GEOLOGY OF THE GALLINAS PEAK AREA
SOCORRO COUNTY, NEW MEXICO

by

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ABSTRACT

The geology of the Gallinas Peak area is characterized by a thick sequence of ash-flow tuffs and less voluminous lavas and sedimentary rocks. The oldest rock units, exposed only in the northeast portion of the study area, are the Crevasse Canyon Formation (Cretaceous) and the Baca Formation (Eocene). These units are overlain successively by Oligocene volcanic and volcaniclastic rocks of the Spears Formation, Hells Mesa Tuff, A-L Peak Tuff, basalts and sedimentary rocks, tuff of South Canyon, and basaltic andesites. The Popotosa Formation (Miocene) overlies this sequence with angular unconformity and is in turn overlain by piedmont gravels.

North-trending normal faults, associated with the development of the Rio Grande rift, are the dominant structures in the area. Uplift and faulting has resulted in a southwestward tilt of the Gallinas Range away from the Mulligan Gulch graben and Colorado Plateau, and has produced a series of horsts and grabens across the range. In the northeast portion of the study area, early Oligocene displacement along north-trending faults has caused thinning of the lower member of the Spears Formation. Transverse faults, probably contemporaneous with the north-trending faults, can be attributed to either 1) broad uplift of the Gallinas Peak area, 2) movement related to a basement fault zone of the Tijeras lineament, 3) movement of the Colorado Plateau away from its southeast corner or, 4) local stress perturbations in the regional extensional stress field.

Steep easterly dips adjacent to the Mulligan Gulch graben can be attributed to either 1) doming over an inferred intrusive, 2) fault drag, or, 3) doming related to diapiric intrusion of Mesozoic shales and/or Paleozoic evaporites. Other post-Laramide flexures occur in the northeast portion of the area adjacent to normal faults and are probably the result of reverse drag.

Alteration, in the form of weak propylitization, hematite staining, and silicification, is common in the eastern portion of the Gallinas Peak area. This alteration, along with quartz-carbonate veining, the presence of mafic and felsic dikes, and an aeromagnetic high are the basis of an inferred, early Oligocene intrusive. The Spears Formation has low to moderate favorability for precious metal or base metal deposits in the eastern portion of the study area. The Baca Formation contains anomalous radioactivity in Jaralosa Canyon and is recommended for uranium exploration.

INTRODUCTION

Purpose of the Investigation

The primary objective of this thesis is to correlate the volcanic stratigraphy of the Gallinas Peak area with known volcanic stratigraphy of the Socorro-Magdalena area. The secondary objective is to determine the structural geology of the area and to discuss its relationship to rift faulting and regional structural trends. A third objective is to determine the mineral potential of the Gallinas Peak area.

Location and Accessibility

The center of the Gallinas Peak area lies about 15 mi (24 km) northwest of Magdalena (fig. 1). The 25 mi^2 (65 km^2) area is roughly bounded to the north by Three Log Spring Canyon (latitude 34° 26'), to the south by McGee Spring Canyon (latitude 34° 12'), and on the east and west by longitudes 107° 25' and 107° 31', respectively. Access to the northern half of the area is provided by an unimproved road which turns west off of State Road 52 at the head of Corkscrew Canyon. The southern half of the area is reached by taking U.S. Forest Service Road 10 west from State Road 52 to Gallinas Canyon and then driving on unimproved roads westerly to Whiskey Well or easterly to McGee Spring.

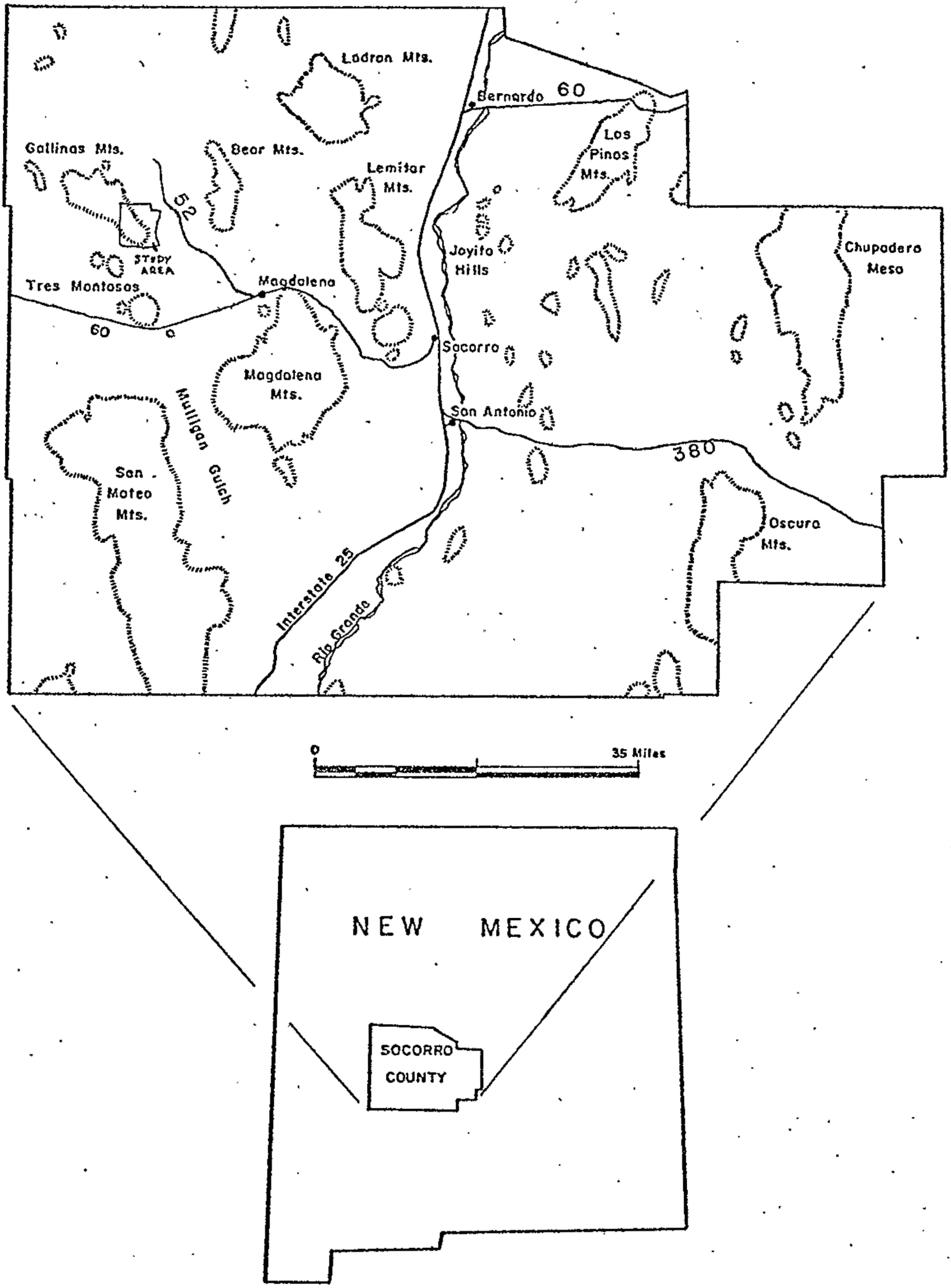

Figure 1. General location map showing relationship of the study area to major mountain ranges in Socorro County.

Four-wheel drive roads provide access to within 2 mi (3 km) of most portions of the area.

Methods of Investigation

Surface geologic mapping of the Gallinas Peak area was completed during the summer and fall of 1978 and the spring of 1979. The mapping was done at a scale of 1:24,000 on a topographic base made from portions of the U.S. Geological Survey Gallinas Peak, Indian Mesa, Indian Spring Canyon, and Lion Mountain 7.5 minute quadrangle maps. U.S. Forest Service color aerial photographs, series 9-29-74 and 6-25-75, at an average scale of 1:19,000, were used as an aid in locating outcrops and indicating structural lineaments.

Classification of aphanitic rocks was based on phenocryst mineralogy as proposed by Lipman (1975, fig. 3). Sandstones and conglomerates were classified according to Folk (1974). Sorting, size, and angularity of constituent grains of sedimentary rocks were visually estimated in the field or in thin section. Seventy-four thin sections were studied to estimate the modal composition of the rocks, describe textures, and determine the nature of mineralization and hydrothermal alteration. Portions of 70 of the thin sections were etched with hydrofluoric acid, then stained with sodium cobaltinitrite to aid in the identification of potassium-bearing minerals.

Physiography

In the Gallinas Peak area, the Gallinas Mountains consist of north-trending ridges capped by ash-flow tuffs, flanked on the east by the Mulligan Gulch graben and on the west by a northern embayment of the Plains of San Augustin. Topography is subdued to the north of the Gallinas Peak area where the terrain grades into the Colorado Plateau. Gallinas Peak, elevation 8442 ft (2573 m), is the highest point in the area, rising 1400 ft (427 m) above the lowest portion. Present topography is controlled by rift faulting, and by relative weathering characteristics and orientation of the bedrock.

Geologic Setting

The Gallinas Peak area is located along the northeast boundary of the Datil-Mogollon volcanic field where it borders the Colorado Plateau. The study area is separated from the Bear and Magdalena Mountains to the east and southeast by the north-trending Mulligan Gulch graben, and from the San Mateo Mountains to the south by the northeast-trending San Augustin rift. The Gallinas Range forms the west edge of the Rio Grande rift at this latitude. The area is comprised predominantly of Middle Tertiary ash-flow tuffs, volcaniclastic sedimentary rocks, and lava flows overlying Lower Tertiary and Upper Cretaceous sedimentary rocks. North- and northeast-trending normal faults are the most abundant stuctures. The regional dip is southwestward, away from the Colorado Plateau uplift and the Mulligan Gulch graben.

Previous Work

The first studies related to the Gallinas Peak area are reconnaissance investigations. Herrick (1900) reported that the Bear, Datil, and Gallinas Mountains were comprised of trachyte and rhyolite intrusives. Lindgren and others (1910), in a U.S. Geological Survey Professional Paper on the Ore Deposits of New Mexico, concluded that the first volcanic rocks of Tertiary age were predominantly andesites and later flows were mainly rhyolites. A section of volcanic rocks in the Alamosa Creek Valley (Rio Salado) was measured by Winchester (1920). He named the sequence of andesite, trachyte, and rhyolite flows and intrusives, with associated conglomerates and sandstones, the Datil Formation and designated a type locality at the northern end of the Bear Mountains. The basal 684 ft (208 m) of sedimentary rocks were later excluded from the Datil Formation and named the Baca Formation by Wilpolt and others (1946).

