DEPARTMENT OF THE INTERIOR

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Geology and mineral deposits of the Steeple Rock and Duncan mining districts, Grant and Hidalgo Counties, New Mexico, and Greenlee County, Arizona

By

D.C. Hedlund[1]

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[1]Denver, Colorado

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LOCATION

The Steeple Rock and Duncan mining districts (fig. 1) are in the Summit Mountains of New Mexico and adjoining Arizona, about 50 miles west of Silver City, about 40 miles northwest of Lordsburg, New Mexico, and a few miles east and northeast of Duncan, Arizona. The present study is part of a mapping program of about 450 mi^2, comprising six 7 1/2′ quadrangles (Goat Camp Spring and Tillie Hall Peak, Arizona-New Mexico, and Crookson Peak, Steeple Rock, Applegate Mountain, and Walker Canyon, New Mexico) and composited parts of two other 7 1/2′ quadrangles (Canador Peak and Nichols Canyon, New Mexico) and the 15′ Canador Peak quadrangle. The mapped area is largely within the Summit Mountains but extends as far south as the Lower Box of the Gila River. This region is within the southwestern part of the Mogollon-Datil volcanic field.

Access to the Summit Mountains is chiefly by county, ranch, and mine roads from several directions. The Steeple Rock district can be reached by a gravel road that turns east from Arizona Highway 75 about 0.5 mi north of the junction of Highway 75 and the Virden turn-off. To the north, the Bitter Creek-Twin Peaks area is reached by a gravel road that turns east from Arizona Highway 75 just north of the Bitter Creek bridge, and about 10 mi north of Duncan on the Clifton highway. Access to the northwestern part of the Steeple Rock quadrangle and the Brushy Mountain-Tillie Hall Peak areas is by a gravel road that leads south from Mule Creek to the radar sites on Brushy Mountain and to the Old Ranch near Bircher Flats. Access to the northeastern part of the Steeple Rock quadrangle and the Sycamore Creek area is by way of the McCauley ranch road that extends westward from New Mexico Highway 260 about 1 mi south of Riverside, New Mexico. To the south, Canador Peak, Black Mountain, and parts of the Lower Box of the Gila River can be reached by a poorly maintained road that extends eastward from New Mexico Highway 92 a few miles southeast of Virden, New Mexico. The Fisherman Point overlook on the south of the Gila River is accessible by means of a gravel road that extends east of New Mexico Highway 70 about 15 mi southeast of Duncan, Arizona.

PHYSIOGRAPHY

The mapped area is in the transition area between the Basin and Range and Colorado Plateau structural provinces. Much of this area consists of gently northeastward-dipping andesitic, basaltic, and dacitic lava flows, intercalated with ash-flow tuffs and volcaniclastic rocks that are a part of the Mogollon-Datil volcanic field. The northwestern part of the area is characterized by low mountains, the Summit and Big Lue Mountains, that have been deeply incised by canyons such as along the Gila and San Francisco Rivers and along Bitter Creek. The southwestern part consists of piedmont slope deposits with a generally subdued, open, and rolling terrain that developed on the basin-fill deposits of the Gila Group and on highly eroded lava flows. A series of cuestas formed by the erosion of gently west-northwest-striking ash-flow tuffs in the Mud Springs and Riley Peaks areas dominate the south-central part of the region. To the northeast the highly incised and radially dissected lava flows of the Brushy Mountain volcanic center form a rolling, bouldery, grassy upland surface. The principal topographic features and their elevations are as follows: Steeple Rock (6,259 ft), Vanderbilt Peak (6,773 ft), Brushy Mountain (7,620 ft), Summit Peak (6,555 ft), Crookson Peak (6,746 ft), Canador Peak (4,782 ft), Saddleback Mountain (6,395 ft), Tillie Hall Peak (7,318 ft), and Hells Hole Peak (6,952 ft).

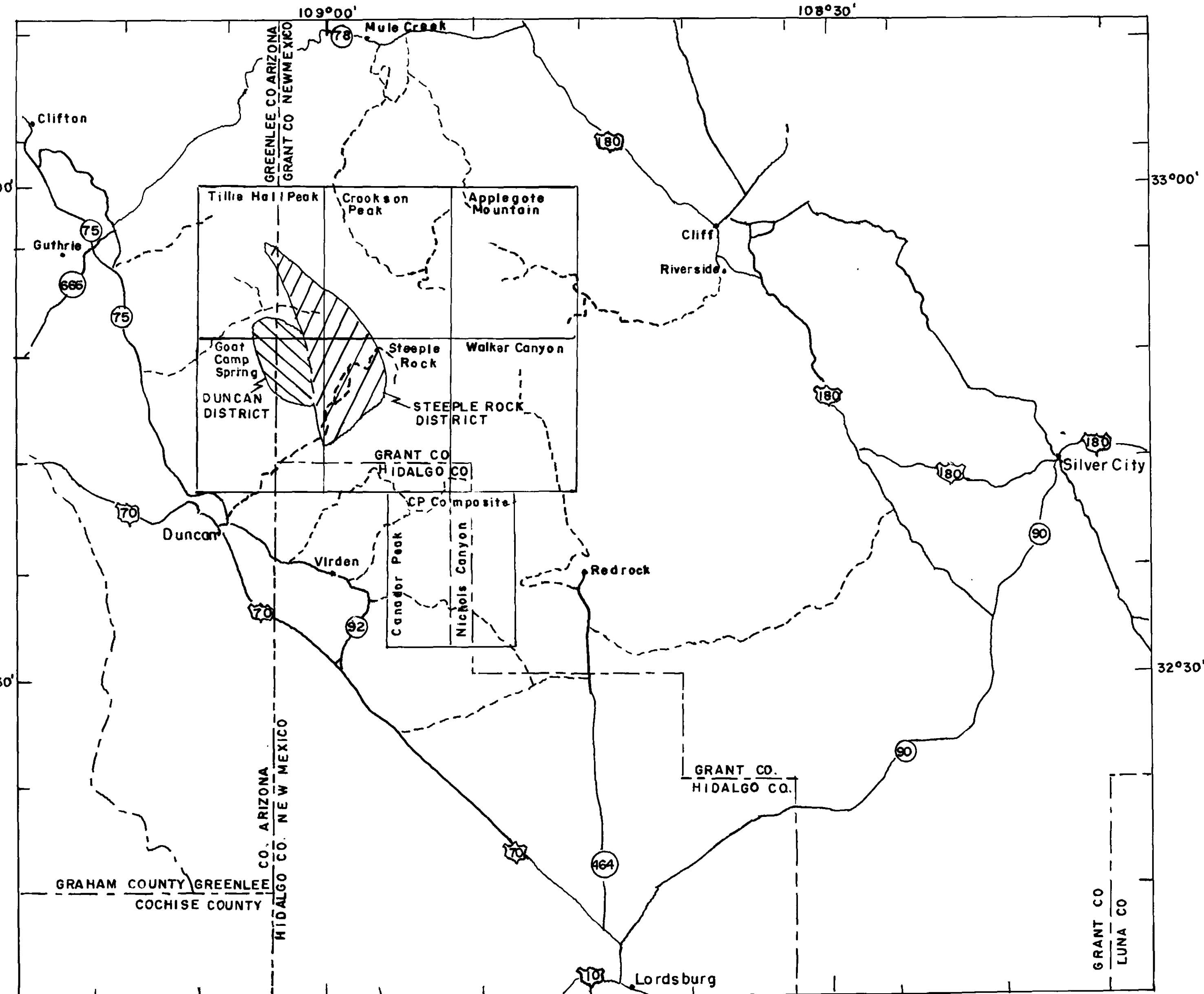

Fig. 1 -- Index map showing location of the Steeple Rock and Duncan mining districts, New Mexico and Arizona, and the recently mapped areas, principal roads, and towns.

PREVIOUS STUDIES

Most published reports on the geology of the Summit Mountains are detailed descriptions of the precious metal mineral deposits of the Steeple Rock district. It has only been in recent years, from 1974 to the present, that geologic maps of the region have become available. Many of these publications have been theses, e.g. Wargo (1959), Biggerstaff (1974), Powers (1976), and Wahl (1980). Along the northern margin of the mapped area, Ratté and Hedlund (1981) have described the geology of the Hells Hole RARE II Planning Area, and Ratté and Brooks (1983) have mapped the Mule Creek quadrangle and the Bear Mountain quadrangle (Brooks and Ratté, 1985) as part of their regional studies in the Clifton $1^{o}x2^{o}$ quadrangle. Finnell (1987) mapped the adjoining Cliff 15′ quadrangle as a part of the regional Silver City $1^{o}x2^{o}$ CUSMAP project. Elston (1960) prepared a reconnaissance geologic map of the Virden 30′ quadrangle as part of a study for the New Mexico Bureau of Mines and Mineral Resources. Richter and others (1983) have mapped the geology of the Guthrie 15′ quadrangle to the west of Duncan. The geology of the Duncan-Canador Peak 15′ quadrangles, with emphasis on the surficial deposits, has been described by Morrison (1965). Recent 1:24,000 scale geologic mapping by the author includes the Applegate Mountain, Crookson Peak, Steeple Rock (Hedlund, 1990), Walker Canyon, and parts of the Canador Peak and Nichols Canyon 7 1/2′ quadrangles, New Mexico, and the Goat Camp Spring and Tillie Hall Peak 7 1/2′ quadrangles, Arizona and New Mexico.

