RC. 808

GEOLOGICAL SURVEY CIRCULAR 808

Background Information to Accompany Folio of Geologic, Mineral Resource, Geochemical, Aeromagnetic, and Gravity Maps of the Hillsboro and San Lorenzo Quadrangles, Sierra and Grant Counties, New Mexico

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By D.C. Hedlund, *with sections on*
Geochemistry *by* K. C. Watts and H. V. Alminas,
and Geophysics, *by* J. C. Wynn and D. C. Hedlund

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CONTENTS

ILLUSTRATIONS

TABLES

Page

Background Information to Accompany Folio of Geologic, Mineral Resource, Geochemical, Aeromagnetic, and Gravity Maps of the Hillsboro and San Lorenzo Quadrangles, Sierra and Grant Counties, New Mexico

By D. C. Hedlund

ABSTRACT

The Hillsboro and San Lorenzo 15-minute quadrangles of southwestern New Mexico have been mapped at a 1:48,000 scale and selected mineralized areas within these quadrangles have been mapped in greater detail. This area of about 550 mi^2 (1,424 km^2) is within the southern part of the Black Range and includes much of the Mimbres Mountains and parts of the adjoining Black Range Primitive area. The region is highly mineralized with Laramide (75.1±2.5 m.y.) and middle Tertiary (about 32 to 35 m.y.) intrusions providing the source for much of the base- and precious-metal mineralization. The porphyry copper deposit at Copper Flat is a subvolcanic Laramide quartz monzonite stock that was intruded into a thick section (>2,700 ft or >823 m) of Upper Cretaceous andesite. Numerous gold-bearing veins radiate from the central quartz monzonite stock, and locally offset a radial system of quartz latite dikes. Gold-bearing veins, chiefly along the south and east periphery of the stock, have provided the source for both gold lode and placer deposits. The middle Tertiary rhyolitic plugs, stocks, and dikes have intruded a dominantly carbonate section of Paleozoic sediments and bedding replacement deposits of zinc, lead, and copper are closely associated with tactite in the Carpenter (Swartz) mining district. The rich oxidized silver deposits of the Kingston district are largely fault controlled and a metallizing pluton is not present at the surface outcrop. Some of the silver-bearing base-metal veins in the Kingston district contain rhodochrosite, rhodonite, and alabandite and the highly oxidized parts of these veins have been mined for manganese ore. Very minor amounts of tungsten, as scheelite, occur in thin tactite zones along Tank Canyon, at the Silver Queen claims near Kingston, and at the Silver Tail group of mines along Pierce Canyon.

INTRODUCTION

Goal and Method

This circular presents background information to accompany a folio of geologic, mineral resource, geochemical, aeromagnetic, and gravity maps for the Hillsboro and San Lorenzo 15-minute quadrangles. This report represents a part of a larger mineral assessment study for southwestern New Mexico that began with the Black Range Primitive area report of G. E. Ericksen and others (1970); the Gila Wilderness map of J. C. Ratté and D. L. Gaskill (1975); and the gold placer studies of K. Segerstrom and J. C. Antweiler, III (1975).

Most of the geologic mapping was done on aerial photos at a scale of 1:15,840 or on topographic maps at a scale of 1:48,000. The geologic mapping program was followed by a geochemical study that involved the extensive sampling of stream sediments and a geophysical survey that included aeromagnetic, ground magnetic, and gravity data. The field studies began in late 1971 and were largely completed in early 1975.

Location and Access

The Hillsboro and San Lorenzo 15-minute quadrangles cover approximately 550 mi^2 (1,424 km^2) in southwestern New Mexico between lat 32°45' and 33°00' N. and long 107°30' and 108°00' W. The area includes the southern part of the Black Range, most of the Mimbres Mountains, and extends from the west margin of the Rio Grande Depression to the Santa Rita horst and Mimbres valley in the west. The crest of the Black Range and Mimbres Mountains forms the Continental Divide and streams flowing to the east comprise the tributary system of the Rio Grande which flows into the Gulf of Mexico. Streams that flow to the west of the divide form the tributary system of the Mimbres River which flows southward into a closed basin just south of Deming. The crest of the range is sinuous and ranges in elevation from about 7,400 ft (2,255 m) in the south to about 10,000 ft (3,048 m) in the north. Generally, the eastern side of the range is more deeply dissected than the western side and older Paleozoic and Precambrian rocks are commonly exposed in tilted fault blocks along the eastern side of the range, whereas the western side is more mantled with Tertiary volcanic rocks and surficial fan deposits.

Access from east to west is by New Mexico State Highway 180 which is an all-weather road that crosses the Black Range at Emory Pass. Partial access along north-south roads is limited to New Mexico State

Table 1.—*Component maps of the Hillsboro and San Lorenzo quadrangles mineral resource assessment*

U.S. Geological Survey Miscellaneous Field Studies (MF) Map		Subject
MF-900-A	(Hedlund, 1977)---------------	Geology
B	(Hedlund, 1977)---------------	Mineral resources
C	(Alminas, Watts, Siems, and Kraxberger, 1978)----------	Silver in stream sediments
D	(Alminas, Watts, Siems, and Kraxberger, 1978)----------	Copper in stream sediments
E	(Alminas, Watts, Siems, and Kraxberger, 1978)----------	Molybdenum in stream sediments
F	(Alminas, Watts, Siems, and Kraxberger, 1977)----------	Zinc in stream sediments
G	(Alminas and Watts, 1978)-----	Interpretive geochemical map
H	(Watts, Alminas, and Kraxberger, 1978)----------	Detrital fluorite and cassiterite
I	(Wattsm Alminas, Nishi, and Crim, 1978)----------------	Tungsten and gold in stream sediments
J	(Alminas, Watts, Nishi, and Crim, 1978)----------------	Lead in stream sediments
K	(Watts, Alminas, Nishi, and Crim, 1978)----------------	Bismuth in stream sediments
L	(Wynn, 1978)-----------------	Aeromagnetic map
M	(Wynn and Dansereau, 1978)----	Gravity map

Highway 61 along the Mimbres valley and to New Mexico State Highway 27 from Lake Valley to Hillsboro. Numerous secondary county and U.S. Forest Service roads provide access to the Royal John and Grandview Mines in the Carpenter (Swartz) district, to East Canyon along the McKnight road, to the Ingersoll mine north of Kingston and to the Log Cabin road along Tierra Blanca Creek. A population of about 400 is chiefly confined to the small villages of Hillsboro, San Lorenzo, Mimbres, Kingston, and San Juan-Sherman.

Mineral Production

Silver-bearing base-metal deposits of the Kingston and Carpenter (Swartz) mining districts were chiefly mined from 1877 to 1893 and, more recently, in the early 1940's within the Carpenter (Swartz) district. In the Las Animas placer district (Hillsboro), the gold-bearing fissure veins and gold placers were chiefly mined from 1877 to 1893, 1906, 1918 to 1920, and 1931 to 1933. From these three districts the total value of mineral production was about $15 million.

The mineral deposits of the Las Animas placer district in order of their past importance are of three main types: (1) the gold placers east of Copper Flat, (2) the gold-bearing fissure veins within the andesite about the Copper Flat stock, and (3) the porphyry copper mineralization within the quartz-monzonite stock of Copper Flat. The gold-bearing fissure veins within the andesite have yielded about 51,000 ounces of gold (Harley, 1934; Segerstrom and Antweiler, 1975), whereas the gold placer deposits just east of Copper Flat have yielded about 98,000 ounces of gold. The total value of the past gold production has been $6,900,000 (Harley, 1934). More recently, and beginning about 1953, the quartz-monzonite stock of Copper Flat has been extensively drilled and a relatively low-grade porphyry copper deposit has been defined. The stock has an outcrop area of 0.4 mi^2 (1.04 km^2), but only about 0.1 mi^2 (0.26 km^2) of the stock is extensively mineralized. The copper reserves of the stock have not been completely evaluated but are probably in the range of 4 million tons of >0.5 percent copper to a depth of 800 ft (244 m) and about 15 million tons of >0.20 percent copper to a depth of 1,000 ft (305 m). Supergene enrichment is negligible.

In the Kingston district, fault-controlled fissure veins and bedding-replacement deposits within dolomite beds of the Silurian Fusselman Dolomite and Ordovician Montoya Group underlying the Devonian Percha Shale have yielded an estimated 6 million ounces (186,600 kg) of silver. Scattered small silver-bearing veins in the Tierra Blanca district yielded about 45,000 ounces of silver. Near-surface manganese deposits derived from the weathering of vein and bedding-replacement deposits in the Kingston district were mined in 1943, 1944, 1952, and 1953, and an estimated 5,689 tons of manganese ore that average 32 percent manganese were shipped from the district (Farnham, 1961).

In the Carpenter (Swartz) mining district, the sphalerite-rich base-metal ores are chiefly present as discontinuous bedding-replacement bodies within silicated cherty limestone beds within the upper part of the Ordovician El Paso Limestone. Past production figures suggest that as much as 60,000 short tons of ore with a value of about $1 million has been mined

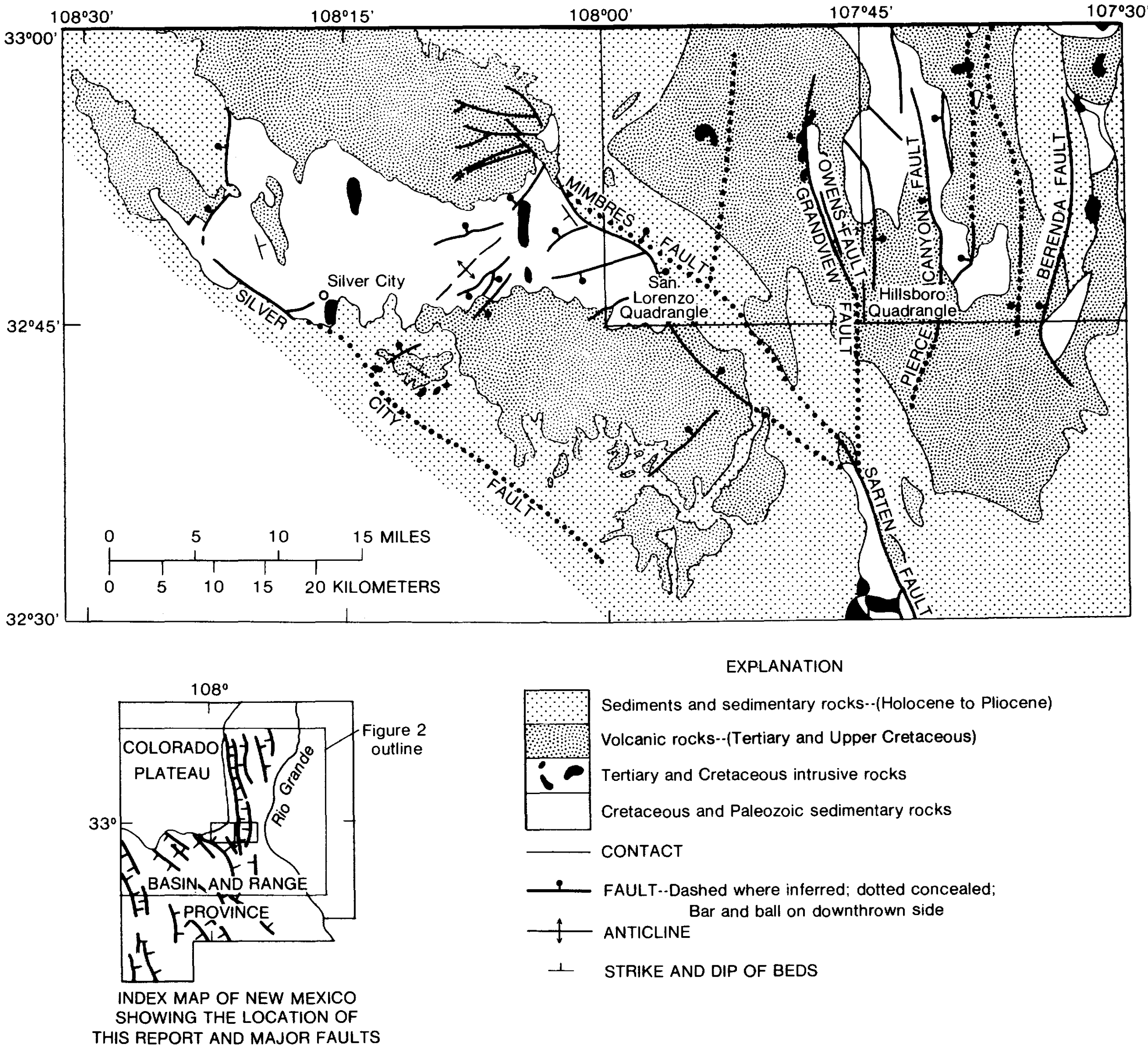

FIGURE 1.—Index map showing location and general geology of the Hillsboro and San Lorenzo quadrangles and adjacent areas.

from the district. Generally, the silver values of the ore are much less than in the Kingston district and past production assay figures indicate 8 percent zinc, 4 percent lead, 0.5 percent copper, and 3-4 ounces/ton of silver.

A description of most of the mines in the various districts is largely dependent on past mining records and on an interpretation of various older mine maps. Only in the areas of more recent development such as at the Royal John, Ingersoll, and Black Colt mines and the Quintana adit has access been more favorable. There has been some reworking of the old mine dumps at the Opportunity mine but only small amounts of gold were recovered from the highly pyritic ores during 1975.

Previous Geologic and Mineral Resource Investigations

The mining of rich silver deposits in the Kingston district from 1882 to 1896 and the discovery of gold deposits in the vicinity of Hillsboro in 1877 was followed by the geologic investigations of Lindgren, Graton, and Gordon (1910). Later Harley (1934) described the various mineral deposits in much greater detail and his descriptions of the various gold mines in the Las Animas placer-Hillsboro districts remain the most comprehensive to date. With the economic decline of 1893, mining activity in the Kingston and Hillsboro districts greatly diminished, and silver and gold mining has been sporadic since then. The low-

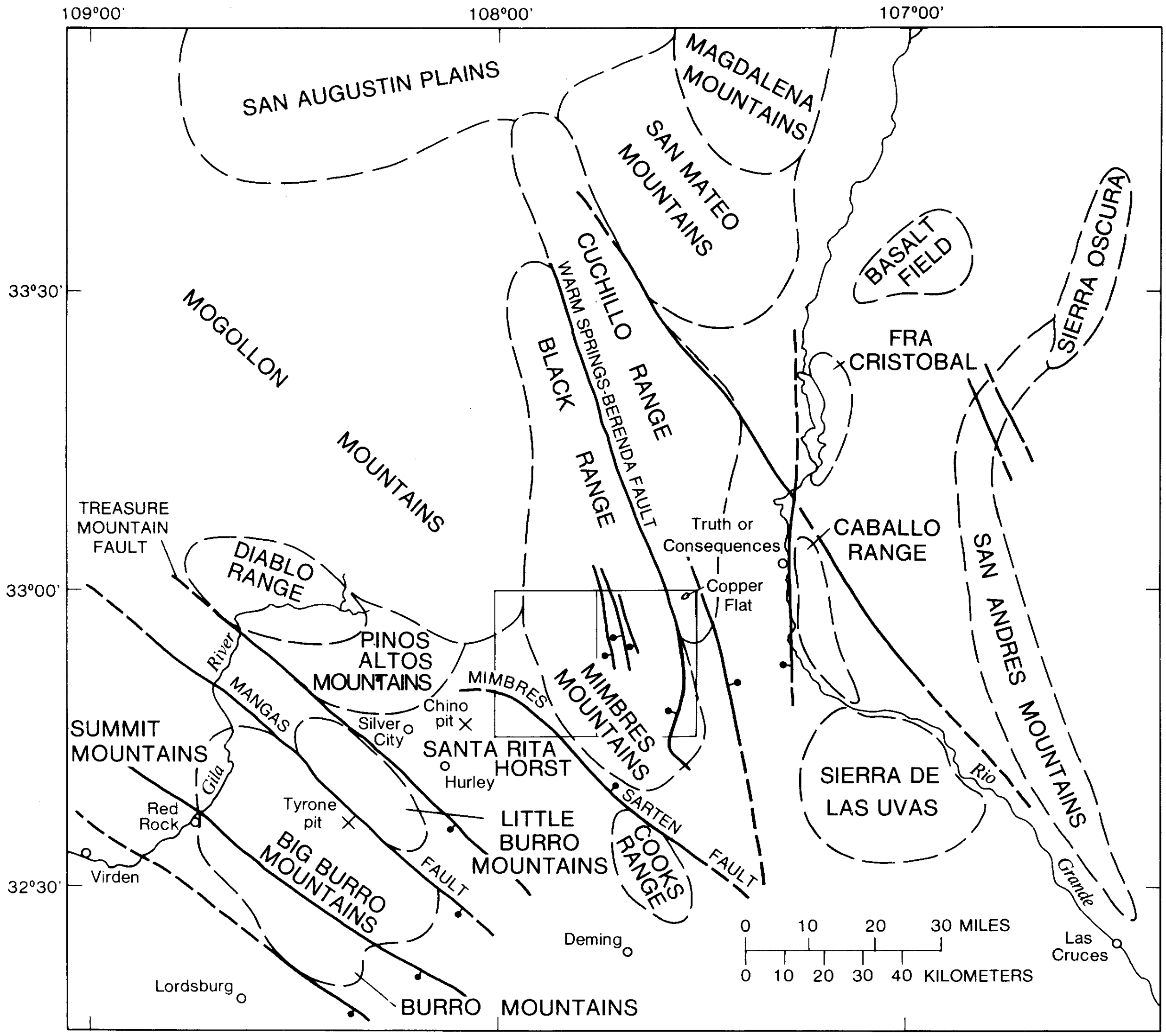

FIGURE 2.—Locality map of major geographic features (long dashes) and major faults, dashed where uncertain; ball and bar on downthrown side.

grade manganese deposits that formed from the weathering of the silver-bearing base-metal deposits in the Kingston district were mined in 1943 and 1944 with some renewed mining in 1952 through 1955 (Farnham, 1961).

