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MAPS SHOWING GRAVITY AND AEROMAGNETIC ANOMALIES IN THE BUTTE 1° × 2° QUADRANGLE, MONTANA

By

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CONTENTS

CUSMAP NOTE

This report is one of a series of reports that present, chiefly with maps at a scale of 1:250,000 and 1:500,000, various aspects of the geology, geochemistry, geophysics, and mineral resources of the Butte 1°×2° quadrangle, southwestern Montana (Elliott and others, 1993). These studies were made mostly under the Conterminous United States Mineral Assessment Program (CUSMAP), the primary purpose of which is to determine the mineral resource potential of selected 1°×2° quadrangles by means of a multidisciplinary approach. The program is intended to provide information on mineral resources to assist Federal, State, and local governments in formulating minerals policy and land-use policy and to produce sound scientific data that may be of value to private industry and the general public in mineral exploration and development.

INTRODUCTION

The Butte quadrangle is characterized by gravity and magnetic anomalies that are useful for making a regional assessment of mineral resources. These anomalies, or perturbations of the earth's gravity and magnetic fields, are caused by lateral variations of rock density and magnetization in the subsurface. These variations translate into information about rock compositions and geologic structures when interpreted in light of mapped geology. Thus, the geophysical data, when combined with geologic knowledge, provide information about configurations of basins, boundaries of intrusive rocks, and orientations of fault surfaces.

Gravity and magnetic studies of the Butte quadrangle extend similar investigations by M.D. Kleinkopf, D.M. Kulik, and Viki Bankey in the Wallace and Choteau quadrangles (Kleinkopf, 1981; Kulik, 1983; Bankey and others, 1985; Kleinkopf and others, 1988); by D.R. Mabey and M.W. Webring (Mabey and Webring, 1985) in the Challis quadrangle; and W.F. Hanna, H.E. Kaufmann, J.H. Hassemer, B.D. Ruppel, R.C. Pearson, and E.T. Ruppel (Kaufmann and Hanna, 1982; Hanna and others, 1993) in the Dillon quadrangle. Geophysical maps of all of these investigators have contributed to geophysical compilations for the United States and North America (Kutina and Hildenbrand, 1987; Hinze and others, 1988; Hanna and others, 1989).

Gravity and magnetic anomaly data in the Butte quadrangle permit delineation of anomalies having an areal extent of a few kilometers or larger. Thus, although the data usually cannot target individual ore bodies, they can help to identify broad geologic terranes that may host mineral deposits. The approach to analysis was to (1) note correlations of anomalies or parts of anomalies with previously mapped rocks or zones of mineral occurrences; (2) predict the gross physical properties of these anomaly-producing sources, based partly on laboratory measurements of physical properties of rock samples; and (3) infer where similar anomaly-producing sources exist in the subsurface.

Gravity studies included (1) Compilation of old data and acquisition of new gravity data; (2) editing and merging of all gravity data sets; (3) reduction of new data to complete (terrain-corrected) Bouguer gravity anomalies; (4) reduction of all data to isostatic residual gravity anomalies; (5) development of derivative maps by analytical continuation and computation of vertical and horizontal derivatives; (6) measurement of densities of collected rock samples; (7) modeling of selected anomaly sources, taking into account the density information; and (8) geologic interpretation of gravity anomaly data based on derivative maps, density measurements, and modeling.

Magnetic studies included (1) Compilation of old magnetic anomaly data; (2) acquisition of new magnetic anomaly data covering the entire quadrangle, followed by comparison of the new data with the old data; (3) merging of new data with sets of old data immediately surrounding the quadrangle in order to reduce unwanted edge effects produced by filtering of maps; (4) development of derivative maps, such as a reduced-to-pole (north) map, a pseudogravity map, a map showing the magnitude of horizontal gradient, a map showing crests of maximums of horizontal gradients, a map showing the second vertical derivative of reduced-to-pole anomalies, and a map showing probable occurrences of subsurface magnetic rocks; (5) measurement of remanent magnetization and magnetic susceptibility of collected rock samples, followed by computation of total magnetization (vector sum of remanent and induced magnetization); (6) modeling of selected anomaly sources, taking into account the total magnetization data; and (7) geologic interpretation of magnetic anomaly data based on derivative maps, magnetization measurements, and modeling.

Some of the derivative maps of gravity and magnetic data are shown as plates and figures in this report.

GEOLOGIC SETTING

The Butte quadrangle occupies part of the Rocky Mountain overthrust belt characterized by rugged mountains and intervening basins (map A). The quadrangle contains igneous, metamorphic, and sedimentary rocks and surficial deposits that range in age from Proterozoic to Quaternary. Proterozoic, Paleozoic, and Mesozoic sedimentary rocks are abundant and widespread as are Cretaceous and Tertiary plutonic rocks; the latter are present with associated metamorphic rocks in the cores of most mountain ranges. Volcanic and volcaniclastic rocks of Cretaceous and Tertiary ages are found mostly in mountain ranges in the eastern and northern parts of the quadrangle. Intermontane basins are filled with

Tertiary and Quaternary sedimentary rocks and deposits that include alluvial and glacial materials (Wallace and others, 1986).

The oldest rocks exposed in the quadrangle are Belt Supergroup rocks that were deposited during Middle Proterozoic time when part of the Belt Basin (Harrison and others, 1974) occupied the area of the Butte quadrangle; clastic and carbonate rocks of the Belt Supergroup have a thickness of at least 16,000 m in the quadrangle. Mafic dikes and sills were intruded into the Belt rocks, probably during Late Proterozoic time. During Paleozoic time near-shore and shallow-water carbonate and carbonate-bearing clastic sediment was deposited and has a thickness of about 2,400 m; Paleozoic strata are mainly in the north, central, and northeastern parts of the quadrangle. About 6,700 m of clastic and carbonate Mesozoic sedimentary rocks were deposited in a foreland basin in the central part of the quadrangle, and about 2,400 m of equivalent strata were deposited in the northeastern part of the quadrangle.

In Late Cretaceous time, magmatic processes resulted in the emplacement of numerous stocks and several batholiths at mesozonal and epizonal depths and the eruption and deposition of volcanic and volcaniclastic rocks. These Upper Cretaceous plutons include the Boulder, Idaho, Sapphire, and Philipsburg batholiths, which are composed chiefly of monzogranite and granodiorite, and numerous stocks of diorite, granodiorite, and monzogranite. Hydrothermal activity during and following the waning stages of magmatism formed many types of mineral deposits. Upper Cretaceous volcanic and volcaniclastic rocks of the Elkhorn Mountains Volcanics exist as roof pendants and along the margins of the Boulder batholith and probably represent early extrusive phases of the Boulder batholith (Knopf, 1964; Hamilton and Myers, 1967, 1974; Robinson and others, 1968; Klepper and others, 1971; Tilling, 1973, 1974a,b; Klepper, 1974).

Volcanism and erosion, as well as sedimentation in intermontane valleys, took place during Tertiary time. Extensive early and middle Tertiary volcanism formed the Lowland Creek Volcanics in the southeastern part of the quadrangle, volcanic fields in the Garnet Range and east of Lincoln, and minor volcanic rocks northeast of Deer Lodge in the northwestern part of the Boulder Mountains. Lacustrine and fluvial deposits accumulated in intermontane valleys during mid- to late-Tertiary time. Concurrent volcanism contributed volcanic debris to the intermontane basins. During late Tertiary time, extensive pediments formed, and gravel, some of which contains valuable placer deposits of gold, was deposited on the pediments. Quaternary time was dominated by extensive alpine glaciation in many of the mountain ranges in the quadrangle. Postglacial time was one of erosion and deposition of alluvium in modern stream channels.

STRUCTURAL ELEMENTS

The principal structural elements in the Butte quadrangle are the Sapphire thrust plate (Ruppel and others, 1981), the southwestern end of the Montana disturbed belt (Mudge, 1972), and strike-slip faults of the Lewis and Clark line (Wallace and others, 1990). The complexly faulted and folded Sapphire thrust plate occupies much of the western and central parts of the quadrangle. The Sapphire plate is estimated to have been transported eastward for a distance of 60–70 km (Hyndman, 1979; Ruppel and others, 1981; Wallace and others, 1984). Similar thrusted terranes include the Rattlesnake thrust plate and the Elkhorn thrust zone, the latter of which is bounded on the north by the Saint Marys-Helena fault, the most prominent element of the Lewis and Clark line within the quadrangle. Unlike the Sapphire and Rattlesnake plates, the Elkhorn thrust zone does not have a basal decollement.

The Montana disturbed belt is in the northeastern part of the quadrangle where it abuts faults of the Lewis and Clark line. This belt is part of the Rocky Mountain fold and thrust belt (Woodward, 1981), which is underlain by a decollement.

The Lewis and Clark line consists of a broad zone of east-southeasterly to southeasterly striking faults that extends across the west-central and northeastern parts of the quadrangle (Ruppel and Lopez, 1984). Some steeply dipping faults of the Lewis and Clark line may have originated during deposition of the Proterozoic Belt rocks; however, most faulting and folding resulted from regional compression during late Mesozoic time. This compression formed an extensive foreland basin east of thrust plates that moved predominantly from west to east. Most of the pre-Tertiary sedimentary rocks in the quadrangle have been moved to their present positions by thrust and strike-slip faults. The most intense deformation occurred during Late Cretaceous time when laterally extensive thrust sheets, zones of imbricate thrusts, and tight and overturned folds were formed. Most Late Cretaceous magmatic events postdate thrust and strike-slip faults; stocks and batholiths emplaced into the faulted terrane probably made the terrane more resistant to continued compressional deformation. Normal faulting during early Tertiary time and subsequent erosion controlled the development of some of the present mountain ranges and drainage systems (Elliott and others, 1985). Some normal faulting along the east side of Deer Lodge Valley and north of Elliston continued into middle Tertiary time. Minor Quaternary faulting may be related to continued activity along some normal faults and along some strike-slip faults of the Lewis and Clark line (Reynolds, 1979; Ruppel, 1982). Extensive Cenozoic strike-slip faulting along the margins of mountains and attendant formation of pull-apart basins has been postulated by Ruppel (1991) for a large region immediately south of the Butte quadrangle.

A continental-scale feature, known as the Great Falls tectonic zone (O'Neill and Lopez, 1985), transects the quadrangle in the form of northeast-trending high-angle faults and shear zones. These geologic features had recurrent movement from middle Proterozoic to Holocene time and controlled the intrusion and orientation of late Cretaceous to early Tertiary dike swarms as well as the uplift and orientation of the Anaconda Range.

MINERAL DEPOSITS

Large quantities of mineral commodities have been produced from the Butte quadrangle during its long mining history (Billingsley and Grimes, 1917; Klepper and others, 1977; Lange, 1977; McClernan, 1981). The Butte or Summit Valley mining district is one of the most productive mining districts in the world, and the value of its metal output, more than $6 billion, is far greater than the combined total, about $400 million, from the rest of the quadrangle. Production from this long-worked district (Sales, 1914) gave rise to Butte's reputation as the "richest hill on earth." The two most important types of deposits that have been mined in the quadrangle are (1) hydrothermal vein and replacement deposits of base and precious metals and (2) placer deposits of gold. Other important deposit types are (3) porphyry or stockwork copper and molybdenum; (4) skarn gold, copper, silver, tungsten, and iron; (5) vein and replacement manganese, tungsten, barite, and fluorite; and (6) strata-bound phosphate (Elliott and others, 1986).

Many commodities, both metallic and nonmetallic, have been produced from the quadrangle but the principal value of production has been in metals, especially copper, gold, and silver. Copper is the most important commodity and has come mainly from the Butte district. This district also has yielded large amounts of silver, zinc, manganese, lead, gold, cadmium, bismuth, molybdenum, selenium, tellurium, and sulfuric acid. Many other districts in the quadrangle also have been substantial producers of gold, silver, lead, zinc, and copper; others have produced major amounts of manganese, tungsten, phosphate, fluorite, barite, sapphires, limestone, and silica.

Mineral deposits and occurrences in the Butte quadrangle range in age from Precambrian to Quaternary. The oldest occurrences of potential economic significance are strata-bound copper and silver minerals in the Middle Proterozoic Belt Supergroup. Strata-bound deposits of phosphate rock in the Lower Permian Phosphoria Formation have been mined in several parts of the quadrangle and are being mined in the eastern part of the Garnet Range. The most important periods of ore formation in the quadrangle were during Late Cretaceous and Paleocene Epochs, when most of the productive hydrothermal vein and replacement, porphyry-stockwork, and skarn deposits were formed. Because most of these types of deposits are related spatially to igneous intrusive or extrusive rocks, magnetic and gravity anomalies associated with subsurface occurrences of intrusive or extrusive rocks are of special interest to mineral exploration. These types of deposits are related temporally, as well as spatially, to plutonic rocks of Late Cretaceous age. Some younger hydrothermal deposits are present in Eocene volcanic rocks, such as the diatreme-hosted gold-silver-zinc-lead deposit that is in the middle Eocene Lowland Creek Volcanics (Sillitoe and others, 1985) at the Montana Tunnels mine in the Wickes district.

PHYSICAL PROPERTIES OF ROCKS

The diverse rock types represented in the quadrangle are characterized by a broad spectrum of rock density and magnetization. Our physical properties analyses, representing 819 rock samples from the Butte quadrangle, are summarized in table 1; locations of sampling sites are shown on map A.

Densities obtained in the present study are mostly commensurate with values obtained by others for rocks within or near the Butte quadrangle (Davis and others, 1963, 1965a,b; Burfeind, 1967, 1969; Biehler and Bonini, 1969; Smith, 1970; Knopf, 1963; Ruppel, 1963; Becraft and others, 1963; Hanna and others, 1993). Only dry bulk densities are given in this report. Wet bulk densities, obtained by weighing rocks into which water has been injected forcibly by use of a vacuum pump, are slightly higher than their dry bulk counterparts. Such wet bulk density values are intended to simulate values corresponding to rocks saturated below the water table. Our measurements of 144 water-saturated rock samples indicate that wet bulk densities range on average from 0.01 to 0.02 g/cm^3 higher than their dry bulk density counterparts.

Densities of Proterozoic, Paleozoic, and Mesozoic sedimentary rocks vary according to lithology, porosity, and degree of contact metamorphism. In order of increasing density, unmetamorphosed shale varies between 1.87 and 2.25 g/cm^3 and argillitic shale varies between 2.66 and 2.80 g/cm^3, (Knopf, 1963), the entire package of shale averaging about 2.56 g/cm^3; quartzite, sandstone, siltstone, and siltite, about 2.62 g/cm^3, although specimens as dense as 2.73 g/cm^3 have been measured (Knopf, 1963); slightly metamorphosed hornfels, 2.64 g/cm^3; limestone and slightly metamorphosed marble, 2.68 g/cm^3; argillite, 2.70 g/cm^3; marble and dolomite, 2.80 g/cm^3; intensely metamorphosed hornfels and skarn, 2.97 g/cm^3; and phosphate rock, 3.40 g/cm^3. A representative density value for all of these sedimentary rocks where considered to be grouped in a single package would be about 2.70 g/cm^3.

Densities of volcanic rocks range from 2.24 to 2.94 g/cm^3. In order of increasing density, Tertiary rhyolitic and latitic rocks average about 2.40 g/cm^3; Cretaceous and Tertiary rhyodacitic to partly andesitic rocks, 2.65 g/cm^3;

Cretaceous andesitic rocks, 2.80 g/cm^3; and Cretaceous non-vesicular basaltic rocks, 2.90 g/cm^3. A representative density value for all Cretaceous volcanic rocks, if considered to be contained in a single package, would be about 2.65 g/cm^3, which is about 0.25g/cm^3 higher than that for Early Tertiary volcanic rocks.