The ore deposits of the Steeple Rock mining district were first described by Graton (1910). In the early 1940′s the U.S. Geological Survey in collaboration with the U.S. Bureau of Mines conducted a thorough study of the Carlisle group of mines in the Steeple Rock district with underground and surface drilling programs, mine mapping, and detailed geologic mapping of the immediate area. The results of this joint study were published by the U.S. Geological Survey (Griggs and Wagner, 1966) and the U.S. Bureau of Mines (Johnson, 1943; Russell, 1947).

GEOLOGY

A highly diverse series of Miocene and Oligocene volcanic rocks, as much as 8,000 ft (2,440 m) thick, represents multiple volcanic eruptive sequences. The volcanic section overlies an early Tertiary-Upper Cretaceous volcaniclastic sequence that is as much as 1,800 ft (540 m) thick and a still older faulted block, consisting of Upper Cretaceous Colorado Formation and Beartooth Quartzite resting unconformably upon Precambrian granite, in the vicinity of Riley Peaks and Mud Springs.

Several source areas are considered for the volcanic rocks with ash-flow tuffs of Late Oligocene age (28, 29 m.y.) from the Bursum caldera being identified in the area, e.g. the Bloodgood Canyon and Davis Canyon tuffs (Ratté and Gaskill, 1975; Rhodes, 1976; and Ratté and others, 1982). The Fall Canyon Tuff (31.4 m.y.) has also been tentatively recognized in the area and may also be a distal outcrop from the Bursum caldera which is about 40-48 km to the north-northeast. To the east in the Walker Canyon quadrangle within the Redrock Basin the volcanic stratigraphy is complex and contains ash-flow tuff units that may be outflow sheets from the Schoolhouse Mountain volcanic caldera. This caldera was first proposed by Wahl (1980) for the thick ash-flow sections in the vicinity of Cliff, New Mexico. The volcanic rocks in the Redrock Basin area are structurally separated from the mid-Tertiary volcanic rocks of the Summit Mountain and Canador Peak areas by several major faults,

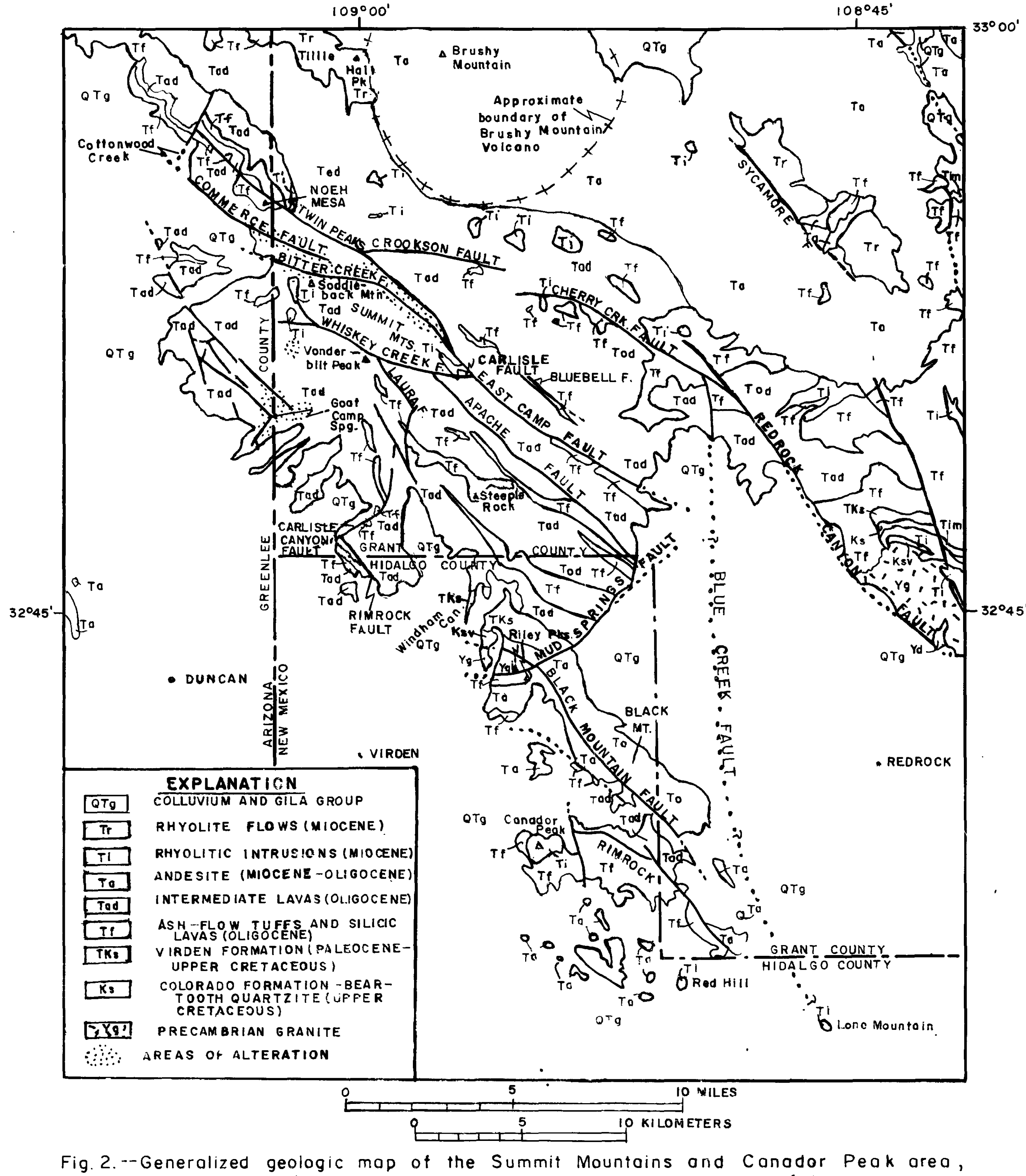

Fig. 2.--Generalized geologic map of the Summit Mountains and Canador Peak area, Grant and Hidalgo Counties, New Mexico and Greenlee County, Arizona

such as the Blue Creek and Red Rock Canyon faults (fig. 2). The map of the Cliff quadrangle (Finnell, 1987) indicates that the Tuff of Mangas Creek intertongues with the Tuff of Redrock Basin and both formations underlie the Cherokee Creek Formation. The ash-flow tuffs in the vicinity of Mud Springs Peak have an uncertain source, have ages ranging from 32-34 m.y., and show interlensing with the andesitic flows of Mud Springs Peak. Some of these ash-flow tuffs may be distal outflow sheets from the Emory caldera in the Black Range, especially since they have ages of 32 to 34 m.y. that are nearly coeval with those of the Kneeling Nun Tuff (34.9 m.y.).[1] Volcaniclastic rocks are present as thin units within the ash-flow sequences and probably represent unconformities of short duration between eruptions.

A younger Miocene volcanic eruptive series is represented by the andesitic lavas of the Brushy Mountain volcano (23.7 and 25.6 m.y.) that correlate with the Bearwallow Mountain Andesite (Marvin and others, 1987) and by the overlying rhyolitic flows of Sycamore Camp (21.3 m.y.) (Finnell, 1987) and Mule Creek (18-19 m.y.) (Marvin and others, 1987). Many of the rhyolite plugs and tuff rings in the Applegate Mountain quadrangle probably correlate with this later rhyolitic eruptive sequence. Some rhyolite domes, such as that of the Hells Hole complex, are coextensive with the Rhyolite of Tillie Hall Peak and are 24-27 m.y. or Late Oligocene in age (Ratté and Brooks, 1983).

The older volcanic sequences of andesitic flows with associated breccias are especially well represented south of Mud Springs and near Mount Royal. Volcaniclastic sandstones of probable Late Cretaceous and (or) Paleocene age are represented by the Virden Formation that locally contains abundant fossil plants and whose uppermost breccias contain boulders of Precambrian granite.

Precambrian granite

Small outcrops, about 1 mi^2, of coarse-grained Proterozoic Y granite in the Riley Peaks area of the Canador Peak 15′ quadrangle have similarities to the Granite of Burro Mountains ($1,450 \pm 50$ m.y.). The granite is highly reddened and is a typical two-feldspar granite with minor amounts of biotite.

Upper Cretaceous sedimentary rocks

The Beartooth Quartzite is about 120 ft (36 m) thick in the Canador Peak 15′ quadrangle and rests unconformably on the Precambrian granite in the vicinity of Riley Peaks. The fault slices of Beartooth Quartzite are characterized by tightly cemented quartzose sandstone beds that dip 25° NE.