Loughlin and Koschmann (1942) conducted a detailed geologic investigation of the Magdalena mining district. They recognized that several Tertiary volcanic units in the district were also present in areas to the north and west of the district. The Puertecito 15-minute quadrangle was mapped by Tonking (1957), who subdivided the Datil Formation into the following three units (from oldest to youngest): Spears, Hells Mesa, and La Jara Peak members. Givens (1957) mapped the Dog Springs 15-minute quadrangle and subdivided the Hells Mesa Member into seven mappable units in the Gallinas Mountains. A portion of the areas mapped by Givens and Tonking overlaps the northern sector of the present study area. Tonking's (1957) La Jara Peak Member was excluded from the Datil Formation by Willard (1959) and Weber (1963). The Datil Formation was raised to group status by Weber (1971), but has since been abandoned as a tenable stratigraphic unit by Elston (1976, p.134) and by Chapin and others (1978a,b). The Spears, Hells Mesa, and La Jara Peak members were elevated to formational rank by Chapin (1971a). In a study of the Bear Mountains, Brown (1972) subdivided the Hells Mesa Formation into a lower, crystal-rich member (informally named the tuff of Goat Spring) and an upper, crystal-poor member (informally named the tuff of Bear Springs). Chapin (1974a), later restricted the Hells Mesa Formation to the quartz-rich, crystal-rich, ash-flow tuff, formerly called the tuff of Goat Spring. Deal and Rhodes (1976) renamed the tuff of Bear Springs the A-L Peak Formation and designated a type section in the northern San Mateo Mountains.

The stratigraphy, structure, and mineralization of the Silver Hill area was the subject of a thesis by Simon (1973). Chamberlin (1974) described the stratigraphy and structure of the Council Rock district and and discussed the mineralization surrounding the Tres Montosas stock. The area mapped by Chamberlin is contiguous with the east half of the southern boundary of the Gallinas Peak area. Wilkinson (1976) investigated the stratigraphy, structure, and nature of hydrothermal alteration and mineralization of the Tres Montosas-Cat Mountain area.

A composite stratigraphic column of the Cenozoic rocks in the Socorro-Magdalena area has been published by Chapin and others (1978a,b). They designate seven overlapping and nested cauldrons as sources for the major ash-flow tuff units. The tectonic style of the Rio Grande rift and its relationship to structural trends in the Bear and Magdalena Mountains is discussed by Chapin (1971b, 1978) and by Chapin and Seager (1975).

Mayerson (1979) has completed a thesis on the Cretaceous and Tertiary stratigraphy in the area adjoining the northeast corner of this study. Cather (1980) studied the environment of deposition and sedimentary transport directions in the Baca Formation north of the Gallinas Peak area. Coffin (in prep.) is completing a thesis project in the area north of North Lake, west of this thesis area; Harrison (1980) has recently completed a thesis study also in the North Lake area.

Several authors have published numerous radiometric dates on the volcanic rocks of the Datil-Mogollon volcanic province. Weber and Bassett (1963) dated a welded ash-flow from the base of Tonking's (1957) Hells Mesa Member in the Bear Mountains. A latite tuff boulder from the top of the Spears Formation and two samples of the Hells Mesa Formation were dated by Burke and others (1963). Radiometric dates on the Spears Member and Hells Mesa Member were also listed by Kottlowski and others (1969). Weber (1971) listed five ages on Tertiary igneous rocks from central New Mexico. An age determination on the La Jara Peak Andesite was published by Chapin (1971a). Elston and others (1973) summarized all K-Ar dates available from the Datil-Mogollon volcanic province. A comprehensive program of K-Ar dating and chemical analysis of volcanic rocks in the Socorro-Magdalena area is in progress by the New Mexico Bureau of Mines and Mineral Resources. Several K-Ar dates and preliminary chemical analyses are reported in Chapin and others (1978a,b,c).

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PREVOLCANIC STRATIGRAPHY

Prevolcanic rocks exposed in the Gallinas Peak area consist of incomplete sections of the Crevasse Canyon (Upper Cretaceous) and Baca Formations (Eocene). Both units are of only minor extent in the thesis area and were not studied in detail. For more detailed descriptions of these units near the Gallinas Peak area, the reader is referred to theses by S. Cather (1980) and Mayerson (1979). The oil, gas, coal, and uranium potential of the Crevasse Canyon and Baca Formations in the Riley-Puertecito area, north of the study area, has been discussed by Chapin and others (1979).

Cretaceous

Crevasse Canyon Formation

The Crevasse Canyon Formation is the oldest exposed unit in the Gallinas Peak area; here, it consists of coal beds, calcareous and carbonaceous mud- and clay-shales, siltstones, and fine-grained sandstones. The name Mesaverde Formation has sometimes been applied to this stratigraphic interval; however, Molenaar's (1974) correlation of the Crevasse Canyon in the San Juan Basin with the Upper Cretaceous, non-marine sequence in the Riley-Puertecito area is now accepted, and the name Mesaverde has been abandoned (S. Hook, 1979, oral commun.).

An incomplete section of the Crevasse Canyon is present in the northeast corner of the map area. The lower contact of the Crevasse Canyon is not exposed in the thesis area; however, a sharp, conformable contact with the overlying Baca Formation crops out on the east side of Jaralosa Canyon, 0.4 mi (0.6 km) west of hill "7582" (fig. 2). In most areas of exposure, however, the Crevasse Canyon is in fault contact with the overlying Baca Formation. South of Corkscrew Canyon, Mayerson (1979, p. 38, 47-48) found Baca- and Crevasse Canyon-type lithologies interbedded over about 30 ft (9.1 m) of section. He found, however, evidence of a slight angular unconformity between the two formations west of Jaralosa Creek.

Tonking (1957) measured a thickness of 1052 ft (321 m) of the Crevasse Canyon in the Puertecito quadrangle (secs. 9 and 16, T. 2N., R. 6W.). Mayerson (1979) estimated a thickness of 1000 ft (305 m) for the Crevasse Canyon Formation based on outcrops just north of this study area. Insufficient exposure of the Crevasse Canyon is present in this study area to give reliable estimates of the thickness of the unit.

In the Gallinas Peak area, the Crevasse Canyon crops out only in arroyos which are separated by low, rounded knolls covered with a mantle of light olive-gray (5 Y 5/2) to medium dark-gray (N 4), weathered rock chips and locally abundant ironstone concretions. The formation

Figure 2. Crevasse Canyon-Baca contact exposed on east side of Jaralosa Canyon, 0.4 mi (0.6 km) west of hill "7582". Bleached sandstones of the Baca Formation overlie carbonaceous shales, siltstones, and sandstones of the Crevasse Canyon Formation.

consists of moderately indurated, light olive-gray (5 Y 5/2) to dusky-yellow (5 Y 6/4), fine-grained, calcareous sandstones and siltstones. These beds are usually less than 1 ft (30 cm) thick and are separated by dark-gray (N 3), poorly indurated, carbonaceous and calcareous shales and coal beds as much as 5 ft (1.5 m) thick. The shales exhibit lenticular parting, are composed of very-thin, carbonaceous laminae, and contain sparse, brittle, white micaceous plates. Shales and occasional thin mudstones sometimes have faint sets of carbonaceous cross-laminae. Coal fragments and a white micaceous mineral are common constituents of the siltstone intervals. Lenticular ironstone concretions, averaging 12 in (30 cm) in length, were found in a shale horizon near the top of the Crevasse Canyon.

Pollen taken from the lower coal beds in the Crevasse Canyon Formation indicate that the lower coals formed in a mixed brackish and fresh water environment (M.S. Chaiffetz, in Chapin and others, 1979). Pollen grains analyzed from the upper coal seams of the unit indicate that the upper coals formed in fresh water swamps inland from a coastal or delta plain.

Tertiary

Baca Formation

Minor exposures of the Baca Formation (Eocene) are present near the northeast margin of the Gallinas Peak area. The immature sandstones, siltstones, and shales of the Baca were originally included in the Datil Formation of Winchester (1920). Wilpolt and others (1946) later excluded the basal 684 ft (208 m) of sedimentary rocks from Winchester's measured section and named it the Baca Formation. Studies concerning the sedimentology of the Baca Formation have since been done by Snyder (1971), Johnson (1978), and Cather (1980). Fossils indicating an Eocene age have been reported by Gardner (1910) and Snyder (1970). Gidley (in Gardner, 1910), identified a fossil tooth from the Carthage area, east of the Gallinas Mountains, as Paleosyops (middle Eocene). Remnants of Protoreodon pumilus found by Snyder (1970), in an area west of the Gallinas Mountains, suggest a late Eocene age for the Baca. However, D. Wolberg (1980, oral commun.) has suggested that these fossils are possibly misidentified.

In the west-central New Mexico area, the Baca Formation crops out in an east-trending belt. Exposures of the unit in the Gallinas Peak area are restricted to the northeast corner of the map area, near Corkscrew Canyon. A sharp contact with the underlying Crevasse Canyon Formation is exposed along the east side of Jaralosa Canyon, where the two formations appear conformable. The upper contact with the Spears Formation is poorly exposed, but the map pattern suggests a slight angular unconformity between the two units. A minimum thickness of 515 ft (157 m) is estimated for the Baca in the thesis area. Tonking (1957) measured a thickness of 617 ft (188 m) near the Gallinas Peak area (secs. 1 and 2, T. 1S., R. 6W.), but noted that the thickness ranged from 0 to 700 ft (213 m) in the Puertecito quadrangle. Mayerson (1979) approximated a thickness of 950 ft (290 m) for the Baca Formation in the Corkscrew Canyon--Abbe Spring area.

In the Gallinas Peak area, the Baca Formation is largely concealed by alluvium, but outcrops are found on arroyo walls and as rounded hummocks between arroyos. Fresh exposures of the Baca vary in color from pale brown (5 YR 5/2) to dark yellowish orange (10 YR 6/6), but are more commonly altered to very pale orange (10 YR 8/2) because of bleaching by ground water and hydrothermal solutions. Sandstone beds range in thickness from very thin laminae (less than 1 mm) to almost 3 ft (0.9 m). Thicker beds will sometimes have thin parting surfaces which are parallel to the bedding surface. Broadly cross-stratified, coarse to very fine, immature sandstone intervals alternate with less abundant conglomeratic horizons and silty sequences. Channel-shaped conglomeratic horizons are usually less than

10 ft (3 m) in cross-section and contain well-rounded, crudely-imbricated cobbles (fig. 3). Cobble lithologies include red to black quartzite, claystone, and minor carbonaceous fragments. Finer constituents of the conglomerates consist of 0.5 to 2 mm, subrounded to rounded quartz (50 to 60 percent), smaller (about 0.5 mm) chalky feldspar, and about 1 percent altered ferromagnesian minerals. Individual grains range from clay-size particles to very coarse, sand-size particles with occasional larger clasts. The relative proportions of feldspar grains, rock fragments, and clays are difficult to estimate in hand sample because of the altered nature of the Baca in the Gallinas Peak area. However, thin section studies of the Baca in adjacent areas indicate that, using Folk's (1974) classification, the Baca sandstones are immature, lithic arkoses to immature, feldspathic litharenites (S. Cather, 1980, oral commun.; Mayerson, 1979, p. 124-125). Laminae that contain a brittle, white, micaceous mineral and carbonaceous fragments are sometimes found in the Baca within the thesis area. Samples of the Baca usually effervesce in HCl, suggesting that the cementing material of these sandstones is a carbonate mineral (probably dolomite and Fe-calcite; S. Cather, 1980, oral commun.).