Densities of plutonic rocks, where relatively unaltered, range from 2.44 to 3.44 g/cm^3; however, densities of some plutonic rocks, such as quartz monzonite, where altered, have been reported to be as low as 2.27 g/cm^3 (Becraft and others, 1963). In order of increasing density, syenite averages about 2.44 g/cm^3; alaskite, granite, and monzogranite, 2.60 g/cm^3; quartz monzonite, 2.65 g/cm^3 (Ruppel, 1963); granodiorite, 2.70 g/cm^3; mafic granodiorite (Knopf, 1963), syenodiorite, and lamprophyre (Klepper and others, 1957), 2.78 g/cm^3; granogabbro (Knopf, 1963) and sulfide-enriched quartz monzonite (Becraft and others, 1963), 2.85 g/cm^3; nepheline shonkonite (Knopf, 1963), 2.93 g/cm^3; gabbro, 3.10 g/cm^3; and pyroxenite, 3.44 g/cm^3. A representative density value for all plutonic rocks, if considered to be contained in a single package would be about 2.67 g/cm^3. Basin-fill deposits, though highly variable in composition, are estimated to have an average density of about 2.25 g/cm^3, in agreement with an average value obtained by Vijay Satoskar of Indiana University (Burfeind, 1967, p. 18), using Nettleton's (1939) density profiling method over Oligocene basins. This value also is similar to the value of 2.3 g/cm^3 estimated by Kinoshita, Davis, Smedes, and Nelson (1964) and by Kinoshita, Davis, and Robinson (1964) to represent the average density of Cenozoic valley fill.

Rock magnetization data include measurements of both remanent magnetization and induced magnetization, the latter expressed in the form of apparent magnetic susceptibility. Magnetization values, in sharp contrast to density values, have a total range of about five orders of magnitude. Magnetic anisotropy, though known for some rocks in the Butte quadrangle to be large enough for accurate laboratory measurement (Hanna, 1977b), is not estimated to be large enough to contribute significantly to aeromagnetic anomalies. For most rocks in the Butte quadrangle, the anomaly-causing vector sum of remanent and induced magnetization, called total magnetization, has a normal polarity. This normal polarity is manifested by directions of total magnetization that depart less than 45° from the direction of the present earth's field. As exceptions, seven units of Elkhorn Mountains Volcanics have either reversed or intermediate polarities of total magnetization; however, only three of these have appreciable intensities of possible interest to aeromagnetic interpretation. Also, five units of Lowland Creek Volcanics have reversed or intermediate polarities; however, only one has appreciable intensity. Finally, several samples of Proterozoic and one sample of Paleozoic sedimentary rock have intermediate polarities; none of these has sufficient intensity to affect aeromagnetic anomalies.

GENERAL CHARACTERISTICS OF ANOMALY SOURCES

An anomaly source is completely described by its spatial distribution (location, shape, and size) and its physical property contrast in a lateral direction. Spatial distribution can be expressed by a variety of terms; two terms used in this report that bracket the spatial distribution of an anomaly source are thickness and areal extent. However, we especially emphasize two source characteristics: Areal extent and physical property contrast. Areal extent often can be estimated by the use of horizontal gradients of measured or derived anomalies; physical property contrast can be estimated from sample measurements (see, for example, Blakely and Connard, 1989; Hanna, 1990b; and Cordell and McCafferty, 1989). Thickness of sources have been estimated only occasionally because of uncertainties of physical property variation at depth and because of the contribution of deeper parts of the source to anomaly signal decreases with depth. Those thickness estimates that have been made are based either on mathematical formulas for the attraction of simply shaped bodies or on computer modeling. Some computer modeling of gravitational sources has been based on an inversion algorithm of Cordell and Henderson (1968) and Cordell (1970); modeling of magnetic sources and some gravitational sources has been based on forward computational algorithms of Webring (1985) and others, many of whose programs are summarized by Bankey and Anderson (1989).

GRAVITY ANOMALY MAP

The Bouguer gravity anomaly map (map B) includes 2,325 observations within and immediately adjacent to the quadrangle (Hassemer, 1981, 1984a,b, 1986), of which 1,900 are new, 262 were made previously by the U.S. Geological Survey, and 163 resided in the nonproprietary data files of the U.S. Department of Defense. All of the new data were obtained by field vehicle, helicopter, animal pack train, or on foot using high-precision Lacoste and Romberg geodetic gravimeters. All measurements are referenced to base stations that are incorporated into the International Gravity Standardization Net 1971 (Morelli and others, 1974; Defense Mapping Agency Aerospace Center, 1974).

Observed gravity was computed using calibration coefficients established by laboratory bench and mountain loop calibrations, and corrections for earth tide and instrumental drift were made using a computer program developed by Michael W. Webring, Ronald R. Wahl, and Gerald I. Evenden of the U.S. Geological Survey. Bouguer gravity anomalies with attendant terrain and earth curvature corrections, assuming a reduction density of 2.67 g/cm^3, were computed relative to theoretical values derived for Geodetic Reference System 1967 (International Association of

Geodesy, 1971; Woollard, 1979). Equations used in this gravity reduction are summarized in Cordell and others (1982) and are implemented in an unpublished computer program of Richard H. Godson, U.S. Geological Survey (1982). Terrain corrections to a distance of 53 m (Hammer, 1939) from each measurement point (station) were visually estimated during the field work using topographic approximations to inclined planes (Sandberg, 1958), conal surfaces, and two-dimensional irregular forms (Hubbert, 1948). Terrain corrections beyond 53 m, extending to a distance of 166.7 km from each station, were computed using a modification of the method of Plouff (1977) and incorporating U.S. Department of Defense terrain data digitized at a 15-second interval. For purposes of editing and display, the latitude and longitude of gravity stations were projected to x-y coordinates at 1:250,000 scale using a Universal Transverse Mercator transformation. Bouguer gravity anomaly values corresponding to these points were gridded using a minimum curvature algorithm (Webring, 1981; Briggs, 1974). The gridded anomaly data were subsequently contoured using an algorithm for splining under tension (Godson and Webring, 1982; Cline, 1974; Evenden, 1975) and were machine plotted (map B). The U.S. Geological Survey data, after contour plotting, were compared to edited and partially field-checked data of Burfeind (1967), to regional data of Biehler and Bonini (1969), and to data of the U.S. Department of Defense Gravity Library (Hittelman and others, 1982).

Because deep roots of crustal layers may isostatically compensate the mass effects of topographically elevated areas, the effects of such compensation on the Bouguer gravity anomaly in mountainous areas may be significant. The effect may be estimated by computing the gravitational attraction of an assumed root (fig. 1); this computed attraction may be subtracted from the Bouguer gravity anomaly to obtain an isostatic residual gravity map that delineates anomaly sources in the shallow crust (Simpson and Jachens, 1989). Such an isostatic residual gravity map (fig. 2) was prepared using the technique of Simpson and others (1983) based on an Airy-Heiskanen model (Heiskanen and Moritz, 1967) of local compensation. Compensation of the surface load was based on a 30-second gridded topographic data set. The parameters chosen for the model were those used by Simpson and others (1985), consistent with Woollard's (1968) best fit of seismic refraction depths to the Mohorovicic discontinuity beneath the United States: depth to the bottom of the root of 30 km for sea level elevations, a density contrast at depth of 0.35 g/cm^3, and a surface load density of 2.67 g/cm^3. The gravitational attraction of the compensating deep root (fig. 1) was computed at sea level to a distance of 166.7 km and computed beyond this distance to the antipode of each gravity station using data of Karki and others (1961). The anomalous features are long in wavelength, and, in essence, represent a geologically parametered regional field, as an alternative to a subjectively estimated regional field.

Because the compensating root is so broad relative to the dimensions of the quadrangle, its long-wavelength gravitational field guarantees that the local features of the isostatic residual anomaly map will look very similar to the local features of the Bouguer gravity anomaly map. For convenience, and in conformity to conventional analyses of areas the size of the Butte quadrangle, we arbitrarily use the Bouguer gravity anomaly map for further discussion of anomalies and refer to characteristics of the isostatic maps where appropriate.

The Bouguer gravity anomaly map (map B) shows that the southern half of the quadrangle is characterized by anomaly values more negative than most of the northern half. These more negative values are part of a vast gravity low that extends nearly 320 km southwest of the Butte quadrangle and that is associated chiefly with the Idaho batholith (Eaton and others, 1978; Bankey and others, 1985; Bankey and Kleinkopf, 1988; Cady and others, 1991). Within the Butte quadrangle, these negative values reflect relatively low densities of plutonic and volcanic rocks in the Boulder batholith, Sapphire batholith, and Idaho batholith areas and of sedimentary fill in the southern part of the Deer Lodge Valley.

In the discussion of anomalies that follows, the label prefixes "GL" and "GH" refer, respectively, to gravity lows and gravity highs. Although the discussion of aeromagnetic anomalies follows the discussion of gravity anomalies, several references to magnetic anomalies are introduced where they bear special relationships to gravity anomalies.

ANOMALIES IN SOUTHERN HALF OF QUADRANGLE

GL1 is a string of lows in the southeastern third of the quadrangle that marks the axis of a broad, northeast-trending, large-amplitude gravity low mainly associated with the Boulder batholith. This string of gravity lows also coincides with a region of magnetic lows, indicating that the weakly magnetic or reversely magnetic plutonic and volcanic rocks of this part of the Boulder batholith area are also relatively low in density. The string of lows also denotes approximately where the batholith is thickest. Because these lows have nearly constant values, they imply that the batholith is nearly constant in thickness along this longitudinal axis. If there is a variation in thickness along the axis, the regional southwestward decrease in gravity values (Eaton and others, 1978) suggests that the batholith may be slightly thicker at its northeast end, near Helena.

This possibility of a slight northeastward thickening of the batholith also may be seen on the isostatic residual gravity map (fig 2). As shown in figure 1, the regional anomaly caused by the inferred crustal root has values that decrease to the south-southwest, thus implying that the residual anomaly along the axis of the batholith has increasingly negative values to the north-northeast. Despite this implication, however, it remains uncertain whether this northeastward increase in amplitude of residual lows along the axis is caused by an axial thickening of the batholith or, for example, by increased subsurface alteration of the batholith to the northeast. The possible influence of rock alteration cannot be dismissed because the northeasternmost anomaly of the GL1 string of lows is known to be associated in part with altered rock having diminished magnetization.

This northeasternmost gravity closure of GL1 coincides with magnetic low ML1 over relatively low-density Lowland Creek Volcanics that are surrounded by Elkhorn Mountains Volcanics and Boulder batholith in the Wickes district. Between the string of gravity lows and GH1 in the extreme southeast corner of the quadrangle, closely spaced, northeast-trending contours mark a steep gradient that is inferred to be caused by the subsurface contrast in densities between relatively dense Precambrian rocks and batholithic rocks that intrude them. This steep gradient and similar steep ones at the northern, northeastern, and eastern margins of the batholith are evidence that intrusion was strongly influenced by the presence of pre-batholithic, steeply dipping faults that bound these sides of the batholith.

Regional gravity studies of the Boulder batholith have been made by Biehler (1958), Biehler and Bonini (1958, 1969), Renick (1965), and Burfeind (1967). We have synthesized these data by remeasuring gravity at some sites previously measured by these other authors, by acquiring new data, and by readjusting all data to render them compatible (Hassemer, 1984a,b, 1986). Because many inferences have been drawn from the geophysical data of previous investigators, we comment further in the following paragraphs about the findings of these investigators.

Renick's (1965) work was confined to a region of steep gravity gradient near Helena. He inferred that the batholithic thickness in this region is about 10,000 ft. He also concluded that the contact between batholith and sedimentary rocks here may dip at 45° to the northeast from the surface to a depth of about 3,500 ft above sea level to where the dip reverses to 68° southwest.

Of relevance to the Renick model for the northern margin of the batholith, Pothacamury (1970) studied by use of his measured magnetizations of the Unionville and Clancy granodiorites an aeromagnetic profile extending from the valley of Little Prickly Pear Creek to the Wickes District. His proposed model shows the northern margin of the batholith dipping 45° northeastward from the surface to a depth of 2.6 km and having a vertical contact from that point to a depth of 10 km. The difference between this magnetization model and Renick's density model is explained in terms of the density values assumed for Renick's model.

Burfeind (1967) computed the gravity anomalies for density models that extend to a depth of about 9 km below the ground surface along five profiles that cross the Boulder batholith. He assumed that (1) the thickness of sedimentary and volcanic rocks bounding the batholith is about 12,000 ft, an assumption quantitatively not very critical to the analysis; (2) rocks underlying the sedimentary and volcanic rocks have an average density of 2.85 g/cm^3 on the basis of a combination of seismic data (Steinhart and others, 1961), velocity-density curves (Woollard, 1959; Nafe and Drake, 1957), and densities of metamorphic rocks in the nearby Tobacco Root batholith to the southeast; and (3) the density of the batholith is uniformly 2.67 g/cm^3, close to the average density of 2.662 g/cm^3 obtained by Biehler and Bonini (1969) for 202 measurements of samples of Ruppel (1963), Knopf (1913, 1950, 1957), and Klepper and others (1957).

Burfeind inferred that the Boulder batholith is a tabular body that dips at a low angle to the northwest to about 8.5 km. The northeastern contact of the batholith was interpreted by him to dip to the southwest at about 45° and to bottom at about 9.1 km. He also concluded that several kilometers northwest of its surface exposure and at a depth of several hundreds of meters, the southeastern contact of the batholith dips at about 45° northwestward to about 9.1 km. He inferred that, throughout much of his study area, an extensive terrane of plutonic rock exists at a crustal level ranging from about 8.5 to 9.1 km.

Biehler and Bonini (1969) developed six density models across the Boulder batholith by assuming that the batholith can be approximated by a two-dimensional body, that the density of the batholith is constant, and that there is no local warping of the Mohorovicic discontinuity. They concluded that the northern part of the batholith is symmetrical with respect to an axis that is displaced northwestward from the center of the outcrop area of the batholith, the greatest thickness being along this axis; the bottom of the anomalous mass is shallower than 15 km and probably shallower than 10 km; the batholith may underlie a considerable area to the west in the vicinity of Deer Lodge and Philipsburg; there is no sharp structural delineation between the Idaho and Boulder batholiths; and, if there is no lateral increase in the density of the batholith toward the margin of the batholith, the subsurface shape must be concave upward.

GL2 is a north-trending low associated with low-density fill in the southern part of the Deer Lodge Valley. Modeling of Cremer (1966), using a 0.6 g/cm^3 density contrast between fill and surrounding rock, implied that this fill has a minimum thickness of more than 5,500 ft in the deepest, southernmost part of the valley and a minimum thickness of 2,300 ft farther north, near Deer Lodge. We note that studies of Davis and others (1965a,b); Kinoshita, Davis, Smedes, and Nelson (1964); Kinoshita, Davis, and Robinson (1964); Burfeind (1965); and Hanna and others (1993) have used density contrasts of 0.40 to 0.45 g/cm^3; thus, Cremer's thicknesses should indeed be construed as minimum values. Cremer also inferred that a major north-striking fault exists along the east side of the valley and that a smaller fault exists along the west side of the valley. Nine of Cremer's more than 500 gravity stations were reoccupied in our work. For reasons involving gravimeter precision, elevation control, and density of coverage, we decided not to recompile Cremer's data set for our regional study.

Along the northwest margin of GL2, the gradient flattens where anomaly contours nose across the southern part of the Mt. Powell batholith and the Philipsburg batholith. This flattening of the gradient is a gravity low (unlabeled) associated with the relatively low densities of the batholiths.

North-northwest of GL2, GL3 is a circular low that is associated with fill of the Gold Creek basin. South and southwest of GL2, at the southern margin of the quadrangle, three local anomalies include GH2, associated with Boulder batholith rocks that are denser than adjacent Lowland Creek Volcanics; GL4, influenced mostly by Tertiary and Quaternary valley fill; and GL5, possibly related to buried plutonic rocks that aeromagnetic anomaly data suggest are moderately to weakly magnetic. West of GL2, GH3 is a broad high that is centered between the Philipsburg batholith and Cable stock and is underlain by Proterozoic and Paleozoic rocks.

West of GH3, linear lows GL6, GL7, and GL8 are associated principally with low-density valley deposits and possibly also with sedimentary and plutonic rocks (Elliott and others, 1985; Tysdal and others, 1988). GL6 correlates with the Philipsburg Valley and GL7 correlates with the valley of the Middle Fork of Rock Creek. GL8 correlates with both valley fill and some plutonic rocks. This low is associated with part of the Rock Creek valley, with the valley of upper Willow Creek, and with part of the Miners Gulch stock where it is pervasively altered (Loen and others, 1989). The southern part of the low is coincident with Tertiary rhyolitic volcanic rocks.