The Colorado Formation of Upper Cretaceous age (Late Cenomanian through early Turonian) is about 800 ft (240 m) thick in the Riley Peaks area where it rests conformably on the Beartooth Quartzite. The Colorado Formation consists of greenish-gray siltstone, mudstone, thin beds of light-brown sandstone, and gray shales with limestone concretions--all of shallow marine origin. Cobban, Hook, and Kennedy (1989) have described in detail the ammonite assemblage that chiefly occurs in the limestone concretions. Near the rhyolite plugs of Riley

[1]McIntosh, W.C., Chapin, C.E., Ratté, J.C., and Sutter, J.F., Ages and distribution of ignimbrites in the Mogollon-Datil volcanic field, southwest New Mexico: Stratigraphic framework using $^{40}Ar/^{39}Ar$ dating and paleomagnetism: in preparation for proposed publication in a Geological Society of America Bulletin.

Peaks the shale of the Colorado Formation is thermally metamorphosed to spotted chlorite mudstone with disseminated magnetite granules.

Lower Tertiary-Upper Cretaceous sedimentary rocks

The Virden Formation (Elston, 1960) consists of fluviatile sandstone, siltstone, and conglomerate beds that crop out along the Mud Springs Ranch road near Riley Peaks. The upper part of the Virden Formation consists of a bouldery conglomerate with coarse blocks of Precambrian granite. The middle and lower parts of the formation contain abundant fossil wood with some tree trunks still in place. This fossil wood has been identified and dated by J.A. Wolfe of the U.S. Geological Survey and by Pradhan and Singh (1960) as being Lance-Montanan age.

Oligocene volcanic rocks and volcaniclastics

The principal volcanic formations can be best summarized in generalized stratigraphic sections (fig. 3). In a region of intensive block faulting the recognition of repeated volcanic units, such as the Bloodgood Canyon Tuff, has proved essential to unravelling the geologic structure in this region. From Late to Early Oligocene the principal formations are as follows:

- Bearwallow Mountain Andesite (Miocene and Oligocene)
- Coarsely porphyritic andesite lava flows ("Turkey Track")
- Lava flows of Crookson Peak
- Andesitic lava flows and volcaniclastic rocks of Pine Cienega Creek
- Rhyolite of Hells Hole (Rhyolite of Tillie Hall Peak)
- Andesitic and basaltic rocks of Dark Thunder Canyon (include interlayered silicic tuff units)
- Latitic flows of Apache Creek
- Andesitic flows of Copper Basin
- Bloodgood Canyon and Davis Canyon ash-flow tuffs (28.2, 29.0 m.y.)
- Dacitic flows of Summit Mountain (31, 32 m.y.)
- Ash-flow tuffs of the Mud Springs area (32, 34 m.y.)
- Andesite, andesitic breccia, sandstone, and basaltic andesite of Mud Springs Peaks

To the east in the Walker Canyon quadrangle and within the Redrock Basin the volcanic stratigraphy is different and more complex as the area has volcanic units that may be outflow sheets from the Schoolhouse Mountain (Cliff) volcanic center. As stated, this assemblage is separated from the Summit Mountain volcanic section by several major faults, such as the Blue Creek and Redrock Canyon faults. From youngest to oldest the principal volcanic formations in the Redrock Basin area are as follows:

- Bearwallow Mountain Andesite (Miocene and Oligocene)
- Latite of Anderson Ranch
- Dacite porphyry of Anderson Ranch
- Rhyolite intrusive-extrusive dome of Redrock Basin
- Ash-flow tuff of Redrock Basin
- Andesite porphyry, latite, and sandstone of Redrock Canyon
- Ash-flow tuff, air-fall tuff, and sandstone of Redrock Canyon (34 m.y.)
- Andesite and rhyolite of Redrock Canyon

The ash-flow tuff of Redrock Basin is intercalated with the Tuff of Mangas Creek in the Cliff quadrangle and has a thickness of about 1,500 ft (457 m) (Finnell, 1987).

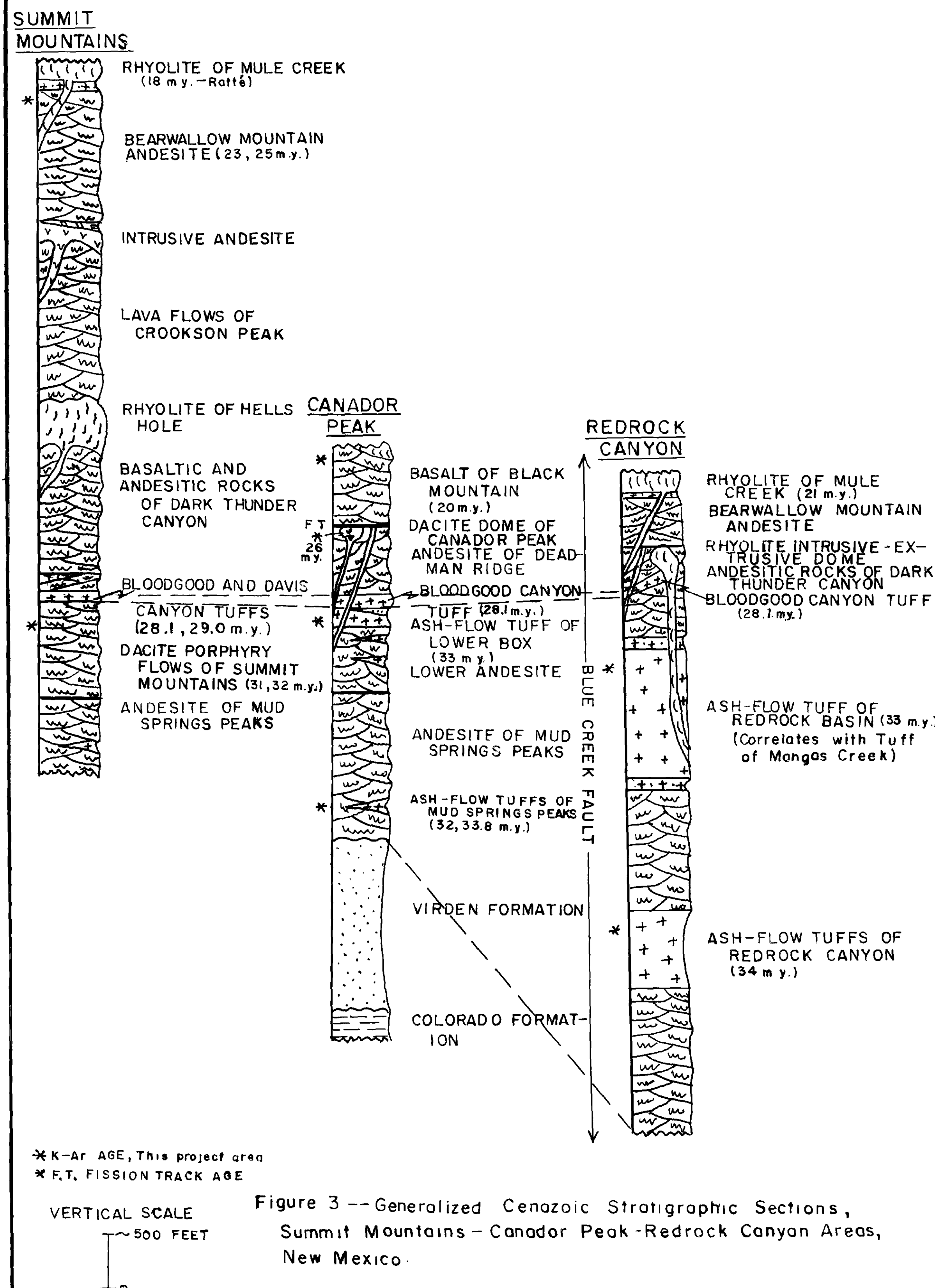

Figure 3 -- Generalized Cenozoic Stratigraphic Sections, Summit Mountains – Canador Peak - Redrock Canyon Areas, New Mexico.

To summarize, multiple sources are considered for the Oligocene volcanic units. The Brushy Mountain andesitic volcano and its extrusive equivalents are Miocene-Oligocene in age (23-25 m.y.) and correlate with the Bearwallow Mountain Andesite (Marvin and others, 1987). The Bursum caldera area in the Mogollon Mountains has been identified as the source of the Bloodgood Canyon, Davis Canyon, and possibly the Fall Canyon ash-flow tuffs as mapped in the Steeple Rock region (Ratté and Gaskill, 1975, and Rhodes, 1976, first identified the Bursum caldera). These widespread ash-flow tuffs underlie the andesitic flows and intercalated silicic tuffs of Dark Thunder Canyon. The ash-flow tuffs in the Mud Springs Peak area probably had their source to the south or southeast, especially since these tuffs thicken to the southeast with greater interlensing of lava flows to the west-northwest.

Oligocene intrusions

The dacite porphyry plug of Canador Peak (34.4±2.2 m.y. from hornblende--Marvin, written commun., 1981), the andesite porphyry intrusion of Horse Camp Peak (about 32 m.y.), and the rhyodacite dome of the Imperial mine area (about 32 m.y.) are all early to mid-Oligocene intrusions of calc-alkaline affinity in the south-central part of the mapped area. Elsewhere, to the northwest, the intrusive andesite of Tillie Hall Canyon is of Miocene to late Oligocene age (about 24 m.y.) and forms a small stock about 4 mi^2 (10 km^2) mainly east of Tillie Hall Canyon (Ratté and Hedlund, 1981; Marvin and others, 1987).