One paleotransport direction of N 68° E was measured on imbricated pebbles in a conglomeratic horizon. This is in agreement with the paleocurrent directions found

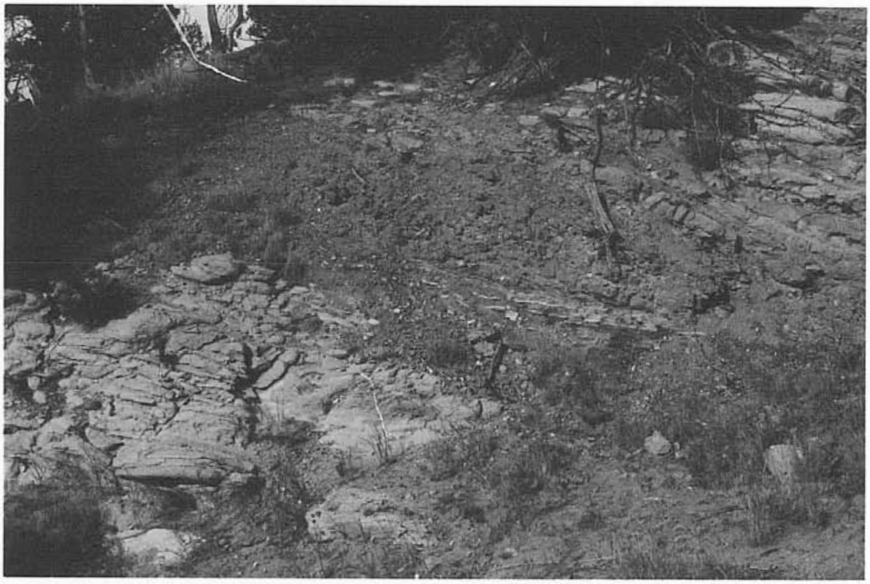


Figure 3. Bleached sandstones of the Baca Formation and an interbed of channel conglomerate. Photo taken on east side of Jaralosa Canyon about 0.9 mi (1.5 km) north of Jones Well.

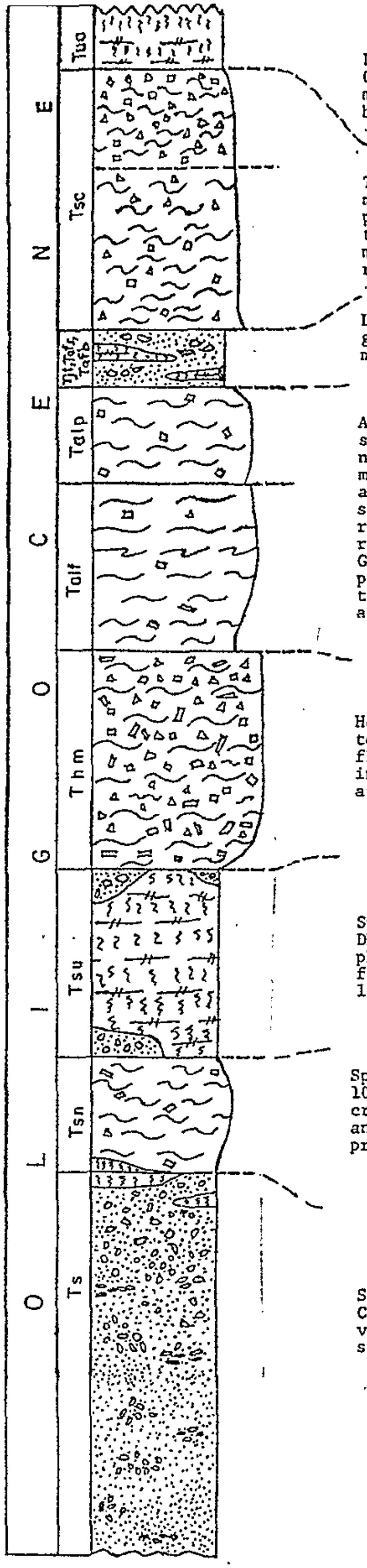
by Cather (1979, oral commun.) in an area about 6 mi (10 km) north of the Gallinas Peak area. In the Gallinas Peak area, the Baca Formation originated as deltaic deposits in a lacustrine environment and as deposits by low-gradient, sandy, braided streams (S. Cather, 1980).

OLIGOCENE STRATIGRAPHY

A maximum thickness of 4150 ft (1270 m) of Oligocene volcanic rocks and volcaniclastic sedimentary rocks is present in the Gallinas Peak area (fig. 4). Rhyolitic and latitic ash-flow tuffs are the most widespread rock types exposed. Intercalated volcaniclastic sedimentary rocks and latitic to basaltic-andesite lava flows are volumetrically important, but less exposed. Detailed lithologic descriptions of these units are emphasized where major differences exist between rocks of the Gallinas Peak area and those elsewhere in the Socorro-Magdalena area.

Spears Formation

Tonking (1957) named a series of quartz latite tuffs and epiclastic volcanic rocks the Spears Member of the Datil Formation and measured a type section in the northern Bear Mountains. The Spears Member was later raised to formational rank by Chapin (1971a). Brown (1972) divided the Spears Formation into a lower member of latitic to andesitic volcaniclastic sedimentary rocks and an upper member of latitic ash-flow tuffs, andesitic lava flows, and volcaniclastic sedimentary rocks that contain andesite and latite clasts. Chamberlin (1974) and Wilkinson (1976) used Brown's (1972) divisions of the Spears Formation with minor revisions concerning the lowermost latite tuff interval. Burke and others (1963) obtained a K-Ar date of 37.1 ± 1.5



Lava flows: (0 to >200 ft, 61 m) ANDESITE TO BASALTIC-ANDESITE LAVAS: Gray to brown, platy to blocky flows. Crude to well-developed alignment of feldspars. Phenocrysts of plagioclase and pyroxene. Flows become increasingly blocky and vesicular upward.

Tuff of South Canyon: 26 m.y. (0-965 ft, 294 m) ASH-FLOW TUFFS: multiple-flow, simple cooling unit of rhyolite ash-flow tuffs. Lower, platy member is gray, crystal-poor, moderately to densely welded tuff with basal vitrophyre. Upper, blocky member is light-gray, moderately to poorly welded, moderately crystal-rich tuff. Thin remnants present in northeast corner of study area.

Lava flows: (0-180 ft, 55m) BASALTS, SANDSTONES, and CONGLOMERATES: gray to brown, vesicular, porphyritic lavas intertongue with sedimentary rocks in southwest corner of study area.

A-L Peak Tuff: 32 m.y. (0-785 ft, 239 m) ASH-FLOW TUFFS: composite sheet with basal gray-massive, middle flow-banded, and upper pinnacles members. Pinnacles member is white to brown, poorly to moderately welded, crystal-poor, simple cooling unit of rhyolite ash-flow tuffs. Basal portion often lithic rich; poorly developed spherulitic zone near base. The flow-banded member is a gray to reddish brown, densely welded, crystal-poor, simple cooling unit of rhyolite ash-flow tuffs with crude to well-developed flow lineation. Gray-massive member is gray, moderately welded, pumice-poor, crystal-poor simple cooling unit of rhyolite ash-flow tuffs which are gradational with the flow-banded member. Minor white to pink ash-flow and ash-fall tuffs at base.

Hells Mesa Tuff: 32-33 m.y. (0-650 ft, 198 m) ASH-FLOW TUFFS: gray to reddish brown, moderately to densely welded, crystal-rich, multiple-flow, simple cooling unit of rhyolite ash-flow tuffs; abrupt increase in quartz phenocrysts 40 to 50 ft above base; local black vitrophyre at base. Thin remnants present in northeast corner of study area.

Spears Formation-upper member: (0-560 ft, 170 m) LAVAS and MUDFLOW DEPOSITS: black to brown basaltic-andesite flows, some with large phenocrysts of pyroxene and smaller plagioclase; local homolithic flow breccias, mudflow deposits; local biotite-rich rhyodacite to latite lava flows near base. Member thins to northeast and northwest.

Spears Formation-upper member, tuff of Nipple Mountain: (0-325 ft, 100 m) ASH-FLOW TUFFS: brown to gray, poorly to densely welded, crystal-poor, compound cooling unit of latite ash-flow tuffs. Local andesite with phenocrysts of plagioclase present at base. Remnant present in northeast corner of study area.

Spears Formation-lower member: (1125 ft, 343 m) MUDFLOW DEPOSITS, CONGLOMERATES, SANDSTONES, SILTSTONES, and LAVAS: gray to purple, volcanic conglomerates, some with Paleozoic clasts, sandstones and siltstones; andesite to latite lava flows locally at top of unit.

Figure 4. Stratigraphic column showing relative maximum thicknesses of Oligocene rocks in the Gallinas Peak area.

m.y. on a latite tuff boulder from the upper part of the Spears Formation in the La Joyita Hills.

Both the upper and lower members of the Spears Formation are exposed in the Gallinas Peak area. Cross-sections indicate a maximum thickness of the Spears Formation in the thesis area of approximately 1990 ft (607 m). At the type section, Tonking (1957) measured a thickness of 1340 ft (408 m) for the total Spears section.

Lower Member

The lower member of the Spears Formation crops out in a broad, north-trending belt in the eastern half of the study area. This unit consists of mudflow deposits, volcanic conglomerates, less abundant volcanic sandstones, and minor latitic and andesitic lava flows. The basal contact of the Spears Formation with the Baca Formation was placed at the first appearance of volcanic-derived detritus. The only exposure of this lower contact is found in the northeast corner of the study area where the Spears Formation rests on the Baca Formation with angular unconformity. Brown (1972), Chamberlin (1974), and Wilkinson (1976) used the base of an amygdaloidal "turkey-track" andesite below the tuff of Nipple Mountain to define the upper contact of the lower member of the Spears Formation. A "turkey-track" andesite is present in the Gallinas Peak area only as isolated outcrops. Thus, where this andesite is absent, the base of the tuff of Nipple Mountain was mapped as the base of the upper member. In the northeast portion of the thesis area, the lower member is disconformably overlain by the Hells Mesa Formation. Elsewhere, the lower member is conformably overlain by the tuff of Nipple Mountain.

In the Gallinas Peak area, the thickness of the lower member is about 1125 ft (343 m) (obtained from cross-section B-B', Plate 1). This thickness probably varies because of the nature of the unit. However, in the northeast Gallinas Peak area, a maximum thickness of 775 ft (236 m) for the lower member can be attributed to thinning of the unit across down-to-the-west faults. Brown (1972) estimated the minimum thickness of the lower member in the Bear Mountains to be 1500 ft (457 m), but acknowledged the possibility that concealed faulting may have exaggerated the thickness. Although Chamberlin (1974) did not have a complete section of the lower member, he suggested that a thickness of 1200 ft (366 m) was reasonable in the Council Rock district.

The lower member is a slope-forming unit that is often covered by sand or alluvium and consists mainly of medium-gray (N 5) to very dusky red-purple (5 RP 2/2) mudflow deposits and muddy to muddy-sandy conglomerates. The mudflow deposits and conglomerates are interbedded with planar-bedded to broadly cross-stratified, 0.3- to 30-cm thick immature sandstones. In the mudflow deposits, clast lithologies are dominantly andesites and latites (fig. 5), but Paleozoic limestone and sandstone clasts are locally abundant. The larger volcanic clasts range from 35 cm to 2 mm in largest diameter and are angular to well-rounded. They are composed of 3 to 25 percent, chalky to glassy phenocrysts of plagioclase and potassium(?) feldspar. Other phenocrysts normally recognizable in the clasts are hornblende or biotite.

