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AEROMAGNETIC MAP OF THE WALKER LAKE 1° BY 2° QUADRANGLE, CALIFORNIA AND NEVADA

By

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INTRODUCTION

This aeromagnetic map and accompanying maps are part of a folio of maps of the Walker Lake 1° by 2° quadrangle, California and Nevada, prepared under the Conterminous United States Mineral Assessment Program. The quadrangle encompasses an area of about 19,500 km^2 along and to the east of the east flank of the Sierra Nevada (fig. 1).

The aeromagnetic map of the Walker Lake quadrangle (sheet 1) was compiled from six published aeromagnetic surveys (fig. 2). Arbitrary constant magnetic levels were added to each survey in order to minimize datum shifts across common borders. A map of flight altitudes (sheet 2) was prepared to simplify the identification of magnetic anomalies correlated with topography and to provide previously unpublished flight altitudes, which are indispensable for quantitative interpretation of the aeromagnetic map. Factors that limit the accuracy of the aeromagnetic map are evaluated in the following sections of this report.

The geologic interpretation of the aeromagnetic map is based on sample measurements and correlation with other maps of the folio including a geologic map (Stewart and others, 1982), a map showing Mesozoic plutonic rocks (John, 1983), and a map showing rock alteration (Rowan and Purdy, 1984). The purpose of the interpretation is to outline methods used and to provide examples of the correlation of magnetic anomalies with bodies of metamorphic, plutonic, and intrusive rocks. A model of a body of metamorphic rocks, parts of which occur in two aeromagnetic surveys, is used to illustrate the facility of the modeling method and to suggest a probable extension of the mineralized contact with plutonic rocks beneath a cover of volcanic rocks. Interpretation of the aeromagnetic map was applied in discussions with W.D. Mengie (oral commun., 1982) as one of the criteria used to identify and to delineate areas of mineral resource potential.

OTHER SURVEYS

The U.S. Geological Survey conducted an aeromagnetic survey of the Emigrant Basin Primitive Area near the southwest corner of the Walker Lake quadrangle (Oliver, 1970). The data, which were collected at a constant barometric elevation of 3,500 m above sea level, were superceded by a later draped survey flown closer to ground level (U.S. Geological Survey, 1979a). Henyey and Palmer (1974) show 18 km of shipborne magnetometer data collected in the Walker Lake quadrangle during their survey of Lake Tahoe. Their magnetic map includes two elongated magnetic maxima within 2 km of the east shoreline that are not on the U.S. Geological Survey (1971) map.

The U.S. Department of Energy sponsored airborne radioactivity and supplementary aeromagnetic surveys of the Walker Lake quadrangle (Geodata International, Inc., 1978) as part of the National Uranium Resource Evaluation (NURE) program. The flight level of the survey was 120 m (400 ft) above the average terrain, which provided greater sensitivity to changes in rock magnetization than other surveys in the present compilation. The average flightline spacing of 5 km (with tie lines at 20 km) generally was too wide to infer values of the magnetic field between flightlines (fig. 3). Prominent beadlike contour patterns and abrupt changes along flightlines resulted from magnetic anomalies with wavelengths significantly less than the flightline spacing. The map of NURE data (fig. 3), however, delineates regional anomalies without discontinuities at survey boundaries inherent to the present compilation (fig. 4). Magnetic profiles (Geodata International, Inc., 1978) from which the NURE map was derived provide more accurate, although widely spaced, representations of the near-surface magnetic field, because the flight levels generally were closer to the ground than surveys used in the present compilation. Flight locations of the NURE survey also may be relatively accurate, because frequent occurrence of bends in plotted flightlines implies more ground control points than implied by unrealistically straight and parallel flightlines in draped surveys of the present compilation.

EVALUATION AND INTERPRETATION OF AEROMAGNETIC DATA

METHODS OF DATA COLLECTION AND COMPILATION

Correct location of bodies or edges of bodies that are sources of magnetic anomalies depends on an accurate portrayal of the magnetic field on topographic and geologic maps at the largest available scale. The primary source of error in aeromagnetic surveys within the category of "processing errors" described by Reford (1980, fig. 11 and p. 1654) occurs at the stage where positions and corresponding altitudes along flight paths are determined. The shapes of actual flight paths are more sinuous than the straight lines shown on preflight maps or photographs, because the pilot must attempt to reproduce the intended flight locations in rugged and unfamiliar terrane while simultaneously attempting to safely adjust altitudes for drape flying and to compensate for dislocative effects of air currents. Plotted flightlines consist of a series of straight line segments connecting points where the position has been determined. Paradoxically, the longer the interval between bends on plotted flightlines and the more regularly spaced are lines, the less likely it is that positions were correctly determined. On this basis, positions determined for the Hoover-Walker Lake (U.S. Geological Survey, 1979a) and the Mokelumne (U.S. Geological Survey, 1979b) surveys of the present compilation generally appear not to be as well defined as those of the Dardanelles area survey (U.S. Geological Survey, 1981) and the NURE (fig. 3) survey. The sparsity of known positions probably resulted from attempting to transfer locations from strip films of the ground beneath the plane directly to topographic maps rather than first transferring the photo centers to aerial photographs or orthophoto quadrangles. A relatively small error of horizontal position also can cause a relatively large error in converting altitudes from radar altimeter records to sea-level elevations, which are indispensable for quantitative and, to some extent, qualitative interpretation of aeromagnetic maps.

Tie lines, which are lines transverse to normal flightlines, are shown for all surveys of the Walker Lake quadrangle except the Dardanelles area (U.S. Geological Survey, 1981). Tie lines presumably provided diurnal drift and datum control between adjacent sets of flightlines flown on different days and verified that no magnetometer malfunctions occurred during the survey. Altitude variations shown on the map of flight altitudes (sheet 2) demonstrate that the elevations of points where flightlines and tie lines intersect would seldom coincide. For example, altitude differences between successive east-west flightlines were nearly 200 m at tie-line crossings near Mono Lake. Inasmuch as the magnetic sources are close to the surface, observed magnetic intensities are strongly dependent on flight elevation. Therefore, tie lines may have been of doubtful use because the differences of the observed magnetic intensity at tie-line crossings--especially for draped surveys--are more dependent on the elevation difference and location errors at intersections than instrumental drift or temporal field changes. Empirical adjustments to obtain the same total intensity for both lines at intersections without adjustments for vertical magnetic gradients consequently may have generated artificial anomalies reflecting elevation differences near intersections. Tie lines, probably were useful to control the magnetic datum for constant-elevation surveys in the eastern part of the quadrangle, where the flightlines are long, at relatively constant level, and fairly far apart (1.6 km).

Computer programs directed contouring of magnetic intensities for draped aeromagnetic surveys in the Walker Lake quadrangle. Contouring was accomplished by gridding magnetic intensities along flightlines and then interpolating among the grid values. Grid intervals reported for the draped surveys varied from 150 to 175 m along flightlines and 155 to 400 m perpendicular to flightlines. Although not as noticeable at the regional compilation scale (1:250,000) compared to an interpretative scale (for example, 1:62,500), the gridding process diminishes amplitudes and shifts locations of observed anomalies and gradients. The somewhat adverse nature of the gridding process is recognized because tight bends or closures occur between flightlines and contours occur outside the area of coverage.

TOPOGRAPHIC AND ELEVATION EFFECTS

The aeromagnetic map reflects diversity in magnetization of the surficial and underlying rocks (sheet 1). Moderate to strong magnetization of rocks at the surface results in strong topographic effects on the aeromagnetic map. That is, magnetic maxima (highs) tend to occur over ridges and hilltops, and minima (lows) occur over canyons and depressions. The topographic effect is present in areas covered by draped surveys as well as in areas with constant-barometric surveys.

A map of flight altitudes (sheet 2) was prepared to identify areas with strong topographic effects and to provide heights of observation needed for quantitative interpretation of the aeromagnetic map in drape-flown areas. Although the magnetic effect of topography may interfere with interpretation of underlying magnetic bodies, anomalies caused by topography provide useful estimates of the magnetic properties of substantial volumes of rock not readily accessible to surface-sampling techniques (Plouff, 1976).