The intrusive-extrusive rhyolite dome complex of Hells Hole is about 27-28 m.y. (Marvin and others, 1987) and is coextensive with the rhyolite of Tillie Hall Mountain. The rhyolite dome complex of Hells Hole is exposed over an area of about 30 mi^2 (75 km^2). The highly eroded intrusive-extrusive dome of Redrock Basin in the Walker Canyon quadrangle is about 32 m.y. in age and is characterized by several erosional windows. Several small rhyolitic plugs in the Tillie Hall Peak quadrangle intrude the dacite porphyry flows of Summit Mountain (about 32 m.y.) and are locally slightly alunitized; this suggests a mid-Tertiary age for these intrusions.

Miocene volcanic rocks

The andesitic lava flows (Bearwallow Mountain Andesite) of the Brushy Mountain volcano are 23-26 m.y. in age or Miocene-Oligocene. The center of the volcano is near Old Basin and is about 5-7 mi across. In many areas the andesitic lavas are underlain by the dacite flows of Crookson Peak or by the coarsely porphyritic "turkey track" andesite. The Bearwallow Mountain Andesite is locally intruded by rhyolite plugs and dikes and by rhyolite flows of the Sycamore Camp Formation (21.3 m.y.) (Finnell, 1987) in the Applegate Mountain quadrangle. To the northwest in the Mule Creek region the Bearwallow Mountain Andesite is overlain by rhyolite flows and pyroclastics of the Rhyolite of Mule Creek (18 m.y.; Marvin and others, 1987).

Miocene intrusions

The numerous high-silica intrusions of Miocene age (18-21 m.y.) are represented by the numerous rhyolite dike swarms and plugs in the Steeple Rock quadrangle where the intrusions strike northwest. Locally the dikes expand into elongate plugs such as those south of Vanderbilt Peak, on Pinon Mountain, and Telephone Ridge. A quartz monzonite dike (21.4 m.y.) in the Walker Canyon quadrangle is as much as 5 mi (8 km) long and 100 ft (30 m) wide. The rhyolite plugs and tuff rings of the Crookson Peak, Steeple Rock, and Applegate Mountain quadrangles are of Miocene age and include the intrusions of Deer Peak, Apache Box, Cherry Creek, Sycamore Camp, and at Mathews Place along Blue Creek. Many of these plugs have partial to complete tuff rings that dip inward toward a central intrusion; in places the tuff rings contain abundant fragments of the surrounding wall rocks.

Late Tertiary-Quaternary basin-fill deposits

These sediments, though poorly indurated, consist of coarse rhyolitic sedimentary breccias and fanglomerate east of Black Hill, and less consolidated silty and sandy rocks with intercalated pebbly sands, lacustrine clays, and cherty diatomite beds elsewhere. A zeolitized (clinoptilolite) tuff bed is present in the upper part of the Gila Group at the Willis Ranch. This tuff bed has been correlated with the Lava Creek B Ash (620,000 years) by Izett and Wilcox (1982).

The Red Hill and Lone Mountain plugs in the Canador Peak 15′ quadrangle (Hidalgo County) may be Pliocene-Miocene age as they appear to intrude the Gila Group. Rhyolitic intrusions and flows(?) of this age probably account for the numerous rhyolitic clasts within the lower part of the Gila Group just east of Black Hill.

Structure

The south-central part of the Summit Mountain region is characterized by gently northeast dipping (10^{o}-15^{o}), and west-northwest-striking ash-flow tuffs and lavas. The series of cuestas formed from the erosion of this volcanic section dominates the Steeple Rock area.

Faults of two major regional systems can be recognized within the mapped area (fig. 2): (1) Older Laramide faults define a small wedge of uplifted Precambrian granite and Upper Cretaceous strata near the Riley Peaks in the Canador Peak 15′ quadrangle. These faults, the Black Mountain and Mud Springs, were active in post-Lance-Montana time as shown by the coarse Precambrian granite clasts in the upper part of the Virden Formation. Other Laramide faults are not as well exposed and most probably are concealed by the mid-Tertiary volcanic section. (2) Strong west-northwest-striking faults of Miocene age (probably 17-21 m.y.) include the East Camp, Apache, Bluebell, Laura, Twin Peaks, Bitter Creek, Whiskey Creek, Commerce, Rimrock, and Carlisle Canyon faults. Two of the most prominent Miocene faults are the East Camp and Apache faults. Both of these faults have displaced the Bloodgood Canyon Tuff such that the aggregate displacement of this ash-flow tuff unit is as much as 1,400 ft (420 m). The East Camp fault can be traced from Blue Creek on the southeast to Cottonwood Creek on the northwest, a distance of about 18 mi (29 km). The East Camp fault splits near the head of Bitter Creek where the splayed northeast segment joins the Twin Peaks fault and southwest segment becomes the Bitter Creek fault near the Chapman Place (Crookson Peak quadrangle). The Carlisle fault is a cross or conjugate fault that joins the East Camp fault with the Whiskey Creek-Apache fault system. The largest base- and precious-metal vein deposits are localized along the East Camp and Carlisle faults (fig. 2). The Carlisle Canyon fault is a curvilinear east-northeast- to northeast-striking fault that is displaced by a northwest-striking fault near the Mount Royal mine; this offset of the Carlisle Canyon fault is suggestive of a ring fault along the west margin of the Steeple Rock quadrangle. In places rhyolite dikes (18-21 m.y.) are coextensive with the major faults, e.g. the Bluebell, East Camp, and Apache faults. Most faults are steeply dipping, 80^{o}-90^{o}, and some are highly splayed and slivered, e.g. the East Camp and Apache faults. The direction of throw is not consistent, e.g. the northeast block of the East Camp fault is downthrown, whereas the northeast block of the Apache fault is upthrown.

The Redrock Canyon fault in the Walker Canyon quadrangle is a branching north-northwest- to northwest-striking fault that terminates the Blue Creek fault and lineament. Except at the north end, the Blue Creek fault is located on the basis of ERTS satellite imagery and aeromagnetic data; ground-based mapping is not effective in locating most parts of this concealed fault. The Blue Creek fault separates the volcanic sequence of the Cliff 15′ quadrangle from the volcanic series of the Steeple Rock-Summit Mountain area.

Recurrent movement has occurred on some of the Miocene faults such that sediments of the Gila Group are displaced, e.g. the Commerce fault in the Tillie Hall Peak quadrangle. Other displacements of the Gila Group can be observed in the York Valley area to the northwest and just north of Duncan.

Alteration

Altered volcanic and intrusive rocks are common in the Steeple Rock-Bitter Creek-Goat Camp Spring (Duncan fluorspar district) areas (fig. 2) and include a mid-Tertiary (31-32 m.y.) solfataric or fumarolic type of alteration that is essentially synchronous with the extrusion of the lava flows and a younger (18-21 m.y.) more limited propylitic and sericitic-silicic alteration that is largely fault controlled. This latter type of alteration will be considered under vein formation.

The solfataric alteration of the dacitic to andesitic flows, intercalated volcaniclastic beds, and diverse rhyolitic intrusions is characterized by extreme bleaching; the formation of limonitic Liesegang banding; the development of alunite, sericite, and minor clay minerals; an increase in density of the alunitized rock; and the localized introduction of silica as cristobalite or chalcedony. In the Bitter Creek area, alunite is locally abundant (29-30 percent), especially near Saddleback Mountain, and Hall (1978) has estimated an alunite resource of as much as 55 million tons. The alunite-quartz rock at the west end of Saddleback Mountain has yielded a K/Ar age of 31.3 ± 1.1 m.y. (R.F. Marvin, R.B. Hall, and J.C. Ratté, written commun., 1984). The volcaniclastic beds that are intercalated within the dacitic flows of the Bitter Creek area are especially susceptible to alteration and are locally altered beyond recognition. In some areas the alteration is confined to the volcaniclastic rocks and the enclosing dacitic flows are largely unaltered. This feature suggests that the porosity and permeability of the volcaniclastic strata were factors in the alteration.

In the Goat Camp Spring area, sericite and clay minerals are far more abundant and alunite is present in only very minor amounts. A brecciated, siliceous caprock is especially well developed just north of Goat Camp Spring in the SE1/4 sec. 10, T. 7 S., R. 32 E. This siliceous capping on dacite flows is highly fractured and pervaded by manganese oxide veins. Other silicic caprocks are found in sec. 16, T. 17 S., R. 21 W. and probably represent silicified rhyolite sills and plugs. The argillized and silicified dacitic flows in the vicinity of Goat Camp Spring are highly faulted and intruded by rhyolite porphyry dikes; many of the dikes, of probable Miocene age, are also altered to sericite and carbonates, but this later alteration is probably related to fluorite vein formation. Thus two stages of alteration are present in the Goat Camp Spring area: an earlier widespread and locally intensive solfataric alteration and a later sericitic type of alteration related to Miocene faulting, rhyolite dike intrusion, and fluorite vein formation about 18-21 m.y. ago.