The larger non-volcanic clasts are as small as 3 cm in largest diameter, although one block of limestone was measured by the author to be 25 ft (8 m) in length. In hand specimen, the limestone clasts are medium-gray (N 5) micrites with locally abundant brachiopods and fusulinids. The fusulinids are mid-Desmoinesian to late-Virgilian in age (D.A. Myers, 1979, written commun.). One thin section of a limestone clast was examined. Mineralogically, the sample consists of 90 percent micrite and 10 percent irregular patches of sparry calcite. Fossils (foraminifera, crinoids, pelecypods) make up about 2 percent of the thin section, and are partly or completely replaced by sparry calcite. Complete foraminifera tests and crinoid stems are sometimes present. Pelecypods have only one valve present, but are otherwise unbroken. A trace of chert is also seen in the thin section.

Figure 5. Mudflow breccia in lower Spears Formation in Jaralosa Canyon, about 0.2 mi (0.3 km) north of Jones Tanks.

A second type of sedimentary clast found in these mudflow deposits is a moderate-brown (5 YR 3.5/4), well-indurated, very-fine sandstone. These clasts have a maximum size of 16 cm (along their largest diameter) and are usually angular. The sandstones display cross-bedding with the cross-bed sets ranging from 0.4 cm to 1.2 cm in thickness. Microscopic study of the sandstone clasts reveals that 85 to 90 percent rounded to subangular quartz grains averaging 0.1 mm (range: 0.02 to 0.19 mm) in diameter are present. The quartz is elongate to equant in shape and about half of the grains exhibit undulose extinction. Chert makes up about 2 percent of these clasts, with magnetite, muscovite, and plagioclase present in trace amounts. About 10 percent of the sandstone consists of iron-oxide cement. The cross-bedding observed in hand sample is seen in thin section to be comprised of individual laminae 0.05 to 0.17 mm thick (usually one or two grains thick). Magnetite and quartz, when they have an elongate habit, are oriented parallel to the laminae.

The limestone clasts are typical of the Madera Limestone (Pennsylvanian) and the sandstone clasts are probably derived from the Abo Formation (Permian), (W.T. Siemers, 1979, oral commun.). The nearest known possible source areas for the Paleozoic clasts are the outcrops at Olney Ranch and Tres Montosas measured and described by Siemers (1973). At Tres Montosas, Wilkinson (1976) found the upper member of the Spears Formation in depositional contact with the Abo Formation. There, the Abo Formation contains clasts of Madera Limestone. Wilkinson (p. 12) proposed that the Abo outcrops formed a topographic high in the Tres Montosas area during the deposition of the Spears Formation. The Paleozoic rocks near Tres Montosas thus could have provided some of the non-volcanic clasts found in the lower member.

In thin section, one mudflow of the lower Spears contains about 30 percent 0.01 to 0.4 mm long plagioclase (An35, maximum value from 9 measurements, Michel-Levy method) and about 65 percent subangular, porphyritic latitic fragments which average 0.5 to 0.6 mm in diameter. About 1 percent of the thin section is comprised of subround, 0.1 mm long sanidine. About 5 percent magnetite, averaging about 0.3 mm in diameter, is present near the borders of lithic fragments. A trace of secondary hematite is disseminated throughout.

Finer-grained intervals of the lower member consist of clay-rich laminae and siltstone and immature sandstone beds as much as 25 cm thick, locally with well-developed cross-stratification. In hand specimen, feldspar and sand-size porphyritic clasts are set in a grayish-red (5 R 4/2) to medium-gray (N 5), silt- to clay-size matrix. The lithic fragments are subrounded to subangular and contain phenocrysts of white feldspar.

Euhedral, fresh biotite is present in amounts which range from 0 to 2 percent. The amount of volcanic clasts in these intervals is variable; with increasing clast abundance, siltstones and sandstones grade into conglomerates and mudflow deposits. The sandstones are generally medium-grained, immature, feldspathic-volcanic arenites to medium-grained, immature, volcanic arkoses.

One thin section of a sandstone contained about 50 percent plagioclase grains (An39, maximum value from 20 measurements, Michel-Levy method) and about 40 percent lithic fragments. The plagioclase grains exhibit a complete range in size from 0.3 mm to silt-size. Subround to subangular sanidine, averaging between 0.1 mm and 0.2 mm in length, comprises about 5 percent of the thin section. As much as 3 percent subangular magnetite crystals, as large as 1 mm in diameter, are present. The lithic fragments are usually subround and contain abundant plagioclase and traces of amphibole, pyroxene and olivine. Amphibole and olivine are partially replaced by magnetite and/or calcite.

Immature sandstone intervals predominate in the area 1.2 mi (1.9 km) northwest of Sawmill Well and in the vicinity of Three Log Well. Here, the sandstone beds are less than 50 cm thick and are interbedded with minor mudflow deposits. The sandstones range from pale brown (5 YR 5/2) to medium-light gray (N 6) and contain abundant, clear, euhedral laths of plagioclase. Other minerals recognizable in hand sample include fresh biotite and traces of quartz. In hand specimen, about 5 percent or less rounded to subangular, porphyritic lithic fragments are present. These fragments are brown to creamy white and average between 1 and 4 mm in largest diameter.

In thin section, the sandstones near Three Log Well contain about 40 percent, 0.5 mm, subparallel plagioclase laths (An44, maximum value from 24 measurements, Michel-Levy method), about three-quarters of which have oscillatory zonation. Also present is 2 to 3 percent anhedral biotite about 0.2 mm in length and 3 to 5 percent subhedral grains of magnetite. Traces of anhedral, strained quartz xenoclasts and disseminated hematite (as an alteration product of magnetite) are also present. The finer matrix has a cherty texture, averages about 40 percent of the rock, and consists of grains about 0.002 mm in diameter. Lithic fragments contain subhedral plagioclase and amphibole phenocrysts in either an aphanitic, hematitic groundmass, or in a groundmass of anhedral quartz(?) and minor plagioclase.

Local, thin mudflow deposits are also present in the area north of Sawmill Well. Here, they are of similar mineralogy as the surrounding sandstones, except they contain 15 to 30 percent lithic fragments. The lithic clasts range from 1 mm to about 1 cm, are subangular to subrounded, and are randomly oriented. In hand samples, the matrix consists of about 30 to 40 percent fine groundmass and about 30 percent clear, blocky to lathlike plagioclase. In thin section, the plagioclase average about 0.4 mm in length and have a composition of about An39 (maximum value from 14 measurements, Michel-Levy method). About 2 percent ragged biotite and 1 percent anhedral to euhedral amphibole along with traces of strained quartz and magnetite are also present. Lithic fragments have phenocrysts of plagioclase, amphibole, and biotite, set in a cherty-textured groundmass. Two or three lithic fragments consist of spherulitic masses which enclose biotite and amphibole.

Reineck and Singh (1975, p.253-257) state that, in an alluvial-fan environment, stream-deposited sediments are interlayered with mudflow deposits. Features which Reineck and Singh indicate as characteristic of the stream-deposited sediments, which are also present in the Gallinas Peak area, are: 1) well-developed bedding with local, large-scale cross-bedding; 2) alternating conglomeratic and fine-grained (sandstone, siltstone, and claystone) beds; and 3) poor sorting of the deposit. It is concluded that, at this locality, the sedimentary rocks of the lower member represent an alluvial-fan environment.

Hydrothermally altered portions of the lower Spears sedimentary rocks range in color from dark yellowish orange (10 YR 6/6) to greenish gray (5 GY 6/1) or grayish yellow-green (5 GY 7/2). Altered exposures are usually intensely sheared; however, original sedimentary structures are sometimes discernable. Effervescence of the hand sample in HCl is common. Thin sections reveal that the greenish color in outcrop is caused by replacement of the groundmass by bowtie-shaped crystals of chlorite. Sparse epidote crystals, as much as 0.2 mm diameter, are sometimes corroded or bordered by chlorite. Plagioclase is partly to completely altered to calcite. Interstices of brecciated portions are filled by veinlets of polycrystalline, 0.02 mm quartz (with undulose extinction) plus calcite, magnetite, and hematite.

Andesite and latite flows usually occur at the top of the lower member in the southeast portion of the study area. A hornblende-latite flow was also found north of the study area, 1.0 mi (1.7 km) east of Three Log Well. Individual flows are poorly exposed; they are often partially concealed by blow sand or by talus from the overlying, more resistant tuff of Nipple Mountain. The flows are estimated to average about 30 ft (9 m) in thickness; however, it is difficult to trace any flow laterally or vertically.

In hand specimen, these intermediate flows consist of 7 to 35 percent plagioclase phenocrysts set in a brownish-gray (5 YR 4/1) to medium-gray (N 5) aphanitic matrix. The feldspars normally lack orientation, although a trachytic texture is sometimes present. Plagioclase occurs as 1 to 3 mm, euhedral to subhedral (rarely anhedral), glassy to chalky laths. Hornblende occurs as euhedral, prismatic, black crystals commonly 3 mm (but as much as 7 mm) long. The hornblende is sometimes altered to epidote and outlined by a fine line of black, opaque minerals.

Thin sections reveal that the plagioclase has a composition of about An38 (maximum value obtained from two thin sections, 52 measurements, Michel-Levy method) and is commonly altered to calcite. Euhedral amphibole is either replaced by magnetite with a core of polycrystalline quartz, or rimmed by magnetite with a core of epidote, or completely replaced by magnetite. The amphibole originally comprised 3 to 5 percent of the rock. Eight-sided relict clinopyroxene(?) crystals, almost entirely altered to calcite, comprise about 3 percent of the rock. Quartz and magnetite fill fractures within the clinopyroxene(?) relics. The groundmass, averaging 60 to 65 percent of the rock, is composed of laths of plagioclase about 0.01 mm long. In one thin section, the microlites show parallel alignment. Veinlets of calcium carbonate and quartz, along with yellowish-brown stained potassic clays, are common secondary constituents of the groundmass. One euhedral crystal of apatite was seen in thin section.

Chapin and Seager (1975) suggest a northeasterly transport direction for the Spears Formation, away from source areas in the Magdalena Mountains and San Mateo

Mountains. The predominance of lava flows toward the upper portion of the lower member, and the general restriction of the flows to the southern portion of the study area, may be a reflection of the northerly encroachment of the volcanic rocks from which the Spears' alluvial apron was derived.

Upper Member

Continuous outcrops of volcanic rocks and volcaniclastic sedimentary rocks comprising the upper member of the Spears Formation are found in a north-trending swath in the center of the map area. The upper member has been subdivided into two mappable units in the Gallinas Peak area. These units are the tuff of Nipple Mountain and an overlying, distinctive series of pyroxene-bearing, "chocolate-chip"-textured, basaltic andesites and minor mudflow deposits. In the Council Rock and Tres Montosas areas to the south, Chamberlin (1974) and Wilkinson (1976) mapped the tuff of Granite Mountain at the top of the upper member; however, the tuff of Granite Mountain was not recognized in the Gallinas Peak area. The upper member, as estimated from cross-sections, varies in total thickness from a maximum of 865 ft (264 m) in the west-central portion of the area to less than 295 ft (90 m) in the northwest portion of the map area, and pinches out in the northeast portion of the area.