The nominal flight altitude of 300 m was closely attained in three areas: between Bridgeport and Mono Lake, between Emigrant Lake and Pinecrest Lake, and between the Dardanelles area and Markleeville, Calif. There are marked departures from the nominal flight altitude of 300 m above ground level in most other areas of draped surveys (sheet 2). Helicopter-borne magnetometer measurements of the NURE survey commonly show 150-m departures from the nominal flight altitude on radar altimeter records (Geodata International, Inc., 1978). Elongated flight-altitude highs occur over most drainages, small lows occur over many hilltops, and larger lows occur over a few ridges that intersect flightlines nearly at right angles. The chevron-shaped contour pattern at Mono Lake reflects precautionary flying as the pilot alternately ascended toward and rapidly descended from the steep east flank of the Sierra Nevada along consecutive flightlines. A corresponding pattern apparently is not discernable on the magnetic map because the elevation effect is small compared to changes in underlying rock magnetization and is smoothed by gridding.

Horizontal positions of magnetic highs or lows are offset from the centers of the magnetic bodies by distances that depend on the heights of observation above the body and the inclination of the total magnetizations of the bodies. The offset, which generally would be in the direction of magnetic south (S17°W) and dependent on the inclination of the Earth's field (about 63°), is insignificant compared to location errors in the Walker Lake quadrangle.

The intensity of the Earth's normal magnetic field decreases as elevation of the observation increases. A calculated change of 16 nanoteslas (nT) (Fabiano and Peddie, 1969) between the constant-barometric surveys flown at levels that are 610 m apart, is small, for example, compared to an accuracy of 100 nT for the average datum shift along the border between surveys. The normal elevation effect also is small compared to the amplitude of most magnetic anomalies in draped surveys, as illustrated by a calculated change of 34 nT, which corresponds to a change of flight elevation from 1,980 to 3,660 m above sea level along the east edge of the Sierra Nevada.

METHODS OF INTERPRETATION

The higher the magnetic gradients or curvature of contours, the closer the sources of the anomalies are to the level of observation. High gradients between flightlines also depend on the choice of contour interval, flightline spacing, variations of altitudes along adjacent flightlines, and location errors.

The magnetic effect of two-dimensional models can be calculated (Talwani and Heirtzler, 1964) if anomalies have an elongated shape (fig. 5) Three-dimensional models of geologic bodies also can be constructed (Plouff, 1976). Correlating magnetic intensities with models of gridded elevations (Blakely and Grauch, 1983) helps to identify magnetic anomalies that are not primarily caused by topography. Although models are not inherently unique, they provide useful constraints on possible shapes and magnetizations of underlying anomalous bodies. Further constraints can be provided by detailed geologic mapping, sampling, ground magnetometer surveys, and other geophysical methods.

SAMPLE MEASUREMENTS

Measurement of magnetic properties of rock samples is useful for interpreting sources of magnetic anomalies. Ware (1979) measured magnetic susceptibility at about 15,000 points in a 150- by 900-m area of the Anaconda mine at Yerington, Nev. He concluded that this method of mapping the spatial distribution of magnetite in combination with instantaneous potential measurements of the copper-iron sulfide components of mineralization are useful to project intrusive contacts, fault structures, and mineralization patterns. Oliver (1970, table 6) reported the results of measurements of magnetization for samples of granitic and metamorphic rocks collected near Emigrant Lake in the southwest corner of the Walker Lake quadrangle. Kleinhampl and others (1975) used magnetization measurements to interpret the magnetic map near Bodie, Calif. (U.S. Geological Survey, 1971).

Remanent magnetizations and magnetic susceptibilities were measured by K.S. Grafft and R.F. Sikora for 85 representative rock samples during the present study. Many of the samples were collected during concurrent studies of U.S. Forest Service wilderness and roadless areas (Plouff and McKee, 1981; Plouff, 1982; 1983a, b). Measured values of remanent magnetization were not analyzed for possible augmentation by lightning strikes.

Values of total magnetization shown near sample localities on sheet 3 are the scalar sum of the remanent and induced magnetization. Total magnetization for 12 metamorphic rocks averaged 1.2 amperes/meter (A/m) with a standard deviation of 1.2 A/m. The total magnetization was 1.8 A/m for 41 Mesozoic plutonic rocks and 25 A/m for 32 samples of Tertiary volcanic rocks with standard deviations of 2.4 and 49 A/m, respectively. The wide scatter of the magnetization of volcanic rocks was reduced by removing two altered samples with no magnetization and three samples with magnetizations that exceeded 100 A/m from the average to obtain a new average of 10±16 A/m for the remaining 27 samples. Sedimentary rocks presumably have negligible magnetization and were not sampled. Sample measurements indicate that most of the igneous and metamorphic rocks in the quadrangle are moderately to strongly magnetic; this conclusion can also be inferred from the complexity of the aeromagnetic map (sheet 1). Judging from these magnetic measurements, metamorphic rocks generally are associated with moderate magnetic lows or moderate highs, plutonic rocks with moderate highs, and volcanic rocks with intense magnetic anomalies.

DISCUSSION OF AEROMAGNETIC ANOMALIES

BROAD ANOMALIES IN AREAS OF CONSTANT-ELEVATION SURVEYS

Flight levels of the constant-elevation surveys average over 1,000 m above the ground surface. Consequently, those areas of the Walker Lake aeromagnetic map (sheet 1) indicate less response to near-surface magnetic bodies than areas of draped surveys where flight levels averaged less than 400 m above the ground (sheet 2). The area of constant-elevation surveys, which covers most of the Nevada part of the quadrangle, has a pattern of magnetic anomalies that helps to delineate broad rock units. For example, an intense magnetic high, which extends southward for 18 km in the Wassuk Range from a location 5 to 10 km west of Walker Lake Boat Harbor, encompasses a few outcrops of gabbro (John, 1983). The magnetic high may reveal the location of an extensive underlying gabbroic pluton concealed by metamorphic rocks at the surface. Similarly, outcrops of gabbro that cover an area of less than 4 km in diameter occur in the southeast corner of a complex, 13-km-diameter magnetic high south of Mount Siegel in the Pine Nut Mountains. The aeromagnetic map also shows that a large body of quartz monzonite north of Mount Siegel has low or possibly reversed magnetization compared to similar quartz monzonite in the Singatse Range to the east (John, 1983).

Several broad magnetic anomalies conform to regional geologic trends (sheet 3). The shapes of the anomalies are largely controlled by topography with broad magnetic highs occurring over ranges and magnetic lows over valleys. For example, magnetic highs near Garfield Hills, Monte Christo Mountains, the Singatse Range, and Wellington Hills and magnetic lows over Carson River valley southeast of Minden, over Walker River valley between Schurz and Hawthorne, and near Whisky and Garfield Flats generally reflect topography. A prominent magnetic low that extends nearly 50 km eastward from Mono Valley along the north flank of the Adobe Hills overlies thinly covered Tertiary andesite, which apparently has low magnetization compared with basalt forming the Adobe Hills. A regional magnetic high that extends for more than 50 km is located over a topographic low between the Gillis and Gabbs Valley Ranges. Six iron deposits occur as contact-metasomatic replacement deposits (skarns) in limestone or dolomite in contact with granitic rocks (Reeves and others, 1958) along this magnetic high. Prominent magnetic highs occur only over small parts of the Pine Nut Mountains and the Wassuk Range. A complex magnetic high extends for more than 30 km north from the Pine Grove Hills and nearly joins the prominent high of the Singatse Range. These magnetic highs may reveal locations of large plutons. Local maxima of this west-northwest-trending, complex high occur over disconnected outcrops of the quartz monzonite of Mount Siegel, the Wedertz Spring pluton, and the Ivy Ranch pluton (John, 1983).

METAMORPHIC ROCKS

Rocks deposited before the intrusion of the Sierra Nevada batholith are identified by the symbols "Pzs" and "Mzv" on the geologic base (sheet 3). These rocks are usually metamorphosed in the Sierra Nevada and where located near plutonic rocks farther to the east. Contact-metasomatic replacements of carbonate rocks (skarns) that occur along contacts with plutonic rocks are important locations of ore deposits in this region (Moore, 1969). The magnetic map was studied to determine if magnetic anomalies could be used to infer the continuation or existence of metamorphic bodies beneath surficial deposits, to locate contacts between metamorphic and plutonic rocks, or to estimate the size and depth of metamorphic bodies.