Northeast of GL8, local anomalies GH4 and GL9 have unknown sources; northwest and southwest of GL8, local anomalies GL10 and GL11 also have unknown sources. Although GH4 may be a residual high associated with moderately dense sedimentary rocks, GL9 may reflect a combination of low-density sediment and a hidden low-density, relatively nonmagnetic intrusive body. GL10 and elongate GL11 partly subtend lower topographic elevations; GL10 has an unknown source that may in part consist of valley fill. GL11, which traverses the eastern margin of the Big Spring Creek stock, may be caused in part by silicic intrusive rocks in the subsurface that are similar in composition to Tertiary volcanic rocks to the south.

GL12, surrounded concentrically by GH5, approximately mirrors magmatic zonation of the Sapphire batholith (Wallace and others, 1984). The density zonation that is apparent from the gravity anomaly map is accompanied by a magnetization zonation that is apparent from the aeromagnetic anomaly map. GL12 is generated by muscovite-biotite monzogranite that is lower in density than the biotite-hornblende granodiorite that rims it and that generates GH5. The granodiorite, in turn, appears to be slightly denser than Precambrian Belt rocks that surround it. The gravity data suggest that the Sapphire batholith is thicker than the Philipsburg batholith to the northeast; however, comparisons of their thicknesses must take into account the different compositions of these batholiths.

Southwest of GL12, local low GL13, which is associated in part with magnetic high MH29, indicates that intrusive rocks of this part of the Idaho batholith are less dense than surrounding Precambrian Belt rocks.

ANOMALIES IN NORTHERN HALF OF QUADRANGLE

Extending into the western margin of the quadrangle, lows GL14 and GL15 are associated, respectively, with low-density fill of the Bitterroot Valley and the valley of Clark Fork at Missoula. East of GL14, high GH6 overlaps Idaho batholith rocks and Belt rocks, indicating that these plutonic and sedimentary rocks here are similar in density. East of GL15, a cluster of highs (GH7) reflects Belt rocks of typically moderate density. Similarly, farther east, another cluster of highs reflects both moderately dense Belt rocks and Phanerozoic sedimentary rocks. Between these clusters of highs, the string of lows (GL16) is influenced presumably by low-density gravel deposits of Gold Creek and part of the valley of Blackfoot River; however, part of the source may be hidden intrusive rocks. Low GL17 is associated with low-density fill of Camas Prairie, and similarly, GL18 is associated mainly with low-density fill of Ninemile Prairie and the valleys of Elk Creek and Clearwater River. East of GL18, low GL19 is associated with low-density plutonic rocks of the eastern half of the Garnet stock whereas high GH9 reflects the higher densities of surrounding Belt rocks.

South of GL19, a cluster of lows (GL20) correlates with low-density sediment underlying Flint Creek Valley and Tertiary sediment and felsic volcanic rocks along the Clark Fork River valley. Similarly, to the north-northeast, lows GL21 and GL22 reflect where low-density sedimentary fill is thickest beneath Nevada Valley and Douglas Creek valley. It may be noted that an extensive broad zone of high gradients extends west from GL9, GL20, and GL21 to the edge of the quadrangle, suggesting the presence of a buried structure akin to the Lewis and Clark line (M.D. Kleinkopf, oral commun., 1993).

East of GL22, GH10 is an elongate, southward-nosing high that overlaps part of the Ogden Mountain stock and surrounding Belt rocks. Two inferences may be drawn. First, the densities of plutonic and sedimentary rocks may be too similar to permit development of a gravity gradient across the boundary separating these rocks. Second, if a density contrast exists, the plutonic rocks of the stock may be very thin where the gravity high occurs. Magnetic anomaly data suggest that the second inference may be correct because the gravity high marks a zone where the stock does not generate an appreciable magnetic anomaly.

South of GH10, a cluster of highs GH11 (lacking good data coverage) is associated with moderately dense Phanerozoic sedimentary rocks, Elkhorn Mountains Volcanics, and other volcanic rocks, including those of the Emery District.

Northeast of GH11, the conspicuous string of lows GL23 is associated with low-density fill of Avon Valley.

North of GL23, low GL24 is associated with low-density fill of the upper drainages of Blackfoot River near Lincoln. Southeast of GL24, low GL25 may reflect the subsurface extent of the Silver Bell (Stemple Pass) stock composed of syenodiorite that is inferred to be strongly magnetic on the basis of aeromagnetic anomaly data. This Tertiary stock is therefore inferred to have an average density lower than that of surrounding Belt rocks (Empire Formation).

Southeast of GL25, elliptical low GL26 confirms an inference that can be drawn from aeromagnetic anomaly data that most of the Marysville stock underlies an area southwest of its mapped boundary. Although other stocks of granitic composition and much younger than the Marysville stock are probably present (Blackwell and others, 1974), these felsic stocks would not be expected to be strongly magnetic. The gravity low implies that the stock, or an adjacent intrusive body, thickens southwestward, beyond the most magnetic part of the body (labeled MH51 on map C), which is also southwest of most of the exposed boundary.

East-northeast of GL26, low GL27 is associated with low-density sediment beneath the drainages of Canyon Creek, near Silver City. North and west of there, the St. Marys-Helena fault is sharply expressed.

North-northwest of GL27, high GH12 correlates with a major magnetic high that is inferred by Kleinkopf and Mudge (1972) to be caused by buried mafic rocks that extend at least 25 km northeastward beneath the Choteau quadrangle. These mafic rocks presumably are more massive than the relatively thin diabasic sills that commonly intrude Belt rocks.

Southeast of GH12, high GH13 occurs over Belt rocks and is only slightly influenced on its southern flank by low-density sediment of Hilger Valley that is inferred to be thin. GH13 overlaps moderately high topography in a region that is moderately magnetic; its source is unknown.

South of GH13, high GH14 (defined by sparse data) is associated with the Scratchgravel Hills stock. The eastern flank of this high is steep because the stock abuts against low-density sediment of Helena Valley. The augite-hornblende monzonite of this stock, which is strongly magnetic, is denser than adjacent Belt rocks. The anomaly contours southwest of the gravity high form a broad nose over the northern part of the Priest Pass stock, which is inferred to thicken southward as anomaly values progressively decrease.

AEROMAGNETIC ANOMALY MAP

The aeromagnetic anomaly map (map C) is based on total-field measurements made by Airmag Surveys, Inc. (Schmunk, 1990) along 70 flight lines in an east-west direction, spaced 1.6 km apart at an average altitude of 2.7 km above mean sea level (U.S. Geological Survey, 1984). Data along these flight lines were adjusted or controlled using data acquired along 11 north-south tie lines, flown at the same elevation but with variable spacing. Anomalies were computed by subtracting from the adjusted total-field data the International Geomagnetic Reference Field (IGRF) 1983.65, a reference field updated to the time of the survey and corrected for flight elevation (Peddie, 1983). The resulting anomaly data were compared with data from 11 smaller surveys covering parts of the quadrangle (Johnson and others, 1965; U.S. Geological Survey, 1966, 1980a,b, 1981; Mudge and others, 1968; Kleinkopf and Mudge, 1972; Douglas, 1972; Hanna, 1990a; Lidke and others, 1983; Madson, 1983), many of these smaller surveys had been mosaicked by Hassemer and Hanna (1982).

In order to achieve consistency with merged aeromagnetic anomaly data of the Dillon 1°×2° quadrangle that borders the Butte quadrangle to the south, the original data were upward continued 455 m to simulate an airborne survey flown at 3.2 km altitude (map C). For purposes of regional anomaly interpretation, this "3.2-km" anomaly map is similar to the original "2.7-km" anomaly map but not quite as detailed. However, because the Butte upward continued data set is compatible with the Dillon merged data set, derivative data sets covering both quadrangles can be and have been produced, thereby permitting geophysical inspection of geologic features that overlap the quadrangles.

Thus, Butte aeromagnetic anomaly maps have been compiled in at least four forms: (1) A mosaic of many small surveys flown by diverse groups (Hassemer and Hanna, 1982); (2) a reconnaissance survey flown as part of the National Uranium Resource Evaluation (NURE) program of the Department of Energy, available from the U.S. Geological Survey as NURE Reports GJBX-126(79) and GJM-287 (Hill, 1986); (3) the "2.7-km" survey noted above (U.S. Geological Survey, 1984); and (4) the "3.2-km" product derived for use in this report.

The aeromagnetic anomaly map (map C) shows two contrasting regions: (1) The southeastern quarter of the quadrangle is mostly covered by a dense cluster of highs and lows that cuts diagonally across the quadrangle, and (2) the remainder of the quadrangle is characterized mainly by numerous, relatively isolated highs. The dense cluster of anomalies in the southeastern quarter of the quadrangle is associated with rocks of the Boulder batholith, the Elkhorn Mountains Volcanics, and the Lowland Creek Volcanics. The relatively isolated highs in the remainder of the quadrangle are associated mainly with isolated plutons of Cretaceous or Tertiary age that have intruded thrust plates composed of rocks of the Proterozoic Belt Supergroup and Phanerozoic sedimentary rocks.

These magnetic anomalies are affected by many factors of the original survey, most notable among which are (1) The proximity of the airborne magnetic sensor to magnetic anomaly sources and, because the present survey was flown level, the topography of the land surface where sources are exposed or contained therein; (2) the magnitude and direction of the total magnetization of sources, which is determined in part by the inclination of the present-day Earth's field, magnetic anisotropy, and magnetizations acquired in earlier Earth's fields; (3) variation of magnetization intensity or direction within a source; (4) the geometry of the subsurface distribution of sources, including source shape and depths to top and bottom of the source; and (5) the exposure of sources to strong magnetization changes, such as capture of isothermal remanent magnetization by sources struck by lightning.

Regardless of the diverse effects of the above factors, a single aeromagnetic survey over a large area, such as the Butte quadrangle, made at constant height along closely spaced flight lines offers an exceptionally valuable tool for predicting subsurface geology. This tool can be used directly for identifying buried extensions of exposed magnetic rocks, occurrences of completely hidden magnetic rocks, and relatively nonmagnetic zones of partly mapped rock known normally (in unaltered condition) to be magnetic.

The direct advantage of such an aeromagnetic anomaly map is that, when used in conjunction with a geologic map, specific contours can be immediately selected that approximately delineate subsurface extensions of mapped magnetic rocks. For example, simultaneous inspection of both the aeromagnetic anomaly map and the geologic map suggests that the "400 nT" contour generally outlines the more strongly magnetic regions whereas the "500 nT" contour generally outlines the more weakly magnetic regions.

We also note that magnetic rocks can be identified by inspection of either map C or a reduced-to-pole (north) anomaly map (fig. 3), the latter tending to laterally shift anomaly centers directly over their anomaly sources. On a large-scale version of the reduced-to-pole anomaly map, comparison of contours with mapped igneous rocks suggests that magnetic terrane is outlined approximately by the zero contour line.

The magnetic anomaly data also may be transformed to a pseudogravity anomaly map (fig. 4) by use of Poisson's relation (Lourenco, 1972; Baranov, 1975; Hildenbrand, 1983; Cordell and Grauch, 1985). This transformation achieves three purposes: (1) It shifts anomaly centers directly over their causative sources, effectively correcting for the magnetic inclination of the earth's magnetic field, just as does the reduced-to-pole anomaly map; (2) unlike the reduced-to-pole transformation, it converts magnetic anomalies to gravity anomalies on the assumptions that causative sources generate both types of anomalies and that the average ratio of density to magnetization is known (thus, locations of pseudogravity anomalies can be compared directly to locations of measured gravity anomalies to determine which causative sources actually generate both types of anomalies); and (3) it offers a mathematically noise-reduced function from which magnitudes of horizontal gradients can be computed (fig. 5), thereby areally highlighting narrow regions where causative sources have steep boundaries in the shallow subsurface. Comparison of the pseudogravity anomaly map (fig. 4) with the gravity anomaly map (fig. 2) at a common scale shows that the most conspicuous causative sources to both types of anomalies are the Boulder and Sapphire batholiths. The map showing horizontal gradients of pseudogravity anomalies (fig. 5) was contoured (at the sacrifice of some clarity of labeling) using an interval that clearly delineates by closely spaced contours those zones at the peripheries of magnetic bodies where source boundaries are steepest in the shallow subsurface.

As a further refinement to the delineation of magnetic terrane by use of filtered data, figure 6 shows lines that bound inferred thick occurrences of igneous rocks and spot locations that delineate other edges of causative sources (Blakely and Simpson, 1986), assuming that they have steep boundaries in the shallow subsurface. The accuracy of the locations of these lines and spot locations depends upon how well the boundaries approximate steeply dipping planes, interference from neighboring anomalies, terrain effects, data control, and the choice of magnetization direction in the pseudogravity transformation (Grauch and Cordell, 1987). The lines represent a combination of (1) elongate crests of gradient maximums of figure 5, and (2) the zero contour lines of a wavelength-filtered version of the second vertical derivative of the reduced-to-pole anomaly map of figure 3. The spot locations are an additional representation of maximums of the horizontal gradient of pseudogravity anomalies.

For purposes of the following discussions, we arbitrarily assign adjectives to describe the relative magnetic strength of rocks as follows, where total magnetization is expressed in SI units of amperes per meter (A/m):

<0.005	extremely weakly magnetic or nonmagnetic;
0.005 to 0.05	very weakly magnetic;
0.05 to 0.5	weakly magnetic;
0.5 to 1	moderately magnetic;
1 to 10	strongly magnetic;
10 to 100	very strongly magnetic; and
>100	extremely strongly magnetic.

In the present study, some of the magnetic properties of greatest interest are (1) moderate to strong magnetizations of rocks in regions of magnetic highs, especially those having measured directions that are normal (parallel to the present Earth's magnetic field); (2) moderate to strong magnetizations having directions that are reversed (anti-parallel to the present Earth's magnetic field) in regions of magnetic lows; and (3) weakly magnetic to relatively nonmagnetic rocks in regions of magnetic lows. Most other magnetic rocks in regions of magnetic lows or weakly magnetic rocks in regions of magnetic highs, although of considerable local interest, do not contribute significantly to regional interpretations at the scale of the present investigation. It is emphasized that the term "nonmagnetic" is used interchangeably with and has the same meaning as "extremely weakly magnetic" in this report. Rocks in this category almost always exhibit some ferrimagnetism and always exhibit paramagnetism that can be detected by sensitive measurement equipment.

ANOMALIES IN SOUTHEASTERN PART OF QUADRANGLE, EAST OF THE DEER LODGE VALLEY

The first region of interest is the southeast corner of the quadrangle where anomalies are associated with most rocks of the Boulder batholith and some rocks of the Elkhorn Mountains Volcanics and Lowland Creek Volcanics. Highs MH1 through MH16 and lows ML1 through ML5 are labeled within this region. When viewed on small-scale magnetic anomaly maps, such as those of Montana, the United States, or North America [see, for example, Zietz and others (1980) and Hinze and others (1988)], this region of anomalies appears as a U-shaped high, convex to the northeast, suggestive of magnetic zonation correlative with magmatic zonation of a large intrusive complex. Rock magnetic studies have confirmed the presence of some magnetic zonation (Hanna, 1969; Pothacamury, 1970; Geissman and others, 1980a,b). For example, the Unionville granodiorite (Knopf, 1963), which rims the northern part of the batholith, was found to be more magnetic than Clancy granodiorite (Knopf, 1963), inwardly adjacent to it. Also, Butte quartz monzonite occupying most of the central part of the batholith was found to be less magnetic than bordering Clancy and Unionville granodiorites.

However, closer inspection at larger scale reveals that, in addition to the observed magnetic zonation, much of the U-shaped regional high can be attributed to a combination of volcanism and alteration. Specific anomalies, keyed to labels on map C, are now discussed with reference to measured rock samples.

MH1 occurs mainly over an isolated part of the Boulder batholith and a small part of the Lowland Creek volcanic field. Some samples of rhyolite and porphyritic dacite of the Lowland Creek Volcanics along the southeastern flank of MH1 and of MH2, the latter an arcuate trio of highs immediately to the northeast, are strongly magnetic. These rock magnetic measurements support the inference that some units of the Lowland Creek Volcanics contribute to the magnetic high.

