet magnetic zone in eastern Nevada. That part of the continental crust accreted since Precambrian time is more complexly magnetized than the crust immediately to the east. No pronounced gravity anomaly is coincident with the inferred edge of the Precambrian crust. Apparently, any major difference in crustal thickness or density across the edge is in approximate isostatic equilibrium. Most of the changes in crustal thickness that are reflected in the Bouguer anomaly probably relate to crustal thinning in Cenozoic time, but older contrasts in the composition and structure of the crust may control the amount and nature of thinning that has occurred in response to the regional tension.

Major igneous events during Paleozoic time were confined to the western part of the northern Basin and Range Province while sedimentary rocks were deposited over most of the province. Part of the complex magnetic pattern in the west may reflect these igneous events, but few magnetic anomalies that can be attributed to Paleozoic events can be identified elsewhere in the province.

Most of the igneous and sedimentary rocks of Paleozoic age in the northern Basin and Range Province are well indurated. The volcanic and carbonate units are generally more dense than the clastic units. Where Paleozoic rocks of contrasting density are juxtaposed by structures, such as the Roberts Mountains thrust, gravity anomalies exist, but they are low in amplitude and difficult to isolate from the much higher amplitude anomalies produced by younger rocks and structures.

As the North American plate began to move westward in Mesozoic time, a volcano-plutonic terrane developed in an arc environment in the western part of the province, and large batholiths related to the Sierra Nevada batholith developed. Numerous magnetic anomalies are produced by these igneous rocks. Some of the batholiths produce large gravity lows and the smaller igneous units produce both gravity highs and lows depending on the density contrast with adjacent rocks. Some of the Mesozoic intrusions produce large magnetic highs.

In the central and eastern part of the province are scattered igneous intrusions and extensive nonmarine sedimentary rocks of Mesozoic age, including evaporites. The Sevier orogeny near the end of the Mesozoic involved major thrusting with generally older, denser rocks moving relatively eastward over younger rocks. Gravity anomalies associated with the thrust faults and related tear faults are generally low amplitude but can be identified in regional surveys. To the west of the thrust belt a zone of metamorphic core complexes developed. The core complexes are usually topographic highs with associated regional Bouguer anomaly lows and modest magnetic highs. The Sevier orogeny probably thickened the crust along the Cordilleran hingeline and produced both a regional Bouguer anomaly low and isostatic anomaly high. Parts of these anomalies may have persisted to the present.

During early and middle Cenozoic time the eruption of silicic volcanic rocks was widespreac over the northern Basin and Range Province. The volcanism started in the north and generally progressed southward over a period of about 20 million years (Stewart and Carlson, 1978). In western Utah the progression was in three clearly defined steps that produced three igneous belts (MB1, MB2, MB3, fig. 3). These belts, which are clearly expressed on the regional anomaly magnetic maps, contain abundant intrusive rock and related mineral deposits. Farther west the distribution of igneous rocks and related magnetic anomalies is more diffuse. However, the east-west grain is apparent across Nevada consisting primarily of "interruptions" of magnetic anomalies (Fuller, 1964 and Mabey and others, 1978). Some of these linear features coincide with structural lineaments described by Ekren and others (1976), who concluded that the lineaments reflect pre-Oligocene structural trends. Clearly, deep east-trending structures have controlled Tertiary igneous events. The best geophysical evidence for these east-trending structures is the magnetic anomalies; however, there is subtle expression of some of them in the gravity anomalies. Important mineralization is related to this extensive igneous activity over much of the province. The northern Basin and Range Province probably developed as a crustal unit during this time, but the rapid extension that has characterized the province in Neogene time does not appear to have been widespread then.

Regional extension of the northern Basin and Range Province became widespread after about 17 m.y. ago. At the beginning of this extension the crust was probably thicker and more competent than now. Numerous older structures including large uncompensated mass anomalies controlled response to the extension. One of the first features to form in response to the regional extension was the northern Nevada rift.[1] The rift is expressed by one of the most prominent magnetic anomalies in the province, which is produced by basalt flows, a near-surface swarm of basalt dikes, and a deeper large dikelike mass. A low-amplitude regional gravity high is coincident with the rift and extends south beyond the magnetic and surface expression of the rift. Eaton and others (1978) recognized that the southern part of the axis of symmetry of the Bouguer anomalies and topography coincided with part of the rift but concluded that to the north the axis was offset eastward from the rift. The positive mass anomaly associated with the rift is reflected by an isostatic high. We propose that the isostatic high defines the axis of symmetry and that it is coincident with the northern Nevada rift throughout the length of the rift.

[1]The magnetic evidence of a Tertiary rift in northern Nevada was first reported by Mabey (1966b) and modeled by Robinson (1970), but it was not named in those reports. Mabey and others (1978) applied the name Cortez rift to the feature, and Zoback and Thompson (1978) called it the northern Nevada rift. Mabey here proposes that the name northern Nevada rift be accepted.