A strategic metals program conducted by the U.S. Geological Survey and the U.S. Bureau of Mines from 1942 to 1945 led to the mapping and drilling of various base-metal deposits in the Carpenter (Swartz) mining district (U.S. Geological Survey unpublished mapping and data by Griggs, Ellison, Kinney, Wagner, and Weissenborn, 1943, 1944; and the U.S. Bureau of Mines Reports of Investigations by Hill, 1946, and Soule, 1950).

Interest in the porphyry copper deposit of Copper Flat, Las Animas placer mining district, began in the early 1950's and has continued to the present with exploration at various times by the Newmont, Bear Creek, Inspiration, and Quintana mining companies. Numerous drill cores have been taken from the mineralized parts of the stock and a few holes have been drilled in the surrounding andesite in the search for concealed skarn deposits. Probably the first geologic map of the quartz monzonite of the Copper Flat stock and adjacent country rock was that of Harley (1934). Later, a more detailed geologic map of the stock with a report on copper assay values was published by F. J. Kuellmer (1956).

Except for a geologic strip map (scale 1:31,680) along New Mexico State Highway 90 from Kingston to San Lorenzo by Kuellmer (1954), most geologic mapping of the Hillsboro-San Lorenzo quadrangles has been at reconnaissance scales. The Black Range Wilderness report of Ericksen and others (1970) included a geologic map with some coverage of the southern part of the Black Range south of lat 33° N. Kuellmer (1956) published a geologic map of the Hillsboro Peak 30-minute quadrangle, and other geologic maps have been presented by F. J. Kuellmer, F. E. Kottlowski, W. Elston, V. C. Kelley and O. T. Branson in the Fourth Guidebook of the New Mexico Geological Society (1953). The regional geological setting of the Black Range is shown on the geologic map of southwestern New Mexico (Dane and Bachman, 1961).

Numerous theses and some published studies of the Paleozoic and Mesozoic stratigraphy have facilitated the mapping program. A thesis with a geologic map by R. S. Lambert (1973) describes the Paleozoic stratigraphy and geology of a small area southwest of San Lorenzo. Lauden and Bowsher (1949) made a detailed study of the Mississippian rocks within the Hillsboro quadrangle and recognized at least five members and two formations within the Mississippian section. The regional distribution of oolitic hematite-bearing sandstone within the Ordovician and Cambrian Bliss Sandstone was described by Kelley (1951). Regional stratigraphic studies of the Paleozoic and Mesozoic strata of southwestern New Mexico were summarized by Flower (1953a,b) and by Kottlowski (1963). The paleogeography of the Cretaceous strata in the Silver City-Santa Rita areas was briefly summarized by Hayes (1970).

Numerous descriptions of Upper Cretaceous and Tertiary volcanic rocks have been published by Elston (1957, 1968); Elston and others (1973, 1975); Jicha (1954); Ericksen and Wedow (1976); and Fodor (1975). Numerous isotopic age determinations of Tertiary volcanic rocks and a synthesis of the volcanic stratigraphy has been published by McDowell (1971) and by Elston and others (1973). Geologic maps of the surrounding quadrangles have greatly aided in the resolution of the volcanic stratigraphy; these include the maps and reports by Elston (1957) for the Dwyer quadrangle; Jicha (1954) for the Lake Valley quadrangle; Hernon, Jones, and Moore (1964) for the Santa Rita quadrangle; Moore (1948) for the Allie Canyon quadrangle; and Ericksen and others (1970) for the Black Range Primitive area.

Special studies include the mapping and economic appraisal of the gold placer deposits of the Las Animas placer mining district by Segerstrom and Antweiler (1975). The high-temperature pegmatites within the Rabb Park intrusion were studied by Kelley and Branson (1947). A new occurrence of helvite was described from the tactites of the Grandview mine by Weissenborn (1948).

Present Study

Detailed geologic reconnaissance mapping by the U.S. Geological Survey at a scale of 1:48,000 began in late 1971 and continued into 1975 as selected areas were chosen for more detailed mapping. The geochemical investigations began in 1972 and were completed in 1975. Numerous samples of stream sediments were taken within the Hillsboro and San Lorenzo quadrangles as a part of the geochemical surveys of the Cuchillo Range that began in 1966. The aeromagnetic map of parts of the Silver City and Las Cruces 1° by 2° coverage was completed in 1973 and open-file copies of the aeromagnetic maps of the Hillsboro-San Lorenzo areas at a scale of 1:62,500 were available in 1974.

Acknowledgments

Both field and laboratory support by members of the U.S. Geological Survey contributed to the preparation of this report. Greater insight to the volcanic stratigraphy resulted from discussions in the field with James Ratté and Tommy Finnell. The four K-Ar age determinations of Laramide and Tertiary intrusive and extrusive rocks were made by R. F. Marvin, H. H. Mehnert, and V. Merritt. Open-file mine maps and reports by R. L. Griggs, D. M. Kinney, S. P. Ellison, H. C. Wagner, and A. E. Weissenborn furnished valuable subsurface information within the mineralized areas of the Carpenter (Swartz) mining district. Numerous fossil determinations by J. T. Oliver, W. J. Sando, R. C. Douglass, E. L. Yochelson, and W. A. Oliver, Jr. aided in identifying some of the faunal zones within the Pennsylvanian limestones of the Magdalena Group. A special map and open-file report by K. Segerstrom and J. C. Antweiler, III, on the gold placers near Gold Dust provided an appraisal of the gold placer reserves in the Las Animas placer mining district.

Numerous mine operators and company geologists provided access to their properties and, in certain instances, made available past and current mine records. Earl Burke of the Inspiration Development Co. and Peter Dunn of Quintana Minerals Co. allowed the examination and sampling of some drill core from the Copper Flat stock. Other mine operators that provided access to their mines include Oliver Reese, Jack Upton, E. H. Hale, Jr., Roy Tirey, and Donald Fingado.

Of the many local ranchers that allowed access their land we wish to thank A. H. Latham, G. Whittenburg, S. A. Roberts, H. Bounds, J. Bason, F. Yates, R. O. Anderson (owner) and A. Evans (foreman) of the Ladder Ranch, V. Cunningham, G. Miller, and G. Fowler.

DESCRIPTION OF COMPONENT MAPS OF THE HILLSBORO-SAN LORENZO MINERAL RESOURCE ASSESSEMENT

Geology (Map MF-900A)

The Hillsboro and San Lorenzo 15-minute quadrangles are within the Mexican Highlands section of the Basin and Range physiographic province that is characterized by intensive block faulting. Geologically the area is along the southern extension of the Cuchillo and Black Range fault-block mountains with an overlap of volcanic rocks from the Datil-Mogollon volcanic field. Upper Cretaceous and Tertiary volcanic extrusives and ash flows were erupted onto essentially flat-lying Mesozoic and Paleozoic miogeosynclinal limestone, dolomite, sandstone, and shale sedimentary rocks that were later block-faulted in the middle Tertiary (about 20 m.y. ago). About 200 ft (61 m) of Upper Cretaceous sandstone, about 2,700 ft (823 m) of Paleozoic strata, and nearly 6,000 ft (1,800 m) of middle Tertiary volcanic rocks were faulted, tilted, and broadly arched over the crest of the Black Range. Generally, the fault blocks are tilted 20° to 35° east along the east side of the range, and are tilted 10° to 25° to the west along the west side (geologic sections A-A' through D-D'). In places, large north-striking faults have brought Precambrian granitic and hornblendic rocks to the surface outcrop.

The Paleozoic strata range in age from Cambrian to Permian with all systems represented. Carbonate rocks comprise about 75 percent of the sedimentary section and the strata are intensely faulted and locally intruded by stocks, plugs, and sills of Late Cretaceous and Oligocene age. Skarns are locally developed in the cherty limestone and dolomite beds of the El Paso Limestone, Montoya Group, and Fusselman Dolomite adjacent to middle Tertiary rhyolite plutons in the Carpenter district. Smaller skarn deposits in the Tank Canyon and Warm Spring Canyon area are related to Laramide intrusions.

Erosional remnants of Lower Cretaceous Beartooth Quartzite with thin interbeds of shale unconformably overlie red beds of the Permian Abo Formation. A deltaic depositional environment is assumed for most of the sandstone. The maximum remnant thickness of the Beartooth Quartzite is about 200 ft (61 m).

Seven small stocks and plugs of quartz monzonite, quartz monzodiorite, granite, quartz diorite, and diorite intrude Paleozoic rocks and (or) Upper Cretaceous andesite in the northeast quadrant of the Hillsboro quadrangle. The Copper Flat pluton, which is economically most important, was emplaced in the Late Cretaceous (75.1±2.5 m.y.) and probably represents the denuded core of a Laramide volcano because it has a radial dike system and intrudes Upper Cretaceous andesite flows that are at least 2,790 ft (850 m) thick. The other plutons have not been dated but are assumed to be of Late Cretaceous age on the basis of lithology and the proximity to the Copper Flat stock.

Except for the andesite at Copper Flat and the thin basaltic flows of Pliocene age within the Santa Fe and Gila Formations, most of the volcanic rocks in the region are of Miocene-Oligocene age (24-38 m.y.). The andesitic and latitic flows that underlie the Sugarlump and Kneeling Nun Tuffs over a wide area have been considered correlative with the Rubio Peak Formation (Jones and others, 1967). Two recent K-Ar age determinations on correlative andesitic rocks in the Hillsboro and San Lorenzo quadrangles indicate an Oligocene age of about 36.4 m.y. (R. F. Marvin, H. H. Mehnert, and Violet Merritt, written commun., 1975). The thick section of ash-flow tuff and tuffaceous sediments of the overlying Kneeling Nun and Sugarlump Tuffs are also of Oligocene age (33.4±1.0 m.y., McDowell, 1971) and probably represent nuée ardente eruptions from a nearby caldera—possibly the Emory caldera as proposed by Elston, Seager, and Clemons (1975). The margins of this caldera are still imprecise but the southern boundary is probably located in the north-central part of the San Lorenzo quadrangle. The eruption of the Kneeling Nun ash-flow tuff was closely followed by the intrusion of small rhyolite stocks and plugs such as the one at Rabb Park and those along Iron Creek. Locally, intraformational breccias within the ash flow contain xenoliths of the rhyolite plutons suggesting that the rhyolite intrusions were contemporaneous with the ash-flow eruptions. These middle Tertiary rhyolite bodies are considered to be the metallizing source for the base-metal and associated skarn deposits of the Carpenter (Swartz) district. The eruption of the ash flows was followed by the viscous outpouring of the Mimbres Peak Rhyolite of Jicha (1954) and the nearly contemporaneous latite flows of the Pollack Quartz Latite of Jicha (1954). Some of the rhyolite was erupted as mushroom-shaped intrusive domes that were alined along north-striking faults; for example, the rhyolite at Deer Hill, Tierra Blanca Mountain, Sherman Mountain, and Star Peak. After a short erosional interval, there followed the eruption of tuffs of the Caballo Blanco Rhyolite Tuff of Elston (1957), and the subsequent outpouring of basaltic andesite and latitic flows of the Razorback and Bear Springs Formation, both of Elston (1957). Intensive block faulting along a N. 5°-35° W.-strike followed the eruption of the Bear Springs Basalt and this faulting has been placed by Elston and others (1973) as about 20 m.y. B.P. (before the present). Subsequent erosion and deposition within the numerous fault blocks produced thick deposits of fanglomerate that have been termed the Gila Conglomerate and the Santa Fe Formation. The fanglomerate deposits were probably as much as 2,000 ft (610 m) thick, but clastic deposition was interrupted about 6.4 m.y. B.P. when extensive flows of olivine basalt and alkali basalt covered much of the fanglomerate

Mineral Resources (Map MF-900B)

The numbered locations, with brief descriptions of known prospects, mineral occurrences, and inactive mines are shown on the mineral resource map (MF-900B). In addition, potentially favorable areas for further investigative studies or prospecting are shown in their apparent order of decreasing potential. Grab and chip samples of vein and bedding-replacement deposits with a few of porphyry copper were analyzed by semiquantitative spectrographic and atomic absorption analyses (tables 2, 3, 4 and 5). With the exception of the gold placer deposits, reserve estimates have not been adequately determined. Extensive drilling of the quartz monzonite stock of Copper Flat by Quintana Mineral Corporation has largely made the copper reserve estimates of this report obsolete. In the other districts, estimates of reserves have been made very difficult because of lack of access to old underground workings, the paucity of diamond-drill-core data, and the depletion of near-surface, oxidized and silver-enriched base-metal ores.

Alteration zones, generally silicification of limestone or dolomite, and areas of tactite development are indicated on the geologic map (map MF-900B). Areas of silicification are shown in a stippled pattern. In the Hillsboro district, some of the jasperoids contain limonite, cerussite, and plumbojarosite with minor inclusions of sulfide (T. G. Lovering, oral commun., 1974). The larger areas of tactite are shown in an x-pattern. The silicated limestone or dolomite may contain some or all of the following minerals: wollastonite, diopside, epidote, grossular garnet, tremolite,

Table 2.—*Semiquantitave spectrographic analyses of mineralized quartz monzonite and gold-bearing vein material from the Chance mine and from Copper Flat with supplemental atomic absorption analyses (A.A.) for gold and gravimetric analyses for silver*

[Results are reported in parts per million to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.015, and so forth; about 30 percent of the assigned groups for semiquantitative spectrographic results include the quantitative values. G, greater than 10 percent; N, not detected at limit of detection; L, looked for but not detected. Spectrographic analyses by L. A. Bradley, 1973. Silver analyses determined gravimetrically by A. W. Haubert; gold determined by atomic absorption by A. W. Haubert and Claude Huffman, Jr., 1974]

Rock type----	Sulfide concentrate, vein	Vein material	Sulfide concentrate, quartz monzonite	Mineralized quartz monzonite
Field No.----	HL-23-71	HL-23-71A	HL-24-71	HL-24-71B
Lab. No.-----	D161386	D161399	D161387	D161400
		Analyses (ppm)		
Be-----------	1.5	N	L	5
Mg-----------	100	300	500	3000
Ca-----------	1000	3000	2000	20000
Sr-----------	15	300	15	300
Ba-----------	150	1500	30	500
Zn-----------	10000	N	N	N
Pb-----------	5000	150	30	30
Cd-----------	100	N	N	N
Cu-----------	20000	200	G	10000
Ag-----------	150	50	70	5
Ag (chem.)---	(300)	(50)	(100)	(20)
Au-----------	30	N	N	N
Au (A.A.)----	(38)	(0.5)	(3.5)	(0.2)
As-----------	N	N	N	N
Sb-----------	N	N	N	N
Bi-----------	70	30	50	N
Fe-----------	G	70000	G	20000
Mn-----------	200	100	150	500
Ti-----------	1500	1500	10000	2000
Zr-----------	30	100	300	150
Ni-----------	30	L	50	L
Co-----------	300	100	70	10
Cr-----------	150	2	15	3
Mo-----------	20	150	70	50
V------------	20	20	150	70
Nb-----------	15	L	70	10
Sc-----------	15	5	15	10
La-----------	L	N	300	70
Nd-----------	N	N	700	70
Yb-----------	N	N	N	3
Y------------	20	15	100	30

magnetite, talc, serpentine, helvite, fluorite, and phlogopite.

The porphyry copper and gold deposits of the Las Animas placer mining district (Hillsboro) probably have the greatest resource potential. The porphyry copper deposit of Copper Flat probably contains as much as 4 million metric tons of ore containing 0.5 percent copper and about 15 million tons of ore containing 0.20 percent copper. Molybdenum and gold may be important byproducts of any future mining, although the molybdenum values are small (0.009 to 0.024 percent Mo) and the gold content of the sulfide concentrates is about 3.5 ppm (table 2). The gold-bearing veins that radiate outward from the Copper Flat stock have only been worked to shallow depths of 500 to 1,000 ft (152-305 m) and the gold largely occurs in pockets along brecciated veins in andesite. The gold placers within the same area have been extensively worked in the past and attempts were made in the early 1970's to further exploit the remaining placer gold. Segerstrom and Antweiler (1975) have estimated that the total reserves of near-surface placer gold are probably about 28,000 ounces, or about one-fourth of the past production.