Tuff of Nipple Mountain. The name "tuff of Nipple Mountain" was coined by Brown (1972, p. 14) for a "pink ... crystal-poor ash-flow tuff" at the top of Nipple Mountain, about 4 mi (6 km) northeast of Magdalena. Chamberlin (1974, p. 16) redefined the tuff of Nipple Mountain to include the commonly associated "turkey-track" andesites. Chamberlin's definition is adopted in this report. Harrison (1980) and Coffin (in prep.) have correlated the tuff of Nipple Mountain with the tuff of Main Canyon of Lopez (1975).

Several isolated outcrops of the "turkey-track" andesite are found at the southern portion of the map area. In the study area, this andesite is found only at five localities and only at the base of the tuff of Nipple Mountain; elsewhere, it is generally below the tuff of Nipple Mountain but may be intercalated within it (Chamberlin, 1974; Wilkinson, 1976). The thickness of the "turkey-track" andesite ranges from 0 to 30 ft (9 m) in the thesis area. Weathering has reduced the andesite to rubbly outcrops and it is difficult to obtain a fresh surface on the rock. In hand specimen, weathered surfaces are covered by a dark yellowish-brown (10 YR 4/2) oxide stain. Fresher surfaces exhibit a dark-gray (N 3), aphanitic matrix with randomly oriented, clear to white, euhedral to subhedral plagioclase phenocrysts. These phenocrysts, 1 to 8 mm long, account for about 25 percent of the hand sample, and effervesce sightly in HCl. Sparse crystals of a reddish-brown oxidized ferromagnesian mineral are also found in hand specimen.

Microscopic inspection of the "turkey-track" andesite reveals that the matrix consists of euhedral to subhedral plagioclase microlites averaging 0.1 mm in length. The plagioclase phenocrysts have a composition of about An53 (maximum value from 22 measurements, Michel-Levy method) and the groundmass plagioclase has a composition of about An63 (maximum value from 21 measurements, microlite method). A trace of calcium carbonate occurs as patchy replacement of plagioclase phenocrysts and groundmass plagioclase. On a similar "turkey-track" andesite, Chamberlin (1974) obtained compositions of An53 for the plagioclase phenocrysts, and calcic andesine (no range given) for the groundmass plagioclase. Olivine(?) phenocrysts, in amounts of less than 1 percent, are extensively replaced by carbonate and a brown, opaque material. Magnetite associated with the relict phenocrysts lines irregular fractures and crystal boundaries. Magnetite presently accounts for about 15 percent of the thin section.

In the Council Rock District, Chamberlin (1974, p. 17) noted that the "turkey-track" andesite flows are not present in Gallinas Spring Canyon, but thicken to 100 ft (30 m) southward, near Arroyo Montosa. This, along with the sparse occurrence and restriction of the "turkey-track" andesites to the southern portion of the Gallinas Peak area probably indicates a southerly source for these lava flows.

The tuff of Nipple Mountain is an important stratigraphic unit in the Spears Formation, as it provides a distinctive horizon in an otherwise monotonous sequence of volcaniclastic rocks and lava flows. The tuff of Nipple Mountain crops out in a north-trending belt in the thesis area. Thicknesses obtained from cross-sections indicate the tuff is 295 ft (90 m) to 325 ft (100 m) thick in the central portion of the map area. However, the thickness may be less than 295 ft in the northwestern part of the thesis area. Here, some of the tuff of Nipple Mountain was eroded prior to deposition of the Hells Mesa Formation and the relationship between these two units is disconformable. Moreover, the tuff of Nipple Mountain is generally missing in the northeast portion of the map area.

Unaltered outcrops of the tuff of Nipple Mountain are expressed topographically as short, rounded ridges; however, where the unit is silicified it stands out as bold, gray to white ridges. Exposures weather to thin plates or blocks where moderately welded (fig. 6), and small white chips where poorly welded. Subangular to rounded, 0.5 mm to 1 cm lithic fragments comprise less than 2 percent of the rock. The clasts are brown and gray vesicular latites containing phenocrysts of plagioclase and (rarely) hornblende. In the Gallinas Peak area, variations in the amount of pumice and lithic fragments indicate that the tuff

Figure 6. Exposure of massive-weathering, moderately welded portion of the tuff of Nipple Mountain about 0.4 mi (0.6 km) northwest of Sawmill Well.

of Nipple Mountain is a multiple-flow, simple cooling unit. South of this study, evidence that the tuff of Nipple Mountain is a compound cooling unit is the presence of a "turkey-track" andesite that is possibly interbedded with the tuff (Chamberlin, 1974; Wilkinson, 1976).

In hand specimen, a trace to 15 percent of very pale orange (10 YR 8/2) pumice are set in a light-gray (N 7) to pale red-purple (5 RP 6/2) matrix. Samples from the upper and lower portions of the unit contain faint, 1 mm spheroids (cristobalite?). Less than 1 percent blocky, sanidine and a few biotite flakes are seen in the rock. Petrographically, the sanidine phenocrysts are anhedral to subhedral and average 1 mm in longest dimension. Plagioclase phenocrysts are present in trace amounts as elongated to blocky subhedra with irregular embayments. Traces of pleochroic, brown biotite and anhedral magnetite are also present. Hematite occurs as an alteration product of magnetite and as disseminated dust.

Sections from the lower portion of the tuff reveal that the matrix is comprised of 85 to 90 percent axiolitic-devitrified glass shards. The shards generally wrap around phenocrysts and unbroken glass bubbles are compressed to ellipses. About 10 percent of the thin sections examined consist of minute, low-birefringent, cherty-textured aggregates with undulatory extinction (cristobalite?). One thin section from the top of the unit consists of 80 to 85 percent cherty-textured masses, averaging 0.006 mm in size, mixed with about 5 percent pore space and 10 percent randomly oriented shards. The shards are replaced by clear, polycrystalline aggregates with undulose extinction and the groundmass is altered to clay-size potassic minerals.

A thin section taken from a platy-weathering horizon near the center of the tuff of Nipple Mountain is comprised of partly devitrified shards set in a brown glass matrix. The shards wrap around phenocrysts, and pumice fragments are sufficiently compressed so that no pore space remains. This densely welded section lacks cherty-textured replacement products.

Where silicification of the tuff is intense, the groundmass is replaced by cherty silica and veinlets of polycrystalline quartz that cut the fabric. Polycrystalline quartz also occurs as cores in axiolitic-devitrified pumice. Chamberlin (1974, p. 20) briefly discussed the propensity for the groundmass constituents to be replaced by cherty-textured silica in the tuff of Nipple Mountain; he speculated that the tuff of Nipple Mountain "appears to have been a preferrential channelway for hydrothermal solutions and/or meteoric waters, because of its high initial permeability." This is also a possible explanation for the silicification of the tuff of Nipple Mountain in the Gallinas Peak area. Alternatively, the cherty aggregates seen in thin section, and the spherulites seen in hand sample, may be the result of vapor-phase crystallization.

Where hydrothermally altered, the tuff of Nipple Mountain becomes pale reddish brown (10 R 5/4). Altered surfaces have blackened patches of iron oxide, sometimes with hematitic pseudomorphs of pyrite. Biotite flakes are copper-colored and pumice fragments are darker red than the matrix.

Upper Spears lavas and epiclastic rocks. A distinctive sequence of lava flows intercalated with a few coarse volcaniclastic horizons, comprises that portion of the Spears Formation overlying the tuff of Nipple Mountain. This unit of the Spears Formation crops out in two north-trending belts in the central map area. The total thickness of the flows, as estimated from cross-sections, averages 300 ft (91 m) but thickens to 560 ft (170 m) in the west-central portion of the map area. This unit is missing in the northern portion of the thesis area. The map pattern of the contact of the upper Spears with the overlying Hells Mesa Tuff suggests a conformable relationship between the two units. Exceptions are the presence of relief on the upper Spears in the vicinity of McGee Canyon, and the absence of the upper Spears in the northern portion of the thesis area.

In the vicinity of Three Log Spring Canyon, a 30-ft (9-m) sequence of sedimentary rocks, overlying the tuff of Nipple Mountain, contains abundant white clasts of that tuff in an orange, sandy matrix. A few widely separated exposures of blue and gray to moderate reddish-brown (10 R 4/6) argillaceous, coarse volcaniclastic rocks are present in the upper member. Clasts are matrix supported and the deposits generally lack internal stratification; however, clasts are sometimes oriented in a subparallel manner. Clasts range in size from sand-size grains to as large as 20 cm in diameter. Generally, the clasts are latitic to andesitic and contain phenocrysts of plagioclase and hornblende or pyroxene. As no exposures of hornblende-bearing latites are present in the upper member, clasts bearing hornblende were probably derived from either the lower member or from outside of the Gallinas Peak area. The matrix of these coarse volcaniclastic rocks consists of 0.3 mm and smaller, chalky fragments of feldspar along with silt- and clay-size particles. Textural similarities between coarse volcanic rocks of the upper member and those of the lower member suggest that these rocks are also mudflow deposits.

An unconsolidated, pale yellowish-brown (10 YR 6/2), poorly sorted, immature, feldspathic volcanic arenite is present on the southeast slope of Gallinas Peak. Inspection with a binocular microscope reveals that the sediment consists of 40 to 50 percent, 2-cm to 1-mm diameter, subangular to rounded volcanic fragments. Between 50 and 60 percent, 0.1 to 0.5 mm, angular, clear quartz and chalky feldspar grains are also present. This unconsolidated unit is probably the cause of the large slump on the east side of Gallinas Peak.

Sparse occurrences of grayish red-purple (5 RP 4/2) rhyolitic clasts with intensely contorted flow-banding are found in the southeastern portion of the map area, just east of hill "7906". These rhyolites are found only in float and are not seen in outcrop.

Overlying the tuff of Nipple Mountain at two localities in the northeast portion of the map area is a brownish-gray (5 YR 4/1) to yellowish-brown (10 YR 6/2), biotite-rich rhyodacite to quartz latite lava flow. A small outcrop of a flow similar to this was also found in the southern portion of the map area. A complete section of the flow is not exposed in the Gallinas Peak area, but the minimum thickness is about 80 ft (24 m). The flow locally overlies 60 to 80 ft (18 to 24 m) of loosely-consolidated conglomerates or mudflow deposits. Outcrops of the flow exhibit pronounced columnar jointing. The rock is well indurated and gives a ringing sound when struck with a hammer.

Megascopically, the flow consists of 0.3 to 0.5 mm, altered, subhedral to euhedral, prismatic plagioclase phenocrysts that sometimes show preferred orientation. The amount of plagioclase increases upward from 5 percent at the base to about 20 percent. The plagioclase phenocrysts are largely argillized, show some replacement by carbonate, and readily weather out of the rock, leaving a rectangular hole. Other phenocrysts present include 1 to 10 percent fresh, 2 to 3 mm, blocky to elongate sanidine and 2 percent, 0.5 to 2 mm, subhedral, bronzy biotite. Sparse lithic fragments are similar in composition to the host rock and also show alteration of the plagioclase.

