UNITED STATES DEPARTMENT OF THE INTERIOR
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Preliminary aeromagnetic, gravity, and generalized geologic maps of the USGS Basin and Range-Colorado Plateau transition zone study area in southwestern Utah, southeastern Nevada, and northwestern Arizona (the "BARCO" project)

by

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ABSTRACT

Residual total-intensity aeromagnetic, complete-Bouguer gravity anomaly, and generalized geologic map compilations are presented for the U.S. Geological Survey's Basin and Range-Colorado Plateau ("BARCO") study area at a scale of 1:250,000. The area of coverage is a 1.5^{o} x 3^{o} (264 km by 165 km) rectangular block across the structural transition from Basin and Range to Colorado Plateau in the general vicinity of the Hurricane and Grand Wash-Gunlock faults and Pine Valley laccolith. The aeromagnetic map is a composite of seven previously published maps (from surveys flown at 400 ft and 1000 ft draped and 9000 ft and 12,000 ft barometric elevations) and is contoured at an interval of 20 nT. The gravity map was constructed using data from 6919 stations, mostly from Defense Mapping Agency files but including about 700 stations established over the past several years by the USGS. All data are computer-terrain-corrected to 167 km (Hayford-Bowie zones A-O) and the Bouguer anomalies are contoured at an interval of 2 mGals. The geologic map shows seven generalized rock units with strongly contrasting bulk magnetization and density.

INTRODUCTION

The U.S. Geological Survey began in 1988 a geologic study of the Basin and Range-Colorado Plateau structural transition zone in southwestern Utah, southeastern Nevada, and northwestern Arizona, as a project of the National Mapping Program of the USGS Office of Regional Geology. Designated the "BARCO" project (figure 1), the study area covers eight 30' x 60' 1:100,000-scale topographic quadrangles: the Caliente, Clover Mountains, and Overton sheets of the Caliente and Las Vegas 1^{o} x 2^{o} quadrangles, Nevada; the Cedar City, St. George, Panguitch, and Kanab sheets of the Cedar City 1^{o} x 2^{o} quadrangle, Utah; and the Littlefield sheet of the Grand Canyon 1^{o} x 2^{o} quadrangle, Arizona. For these preliminary compilations we have added the Fredonia, Arizona 1:100,000-scale sheet to the coverage, which then fills out a 1.5^{o} x 3^{o} rectangle. The enlarged area provides a transect of more than 300 km from southeast to northwest across the transition from relatively stable interior Colorado Plateau to typical basin-range extended terrane.

Some prominent structural elements of this area are shown in figure 2. The southeastern half of the area, that is, the part within the Colorado Plateau province, consists of a set of east-tilted fault blocks bounded by north-northeast-striking high-angle normal faults of the Grand Wash-Gunlock, Hurricane, Toroweap-Sevier, and Sinyala-Paunsaugunt zones; in the extreme southeast corner is the Kaibab arch, bounded by faulted monoclines. Most of this area is, in fact, a structural transition zone from weakly faulted Colorado Plateau east of the mapped area to Basin and Range province; the west edge of the transition zone trends northeast from the northern Virgin Mountains to the Cedar City-Parowan monocline (Anderson and Christenson, in press), roughly coinciding with the southeastern limit of major Sevier orogenic structures. The Basin and Range province to the west is characterized by more abundant and larger faults and includes uplifts of Precambrian basement rock in the Virgin and Beaver Dam Mountains and, farther north, by a belt of Miocene hypabyssal quartz monzonite intrusions. The latter include the "iron axis" bodies of Bull Valley and Iron Springs, as well as the areally extensive Pine Valley intrusion, a thick sill or laccolith that