MINING DISTRICTS, MINES, AND MINERALIZATION

Steeple Rock district

The Steeple Rock district was first prospected in 1860, but the first period of significant mining began in 1880 and lasted until 1897, during which most of the gold and silver production came from the Carlisle mine. The second period of activity began in 1932 following a rise in the price of gold. Between 1932 and 1957, 34,377 oz of gold and 1,447,114 oz of silver were produced from the district, much of which came from the East Camp group of mines (table 1). The gold mines were closed in 1942 by governmental order and mining activity then turned to the mining of copper, lead, and zinc ores at the Carlisle mine. The Carlisle mine was closed in 1946 and the Steeple Rock district was virtually dormant until the price of gold and silver rose dramatically from 1967 through the 1980's. The most recent activity has been the short-lived, high-grade mining operations at the Center, Summit, East Camp, Gold King, Imperial, and Jim Crow mines from 1978 through 1989. Various intermittent attempts at heap leaching for gold were undertaken at the East Camp mine during the period of this study. The Center mine has been the chief producer of silver in the Steeple Rock district and at various times in the late 1980's has been the third ranked silver producer, after the Tyrone and Ortiz mines, in New Mexico. A summation of the exploration, mining activity, and production figures are shown in tables 1 and 2.

Although most gold and silver production came from the part of the Steeple Rock district that included the Carlisle-East Camp-Mount Royal group of mines, there are various outlying subdistricts such as the Bitter Creek, Twin Peaks, and Mayflower that also produced minor amounts of gold, silver, and fluorspar. The Duncan district is recognized as a separate mining district with chiefly fluorspar deposits (fig. 4).

Base and Precious Metal Veins

There are at least four vein types in the Steeple Rock district that can be characterized as follows (veins can be identified by mines shown on figure 4):

1. Thick, massive to vuggy to brecciated quartz veins that are localized along faults. Drusy, crustiform vugs are locally filled with sulfides and precious metals. Recurrent fault movement may have caused some of the brecciation as well as late-stage boiling and flashing of a shallow hydrothermal system. Example, the Carlisle-Center-Pennsylvania vein.
2. Silicified "blow-out" brecciated vein system that is commonly localized along the margins of rhyolite dikes. Rhyolite dike fragments are common. Example, the New Years Gift-Jumbo veins.
3. Veins within intensively silicified volcanic rock that are characterized by anastomosing quartz veins along branching faults. Some brecciation with slabby rock fragments is generally present. Example, the Billali-Mohawk vein.
4. Reddish-brown, hematite-stained breccias with locally abundant manganese oxides and calcite. Silicified volcanic rock fragments are common. Example, Jim Crow-Imperial-Mount Royal veins.

Table 1.--A chronological summary of exploration and mining activity in the Steeple Rock and Duncan mining districts

[N.A. = Not available]

Period	Activity	Company or governmental agency	Production
	Precious- and base-metal deposits		
1880-1897	Carlisle Mine-Golden Leaf Mining Co., Steeple Rock Development Co., and Laura Consolidated Co.	Carlisle Gold	$5,000,000 of silver.
1914-1936	Jim Crow-Imperial Mines: mining.	N.A.	$98,000 precious metals.
1914-1939	Mount Royal Mine: mining	N.A.	N.A.
1914-1942	Laura Mine: mining	N.A.	N.A.
1919-1921	Norman King, Bilalli, Hoover Tunnel mines.	N.A.	$63,200 precious metals.
1927	Black Willow Mine	N.A.	N.A.
1927	Carlisle Mine: no ore mined; 3 drill holes.	United Metals Corp.	N.A.
1933-1942	East Camp Group of mines: mining.	East Camp Exploration Syndicate.	$1,400,000 precious metals.
1936	Carlisle Group: drilling	Cactus Mining Co.	Nil
1942-1945	East Camp Group	East Camp Exploration Co.	21,500 tons of ore.
1942-1946	Carlisle Group - mining	Carlisle Development Co.	Base metals mined
1943-1944	Carlisle Group - 14 drill holes (8 underground and 6 from surface).	U.S. Geological Survey and U.S. Bureau of Mines.	
1954	Bitter Creek drill hole (SW1/4SE1/4 sec. 20, T. 16 S., R. 21 W.; 2,447 ft, 746 m deep.	Kennecott Co.	Nil
1959, 1960	Carnation Mine: drilling		Nil

Table 1.--A chronological summary of exploration and mining activity in the Steeple Rock and Duncan mining districts--Continued

Period	Activity	Company or governmental agency	Production
	Precious- and base-metal deposits--Continued		
1965	East Camp vein - drilling, 5 holes.	Banner Mining Co.	Nil
1973	East Camp Group - mining and heap leaching.	Mount Royal Mining Co.	Nil
1973	Twin Peaks Mines - drilling (2,000 ft of coring)	Mineral Economics Corp. and Fraser-Martin Mines, Inc.	Nil
1970-1974	Mount Royal Mine: mining		N.A.
1975-1977	Summit and Center Mines	D. Hansen and Dresser Industries.	Nil
1977-1979	Center Mine: mining and 5 drill holes.	Dresser Industries Inc.	At least 10,000 tons of ore.
1978, 1979	Bank and Laura mines: rehabilitated in 1978.	Douglas Hansen	N.A.
1978-1985	Summit Mine: mining	Summit Minerals Inc.	N.A.
1982, 1983	Imperial Mine: mining	Gold King-Imperial Mining Co.	N.A.
1979	Bitter Creek drill hole (SE1/4NE1/4 sec. 27, T. 16 S., R. 21 W., 900 ft, 274 m deep).	Superior Mining Division.	Nil
1983-1987	East Camp and Summit Mines	Summit Minerals Inc. and Sierra Corp., El Paso - 1983 for Summit mines.	Some heap leaching attempted at East Camp mine.
1985-1988	Center mine: mining	Mount Royal Mining and Exploration Co.	Ranked third in silver production for New Mexico.

Table 1.--A chronological summary of exploration and mining activity in the Steeple Rock and Duncan mining districts--Continued

Period	Activity	Company or governmental agency	Production
Fluorspar deposits			
1936-1942, 1960	Fourth of July	Southwestern Minerals Co. and R.T. Ellis Mining Co.	2,900 tons of fluorspar ore.
1942-1944, 1972	Mohawk Mine	Southwestern Minerals Co. and E. Belcher.	6,463 tons of fluorspar ore.
1942, 1943	Powell Mine	N.A.	115 tons of fluorspar ore.
1914-1944	Luckie Nos. 1	Quien Sabe Mining Co.	2,000+ tons of fluorspar ore.
1971, 1972	Leta Lynn	E. Belcher	3 tons of fluorspar ore.
1970's	Rattlesnake Group	R. Hill	120-150 tons of fluorspar ore.

Table 2.--Production of ore and metals between 1932 and 1957 in the Steeple Rock district, Grant County, New Mexico

[Prepared from data published in the Minerals Yearbooks, U.S. Bureau of Mines, and also cited by Griggs and Wagner, 1966]

Year	Mines producing	Tons of ore produced	Gold (oz)	Silver (oz)	Copper (lbs)	Lead (lbs)	Zinc (lbs)	Total value (dollars)
1932	2	?	13	780	--	--	--	493
1933	1	?	2	94	--	--	--	64
1934	1	1,617	421	21,141	1,700	500	--	28,553
1935	5	?	407	19,490	2,200	--	--	28,414
1936	8	3,777	850	54,173	5,600	300	--	72,222
1937	6	16,147	5,552	200,863	57,550	68,175	55,000	364,258
1938	7	14,740	5,687	239,119	33,300	38,500	--	358,654
1939	7	12,772	4,487	237,030	13,000	19,000	--	320,183
1940	11	22,915	5,414	216,374	20,900	74,000	--	349,418
1941	9	39,018	6,685	252,509	53,200	226,000	--	432,697
1942	5	9,426	1,390	60,220	29,000	86,700	--	100,791
1943	1	11,645	250	20,870	202,800	683,000	703,500	177,158
1944	2	15,460	295	21,181	210,800	838,500	944,000	228,541
1945	3	19,366	963	25,494	232,200	1,079,500	1,156,400	309,004
1946	3	9,535	408	8,797	87,800	405,200	328,800	119,893
1947	1	?	203	3,765	33,700	193,000	113,250	66,822
1948	1	428	149	1,735	2,000	3,000	2,000	8,022
1949	2	347	101	1,409	2,000	3,000	3,000	6,050
1950	2	855	259	11,004	1,300	1,700	--	19,523
1951	3	2,228	271	11,259	19,700	36,400	36,700	37,418
1952	--	--	--	--	--	--	--	--
1953	--	--	--	--	--	--	--	--
1954	1	104	8	52	500	1,400	--	667
1955	1	2,619	376	28,410	2,900	--	300	39,990
1956	1	1,979	186	11,345	1,644	--	--	17,476
1957	?	115	10	680	169	--	--	--
Totals			34,377	1,447,114	1,013,794	3,757,875	3,342,950	3,086,311