A thin section of the rock shows conspicuous alteration of the plagioclase to clay and calcite. Biotite is pleochroic from deep-brown to red. Sanidine is partly altered to clay. The matrix consists of glass, partially devitrified to anhedral quartz crystals as much as 1 mm in diameter; small (0.004 mm), low-birefringent crystals of sanidine and/or tridymite are also present. A crude flow structure is enhanced by fine, hematitic bands.

The bulk of the upper Spears, above the tuff of Nipple Mountain, consists of "chocolate-chip"-textured, pyroxene-bearing, basaltic andesites (fig. 7). Thick sequences of these flows are present throughout the upper Spears. The rock weathers to homogeneous, angular float of porphyritic, medium light-gray (N 6) to moderate-brown (5 YR 3/4) clasts. Dark-green to red phenocrysts of pyroxene impart a "chocolate-chip" texture to the clasts. On fresh

Figure 7. "Chocolate-chip"-textured andesite. Dark phenocrysts are pyroxene. Photograph taken in Jaralosa Canyon, 0.6 mi (1.0 km) northwest of Sawmill Well.

surfaces, the phenocrysts are set in a uniform, grayish-red (10 R 4/2) to black (N 1) matrix. Exposures of this slope-forming unit are confined to arroyo and canyon walls. Occasionally, monolithic flow breccias are found between flows and near the top of the sequence. The clasts of the flow breccia tend to lack pyroxene phenocrysts. Outcrops sometimes exhibit columnar jointing (as near the mouth of Three Log Spring Canyon). A crude to well-developed flow foliation and some preferrential orientation of plagioclase and pyroxene phenocrysts are also present. The flow foliation varies in dip from subvertical to subhorizontal. Elongate to blocky pyroxene phenocrysts, in amounts as much as 2 percent, average 5 to 6 mm in length and are of two varieties: a green-weathering type and a red-weathering type. The green pyroxenes are as long as 1.4 cm and the red pyroxenes are stubbier and usually less than 1 cm in length. Phenocrysts of white to clear plagioclase as much as 2 mm long comprise as much as 25 percent of a hand sample.

Microscopically, the plagioclase is anhedral to euhedral, averages 0.5 to 0.6 mm in length, and has poorly to well-developed oscillatory zoning. The plagioclase composition averages An63 (average of 14 measurements, from 6 thin sections, combined Carlsbad-Albite twin method; range: 52 to 70). Phenocrysts of twinned, euhedral to anhedral clinopyroxene, averaging 0.1 to 0.2 mm in size, comprise from 1 to 10 percent of any given thin section.

Orthopyroxene (probably hypersthene) is present as subhedral, prismatic phenocrysts, usually smaller than the clinopyroxene, and is sometimes enclosed by the more abundant clinopyroxene. A glomeroporphyritic cluster of clinopyroxene, biotite, and plagioclase was observed in one thin section. Several red, altered pyroxene phenocrysts seen in thin section are bordered by minute aggregates of chlorite(?), hematite, and/or magnetite; the cores of these phenocrysts are altered to hematite, polycrystalline quartz, and sparse, shredded aggregates of chlorite(?). In a thin section from the south portion of the map area, clinopyroxene shows partial to complete alteration to an intense green, chlorite-like mineral plus calcite, minor polycrystalline quartz (with undulose extinction), and magnetite. In the same thin section, portions of the plagioclase have been altered to calcite. In another thin section, pyroxene was partly to completely replaced by shredded masses of chlorite(?) and the remainder of the thin section was unaltered.

The matrix of the flows, averaging about 70 to 75 percent of any given thin section, consists of felted, 0.01 to 0.04 mm microlites of plagioclase and magnetite usually set in glass. Hematite is often disseminated throughout the thin section, giving a brown color to the glass. Magnetite is usually surrounded by a halo of hematite or is altered to limonite. A trace of potassic-clays in the matrix and a trace of corroded biotite with inclusions of magnetite are found in some thin sections.

Wilkinson (1976), in the Tres Montosas-Cat Mountain area, found flows in the upper Spears which contained red-weathering pyroxene phenocrysts as much as 6.6 mm long. Similar "chocolate-chip"-textured, basaltic andesites have been found in float of the Spears Formation in an area 9 mi (14 km) to the west-northwest of the Gallinas Peak area (G.C. Coffin, 1979, oral commun.). No source vent for these flows was exposed in the Gallinas Peak area. However, westward thickening of these flows to greater than 500 ft (152 m) may reflect a possible buried intrusive center near the western margin of the study area.

Hells Mesa Tuff

Tonking (1957) named the Hells Mesa Member of the Datil Formation and measured a type section in the northern Bear Mountains (sec. 31, T. 2N., R. 4W.). Chapin (1974a) and Deal and Rhodes (1976) have since upgraded the Hells Mesa Member to formational rank and restricted the Hells Mesa Tuff to the crystal-rich, quartz-rich portion of Tonking's original Hells Mesa Member. The Hells Mesa Tuff was referred to as a rhyolite-porphyry sill by Loughlin and Koschmann (1942) and was called the tuff of Goat Spring by Brown (1972).

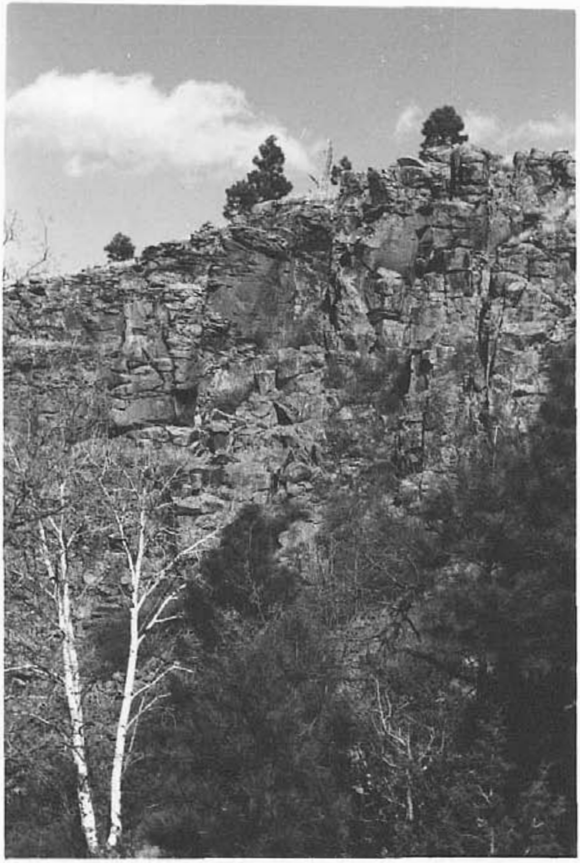
The Hells Mesa Tuff has been recognized as a unit of regional importance through geologic mapping in the Gallinas, Bear, San Mateo, Magdalena, Chupadera, and Lemitar Mountains, as well as east of the Rio Grande in La Joyita Hills. Weber and Basset (1963) obtained a date of 30.6 ± 2.8 m.y. using the K-Ar method on biotite from near the base of the formation at Hells Mesa. In better agreement with other dated units are the K-Ar dates of 32.1 ± 1.5 m.y. and 32.4 ± 1.5 m.y. obtained on biotite from the Hells Mesa Tuff in the Gallinas Mountains and La Joyita Hills by Burke and others (1963). The Hells Mesa Tuff originated from the North Baldy Cauldron in the Magdalena Mountains (Chapin and others, 1978a).

The Hells Mesa Tuff usually conformably overlies the Spears Formation in the Gallinas Peak area. This relationship becomes unconformable in the northern portions of the map area where the Hells Mesa directly overlies the tuff of Nipple Mountain and the lower Spears. The Hells Mesa Tuff also fills a paleovalley in the upper Spears near the head of McGee Canyon. When the local dip on the Hells Mesa is removed, the Spears Formation dips 10° to the northeast and the paleovalley strikes north. The Hells Mesa is separated from the overlying A-L Peak Tuff by a thin sequence of ash-flow and ash-fall tuffs. A local, thin arkosic sandstone, bearing lithic fragments of the Hells Mesa, is found at the top of the Hells Mesa Tuff in the vicinity of Whiskey Well.

Chamberlin (1974), suggested a minimum thickness of 800 ft (244 m) for the Hells Mesa Tuff at Gallinas Springs, near the southern boundary of the Gallinas Peak area. To the east of Jaralosa Creek, north of this study, Mayerson (1979) found the thickness of the tuff varied from 0 to a maximum of about 200 ft (61 m). About 12 mi (19 km) northwest of the Gallinas Peak area, Harrison (1979, oral commun.) has found between 300 and 400 ft (91 to 122 m) of Hells Mesa. In the southern portion of this study area, cross-sections indicate a thickness for the Hells Mesa Tuff of 650 ft (198 m). In the northwestern portion of the Gallinas Peak area, the thickness of the tuff decreases to about 350 ft (107 m). Thin remnants of the Hells Mesa along the piedmont escarpment to the northeast of the study area suggest that, in this region, the unit was deposited in localized channels.

Outcrops of the Hells Mesa Tuff are usually prominent cliffs with crude columnar jointing (fig. 8); talus from these cliffs conceals the contact with the underlying Spears Formation. In good exposures, the relatively pumice-rich basal horizons, which break easily into thin, slabby chunks, grade sharply upward into well-indurated, pumice-poor horizons.

Lithic fragments in the Hells Mesa Tuff are common locally near the base of the section, but are rare overall. Usually, the lithic fragments are purple to gray, aphanitic,



gure 8. Crudely developed columnar jointing in the Hells Mesa Tuff. Note also crude jointing developed parallel to subhorizontal compaction foliation. Photo taken about 770 ft (235 m) southwest of Sawmill Well.

subangular to rounded, and less than 1 cm in greatest dimension; they normally have phenocrysts of feldspar and altered ferromagnesian minerals. Elongate lithic fragments are oriented in the plane of compaction foliation. Most of the lithic fragments are probably derived from the Spears Formation. Variations in clast content, pumice content, and mineralogy suggest that in the Gallinas Peak area, the Hells Mesa is a multiple-flow, simple cooling unit.

Megascopically, specimens from the base of the Hells Mesa vary in color from medium gray (N 5) to light brownish gray (5 YR 6/1) and contain 10 to 15 percent, flattened, creamy-white pumice. Glassy, blocky, feldspar phenocrysts, averaging 0.5 mm in length, comprise about 25 percent of the basal portion of the tuff. A trace of quartz and 2 percent, euhedral, black to bronzy biotite are also present.

Commonly, within a few feet of the base of the unit, a moderate-brown (5 YR 3/4 to 5 YR 4/4) vitrophyre, as much as 12 ft (4 m) thick, is present. The vitrophyre contains about 25 percent feldspar phenocrysts, a trace of quartz, and 2 to 3 percent bronzy to black biotite. Pumice fragments are compressed into black, homogeneous glass (piperno) and are set in an aphanitic matrix.

Samples from the middle of the unit are pale red (10 R 6/2), contain 30 to 35 percent phenocrysts, and have 5 percent or less pumice. Quartz anhedra, as much as 3 mm in greatest dimension, are usually rounded and make up 5 to 10 percent of any given sample. Feldspar grains are blocky, partly rounded subhedra and have a glassy to chalky luster. Biotite flakes are black to bronzy, are present in trace amounts, and are often crudely arranged parallel to the compaction foliation. Rarely, glass shards can be distinguished wrapping around phenocrysts in hand sample.