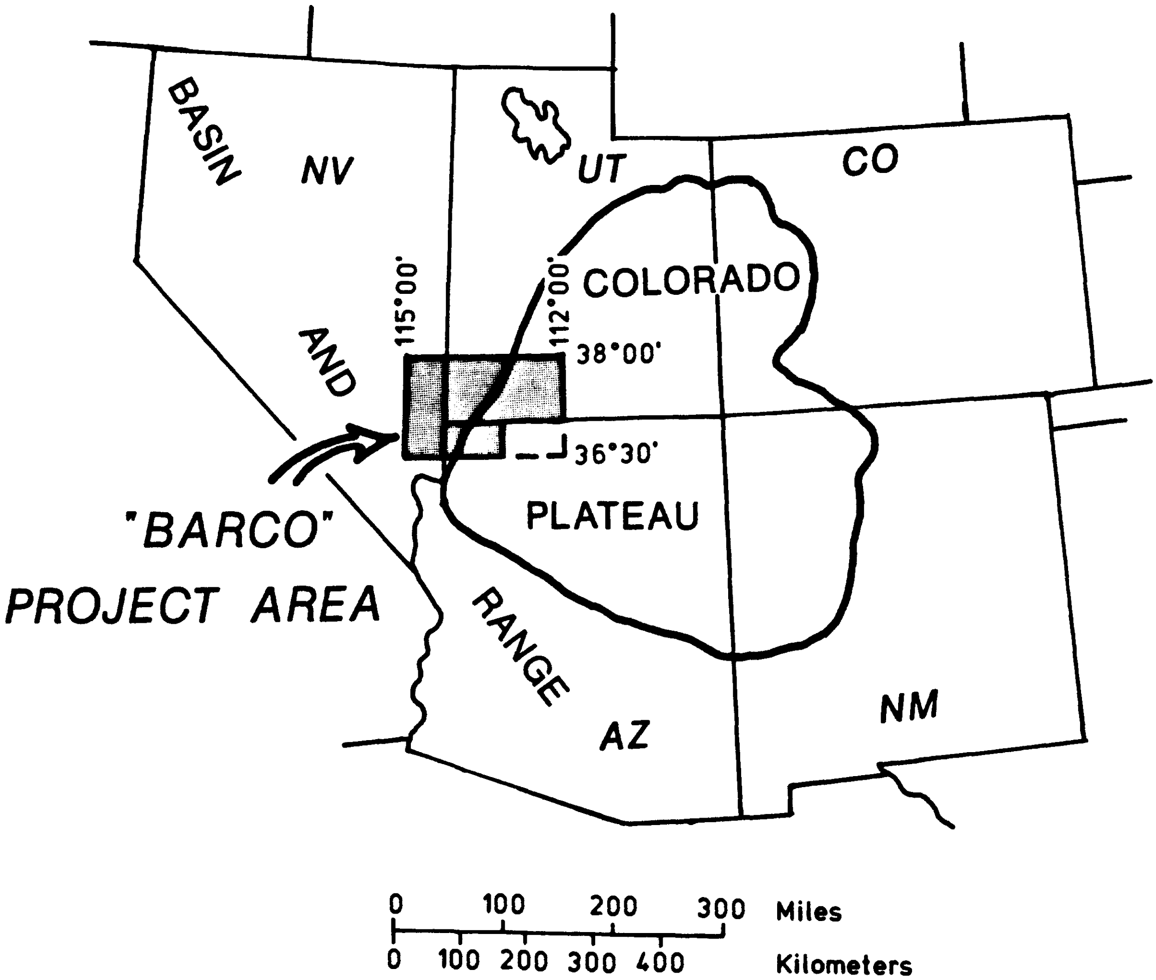

Figure 1. Index map showing location of BARCO project area (stippled) in relation to Colorado Plateau. Coverage in this report includes Fredonia 30' x 60' quadrangle of Arizona (dashed extension).