The near-surface silver-rich base-metal deposits of the Kingston district have largely been exploited, but there still remains a potential for more lower grade silver ores at greater depths in the lower Paleozoic carbonate strata. The chert-bearing limestone beds in the upper part of the El Paso Limestone should be favorable exploration target sites. Most past mining operations were in the Fusselman Dolomite near the contact with the Percha Shale, and mining was generally done at levels less than 460 ft (140 m) below the surface. It is generally conceded by most geologists that the impermeable Percha Shale served to dam the upward and laterally migrating ore fluids at the contact with the underlying Fusselman Dolomite. The silver values of the oxidized base-metal ore are very high and some spectrographic and atomic absorption analyses indicate as much as 790 ppm silver (table 4).

Table 3.—*Semiquantitative spectrographic analyses of ore samples from the Carpenter (Swartz) mining district with supplemental gravimetric analyses for silver*

[Results are reported in parts per million to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.015, and so forth; about 30 percent of the assigned groups for semiquantitative spectrographic results include the quantitative values. G, greater than 10 percent; N, not detected at limit of detection; L, looked for but not detected. Leaders (---) indicate not determined. Spectrographic analyses by J. C. Hamilton and L. A. Bradley, 1973. Silver analyses determined gravimetrically by G. D. Shipley and Claude Huffman, Jr., 1974]

Mine-------	Royal John	Acklin	Patsy	Columbia	Grandview	Mineral Mountain
Field No.--	SL-5-RJ	SL-143-73	SL-179-73	SL-167-73	SL-152-73	SL-303-73
Lab. No.---	D161395	D163856	D163857	D163858	D163859	S163860
			Analyses (ppm)			
Be---------	N	N	5	10	150	2
Mg---------	3000	2000	20000	7000	20000	5000
Ca---------	30000	30000	G	G	70000	G
Sr---------	15	15	15	70	15	700
Ba---------	5	20	3	10	5	3
Zn---------	G	7000	5000	10000	G	70000
Pb---------	G	7000	3000	2000	G	70000
Cd---------	1500	L	N	L	700	300
Cu---------	700	15000	7000	15000	2000	15000
Ag---------	100	300	50	7	150	30
Ag (chem.)-	---	(185)	---	---	(93)	---
Au---------	N	N	N	N	N	N
As---------	N	N	N	N	N	N
Sb---------	N	N	N	N	N	N
Bi---------	N	300	300	20	200	N
Fe---------	50000	70000	G	G	10000	70000
Mn---------	10000	3000	5000	20000	20000	20000
Ti---------	150	150	1500	200	700	30
Zr---------	N	N	30	20	30	N
Ni---------	20	7	10	L	10	10
Co---------	70	70	70	5	10	7
Cr---------	70	3	30	5	15	7
Mo---------	10	7	150	7	70	N
V----------	10	N	150	70	30	70
Nb---------	L	N	10	N	N	N
Sc---------	N	N	7	N	N	N
La---------	N	N	50	N	N	N
Nd---------	N	N	N	N	N	N
Yb---------	N	N	N	N	N	N
Y----------	N	N	50	N	10	10

Table 4.—*Semiquantitative spectrographic analyses of base-metal ore samples from the Kingston mining district with supplemental atomic absorption analyses (A.A.) for gold and gravimetric analyses for silver*

[Results are reported in parts per million to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.015, and so forth; about 30 percent of the assigned groups for semiquantitative spectrographic results include the quantitative values. G, greater than 10 percent; N, not detected at limit of detection; L, looked for but not detected. Spectrographic analyses by L. A. Bradley, 1973. Silver analyses determined gravimetrically by A. W. Haubert, 1974. Gold determined by atomic absorption, by A. W. Haubert and Claude Huffman, Jr., 1974]

Mine-------	Base-metal ore						
	Black Colt	Black Colt	Blackie	Iron King	Brush Heap	Gray Eagle	Gypsy
Field No.--	Hb-90-73	Hb-1-BC	Hb-93-73	HL-7-73	Hb-73-73	Hb-131-73	HI-46-72
Lab. No.---	D161388	D161389	D161390	D161397	D161391	D161394	D161393
	Analyses (ppm)						
Be---------	N	N	N	N	N	N	N
Mg---------	500	1500	10000	1500	3000	1000	7000
Ca---------	3000	20000	30000	50000	7000	1500	1500
Sr---------	N	7	7	N	N	N	N
Ba---------	5	10	5	7	5	30	3
Zn---------	G	G	30000	7000	G	70000	5000
Pb---------	G	30000	5000	3000	50000	100000	1000
Cd---------	1000	1500	150	N	1500	150	N
Cu---------	5000	10000	1000	300	10000	5000	500
Ag---------	300	300	150	70	500	200	1500
Ag (chem.)-	(660)	(790)	(130)	(60)	(740)	(250)	(2650)
Au---------	N	N	N	N	N	N	N
Au (A.A.)--	(1.4)	(0.7)	(0.2)	(0.1)	(0.3)	(0.8)	(21)
As---------	N	N	N	N	N	N	G
Sb---------	N	N	N	N	1500	N	7000
Bi---------	N	N	N	N	N	N	N
Fe---------	G	G	15000	15000	70000	G	G
Mn---------	10000	20000	20000	20000	3000	1500	700
Ti---------	100	1000	150	30	200	150	150
Zr---------	N	30	N	N	N	N	30
Ni---------	70	20	7	L	7	70	70
Co---------	30	15	N	N	N	20	15
Cr---------	500	100	50	1	3	300	700
Mo---------	15	30	7	7	30	3	15
V----------	30	15	10	L	N	30	50
Nb---------	N	N	N	10	L	L	L
Sc---------	N	N	N	N	N	N	N
La---------	N	N	N	N	N	N	N
Nd---------	N	N	N	N	N	N	N
Yb---------	N	N	N	N	N	N	N
Y----------	L	L	N	L	L	15	15

Both fissure veins and tabular bedding-replacement bodies of sphalerite-rich base-metal deposits are localized along faults and sporadic skarns in the Carpenter (Swartz) mining district. The ore bodies are closely associated with a zone of thermal metamorphism that extends for about 6 mi (9.7 km) along the strike of the faulted Paleozoic section. The silicated cherty limestone beds in the El Paso Limestone that are generally 20-70 ft (6.1-21 m) below the contact with the dolomite beds of the Montoya Group have been especially favorable host rocks for mineralization throughout the district. Past production records indicate that the 60,000 short tons of zinc-rich base-metal ore mined from 1916 to 1949 had relatively low silver values that averaged about 140 ppm. Chip samples from the bedding-replacement deposits in six mines were analyzed by semiquantitative spectrographic and quantitative methods and the results are shown in table 3.

The manganese deposits of the Kingston district have largely been depleted. Most of the manganese ore occurs in small pods, shoots, and replacement bodies along fractures and faults within dolomite beds of the Fusselman Formation and Montoya Group. The manganese oxides have formed through the weathering and oxidation of silver-bearing base-metal veins that have rhodochrosite, alabandite and rhodonite gangue minerals.

There are three areas of known tungsten deposits: (1) the Silver Tail property along Pierce Canyon, (2) the Silver Queen claims near Kingston, and (3) the small prospects within tactite along the south side of Tank Canyon. It is only from the Silver Tail group of mines that Dale and McKinney (1959, p. 66-67) report any appreciable tungsten ore production—about 55 short tons of scheelite-bearing ore averaging 3-4 percent WO_3. At this locality, the molybdenum-bearing scheelite occurs as disseminations and veinlets in highly fractured andesite.

Table 5.—*Semiquantitative spectrographic analyses of ore samples from the Jap, Log Cabin, and Ingersoll mines with supplemental atomic absorption analyses (A.A.) for gold and gravimetric analyses for silver*

[Results are reported in parts per million to the nearest number in the series 1, 0.2, 0.5, 0.3, 0.2, 0.015, and so forth; about 30 percent of the assigned groups for semiquantitative spectrographic results include the quantitative values. G, greater than 10 percent; N, not detected at limit of detection; L, looked for but not detected. Spectrographic analyses by L. A. Bradley, 1973. Silver analyses determined gravimetrically by A. W. Haubert, G. D. Shipley, and Claude Huffman, Jr., 1974. Gold determined by atomic absorption by A. W. Haubert and Claude Huffman, Jr., 1974]

Rock type---- and mine	Vein sample, Jap mine	Sulfide concentrate from vein, Jap mine	Vein sample, Log Cabin mine	Sulfide concentrate from vein, Ingersoll mine
Field No.----	S1-283-73	SL-1-JAP	Hb-81-72	HS-68-72
Lab. No.-----	D163861	D161396	D161398	D161392
	Analyses (ppm)			
Be-----------	2	N	N	N
Mg-----------	3000	700	10000	70
Ca-----------	30000	10000	30000	150
Sr-----------	30	N	15	N
Ba-----------	30	2000	15	7
Zn-----------	G	G	300	G
Pb-----------	G	70000	1500	30000
Cd-----------	700	2000	N	2000
Cu-----------	50000	30000	100	10000
Ag-----------	300	1000	1000	20000
Ag (chem.)---	(230)	(1430)	(1420)	(17,800)
Au-----------	N	N	N	N
Au (A.A.)----	(n.d.)[1]	(0.05)	(6)	(11)
As-----------	N	N	N	1500
Sb-----------	N	N	N	10000
Bi-----------	N	2000	N	N
Fe-----------	70000	50000	1000	70000
Mn-----------	1500	2000	1000	500
Ti-----------	1500	200	30	30
Zr-----------	30	N	N	N
Ni-----------	30	20	L	15
Co-----------	30	150	N	15
Cr-----------	10	20	2	2
Mo-----------	50	500	7	30
V------------	50	L	1	N
Nb-----------	N	L	L	L
Sc-----------	7	N	N	N
La-----------	70	N	N	N
Nd-----------	100	N	N	N
Yb-----------	7	N	N	N
Y------------	70	L	N	N
Ce-----------	200	N	N	N

[1]Not determined.

The vanadium, iron, and fluorspar deposits are all small and subeconomic. The sand and gravel deposits along Middle Percha Creek have been periodically quarried for road construction but are generally too small and too far from any major population center to be of value. Similarly the other nonmetallics such as limestone, dolomite, and perlite are all uneconomic deposits.

Descriptions of the tungsten deposits were omitted on the mineral resources map (MF-900B.)

Geochemistry (Maps MF-900C-K)

By K. C. Watts and H. V. Alminas

Geochemical field work in the Hillsboro and San Lorenzo quadrangles, New Mexico was completed in the fall of 1974. Some of the geochemical data within the Hillsboro quadrangle was published in Alminas and others (1975a,b,c) and includes data acquired before 1973. Those publications include the entire Sierra Cuchillo as well as part of the data presented here for the Hillsboro quadrangle. Subsequent to the completion of the miscellaneous geologic investigations maps (Alminas and others, 1975a,b,c) additional geochemical sampling in the Hillsboro quadrangle was continued through the fall of 1974 in order to better define the anomaly configuration along the crest of the Black Range between the two quadrangles; concurrent sampling occurred in the San Lorenzo quadrangle.

The work consisted of systematic sampling of stream sediments primarily from first- and second-order drainages. Small drainages were sampled because the area is a critical one from the standpoint of ore deposit potential and, in our estimate, it deserved more than a reconnaissance approach. Very often, in areas where closer control was desired, large well-developed drainages did not exist; sampling of very small drainages was therefore required in order to achieve the desired sample-site control. Large drainages also contribute prohibitively large amounts of barren material that dilute anomalies. We found that sampling on small drainages at angles oblique to the main streams showed anomalies having a very local bedrock source. Anomalies might otherwise be attributed to known mineralization derived from areas, like the Black Range crest, at the head of some large tributaries. The sampling scheme has shown that many anomalies are not derived from these areas of known mineralization. The sample design also provided for anomalies to be substantiated by more than one sample—often on opposite sides of a ridge, and often sampled by different individuals at different times.

The geochemical maps have been constructed from data derived from pan-concentrated heavy-mineral samples collected from 1,102 sample sites. The principle sample material used for exploration purposes was the pan-concentrated heavy-mineral sample derived from stream sediment; but, in addition, the conventional -80 mesh sample was collected and analyzed over the same area for census and purposes of comparison. The -80 mesh sample does not provide suitable contrast for use as an exploration sample medium in the area. Rocks displaying evidence of mineralization, such as gossan, veinlets, and stringers were sampled as well as rocks from favorable formation contacts and mine dumps, where these materials were located near the stream-sediment site. Many of these samples proved to be anomalous in at least one metallic element. Samples of fresh unaltered rock were also collected for the purpose of estimating background for each rock type. Analytical results indicate that lithology has less influence on the metal values obtained in heavy-mineral concentrates than it does with -80 mesh stream sediments. The reasons for this are the following: (1) Much of the trace-element variation due to lithology is removed by panning because of the loss of clays and feldspar; the trace elements related to mineralization are therefore more isolated. (2) The variation and level of anomalous metal content for heavy-mineral samples is often much greater than for the -80 mesh stream sediments and bulk rock. Anomalous metal values are therefore easier to distinguish from the background.

Earlier work at Monticello Box (Griffitts and Alminas, 1968), in the San Mateo Mountains (Griffitts and others, 1972a-f), and in the Winston, Chise, and Priest Tank quadrangles (Alminas and others, 1972a-e, 1973a-d), demonstrated that the use of heavy-mineral concentrate samples greatly enhanced the anomaly-background contrast and removed much of the "noise" caused by variations in lithology and dilution from barren material in these areas. The method seems particularly useful in those places where the concealed mineral deposits are overlain by possibly barren, but probably pre-ore, caprock. Near-surface deposits can sometimes be detected with conventional -80 mesh stream sediments, although the anomalies are less pronounced and frequently only the peaks are detected. To detect mineralization beneath caprock usually requires the enhancement of anomaly-background contrast, such as used here.

Limonite and manganese oxides containing high trace-metal values occur in the magnetic (M-1) concentrate fraction and are derived from joint surfaces, fractures, and dispersions in caprock. This material is then mechanically transported to the stream bed. The trace-metal-rich limonite and manganese oxides are thought to result from processes associated with mineralization and later weathering. Much of the limonite is pseudomorphic after pyrite. In areas where the trace-metal-rich limonite is found, it may be derived from weathered primary halos of disseminated pyrite, possibly with other sulfides which may exist above blind mineral deposits. Perhaps ground water moving upward along the structural weakness has also deposited high trace-metal oxides from mineralization at depth; this mechanism is probably at work, but it is not regarded as a dominant factor except perhaps where late subvolcanic intrusions may have provided a mechanism for convection, such as may have occurred near Noonday Peak.

High metal concentrations in the nonmagnetic (NM-1) concentrate fraction occur where primary and secondary ore minerals are exposed at the surface and mechanically enter the stream bed.

Metals and combinations of metals shown on the geochemical maps were selected on the basis of the geochemical relation they may have to the occurrence of mineral deposits. The observed distribution of fluorite and cassiterite in heavy-mineral concentrates is also shown on map MF-900H. This data was derived from routine scans of all the samples by binocular microscope. Specific metals, such as anomalous lead in limonite (M-1 concentrate fraction), and bismuth (NM-1 concentration fraction) may indicate areas in which metal values are controlled by subsurface structural features because these metal anomaly zones sometimes occur as well-defined linear patterns both trending across mapped surface geology and occurring as surficial indications of mineralized structural features projected on strike into covered areas.

Tungsten mainly defines skarn zones which have ore potential. Tungsten and other metallic elements also define at least one structural feature that apparently was a conduit for hydrothermal solutions (Pierce Canyon fault). A number of target areas contain several elements in anomalous concentrations. These multi-element anomalies, many supported by favorable geological conditions and geophysical evidence, may overlie blind mineral deposits.

Geophysics (Maps MF-900L and M)

By J. C. Wynn and D. C. Hedlund

Abstract

Gravity and aeromagnetic studies in the Hillsboro and San Lorenzo quadrangles of southern New Mexico are a part of a larger study by the U.S. Geological Survey that includes geologic mapping and geochemical stream-sediment sampling. There are several large structural features in the map area that have pronounced gravity and magnetic expressions. These include the Mimbres fault, which has a normal throw (east side downthrown) of nearly 2 km, and the southern third of the Emory Pass caldera (a 34-milligal gravity low). This latter feature has been modeled as a 4-km-deep depression filled with a low density material, all of which may be Kneeling Nun Tuff. Zones of altered rock may also exist beneath this tuff layer in the margins of the caldera.