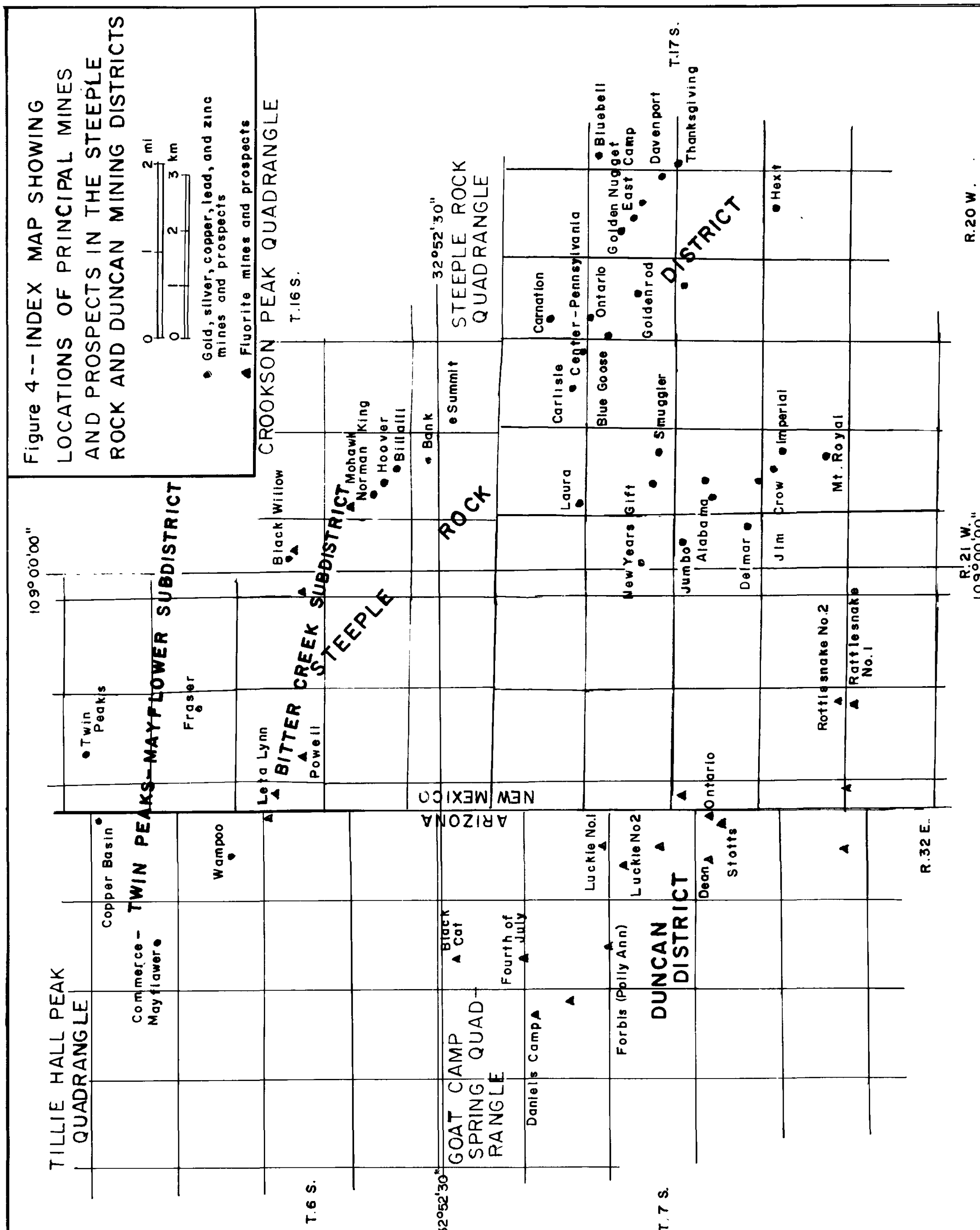

Figure 4--INDEX MAP SHOWING LOCATIONS OF PRINCIPAL MINES AND PROSPECTS IN THE STEEPLE ROCK AND DUNCAN MINING DISTRICTS

In summary, most veins are coextensive with faults and in places with rhyolite dikes. Some of the dikes expand into pluglike bodies such as those south of Vanderbilt Peak. Fission-track dating of the zircon from some dikes indicate an age of 21 m.y. (C.H. Thorman, written commun., 1983) for the rhyolite. Wahl (1983) has indicated that some adularia-rich samples from the East Camp vein have a K/Ar age of about 18 m.y. The ages for the dikes and veins are nearly the same and suggest a close relationship between rhyolite dike intrusion and the vein mineralization process. The veins are clearly epithermal and the mineralized veins occur as open-space fillings at shallow level in volcanic host rocks.

The chief producing mines in the Steeple Rock district were those along the Carlisle fault (Carlisle, Center, and Pennsylvania mines) and along the East Camp fault (East Camp, McDonald Tunnel, Davenport, and Thanksgiving mines). From these two groups about 7 million dollars (1883 value) in metals, chiefly gold and silver, was mined. Most of this production was from 1880 to 1897, but an additional $3 million worth of ore is indicated by the metal production figures for the period between 1932 and 1957 (table 2).

The Carlisle vein strikes N. 80^{o}-85^{o} W. but is locally branching, dips 60^{o} to 65^{o} south, and is as much as 50 ft wide. The vein is brecciated and the ore occurs as pods and irregular masses in the interstices of the breccia fragments; generally the higher grade vein segments are where the brecciation has been most intense (Gillerman, 1964). There is no evidence of supergene enrichment and the gold values appear to be higher within the vuggy upper parts of the quartz vein.

The East Camp group of mines extends along the East Camp fault for about 1 mi (1.6 km). The East Camp fault strikes N. 70^{o} W., generally dips steeply SW, and like the Carlisle fault the andesitic to dacitic country rocks are highly brecciated. The veins are up to 10 ft (3 m) wide and consist of andesite fragments with interstitial quartz, calcite, minor fluorite, limonite, and ore minerals. The ore minerals occur in vugs and as crustified banded segregations. The gold occurs as disseminations and as vug fillings in quartz.

The vein mineralogy at the Carlisle and Center mines is relatively simple, chiefly pyrite, chalcopyrite, sphalerite, galena, native silver, and native gold. Covellite is present in trace amounts and steely chalcocite has been reported from the Carlisle mine (Griggs and Wagner, 1966). The sphalerite commonly has exsolution blebs of chalcopyrite and is the chief sulfide. The sphalerite contains 500 to 700 ppm cadmium (table 3). Galena is intergrown with sphalerite and comprises as much as 40 percent of the sulfides. In some ores acanthite forms discontinuous rims about the grains of galena. The pyrite content is highly variable and ranges from a trace to as much as 60 percent of the sulfides. Native gold occurs in the upper vuggy parts of the quartz vein breccias. Specularite is locally intergrown with quartz and is early in the paragenetic sequence. Most ores are brecciated and the andesite fragments in the veins are highly chloritized. In some ores the sulfides occur as very fine grained lenses in a matrix of coarser grained sulfide aggregates and in other ores a crustiform banding of the sulfides on andesite rock fragments is present. The principal gangue minerals are quartz, locally the amethyst variety, calcite, barite, fluorite, manganese oxides, and traces of specularite.

A vertical zonal distribution of ore minerals is apparent at the Center, Carlisle, Pennsylvania, and East Camp mines. Generally the best gold values occur in the upper vuggy parts of the veins, and the silver-bearing base metal sulfides in the lower parts. The gold values in the upper parts of the vein

Table 3.--Semiquantitative spectrographic analyses of mineralized samples

[Analyses by M.J. Malcolm and J.C. Hamilton. Values reported in parts per million. Number below element is lower limit of determination. Elements determined but not reported here are: Fe, Mg, Ca, Na, K, Cr, Ga, La, Cr, Sc, Sr, Yb, and Zr. L, detected but below limit of determination; N, not detected; (26), values of silver and gold as determined by atomic absorption]

Lab No.	Mine	Ag (0.5)	Au (10)	As (200)	Ba (20)	Be (1)	B (10)	Cd (20)	Co (5)	Cu (5)	Mn (20)	Mo (5)	Ni (5)	Pb (10)	Sb (100)	Sn (10)	V (10)	W (50)	Y (5)	Zn (200)
									Steeple Rock quadrangle											
D-221175	Laura	70	N	N	150	N	N	N	N	1,000	700	20	5	700	N	N	30	N	N	1,500
D-221176	Summit	5	N	N	200	10	N	N	N	30	70	7	10	20	N	N	30	100	10	N
D-208617	Jim Crow	70	N	N	150	N	N	N	L	1,000	200	100	10	1,000	N	N	70	N	N	1,500
D-208615	Norman King	100	N	N	100	N	N	150	L	5,000	1,000	L	5	20,000	N	N	20	N	L	50,000
D-208616	Alabama	700 (930)	20 (26.2)	N	150	1.5	N	N	L	700	1,000	20	10	1,000	N	N	150	N	L	1,000
D-208620	Carlisle	50	N	N	70	N	N	500	10	5,000	300	N	5	30,000	N	N	10	L	N	50,000
D-208618	Center	150	N	N	200	N	N	700	10	10,000	700	3	10	30,000	N	N	20	N	N	70,000
D-208619	Pennsylvania	70	N	N	150	N	N	100	N	5,000	300	L	5	5,000	N	N	30	N	N	10,000
									Tillie Hall Peak quadrangle											
D-221178	Mayflower	200	N	N	1,000	N	N	N	20	30,000	700	N	20	70	N	N	150	N	15	N
									Goat Camp Spring quadrangle											
D-221180	Ontario	.7	N	N	150	N	N	N	7	15	150	20	5	N	N	N	30	N	100	N
D-221179	Luckie No. 2	1	N	N	150	N	N	N	N	15	20	N	L	15	N	N	50	N	20	N
D-221181	Rattlesnake No. 1	.5	N	N	70	N	N	N	N	5	700	N	5	N	N	N	20	N	100	N

systems are highly variable and range from 0.08 to 0.6 oz/ton (troy). The silver values range from 0.5 to 40 oz/ton, but most commonly the base metal ores contain 1 to 4 oz/ton. In some of the manganese oxide-rich veins, such as at the Alabama mine, the silver may be present in aurorite [$(Mn,Ag,Ca)Mn_3O_7.3H_2O$] or in other silver-bearing manganese oxides (table 3).