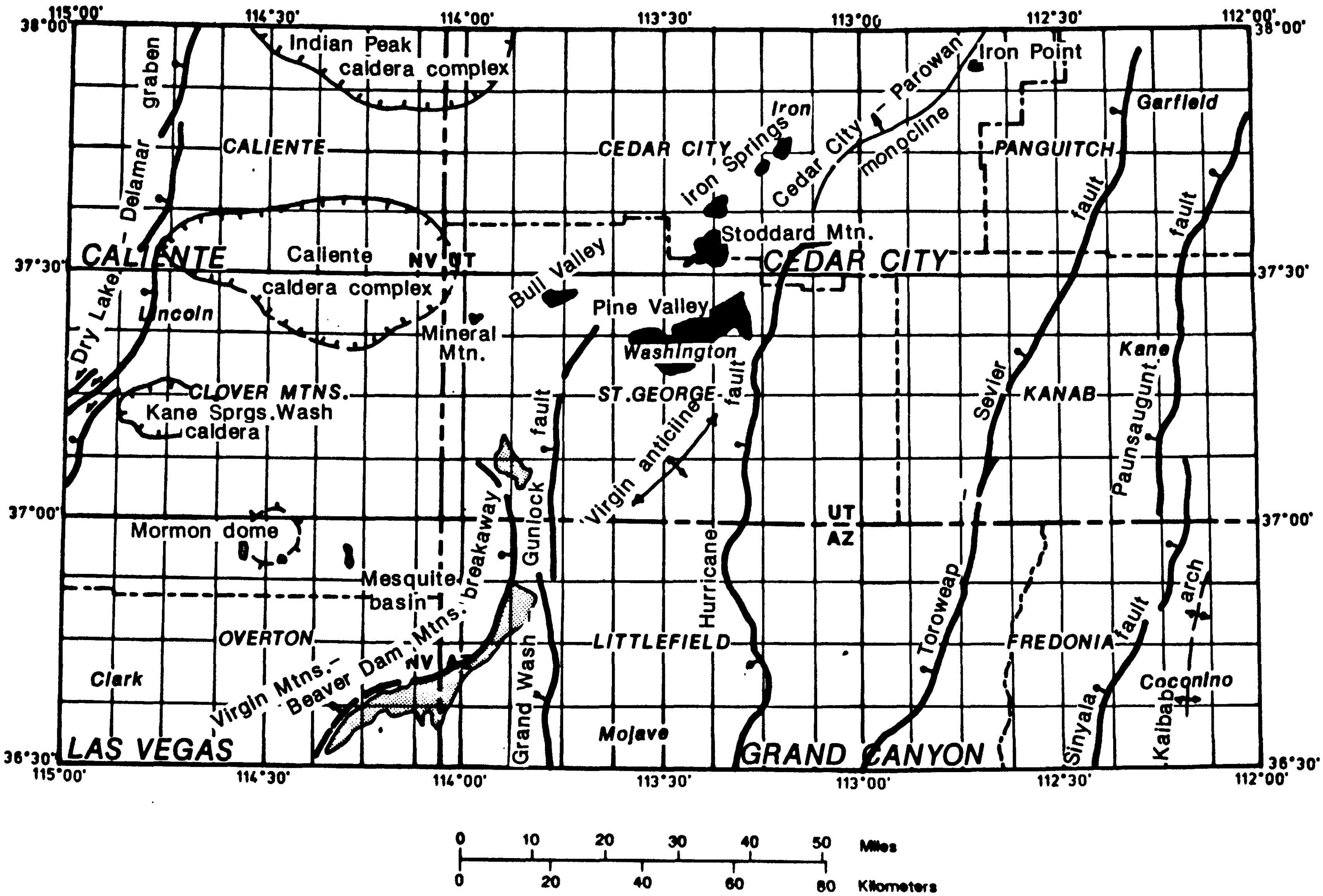

Figure 2. Some prominent structural elements. Tertiary intrusive rocks are shown in black; Precambrian crystalline basement rocks are shaded. Counties and quadrangles are labeled in italics.

erupted onto the surface as viscous lava (the Pine Valley Mountains, and all of the area bounded east-west by the Hurricane and Gunlock faults, are considered to belong to the Basin and Range province by some authors and to the Colorado Plateau province by others). The domoform Mormon Mountains uplift, which also exposes crystalline basement, is separated from the Virgin-Beaver Dam front by an extremely deep tectonic depression, the Mesquite basin. Terrane to the northwest of these features is dominated by volcano-tectonic structures of the Kane Springs Wash caldera and the Caliente and Indian Peak caldera complexes, which were loci of voluminous ash-flow tuff eruptions in Oligocene and Miocene time. Finally, the Dry Lake-Delamar graben in the extreme northwest corner of the study area appears to be a more or less linear "pull-apart" graben typical of many in the eastern Basin and Range province.

The geophysical maps in this report reflect the status of coverage at the onset of the BARCO project; acquisition of additional data is a component of the BARCO work plan. Similarly the geologic base map, with a few exceptions, is derived from research carried out prior to initiation of the BARCO project. It is mainly a generalized composite of regional compilations of a decade or more ago and its primary purpose is to provide a geologic framework for interpretation of the preliminary aeromagnetic and gravity data. In the following text, we furnish a brief explanation of each map and point out some of the highlights of the aeromagnetic and gravity fields.

AEROMAGNETIC MAP

The aeromagnetic map of the BARCO area (plate 1) was made by compositing data from portions of seven discrete surveys flown for the USGS, the Universities of Utah and Arizona, and the National Uranium Resource Evaluation (NURE) program (figure 3). Data from these surveys are included on published aeromagnetic maps of the Las Vegas and Caliente $1^{o} \times 2^{o}$ quadrangles, Nevada (Saltus and Ponce, 1988; Saltus and Snyder, 1986), and on aeromagnetic maps of the States of Nevada (Hildenbrand and Kucks, 1989), Utah (Zietz and others, 1976, 1978), and Arizona (Sauck and Sumner, 1970). The surveys were flown at different times and under different specifications (see figure 3). The International Geomagnetic Reference Field adjusted for the survey date was removed from each data set, and the residual anomaly data were gridded at 0.5 km prior to contouring. Where two surveys adjoin, a mismatch has been avoided by stripping data to create a narrow data gap. Surveys of the Virgin Mountains and part of the Las Vegas $1^{o} \times 2^{o}$ quadrangle, both of which were flown east-west at 1000 ft above ground, had previously been merged and so in this case no trimming was necessary. NURE data were used to patch a large gap in coverage between surveys of the Basin and Range and Colorado Plateau in Utah. The data gap between the Nevada-Utah border and 114^{o} west longitude represents a hiatus in coverage of USGS surveys that was considered too narrow to warrant NURE infill.