The principal aeromagnetic anomaly in the map area is a circular feature located just south of the Copper Flat stock near Hillsboro, which may be attributed to a small batholith that has a limited depth extent of about 7 km. Gravity data show a linear high associated with the magnetic anomaly, but extending several kilometers to the south of it. This ridge may come to within a few hundred meters of the surface at a point about 5 km southeast of Hillsboro, and could be explained by an intrusion-related horst structure delimited on the west by the Berenda fault and on the east by another major north-south offset in the Skute Stone Arroyo quadrangle. The location of the high point of this ridge coincides with local geochemical anomalies mapped in the area by the U.S. Geological Survey.

Introduction

The Hillsboro and San Lorenzo 15-minute quadrangles are located east of the Santa Rita (San Juan) mining district, between Silver City and Truth or Consequences, N. Mex. (fig. 3). The two quadrangles lie just south of the Gila Wilderness, and include the southern end of the Black Range in the Mexican Highland section of the Basin and Range province. Figure 1 is a generalized geologic map with place names.

Within the mapped area, volcanic and volcaniclastic rocks of the Datil-Mogollon field have been extruded and deposited over Paleozoic strata and remnant outcrops of Upper Cretaceous sandstone and andesite. Ash-flow tuffs of the Kneeling Nun Tuff (33.4 m.y.) are especially extensive and are thought to be derived from the Emory Pass caldera (Elston and others, 1975). This caldera is not completely defined, but the southern part appears to extend into the northern parts of the map area.

Late Tertiary (about 20 m.y.) block faulting has tilted and arched about 820 m of Paleozoic strata and the 1800-2000 m of overlying volcanic rocks near the crest of the Black Range. Subsequent erosion has exposed the Paleozoic rocks and the economically important Laramide (75.1±2.5 m.y.) copper porphyry deposit of the Copper Flat stock, the middle Tertiary (34.8±1.2 m.y.) skarn deposits of the Carpenter (Swartz) district, and the middle Tertiary(?) silver and base-metal deposits of the Kingston district (Elston and others, 1975).

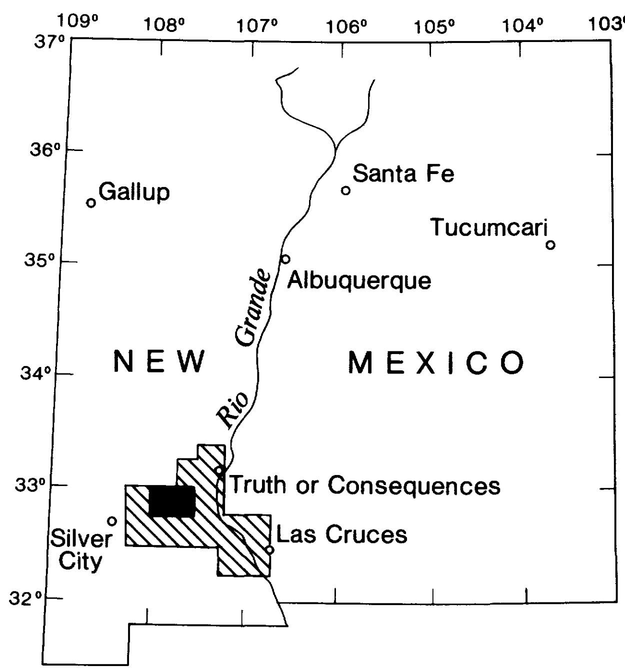

FIGURE 3.—Index map showing location of the Hillsboro and San Lorenzo quadrangles (solid), and the aeromagnetic map of parts of the Silver City and Las Cruces 1° by 2° quadrangles (patterned), New Mexico.

Gravity, ground magnetic, and aeromagnetic data were collected as part of a U.S. Geological Survey study that included geochemical stream-sediment sampling and geologic mapping (Hedlund, 1975a,b; Watts, Alminas, and Kraxberger, 1976; Watts and others, 1976). Using this data, several gravity and aeromagnetic models were calculated to give quantitative information about subsurface features of possible economic interest. It is well known that, under special circumstances, gravity and magnetic anomalies may be caused directly by deposits of metallic ores; for instance, massive sulfides or iron ore bodies. Generally, however, gravity and magnetic methods are used primarily as reconnaissance tools to isolate geologic settings that may be favorable for the occurrence of ores. Thus, the geophysical studies in this investigation mainly serve to outline parts of the Emory Pass caldera, to identify faults, and to isolate, among other things, possible buried tracts of rocks that might be hosts for ore deposits.

Aeromagnetic Data

Collection and processing

In 1973, an aeromagnetic survey was flown and compiled by Aerial Surveys LTD. for the U.S. Geological Survey and the New Mexico Bureau of Mines and Minerals, as part of a cooperative program. The survey was flown at a constant barometric elevation of 3.05 km above sea level, in east-west traverses spaced 1.6 km apart. The original survey was compiled at a scale of 1:250,000 from individual maps of 1:62,500 scale, with a contour interval of 10 gammas (U.S. Geological Survey, 1974).

For the purposes of this investigation, the digitized data from this survey were gridded on a 0.5-km equal interval, using bicubic splines, and a regional quadratic surface (derived from the 1965 IGRF—International Geomagnetic Reference Field—updated to 1973) was removed to facilitate subsequent processing. Because the topographic relief in the map area exceeds 1500 m, with elevations as high as the stated flight elevation, the data show strong topographic effects, especially in the central part of the two-quadrangle area, where magnetic rocks are exposed in high relief.

In order to minimize these topographic effects, a new method of aeromagnetic data-processing called parallel-surface continuation was applied to the gridded data set. This method was developed by Bhattacharyya and Chan (1977), and, in essence, calculates the magnetic field at a surface everywhere parallel to the topography. The effect is to simulate a perfect drape flight by the recording aircraft, where the effects of magnetized peaks are diminished until they contribute the same relative influence as the surrounding valleys. The results are a selective upward continuation of the aeromagnetic data set, where only data over peaks are continued. They are presented here in a contoured polyconic projection as the parallel-surface-continued aeromagnetic map of the San Lorenzo and Hillsboro quadrangles, New Mexico (fig. 4 of this report; MF-900L). The mean distance between the continued magnetic surface and the ground was 1.5 km.

Description and analysis

A comparative examination of the original aeromagnetic map (U.S. Geological Survey, 1974) and the parallel-surface-continued aeromagnetic map show that most of the topography-caused magnetic highs over the Kneeling Nun Tuff in the Black Range have been removed; these magnetic highs all appear to be economically uninteresting. The result is that several magnetic lows, one of which was almost totally obscured by topography, show up clearly along the south margin of the Emory Pass caldera. An extensive magnetic high over the Carpenter (Swartz) mining district was probably caused by intense but sporadic tactite development within the Paleozoic limestones, and in part by topgraphy; the crest of the magnetic high has been shifted several kilometers to the south on the new map. Most of the other magnetic features on both sides of the Black Range remain unaffected by the parallel-surface continuation.

The parallel-surface-continued aeromagnetic map (hereafter called the aeromagnetic map or aeromagnetic data) is dominated by a very strong circular magnetic high on its east side, situated approximately over the southern part of the andesite of Copper Flat in the Hillsboro mining district (anomaly 1 on fig. 4). A series of north-south trending magnetic lows (anomalies 2, 3, and 4 on fig. 4) dominate the west side of the Hillsboro quadrangle, and are coincident with the outcrops of Paleozoic strata. The Pierce Canyon fault marks the western edge of these lows. The San Lorenzo quadrangle contains the magnetic high (anomaly 5 on fig. 4) with the greatest overall areal extent of any of the closed anomalies. The maximum amplitude point of the multi-armed feature is centered a few kilometers south of the Carpenter (Swartz) mining district, and auxiliary extensions of the anomaly are underlain by Sawyers Peak, Pine Flat Mountain, and Noonday Peak, which are also areas of geochemical anomalies. A magnetic high (anomaly 6 on fig. 4) centered approximately over the Rose Mine west of the Mimbres River, a string of magnetic lows (anomalies 7, 8, and 9 on fig. 4), and a magnetic high (anomaly 10 on fig. 4) in the northern part of the San Lorenzo quadrangle, complete the list of important aeromagnetic features.

Anomaly 1 is important because of its proximity to the quartz monzonite stock of Copper Flat. It was necessary to use a three-dimensional model to fit this feature; the results are shown in figure 5. The anomaly appears to be caused by a prism-shaped body which dips 45° in a north-northwesterly direction. The apparent top of the body at the center of the anomaly is at roughly 1280-m elevation (300-600 m below the ground surface), and the vertical extent of the body attains roughly 8 km, plus or minus 2 km. This model, like most models, is probably a gross simplification of the true geologic configuration of the causative body. The calculation was made with the original constant (3.05 km) elevation data and the imperfect fit of model to data is largely due to the limitation of the modeling program to use only a single prism. The result, nevertheless, seems to clearly indicate a small pluton whose top is located beneath the southern margin of the Hillsboro andesite field. The Copper Flat

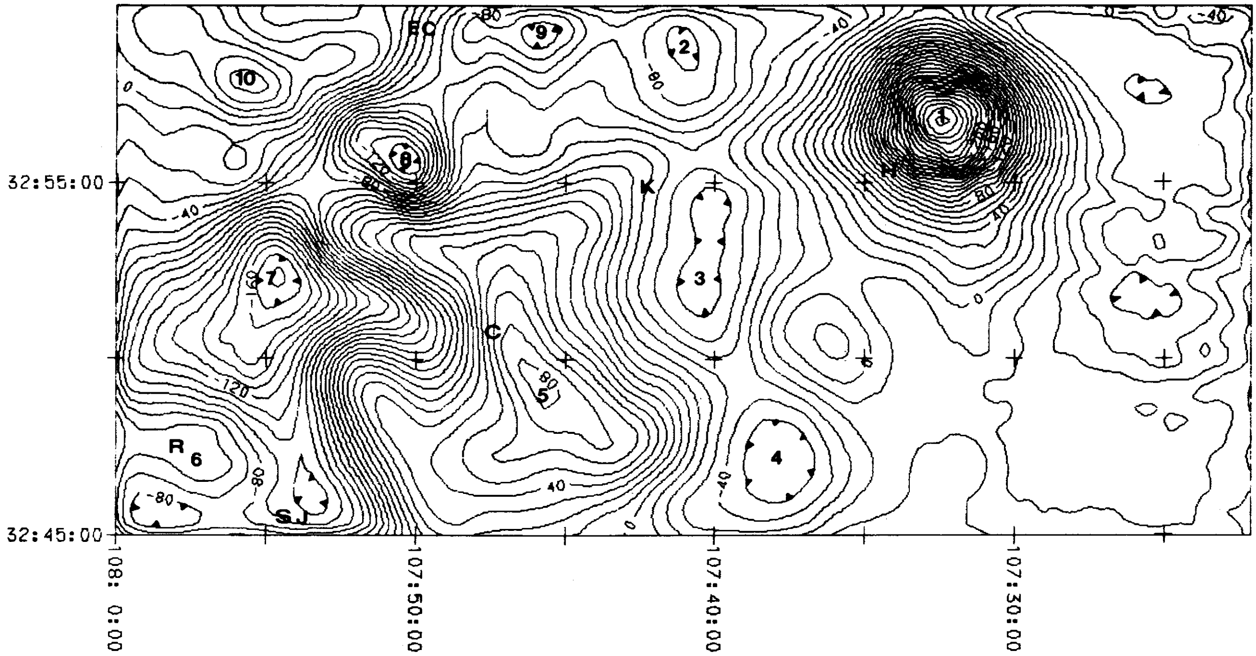

FIGURE 4.—Parallel-surface-continued aeromagnetic map of the San Lorenzo-Hillsboro quadrangles, gridded at 600 m intervals. Individual features referred to in the text are located by the following symbols: H, Hillsboro; K, Kingston; C, Carpenter (Swartz) district; EC, Emory Pass caldera; R, Rose Mine; and SJ, San Juan. Anomalies 1-10 are referred to in the text. Scale is 1:250,000.

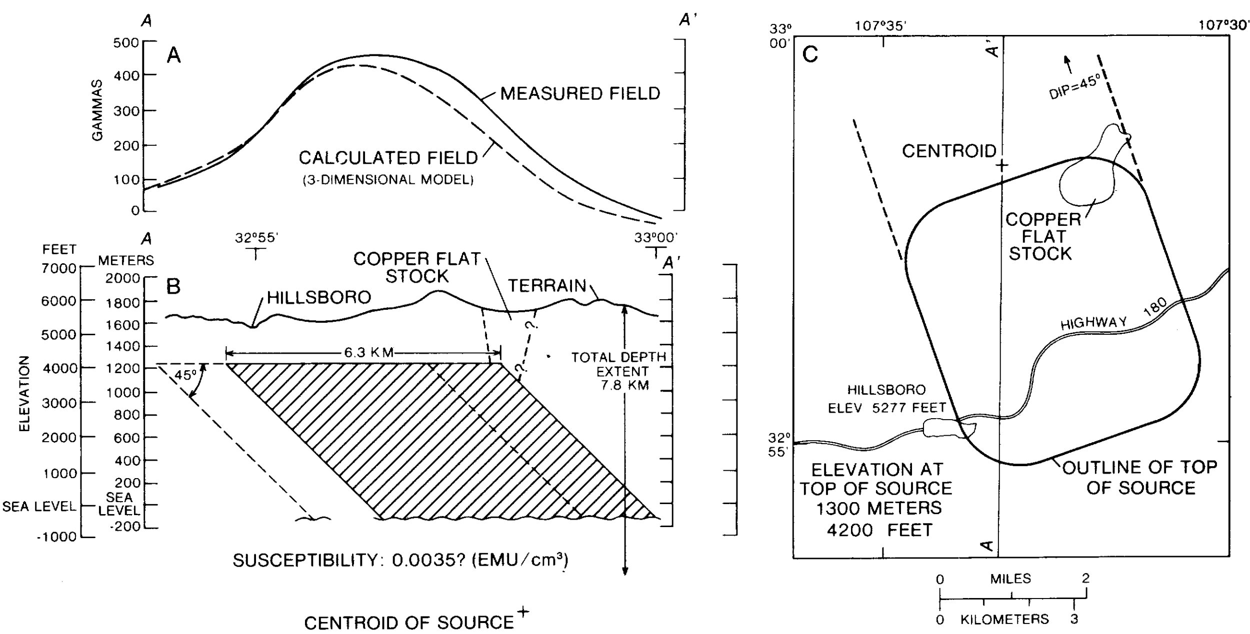

FIGURE 5.—(A) Magnetic anomaly in the Hillsboro district; (B) north-south section showing the measured field, the calculated field, and; (C) the cross section of the source body.

stock is located above the north edge of the prism top, and unaltered monzonite from it is known to have a similar high magnetic susceptibility (see table 6). It is reasonable to believe that this stock may be a mineralized apophysis of the pluton. The identification of the pluton appears to be further verified by the presence of the Warm Spring Canyon stock and by two small plug-like bodies of quartz monzonite in secs. 10 and 11, T. 16 S., R. 7 W. near its southern margin (Hedlund, 1975a). The stock of Warm Spring Canyon includes components of granite, quartz monzonite, and quartz monzodiorite. Dioritic xenoliths in the Copper Flat stock and the presence of a nearby small quartz diorite pluton along Tank Canyon imply a dioritic composition for the buried pluton.

Table 6.—*Magnetic susceptibility and density data for some of the rock units described in the geophysical interpretation and accompanying maps. Measurements by W. C. Rivers (1974) and J. C. Wynn (1975)*

[ND, data not available]

Rock unit on geologic map	No. of samples	Susceptibility (10^{-6} emu/cm^3)	Specific gravity
Basalt of Santa Fe--------- Formation.	2	3723 4480	2.92
Basalt of Bear Springs-----	1	466	2.64
Rhyolite of Mimbres Peak---	2	8.34 88.3	2.43
Rhyolite porphyry----------	1	3.34	2.56
Kneeling Nun Tuff----------	4	38 293 324 332	2.50
Rubio Peak andesite--------	1	1000	2.60
Andesite of Copper Flat----	2	758 947	2.64
Quartz monzonite of Copper-Flat.	4	182 733 3399 3680	2.60
Sericitized quartz--------- monzonite of Copper Flat.	3	366 370 393	2.60
Sulfide ore from Copper---- Flat.	3	15 15 21	ND
Quartz latite porphyry----- dike from Copper Flat.	1	ND	2.56
Hornblende latite sill-----	1	ND	2.60
Hornblende latite (Pollack-Quartz Latite).	1	ND	2.58
Skarn from the Royal John-- Mine.	3	8 8 341	ND
Skarn from the Franklin---- Mine.	1	6	ND
Granite of Seven Brothers-- Mountain (p€).	1	205	ND
Quartz monzo-diorite of---- Warm Spring Canyon.	1	ND	2.76
Leuco-granite of Warm------ Spring Canyon.	1	ND	2.71

There are several extensions of anomaly 1; one to the west under Warm Spring and North Percha Creek Canyons, where hot springs and altered rock may be found, another to the southwest underlying McClede Mountain, and a third to the south. It will be shown later that the southern extension coincides with a horstlike structure evident for the gravity data.