The wall rock alteration associated with the veins is dominantly propylitic, but silicic and sericitic alteration is common along the splayed East Camp fault near Bitter Creek. Generally, the propylitic alteration does not extend far into the volcanic wall rocks, usually less than 1 to 2 m. Silicic and hematitic alteration is especially observed at the Imperial and Mount Royal mines.

Bitter Creek subdistrict

Near the head of Bitter Creek the East Camp fault has split into several silicified branch faults; the quartz veins along the various fault segments have been exploited for precious metals and fluorspar. The principal mines have been the Norman King, Bank, Hoover Tunnel, Billali, and Mohawk, and except for the Mohawk, these mines were chiefly developed for gold and silver in the 1920's and 1930's when ore valued at more than $63,200 was produced. The Mohawk Mine has yielded appreciable amounts of fluorspar (6,463 tons averaging 60-70 percent CaF_2) from discontinuous shoots and pods along the brecciated quartz vein in the East Camp fault. The vein is about 20 ft (6 m) wide at the mine site and contains minor amounts of pyrite, limonite, and manganese oxides, as well as green and colorless fluorite.

The Powell and Leta Lynn fluorspar prospects are located along Bitter Creek just east of the New Mexico-Arizona state line. The Powell prospect has produced about 127 tons of fluorspar from workings along the N. 70° W.-striking Bitter Creek fault zone (McAnulty, 1978, p. 33, 34). The silicified fractures contain abundant manganese oxides associated with a pale-green fluorite. The Leta Lynn prospect has a recorded production of only about 3 tons of fluorspar from a silicified branch fault that strikes N. 45° W. from the Bitter Creek fault (McAnulty, 1978, p. 34).

Twin Peaks-Mayflower subdistrict

The mine workings of this subdistrict are localized along the late-Tertiary Commerce and Twin Peaks faults and the various branch faults north of Bitter Creek (fig. 2). The Twin Peaks fault is an extension of the East Camp fault system that can be traced about 18 mi to the southeast; the Commerce fault is probably a branch of the Bitter Creek fault system. The various mines in this subdistrict can be placed into two groups: (1) Twin Peaks-Fraser-Martin-Copper Basin group and (2) the Commerce-Mayflower group. In the 1970's these mines were extensively prospected by Fraser-Martin Mines Inc. and by the minerals division of EXXON. Briggs (1981) cited the production figures for the mines of this subdistrict as follows: silver (3,640 oz), gold (1,115 oz), and copper (1,965 lbs). The production from the old Yellowjacket mine on the west flank of Yellowjacket Peak is unknown, but was probably small.

During the period of this study, 1978-1980, the Commerce-Mayflower prospects were reopened and an open cut along the fault revealed numerous native copper veinlets a few millimeters thick in the fractured and faulted dacite; other minerals are chalcopyrite, chalcocite, acanthite, and chrysocolla. Silver values of about 5 to 6 oz/ton are indicated for veins containing as much as 3 percent copper.

Secondary copper minerals are present at the Copper Basin and Twin Peaks mines, but the inaccessibility of the caved workings prevented an evaluation of the resource potential. Anomalous arsenic (1,500 ppm) is reported from panned concentrates in the vicinity of the Copper Basin mines (Hassemer and others, 1981a).

Duncan district

Fluorspar mining began in this district in 1918, but the production was small through 1920 and ceased from 1921 to 1935. Production resumed in 1936 and continued until the end of 1944; during this period the production was 6,500 tons of ore valued at $124,000. During 1952 and 1953, probably another 2,000 tons of fluorspar ore was mined. In the early and mid-1970's the fluorspar deposits on the Rattlesnake claims were briefly worked, and in 1982 the Forbis mine was in operation for a brief period. The total fluorspar production from this district is not completely known but is estimated at 11,000 tons. The most productive mines were those of the Fourth of July Group (2,900 metric tons) and the Luckie No. 1 and 2 mines (2,000+ metric tons) (Richter and Lawrence, 1983). Much of the district is located in Greenlee County, Arizona, near the Grant County, New Mexico, state line.

The veins of the Fourth of July Group and Luckie mines were studied and mapped by the U.S. Geological Survey in 1944 (Trace, 1947) as a part of the USGS Strategic Minerals Investigations. In the mid-1960's some fluorspar mines were examined for their beryllium content by the U.S. Bureau of Mines (Meeves, 1966).

The fluorspar deposits of the Duncan District are fissure vein fillings along northwest- and north-northeast-striking faults of probable Miocene age (18-21 m.y.). The fluorite occurs as small pods and lenses that show an erratic distribution along the faults. Most veins are less than 400 ft (122 m) in length and 3 ft (1 m) in width. Locally, as at the Luckie No. 1 mine, the fluorite occurs in fault breccias along the margins of a rhyolite dike. Rhyolite dikes are common in the vicinity of Goat Camp Spring, an area of intensive argillic alteration. However, the wall rock alteration about the individual fluorite veins is generally weak, and except for some minor argillic and silicic alteration, there is little evidence for thermal effects in the adjacent wall rocks.

The fluorite is commonly light green to colorless and fine to very coarsely crystalline. Ribbon and crustiform textures are common, and in some deposits thin botryoidal masses and crusts of psilomelane and pyrolusite coat the fluorite-cristobalite aggregates. Ribbon-textured and fine-grained calcite is commonly present along the walls of some veins. Small amounts of pyrite and chalcopyrite are present in the Luckie No. 1 vein and drusy amethystine quartz is locally abundant. In some of the more productive veins, the ore bodies contain 62-70 percent CaF_2 and 25 to 30 percent silica.

The fluorite veins of the Duncan district have been analyzed for trace elements. The manganese oxides in some veins contain trace amounts of tungsten and Trace (1947) reported as much as 1.97 percent WO_3 in some psilomelane concentrates. Other elements detected by spectrographic analyses are Y (20-100 ppm), Pb (15-70 ppm), Cu (5-15 ppm), Ba (70-150 ppm), and Ag (0.5-1 ppm) (see table 2). Meeves (1966) reported as much as 100 ppm beryllium in some veins, but Be was not detected in the samples submitted in the present study.

GEOCHEMISTRY

As a part of the Hells Hole RARE II Planning Area survey, Hassemer and others (1981) analyzed 41 panned stream concentrates from the Tillie Hall Peak and Crookson Peak quadrangles. In addition to verifying the silver-gold-bearing veins along northwest-striking faults, the analytical data also defined small areas of tin, niobium, and titanium anomalies that are probably related to the weathering and erosion of rhyolitic flows and domes of Tillie Hall Peak, Winchester Peak, and the rhyodacitic flows near the confluence of Apache and Cottonwood Creeks (Hassemer and others, 1981).

Anomalous tin values occur at the following localities (Hassemer and others, 1983): (1) stream concentrates near the head of Apache Creek near Sid's Place, >1,000 ppm Sn; (2) panned concentrates near the Hoover Tunnel, 700 ppm Sn; (3) panned stream sediments along Tillie Hall Canyon about 0.5 mi southwest of Winchester Peak, 700 ppm Sn; also present 150 ppm Nb; (4) stream concentrates about 0.5 mi north of Fulcher Ranch, 700 ppm Sn; and (5) panned concentrates in the vicinity of Apache Box, 700 ppm Sn.

Anomalous niobium values (200 ppm) are present in stream sediments of Copper Basin, and as much as 5 percent titanium is reported from panned stream concentrates at the head of Lop Ear Creek in sec. 15, T. 5 S., R. 31 E., in Arizona. Arsenic, antimony, boron, and bismuth are absent in most veins, although tetrahedrite in association with native copper has been reported from the Commerce mine. Anomalous arsenic (1,500 ppm) is reported from panned stream concentrates in the vicinity of the Copper Basin mines (Hassemer and others, 1981).

A beryllium anomaly is noted in stream concentrates along Skully Creek above the Hoverrocker Ranch in sec. 30, where as much as 150 ppm Be is reported by Hassemer and others (1981). The Hoverrocker sample site has panned concentrates with as much as 700 ppm arsenic.

GEOPHYSICS

Aeromagnetic coverage for the Hells Hole Further Planning Area (Martin, 1981) and for the encompassing Silver City $1^{o}x2^{o}$ quadrangle (Klein, 1987) have served to delineate several important magnetic anomalies. The Brushy Mountain volcanic center is defined by several magnetic highs surrounded by an arcuate pattern of magnetic lows (fig. 5). This particular feature has not been completely corrected for topographic effects but does fit with geologic interpretations for this andesitic volcanic center.