Steeply-dipping metasedimentary rocks crop out in a prominent magnetic low located west of Markleeville, Calif., near the west edge of the Walker Lake quadrangle (sheet 3). D.A. John collected 9 oriented samples of metamorphic rocks. Two samples had moderately high reversed magnetization relative to the inclination of the Earth's present magnetic field (without regard to the structural orientation of the rocks). Two samples had low normal magnetization and the other 5 samples (just west of sheet 3) had negligible magnetization (Plouff, 1983b). Assuming overall negligible magnetization relative to the surrounding plutonic rocks, a two-dimensional magnetic model was developed to show that the large body of metamorphic rocks has steep sides and could extend downward approximately to sea level (profile A-A' on sheets 1 and 3 and fig. 5). Two mines and a prospect are located in a 4-km interval along the northeast edge of the magnetic low. The edge of the low apparently delineates the contact between the metamorphic rocks and the surrounding plutonic rocks. Therefore, mineralization similar to that found at the mines may occur along other edges of the magnetic low but is concealed beneath thin covers of sediments, volcanic rocks, or plutonic rocks. Although no metamorphic rocks crop out in the 3- by 8-km closed magnetic low to the southeast, an underlying, northwest-trending body of metasedimentary rocks can be inferred. Steep gradients around a northwest-trending magnetic low near the northeast end of profile A-A' (sheet 1) may delineate a thick part of the adjacent narrow belt of metamorphic rocks. The Burnside and Cal-Pine Mines are located near the axis of this magnetic low.

A magnetic low to the northeast of Sweetwater Canyon at the east edge of the Sweetwater Mountains similarly seems to be associated with a thick body of metamorphic rocks. A magnetite deposit within the low and steep gradients around the low indicate strongly reversed magnetization of the underlying metamorphic rocks. Three magnetic lows follow the north trend of metamorphic rocks that crop out to the east of Corral Valley (west of the Sweetwater Mountains)(sheet 3). The west half of the southernmost low, however, reflects adjacent reversely magnetized volcanic rocks of Tertiary age, as indicated by a sample with a magnetization of 186 A/m collected on a hillcrest. Although not forming a closed magnetic low within the quadrangle, a 600-nT contour to the north of Lundy Lake near the south edge of the quadrangle follows a north-northwest-trending belt of metamorphic rocks for 14 km toward Twin Lakes. Magnetizations of two samples of plutonic rock, as well as two samples of metamorphic rocks collected within the complex belt, were very low. The northwestern part of the anomaly extends over a large body of the Cathedral Peak Granodiorite, which has relatively low magnetization.

As indicated by relatively high, although reversed, values of magnetization for two samples and high values of normal magnetization apparently related to metadiorite and metagabbro (McKee and Howe, 1980) near the southwest end of profile A-A' (fig. 5), magnetic highs also can be associated with metamorphic rocks. Oliver (1979, table 10) reported values of total magnetization that average 15±19 A/m for eight samples of metavolcanic rocks and 1.1±1.1 A/m for six samples of metasedimentary rocks collected from an area along the east flank of the Sierra Nevada located between 7 and 55 km south of the Walker Lake quadrangle.

Small magnetic highs apparently associated with metamorphic rocks are located east of East Canyon (20 km northeast of Bridgeport, Calif.), north of Sweetwater Ranch (10 km east of the Sweetwater Mountains), 4 km northwest of Lobdell Lake (in the Sweetwater Mountains), near Rickey Canyon (at the northwest flank of the Sweetwater Mountains), and 4 km west of Paynesville, Calif. (15 km south of Minden, Nev.). Metamorphic rocks underlie the crest of a prominent 6- by 18-km magnetic high located 6 km northeast of Paynesville. The prominent anomaly may not be entirely caused by a concealed body of metamorphic rocks because the mafic pluton associated with the quartz monzodiorite of Dresslerville (John, 1983) that borders the metamorphic rocks also might contribute to the size of the anomaly. A 500-nT magnetic high at the north end of the Bridgeport Reservoir may reveal a concealed metamorphic body because metamorphic rocks crop out beneath an apparent northeastward extension of the anomaly. The high intensity and concentricity of the anomaly, however, more likely suggest a concealed pluton.

MESOZOIC PLUTONIC ROCKS

A magnetic high with an amplitude of about 1,300 nT is centered near the north edge of a body of metamorphic rocks located 5 km north of Twin Lakes (10 km southwest of Bridgeport). A substantial part of the outcrop of metamorphic rocks is located outside the magnetic high. The primary source of the anomaly may be an underlying mafic pluton, because Chesterman (1975) mapped diorite of Jurassic age within 1 km from the crest of the anomaly. Two small bodies of serpentinite crop out on the southeast flank of the anomaly (Chesterman, 1975; D.A. John, oral commun., 1982). The source of the magnetic high is not attributed to a southward extension of younger plutonic rocks to the north because a magnetic low overlies most of that pluton.

Previously discussed magnetic highs that may be associated with plutons are located in the Wassuk Range, the Pine Nut Mountains, the Singatse Range, north of the Pine Grove Hills, northeast of Paynesville, north of Twin Lakes, and at the north end of Bridgeport Reservoir. Other magnetic highs that occur near outcrops of gabbro or diorite on John's (1983) map are located 6 km east of Lake Tahoe, 4 km east of Freel Peak (15 km southeast of Lake Tahoe), at the west edge of the quadrangle (15 km south of Lake Tahoe) (Plouff, 1983b), 5 km southeast of Coleville, Nev. (northwest edge of the Sweetwater Mountains), northwest of Mack Canyon (south edge of the Sweetwater Mountains), southeast and northeast of Granite Lake (15 km east of Pinecrest, Calif.), 3 km southwest of Chain Lakes (10 km southeast of Pinecrest), 1 km south of Thunder Mountain (east edge of Excelsior Mountains), 9 km southeast of Mina, Nev., 5 km southeast of Gillis Canyon (10 km northeast of Walker Lake), and 18 km northeast of the northeast edge of Walker Lake. The major magnetic high between the Gillis and Gabbs Valley Ranges is centered more than 3 km northwestward from large outcrops of diorite. Although the source of the last anomaly is not clear, the sense of apparent right-lateral dislocation of the crest of the high agrees with other offsets in the Walker Lane (Nielsen, 1965).

Several large outcrops of plutonic rocks shown on John's (1983) map have distinct characteristics on the magnetic map. For example, the Cathedral Peak Granodiorite, which extends more than 20 km southeastward in a 12-km-wide belt from Beartrap Lake (14 km northwest of Twin Lakes), appears nearly nonmagnetic on the magnetic map (sheet 3). On the other hand, a magnetic high that overlies a 4- by 18-km outcrop of the granodiorite of Tilden Lake, which borders the Cathedral Peak Granodiorite to the southwest, indicates that that pluton has a relatively high content of magnetite. The strong magnetic gradient between these plutons closely parallels their contact and, and on the basis of an estimate of the horizontal extent of the steepest magnetic gradient, indicates that the contact dips steeply downward for about 2 km. Farther southwest, a magnetic low is associated with the quartz monzonite of Avonelle Lake, although many small outcrops of diorite are enclosed within the 6- by 16-km outcrop. The low is partly enhanced as a normal polarization effect of the adjacent quartz diorite of Mount Gibson, which is associated with the intense magnetic high near Tiltill Mountain. The broad magnetic low farther to the west indicates that a 9- by 14-km outcrop of the underlying granodiorite of Boundary Lake is rather uniformly nonmagnetic and thick.

The nonmagnetic character of the granodiorite of Topaz Lake (John, 1983) is reflected by an irregular belt of magnetic lows that extends for 40 km between Corral Valley and Emigrant Lake. A steep magnetic gradient along the south edge of a prominent 8- by 13-km closed low within the granodiorite of Topaz Lake is located 3 km south of Fish Valley Peak. The steep gradient, which is both accentuated and interrupted in places by volcanic rocks to the south with intense normal and reversed magnetizations, delineates the steep south edge of the pluton. Decreasing values to the south within the magnetic low, which is outlined by a 600-nT contour, may reflect southward dip at the base of the pluton. A fairly linear 15-km segment of the 800-nT contour to the west of the low and to the west of the East Fork of the Carson River follows the steeply-dipping west edge of the northern part of the pluton.