Anomalies 2, 3, and 4 comprise a string of north-south-trending magnetic lows in the western half of the Hillsboro quadrangle. These lows appear to closely follow outcrops of Paleozoic rocks; there are few intrusives, no metamorphic rocks, and the anomalies are, therefore, probably caused by a lack of magnetic rocks.

Anomaly 5 is a multilobed magnetic high that reaches its peak expression in the San Lorenzo quadrangle just south of the Royal John Mine in the Carpenter (Swartz) mining district (Hedlund, 1975b). A two-dimensional iterative magnetic modeling program was used to model an east-west profile through the Royal John Mine, (located just southeast of point C in figures 4 and 7) and the results of the modeling effort are shown in figure 6. The better fit was obtained by assuming a body with purely remanent magnetization; however, induced magnetic effects are almost certainly involved (see table 1). All the models imply a semi-infinite dikelike body that reaches to within 200 m of the ground surface; considering the precision of the model, the dike must essentially outcrop.

The anomaly is underlain by rhyolite porphyry on the northern end and rhyolite on the southern end. There are latite and rhyolite plugs and dikes within the Paleozoic strata in the central and northern part of the Carpenter (Swartz) district, and there are sporadic skarns present. The skarns, however, are only in the El Paso Limestone (therefore cannot exceed 150 m in thickness), and only beneath the northern part of the magnetic high. The mineralization in the Carpenter (Swartz) mining district is near-surface in origin, and was probably caused by thermal metamorphism in rocks beneath the volcanic cover. The source body for much of anomaly 5 might, therefore, be pneumatolitic magnetite (consistent with tactite development) in buried Precambrian rocks of granitic to monzonitic character, probably in association with overlying small and sporadic skarn deposits.

Anomaly 6 lies to the southwest of the Mimbres fault in the southwestern corner of the San Lorenzo quadrangle. The magnetic high is centered roughly over the Rose Mine, just south of New Mexico State Highway 180. The source for this magnetic high could be volcanic rocks upthrown to the southwest, but copper and molybdenum halos and the anomaly shape imply a possible buried porphyry system which, like the postulated pluton at anomaly 1, may have a good economic potential.

The magnetic lows labeled 7, 8, and 9 are connected with each other, and together trend northeast across the northern half of the San Lorenzo quadrangle. These anomalies are not easily explained by surface geology. They connect on the northern edge of the map area with anomalies 2, 3, and 4, and it is

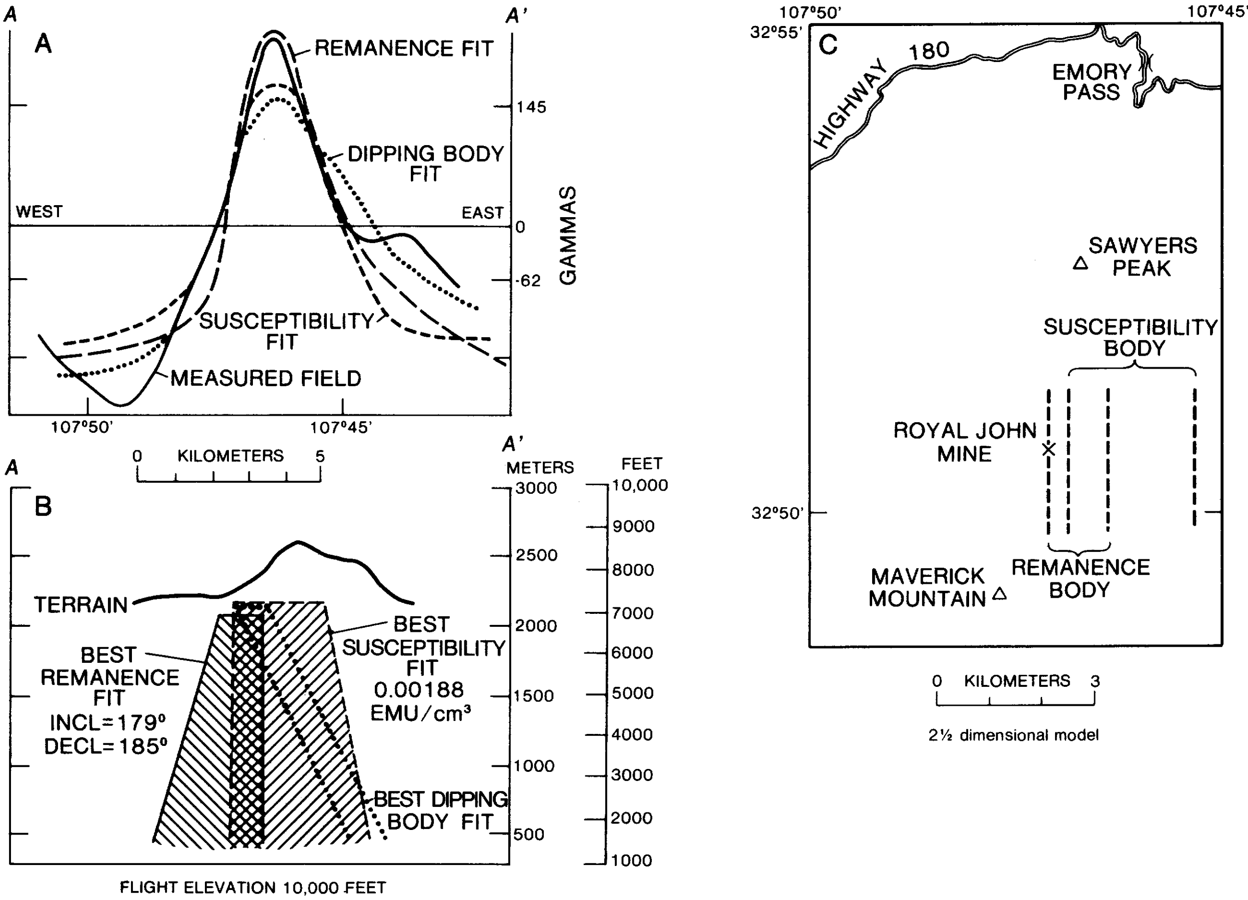

FIGURE 6.—(A) Magnetic anomaly in the Carpenter (Swartz) district; (B) east-west section showing the measured field, the best susceptibility-fit field, the best remanent-fit field, and the best dipping-body susceptibility-fit field; and (C) the cross section of the source body.

tempting to relate anomalies 7, 8, and 9 also to buried Paleozoic rocks, because of their spatial relationship to anomaly 2. The gravity data, however, clearly show that these anomalies cut across the gradational south margin of the Emory Pass caldera, and thus imply another source. Anomaly 8 is particularly intense—its source extending both close to the surface and to considerable depth. It is located over the head of Bear Trap Canyon, an area covered by Kneeling Nun Tuff. There is no apparent localized alteration, although low-grade regional metamorphism is known to have taken place in the pre-Kneeling Nun rocks. Anomalous amounts of bismuth and tungsten form characteristic halos around the Copper Flat, Hanover-Fierro, and Pinos Altos orebodies, and a low-level bismuth anomaly forms a halo around anomaly 8. The possibility exists that lows 8 and 9 (at least) are the result of hydrothermal alteration of tuffs or andesite flows in the buried rocks beneath the Kneeling Nun Tuff. These aeromagnetic lows lie on the apparent margin of the Emory Pass caldera, as inferred from the gravity data; this type of geologic association is known to be favorable for mineralization.

Anomaly 10 is a magnetic high that lies in the northwestern corner of the San Lorenzo quadrangle. This high lies over latitic rocks which contrast on the east with rhyolitic rocks and on the west with colluvium.

Gravity Data

Collection and processing

One hundred and forty gravity stations were established in and around the Hillsboro and San Lorenzo quadrangles. The data were obtained using high-precision gravity meters, and all stations were tied to a U.S. Department of Defense (DOD) gravity base at Silver City, N. Mex. (979006.48 milligals). An additional 18 stations were obtained from DOD sources and added to those obtained by the U.S. Geological Survey.

Elevation control was taken from published topographic maps of the U.S. Geological Survey, and, where bench marks and survey points were not readily available, a theodolite was used to establish elevations from at least three nearby peaks of known elevation, or by running a level line from a known elevation point. Station elevation accuracy is, therefore, better than 3 m in all cases except those elevations obtained by referencing to three or more peaks. In the latter cases, only those stations with closure (for three measurements) within 4 m were used, giving a resulting maximum error for these stations of 0.7 milligals due to elevation error. Terrain corrections to a distance of approximately 3 km were made for all stations.

Powder densities for the volcanic rocks in the two quadrangles ranged from 2.43 gm/cm^3 for Mimbres Peak Rhyolite to 2.92 gm/cm^3 for basalt of the Santa Fe Formation (see table 1). The density varied around a mean of 2.67 gm/cm^3, and the simple Bouguer and terrain corrections were made using this standard value. It should be noted, however, that if there are prominent topographic features in an area caused largely from surface rocks whose density differs greatly from 2.67 gm/cm^3, small systematic errors will exist in the reduced gravity values. Such an error, in fact, may exist in the data around Hillsboro Peak. The complete Bouguer gravity values thus obtained were gridded on a 2-km equal interval and plotted with a polyconic projection (fig. 7; MF-900M). This was done using the gridding and contour computer programs of R. Codson (unpub. data). The polyconic projection was chosen to permit overlaying of the gravity onto the geology map (MF-900A).

Description and analysis

Regional gravity surveys, discussed by Ramberg and Smithson (1975), and by Eaton (Ericksen and others, 1975), place the San Lorenzo and Hillsboro quadrangles in a context of north-northwest trending structures that are oblique to the trend of the Rio Grande Rift located 45 km to the east. These oblique structures are probably related to tensional forces that broke open the rift along pre-existing fractures in the late Cenozoic (Ramberg and Smithson, 1975).

Three major features dominate the gravity map (fig. 7): a gradient coincident with the Mimbres fault on the southwest corner, a deep gravity low which outlines the southern boundary of the Emory Pass caldera, and a north-trending gravity ridge in the Hillsboro district. In addition to these features, there is a broad north-trending gradient in the west half of the Hillsboro quadrangle that probably stems from uplifted basement and related magmatic intrusions in the Black

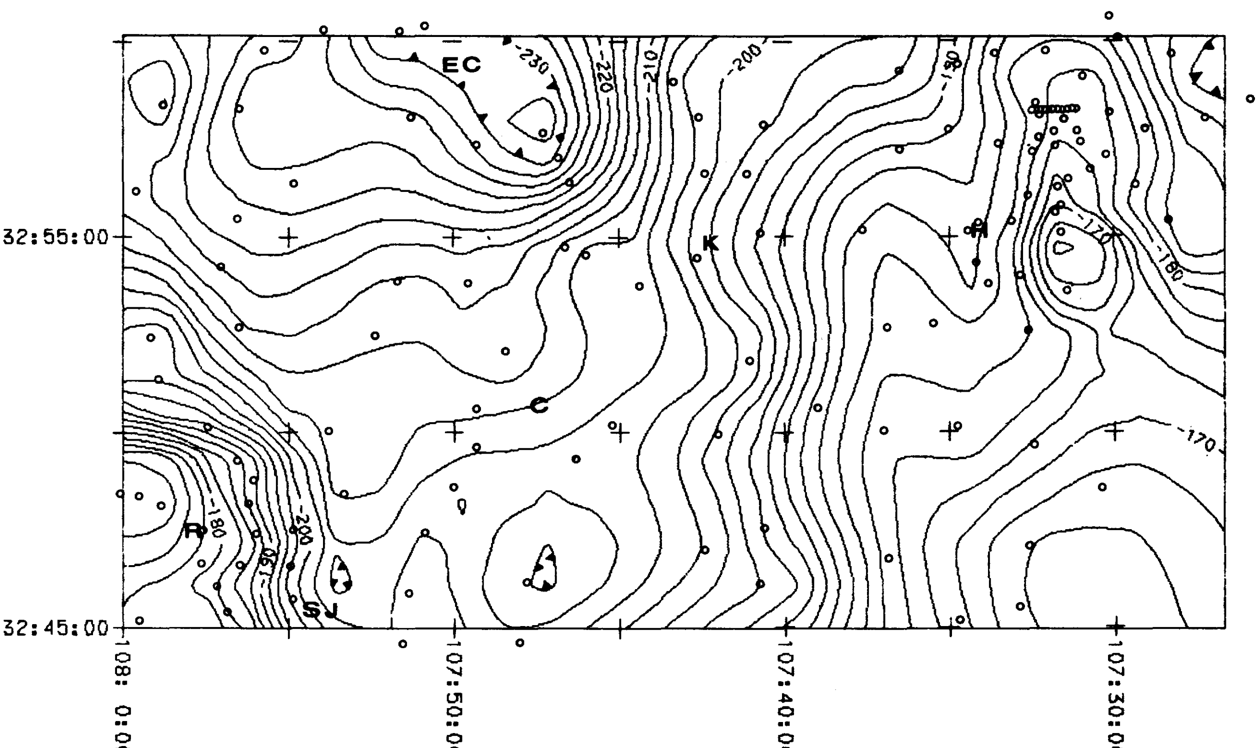

FIGURE 7.—Complete Bouguer gravity map of the San Lorenzo and Hillsboro quadrangles, gridded at 2,000 m intervals. Circles indicate gravity station localities; H, Hillsboro; K, Kingston; C, Carpenter (Swartz) district; EC, Emory Pass caldera; R, Rose Mine; and SJ, San Juan. Simple Bouguer and terrain corrections were made assuming an average rock density of 2.67 gm/cm^3. Contour interval is 25 milligals; scale is 1:250,000.

Range, where a broad arching is apparent in the geology.

The expression of the Mimbres fault (see MF-900A) is difficult to separate from the southwestern edge of the Emory Pass caldera. This complication is not as serious near the town of San Juan (SJ in fig. 7) on the southern margin of the map area, however, and a two-dimensional gravity profile was modeled to calculate the apparently gradational or en echelon displacement on the Mimbres fault. For a density contrast of 0.4 gm/cm^3 the (normal) cumulative throw on the Mimbres fault is 2.0±0.2 km, with the downthrown side to the northeast. The trace of the fault agrees closely with that mapped by Hedlund (1975b).

The Emory Pass caldera, as inferred from the gravity map, (fig. 8) shows a 34-milligal gravity low having a rather sharp eastern boundary with more gradual southern and western margins. The eastern edge at lat 33°00' N. is located about 3 km west of the juncture of the San Lorenzo and Hillsboro quadrangles. The southeast bulge of the caldera margin may be partly due to the 2.67 gm/cm^3 Bouguer and terrain correction for the station atop Hillsboro Peak; the mountain consists mainly of Kneeling Nun Tuff overlain in part on the north by Pollack Quartz Latite. The Kneeling Nun Tuff has a density of 2.50 gm/cm^3 and the quartz latite has a maximum density of 2.58 gm/cm^3. As a result, the complete Bouguer value for the Hillsboro Peak station may be 1 or 2 milligals low with respect to surrounding values; the exact value is not obtainable, however, without precise additional information about the thicknesses and three-dimensional distribution.

Elston, Seager, and Clemons (1975) thought that the Kneeling Nun Tuff filled the caldera after its collapse, and was subsequently raised and faulted by resurgent doming. A three-dimensional gravity modeling program (Cordell and Henderson, 1968) was used to obtain an estimate of the shape of the buried caldera, assuming the conceptual model of Elston, Seager, and Clemons (1975). The data were initially converted to a residual gravity map by adding +196.78 milligals to all values in the 9 by 15 grid (fig. 9). The program was then allowed to iterate three times, using a density contrast of -0.35 gm/cm^3, and the resulting calculated field is shown in figure 10.