MH3 and MH4 occur, respectively, where samples of porphyritic biotite-hornblende monzogranite and granodiorite of the Boulder batholith are strongly magnetic. MH5 is an arcuate trio of highs over Elkhorn Mountains Volcanics, where samples of basalt and mineralized basalt are strongly magnetic. MH6 also is associated with Elkhorn Mountains Volcanics and the Vaughn member of the Blackleaf Formation. A sample of the latter was found to be moderately magnetic.

MH7, over Boulder batholith, correlates with samples of mafic granodiorite, perhaps lightning-struck, that are strongly to very strongly magnetic.

A cluster of four highs [five highs are shown on the more detailed anomaly map (U.S. Geological Survey, 1984)], centered at MH8, is associated with combinations of Elkhorn Mountains Volcanics and Boulder batholith having unknown magnetic properties. MH9, shown as a cluster of four highs, is associated mainly with Boulder batholith, samples of which are moderately to strongly magnetic granodiorite, and with Elkhorn Mountains Volcanics, samples of which are moderately to strongly magnetic andesite. A small body of Tertiary quartz latite in this area, a sample of which is strongly magnetic, probably contributes little to the anomalous field because of its small size. A neighboring pair of highs, denoted MH10, are influenced principally by monzonite and granodiorite of the Priest Pass stock, 10 samples of which are moderately to strongly magnetic and another sample of which is strongly magnetic.

MH11, a cluster of seven highs over Boulder batholith, is partly influenced by strongly magnetic Unionville granodiorite, strongly magnetic Clancy granodiorite, and strongly magnetic biotite adamellite. As noted previously, the relatively mafic Unionville granodiorite forms the northern rim of the Boulder batholith in this area and thereby gives rise to some magnetic zonation correlative to lithologic zonation. Pothacamury (1970) found that samples from 6 out of 15 sites of Unionville granodiorite have tightly grouped, normal directions and moderate intensities of remanent magnetization; their magnetic susceptibilities are sufficiently high to render them strongly magnetic. In contrast, he found that samples from 11 out of 18 sites of Clancy granodiorite have tightly grouped, normal directions but weak intensities of remanent magnetization; however, their magnetic susceptibilities are also sufficiently high to render them strongly magnetic, although about 15 percent less magnetic than Unionville granodiorite.

MH12 occurs over Boulder batholith in the Elkhorn Wilderness Study Area (Greenwood and others, 1990), where altered granodiorite is strongly magnetic; this relationship is unusual in the quadrangle because rock alteration is normally accompanied by a decrease of magnetization. MH13, immediately south of MH12, is associated with a combination of Elkhorn Mountains Volcanics and monzogranite porphyry (Becraft and others, 1963). The principal source of the high is inferred to be strongly magnetic Elkhorn Mountains Volcanics, similar in magnetic properties to those of this same formation a few miles to the east (Hanna, 1990a).

Numerous clusters of highs, designated MH14 and MH15, are associated mainly with Boulder batholith at elevations above 8,000 ft, having some magnetization of unknown origin. MH16 is an arcuate anomaly cluster associated mainly with Elkhorn Mountains Volcanics at elevations above 8,000 ft. In this area, three groups of samples of andesite are strongly magnetic, one grouping of these probably having been remagnetized by lightning. At the extreme southeastern corner of the quadrangle, a sample of quartz monzonite of the Wilson Park stock is strongly magnetic, indicating that this stock is also a contributor to the anomaly cluster.

The inner part of the U-shaped regional high, while higher in anomaly magnitude than many other parts of the quadrangle, is an area characterized by many magnetic lows. A part of this region of lows within the Wickes district was one of the first areas to be analyzed (in 1966) with regard to the relationship among magnetic lows, areas of mineralization, remanent magnetization, and direction and magnitude of total magnetization (Hanna, 1969).

ML1, the most negative of a grouping of four lows, is associated with Lowland Creek Volcanics and Elkhorn Mountains Volcanics, and parts of the Boulder batholith. This area is pervasively altered and encompasses several mining districts, including the Wickes district. Six samples of Lowland Creek Volcanics, four samples of Elkhorn Mountain Volcanics, and one sample of lithified alluvium are very weakly to weakly magnetic; one sample of Elkhorn Mountains Volcanics is moderately magnetic. Although some units of Lowland Creek Volcanics and Elkhorn Mountains Volcanics in the quadrangle are reversely magnetized, these units here are too weakly magnetized to generate magnetic lows. Thus, the main cause of the magnetic lows probably is alteration.

The southerly extension of the ML1 group of lows covers an area where two Boulder batholith samples are moderately to strongly magnetic, whereas another sample of the batholith is weakly magnetic.

ML2, ML3, ML4, and ML5 are associated mostly with Lowland Creek Volcanics in a graben-like structure northwest of Butte. Hanna (1977a) discovered that many of these volcanic units exhibit reversed remanent magnetization and that they have highly variable intensities of magnetization. More detailed studies of Geissman and others (1980a) confirmed the common occurrence of reversed remanent magnetization but added more information about magnetic intensities. With respect to remanence alone, among 32 sites sampled, one is very strongly magnetic, fourteen are strongly magnetic, three are moderately magnetic, eight are weakly magnetic, and seven are very weakly magnetic. That is, most are either strongly magnetic or weakly magnetic, from the standpoint of remanence alone. Thus, unlike the situation at ML1, it is inferred that ML2, ML3, ML4, and ML5 may be caused to some unknown extent by reversed magnetization directions of some of the more strongly magnetic units. More comments about these lows follow, including information about some of our rock magnetic data.

ML2 covers an area where samples of Lowland Creek Volcanics and Elkhorn Mountains Volcanics are very weakly to weakly magnetic.

ML3 is associated with an area where 7 samples of Lowland Creek Volcanics dacite are nonmagnetic to weakly magnetic. At or near the margin of this low, groups of 20 samples of Lowland Creek Volcanics intrusive latite, 21 samples of Lowland Creek Volcanics welded tuff, 11 samples of Boulder batholith alaskite, 1 sample of Boulder batholith quartz monzonite, and 1 sample of Lowland Creek Volcanics latite are very weakly to weakly magnetic.

ML4 represents a pair of lows covering an area where two groups of Lowland Creek Volcanics were sampled. One group of 23 samples of vitrophyre is strongly magnetic, just as glassy volcanic units of the Two Medicine Formation about 100 km to the north-northeast are strongly magnetic, probably because of an abundance of dispersed, extremely small, magnetically energetic, iron oxide particles within the amorphous matrix (Hanna, 1973a). Another group of latitic lava samples, near the edge of the area, is nonmagnetic.

ML5 includes a cluster of lows at the southern margin of the quadrangle; this cluster continues southward into the Dillon quadrangle. The deepest part of the cluster is centered on the Butte district where nearly all of the Butte quartz monzonite is pervasively altered. Among Lowland Creek Volcanics also associated with the cluster, a group of 13 samples of welded tuff and a group of 35 samples of vitrophyre are moderately magnetic, whereas groups of 10 samples of welded tuff and 19 samples of intrusive latite are weakly magnetic to nonmagnetic. In the vicinity of the Berkeley Pit, one sample of Boulder batholith quartz monzonite is strongly magnetic, whereas another sample of its altered, felsic equivalent is very weakly magnetic.

Relevant to this area, detailed paleomagnetic studies (Geissman and others, 1980a, b) of Butte quartz monzonite from surface exposures, from the Berkeley Pit, and from underground mines imply that this quartz monzonite has variable magnetization that is more commonly weak than moderate or strong. Measurements of magnetization intensities were restricted to remanence and thus are minimum values of total magnetization. Considering remanent magnetization alone, among 15 groups of rock from surface exposures, six are strongly magnetic, one is moderately magnetic, and eight are weakly magnetic. Among nine groups of rocks from various levels of the Berkeley Pit, three are moderately magnetic and six are weakly magnetic. Among six groups of rocks from underground mines, one is strongly magnetic, one is moderately magnetic, and four are weakly magnetic. Geissman and others (1980a,b) also inferred that the thermally altered, deep body of quartz monzonite was subjected to temperatures sufficiently high to completely unblock the original thermoremanent magnetization of the rock. As the rock cooled, a secondary thermoremanent magnetization was acquired, presumably during a reversed epoch of Earth's magnetic field, imparting to the rock a reversed magnetic polarity. Our inference for the present study is that the effect of this remagnetization on anomaly generation is small because of the small size of the altered rock body and because of the large distance between the deeply buried altered body and the magnetic sensor. If the reversely polarized body does have an effect on anomaly generation, it is to diminish the total magnetization by vectorially subtracting from the induced magnetization.

West of the U-shaped regional high but east of the Deer Lodge Valley, ML6 represents a cluster of lows that surround a subtly higher inner subregion; this cluster of anomalies subtends some Elkhorn Mountains Volcanics and other volcanic rocks of the Emery mining district. In this region, a group of 25 samples of Elkhorn Mountains Volcanics breccia is weakly magnetic. Within the Emery District, groups of 11 samples and 13 samples of altered basalt are weakly magnetic. In contrast, another group of 15 samples of altered basalt is strongly magnetic. However, because these strongly magnetic samples have an intermediate direction (between the normal and reversed directions) of total magnetization, the volcanic unit they represent probably contributes more to laterally offsetting any associated anomaly than to increasing its amplitude. It also is possible that this region is underlain by strongly altered Butte quartz monzonite.

ANOMALIES IN SOUTH-CENTRAL PART OF QUADRANGLE

MH17 is a classic example of a broad high having a large, presumably intrusive, strongly magnetic rock source that is completely hidden. The source of this high is inferred to be batholithic in size and possibly similar in composition to the Boulder batholith or the Royal stock. No broad large-amplitude anomaly is associated with the Mt. Powell batholith and therefore it is inferred to be weakly magnetic. This inference is supported by magnetic measurements of three widely separated samples of monzogranite found to be weakly magnetic. West of the main part of the batholith, however, MH18 and MH19 appear as short-wavelength large-amplitude highs that occur near or at the margins of the batholith. MH18 correlates with a small granodiorite pluton adjacent to the Mt. Powell batholith where altitudes range from 8,000 ft to more than 9,000 ft and where the surveying aircraft had to climb to safely avoid topography. MH19 is associated with the Racetrack Creek intrusive and metamorphic complex at altitudes exceeding 8,000 ft. This high may be caused by a strongly magnetic, dioritic phase of the complex, and also possibly by skarn. Occurrences of skarn commonly show significant magnetite enrichment. One sample of marble, which ordinarily is found to be nonmagnetic, possesses a weak total magnetization that is associated exclusively with remanence, the magnetic susceptibility being too small to measure precisely with the instrument used. At MH19 the aircraft was sufficiently close to topography to detect even small bodies of skarn.

Northeast of MH17, the narrow high MH20 is coincident with areas of Elkhorn Mountains Volcanics and other volcanic rocks; however, its source may be a hidden intrusive body, similar to that postulated for MH17.

Northwest of MH17, arcuate high MH21 is associated with the strongly magnetic Royal stock. The southeasternmost nose of this high is coincident with altitudes exceeding 8,000 ft. Although one of three samples of hornblende-biotite granodiorite measured is weakly magnetic, the others are strongly magnetic and are believed to have magnetic properties characteristic of most of the stock.

South of MH17, high MH22 may be caused by strongly magnetic units of the Lowland Creek Volcanics or by a buried plutonic body, similar to the Royal stock. Geissman and others (1980a,b) studied the remanent magnetization of Lowland Creek Volcanics at 32 sites of the Boulder batholith area and discovered that, among the 32 groups of rocks, one is very strongly magnetic, fourteen are strongly magnetic, three are moderately magnetic, eight are weakly magnetic, and seven are very weakly magnetic. Based on remanent magnetization alone, we may generalize that about half are strongly magnetic and half weakly magnetic. The nearby Lost Creek stock does not appear to be a contributor to MH22; two biotite monzogranite samples of the stock are very weakly to weakly magnetic.

Southwest of MH22, MH23 is the northwest gradient of the nose of a high. This gradient is associated with parts of the Mill Creek, Short Peak, Hearst Lake, and Storm Lake stocks, all of which appear to be heterogeneously magnetic. Much of this terrane is above 8,000 ft in altitude. One sample of monzogranite from the Hearst Lake stock is weakly magnetic, whereas a sample of quartz monzogranite from the Storm Lake stock is moderately magnetic. This latter sample may be representative of a source that contributes to generation of the anomaly.

Farther southwest, elongate high MH24 (labeled "M2" in Elliott and others, 1985) is coincident with the Storm Lake stock. Anomaly values also are high over the Hearst Lake stock and the Pintlar Creek batholith, especially where altitudes exceed 8,000 ft, but not over the Seymour Creek stock, which is the youngest intrusive body in the area. Among three samples of the Storm Lake stock, one diorite and one quartz monzonite sample are moderately to strongly magnetic, and one diorite sample is strongly magnetic. Of two monzonite samples of the Hearst Lake stock in this area, one is weakly magnetic and the other is weakly to moderately magnetic. It may be noted that south and southwest of MH24, along the southern edge of the quadrangle, anomaly contours outline much of those parts of the Pintlar Creek batholith and the Maloney Basin, Beaverhead Mountain, and LaMarche stocks that extend into the quadrangle, suggesting that these intrusive bodies are weakly to moderately magnetic.

North of MH24, MH25 is a short-wavelength, large-amplitude high coincident with the Cable stock, which, although not sampled, is inferred to be composed of strongly magnetic rock.

Immediately north of MH25, MH26 is a broad, high-amplitude anomaly associated with the Philipsburg batholith, some of the terrane of which has topographic altitudes exceeding 8,000 ft. Three samples of hornblende-biotite granodiorite and of Philipsburg batholith are strongly magnetic. The batholith may be connected southward to the Cable stock in the subsurface and may have a southeastward buried offshoot on the basis of elongations of anomaly contours.

ANOMALIES IN SOUTHWESTERN PART OF QUADRANGLE

Near the southern margin of the quadrangle, MH27 (labeled "M1" in Elliott and others, 1985) is a short-wavelength, high-amplitude anomaly over a small hidden magnetic body that is inferred to be composed of intermediate plutonic rocks.

West of MH27, MH28 is an areally extensive, annular anomaly, somewhat elongate and tapering in plan view toward the south, and to the west consisting of a strongly zoned cluster of highs coincident with the Sapphire batholith.

The Sapphire batholith is an epizonal complex of six comagmatic monzogranite and granodiorite rocks that were intruded by late-stage felsic dikes, sills, and pods (Wallace and others, 1984). The expected increase of magnetic susceptibility—an indicator of the amount of magnetic mineral content—and of density with increasing mafic composition of these plutonic rocks is true only in a general way, according to data obtained from representative samples of the six predominant rocks. These data are listed below in order of increasing mafic mineral content (because of the numeric rounding technique, percents do not sum necessarily to 100%).

(1) Biotite-muscovite monzogranite

Plagioclase	38%
Quartz	30%
Orthoclase	14%
Microcline	11%
Biotite, brown	3%
Muscovite	3%
Density (dry)	2.59 g/cm^3
Density (wet	2.61 g/cm^3
Susceptibility	0.186×10^{-2} SI

(2) Biotite-muscovite granodiorite

Plagioclase	43%
Quartz	35%
Orthoclase	7%
Microcline	10%
Biotite, brown	5%
Muscovite	1%
Density (dry)	2.60 g/cm^3
Density (wet)	2.62 g/cm^3
Susceptibility	0.171×10^{-2} SI

(3) Biotite granodiorite

Plagioclase	40%
Quartz	35%
Orthoclase	14%
Microcline	5%
Biotite, brown	5%
Hornblende, green	1%
Density (dry)	2.64 g/cm^3
Density (wet)	2.66 g/cm^3
Susceptibility	0.798×10^{-2} SI

(4) Biotite-hornblende granodiorite 3

Plagioclase	42%
Quartz	27%
Orthoclase	5%
Microcline	18%
Biotite, green & brown	7%
Hornblende, green	2%
Density (dry)	2.64 g/cm^3
Density (wet)	2.66 g/cm^3
Susceptibility	1.53×10^{-2} SI

(5) Biotite-hornblende granodiorite 2

Plagioclase	43%
Quartz	31%
Orthoclase	4%
Microcline	13%
Biotite, green & brown	8%
Hornblende, green	3%
Density (dry)	2.65 g/cm^3
Density (wet)	2.68 g/cm^3
Susceptibility	1.41×10^{-2} SI

(6) Biotite-hornblende granodiorite 1

Plagioclase	45%
Quartz	29%
Orthoclase	8%

Microcline	8%
Biotite, brown	9%
Hornblende, green	2%
Density (dry)	2.64 g/cm^3
Density (wet)	2.66 g/cm^3
Susceptibility	1.29×10^{-2} SI

These data reveal that, with the exception of (5) above, densities increase slightly as compositions become increasingly mafic. Susceptibilities follow a less predictable pattern: some even vary inversely with mafic content, as is evidenced if the rocks are divided into groups of muscovite-bearing ones [(1) and (2)] and muscovite-deficient ones [(3) through (6)]. However, despite this variation of susceptibilities within each group, values of the more mafic muscovite-deficient group are about 5–10 times larger than values of the more felsic muscovite-bearing group. This pattern of susceptibility values tends to support our use of a two-fold categorization of Sapphire batholith rocks for geophysical purposes—namely monzogranite and granodiorite.