The difference between the magnetization of rocks is less distinct in areas of the magnetic map flown at constant elevation because the topographic effect is subtle and the resolution is reduced at higher altitudes. Plutons shown by John (1983) in the Wassuk Range have the following characteristics based on associations with magnetic anomalies: (1) the granodiorite of Alum Creek (magnetic highs 5 km east of and 12 km northwest of Buller Mountain) and the granite of Powell Mountain appear to be relatively magnetic; (2) the granite of Walker Lake, the granodiorite of Cat Canyon, and the granite of Cory Creek are relatively nonmagnetic in a 9- by 12-km area west of Hawthorne, Nev.; and (3) the Bald Mountain pluton to the northwest of Walker Lake appears to have moderate magnetization.

Magnetic highs of intermediate size indicate locations of relatively magnetic rocks within larger plutons. Sources of the highs may be mafic differentiates within the surrounding plutons, separate smaller plutons, or, as discussed later, underlying Cenozoic plutons. A 3- by 10-km magnetic high located south of Red Peak (30 km northeast of Pinecrest) reflects relatively magnetic rocks within the granodiorite of Topaz Lake. Two outcrops of the granodiorite of Topaz Lake located 12 km south of Topaz Lake seem to have high magnetization relative to surrounding sediments, volcanic rocks, and metamorphic rocks. Moderate magnetic highs prevalent in the granodiorite of Kinney Lakes (5 km southwest of Raymond Peak) indicate that that pluton generally has intermediate magnetization. Small magnetic highs north of Lost Lake (25 km north of Pinecrest) and west of Emigrant Lake (25 km east of Pinecrest) reflect rocks of greater magnetization within the granodiorite of Kinney Lakes. The latter anomaly also may indicate a concealed body of diorite similar to that underlying an adjacent high to the north of Granite Lake.

Magnetic highs may reveal plutons concealed beneath other rocks. Although magnetic anomalies associated with volcanic rocks generally are more intense than those associated with plutonic rocks, magnetic highs extending from Tertiary outcrops into plutonic rocks suggest that plutonic rocks may underlie surficial rocks at shallow depth. Examples are the sharp high north of Waterhouse Lake (10 km northeast of Pinecrest) and the pair of highs north of Silver Creek (28 km northwest of Bridgeport). As discussed previously, the prominent magnetic high at the north end of Bridgeport Reservoir indicates that a pluton is concealed at shallow depth beneath alluvium. The shape and trend of isolated outcrops of plutonic rocks within the complex magnetic high north of the Pine Grove Hills seem to reflect a large underlying pluton. Outcrops of plutonic rocks are located near all four local maxima of the complex high, which is enclosed by the 800-nT contour. A local maximum of a 5- by 10-km gravity high (Plouff, 1983c) nearly coincides with a large outcrop of plutonic rock and the westernmost local magnetic high. The rest of the gravity high extends southeastward into the Pine Grove Hills south of the large magnetic high, thus diminishing the likelihood of a continuous pluton beneath the large magnetic high. Small outcrops of diorite (Hardyman, 1980), the granodiorite of Hidden Wash (Hardyman, 1980; John, 1983), and Mesozoic volcanic rocks (Stewart and others, 1982) on the flanks of a magnetic high southwest of Nugent Wash (15 km northeast of Walker Lake) indicate that a large body of pre-Tertiary rocks exists at a relatively shallow depth beneath the high. This association decreases the likelihood of a suspected underlying caldera of Tertiary age (F.J. Kleinhampl, oral commun., 1982). An unclosed magnetic high indicates that a fault-bounded basement ridge extends southward along the Monte Christo Mountains and 10 km southwestward to apparently split Gabbs Valley into two basins of deposition. A narrow gravity high follows the magnetic ridge for 23 km (Plouff, 1987).

Magnetic lows caused by plutonic rocks with reversed remanent magnetization are unusual because the induced magnetization of plutonic rocks generally is greater than their remanent magnetization (Oliver, 1977, table 3; Plouff, 1983b, table 1). A small magnetic low on the west edge of a larger low east of Black Bear Lake (30 km east of Pinecrest) and another closed low 3 km to the southwest over topographic highs (sheets 1 and 3) indicate that the gabbro of Twin Lakes (Keith and Seitz, 1981) exposed at the surface is reversely magnetized (Plouff, 1982). The Cherry Creek Mine is located in metamorphic rocks within the magnetic gradient along the northwest flank of these magnetic lows. The Montezuma Mine is located on the northwest edge of the same magnetic gradient, which continues mostly over metasedimentary rocks for more than 5 km northeastward from the Cherry Creek mine (Plouff, 1982). This magnetic gradient may delineate skarn deposits along the contact between metasedimentary and plutonic rocks similar to those in the area west of Markleeville (fig. 5).

Major porphyry-copper deposits occur in the Yerington batholith, a composite pluton of granodiorite and quartz monzonite porphyry near Yerington, Nev. (Proffett, 1979, p. 18-20). The mining district to the west of Yerington appears beneath a small westward extension of the magnetic low associated with the thick sediments of Mason Valley (sheet 1). A small magnetic high observed over Yerington may reflect iron in buildings and vehicles. The flight altitudes in areas of constant-elevation surveys generally are too high (for example, 1,400 m near Yerington) (sheet 2) to delineate porphyritic plutons or associated mineralized areas.

CENOZOIC VOLCANIC ROCKS

Cenozoic volcanic rocks have high and variable magnetizations and, hence, are associated with magnetic anomalies of high amplitude and short wavelength unless the rocks are relatively thin or intensely altered. For example, a prominent, 900-nT magnetic high is centered over Mount Emma, a stratovolcano located 22 km west of Bridgeport, Calif. A large part of the anomaly is caused by the topography of the edifice, which includes a thick section of volcanic rocks with magnetite visible at the surface (F.J. Kleinhampl, oral commun., 1982). A substantial part of the anomaly reflects deeper lying igneous rocks beneath this major volcanic center (Plouff, 1982). The magnetic low centered 10 km northeast of Mount Emma reflects the thickest part of sedimentary rocks in the Little Walker caldera, which collapsed following the eruption of the Miocene Eureka Valley Tuff (Noble and others, 1974). The configuration of the underlying sediments was estimated by modeling an accompanying gravity low (Plouff, 1982, fig. 2). The shape of a 15-km arc of magnetic highs located 5 km north of the magnetic low may reflect the wall of the caldera.

Other volcanic centers in the Walker Lake quadrangle may be delineated by sharp magnetic highs bounded by steep magnetic gradients. Kleinhampl and others (1975) suggested that the magnetic high 5 km west of Bodie, Calif., is associated with a source of lava and breccia. They also suggested that the magnetic high near Aurora (15 km northeast of Bodie) is associated with mafic flows and an underlying volcanic plug. A magnetic high 8 km south of Bodie encloses Tertiary intrusive rocks and may outline a volcanic center. A 5- by 8-km magnetic high, located where aeromagnetic surveys join at the south edge of Mono Valley, may reveal a volcanic center concealed beneath alluvium. This high might be an outlier of a Cenozoic pluton beneath the Adobe Hills whose north edge may approximately coincide for 35 to 40 km eastward with the 700-nT contour. Although the anomaly is strongly shaped by topography, a prominent 3- by 10-km magnetic high over the Wellington Hills may outline a volcanic center. A small magnetic high to the northwest of Sweetwater Canyon in the Sweetwater Mountains may delineate the Sweetwater volcanic center (Brem, 1984). The shape of the high is controlled by topography and is influenced to an unknown extent by large metavolcanic or plutonic bodies that may underlie small outcrops within the high. A smaller high located 7 km to the northeast of this high reflects granitic rocks exposed at East Sister. A small body of mafic intrusive rocks (Stewart and others, 1982) at the south flank of a 3-

by 5-km magnetic high over Mount Ferguson in the Gabbs Valley Range indicates that a volcanic center may be outlined by the high.