The source model giving this result is a 4-km-deep caldera, and is shown in figure 11, where the contour intervals are 0.5 km. The fit using this model is excellent (compare figs. 9 and 10) due to the limited number of points being calculated (only 135 grid points were possible due to the sparseness of the original data). If a density contrast of -0.1 gm/cm^3 was used, a somewhat broader caldera shape was obtained, due to the caldera floor now extending to a depth of 20 km (fig. 12). The best-fit calculated model (fig. 13) is not nearly as close to the original field (fig. 9) as the calculated field from the $\rho = -0.35$ model (fig. 10). Both of these models show a steeper topographic gradient on the eastern edge, with more gradual thinning to the

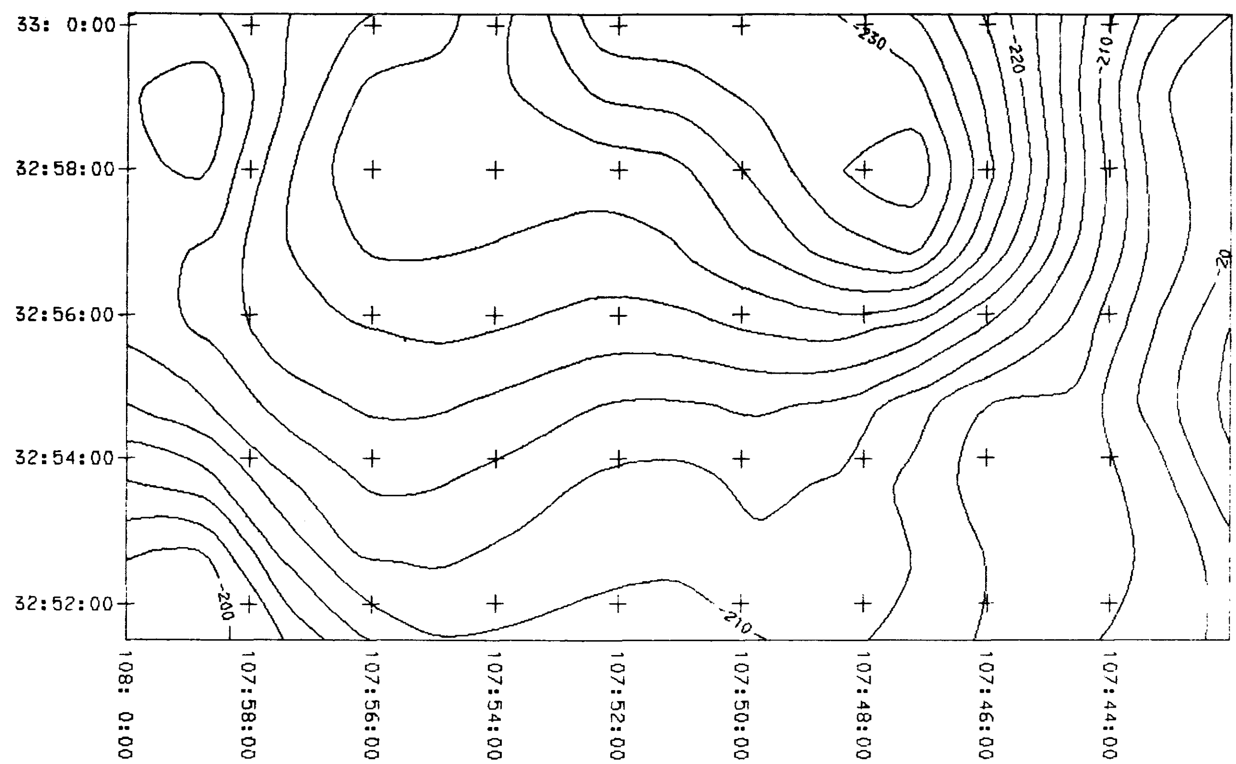

FIGURE 8.—Gravity map of the Emory Pass caldera, taken from figure 7. Contour interval is 2.5 milligals; scale is 1:125,000.

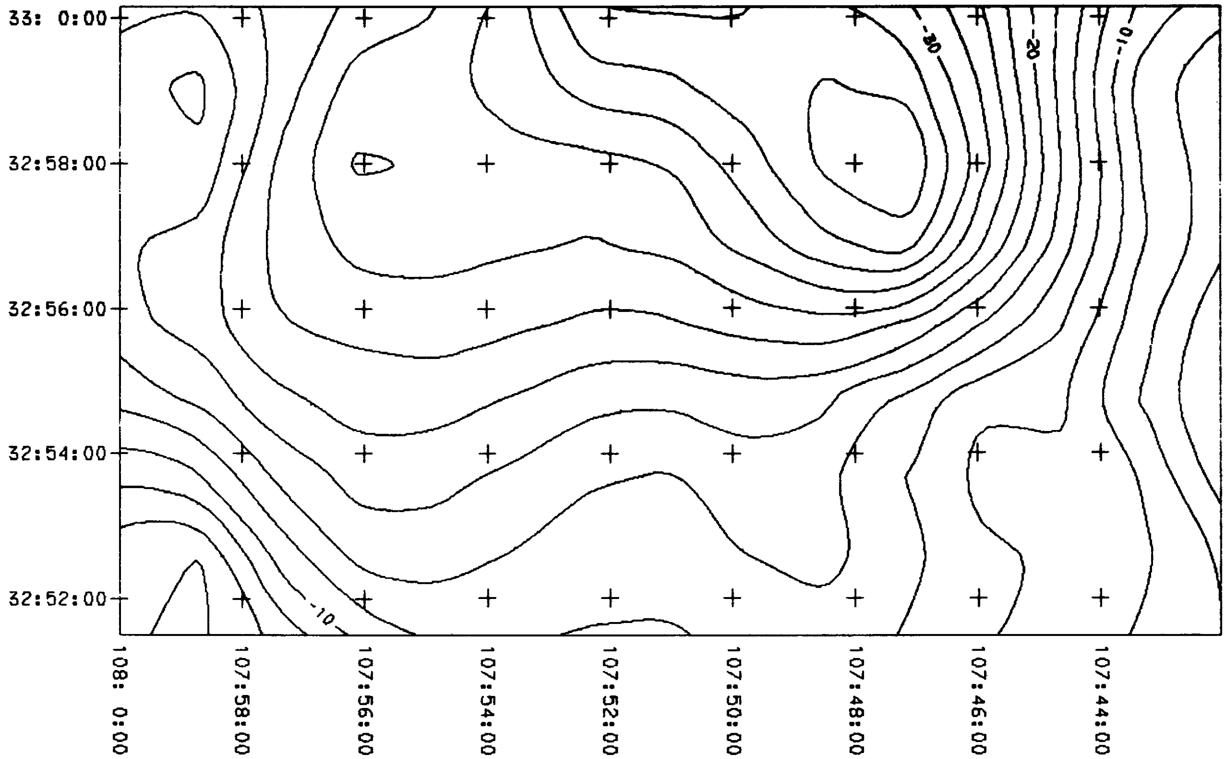

FIGURE 9.—Residual gravity map of the Emory Pass caldera, using an offset of 196.78 milligals. Contour interval is 2.5 milligals; scale is 1:125,000.

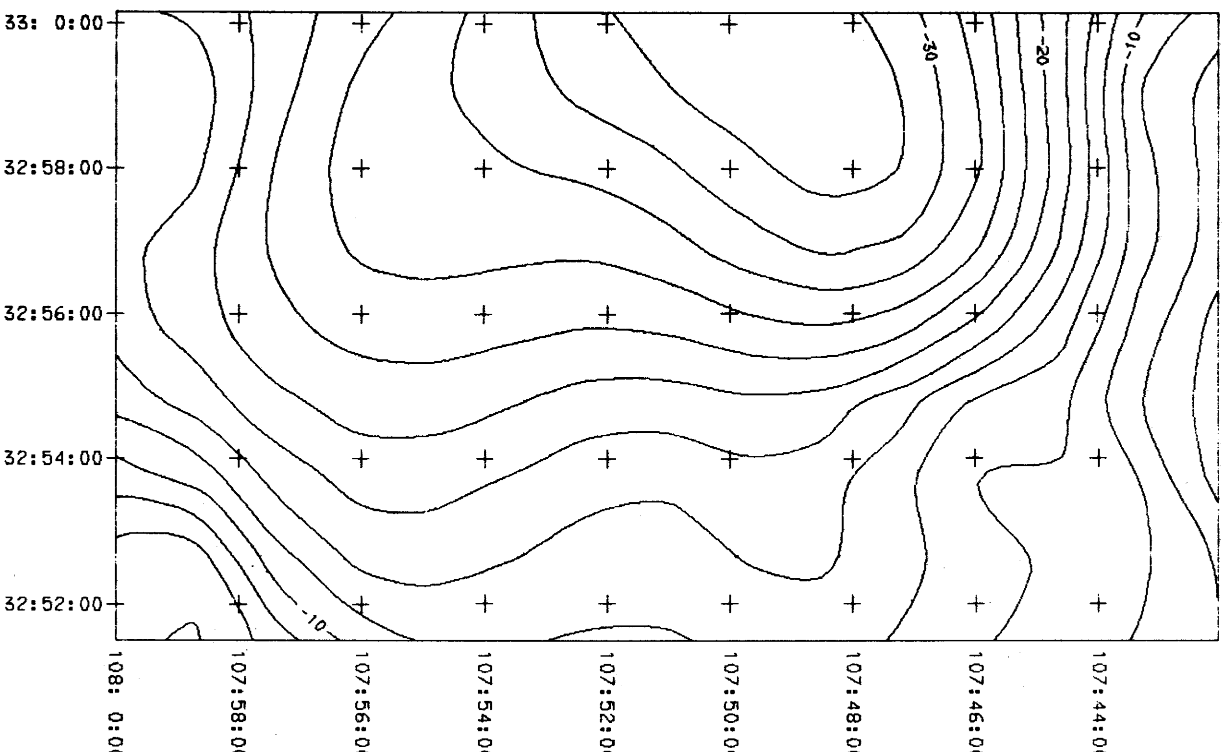

FIGURE 10.—Calculated gravity map of the Emory Pass caldera, from the three-dimensional model using -0.35 gm/cm^3 density contrast. Contour interval is 2.5 milligals; scale is 1:125,000.

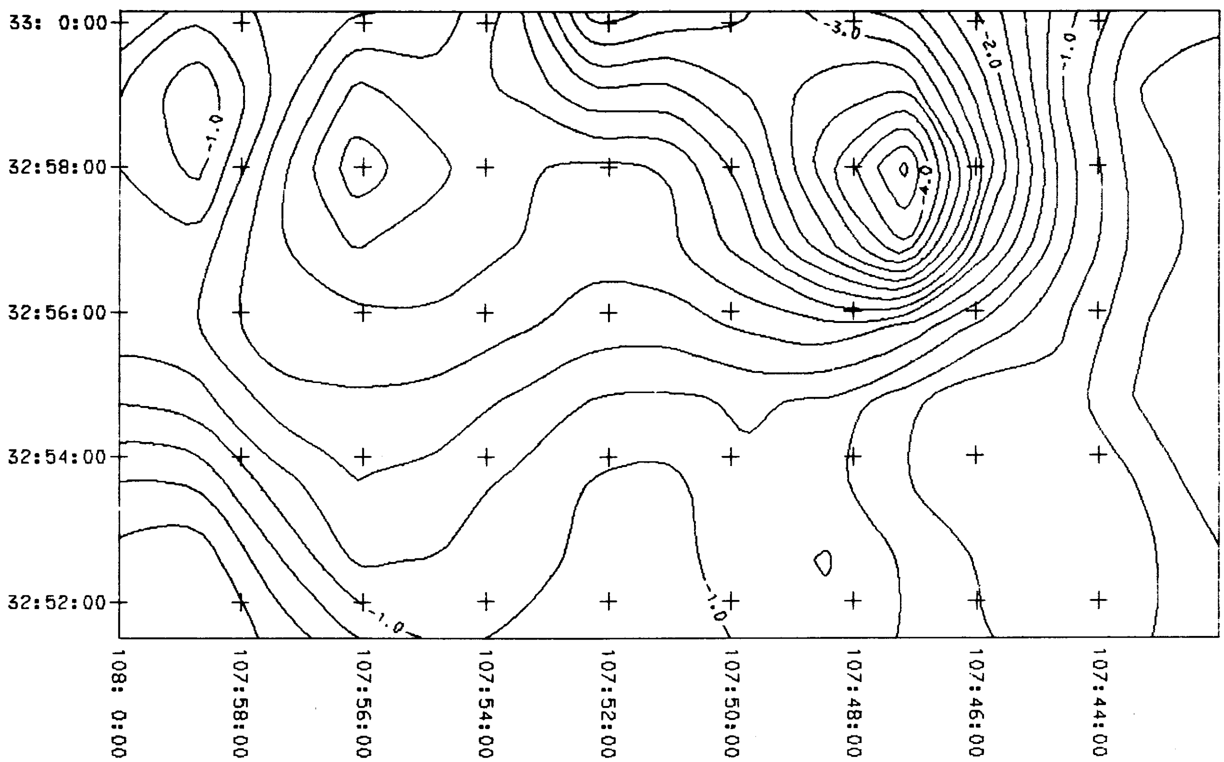

FIGURE 11.—Three-dimensional model of the Emory Pass caldera, using -0.35 gm/cm³ density contrast, and 0.5 km contour intervals, and datum is mean ground elevation over the map area. Scale is 1:125,000.

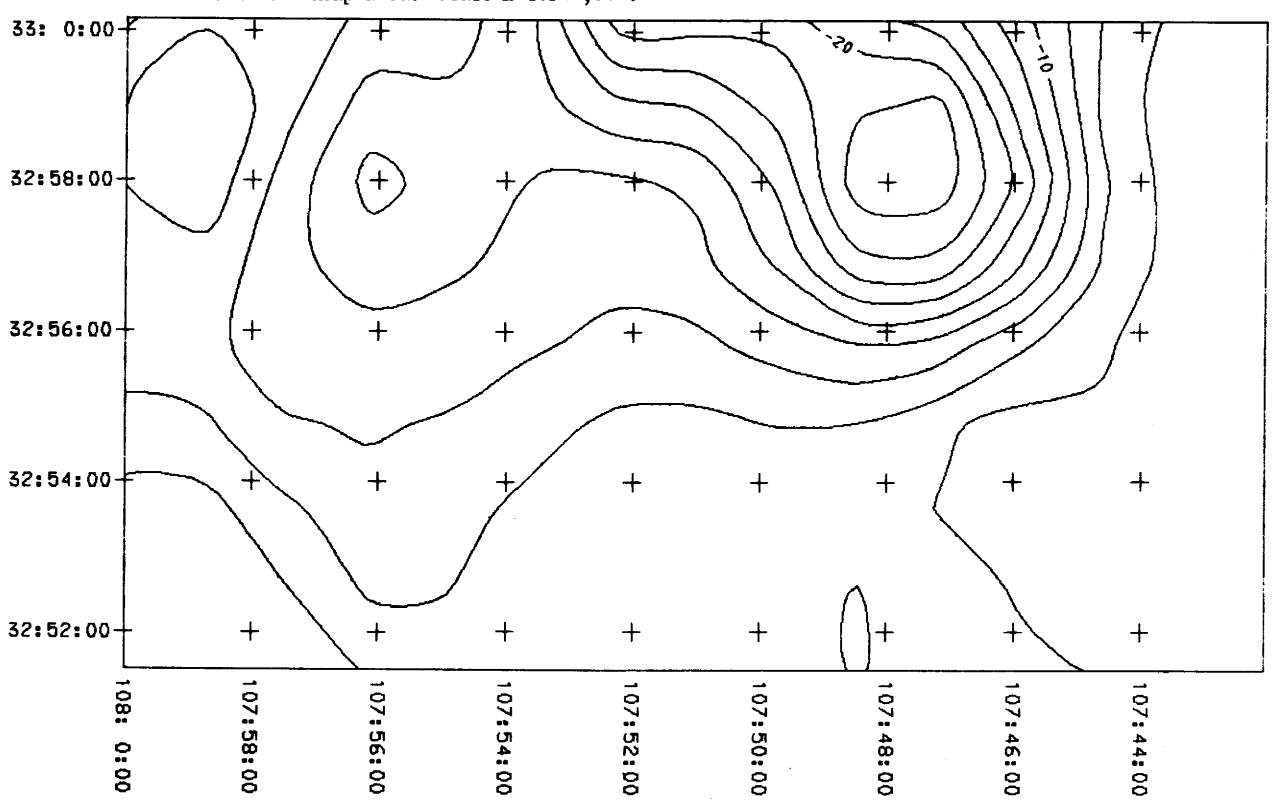

FIGURE 12.—Three-dimensional model of the Emory Pass caldera, using -0.10 gm/cm³ density contrast, and 2.5 km contour intervals, and datum is mean ground elevation over the map area. Scale is 1:125,000.