The main sources of aeromagnetic anomalies in the BARCO area are 1) Precambrian crystalline basement rocks, 2) Tertiary granitoid intrusive rocks, and 3) Quaternary and Tertiary volcanic rocks. The entire Mesozoic-Paleozoic stratified succession in this region can be regarded for present purposes as non-magnetic. Long-wavelength anomalies over the Colorado Plateau sector of

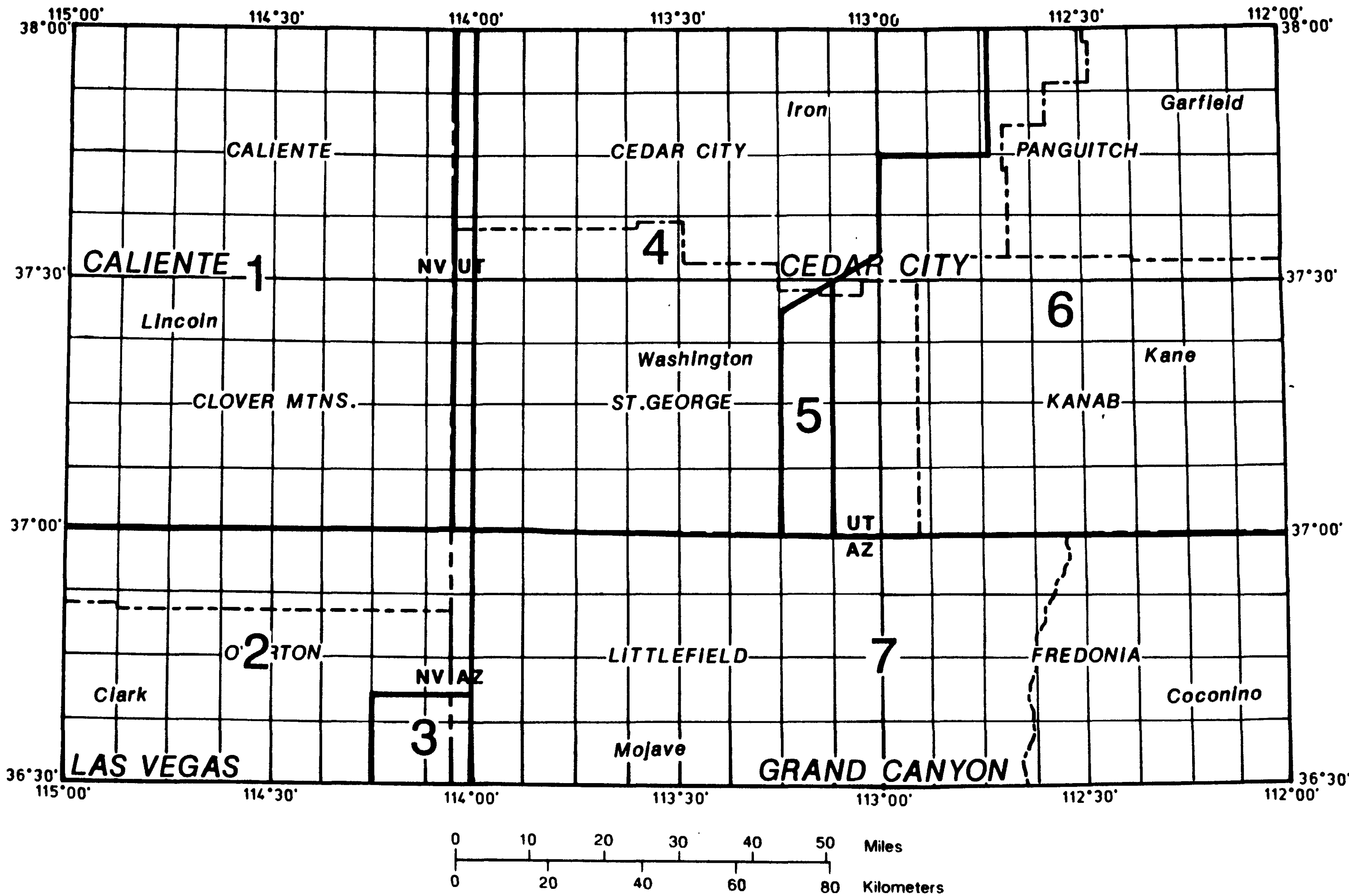

Figure 3. Index map of aeromagnetic surveys. Key: 1, USGS, 1973: Flown N-S, 9000 ft B, 1-mi spacing; 2, USGS, 1983: Flown E-W, 1000 ft D, 1-mi spacing; 3, USGS, 1979: Flown E-W, 1000 ft D, 0.5-mi spacing; 4, USGS, 1972: Flown N-S, 9000 ft B, 2-mi spacing; 5, Geodata International, Inc., 1980 (U.S. Department of Energy, NURE program): Flown E-W, 400 ft D, 3-mi spacing; 6, Shuey and others, 1973 (University of Utah): Flown N-S, 9000 ft B, 2-mi spacing; 7, Sauck and Sumner, 1970 (University of Arizona): Flown E-W, 9000 ft B, 3-mi spacing. NOTE: B = barometric; D = draped.