Magnetic highs with steep gradients along their edges may delineate Cenozoic plutons that are mostly concealed beneath older plutonic rocks in the Sierra Nevada. Several small outcrops of Tertiary and Quaternary mafic rocks (Slemmons, 1953; Keith and others, 1982; Stewart and others, 1982) within a 4- by 11-km magnetic high to the south of Red Peak and Bald Peak (25 km northeast of Pinecrest) may be apophyses from an underlying Cenozoic pluton that is outlined by gradients near the 1,000-nT contour level along the edges of the high. On the basis of occurrence of more than 20 augite latite dikes between the Dardanelles and Sonora Pass, Slemmons (1966, p. 205) suggested that a volcanic source exists somewhere in this vicinity. He also suggested that anomalously thick sections of volcanic rocks between Sonora Pass and Pinecrest are associated with nearby volcanic sources. Outcrops of Tertiary mafic intrusive rocks occur beneath a sharp magnetic high northwest of Relief Peak and between two highs located 6 km to the northwest. Farther northwest, a small mafic intrusive body crops out at the north edge of a magnetic high northeast of Niagara Creek. These magnetic highs are located in or adjacent to an area of magnetic intensity exceeding 1,000 nT, which extends northwest for 30 km between Emigrant Lake and the Dardanelles. Mafic intrusive rocks also were mapped near a magnetic high at Disaster Peak, small highs near Iceberg Peak (Keith and others, 1982), and beneath a high to the south of profile A-A' at the west edge of the quadrangle.

Volcanic units with reversed remanent magnetization can be distinguished by magnetometer measurements (for example, Noble and others, 1974, p. 141). If the magnitude of remanent magnetization is high and markedly exceeds that of induced magnetization, magnetic lows may occur over reversely magnetized igneous rocks. Reversed magnetization of the underlying rocks is confirmed where magnetic lows are centered near topographic highs or flight-altitude lows. For example the pronounced magnetic low centered at Mount Biedeman (8 km southeast of Bodie, Calif.) overlies a topographic high. Kleinhampl and others (1975, p. 27) reported that two samples of andesite collected nearby had weak magnetization and one sample had a reversed remanent magnetization of 4 A/m and an induced magnetization of 1 A/m. A magnetic low centered over a topographic high 5 km south of Bodie similarly indicates that the andesite at the surface is reversely magnetized. Although the magnetic low 25 km east of this low (at the border of two flight levels) does not overlie a topographic high, the intensity of the anomaly indicates that the young andesitic rocks (Stewart and others, 1982) exposed at the surface are locally thick and reversely magnetized. Older Tertiary andesitic rocks within the magnetic low at Miller Mountain in the southeast corner of the quadrangle similarly seem to be reversely magnetized.

Although the aeromagnetic map is extremely complicated because of large variations of rock magnetization and topographic effects in the Sierra Nevada, magnetic lows associated with magnetic reversals clearly exceed background variations at two localities. Reversed magnetizations of four rock samples collected at two sites on the south flank of Leviathan Peak (6 km west of Topaz Lake) confirm that the sharp magnetic low over the topographic high is caused by reversely magnetized andesite flows and shallow intrusions (John and others, 1981b). Similar rocks are exposed along the flanks of two magnetic lows centered 3 km west of and 8 km southwest of Leviathan Peak. A 5- by 10-km magnetic low is centered over a 1- by 2-km outcrop of Tertiary intrusive andesite located 8 km north-northwest of Leviathan Peak. It can be inferred that the magnetic low, outlined by the 600-nT contour, depicts a body of reversely magnetized andesite. The north half of a prominent north-trending magnetic low to the south of the Leviathan Peak low overlies the granodiorite of Topaz Lake, which has low magnetization. The more intense, south half of the low probably overlies reversely magnetized Tertiary andesite. Two samples of pyroxene andesite collected from an overlying flow at a site to the northwest have an average remanent magnetization of 15 A/m. The measured 3° inclination of the remanent magnetization vector was higher when the flows cooled because the rocks causing the associated magnetic high now dip nearly 40° WNW (John and others, 1981b). A rather unusual magnetic high over the topographically low Slinkard Creek may indicate that down-faulted andesite flows with high normal magnetization of the same age as the sampled flow underlie Slinkard Valley. Block faulting and westward-dipping strata apparently control the shapes of the adjacent magnetic lows and highs.

Local magnetic lows over Highland Peak (23 km southwest of Topaz Lake) and over two topographic highs 3 km to the north and south indicate that outcrops of rhyolitic to dacitic rocks (open triangles on sheet 3) are reversely magnetized. A thick underlying mass of these rocks is delineated by the 4- by 10-km magnetic low, which encloses the three disconnected outcrops. The anomaly may reflect a concealed intrusive source whose shape is modified by block faulting. Outcrops of similar rocks (Keith and others, 1982) 6 km north and 7 km southwest of Highland Peak underlie two small closed magnetic lows.

Magnetic lows also occur over rocks that have lost their content of magnetite or pyrrhotite through alteration. These magnetic lows, however, are difficult to attribute to alteration without examining the outcrops because they can not be distinguished from lows over reversely magnetized rocks or arc-shaped lows to the north of normally magnetized rocks. For example, two samples of Tertiary intrusive rhyolite collected 6 km southeast of Markleeville typify the nonmagnetic, intensely altered rocks of Colorado Hill. The expected magnetic low, however, cannot be distinguished on the southeast flank of a sharp magnetic high that probably delineates an intrusive body concealed at shallow depth beneath the northwest flank of Colorado Hill. An extensive area in which the volcanic rocks are modified by propylitization and other alteration processes is located to the south and southeast of Markleeville (Plouff, 1983a). Unlike most of the surrounding area, this moderately rugged terrane lacks conspicuous anomalies. The magnetization of a sample collected within a small magnetic high 2.5 km south of Markleeville was negligible. A chain of magnetic lows locally accentuated by canyon topography and reversed magnetization seems to be associated with areas of intense alteration (D.A. John, oral commun., 1982) to the north and to the southeast of the IXL mine (8 km south of Markleeville).

Wallace (1979, p. 74) suggested that the Markleeville and Masonic mining districts have some characteristics common to the upper levels of porphyry systems, including alteration, sulfide mineralogy, and proximity to volcanic centers. The magnetic low to the north of Masonic Mountain (13 km northeast of Bridgeport) reflects low magnetization of an area of propylitic, argillic, and locally silicic alteration (F.J. Kleinhampl, oral commun., 1982) of rhyodacitic to andesitic flows and tuffs (Kleinhampl and others, 1975). Kleinhampl and others (1975) suggested that a chain of magnetic lows to the north of Bodie, which forms a 15-km low enclosed by the 800-nT contour, is caused by a combination of nonmagnetic rhyolite tuff, crushed rock in fault zones, and altered rhyolite and andesite. A magnetic low extends 5 km northeast from

Wheeler Peak (in the Sweetwater Mountains) and delineates an area where volcanic rocks are sheared, fractured, and intensely altered; a magnetic low to the southeast of Wheeler Peak overlies an area of extensive silicification (G.F. Brem, written commun., 1982). Other areas where hydrothermally altered Tertiary volcanic rocks (F.J. Kleinhampl, oral commun., 1982) underlie magnetic lows are located 9 km west of Buller Mountain (20 km northeast of Aurora), northeast of Thunder Mountain (east edge of the Excelsior Mountains) (Garside, 1979), and 4 km southwest of Mount Ferguson (12 km north of Luning, Nev.) where a northwest-trending low overlies altered and intensely faulted tuffaceous rocks. The previously discussed magnetic lows associated with extensive areas of hydrothermal alteration are discernible on the simplified magnetic map (sheet 3). Magnetic lows also may be associated with rock alteration at the following locations on the detailed map (sheet 1): east of Carter Spring (20 km southeast of Minden); 8 km south-southeast of Wellington; Pine Grove Canyon 35 km south of Yerington; north edge of quadrangle at about long 119°20'; two lows centered 9 km and 15 km east-southeast of Yerington; 5 km southwest of Bald Mountain (Wassuk Range); near Wildhorse Canyon (6 km northeast of Walker Lake); Nugent Wash (25 km northeast of Walker Lake); 10 km to the northwest of Nugent Wash; Pilot Cone (near the north edge of the quadrangle); northwest of Columbus Salt Marsh (southeast corner of quadrangle); 16 km northwest of Basalt; and south of Rough Creek (11 km southwest of the center of the quadrangle). Small areas of alteration shown on a map of rock alteration by Rowan and Purdy (1983a) are either not discernible on the simplified map (sheet 3) or are marginally discernible on the detailed magnetic map (sheet 1).