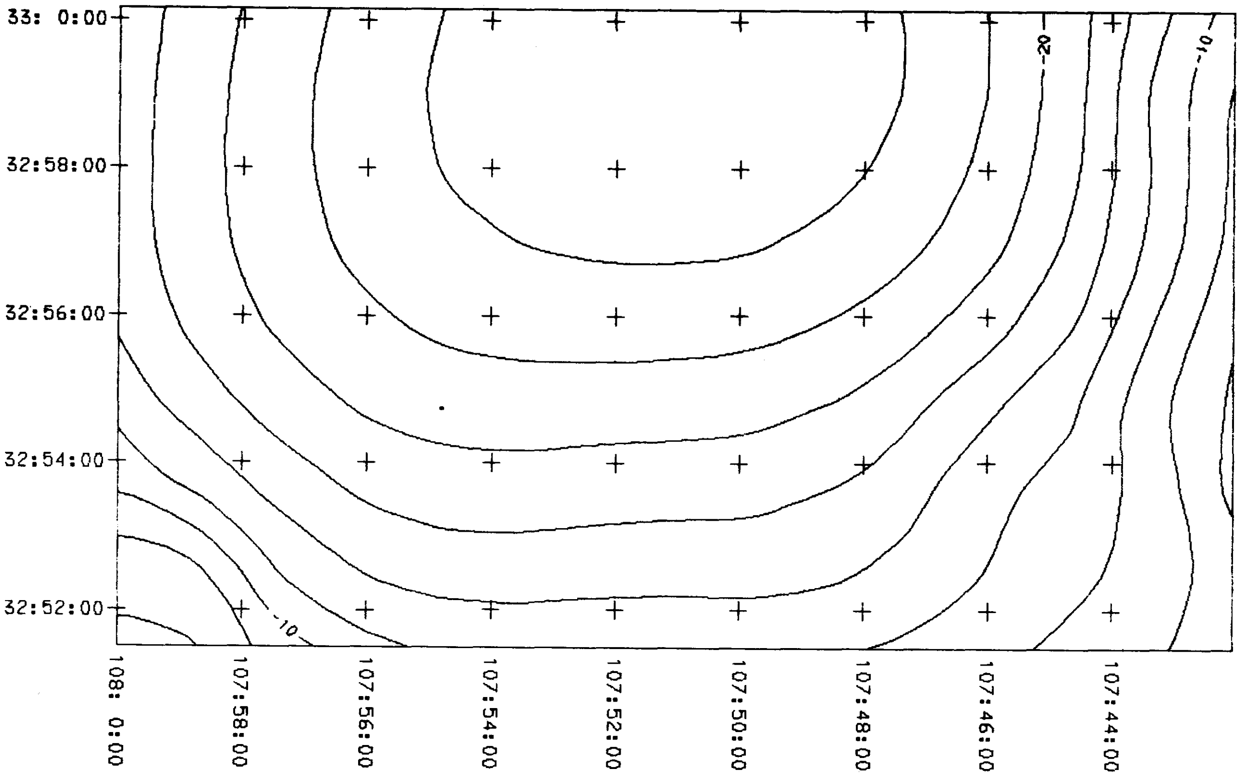

FIGURE 13.—Calculated gravity map of the Emory Pass caldera, from the three-dimensional model using -0.10 gm/cm^3 density contrast. Contour interval is 2.5 milligals; scale is 1:125,000.

south and southwest; the density on the -0.35 gm/cm^3-model is preferable because of its better fit. The caldera margin on the south would then be a gradually thinning wedge of Kneeling Nun Tuff, extending to perhaps lat 32°50' N.

One of the most important features on the gravity map (fig. 7) from an economic point of view is the gravity ridge that projects in from the Lake Valley mining district (off the southeast corner of the map) to as far as the andesite cone of Copper Flat on the northeast edge of the map (fig. 14). This gravity ridge crests at lat 32°55' N., and the nose of the ridge brackets the Copper Flat quartz monzonite stock almost exactly. The axis of the ridge, however, lies about 2 km east of the center of the assumed prismatic body, which apparently caused the aeromagnetic high discussed and modeled earlier.

There is no guarantee that the gravity ridge is caused by a single source. The geologic evidence, however, supports the hypothesis that the source could be a horstlike feature delimited by the Berenda fault (Hedlund, 1975a) on the west and another north-trending fault on the east in the Skute Stone Arroyo quadrangle. The geologic evidence indicates at least 250 m of displacement (west side down) on the Berenda fault, and that the sediments deepen rapidly to unknown depth on the east in the Skute Stone Arroyo quadrangle, as one moves towards the Rio Grande 45 km to the east.

A residual gravity map was obtained (fig. 15) by adding +197.43 milligals to all the values in the 9 by 9 grid. The computer program of Cordell and Henderson (1968) was used to obtain a good fit with the data with a three-dimensional model of the anomalous mass, using a density contrast of +0.40 gm/cm^3, a reference plane of -3.00 km, and three iterations. The reference plane is the level from which the model prisms are constructed in an upwards direction (in this case), subject to the constraint that they cannot exceed the level of the ground surface. The calculated field is shown in figure 16, and the source model is shown in figure 17.

The results indicate a horstlike uplifted block, with cumulative displacements of more than 2 km. The top of the block comes to within a few hundred meters of the surface at a point about 5 km southeast of the town of Hillsboro. The density difference of 0.40 gm/cm^3 is caused by alluvium contrasted against the volcanics. There is a tungsten-gold anomaly, possibly indicative of skarn in the vicinity of this high point, which is on the southern edge of the aeromagnetic anomaly described previously. The uplift may have been caused by the emplacement of a small batholith beneath the gravity ridge. The quartz monzonite of the Copper Flat stock is probably a mineralized apophysis or hood cupola of a batholith of quartz dioritic composition. The aeromagnetic anomaly could then be caused by a dioritic intrusion in the subsurface enhanced possibly by tactite minerals. All of these lines of evidence taken together make the center of the gravity high an interesting exploration target, and there is a possibility that deep-electrical mining-geophysical methods might locate mineralized rocks below this gravity high.

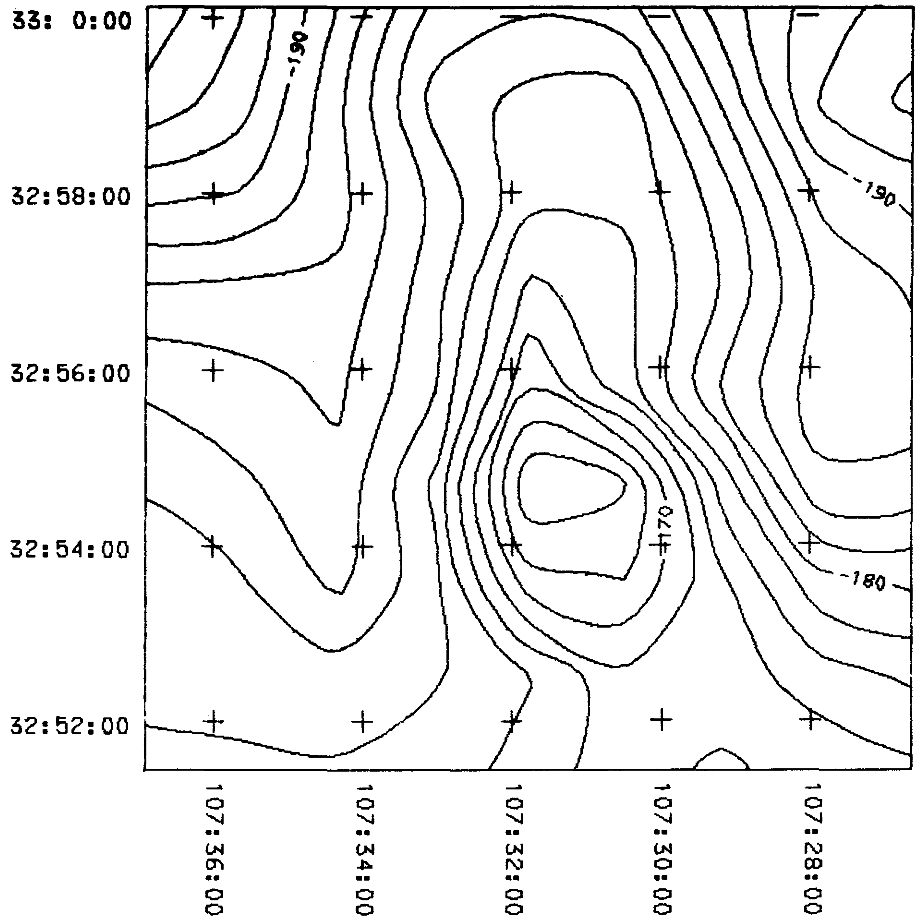

FIGURE 14.—Gravity map of the Copper Flat gravity anomaly, enlarged from figure 7. Contour interval is 2 milligals; scale is 1:125,000.

Conclusions

The Mimbres fault is a normal fault with a throw of about 2 km in the vicinity of San Juan, N. Mex. The Emory Pass caldera has a sharply defined eastern boundary, while the southern and western margins are more gradational; zones of hydrothermal alteration may be indicated in at least two places on the caldera margins. The Rose Mine may lie atop a discrete magnetized porphyry system, possibly similar to the Caballo Blanco porphyry discovery to the southwest. The Copper Flat stock near Hillsboro, N. Mex., and a small quartz diorite pluton along Tank Canyon, may be apophyses of a small dioritic batholith emplaced at shallow depth beneath and to the south of the Hillsboro andesite field. The uppermost parts of this batholith and its related horst may be within reach of mining-geophysical (electrical) methods to the southeast of Hillsboro, in an area already noted for anomalous geochemical measurements.

Acknowledgments

Several members of the U.S. Geological Survey contributed to the preparation of this section. Danny A. Dansereau and Gary Brougham both helped in the collection of the gravity data. In addition, Dansereau contributed a great deal towards the gravity data reduction and in obtaining the digitized aeromagnetic data. Tom Hildenbrand and John Cady provided modeling programs for the magnetic data, and Lindrith Cordell provided the gravity modeling program.

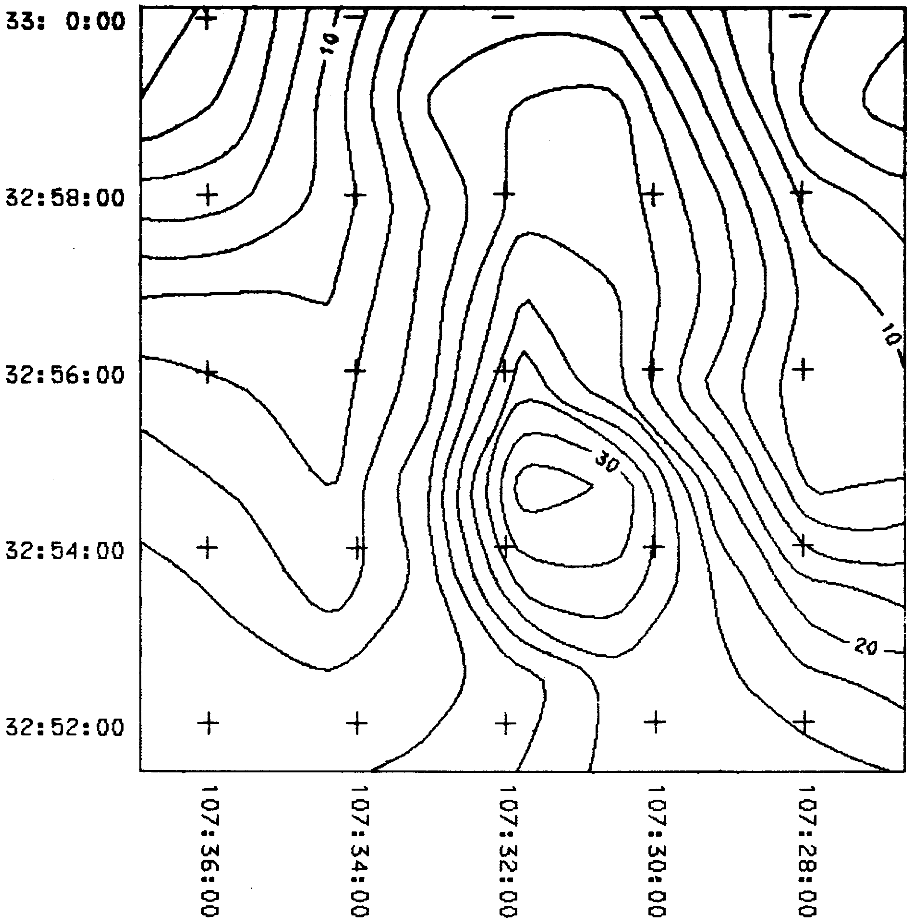

FIGURE 15.—Residual gravity map of the Copper Flat gravity anomaly, using an offset of +197.43 milligals. Contour interval is 2 milligals; scale is 1:125,000.

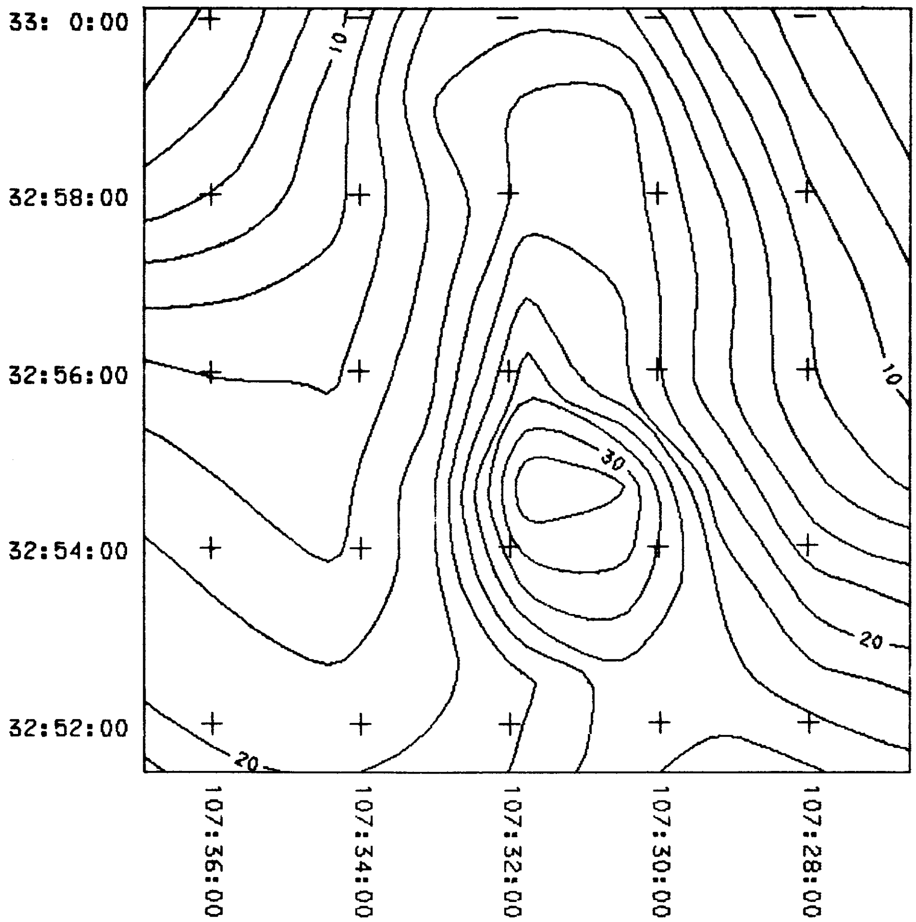

FIGURE 16.—Calculated gravity map of the Copper Flat gravity anomaly, from the three-dimensional model using a density contrast of +0.40 gm/cm^3. Contour interval is 2 gammas; scale is 1:125,000.

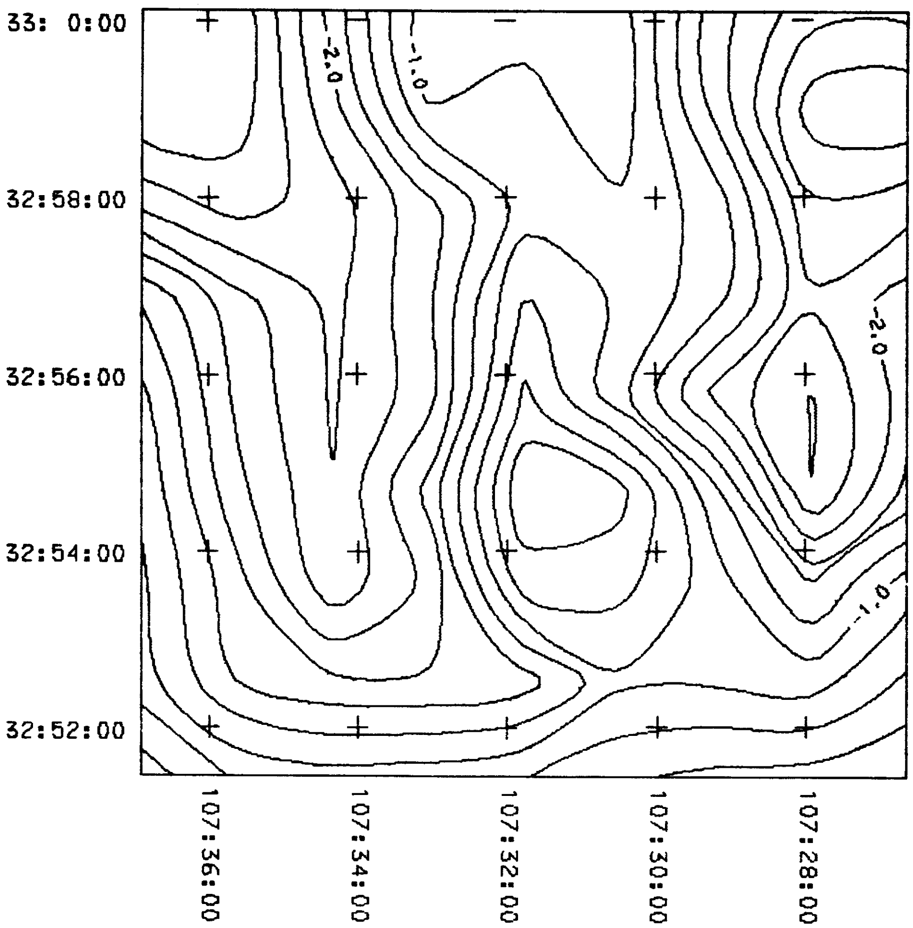

FIGURE 17.—Three-dimensional model of the Copper Flat gravity anomaly, using +0.4 gm/cm^3 density contrast and 0.25 km contour intervals. Datum is mean ground elevation over the map area. Scale is 1:125,000.