A northwest-trending magnetic low extends through the Twin Peaks area, southeast through Saddleback Mountain to Summit Mountain (fig. 2). This negative anomaly roughly corresponds to the continuation of the East Camp, Apache, Twin Peaks, Bitter Creek, and Commerce faults through this area. These strong faults juxtapose lava flows with different magnetic susceptibilities and locally are sites of strong alteration, which probably has destroyed most of the original magnetic minerals.

Other northwest-trending magnetic anomalies in the Steeple Rock district reflect the relatively low magnetic susceptibilities of the northwest-striking ash-flow tuffs and rhyolite flow units as compared with the more magnetic dacitic to andesitic lava flows that are intercalated with the tuffs or rhyolite (table 4).

Several east-northeast-trending negative anomalies coincide with the Carlisle Canyon fault, but this correlation is only tentative as shown on the aeromagnetic map by Klein (1987).

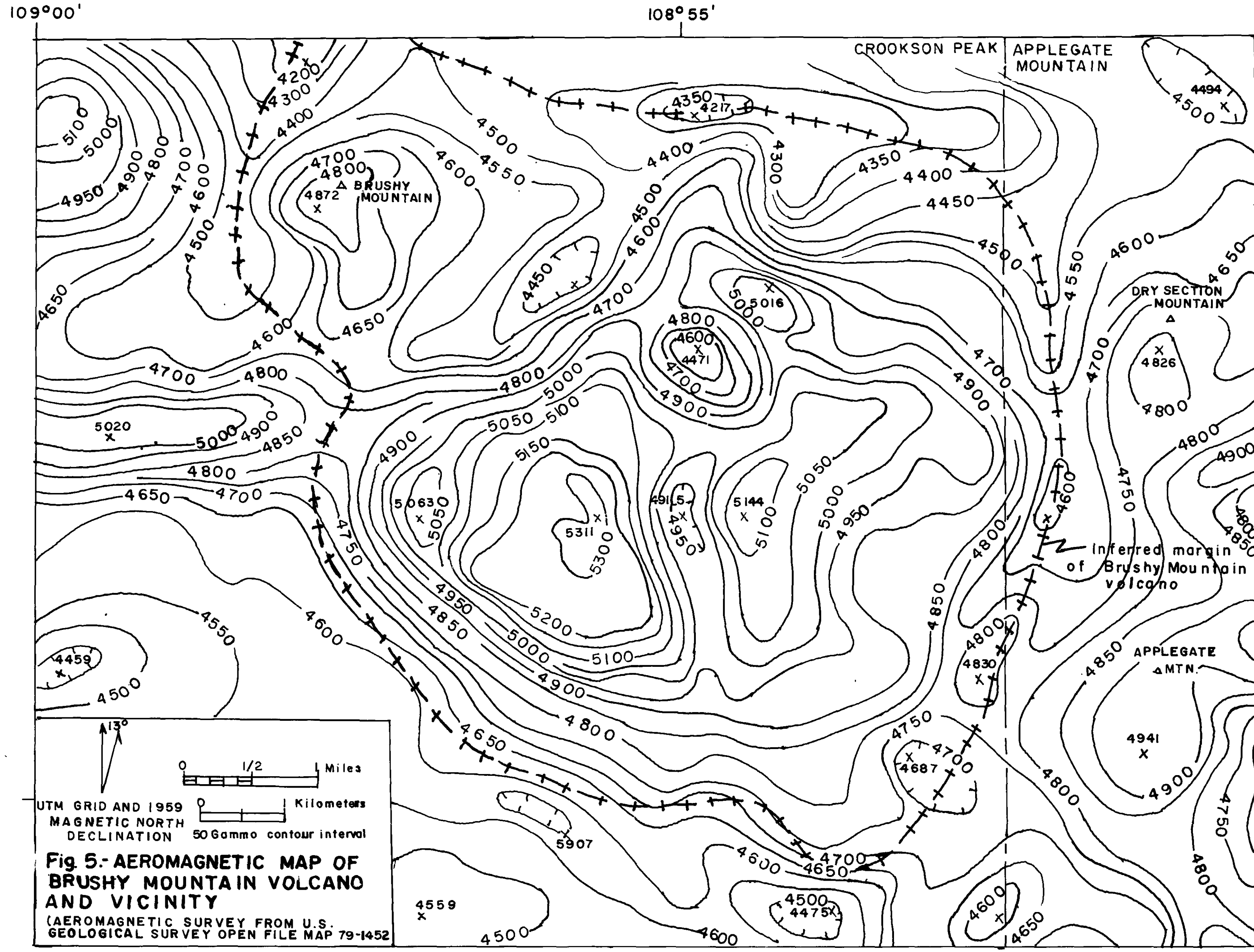

Fig. 5.- AEROMAGNETIC MAP OF BRUSHY MOUNTAIN VOLCANO AND VICINITY
(AEROMAGNETIC SURVEY FROM U.S. GEOLOGICAL SURVEY OPEN FILE MAP 79-1452

Table 4.--Magnetic susceptibility data for diverse rock types from the Steeple Rock, Crookson Peak, Tillie Hall Peak, Goat Camp Spring, and Canador Peak quadrangles, New Mexico-Arizona

[All measurements in field with Scintrex Model SM-5 Digital Magnetic Susceptibility Meter]

Rock type	Formation	Number of samples	K-values (emu/cm^3) x10^{-3}
A. Crookson Peak and Steeple Rock quadrangles:			
Rhyolite plug	Intrusives of the Mule Mountain Rhyolite	1	0.2
Basaltic-andesite	Basaltic andesite of Brushy Mountain	4	0.6, 0.8, 0.8, 1.1
Andesite porphyry ("Turkey Track")	Andesite porphyry	2	0.6, 1.4
Dacite porphyry	Lava flows of Crookson Peak	6	0.2, 0.3, 0.4, 0.4, 0.5, 0.5
Andesite	Andesite of Pine Cienega	1	1.3
Rhyolite	Rhyolite dome of Hells Hole	1	0.2
Andesite	Basaltic andesite of Dark Thunder Canyon	2	0.8, 0.9
Dacite porphyry	Dacite porphyry of Summit Mountain	2	0.1. 0.3
Rhyolite	Rhyolite of Steeple Rock	2	0.0, 0.1
Basalt	Basalt of Black Hill	2	0.4, 1.6
Ash-flow tuff	Tuff of Bloodgood Canyon	3	0.1, 0.1, 0.2
Quartz diorite plug	Intrusive into Mud Springs Group	1	2.3
B. Tillie Hall Peak and Goat Camp Spring quadrangles:			
Rhyolite	Rhyolite dome of Hells Hole	3	0.1, 0.1, 0.2
Andesite	Basaltic andesite of Dark Thunder Canyon	2	0.8, 0.8
Andesite	Andesite of Copper Basin	1	0.4
Basalt	Basalt of Black Hill	1	1.6
Andesite	Andesite of Daniels Camp	1	0.5
Dacite porphyry	Dacite porphyry of Charlie Hill	2	0.1, 0.2
Dacite porphyry	Dacite porphyry of Summit Mountain	3	0.4, 0.3, 0.5

Table 4.--Magnetic susceptibility data for diverse rock types from the Steeple Rock, Crookson Peak, Tillie Hall Peak, Goat Camp Spring, and Canador Peak quadrangles, New Mexico-Arizona--Continued

	Rock type	Formation	Number of samples	K-values (emu/cm^3) x10^{-3}
C.	Canador Peak quadrangle:			
	Basalt	Basalt of Black Mountain	2	0.8, 1.1
	Andesite	Andesite of Deadman Ridge	1	1.1
	Rhyodacite	Rhyodacite dome of Canador Peak	1	0.2
	Ash-flow tuff of Lower Box	Ash-flow tuff	5	0.1, 0.1, 0.1, 0.1, 0.1
	Mudstone-siltstone	Colorado Formation, slightly metamorphosed near contact with rhyolite plug	1	1.7
	Granite	Precambrian of the Riley Peaks area	1	0.1

The Black Mountain magnetic high is separated from the magnetic high in the nearby Windham Canyon area by the magnetic low over the Precambrian granite outcrops near the junction of the Black Mountain and Mud Springs fault (fig. 2).

Bouguer gravity maps of the area have been prepared by Martin (1981) and Wynn (1981), and the interested reader is referred to these maps. A northwest-striking regional pattern of the Bouguer gravity map (Wynn, 1981) reflects the general northwest strikes of the volcanic formations and fault systems; the gravity ridges are broken by the gravity high over the Tillie Hall Peak area and a gravity low over Noeh Mesa (Wynn, 1981). A gravity high over the Upper Cretaceous Colorado and Beartooth Formations reflects the close proximity of the Precambrian basement in the area at the junction of the Black Mountain and Mud Springs faults (fig. 2). Another gravity high is positioned near the Rimrock fault.

ERTS satellite imagery has proved useful in combination with aeromagnetic maps to delineate the Blue Creek fault or lineament (NASA ERTS E-1515-17185-5-02). This north-northwest-trending lineament crosses the Gila River at the southeast end of Black Mountain and is clearly visible with color-enhanced imagery.

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