The top of the Hells Mesa is moderate brown (5 YR 3/4), lacks pumice, and contains as much as 20 to 25 percent quartz. The clear to black (smokey) quartz anhedra are angular to well rounded, and as much as 3 mm in diameter. Glassy feldspar grains comprise about 15 percent of a hand sample, and biotite flakes are present in trace amounts.

Petrographically, the groundmass of the Hells Mesa Tuff is glass which has largely devitrified to low-birefringent crystals barely discernable from the groundmass. Pumice fragments, when present, are often devitrified to axiolites of low or moderate birefringence. The fibrous texture of unaltered pumice fragments is often enhanced either by incipient crystals, or by finely disseminated hematite. The pumice fragments are warped around phenocrysts and compressed so that no pore space normally remains. Glass shards are rare; when present, they can be seen to bend around phenocrysts. The Hells Mesa Tuff is densely welded throughout.

Although feldspar phenocrysts sometimes appear euhedral in hand sample, thin sections reveal they have been comminuted to anhedral and subhedral grains. Additionally, feldspar and quartz grains are often rounded. In some thin sections, pumice and trains of broken crystals are squeezed between phenocrysts. Subhedral to euhedral biotite, pleochroic in greens, reds, and browns, is often bent to partially conform to the surface of adjacent crystals. Euhedral to subhedral, pleochroic (from dark-brown to yellow) amphibole is usually present in trace amounts. Anhedral magnetite is a common accessory constituent.

Plagioclase is the dominant phenocryst near the base of the Hells Mesa Tuff, where it can make up 25 to 30 percent of the rock. The top of the formation, however, contains 5 to 10 percent sanidine and less than 5 percent plagioclase. Plagioclase grains sometimes show oscillatory zonation or strong normal zonation. The composition of the plagioclase from the bottom of the unit is about An34 (2 measurements, combined Carlsbad-albite twin method; averaged with the maximum value from 8 measurements, Michel-Levy method; range: 32 to 39). In a thin section from within 5 ft (1.5 m) of the top of the unit, the plagioclase has a composition of about An37 (maximum value from 11 measurements, Michel-Levy method).

The Hells Mesa Tuff acquires a dark yellowish-orange (10 YR 6/6) to light olive-brown (5 Y 5/6) color where hydrothermally altered. Sometimes, the only indications of alteration seen in hand specimen are the chalky appearance of the feldspars and their slight effervescence in HCl. Thin sections of altered Hells Mesa Tuff show that many plagioclase grains are partly replaced by patches of calcite and chlorite. Where the alteration is more intense, plagioclase is partly replaced by chlorite and epidote(?), and amphibole is altered to limonite and hourglass-shaped aggregates of chlorite. Disseminated limonite and hematitic pseudomorphs of pyrite are found in the groundmass. Polycrystalline quartz veinlets are sometimes found in these altered portions of the tuff.

A-L Peak Tuff

The A-L Peak Rhyolite was named by Deal and Rhodes (1976) for a 2000 ft (610 m) section on A-L Peak in the San Mateo Mountains, 24 mi (39 km) south of the Gallinas Peak area. Deal and Rhodes proposed that the tuff was erupted from a cauldron located in the San Mateo Mountains. Smith and others (1976), using the fission-track technique, obtained an age of 31.8 ± 1.7 m.y. on a sample collected near A-L Peak in the San Mateo Mountains. Regional mapping in the Socorro-Magdalena area indicates that the A-L Peak is comprised of three distinct members. Mapping in the Magdalena Mountains, 28 mi (45 km) southwest of the thesis area indicates that probably all three of these members originated from cauldron sources in the southern Magdalena Mountains (Chapin and others, 1978a,b). Thus, Deal and Rhodes' type-section may not be representative of, or even the equivalent of, the A-L Peak as presently mapped in this and other parts of the Socorro-Magdalena area.

The A-L Peak Rhyolite was renamed the A-L Peak Tuff by Chapin and others (1978a, p. 117). Equivalent, older terminology used in the Magdalena area includes the "banded rhyolite" of Loughlin and Koschmann (1942), the middle portion of Tonking's (1957) Hells Mesa Member, and the tuff of Bear Springs of Brown (1972).

In the Gallinas Peak area, outcrops of the A-L Peak Tuff are found in a southwesterly dipping band on the area's western margin and in scattered remnants on the area's northeastern margin. The tuff consists of an upper and lower cooling unit with a combined thickness of about 785 ft (239 m). The lower cooling unit consists of two members (Chapin and others, 1978b): a basal gray-massive member, and an overlying, flow-banded member. The upper cooling unit is called the pinnacles member for its characteristic outcrop appearance. South of the study area, Chamberlin (1974) described three cooling units in the A-L Peak; his lower cooling unit represents the lower and upper cooling units described in this study. The mafic lavas and upper two cooling units in the west portion of Chamberlin's (1974) study area are now known to be equivalent to the basalts of Jones Tanks and Antelope Flats, and the tuff of South Canyon of this study. The mafic lavas lie entirely above the A-L Peak Tuff south of the southwest portion of this study area (G.R. Osburn, 1980, oral commun.). A sequence of mafic lavas which often separates the flow-banded member from the pinnacles member elsewhere in the Socorro-Magdalena area, is present as thin, discontinuous outcrops found only in the northeastern Gallinas Peak area (basalt of Jones Tanks).

A thin sequence of ash-flow and ash-fall tuffs, herein described as "Lower Tuffs", is present at the base of the A-L Peak Tuff. These tuffs are mapped with the A-L Peak Tuff because of a mutually similar phenocryst composition and phenocryst abundance.

Lower Tuffs

In the thesis area, a thin sequence of poorly welded, moderately crystal-poor, ash-flow and ash-fall tuffs normally separates the lower cooling unit from the Hells Mesa Tuff (fig. 9). At the base of this sequence is a poorly welded, pumice-rich zone, 1 to 2 ft (0.3 to 0.6 m) thick. In hand specimen, 5 to 10 percent, small (1 to 10 mm), slightly compressed pumice fragments are set in a grayish orange-pink (5 YR 7/2) to pale red-purple (5 RP 6/2) matrix. Clear, subhedral, 1 mm phenocrysts of sanidine comprise 2 to 3 percent of any given hand sample. One to

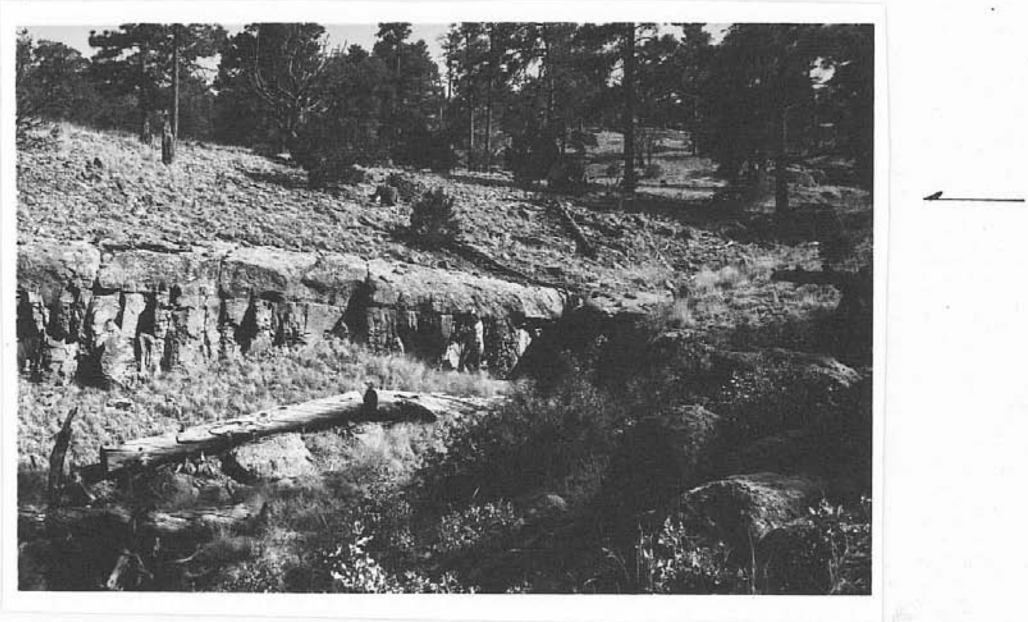


Figure 9. Conformable contact between the Hells Mesa Tuff and an overlying, thin sequence of tuffs. Break in slope at right background is the gray-massive member of the A-L Peak Tuff (arrow). Photo taken at head of Three Log Spring Canyon.

two percent, 1 mm quartz anhedra are also present. Most of the pumice fragments contain minute (less than 0.5 mm) spherulitic aggregates, and portions of the groundmass also contain minute spherulites. Yellow and black staining of the matrix and pumice is sometimes found. Sparse, subrounded to rounded, mafic rock fragments, less than 1 cm in diameter are also found in hand specimen.

Overlying the poorly welded tuff is a thinly bedded, moderately indurated, ash-fall tuff. This horizon is usually about 1 ft (0.3 m) thick and consists of 0.5 cm to 3 cm, pinkish-gray (5 YR 8/1), planar beds. Subhedral to anhedral sanidine, averaging less than 1 mm comprises less than 1 percent of the rock. Anhedral to euhedral, dipyramidal quartz is slightly more abundant than sanidine and averages between 0.5 and 1 mm in size. Minute grains of a ferromagnesian mineral, altered to hematite, dot the aphanitic matrix.

The ash fall is overlain by a poorly welded, pumice-rich, pinkish-gray (5 YR 8/1) ash-flow tuff. This tuff is 1 to 3 ft (0.3 to 0.9 m) thick and contains 3 to 5 percent, clear, quartz anhedra, about 1 mm in diameter. Subhedral sanidine is about the same as quartz in size and abundance. Fibrous, crudely oriented pumice fragments, as much as 1 cm in length comprise about 15 percent of the rock. The tuff contains sparse, pink, rounded, aphanitic lithic fragments that average about 5 mm in diameter.

Patches of black, oxide coatings are common in hand specimen. Petrographically, shards have a general random orientation and unbroken glass bubbles are uncompressed, although some shards wrap around phenocrysts. The shards are devitrified to axiolites of low to moderate birefringence, and the groundmass is devitrified to microlites. Prismatic sanidine phenocrysts are sometimes slightly bent and have undulose extinction.

A pale-red (5 R 6/2), poorly welded, crystal-poor, ash-flow tuff several feet thick is present overlying the more pumice-rich, crystal-rich ash-flow tuff. In hand specimen, slightly compressed, creamy-white pumice fragments, as much as 4 cm long comprise about 5 percent of the rock. One to two mm, glassy sanidine phenocrysts account for about 1 percent of the rock. Anhedral quartz, slightly smaller than sanidine, is present in trace amounts. In thin section, some of the sanidine has been strained, imparting a wavy extinction to the grains. Trace minerals include anhedral plagioclase, and euhedral amphibole partly replaced by chlorite and hematite. Glass shards are slightly bent around phenocrysts, but unbroken glass bubbles remain circular. The randomly oriented shards are set in a groundmass that is stained red by disseminated hematite. Shards show some axiolitic devitrification. The fibrous nature of the pumice is enhanced by its partial devitrification.