The higher levels of anomaly magnitude are associated with mafic granodiorite comprising the outer rim of the batholith. The lower levels of anomaly magnitude, over the inner part of the batholith, are associated with a core of monzogranite. Among 13 samples of outer-zone mafic granodiorite measured, nine are moderately magnetic, whereas four are weakly magnetic. Among 13 samples of inner-zone monzogranite measured, including one sample of leucomicromonzogranite intrusive, twelve are weakly magnetic, whereas one is strongly magnetic. These rock magnetic data indicate that the outer zone is, on average, about 510 times more highly magnetic than the inner zone. As noted in Wallace and others (1984), the anomaly data suggest that the contact between the east side of the batholith and Belt rocks may dip steeply to the east, whereas the contact between the west side of the batholith and Belt rocks may dip more gently to the west. The anomaly contours also imply that a narrow finger of subsurface intrusive rock is buried in a region between the northwest margin of the batholith and the Gird Creek (Gird Point) stock.

We have computed the gravity and magnetic anomalies associated with models of the batholith using the 2.5-dimensional technique of Webring (1981). For example, one model of the batholith consisted of an assemblage of 10 prismatic bodies, each corresponding to a mapped lithologic unit. Boundary conditions used included the known topography of the ground surface, the mapped surficial geology, the aircraft observation height as defined by radar altimetry, and some averages of our measured densities and magnetizations for physical properties contrasts. The most important result of the modeling, which unfortunately does not permit the achievement of a uniquely correct result, is that both gravity and magnetic anomaly data are consistent with a batholithic mass having a thickness ranging from 4.0 to 4.5 km and averaging about 4.25 km.

Southwest of MH28 and the Sapphire batholith, in the southwestern corner of the quadrangle, MH29 is a cluster of medium-amplitude highs associated with lobes of the Idaho batholith that extend into the quadrangle. Although samples of Idaho batholith were not measured, it is inferred that much of the batholith inside of the quadrangle is weakly to moderately magnetic. Magnetizations elsewhere in the Idaho batholith (Criss and Champion, 1984) are known to be highly variable.

Northwest of MH28 and the Sapphire batholith, MH30 is a short-wavelength, high-amplitude high associated mostly with ultramafic rocks of the Skalkaho Mountain stock. Whereas samples of syenite are nonmagnetic to weakly magnetic, a sample of pyroxenite is very strongly magnetic. This pyroxenite is one of the most strongly magnetic rocks found within the quadrangle. Also in this area, a sample of magnetite-rich hornfels at the contact of these intrusive rocks and Belt rocks is strongly magnetic. It is not known if the magnetic hornfels has sufficient volume to be a contributor to the magnetic high.

Northeast of MH28 and the Sapphire batholith, MH31 is a circular, short-wavelength, large-amplitude anomaly controlled only by a single flight line; however, its authenticity and dipolar character are suggested by the smaller amplitude low controlled by the adjacent flight line to the north. Similar to MH27, which is about 21 km due south, MH31 is inferred to have a small intrusive rock source, intermediate in composition, that is hidden. The source creates a slightly positive gravity effect, as manifested by a saddle in the elongate gravity low GL8. Because the inferred source underlies part of the Sapphire volcanic field, it may represent an intrusive center in the volcanic pile.

North of MH28 and the Sapphire batholith, MH32 is a high having two peaks [four peaks show on the more detailed anomaly map (U.S. Geological Survey, 1984)]. The northern peak is coincident with the western margin of the Big Spring Creek stock; the southern peak lies immediately south of this stock (Tysdal and others, 1988). Some of this terrane has elevations that exceed 8,000 ft. The anomaly data suggest that the main mass of the Big Spring Creek stock is weakly magnetic relative to rocks that underlie much of its margin. The northern peak appears to be caused by partly exposed, but mainly buried, hornblende-biotite granodiorite that one of the authors (C. A. Wallace) found to border the large exposure of monzogranite on the western and southern margins of the stock. This zonation of monzogranite to granodiorite is similar to that of the Sapphire batholith 19 km to the south.

Northeast of MH32, MH33 is a broad circular high coincident with the Miners Gulch stock. One sample of granodiorite from this stock is moderately magnetic. An indentation of contour lines over the eastern third of the stock indicates less strongly magnetic rocks. This zone of less magnetic rocks may correlate with a mapped porphyritic granodiorite body that is younger than the main phase of the Miners Gulch stock and that has an associated zone of alteration (Loen and others, 1989; Tysdal and others, 1988).

Northeast of MH33, MH34 broadly overlaps the small mapped exposure of the Henderson Creek stock. The anomaly gradients clearly indicate that the stock is over a hundred times more extensive areally than its exposed part and that it extends southwestward in the subsurface to within 56 km of the Miners Gulch stock. The intrusive body probably is present below the Black Pine (Combination) mine, a major silver producer in the quadrangle (Elliott and others, 1986).

Northwest of MH33 and north of MH32, MH35 is an arcuate feature consisting of three highs; this feature broadly overlaps disconnected exposures of gabbro, microgabbro, and diorite. The northeasternmost of the highs partly overlaps the Welcome Creek stock (Lidke and others, 1983) where the biotite monzogranite of the stock is inferred to be weakly to moderately magnetic. Sources of the anomaly cluster appear to extend continuously in a northeast-trending narrow belt for a distance of about 10 miles.

ANOMALIES IN NORTHWEST PART OF QUADRANGLE

Northwest of MH34 in part of the Bitterroot Valley, the smoothly elliptical MH36 coincides with a large lobe of the Idaho batholith that extends into the quadrangle. This high, which aeromagnetic data west of the quadrangle show to be connected to a nose over similar rocks of the Idaho batholith 15 km to the south, indicates that the batholith has relatively uniform magnetization and that it or Eocene intrusive rocks associated with it, or both, are probably moderately magnetic. Thus, all of the highs, including those discussed previously, over rocks of the Idaho batholith at the western margin of the quadrangle imply that the batholith is weakly to moderately magnetic within the quadrangle—perhaps more of it being moderately than weakly magnetic. It may be noted that north of MH36, in the northwestern corner of the quadrangle, sporadic slivers or other occurrences of Proterozoic Z diabase intrusions (Wallace and others, 1983) are volumetrically too small to generate significant anomalies at the high flight level of magnetic data acquisition.

Northeast of MH36, MH37 includes exposures of both the Wallace Creek stock and the Ashby Creek stock. This anomaly, associated with porphyritic hornblende-biotite granodiorite, suggests that these stocks are continuous or are contiguous in the subsurface. Some of the anomaly contours on the more detailed anomaly map (U.S. Geological Survey, 1984) bend southeastward and extend to an area 8 mi southeast of the Wallace Creek stock where they form a small-amplitude high. This high is associated with the Gillespie stock that may be connected to the Wallace Creek stock in the subsurface along the narrow northwest-trending zone followed by the contours.

Immediately northeast of MH37, MH38 is a circular high that has a large, stock-size, mostly hidden source. The small body of diorite porphyry at or just beyond the northern extremity of the high may be a contributor to part of the anomaly. The magnetic anomaly is similar in size and magnitude to that associated with the Wallace Creek and Ashby Creek stocks. The buried source is inferred to be composed of rock similar in composition to rocks of these stocks.

East of MH38, MH39 is a large elongate high that is associated with the Garnet stock. Both measured samples of porphyritic hornblende-biotite granodiorite from the stock are strongly magnetic. The anomaly data indicate that the Garnet stock, the source of MH38, the Ashby Creek stock, and the Wallace Creek stock are connected at depth. These stocks thus are the tops of an east-northeast trending batholith. Sources of local magnetic highs 6–10 km southeast of the Garnet Mountain stock are associated with Tertiary andesitic volcanic rocks of the Garnet Range.

ANOMALIES IN NORTHEAST QUARTER OF QUADRANGLE

East of MH39 and the Garnet Mountain stock, MH40 is associated with much of the Ogden Mountain stock. Even when shifted northward to correct for induced magnetization inclination, this anomaly remains skewed to the south part of the intrusive body, suggesting that the southwestern part of the stock is more strongly magnetic than its more northern and eastern parts. In support of this inference, one sample of hornblende-biotite granodiorite from the southwestern part of the stock is strongly magnetic.

Northwest of MH40, MH41 is a circular, short-wavelength, high-amplitude anomaly associated with the small Mineral Hill stock. The high is inferred to be caused by the subsurface extension southward of intermediate rocks of the stock. Due east of MH41, MH42 is a similar circular high having a source that is totally buried. The source of MH42 is inferred to be a stock similar in composition and size to the Ogden Mountain and Mineral Hill stocks.

Southeast of MH40 and the Ogden Mountain stock, MH43 coincides with much of the Dalton Mountain stock (McClellan Gulch stock of Kleinkopf and Mudge, 1972). The spatial relationship of MH43 to the Dalton Mountain stock is similar to the relationship of MH40 to the Ogden Mountain stock: the anomaly extends southward far from the exposed stock. One sample of gabbro from the predominantly granodioritic Dalton Mountain stock is strongly magnetic. The anomaly data indicate that the southward subsurface extension of the Dalton Mountain stock is much larger than indicated by surface exposures.

East-northeast of MH43, MH44 is associated with the Granite Butte stock (Granite Peak stock of Kleinkopf and Mudge, 1972). This stock is composed mainly of hornblende-clinopyroxene-biotite granodiorite, and it is presumed to be at least as strongly magnetic as the hornblende-biotite granodiorite stocks previously discussed.

Northwest of MH44, MH45 is coincident with the Silver Belle (Stemple Pass) stock. The granodiorite of this stock is inferred to be strongly magnetic; its subsurface areal extent is two to three times the area of its mapped boundary.

Northeast of MH45, MH46 is a feature [a composite of three highs on the more detailed anomaly map (U.S. Geological survey, 1984)] that overlies part of the Lincoln volcanic field. Although one sample of tuffaceous andesite is intermediate between weakly and strongly magnetic, two other samples of andesite are strongly magnetic. An occurrence of Proterozoic Z mafic rock about 2 km south of this high is composed partly of weakly magnetic basalt and strongly magnetic gabbro; the mafic rock, however, is too limited in size to be a contributor to an anomaly. Northeast of MH46, the southern extremity of a broad, large-amplitude high, which is centered in the Choteau quadrangle to the north (Kleinkopf and others, 1972), is inferred to be underlain by mafic rock that extends for at least 25 km northwestward beneath that quadrangle.

Northeast of MH46, in the northeast corner of the quadrangle, a unit of glassy welded tuff of the Cretaceous Two Medicine Formation, sandwiched between two devitrified welded tuffs of the same formation, is one of the most strongly magnetic rocks of the quadrangle (Hanna, 1973a). Most of 29 samples of glassy welded tuff are very strongly magnetic, whereas 13 samples of devitrified tuff above the tuff and 12 samples below the tuff are very weakly to weakly magnetic. The glassy welded tuff unit, however, is too thin to generate a significant anomaly at the height of the airborne survey.

South of MH43, MH47 and MH48 are short-wavelength highs that are generated by magnetic rock buried beneath Avon Valley. The source of MH47 is adjacent to the mapped edge of the Garnet Range volcanic field (mainly andesitic in composition) and thus may be an intermediate (diorite) intrusive body. The source of MH48 is approximately 5 mi northwest of the Blackfoot City stock and may be similar in composition.

Southeast of MH48, MH49 includes much of the Blackfoot City stock and it extends in the subsurface much beyond its mapped contacts to the southwest. The source of the anomaly is about twice as big as the surface expression of the stock. Two samples of hornblende-biotite granodiorite are strongly magnetic.

Southeast of MH49, MH50 is a short-wavelength elliptical high, elongate east-west and thus oblique to most regional structural trends, that subtends a small mapped outcrop of granodiorite. The buried source of this high, while much larger than the mapped boundary, is less extensive than most of the named stocks in the quadrangle.

North-northeast of MH50, MH51 is associated with part of the Marysville stock and extends for at least 3 mi southwest of the mapped boundary of the stock. The anomaly data suggest that the northeastern margin of the stock is less magnetic than the remainder of the stock to the southwest. Although a single sample of quartz monzonite was found to be only moderately magnetic, a group of 17 samples of quartz monzonite was found to be strongly magnetic. The subsurface extent of the stock is about twice its surface area.

Southeast of MH51, MH52 is a very large-amplitude high associated with the Scratchgravel Hills stock. A sample of augite-hornblende monzonite from the stock is intermediate between strongly magnetic and very strongly magnetic, commensurate with the large amplitude of the high. The anomaly data suggest that the source of the high has an areal extent about twice that of the exposed body and that it has a distinct northeast-southwest elongation. The strong magnetic character of this source is highlighted by a south-southwestward extension of a few anomaly contours that wrap in a circular fashion around much of the smaller Broadwater stock about 3 km south of MH52. The biotite monzogranite of the Broadwater stock is inferred to be at least an order of magnitude less magnetic than the augite-hornblende monzonite of the Scratchgravel Hills stock.

SUMMARY AND CONCLUSIONS

SIGNIFICANCE OF NEW DATA

The aeromagnetic anomaly and complete Bouguer gravity anomaly data sets that we have acquired or compiled significantly exceed in quantity and quality previous geophysical data sets that were available to Biehler and Bonini (1969) and many other researchers who have contributed successfully to geophysical knowledge of the Butte quadrangle. New remanent and induced magnetization data and rock density data add to the previously established data base of physical properties of rocks in the quadrangle.

Most notably, the aeromagnetic anomaly data indicate clearly for the first time the spatial distribution of shallowly emplaced plutonic rocks west of the Boulder batholith to the eastern margin of the Idaho batholith. This distribution could not be discerned from gravity anomaly data because of the lack of a sufficiently large contrast of subsurface lateral density in this region.

The new physical properties measurements reveal that magnetic properties are highly variable in igneous rocks, with stronger magnetizations generally correlating, as expected, with the more mafic rocks. Just as Duval and others (1978), for example, have found that variations of uranium content deduced from aerial gamma-ray data are just as great within single plutons of the Boulder batholith as they are across the batholith itself, we have found that density and magnetization variations within a single pluton are sometimes just as great as those across an entire batholithic complex.

ANOMALIES AND LITHOLOGY

(1) Most magnetic highs in the Butte quadrangle are associated wholly or in part with mapped intermediate and mafic igneous rocks having normally polarized and at least moderately strong total magnetization.

(2) The source of magnetic highs in most of the plutonic rocks is inferred to be titanium-poor magnetite and in most volcanic rocks is inferred to be titanomagnetite, on the basis of thermomagnetic studies and petrographic inspection of polished rock slabs under reflected light (Hanna 1973a,b, 1977a). Low-titanium phases of titanomagnetite are present in some rocks, consistent with observations of other researchers (Reynolds and others, 1990) for similar intrusive rocks in the earth's upper crust. Using the classification scheme of Sanderson (1974) for the origin of magnetite, we infer that the magnetite or titanomagnetite of igneous rocks was formed mostly by direct precipitation and by oxidation reaction that accompanies the conversion of one ferromagnesian mineral to a second one under oxidizing conditions during the normal sequence of crystallization (Czamanske and Wones, 1970). Although some magnetite owes its origin to chemical alteration that accompanied the high-temperature development of skarn, it is probable that most chemical alteration, whether hydrothermal or deuteric, has tended to destroy more magnetite than it has created.