SUMMARY

Although the magnetic map (sheet 1) seems complex, a detailed examination shows close correlation between magnetic anomalies and geology. Interpretation of magnetic anomalies helps to estimate the subsurface extent of rocks mapped at the surface and to infer the kind, the proximity to the surface, and the extent of rocks concealed beneath the surface. Several localities have been discussed where magnetic highs or strong magnetic lows apparently outline the subsurface extent of larger igneous bodies that encompass small outcrops of Mesozoic or Cenozoic igneous rocks. Magnetic lows also were interpreted, for example, to indicate the subsurface extent of a large body of Mesozoic metasedimentary rocks near the west edge of the quadrangle and to outline areas of hydrothermal alteration near the Sweetwater Mountains. Local magnetic highs reveal plutonic or metavolcanic rocks concealed at shallow depth beneath nonmagnetic surface rocks at many localities. But the identification of the associated rock type remains speculative in most cases without additional geologic or geophysical data. For example, the intense magnetic high at the north end of Bridgeport Reservoir could be associated with Mesozoic metavolcanic rocks, a Mesozoic pluton, or a Cenozoic volcanic center.

SIGNIFICANCE OF MAGNETIC ANOMALIES

Interpretation of magnetic anomalies generally can help to extrapolate, connect, or identify distributions of geologic units that are favorable to ore deposition and occasionally can be used to directly locate ore bodies. For example, Stewart and others (1977) correlated broad aeromagnetic highs with east-trending Cenozoic igneous rocks and mineral belts in Nevada. Examples of magnetic anomalies that may directly locate ore bodies in the Walker Lake quadrangle include an intense local magnetic high 4 km north of Twin Lakes (15 km southwest of Bridgeport) and highs near Tiltill Mountain (south edge of the quadrangle) and near Excelsior Mountain (20 km southwest of Mina), where local accumulations of magnetite might constitute iron ore. Albers and Kleinhampl (1970) suggested that many mineralized areas are associated with Tertiary volcanic centers. Intense magnetic highs overlie volcanic centers at Mount Emma and Relief Peak, whereas intense lows overlie Mount Biedeman, Leviathan Peak, Highland Peak, and the Little Walker caldera (sheet 1). If mineralization is associated either with these volcanic centers or with possible centers of volcanism indicated by other magnetic anomalies, the boundaries of the anomalies might help to delineate deposits that occur within the contact aureole or vein system of the intrusive centers. Although the rocks at the surface are intensely altered and nonmagnetic, a local magnetic high apparently identifies an intrusive body centered beneath and northwest of the mining area at Colorado Hill (5 km southeast of Markleeville). Small magnetic lows and a general absence of magnetic anomalies occur in an area of moderate to intense alteration to the south of Markleeville.

Plouff and Isherwood (1980) suggested that magnetic lows over some felsic Mesozoic plutons may be associated with relatively high permeability for the flow of mineral-rich hydrothermal fluids. Gradients along the edges of magnetic highs can identify potentially mineralized areas along the edges of Mesozoic plutons, where ore deposits occur in a zone of contact metasomatism (Moore, 1969). Skarn deposits are found in carbonate lenses within sedimentary or metasedimentary rocks adjacent to plutonic rocks. The contact zone between plutonic rocks and possibly skarn-bearing metasedimentary rocks with low average magnetization can be delineated by a magnetic gradient, as is the case near Stephens Peak (northwest of profile A-A' on sheet 3).

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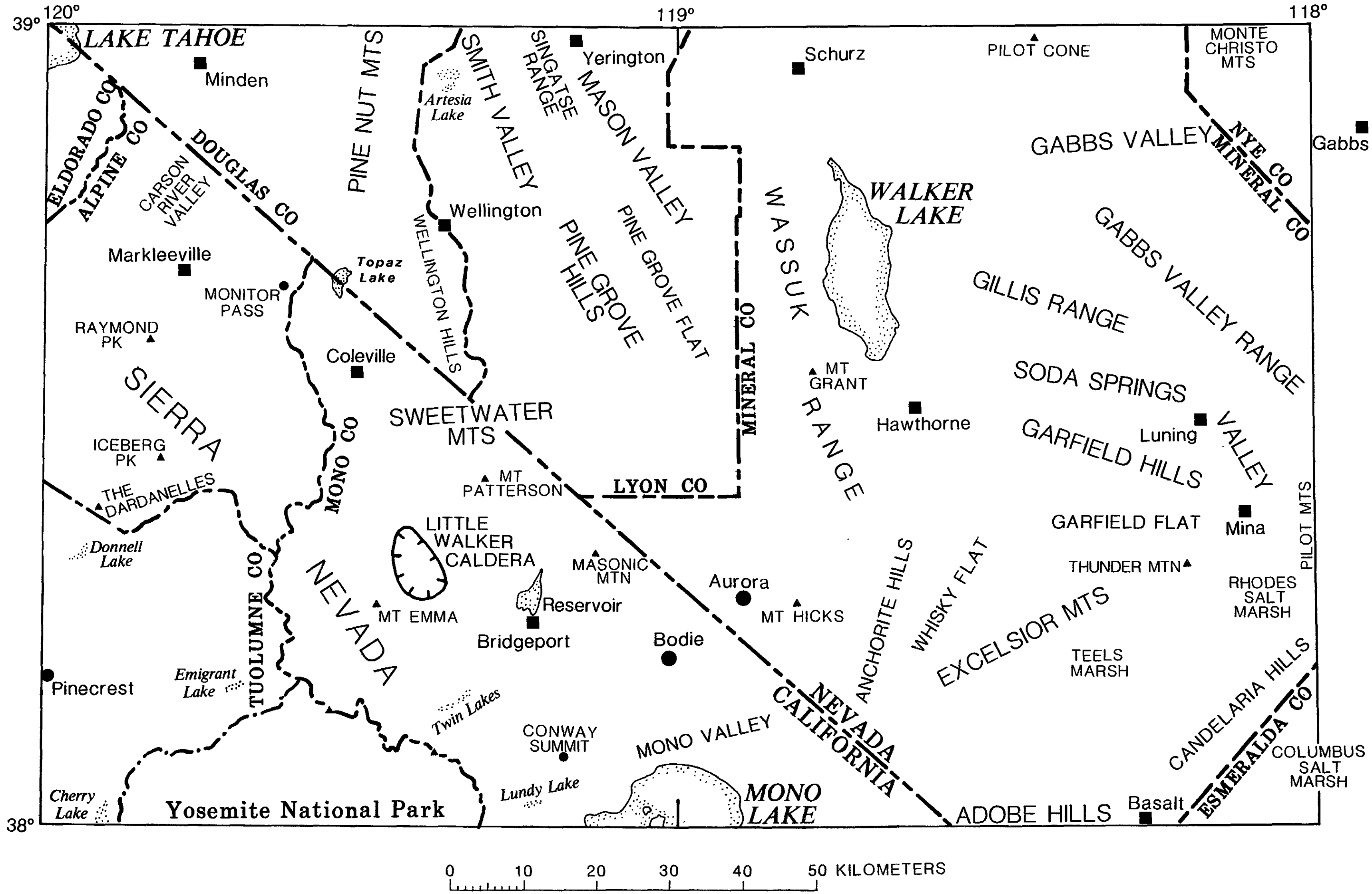
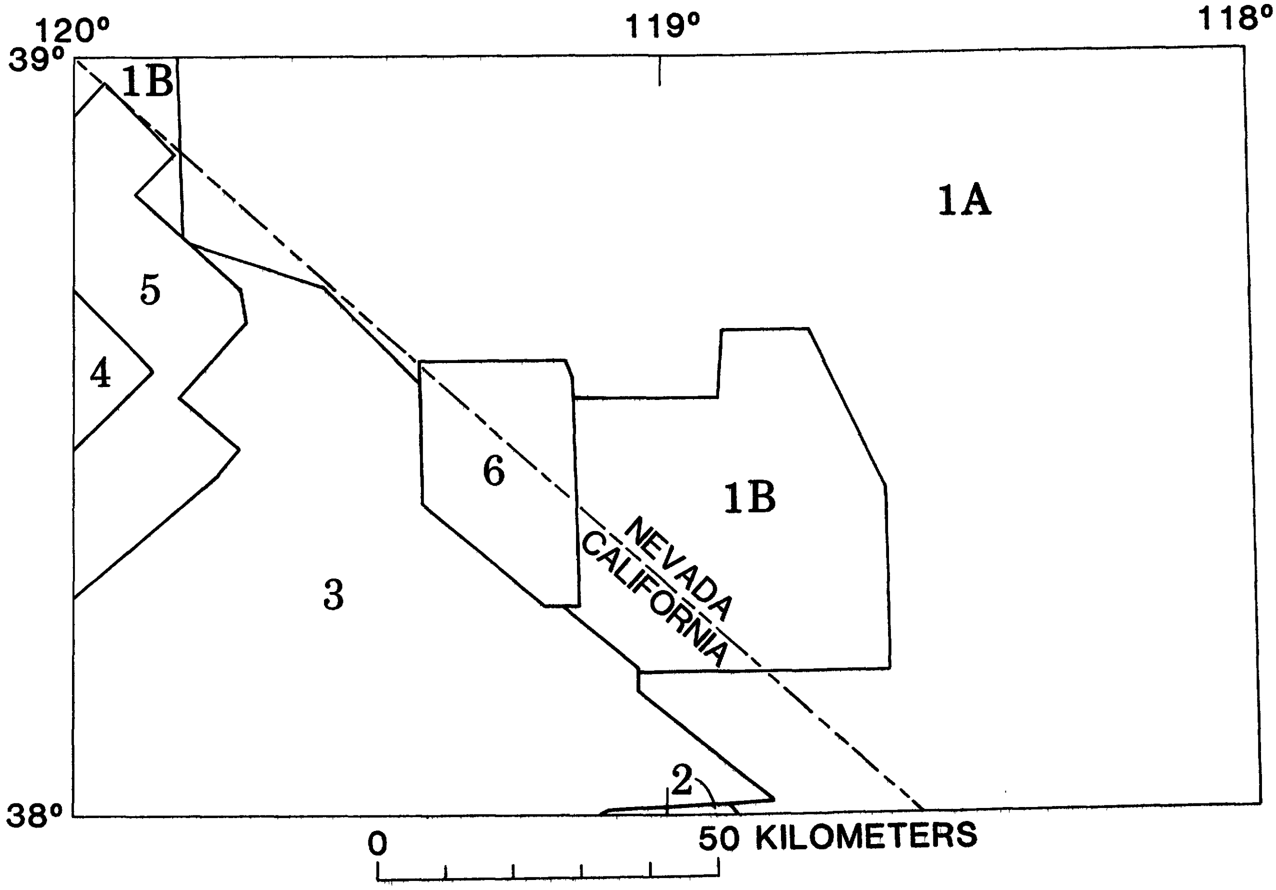