BIBLIOGRAPHY

Starred references indicate those cited in this circular.

Geology

Bachman, G. O., editor, 1965, Mineral and water resources of New Mexico: New Mexico Bur. Mines and Mineral Resources Bull. 87, 437 p.

*Dale, V. B., and McKinney, W. A., 1959, Tungsten deposits of New Mexico: U.S. Bur. Mines Report. Inv. 5517, p. 65-68.

*Dane, C. H., and Bachman, G. O., 1961, Preliminary geologic map of the southwestern part of New Mexico: U.S. Geol. Survey Misc. Geol. Inv. Map I-344.

*Elston, W. E., 1957, Geology and mineral resources of the Dwyer quadrangle, Grant, Luna, and Sierra Counties, New Mexico: New Mexico Bur. Mines and Mineral Resources Bull. 38, 86 p.

*____1968, Terminology and distribution of ash-flows of the Mogollon-Silver City-Lordsburg region, New Mexico: Arizona Geol. Soc. Guidebook to Southern Arizona, III, p. 231-240.

*Elston, W. E., Damon, P. E., Coney, P. J., Rhodes, R. C., Smith, E. I., and Bikerman, Michael, 1973, Tertiary volcanic rocks, Mogollon-Datil Province, New Mexico, and surrounding region—K-Ar dates, patterns of eruption, and periods of mineralization: Geol. Soc. America Bull., v. 84, p. 2259-2274.

*Elston, W. E., Seager, W. R., and Clemons, R. E, 1975, Emory cauldron, Black Range, New Mexico, source of the Kneeling Nun Tuff: New Mexico Geol. Soc. Guidebook, 26th Field Conf., p. 283-292.

*Ericksen, G. E., Wedow, Helmuth, Jr., Eaton, G. P., and Leland, G. R., 1970, Mineral resources of the Black Range Primitive area, Grant, Sierra, and Catron Counties, New Mexico: U.S. Geol. Survey Bull. 1319-E., p. El-E162

*Ericksen, G. E., and Wedow, Helmuth, Jr., 1976, Tertiary extrusive sheets and related intrusions in the Black Range, New Mexico, in Cenozoic volcanism in southwestern New Mexico: New Mexico Geol. Soc. Spec. Pub. 5, p. 63-67.

*Farnham, L. L., 1961, Manganese deposits of New Mexico: U.S. Bur. Mines Inf. Circ. 8030, 176 p.

*Flower, R. H., 1953a, Age of Bliss Sandstone: Am. Assoc. Petroleum Geologists Bull., v. 37, p. 2054-2055.

*____1953b, Paleozoic sedimentary rocks of southwestern New Mexico: New Mexico Geol. Soc. Guidebook, Southwestern New Mexico, 4th Conf., p. 106-112

*Fodor, R. V., 1975, Petrology of basalt and andesite of the Black Range, New Mexico: Geol. Soc. America Bull., v. 86, no. 3, p. 295-303.

*Harley, G. T., 1934, The geology and ore deposits of Sierra County, New Mexico: New Mexico School of Mines Bull. 10, 220 p.

Hawley, J. W., Kottlowski, F. E., Seager, W. R., King, W. E., Strain, W. S., and Le Mone, D. V., 1969, The Santa Fe Group in the south-central New Mexico border region: New Mexico Bur. Mines Circ. 104, p. 72-75.

*Hayes, P. T., 1970, Cretaceous paleogeography of southeastern Arizona and adjacent areas: U.S. Geol. Survey Prof. Paper 658-B, p. B33-B34.

*Hernon, R. M., Jones, W. R., and Moore, S. L., 1964, Geology of the Santa Rita quadrangle, New Mexico: U.S. Geol. Survey Geol. Quad. Map GQ-806.

*Hill, R. S., 1946, Exploration of Gray Eagle, Grandview, and Royal John claims, Grant and Sierra Counties, New Mexico: U.S. Bur. Mines Inv. Report Inv. 3304, 31 p.

*Jicha, H. L., Jr., 1954, Geology and mineral deposits of Lake Valley quadrangle, Grant, Luna, and Sierra Counties, New Mexico: New Mexico Bur. Mines and Mineral Resources Bull. 37, 93 p.

Johnson, M. G., 1972, Placer gold deposits of New Mexico: U.S. Geol. Survey Bull. 1348, 46 p.

*Jones, W. R., Hernon, R. M., and Moore, S. L., 1967, General geology of Santa Rita quadrangle, Grant County, New Mexico: U.S. Geol. Survey Prof. 555, 144 p.

*Kelley, V. C., 1951, Oolitic iron deposits of New Mexico: Am. Assoc. Geologists Bull., v. 35, no. 10, p. 2199-2228.

*Kelley, V. C., and Branson, O. T., 1947, Shallow, high-temperature pegmatites, Grant County, New Mexico: Econ. Geology, v. 42, no. 8, p. 699-712.

*Kottlowski, F. E., 1963, Paleozoic and Mesozoic strata of southwestern and south-central New Mexico: New Mexico Bur. Mines and Mineral Resources Bull. 79, 100 p.

Kottlowski, F. E., and Kuellmer, F. J., 1953, Road log from Las Cruces to Silver City: New Mexico Geol. Soc. Guidebook, Southwestern New Mexico, 4th Field Conf., p. 29-63.

Krohn, D. H., 1969, Gravity survey of the Mogollon Plateau volcanic province, southwestern New Mexico: New Mexico Univ., Masters Thesis, 31 p.

*Kuellmer, F. J., 1954, Geologic section of the Black Range at Kingston, New Nexico: New Mexico Bur. and Mineral Resources Bull. 33, 100 p.

____1955, Geology of a disseminated copper deposit near Hillsboro: New Mexico Bur. and Mineral

Resources Circ. 34, 46 p.
____1956, Geologic map of Hillsboro Peak thirty-minute quadrangle: New Mexico Bur. Mines and Mineral Resources Geol. Map 1.
*Lambert, R. S., 1973, Geology of the country east of the Santa Rita mining district, Grant County, New Mexico—The San Lorenzo area: New Mexico Univ., Masters Thesis, 81 p.
*Laudon, L. R., and Bowsher, A. L., 1949, Mississippian formations of southwestern New Mexico: Geol. Soc. America Bull., v. 60, p. 1-87.
*Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., 1910, The ore deposits of New Mexico: U.S. Geol. Survey Prof. Paper 68, p. 260-276.
*McDowell, F. W., 1971, K-Ar ages of igneous rocks from the Western United States: Ischron/West, no. 2, p. 1-16.
*Moore, S. L., 1948, Preliminary geologic map of the Allie Canyon quadrangle, Grant County, New Mexico: U.S. Geol. Survey Open-file rept.
Pratt, W. P., and Jones, W. R., 1961, Montoya Dolomite and Fusselman Dolomite in Silver City region, New Mexico: Am. Assoc. Petroleum Geologists Bull. v. 45, p. 484-500.
*Ratté, J. C., and Gaskill, D. L., 1975, Reconnaissance geologic map of the Gila Wilderness study area, southwestern New Mexico: U.S. Geol. Survey Misc. Geol. Inv. Map I-886.
Reeves, C. C., Jr., 1963, Economic geology of a part of the Hillsboro, New Mexico, mining district: Econ. Geology, v. 58, p. 1278-1284.
*Segerstrom, Kenneth, and Antweiler, J. C., 1975, Placer gold deposits of the Las Animas district, Sierra County, New Mexico: U.S. Geol. Survey Open-file Rept. 75-206, 39 p.
*Soule, J. H., 1950, Investigation of the Royal John lead-zinc deposits, Grant County, New Mexico: U.S. Bur. Mines Rept. Inv. 4748, p. 1-8.
*Weissenborn, A. E., 1948, A new occurrence of helvite [New Mexico]: Am. Mineralogist, v. 33, nos. 9-10, p. 648-649.

Geochemistry

*Alminas, H. V., Watts, K. C., and Siems, D. L., 1972a, Maps showing lead distribution in the Winston and Chise quadrangles and in the west part of the Priest Tank quadrangle, Sierra County, New Mexico: U.S. Geol. Survey Misc. Field Studies Map MF-398.
*____1972b, Maps showing molybdenum distribution in the Winston and Chise quadrangles and in the west part of the Priest Tank quadrangles, Sierra County, New Mexico: U.S Geol. Survey Misc. Field Studies Map MF-399.
*____1972c, Maps showing silver and gold distribution in the Winston and Chise quadrangles and in the west part of the Priest Tank quadrangle, Sierra County, New Mexico: U.S. Geol. Survey Misc. Field Studies Map MF-400.
*____1972d, Maps showing tungsten distribution in the Winston and Chise quadrangles and in the west part of the Priest Tank quadrangle, Sierra County, New Mexico: U.S. Geol. Survey Misc. Field Studies Map MF-401.
*____1972e, Maps showing fluorite distribution in the Winston and Chise quadrangles and in the west part of the Priest Tank quadrangle, Sierra County, New Mexico: U.S. Geol. Survey Misc. Field Studies Map MF-402.
*____1973a,Maps showing barium distribution in the Winston and Chise quadrangles and in the west part of the Priest Tank quadrangle, Sierra County, New Mexico: U.S. Geol. Survey Misc. Field Studies Map MF-496.
*____1973b, Maps showing copper distribution in the Winston and Chise quadrangles and in the west part of the Priest Tank quadrangle, Sierra County, New Mexico: U.S. Geol. Survey Misc. Field Studies Map MF-498.
*____1973c, Maps showing tin distribution in the Winston and Chise quadrangles and in the west part of the Priest Tank quadrangle, Sierra County, New Mexico: U.S. Geol. Survey Misc. Field Studies Map MF-499.
*____1973d, Maps showing zinc and antimony distribution in the Winston and Chise quadrangles and in the west part of the Priest Tank quadrangle, Sierra County, New Mexico: U.S. Geol. Survey Misc. Field Studies Map MF-500.
*Alminas, H. V., Watts, K. C., Griffitts, W. R., Siems, D. L., Kraxberger, V. E., and Curry, K. J., 1975a, Map showing anomalous distribution of tungsten, fluorite, and silver in stream-sediment concentrates from the Sierra Cuchillo-Animas uplifts and adjacent areas, southwestern New Mexico: U. S. Geol. Survey Misc. Geol. Inv. Map I-880.
*____1975b, Map showing anomalous distribution of lead, tin, and bismuth in stream-sediment concentrates from the Sierra Cuchillo-Animas uplifts and adjacent areas, southwestern New Mexico: U.S. Geol. Survey Misc. Geol. Inv. Map I-882.
*____1975c, Map showing anomalous distribution of molybdenum, copper, and zinc in stream-sediment concentrates from the Sierra Cuchillo-Animas uplifts and adjacent areas, southwestern New Mexico: U.S. Geol. Survey Misc. Geol. Inv. Map I-882.
*Griffitts, W. R., and Alminas, H. V., 1968, Geochemical evidence for possible concealed mineral deposits near the Monticello Box, north Sierra Cuchillo, Socorro County, New Mexico: U.S. Geol. Survey Circ. 600, 13 p.
*Griffitts, W. R., Alminas, H. V., and Mosier, E. L., 1972a, Zinc and antimony distribution in the Monticello and Sierra Fijardo 7-1/2-minute quadrangles, Socorro and Sierra Counties, New Mexico: U.S. Geol. Survey Open-file rept.
*____1972b, Niobium and gold distribution in the Monticello and Sierra Fijardo 7-1/2-minute quadrangles, Socorro and Sierra Counties, New Mexico: U.S. Geol. Survey Open-file rept.
*____1972c, Strontium distribution in the Monticello and Sierra Fijardo 7-1/2-minute quadrangles, Socorro and Sierra Counties, New Mexico: U.S. Geol. Survey Open-file rept.
*____1972d, Tin distribution in the Monticello and Sierra Fijardo 7-1/2-minute quadrangles, Socorro and Sierra Counties, New Mexico: U.S. Geol. Survey Open-file rept.
*____1972e, Lead distribution in the Monticello and

Sierra Fijardo 7-1/2-minute quadrangles, Socorro and Sierra Counties, New Mexico, U.S. Geol. Survey Open-file rept.

* ____1972f, Lanthanum and silver distribution in the Monticello and Sierra Fijardo 7-1/2-minute quadrangles, Socorro and Sierra Counties, New Mexico: U.S. Geol. Survey Open-file rept.

Harley, G.. T., 1934, The geology and ore deposits of Sierra County, New Mexico: New Mexico Bur. Mines and Mineral Resources Bull. 10, 220 p.

Hedlund, D. C., 1975a, Geologic map of Hillsboro quadrangle, Sierra and Grant Counties, New Mexico: U.S. Geol. Survey Open-file Rept. 75-108.

____1975b, Geologic map of San Lorenzo quadrangle, Grant and Sierra Counties, New Mexico: U.S. Geol. Survey Open-file Rept. 75-109.

Kuellmer, F. J., 1955, Geology of a disseminated copper deposit near Hillsboro, Sierra County, New Mexico: New Mexico Bur. Mines and Mineral Resources Circ. 34, 46 p.

____compiler, 1956, Geologic map of Hillsboro Peak 30-minute quadrangle: New Mexico Bur. Mines and Mineral Resources Geol. Map 1.

U.S. Geological Survey, 1974, Aeromagnetic map of parts of Silver City and Las Cruces 1° and 2° quadrangles, southwestern New Mexico: U.S. Geol. Survey Open-file rept., scale 1:250,000.

Watts, K. C., Alminas, H. V., and Kraxberger, V. E., 1978, Map showing areas of detrital fluorite and cassiterite and the localities of rock samples, Hillsboro and San Lorenzo quadrangles, exclusive of the Black Range Primitive area, Sierra and Grant Counties, New Mexico: U.S. Geol. Survey Misc. Field Studies Map MF-900-H.

Geophysics

*Bhattacharyya, B. K., and Chan, K. C., 1977, Reduction of magnetic and gravity data on arbitrary surfaces acquired in a region of high topographic relief: Geophysics, v. 42, p. 1411-1430.

*Cordell, L., and Henderson, R. G., 1968, Iterative three-dimensional solution of gravity anomaly data using a digital computer: Geophysics, v. 33, no. 4, p. 596-601.

*Elston, W. E., Seager, W. R., and Clemons, R. E., 1975, Emory Cauldron, Black Range, New Mexico, source of the Kneeling Nun Tuff: New Mexico Geol. Soc. Guidebook, 26th Field Conf., p. 283-292.

*Ericksen, G. E., Wedow, Helmuth, Jr., Eaton, G. P., and Leland, G. R., 1970, Mineral resources of the Black Range Primitive area, Grant, Sierra, and Catron Counties, New Mexico: U.S. Geol. Survey Bull. 1319-E, p. E1-E162.

*Hedlund, D. C., 1975a, Geologic map of the Hillsboro quadrangle, Sierra and Grant Counties, New Mexico: S. Geol. Survey Open-file Rept. 75-108.

* ____1975b, Geologic map of the San Lorenzo quadrangle, Grant and Sierra Counties, New Mexico: U.S. Geol. Survey Open-file Rept. 75-109.

*Ramberg, I. B., and Smithson, S. B., 1975, Gridded fault patterns in a late Cenozoic and Paleozoic continental rift: Geology, v. 3, p. 201-205.

*U.S. Geological Survey, 1974, Aeromagnetic map of parts of the Silver City and Las Cruces 1° and 2° quadrangles, southwestern New Mexico: U.S. Geol. Survey Open-file rept., scale 1:250,000.

*Watts, K. C., Alminas, H. V., and Kraxberger, V. E., 1976, Map showing areas of detrital fluorite and cassiterite and the localities of rock samples, Hillsboro and San Lorenzo quadrangles, exclusive of Black Range Primitive area, Sierra and Grant Counties, New Mexico: U.S. Geol. Survey Misc. Field Studies Map MF-900H.

*Watts, K. C., Alminas, H. V., Nishi, J. M., and Crim, W. C., 1976, Map showing anomalous tungsten and gold distribution in the sediment concentrates, Hillsboro and San Lorenzo quadrangles exclusive of the Black Range Primitive area, Sierra and Grant Counties, New Mexico: U.S. Geol. Survey Misc. Field Studies Map MF-900I.

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