(3) Although induced magnetization is predictably the most important contributor to anomalies caused by the igneous rocks, remanent magnetization also is a noteworthy contributor. This remanence is inferred to have a significant component that is isothermal and of the viscous type, according to results of partial demagnetization of rock samples in alternating fields.

(4) Although most large-amplitude magnetic highs correlate with magnetite-rich plutonic and co-magmatic volcanic rocks, some of these highs having short wavelength appear to be caused in part by magnetic skarn in topographically elevated regions where the distance between anomaly source and magnetic sensor was small. Other large-amplitude, short-wavelength highs in mountainous areas are caused principally by isothermal remanent magnetization associated with lightning discharges, according to results of partial demagnetization of rock samples in alternating fields and general knowledge about the frequency of lightning strikes. Magnetic anomalies otherwise correlate only in a limited way to topography; some of the most salient magnetic features occur over regions that are topographically low. About 2% of the quadrangle has elevations between 8,000 and 9,000 ft; only about 0.5% of the quadrangle has elevations exceeding 9,000 ft. Only three magnetic highs (MH18, MH23, and MH24), and possibly a fourth (MH21) are affected by deviations of flight height where topographic elevations exceeded 9,000 ft. It is of interest that some of the most strongly magnetic rocks of the quadrangle, such as some glassy volcanic rocks, diabase dikes and sills, skarn zones, and magnetite-rich sandstone, are too small to generate significant aeromagnetic anomalies.

(5) Some magnetic lows of various amplitudes and wavelengths are inferred to be caused by rock alteration, accompanied by chemical transformation of primary magnetite or titanomagnetite to relatively nonmagnetic oxidized and hydrated mineral products (see, for example, Hanna, 1969). In some places, magnetic lows are associated with areas of hydrothermal alteration and mining districts which contain many productive metallic mineral deposits.

For plutonic rocks containing an unusually broad spectrum of magnetite grain sizes, their total magnetization consists mostly of induced magnetization carried by large multidomain grains and remanent magnetization carried by small single-domain or quasi-single-domain grains, although all grains carry some amounts of both types of magnetization. Magnetic lows associated with such rocks that also have characteristically small ratios of remanent-to-induced magnetization may be inferred to be caused more by alteration of the larger grains, perhaps because they offer larger surfaces for chemical contact, than by alteration of small grains.

Petrochemical data were insufficient for us to classify magnetic rocks of the quadrangle as belonging to a "magnetite series" or an "ilmenite" series (Isihara, 1977, 1981) or to classify them according to igneous (I-type) or sedimentary (S-type) source regions (Chappell and White, 1974; O'Neill and Chappell, 1977) as other investigators have done elsewhere. However, investigations of Criss and Champion (1984) in the southern Idaho batholith suggest that such magnetic-petrochemical correlations may be valuable, for example, to ascertain whether magnetite would be expected to be created or destroyed as a result of rock alteration.

(6) Smaller-amplitude magnetic highs or even magnetic lows (such as that associated with the Mt. Powell batholith) are associated with some intrusive and extrusive rocks known or inferred to be more felsic and silicic. Highs over regions of basin or valley fill, such as those associated with parts of the Bitterroot, Nevada, Avon, Helena, and Deer Lodge Valleys, are inferred to be caused by plutonic rocks that underlie the basin or valley. Any magnetic signatures that might be associated with diagenetically altered sedimentary rocks or sediment within these basins or valleys, of interest in petroleum exploration, remain undetected. Such anomalies are so small that their detection is possible only by use of ground-based or helicopter-based magnetic gradiometers along closely spaced lines.

(7) Large-amplitude gravity lows generally correlate with thick sections of low-density basin fill or valley deposits in the Butte quadrangle or with thick intrusive rock, such as the Boulder and Sapphire batholiths. The lows associated with intrusive rocks in the Butte quadrangle are subdued relative to some of the lows associated with intrusive rocks, such as the Tobacco Root batholith emplaced in Archean rocks, in adjacent quadrangles because of lower density differences with surrounding Belt rocks. In general, rocks

intrusive into basement terrane on the northwest side of the Great Falls tectonic zone (O'Neill and Lopez, 1985) have lower gravity expressions than those intrusive into basement rocks on the southeast side of this tectonic zone.

(8) Smaller-amplitude gravity highs correlate with relatively thick occurrences of Proterozoic and Phanerozoic sedimentary rocks that have average densities higher than densities of some of the intrusive rocks and higher densities than basin and valley fill.

(9) Magnetization zonation, and to a lesser extent, density zonation, is manifested by concentric or horseshoe-shaped anomalies associated with the Boulder and Sapphire batholiths and some stocks in the Butte quadrangle, just as they are in the Pioneer batholith and some stocks in the Dillon quadrangle to the south. This zonation is inferred generally to conform to magnetite content, which tends to correlate positively with the content of ferromagnesian minerals.

ANOMALIES AND STRUCTURE

(1) Some regional structures that traverse the quadrangle and that are expressed as lateral discontinuities, such as faults, have geophysical signatures while many others do not. The main factors that influence whether or not a fault has a geophysical signature are (a) amount of contrast in rock density or magnetization, and (b) the spacing of geophysical measurements, sometimes designated the resolution of geophysical measurements. In the Butte quadrangle, magnetic data are superior to gravity data for structural interpretation in two respects: the magnetic data are closer spaced and they respond to a physical property (magnetization) that varies by many orders of magnitude more than the corresponding physical property (density) for gravity. On the other hand, gravity data are superior to magnetic data in one respect: they respond to a physical property (density) that exists everywhere throughout the subsurface, whereas magnetic data respond only to a crustal zone of magnetized material above the Curie isotherm.

(2) In general, sedimentary rocks in thrust plates in the quadrangle have no distinctive anomalies, with the occasional exception of small-amplitude gravity highs that occur where these sedimentary rocks are thick and dense relative to intrusive rocks and valley fill. However, other features of thrust plates may be deduced on the basis of gravity and magnetic anomaly data. For example, both magnetic and gravity anomalies help to delineate igneous rocks and valley deposits that, respectively, intrude from below and fill from above zones in the thrust plates that may have been structurally weak.

(3) Magnetic anomaly data show that, especially in the eastern three-fourths of the quadrangle, many intrusive rock bodies are oriented in a northeasterly direction, as is the longitudinal axis of the Boulder batholith. Examples of these bodies include the Philipsburg batholith, Garnet stock, Wallace Creek stock, Blackfoot City stock, and Ogden Mountain stock. This preferred orientation is not reflected strongly by topography and is suggested only vaguely by geologic mapping because much of the intrusive rock is concealed. A few intrusive bodies, such as the Dalton Mountain stock and Marysville stock, trend northwest, orthogonal to the majority of intrusions. It remains unknown if the northeast to east-northeast alinements reflect a geometry of tectonic significance.

(4) Magnetic highs associated with many intrusive bodies are boomerang-, horseshoe-, or crescent-shaped, and reflect zonation of these bodies. Examples of these highs include those associated with the Sapphire batholith, Philipsburg batholith, Royal stock, Garnet stock, Miners Creek stock, and Big Spring stock. The high associated with the Pioneer batholith in the Dillon quadrangle to the south also fits into this family of anomalies.

(5) Lateral subsurface discontinuities in the quadrangle, denoting possible faults, fractures, or zones of structural weakness, can be inferred in some localities from the gravity or magnetic anomaly data. For example a magnetic lineament can be discerned to approximately coincide with the west-northwest-trending, left-lateral Lewis and Clark line (sometimes known as the Lewis and Clark lineament or, in the Butte quadrangle, as the Montana lineament, marked in part by the Swan fault and St. Marys-Helena fault). However, it should be noted that many dozens of other magnetic lineaments, having little obvious geologic significance, could be drawn on the basis of contoured data. O'Neill and Lopez (1985) have used linear gravity and magnetic anomalies to help define their northeast-trending Great Falls tectonic zone that transects the Butte quadrangle. Alternative displays of geophysical data, such as stereoscopic pairs of contoured data for three-dimensional analysis (Gay, 1971, 1972) and gray scale or color raster-based images with or without directional shading (Cordell and Knepper, 1986; Cady, 1990; Phillips, 1990; Reeves and others, 1990) may offer advantages for recognizing lineaments or patterns that cannot be realized by conventionally contoured data. For example, Gay (1972, p. 14) has recognized by using his stereoscopic technique a magnetic lineament coincident with the north-trending Continental fault about 5 km east of Butte.

(6) A long-wavelength, regional gravity field that subtends the Butte quadrangle and that may be identified without recourse to geology on the basis of wavelength filtering alone, can be geologically modeled by an isostatically compensating root of Airy-Heiskanen type. It is probable that this model would need to be refined to include some lateral density contrasts of Pratt type to accommodate both gravity and seismic data (McCamy and Meyer, 1964) across the Rocky Mountain physiographic boundary. For purposes of studying gravity anomaly sources in the shallow crust of the Butte quadrangle, the original Bouguer gravity anomaly data can be corrected not only for isostatic effects but also for dis-

tracting lows caused by low-density basin fill and valley deposits where seismic or drill-hole information is available.

ANOMALIES AND SOURCE CHARACTERISTICS

Our computer modeling suggests that maximum thicknesses of valley fill in the quadrangle range from about 2 to 3 km. Thicknesses of intrusive rocks may vary from about 0.5 km to less than 10 km.

For example, the Boulder batholith, known from field evidence to be at least 2 km thick near Butte (Tilling, 1974a,b), has been modeled as about 3 km thick at its northern extremity (Renick, 1965); about 9 km thick throughout much of its interior (Burfeind, 1967); less than 15 km thick and probably less than 10 km thick, considered as a whole (Biehler and Bonini, 1969); and about 10 km thick in its northeastern part (Pothacamury, 1970). The variation in estimates of the thickness of the Boulder batholith relates strongly to uncertainties of density contrast at depth. The relationship of thickness to density contrast is remarkably simple if the Boulder batholith, which has a gravity anomaly amplitude of about -42 mGal, is assumed as a first approximation to be an infinitely extensive plate: the thickness in kilometers equals the reciprocal of density contrast when expressed as grams per cubic centimeter. Thus, density contrasts of 0.10, 0.20, and 0.50 g/cm^3 imply thicknesses, respectively, of 10, 5, and 2 km. These values of thickness more than double if the mass is assumed to have the shape of a hemisphere or they increase fractionally if the mass is considered to have the shape of a circular cylinder. If the batholith were approximated by a circular cylinder having a density contrast of 0.15 g/cm^3 and a known areal extent of about 1,300 km^2, its thickness would be about 8 km. This is about twice the thickness of the Sapphire batholith which we have modeled as an ensemble of bodies on the basis of both magnetic and gravity anomaly data and physical properties measurements.

We agree with the conclusion of Biehler and Bonini (1969) that the shape of the Boulder batholith and other intrusions cannot be precisely deduced on the basis of potential-field data alone. Much of the uncertainty revolves around the possible vertical zonation of physical properties, counterpart to horizontal zonation. The density contrast between intrusive rocks and Precambrian Belt rocks, vital to an accurate interpretation of the geometry of the intrusions, appears to fluctuate significantly within the quadrangle. Subsurface distributions of intrusive bodies can be estimated most confidently by a combination of reflection seismology (provided that the nonreflecting intrusions are floored by reflectors) and deep drilling. It remains unknown whether some exposed intrusive bodies, such as the Storm Lake stock, are flat-bottomed or whether some concealed intrusive bodies are flat-topped because they have been sliced at low angle by thrusting; the anomaly data are much less sensitive to the topography atop a uniform source than to a lateral heterogeneity within the source or adjacent to the source.

ANOMALIES AND TECTONICS

Rotations or translations of thrust-faulted tectonic blocks postulated by others (see, for example, Hyndman, 1980) and by us on the basis of geologic and petrochemical data cannot be accurately deduced on the basis of aeromagnetic anomaly data because magnetic rocks that might have been affected have a high ratio of induced plus viscous remanent magnetization to nonviscous remanent magnetization. Geophysical inferences about movements of tectonic blocks therefore should be based on paleomagnetic studies that include identification and separation of pre-tectonic magnetization components that may have been acquired or modified throughout a complex history of thermal events (see, for example, Barton and Hanson, 1989; Kerrich and Hyndman, 1986; Geissman and others, 1980a,b; Eldridge and Van der Voo, 1988; Hillhouse, 1989). Such paleomagnetic data may also help to determine the relative ages of mineralization products and host rocks (Callahan, 1977).

ANOMALIES AND HYDROCARBON POTENTIAL

Vast magnetically "quiet" zones between isolated bodies of intrusive rocks occur throughout the western half of the quadrangle. Should any formations underlying the thrusts of Precambrian Belt rocks have the necessary combination of feasible sources for hydrocarbons, suitable reservoir rocks, and favorable structural traps, these "quiet" zones suggest that the hydrocarbons may remain intact, not having been driven away by the high-temperature environment of igneous intrusions.

ANOMALIES AND MINERAL OCCURRENCES

We have used the geophysical data as parameters in ore occurrence models, such as those for vein and replacement deposits, stockwork molybdenum deposits, and skarn deposits in studies coordinated by one of the authors (J.E. Elliott). In some instances the anomaly data may be used directly; for example, magnetic lows are commonly associated with hydrothermally altered intrusive rock. In general, the use of the geophysical data in mineral deposit models has been to delineate regions of subsurface magnetic intrusive rocks as shown in figure 6. Where mapped intrusives, such as the Big Spring Creek stock, are not bounded by solid lines in figure 6, they are partly outlined by spot locations that were plotted on the basis of various criteria. Most of these rocks, whether outlined by solid boundary lines or spot locations, can be recognized more accurately by using magnetic anomaly data than by using gravity anomaly data, although gravity anomaly data remain useful for verification.

One of the many uses of a map of magnetic terranes (fig. 6) is to note those regions of mapped intrusive rocks that lie outside of the geophysically estimated boundaries of subsurface intrusive rocks. These regions presumably denote intrusive rocks that are very thin or relatively nonmagnetic. If relatively nonmagnetic and not extremely felsic, they may be inferred to be altered and therefore to be of interest to exploration for mineral deposits.