the map are probably caused in part by structural relief on the surface of the Precambrian basement and in part by intrabasement magnetization contrasts, as suggested by anomalies associated with crystalline rocks exposed at the plateau margins in the Beaver Dam and Virgin Mountains. Positive long-wavelength anomalies occur over the Mormon Mountains dome and over an inferred deeply buried basement uplift in the southwest corner of the mapped area (centered on the California Wash and Hidden Valley area in the Overton 30' x 60' quadrangle). All of these aeromagnetic features correlate roughly with gravity highs. Aeromagnetic anomalies of intermediate spatial wavelength are produced by partly concealed granitoid (chiefly quartz monzonitic) intrusions of the "iron axis" in southwestern Utah (see, for example, Blank and Mackin, 1967), and by related, but completely concealed, intrusive bodies inferred to lie farther northeast along the same trend and beneath Sevier Valley. Other anomalies, probably also produced by buried intrusions, are associated with the Caliente and Indian Peak caldera complexes. Aeromagnetic and gravity lows immediately north of the Kane Springs Wash caldera suggest the presence of a concealed caldera at that location. Relatively short-wavelength but intense anomalies are generally associated with the volcanic rocks, including those of basaltic vents of Quaternary age on the Colorado Plateau.

Two very broad (50-75 km diameter), east-northeast-aligned aeromagnetic lows are present in the regions centered approximately over Pine Valley and Sevier Valley. These anomalies are distinct from the relatively short-wavelength signatures of volcanic rocks and hypabyssal intrusions in the vicinity, and their origins are not well understood. Both are more or less coincident with similarly broad Bouguer and residual isostatic gravity anomaly lows (see discussion of gravity map which follows this section). The aeromagnetic and gravity lows seem to reflect fault-bounded depressions of the Precambrian crystalline basement at the intersection of north-northeast-trending Plateau structures and the east-northeast-trending southern Nevada-southwestern Utah magmatic-tectonic belt. The relation of these depressions to the magmatic belt, and to the high-level granitoid bodies (the Pine Valley and Sevier Valley intrusions) that perhaps are indicative of a silicic substrate, is as yet unclear.

GRAVITY MAP

The complete-Bouguer gravity anomaly map of the BARCO area (plate 2) was compiled from about 6200 gravity stations obtained from the National Defense Mapping Agency (DMA) data base (via the National Center for Geophysical and Solar-Terrestrial Data, Boulder, CO 80303), supplemented by about 700 stations established during the past several years by the USGS. The DMA data were derived mainly from earlier surveys of the USGS and surveys of the Universities of Utah and Arizona. Observed gravity values were reduced to Bouguer anomalies with respect to the Geodetic Reference System 1967 (International Association of Geodesy, 1967), using base stations (U.S. Defense Mapping Agency, 1974) referred to the International Gravity Standardization Net 1971 (Morelli, 1974) and a reduction density of 2.67 gm/cm^3. This procedure is described by Cordell and others (1982). All stations have been computer-terrain-corrected from the point of observation out to a radius of 167 km (Hayford-Bowie zones A-O) using the method of Plouff (1977) with 15" digital topography. Several stations of the DMA set with suspect anomaly values were deleted because their recorded elevations were found to be in error. A 1-km grid was generated from the irregularly spaced, screened data prior to contouring.

Previously published gravity anomaly maps of various portions of the study area are indexed on figure 4. In addition, much of the data is included in Bouguer anomaly maps of the Las Vegas and Caliente 1^{o} x 2^{o} quadrangles, Nevada (Kane and others, 1979; Healey and others, 1981), and the Grand Canyon 1^{o} x 2^{o} quadrangle, Arizona (Lysonski and others, 1981), as well as in Bouguer anomaly maps of the States of Nevada (Saltus, 1988), Utah (Cook and others, 1975), and Arizona (West and Sumner, 1973).

The total Bouguer anomaly relief in the BARCO area is about 145 mGals (>-98 mGals in the Virgin Mountains to <-244 mGals in Sevier Valley). The anomaly relief can be reduced by about one half by applying a standard isostatic correction (H.R. Blank, unpublished data; also see Eppinger and others, 1989), but a pronounced down-to-the-north gradient that extends all the way across the map area still remains. This gradient corresponds to a northerly increase in regional elevation in both the Basin and Range and Colorado Plateau provinces. In the Great Basin, it also corresponds to an increase in thickness of calc-alkaline volcanic products. The gradient belt extends westward as far as the Sierra Nevada; the Nevada segment was analyzed by Eaton and others (1978) and interpreted as the expression of a fundamental change in composition of the crust and upper mantle associated with extensive silicic magmatism. Very long wavelength anomaly lows centered on Pine Valley and Sevier Valley may reflect southeastward encroachment of the more silicic crust by deep-seated magmatism, as implied above in the discussion of aeromagnetics.