Figure 1.--Index map showing locations discussed in text.



EXPLANATION

Survey, number shown in figure. Year, year of cited U.S. Geological Survey publication. Elev, nominal flight altitude above the ground (a) or barometric elevation in meters above sea level (b). Spacing, nominal distance in kilometers between flightlines. Dir, direction of flightlines. Datum, constant in nanoteslas subtracted from magnetic intensities of original aeromagnetic map.

Survey	Year	Elev	Spacing	Dir	Datum	Contractor, year flown
1A	1971	2,740b	1.6	east	variable	Lockwood, Kessler and Bartlett, Inc. 1967
1B	Do.	3,350b	1.6	do.	do.	Do.
2	1974	4,110b	1.6	do.	-910	Aerial Surveys, Ltd., 1973
3	1979a	300a	0.8, 1.6	do.	52,500	Aero Service (Litton), 1978
4	1979b	300a	0.8	north-east	53,100	LKB Resources, Inc., 1978
5	1981	300a	0.8	do.	4,000	Applied Geophysics, Inc., 1980
6	1982	300a	0.8	east	-800	High Life--QEB, Inc., 1981

Figure 2.--Sources of aeromagnetic data.

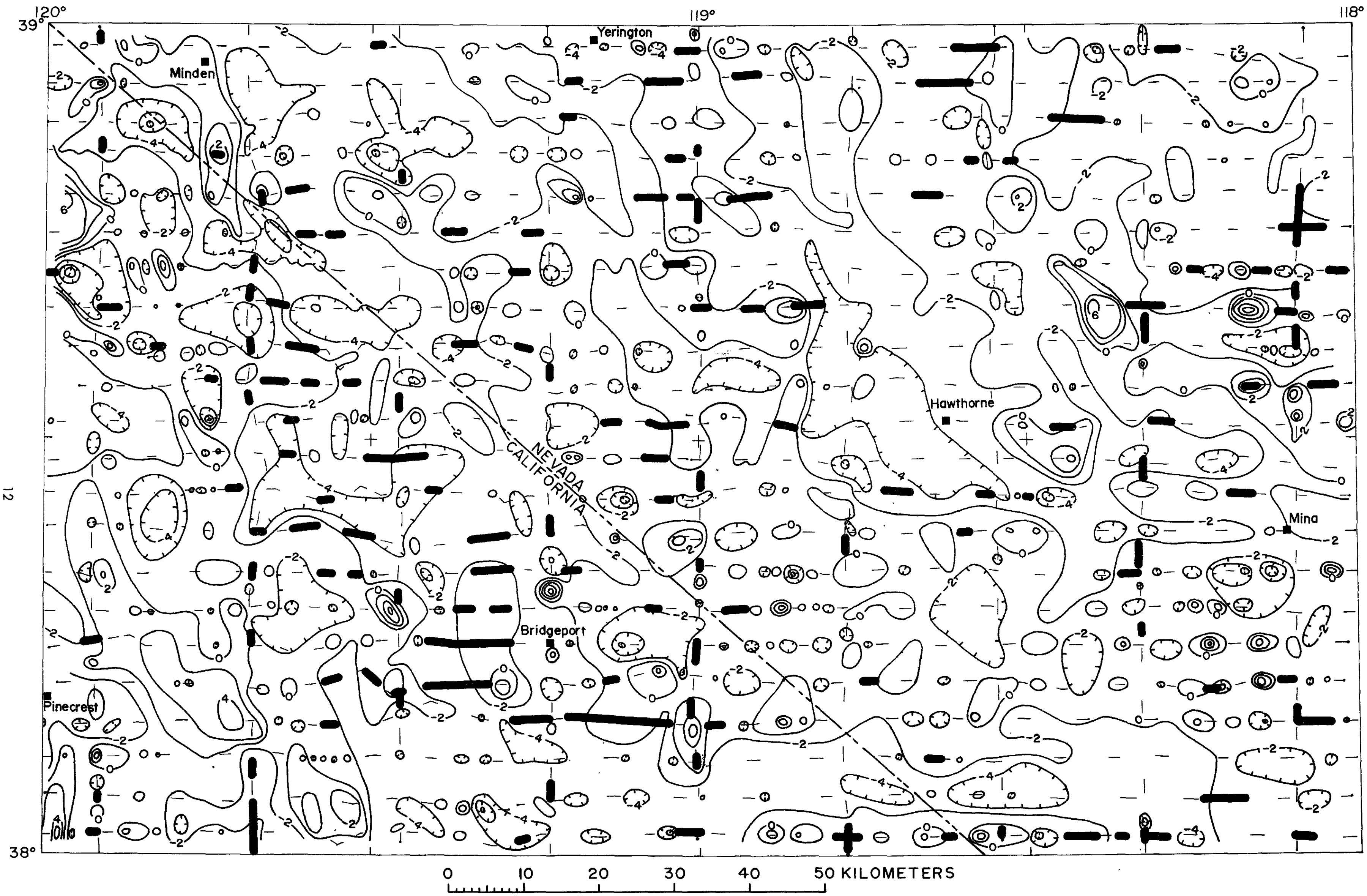


Figure 3.--Aeromagnetic map of data from the National Uranium Resource Evaluation (NURE). Contoured from profiles by Geodata International, Inc. (1978, v. 2). Thin line segments indicate location of flightlines. Dots indicate ends of flightlines. Thick line segments along flightlines indicate locations where high-amplitude changes of the magnetic field occur in too short a distance to be shown by contouring. Hachures indicate magnetic low. Contour interval 200 nT. Contour labels in units of 100 nT.