Later in Miocene time thick sections of non-marine sedimentary rocks accumulated in local basins. In the northeast part of the province the distribution of the sedimentary rocks over some of the ranges suggests that the Miocene basins were wider than the present basin and range basins. If the brittle part of the crust was thicker in the Miocene than now, the Miocene normal faults likely penetrated the crust to a greater depth and at a higher angle than do the younger basin and range faults. As the crust thinned, mass anomalies that had formed earlier but had been held in vertical position by the strength of the crust now moved vertically to achieve a degree of local isostatic equilibrium. Most topographic features more than about 25 km wide are in approximate isostatic equilibrium. The Lake Bonneville basin may be an example of a positive mass anomaly that, in response to isostatic forces, subsided relative to the surrounding areas. The sensitivity of this basin to isostatic forces is demonstrated by the subsidence and rebound when the water load of Lake Bonneville was applied and then removed (Crittenden, 1963).

The local gravity and magnetic anomalies in the northern Basin and Range Province are two important sources of information on the basin-and-range structure. The gravity lows produced by the low-density basin fill indicate the approximate depth and configuration of the basins and the location of the major normal faults. The basin fill is often several kilometers thick and produces gravity lows of more than 70 mgal (Oliver and others, 1982). Density variations within the basin fill and problems in isolating the gravity effect of the fill from effects produced by the underlying older rocks often determine the limit to which a quantitative analysis can be carried.

Magnetic data usually indicate if the basin fill includes abundant volcanic rock and if normal faults displace a magnetic basement. Idealized gravity and magnetic profiles across basin-and-range structures in the eastern and western parts of the province are shown in Figure 4. In the east the Bouguer gravity anomalies primarily reflect two sources: the near-surface basin-and-range structure and a deeper source that is the compensating mass for the regional topography. Generally, the basin-and-range structures in the east are not apparent in the magnetic data. This pattern of gravity and magnetic anomalies is suggestive of a system of listric faults that do not displace major density or magnetization horizons. In the west both the gravity and the magnetic patterns are more complex. In addition to gravity anomalies produced by the shallow and deep structures, there is evidence of intermediate- depth sources. Some basin-and-range structures are also reflected in the magnetic data with highs over the ranges. The normal faults appear to juxtapose pre-Miocene units of differing

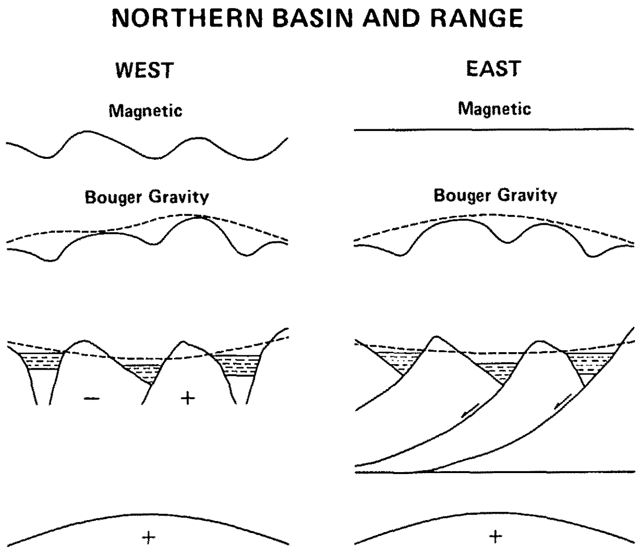

Figure 4 - Diagram of generalized gravity and magnetic anomalies over basin and range structures in northern Basin and Range Province. Positive mass anomalies indicated by + and negative by - .

density and magnetization. Density and magnetization differences are common in pre-Tertiary rocks of this part of the province. The pattern of the gravity and magnetic anomalies suggests but does not prove that the faults penetrate to greater depths than the faults in the east. In northwest Nevada the northeast structural grain of the Humboldt zone (Mabey and others, 1978) influenced the trend of the faults which are generally northeasterly rather than normal to the direction of extension and thus involve considerable strike-slip movement, a style of faulting that also argues against a listric character. In southwest Nevada complex interaction has occurred with deformation related to the San Andreas fault system.

Most of the known hydrothermal convection systems in the northern Basin and Range province are controlled, at least in part, by normal faults. Deep circulation within normal fault zones is commonly thought to be an essential element of the systems. Many of the systems are located where there is evidence for anomalous geometry of the fault zone. For example, the hot springs along the Wasatch Range are at salients where the faults may depart from the listric pattern that is inferred to be characteristic elsewhere.

Only a few igneous events have been associated with the last few million years of extension of the northern Basin and Range Province. Important exceptions are the southwest and southeast edges of the province. Here major eruptions of silicic volcanic rocks and basalt have occurred, and some of these igneous systems appear to still be active. Some of the volcano-tectonic depressions produce large gravity lows, and magnetic anomalies are produced by the extrusive rocks. These young igneous events are important in the development of the geothermal resources of the province.

Conclusions

Gravity and magnetic anomalies in the northern Basin and Range Province can be related to the development of the upper crust. Understanding the development of the geophysical anomalies contributes to understanding the geologic processes that have operated in the province. Quantitative interpretation of the anomalies often helps define the present geology. The digital data sets have opened important opportunities for using the geophysical data in a variety of investigations that will make major contributions to the knowledge of the geology of the province. These include the use of filtered maps to isolate anomalies with distinctive trends and wave-lengths and the preparation of isostatic maps with a range of compensation depths and densities.

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