In the High Plateaus subprovince of the Colorado Plateau in southwestern Utah, significant anomalies are due to mass deficiencies in the topography, because the standard reduction density, 2.67 g/cm^3, is much greater than the bulk density of the Mesozoic-Cenozoic section. The Hurricane, Toroweap-Sevier, and Sinyala-Paunsaugunt fault zones commonly juxtapose rocks of strongly contrasting densities and produce strong gravity anomalies. Long-wavelength anomaly highs in general reflect structural highs of dense Precambrian crystalline and Paleozoic carbonate rocks, and, to an unknown extent, the distribution of relatively dense lithologies within the basement complex. Other highs are associated with Sevier-Laramide folds such as the Virgin anticline which have produced sharp relief on the surface of the Paleozoic section. Long- and medium-wavelength anomaly lows are characteristic of alluviated tectonic basins and volcano-tectonic depressions in the region. The deepest low occurs over the Mesquite basin, where the basement surface is interpreted to be depressed as much as 10-15 km relative to its elevation in the adjacent Virgin and Beaver Dam Mountains. A low extending southwest from Mesquite Basin reflects a linear structural depression beneath Mormon Mesa; exploration drilling on Mormon Mesa penetrated crystalline basement at about 19,600 ft depth. Other conspicuous anomaly lows are produced by the Delamar-Dry Lake graben, by calderas of the Indian Peak and Caliente complexes, by inferred basin-range grabens beneath the Escalante Desert, and by the Grand Wash structural trough. All of these structures are manifestations of Tertiary extension.