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Table 1. *Physical properties of selected rock units, Butte 1°x 2° quadrangle, Montana*

[No. on map A, sample locality; n, number of samples; Rem J, magnitude of remanent magnetization[1], exclusive of demagnetization effects, in SI units of A/m; k, apparent magnetic susceptibility, in dimensionless SI units of 10^{-2}; Q, Koenigsberger ratio of remanent to induced magnetization, assuming an ambient magnetic-flux density of 0.575 gauss; total J, magnitude of total magnetization, in SI units of A/m (values enclosed by brackets represent maxima on the assumption that the remanent and induced magnetization have the same direction and polarity; values enclosed by braces, such as {0.0116}, represent the only magnetization measurement available); polarity total J, polarity of the total magnetization vector; bracketed polarities, such as [N], are inferred on the basis of Q values rather than direct measurements (N = normal; R = reversed; I = intermediate); ρ, dry bulk density (g/cm^3)(second value, if listed, is wet bulk density); —, data not available; entries of 0.0 represent measurements below the threshold of detectability]

No. on map A	Rock Unit	n	Rem J	k	Q	Total J	Polarity total J	ρ	References[2]
1	Unionville granodiorite	6	1.66	1.44	2.5	2.25	N	2.74	1
2	Unionville granodiorite	18	3.95	2.75	3.1	5.20	N	2.76	1
3	Unionville granodiorite	5	2.15	2.97	1.6	3.50	N	2.78	1
4	Quartz monzonite	20	0.291	3.52	0.18	1.88	N	2.70	1
5	Quartz monzonite	10	1.16	2.55	.99	2.32	N	2.71	1
6	Quartz monzonite	10	.394	2.86	.30	1.70	N	2.68	1
7	Quartz monzonite, Pulpit Rock pluton	16	.390	3.14	.27	1.80	N	2.67	1
8	Alaskite	11	.092	0.337	.60	0.246	N	2.60	1
9	Biotite adamellite	9	.237	1.77	.29	1.04	N	2.65	1
10	Quartz monzonite, Priest Pass stock	10	.318	1.43	.48	.960	N	2.67	1
11	Granodiorite, Marysville stock	17	.649	4.13	.34	2.53	N	2.72	1
12	Welded tuff	10	.111	.0754	3.2	.0799	R	2.45	2
13	Welded tuff	21	.0228	.0900	.55	.0207	N	2.53	2
14	Lower lava	17	.111	.347	.70	.220	N	2.59	2
15	Vitrophyre	35	.540	.0524	22	.562	N	2.33	2
16	Vitrophyre	23	1.04	.0784	29	1.02	R	2.40	2
17	Welded tuff	13	.549	.236	5.1	.634	N	2.37	2
18	Upper lava	17	.00068	.00707	.21	.0026	N	2.28	2
19	Intrusive	8	.00032	.0322	.022	.0144	N	2.36	2
20	Intrusive	19	.00040	.00538	.16	.00214	N	2.24	2
21	Intrusive	20	.0365	.266	.30	.142	N	2.53	2
22	Vitric tuff	5	5.50	.854	14	5.87	N	2.70	3
23	Welded tuff	7	.230	.0459	11	.250	N	2.58	3
24	Hypabyssal intrusive	9	50.0	3.52	31	51.5	N	2.67	3
25	Stony welded tuff A	13	.133	.103	2.8	.086	R	2.57	4
25	Glassy welded tuff B	29	17.5	.601	64	17.2	R	2.36	4
25	Stony welded tuff C	12	.072	.0372	4.2	.055	R	2.55	4
26	Breccia	25	.163	.810	.44	.371	N	2.54	4
27	Basalt I (altered)	15	.845	1.78	1.0	1.16	I	2.73	4
28	Basalt II (altered)	11	.214	.547	.85	.094	I	2.54	4
29	Basalt III (altered)	13	.180	.0792	5.0	.215	N	2.79	4
30	Quartz monzonite	1	.134	.251	1.2	.246	N	2.74	5
31	Lithified alluvium	1	.0762	.314	.53	.220	N	2.54	5
32	Andesite	1	.145	1.26	.25	.718	N	2.74	5
33	Quartz latite	1	.0347	.264	.29	.0105	N	2.50	5
34	Quartz latite	1	.0286	.188	.33	.0760	N	2.56	5
35	Quartz latite	1	.0004	.0603	.014	.0272	N	2.63	5
36	Quartz latite	1	.00234	.0603	.085	.0259	N	2.73	5
37	Andesite	1	.0691	.415	.36	.227	N	2.88	5
38	Andesite	1	.267	.0339	17	.282	N	2.78	5

Table 1. *Physical properties of selected rock units, Butte 1° x 2° quadrangle, Montana*—Continued

No. on map A	Rock Unit	n	Rem J	k	Q	Total J	Polarity total J	ρ	References[2]
39	Quartz latite	1	.00110	.0339	.071	.0152	N	2.48	5
40	Quartz latite	1	.0736	.955	.17	.366	N	2.45	5
41	Andesite	1	.0054	.0302	.39	.0122	N	2.85	5
42	Andesite	1	.0405	.126	.70	.0921	N	2.70	5
43	Quartz latite	1	1.00	.0603	36	.997	I	2.60	5
44	Quartz monzonite	1	.472	3.52	.29	2.05	N	2.80	5
45	Quartz latite	1	.130	.126	2.2	.152	I	2.31	5
46	Quartz latite	1	.00101	.0251	.088	.0109	N	2.20	5
47	Quartz latite	1	.0821	.226	.79	.0631	I	2.47	5
48	Quartz latite	1	.00797	.0176	.99	.00073	I	2.54	5
49	Quartz latite	1	.00056	.0176	.069	.00083	N	2.48	5
50	Quartz latite	1	.00053	.0176	.066	.00081	N	2.67	5
51	Quartz latite	1	.0268	.0176	3.3	.0199	R	2.46	5
52	Quartz monzonite	1	.0837	.415	.44	.267	N	2.80	5
53	Quartz monzonite (altered)	1	.0003	.0176	.037	.00835	---	2.84	5
54	Andesite	1	1.24	1.46	1.9	1.91	---	2.44/2.50	6
54	Andesite	1	1.21	1.03	2.6	1.64	N	2.38/2.48	6
55	Andesite	1	.348	1.18	.64	.733	N	2.41/2.53	6
56	Andesite	1	.118	.528	.49	.360	---	2.45/2.52	6
57	Tuffaceous andesite	1	.375	.239	3.4	.484	---	2.27/2.41	6
58	Andesite	1	---	.528	---	.420	---	2.59/2.67	6
59	Andesite	1	.986	.339	6.3	1.14	---	2.12/2.28	6
60	Argillite	1	.0019	.0	---	.0019	N	2.73/2.76	6
61	Argillite	1	.0003	.0603	.011	.0279	---	2.64/2.68	6
62	Argillite	1	.0005	.0566	1.0	.0264	---	2.70/2.73	6
63	Argillite	1	.0001	.0478	.0046	.0219	N	2.77/2.78	6
64	Argillite	1	.0304	.0	---	.0304	N	2.70/2.73	6
65	Argillite	1	.0044	.0	---	.0044	I	2.68/2.69	6
66	Argillite	1	.0064	.0	---	.0064	N	2.59/2.65	6
67	Argillite	1	---	---	---	---	---	2.72/2.74	6
68	Argillite	1	.0004	.0679	.013	.314	N	2.73/2.75	6
69	Argillite	1	---	---	---	---	---	2.74/2.74	6
70	Hornfels	1	.0013	.0465	.061	.0226	---	3.00/3.02	6
71	Hornfels	1	.0053	.0189	.61	.0139	---	2.72/2.72	6
72	Hornfels	1	.0153	.122	.27	.0711	---	2.89/2.91	6
72	Magnetite hornfels	1	7.15	.2501	62	7.27	---	2.66/2.72	6
73	Hornfels	1	.0006	.0251	.052	.0120	N	3.07/3.08	6
74	Hornfels	1	.0060	.0	---	.0060	R	2.57/2.60	6
74	Hornfels	1	---	.0251	---	.0115	---	2.55/2.58	6
75	Hornfels	1	.0321	.679	1.0	.0624	N	2.65/2.68	6
76	Dacite breccia	1	---	.0100	---	.0046	---	2.50/2.54	6
77	Porphyritic dacite	1	7.39	.377	43	7.56	---	2.48/2.51	6
78	Tuffaceous dacite	1	.0028	.0679	.09	.0284	N	1.96/2.20	6
79	Diorite	1	.473	2.06	.50	1.42	---	2.91/2.92	6
80	Diorite; Storm Lake stock	1	.517	1.41	.80	1.16	---	2.90/2.92	6
81	Diorite; Storm Lake stock	1	.125	1.83	.15	.964	---	2.77/2.78	6
82	Dolomite	1	.0022	.0	---	.0022	I	2.76/2.79	6
83	Gabbro; Dalton Mountain stock	1	.453	1.12	.88	.965	---	2.87/2.90	6

83	Gabbro; Dalton Mountain...1 stock	2.20	1.00	4.8	2.66	---	3.00/3.01	6
84	Gabbro....................1	---	---	---	---	---	2.89/2.90	6
85	Mafic granodiorite;.......1 Royal stock	.666	1.97	.74	1.57	---	2.68/2.69	6
86	Mafic granodiorite;.......1 Sapphire batholith (outer zone)	.0296	2.06	.031	.973	---	2.66/2.68	6
87	Mafic granodiorite;.......1 Sapphire batholith (outer zone)	.0307	.735	.091	.367	---	2.63/2.66	6
88	Mafic granodiorite;.......1 Sapphire batholith (outer zone)	.0385	.5303	.16	.281	---	2.63/2.65	6
89	Mafic granodiorite;.......1 Sapphire batholith (outer zone)	.0574	1.41	.089	.701	---	2.65/2.68	6
90	Granodiorite; Miners......1 Gulch stock	.0267	1.27	.046	.607	---	2.65/2.66	6
91	Mafic granodiorite;.......1 Sapphire batholith (outer zone)	.095	1.37	.15	.722	---	2.63/2.66	6
92	Mafic granodiorite;.......1 Garnet stock	.357	3.08	.25	1.76	---	2.69/2.70	6
93	Mafic granodiorite;.......1 Sapphire batholith (outer zone)	.0485	.633	.17	.338	---	2.63/2.65	6
94	Mafic granodiorite;.......1 Sapphire batholith (outer zone)	.0730	1.53	.10	.774	---	2.63/2.65	6
95	Mafic granodiorite;.......1 Sapphire batholith (outer zone)	.0201	1.63	.027	.768	---	2.66/2.68	6
96	Mafic granodiorite;.......1 Philipsburg batholith	2.28	2.17	2.3	3.27	---	2.64/2.65	6
97	Mafic granodiorite;.......1 Sapphire batholith (outer zone)	.0200	1.58	.0099	.744	---	2.63/2.65	6
98	Mafic granodiorite;.......1 Garnet stock	.434	3.19	.30	1.89	---	2.67/2.69	6
99	Mafic granodiorite;.......1 Royal stock	.1276	2.11	.13	1.18	N	2.65/2.67	6
100	Mafic granodiorite;.......1 Philipsburg batholith	.126	2.32	.12	1.15	N	2.64/2.67	6
101	Mafic granodiorite;.......1 Royal stock	.0130	.594	.048	.285	---	2.65/2.67	6
102	Mafic granodiorite;.......1 Sapphire batholith (outer zone)	.166	1.76	.20	.971	---	2.63/2.65	6
103	Mafic granodiorite;.......1 Sapphire batholith (outer zone)	.125	1.44	.19	.787	---	2.66/2.67	6

Table 1. Physical properties of selected rock units, Butte 1°x 2° quadrangle, Montana—Continued

No. on map A	Rock Unit	n	Rem J	k	Q	Total J	Polarity total J	ρ	References[2]
104	Mafic granodiorite; Sapphire batholith (outer zone)	1	.0194	1.02	.041	.487	---	2.64/2.66	6
105	Mafic granodiorite; Sapphire batholith (outer zone)	1	.171	1.38	.27	.804	---	2.65/2.66	6
106	Mafic granodiorite; Philipsburg batholith	1	.213	2.85	.16	1.52	---	2.68/2.69	6
107	Mafic granodiorite; Ogden Mountain stock	1	.333	1.50	.49	1.02	---	2.64/2.68	6
107	Quartzite	1	.0116	---	---	{0.0116}	---	2.59/2.63	7
108	Mafic granodiorite; Marysville stock	1	.0947	1.41	.15	.739	---	2.69/2.71	6
109	Hornfels	1	.0001	.0151	.014	.0070	N	2.65/2.67	6
110	Hornfels	1	.0001	.0276	.0079	.0126	---	2.65/2.67	6
111	Leucomicromonzogranite; Sapphire batholith (intrusive)	1	.0962	.0214	9.8	.106	---	2.52/2.56	6
112	Limestone	1	.0002	.0	---	.0002	---	2.65/2.68	6
113	Limestone	1	.0001	.0390	.0056	.0179	---	2.63/2.66	6
114	Limestone	1	.0	.0176	.0	.0080	---	2.67/2.69	6
115	Silty limestone	1	.0006	.0	---	.0006	---	3.00/3.01	6
116	Limestone	1	.0384	.0	---	.0384	N	2.90/2.95	6
117	Silty limestone	1	.0016	.0038	.93	.0033	---	2.64/2.65	6
118	Silty limestone	1	.0004	.0	---	.0004	N	2.63/2.70	6
118	Gabbro (altered)	1	.00060	.578	.023	.0270	---	2.66/2.70	7
119	Limestone	1	.0012	.0	---	.0012	N	2.68/2.70	6
120	Silty limestone	1	.0051	.0264	.42	.0172	---	2.66/2.67	6
121	Silty limestone	1	.0039	.0	---	.0039	I	2.67/2.68	6
122	Marble	1	.0	.0038	0.0	.17	---	2.78/2.79	6
123	Marble	1	.225	.0	---	.225	N	2.73/2.74	6
124	Marble	1	.0002	.0	---	.0002	---	2.68/2.70	6
125	Marble	1	---	---	---	---	---	2.67/2.69	6
126	Monzogranite; Mt. Powell batholith	1	.0007	.186	.0088	.0858	N	2.58/2.61	6
127	Monzogranite; Mt. Powell batholith	1	.0296	.462	.14	.241	N	2.61/2.63	6
128	Monzogranite; Sapphire batholith (inner zone)	1	.0166	.420	.086	.209	---	2.62/2.64	6
129	Monzogranite; Sapphire batholith (inner zone)	1	.0185	.258	.16	.136	---	2.62/2.64	6
130	Monzogranite; Sapphire batholith (inner zone)	1	.0053	.122	.095	.0611	---	2.57/2.59	6
131	Monzogranite; Sapphire batholith (inner zone)	1	.0056	.346	.035	.164	---	2.61/2.62	6
132	Monzogranite; Sapphire batholith (inner zone)	1	.0088	.157	.12	.0807	---	2.60/2.62	6

133	Monzogranite;.............1 Sapphire batholith (inner zone)	.0218	.185	.26	.106	---	2.59/2.61	6
134	Quartz monzonite;.........1 Boulder batholith	.137	3.98	.075	1.92	N	2.66/2.68	6
135	Monzogranite;.............1 Sapphire batholith (inner zone)	.0188	.226	.18	.122	---	2.61/2.63	6
136	Monzogranite;.............1 Sapphire batholith (inner zone)	1.25	.050	54	1.27	---	2.56/2.60	6
137	Monzogranite;.............1 Sapphire batholith (inner zone)	.0115	.694	.036	.329	---	2.65/2.66	6
138	Monzogranite;.............1 Sapphire batholith (inner zone)	.113	.181	1.4	.195	---	2.58/2.61	6
139	Monzogranite;.............1 Sapphire batholith (inner zone)	.0045	.137	.072	.0672	---	2.60/2.61	6
140	Monzogranite;.............1 Sapphire batholith (inner zone)	.0098	.123	.17	.0662	---	2.59/2.61	6
141	Biotite monzogranite;.....1 Lost Creek stock	.0385	.510	.16	.272	---	2.56/2.58	6
142	Biotite monzogranite;.....1 Lost Creek stock	.0006	.020	.065	.0098	---	2.60/2.61	6
143	Monzogranite;.............1 Hearst Lake stock	.164	.440	.81	.365	---	2.60/2.62	6
144	Monzogranite;.............1 Hearst Lake stock	.0814	.868	.20	.479	---	2.61/2.62	6
145	Monzogranite;.............1 Hearst Lake stock	.0473	.353	.29	.209	---	2.60/2.62	6
146	Monzogranite; Mt. Powell..1 batholith	.194	.357	1.2	.357	---	2.66/2.67	6
147	Pyroxenite; Skalkaho......1 Mountain stock	37.8	36.5	2.3	54.4	---	3.44/3.44	6
148	Quartz monzodiorite.......1	.101	1.96	.11	.990	N	2.78/2.80	6
149	Quartz monzodiorite;......1 Storm Lake stock	.769	.102	16	.815	---	2.78/2.79	6
150	Quartzite.................1	.0080	.0138	1.3	.0143	---	2.63/2.64	6
151	Quartzite.................1	---	---	---	---	---	2.55/2.58	6
152	Feldspathic quartzite.....1	.0040	.136	.064	.0656	---	2.64/2.66	6
153	Quartzite.................1	---	---	---	---	---	2.62/2.63	6
154	Feldspathic quartzite.....1	---	---	---	---	---	2.63/2.64	6
155	Quartzite.................1	---	.368	---	.168	---	2.64/2.66	6
156	Feldspathic quartzite.....1	.0043	.020	.47	.0135	---	2.60/2.61	6
157	Quartzite.................1	.0009	.0	---	.0009	---	2.59/2.63	6
157	Quartzite.................1	.0128	.0	---	.0128	---	2.62/2.64	6
158	Feldspathic quartzite.....1	.0004	.0	---	.0004	---	2.51/2.56	6
159	Argillaceous quartzite....1	---	---	---	---	---	2.70/2.70	6
160	Feldspathic quartzite.....1	.0004	.0239	.037	.0108	N	2.64/2.65	6
161	Quartzite.................1	---	---	---	---	---	2.58/2.60	6