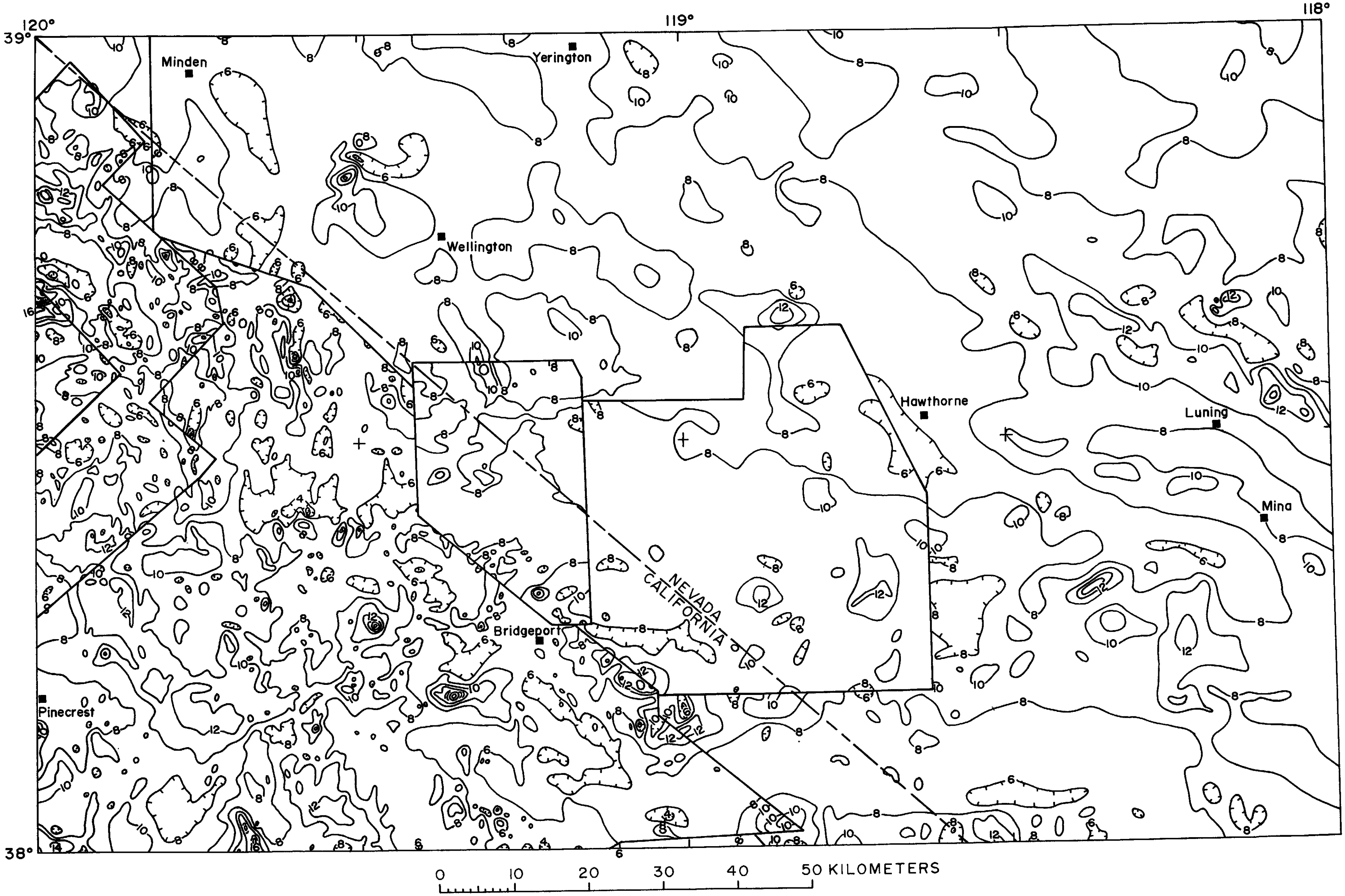


Figure 4.--Simplified aeromagnetic map. See sheet 1 for location of flightlines. See figure 2 for source of data in each outlined survey area. Hachures indicate magnetic lows. Contour interval 200 nT. Contour labels are in units of 100 nT.

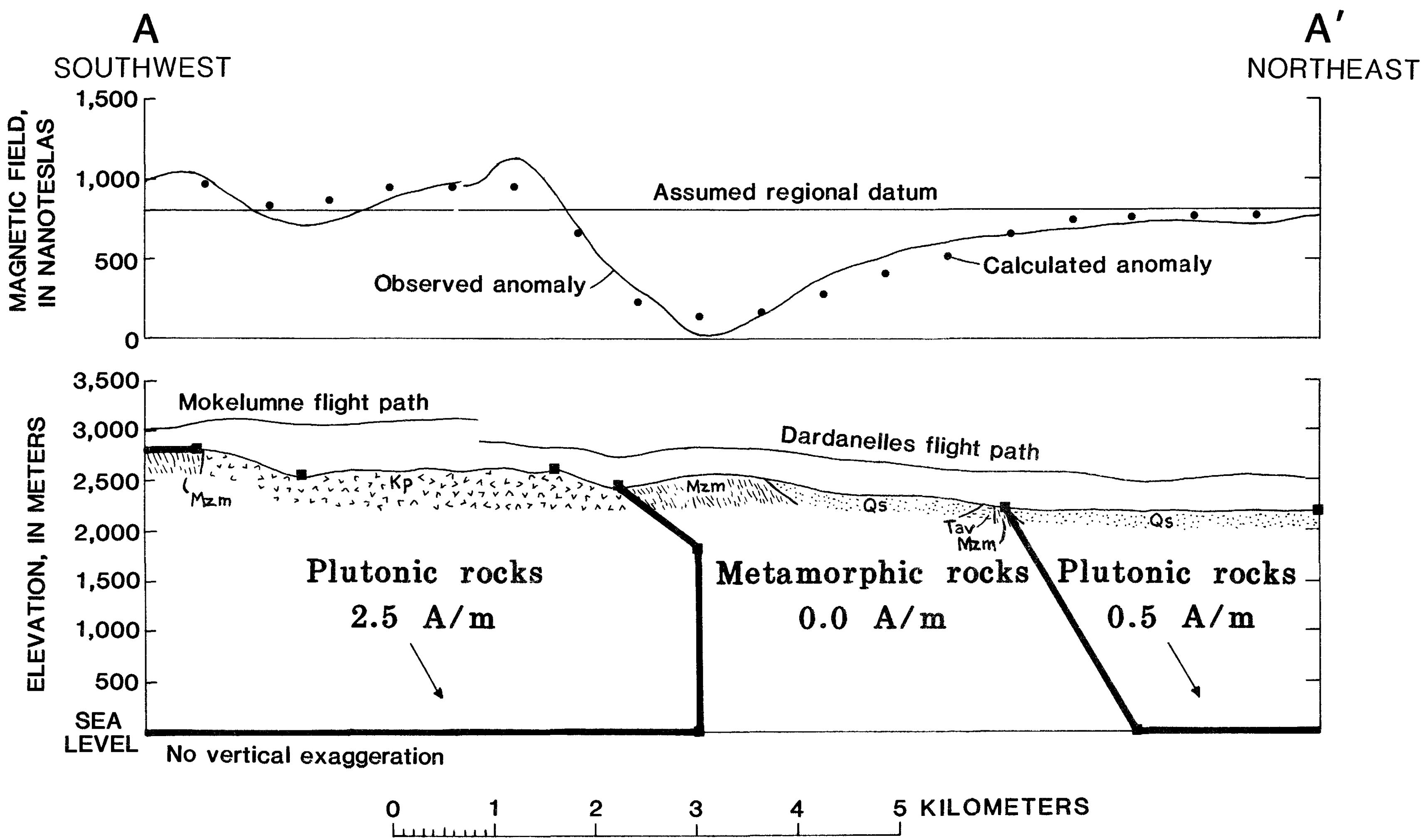


Figure 5.--Interpretation of magnetic anomalies along profile A-A'. See sheet 1 for location of profile. Supplementary magnetic data to the southwest from U.S. Geological Survey (1979b). Flight-altitude data from R.H. Godson (written commun., 1981). Geologic section constructed from John and others (1981a) and McKee and Howe (1980). Kp, Cretaceous plutonic rocks; Mzm, Mesozoic metamorphic rocks; Qs, Quaternary surficial deposits. Tav, Tertiary andesitic volcanic rocks. Model continues 20 km beyond each end of profile. Squares indicate corners of model. Thick lines indicate edges of model. Numbers indicate assumed total magnetization in the direction of Earth's normal field (indicated by arrows).