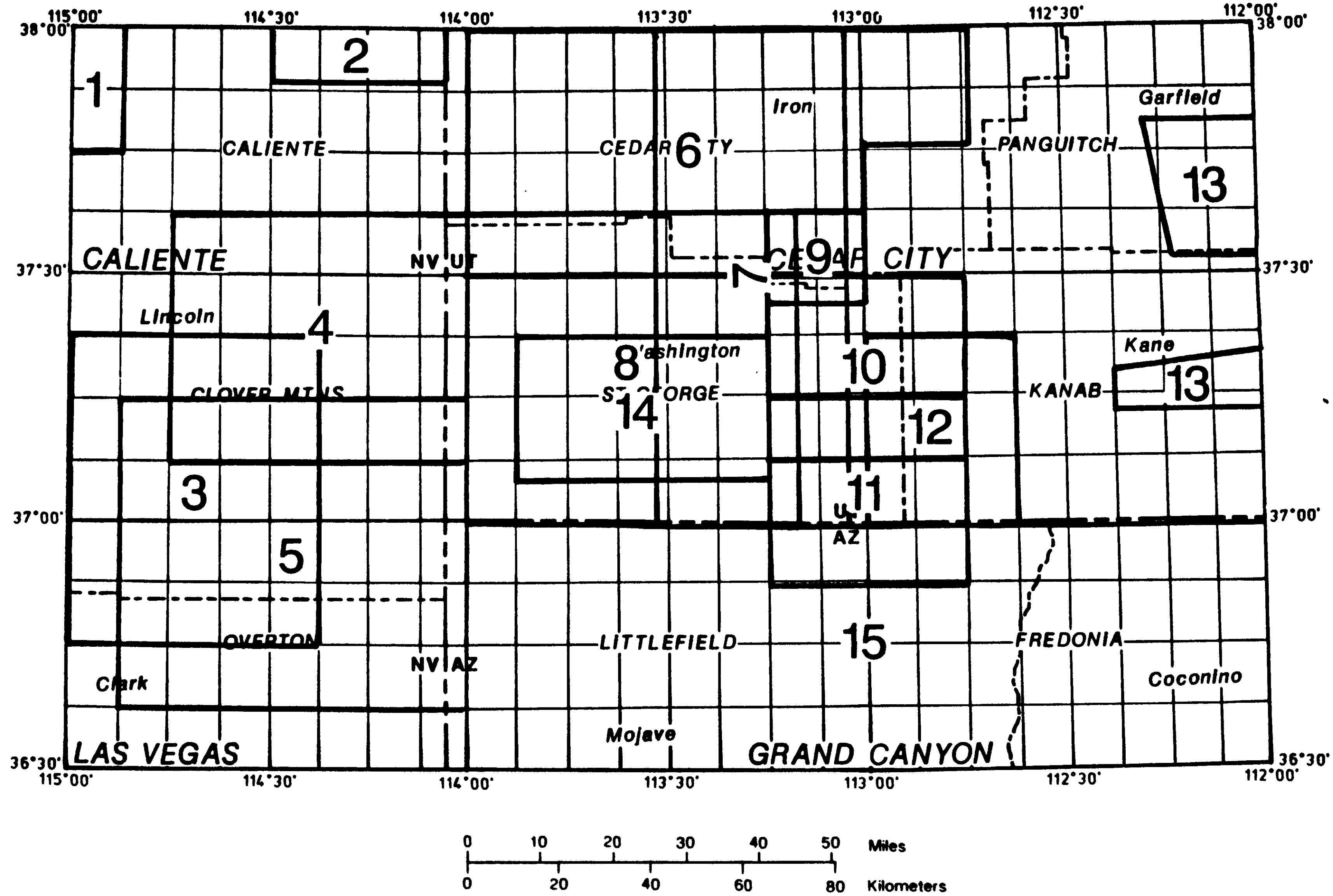

Figure 4. Index map of gravity surveys. Key: 1, Du Bray and others, 1987; 2, Toth and others, 1987; 3, Pampeyan and others, 1988; 4, Moring and others, in press; 5, Shawe and others, 1988; 6, Pe and Cook, 1980; 7, Cook and Hardman, 1967; 8, Green and Cook, 1981; 9, Van Loenen and others, 1989a; 10, Van Loenen and others, 1989b; 11, Van Loenen and others, 1988a; 12, Van Loenen and others, 1988b; 13, Fox, 1968; 14, Houser and others, 1988; 15, Popenoe, 1968. Numbers are centered in survey blocks.

GEOLOGIC MAP

The geologic base map (plate 3) was prepared by generalizing portions of maps published at 1:250,000-scale by Hintze (1963), Tschanz and Pampeyan (1970), Ekren and others (1977), Longwell and others (1965), and Santa Fe Pacific Railroad Company (1988), with the southeast corner of the area filled in from the 1:1,000,000-scale map of Arizona compiled by Reynolds (1988), as indicated on figure 5. Limited modifications of data on these source maps were made to take into account work by Bohannon (1978), Shoemaker and others (1978), Giardina (1979), Hintze (1980, 1986), Novak (1984), Wernicke, Guth, and Axen (1984), Anderson and Rowley (1987), Anderson and others (1987), Lundin (1987), Rowley and others (1987), Pampeyan and others (1988), Best and others (1989), Anderson and Christenson (in press), Doelling and Davis (in press), E. G. Sable (unpublished data), R. B. Scott (unpublished data), and D. L. Schmidt (unpublished data). However, the resulting generalized map falls far short of including revisions from all current geologic literature on the area.

Rock units shown on this map and their bulk physical properties are listed in table 1. Characterization of the physical properties is intended as a general guide only, and is based in part on measurements of density and magnetization of about 160 hand specimens from the Las Vegas 1^{o} x 2^{o} quadrangle (H. R. Blank, unpublished data). For bulk density, the qualitative notations "low", "moderate", et cetera, are generally to be regarded as relative to the reduction density used on the gravity map (2.67 g/cm^3). The bulk magnetizations of igneous and metamorphic rock units range over several orders of magnitude; for some rocks the net magnetization (vector sum of induced magnetization and remanence) is reversed with respect to the present earth's field, and for others the magnetization is probably significantly weakened as a result of hydrothermal alteration. Iron mineralization contributes to aeromagnetic anomalies associated with quartz monzonite porphyry intrusions of the "iron axis" in southwestern Utah.

Although we did not show all available structural information on the generalized map, an attempt has been made to show selected faults and folds that can be traced over long distances and/or that reflect significant displacements. We also show other selected short fault segments in order to indicate regional trends. A fault is identified as "speculative" whether concealed and approximately located, or merely inferred, and no distinction is made between low-angle normal and thrust faults. Many additional faults that can be inferred from the geophysical data are not shown. The outline of the Indian Peak caldera complex is from the gravity interpretation in Best and others (in press); that of the Caliente complex is from Ekren and others (1977), but should probably be extended as much as 10 km farther east on the basis of geophysical data.