Table 1. *Physical properties of selected rock units, Butte 1° x 2° quadrangle, Montana*—Continued

No. on map A	Rock Unit	n	Rem J	k	Q	Total J	Polarity total J	ρ	References[2]
162	Quartzite.................	1	.0772	.0502	3.4	.0757	I	2.66/2.67	6
163	Quartzite.................	1	---	.151	---	.0690	---	2.65/2.67	6
164	Quartzite.................	1	.0048	.0239	.44	.0102	N	2.62/2.63	6
165	Feldspathic quartzite.....	1	.0028	.0314	.19	.0156	N	2.65/2.70	6
166	Feldspathic quartzite.....	1	.0146	.0151	2.1	.0215	I	2.57/2.61	6
167	Rhyolite..................	1	4.33	1.67	5.6	5.09	---	2.33/2.44	6
168	Tuffaceous rhyolite.......	1	5.38	.106	111	5.42	---	2.06/2.25	6
169	Limey siltstone...........	1	.0002	.0	---	.0002	I	2.66/2.70	6
170	Siltite...................	1	.0002	.0	---	.0002	R	2.62/2.65	6
171	Siltite...................	1	.0014	.0302	.10	.0132	N	2.62/2.64	6
172	Siltite...................	1	.0096	.0603	.35	.0235	N	2.62/2.68	6
173	Siltite...................	1	.0019	.0100	.41	.00642	N	2.61/2.62	6
174	Siltite...................	1	.0848	.0289	6.4	.0980	---	2.42/2.55	6
175	Siltite...................	1	.0840	.02513	7.3	.0955	---	2.63/2.65	6
176	Siltite or hornfels.......	1	.0982	.0314	6.8	.112	---	2.71/2.71	6
177	Siltite...................	1	.0202	.0	---	.0202	I	2.56/2.62	6
178	Siltite...................	1	.0149	.0679	.48	.0348	N	2.54/2.61	6
179	Siltite...................	1	.0046	.0	---	.0046	I	2.66/2.69	6
180	Siltite...................	1	.0091	.0	---	.0091	I	2.65/2.67	6
181	Siltite...................	1	.0042	.0	---	.0042	I	2.66/2.68	6
182	Siltite...................	1	.0217	.0	---	.0217	I	2.62/2.64	6
183	Siltite...................	1	.0282	.0226	2.7	.0274	I	2.65/2.67	6
184	Siltite...................	1	---	.0	---	---	---	2.55/2.62	6
184	Andesite (float?).........	1	.0127	---	---	{0.0127}	---	2.58/2.65	7
185	Siltite...................	1	.0001	.0352	.0	.0162	[N]	2.51/2.59	6
186	Feldspathic sandstone;.... Vaughn Member, Blackleaf formation	1	.583	.342	3.7	.656	I	2.60/2.64	6
187	Limey sandstone;.......... Vaughn Member, Blackleaf formation	1	---	---	---	---	---	2.59/2.59	6
188	Feldspathic sandstone;.... Coberly formation	1	.0015	.0591	.056	.0263	N	2.61/2.65	6
189	Sandstone.................	1	.0003	.0	---	.0003	R	2.62/2.66	6
190	Feldspathic sandstone.....	1	.0002	.0	---	.0002	I	2.50/2.57	6
191	Syenite; Skalkaho......... Mountain stock	1	.0001	.0	---	.0001	---	2.44/2.52	6
191	Syenite; Skalkaho......... Mountain stock	1	.0150	.176	.19	.0955	---	2.65/2.68	6
192	Rhyolitic breccia.........	1	.0013	.0	---	.0013	---	2.33/2.44	6
193	Magnetite-enriched........ granodiorite (float?)	1	1.04	28.9	.79	1.60	I	2.75/2.78	7
194	Quartzite.................	1	---	---	---	---	---	2.55/2.58	7
195	Quartzite.................	1	---	---	---	---	---	2.60/2.61	7
196	Quartzite.................	1	---	---	---	---	---	2.55/2.56	7
197	Quartzite.................	1	---	---	---	---	---	2.63/2.65	7
197	Quartzite.................	1	---	---	---	---	---	2.61/2.65	7
198	Siltstone.................	1	---	---	---	---	---	2.64/2.65	7
199	Limestone, siliceous......	1	.0119	.628	.38	[0.0435]	---	2.36/2.45	7
200	Rhyolite (float?).........	1	.00020	---	---	{0.00020}	N	2.51/2.58	7
201	Basalt....................	1	4.45	11.5	8.4	4.85	N	2.74/2.76	7
202	Andesite..................	1	.701	14.7	1.0	1.36	N	2.63/2.70	7
203	Granodiorite (altered)....	1	.196	3.48	.12	1.82	---	2.66	8

204	Andesite..................1	---	---	---	---	---	2.61	9
205	Basalt....................1	5.28	9.15	1.3	9.47	---	2.84	9
206	Altered basalt............1	.00764	.0636	.26	.0367	[N]	2.86	9
207	Mineralized basalt........1	.0651	.255	.56	.182	---	2.85	9
208	Mineralized basalt........1	.588	1.41	.91	1.23	---	2.64	9
209	Quartz monzonite..........1	.117	1.43	.18	.773	---	2.62	9
210	Mafic granodiorite........1	33.6	.544	135	33.8	---	2.71	9
211	Tuff......................2	---	---	---	---	---	2.30	9
212	Quartz latite.............1	---	---	---	---	---	2.37	9
212	Quartz latite.............1	---	---	---	---	---	2.52	9
213	Quartz latite.............1	.864	1.98	1.0	1.71	N	2.54	9
214	Diorite...................1	.760	4.74	.35	2.85	N	2.70	9
215	Quartz latite.............1	1.35	.549	5.4	1.60	---	2.65	9
216	Granodiorite..............1	7.08	3.62	4.3	7.46	I	2.65	9
217	Granodiorite..............1	---	---	---	---	---	2.67	9
218	Granodiorite..............1	.659	2.92	.49	1.99	---	2.71	9
219	Granodiorite..............1	---	---	---	---	---	2.67	9
220	Diorite...................1	6.22	4.93	2.8	8.47	---	2.73	9
220	Granodiorite..............1	1.28	4.90	.57	2.43	N	2.71	9
221	Dolomite..................1	---	---	---	---	---	2.61	9
221	Dolomite..................1	---	---	---	---	---	2.62	9
221	"Marsh shale".............1	---	---	---	---	---	2.53	9
221	"Marsh shale".............1	---	---	---	---	---	2.58	9
221	Flathead quartzite........1	---	---	---	---	---	2.66	9
221	Wolsey shale..............4	---	---	---	---	---	2.68	9
222	Meagher limestone.........3	---	---	---	---	---	2.70	9
223	Park argillite............3	---	---	---	---	---	2.72	9
224	Hasmark dolomite..........4	---	---	---	---	---	2.79	9
225	Red Lion dolomite.........3	---	---	---	---	---	2.72	9
226	Jefferson dolomite.......11	---	---	---	---	---	2.70	9
227	Jefferson dolomite........9	---	---	---	---	---	2.81	9
228	Three Forks formation.....4	---	---	---	---	---	2.70	9
229	Olivine gabbro............1	5.11	3.72	3.0	6.81	---	2.85	9
230	Quadrant quartzite........1	---	---	---	---	---	2.62	9
230	Phosphoria fm,............1 .oolitic phosphate	---	---	---	---	---	3.40	9
231	Morrison fm, carbonate....1	---	---	---	---	---	2.66	9
232	Unionville granodiorite...3 (weathered)	---	---	---	---	---	2.66	9
233	Unionville granodiorite...1	2.42	2.55	2.1	3.58	---	2.75	9
234	Granodiorite..............1	.415	2.44	.37	1.33	N	2.75	9
235	Clancy granodiorite.......2	---	---	---	---	---	2.65	9
236	Clancy granodiorite.......2	---	---	---	---	---	2.63	9
237	Clancy granodiorite.......1	.610	2.95	.45	1.96	---	2.67	9
238	Clancy granodiorite.......1	---	---	---	---	---	2.67	9
239	Clancy granodiorite.......2 (weathered)	---	---	---	---	---	2.60	9
240	Clancy granodiorite.......1	---	---	---	---	---	2.69	9
241	Granodiorite..............1	.0134	.0807	.36	.0503	---	2.83	9
242	Mudstone..................1	---	---	---	---	---	2.60	9
243	Mudstone..................1	---	---	---	---	---	2.64	9
244	Mudstone..................1	.00511	.00828	1.4	.0890	---	2.65	9
245	Rhyolite..................1	4.13	.168	54	4.21	---	2.40	9

Table 1. *Physical properties of selected rock units, Butte 1°x 2° quadrangle, Montana*—Continued

No. on map A	Rock Unit	n	Rem J	k	Q	Total J	Polarity total J	ρ	References[2]
246	Granodiorite, Blackfoot City stock	1	1.45	6.46	.49	4.02	N	2.81	9
247	Granodiorite, Blackfoot City stock (altered)	1	.268	.334	1.8	.421	---	2.63	9
248	Flathead quartzite	1	---	---	---	---	---	2.62	9
249	Fucoidal limestone	2	---	---	---	---	---	2.57	9
250	Granodiorite	1	.302	4.30	.15	2.27	---	2.76	9
251	Limestone	1	---	---	---	---	---	2.86	9
252	Dolomite	1	---	---	---	---	---	2.81	9
253	Sandstone	1	---	---	---	---	---	2.62	9
254	Basalt (altered)	1	.0928	.0425	4.8	.112	---	2.36	9
255	Basalt	1	3.64	2.14	3.7	4.62	---	2.67	9
256	Quartzite	1	---	---	---	---	---	2.63	9
257	Quartzite	2	---	---	---	---	---	2.58	9
258	Quartzite	1	---	---	---	---	---	2.43	9
259	Quartzite	1	---	---	---	---	---	2.72	9
260	Argillite	1	---	---	---	---	---	2.63	9
261	Argillite	1	---	---	---	---	---	2.63	9
262	Argillite	1	---	---	---	---	---	2.64	9
263	Argillite	1	---	---	---	---	---	2.69	9
264	Argillitic limestone	1	---	---	---	---	---	2.73	9
265	Argillitic limestone	1	---	---	---	---	---	2.61	9
266	Argillitic limestone	1	---	---	---	---	---	2.71	9
267	Argillitic limestone	1	---	---	---	---	---	2.70	9
268	Argillitic limestone	1	---	---	---	---	---	2.71	9
269	Hornfels	1	---	---	---	---	---	2.89	9
270	Siltite	1	---	---	---	---	---	2.33	9
271	Argillitic limestone	1	---	---	---	---	---	2.75	9
272	Argillite	2	---	---	---	---	---	2.74	9
273	Argillite	2	---	---	---	---	---	2.64	9
274	Gabbro	1	2.03	3.17	1.4	3.48	---	2.97	9
274	Basalt	1	.304	.0255	26	.315	---	2.74	9
275	Gabbro	1	1.50	2.56	1.3	2.67	---	3.05	9
276	Argillite	1	---	---	---	---	---	2.54	9
277	Argillite	1	---	---	---	---	---	2.70	9
278	Argillite	2	---	---	---	---	---	2.68	9
279	Argillite	1	---	---	---	---	---	2.62	9
280	Shale	2	---	---	---	---	---	2.69	9
281	Granodiorite (weathered)	1	---	---	---	---	---	2.63	9
282	Granodiorite (weathered)	1	---	---	---	---	---	2.63	9
283	Rhyolite	1	---	---	---	---	---	2.41	9
284	Rhyolite	1	.569	1.61	.77	1.30	---	2.59	9
285	Andesite	1	.0301	.293	.22	.164	---	2.82	9
286	Porous silica	1	---	---	---	---	---	2.45	9
287	Andesite	1	2.02	.424	10	2.21	---	2.80	9
288	Andesite	1	.179	.550	.71	.431	---	2.61	9
289	Andesite	1	.0278	.0127	4.8	.0336	---	2.47	9
290	Quartz monzonite (weathered)	1	.153	.0596	.56	.426	---	2.59	9
291	Quartz monzonite	1	.0991	.212	1.0	.196	---	2.64	9
292	Rhyolite	1	2.54	.417	13	2.73	---	2.41	9
293	Quartz monzonite	1	.179	.0255	15	.191	---	2.61	9
294	Granodiorite	1	.584	3.22	.40	2.06	---	2.69	9

295	Granodiorite..............1	.206	1.33	.34	.816	---	2.73	9
296	Andesite..................1	.204	.934	.48	.631	---	2.77	9
297	Quartz monzonite,.........1	1.18	.550	4.7	1.43	---	2.53	9
	Priest Pass stock							
298	Limestone.................1	---	---	---	---	---	2.73	9
299	Andesite..................1	---	---	---	---	---	2.81	9
300	Andesite..................1	.645	.0640	22	.640	I	2.72	9
301	Andesite..................1	---	---	---	---	---	2.58	9
302	Monzogranite..............1	---	---	---	---	---	2.63	9
303	Monzogranite (weathered)..1	---	---	---	---	---	2.59	9
304	Dolomite..................1	---	---	---	---	---	2.69	9
305	Monzogranite,.............1	---	---	---	---	---	2.64	9
	Broadwater stock							
306	Monzonite, Scratchgravel..1	6.84	6.77	2.2	9.87	N	2.73	9
	Hills stock							
307	Shale.....................1	---	---	---	---	---	2.61	9
308	Granodiorite..............1	3.10	2.70	2.5	4.34	---	2.68	9
309	Granodiorite..............1	.235	2.58	.20	1.42	---	2.72	9
310	Monzogranite (weathered)..1	.00254	.00853	.65	.00644	---	2.58	9
311	Quartz latite.............1	.0630	.763	.18	.412	---	2.50	9
312	Quartz latite.............1	.218	.210	2.3	.314	---	2.32	9
313	Andesite..................1	.00660	.00839	1.7	.0104	---	2.56	9
314	Andesite..................1	.658	4.76	.30	2.84	---	2.71	9
314	Monzogranite..............1	1.14	3.39	.74	2.69	---	2.64	9
315	Granodiorite..............1	.110	.0332	7.2	.125	---	2.69	9
316	Granodiorite..............1	.406	2.48	.36	1.54	---	2.71	9
317	Monzogranite..............1	.237	1.58	.33	.961	---	2.62	9
318	Monzogranite (altered)....1	.00315	.00425	1.6	.00509	---	2.59	9
319	Granodiorite..............1	.884	3.19	.60	2.34	---	2.71	9
320	Monzogranite (weathered)..1	---	---	---	---	---	2.42	9
321	Mafic granodiorite........1	1.85	7.93	.51	5.48	---	2.79	9
322	Monzogranite (altered)....1	.848	.0510	36	.871	---	2.58	9
323	Andesite..................1	.530	.0376	31	.547	---	2.64	9
324	Andesite..................1	.136	.256	1.2	.170	N	2.61	9
325	Quartz monzonite,.........1	1.06	2.79	.83	2.34	---	2.76	9
	Wilson Park stock							
326	Andesite..................1	.119	.0127	20	.125	---	2.51	9
327	Quartz latite.............1	.683	.212	7.0	.651	I	2.08	9
328	Granodiorite..............1	.748	2.35	.70	1.82	N	2.67	9
329	Quartz monzonite,.........1	.284	2.10	.30	1.24	---	2.68	9
	Berkeley Pit							

[1]Magnetization in SI units of A/m may be converted to electromagnetic units of emu/cm^3 by dividing by 10^3; volume susceptibility in dimensionless SI units may be converted to electromagnetic units by dividing by 4π; density in g/cm^3 may be converted to SI units of kg/m^3 by multiplying by 10^3.

[2]References: (1) Hanna (1973b); (2) Hanna (1977a); (3) Hanna (1965) and Hanna (1967); (4) Hanna (1973a); (5) Hanna (1969); (6) Hassemer and Lidke (1986); (7) J.H. Hassemer, unpub. data, 1985; (8) Hanna, (1990a); (9) W.F. Hanna, unpub. data, 1985.

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