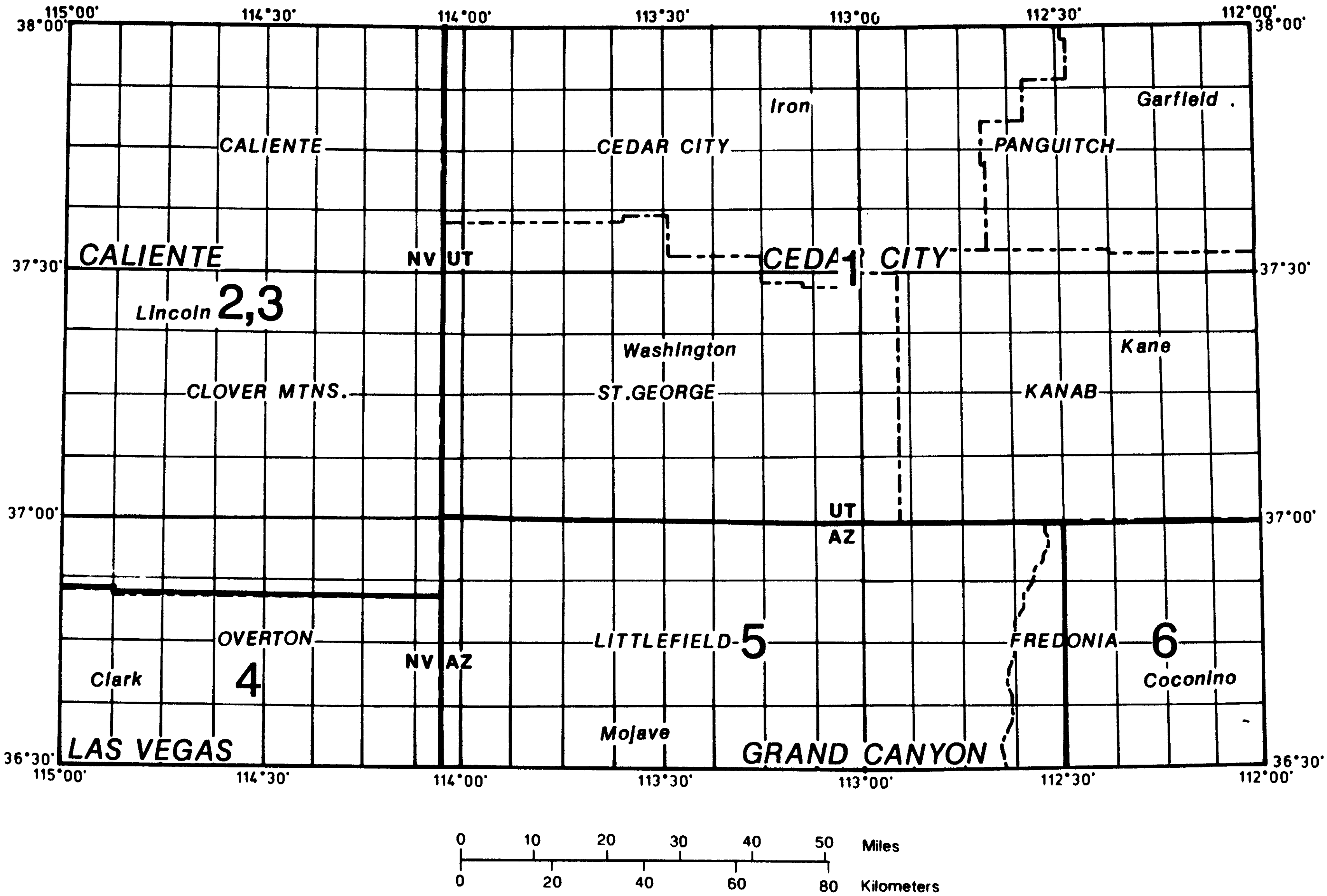

Figure 5. Index map of regional geologic source maps. Key: 1, Hintze, 1963; 2, Tschanz and Pampeyan, 1970; 3, Ekren and others, 1977; 4, Longwell and others, 1965; 5, Santa Fe Pacific Railroad Company, 1988; 6, Reynolds, 1988.

Table 1. Generalized rock units, BARCO project area

Unit	Description	Bulk Density	Bulk Magnetization
QTs	Holocene to Eocene(?) sedimentary rocks and unconsolidated deposits including Claron, Wasatch, Horse Spring, Muddy Creek, Sevier River, Bear Valley, and Panaca Formations.	very low	negligible
QTb	Quaternary and Tertiary basalt; chiefly Miocene age in Nevada and Plio-Pleistocene age in Utah and Arizona; mainly lava flows but includes tephra and possibly intrusive rocks of volcanic vents.	low to high	strong to very strong
Ti	Pliocene and Miocene intrusive rocks; in Utah, mainly porphyritic quartz monzonite of Miocene age; includes smaller bodies ranging in composition from rhyolite-granite or -syenite to andesite-diorite.	moderate	moderate to strong
Tv	Pliocene to Oligocene volcanic rocks and subordinate volcaniclastic sedimentary rocks. Composition variable. Includes voluminous silicic ash-flow tuff; rhyolite to andesite of exogenous domes, lava flows, and debris flows; and minor basalt.	low to moderate	very weak to very strong
Mz	Mesozoic sedimentary rocks, predominantly clastics.	low	negligible
Pz	Paleozoic and Eocambrian(?) sedimentary rocks, predominantly carbonates.	moderate to high	negligible
P€	Precambrian (Proterozoic) rocks of igneous and metamorphic crystalline basement complex.	high to very high	moderate to very strong where exposed, but may include large volumes of weakly magnetic rock in subsurface

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