These thin tuffs overlying the Hells Mesa are of uncertain origin, but may represent an early eruptive phase of the A-L Peak Tuff. G.R. Osburn (1979, oral commun.) has found similar tuffs in the area adjacent to the northwest boundary of the Gallinas Peak area.

Lower Cooling Unit

In the Gallinas Peak area, the lower cooling unit of the A-L Peak Tuff is a multiple-flow, simple cooling unit of poorly to densely welded, crystal-poor, pumice-poor to pumice-rich, rhyolite ash-flow tuffs. The lower cooling unit could have been mapped as two distinct members: a lower, gray-massive member, and an upper, flow-banded member. These members are thought to be erupted from the Magdalena cauldron, or, in part, from the Sawmill Canyon cauldron in the Magdalena Mountains (Chapin and others, 1978a,b; Roth, 1980). A thin sequence of ash-flow and ash-fall tuffs (Lower Tuffs, p. 55) normally separates the gray-massive member from the underlying Hells Mesa Tuff in the thesis area. The pinnacles member of the A-L Peak conformably overlies the flow-banded member in the southwestern portion of the thesis area, but is separated from the flow-banded member by a thin sequence of mafic lavas in the northeastern Gallinas Peak area.

Cross-sections indicate a thickness of about 510 ft (155 m) for the lower cooling unit in the west portion of the study area. In the northeast portion of the Gallinas Peak area, thin remnants of the lower cooling unit are present at the base of a piedmont escarpment. At one place in this vicinity, these tuffs occupy a channel cut into the lower Spears; at another locality, they are in fault contact with the Baca. Along the western margin of the thesis area, the lower cooling unit caps the gentle, southwesterly dipping slopes overlooking the Plains of San Augustin.

Hydrothermal alteration in the lower cooling unit is rare. Near the western boundary of the map area, in an arroyo along the border of the Plains of San Augustin (SW1/4, sec. 12, T. 1S, R. 7W), an exposure of the tuffs was coated with a dull black material which gave a greenish-black streak. No brecciation was seen in the vicinity of this outcrop. In the extreme southwestern portion of the map area, the pumice fragments in the gray-massive member are darkened greenish black to black and the matrix is unaltered. This alteration is in the vicinity of a northwest-trending fault and may bear a genetic relation to the fault.

Gray-massive member. The pumice-poor, crystal-poor, gray-massive member forms an unmistakable break in slope at its contact with the thin, underlying, less resistant ash-flow and ash-fall tuffs (fig. 9). The topographic break is usually small; however, near the border of the Plains of San Augustin, 10 to 20 ft (3 to 6 m) cliffs of the gray-massive member are sometimes present. In the southwest portion of the map area, the maximum thickness for the gray-massive member is estimated to be 300 ft (91 m).

In fresh hand specimens, the gray-massive member consists of sparse, glassy to chatoyant sanidine phenocrysts, averaging about 1 mm in length, set in a very light-gray (N 8) matrix. Pumice fragments are rare near the base of the member, but lenticular-shaped pumice fragments, slightly darker than the matrix, increase in abundance toward the top of the member. Rare, sub-rounded, andesitic fragments are also present. Petrographically, between 1 and 2 percent, prismatic to blocky sanidine phenocrysts are set in a matrix of axiolitic-devitrified glass shards. Unbroken glass bubbles are slightly flattened and the shards are preferentially oriented, bending slightly around phenocrysts. Traces of anhedral plagioclase and magnetite, as well as euhedral, altered amphibole are also present. The amphibole is mostly replaced by magnetite and encloses biotite(?).

Flow-banded member. Overlying the gray-massive member, and welded(?) to it (or possibly gradational with it), is the densely welded, crystal-poor, flow-banded member. The estimated maximum thickness for the flow-banded member is 210 ft (64 m). The flow-banded member caps gently sloping ridges in the southwest and west portion of the thesis area. Outcrops in the northeastern Gallinas Peak area are generally poorly exposed along a piedmont escarpment, because of the thin, discontinuous nature of the unit in this vicinity. In decreasing order of abundance, the most prominant primary flow-features seen in outcrop are lineated pumice, broad flow-folding, and rotated, welded inclusions of the preceeding flow. Flattened, lineated pumice fragments are characteristic of the flow-banded member; thier linear nature becomes less obvious toward the upper portions of the flow and in the northwestern portion of the thesis area. The average trend of these linear features, when the regional strike and dip is removed, is N 16° W (taken from a total of 10 measurements, visually averaged from a stereographic plot). Schmincke and Swanson (1967) have shown that such lineations are the result of primary laminar flowage, and that the lineations parallel the flow direction of the tuff, away from its source. In the Council Rock area, Chamberlin (1974, p.36) found lineations which varied from N 8° W to N 3° E.

Broad flow-folds in the flow-banded member are also found in the thesis area. These folds are poorly exposed and are often expressed as local aberrations in the strike and dip of compaction foliation. The axial planes of the folds are sub-parallel to the average trend of the pumice lineations. These are considered to be the result of minor adjustments of the ash flow which occurred after movement of the flow as a unit ceased. Chamberlin (1974) describes primary flow-folds in the flow-banded member in the Council Rock District; he found the axial planes of the primary flow-folds to be roughly perpendicular to the pumice lineations.

Wildly contorted compaction foliation, surrounding densely welded fragments from the same member, were seen at one outcrop (fig. 10). The fist-size fragments are rotated so that their compaction foliation is almost perpendicular to that of the surrounding matrix. The matrix is partially draped around, and leaves cavities on either side of the inclusions. As both the inclusion and matrix are densely welded, the inclusions could have been ripped up from the underlying flow during initial emplacement of the subsequent flow, but only after much compaction had taken place. Schmincke and Swanson (1967) have described similar features, except that the inclusions were poorly welded tuffs or xenoliths; they interpreted the features as structures produced during initial emplacement of the tuff.

In fresh hand specimens of the flow-banded member, 1 to 3 percent, euhedral to anhedral, glassy sanidine phenocrysts are set in a moderate-brown (5 YR 3/4) to light-gray (N 7) matrix. Quartz anhedra, less than 1 mm in diameter account for 1 percent or less of the tuff. Pumice fragments range from intensely flattened and lineated in the lower and middle portions, to discoid and open in the upper portion of the unit. Small (1 to 4 mm), subrounded to

Figure 10. Rotated, welded inclusions in an intensely contorted, welded matrix of the flow-banded member of the A-L Peak Tuff. Photo taken about 0.4 mi (0.6 km) south of the head of Three Log Spring Canyon.

rounded mafic rock fragments are present in amounts of as much as 1 or 2 percent in some samples.

At the top of the flow-banded member is a semicontinuous, moderately welded zone 0 to 10 ft (3 m) thick. The phenocryst content is similar to the rest of the unit, but its chocolate-brown color and massive appearance make it a distinctive horizon. Fresh hand specimens have euhedral to anhedral sanidine phenocrysts set in a pale yellowish-brown (10 YR 6/2) to pale-red matrix (10 R 6/2). Pumice fragments are less abundant and smaller than in the rest of the flow-banded member.

Microscopic examination of the lower cooling unit shows that 0.1 to 2 mm sandine crystals are usually fresh, but sometimes have a cellular texture and wavy extinction. Euhedral amphibole, shredded biotite, magnetite, and anhedral plagioclase are present in trace amounts. One xenocryst of euhedral microcline was seen. Traces of quartz are also present; one quartz anhedra, about 1 mm in diameter, was strongly embayed.

In thin sections from the basal and middle portions of these tuffs, the original shard texture has been almost completely destroyed as a result of devitrification of the groundmass to minute (less than 0.01 mm diameter) cristobalite(?) and sanidine crystals. Intensely flattened pumice fragments bend slightly around phenocrysts, and are devitrified to axiolites surrounding spherulitic cores and interlocking arrays of low-birefringent crystals. Some pumice fragments include cellular to fresh sanidine phenocrysts. In one thin section, (from a sample near the middle of the flow) arcuate structures (perlitic cracks?) clouded by limonitic dust, pervade the groundmass.

In thin sections from the upper portion of the unit, the shard structure is retained and the pumice is not intensely flattened; however, the compaction foliation is still obvious from the parallel arragement of glass shards and pumice. In all thin sections from the flow-banded member, the matrix is pervaded by fine hematitic dust.

Upper Cooling Unit

Pinnacles member.

The pinnacles member of the A-L Peak Tuff is separated from the flow-banded member by a pronounced cooling break, and is the youngest cooling unit of the A-L Peak Tuff (Chapin and others, 1978a,b). This upper cooling unit is a multiple-flow simple cooling unit of poorly to densely welded, crystal-poor rhyolite tuffs. These tuffs are thought to have originated from the Sawmill Canyon cauldron in the Magdalena Mountains (Chapin and others, 1978a,b).

The pinnacles member of the A-L Peak Tuff is poorly exposed along the piedmont escarpment in the northeastern Gallinas Peak area. Here, outcrops are separated from the underlying flow-banded member and from an overlying sequence of rhyolite tuffs by thin, mafic lava flows. In the southwestern Gallinas Peak area, the pinnacles member conformably overlies the flow-banded member and is overlain by a thick sequence of basalts and coarse sedimentary rocks. Here, these tuffs crop out over about a 0.5 sq mi (1.3 sq km) area and have a maximum estimated thickness of 275 ft (84 m). Faulting in this region has placed the pinnacles member in contact with the Hells Mesa Formation, the flow-banded member, and the overlying sedimentary rocks, lavas and tuffs.

The pinnacles member is usually well indurated, but outcrops are normally low, unimposing ledges. Float of chips and blocks usually forms a coarse mantle on the southwesterly dipping slopes in the vicinity of Whiskey Well.

At the base of the pinnacles member is a thin, pinkish-gray to grayish orange-pink (5 YR 8/1 to 5 YR 7/2), poorly welded horizon. A topographic bench is usually present along the contact of these basal tuffs and the underlying, densely welded tuffs of the flow-banded member. Hand samples of the poorly welded tuffs usually contain 10 to 15 percent, angular, randomly oriented pumice fragments, 1 to 20 mm in diameter. Phenocrysts in these poorly welded tuffs are sparse (1 percent or less); sanidine is the dominant phenocryst, and quartz is present in lesser amounts. Lithic fragments are locally abundant, sometimes comprising about 40 percent of any given hand sample. The lithic fragments include silcified clasts of a banded rhyolite, silicified clasts of the Hells Mesa Tuff, red to black andesitic clasts, and gray, cherty, lithic fragments (fig. 11). The angular to subangular, silicified rhyolite clasts are dark-gray and contain sparse phenocrysts of quartz and sanidine. A rhyolite lava flow similar in composition to these rhyolite clasts was found by G.R. Osburn (1979, oral commun.) south of the southwestern Gallinas Peak area near Lion Mountain.

Fresh hand samples of the pinnacles member, above its poorly welded base, are very light gray to pale yellowish brown (N 8 to 10 YR 6/2), and contain about 1 to 7 percent euhedral to subhedral, glassy to chatoyant sanidine phenocrysts, and a trace of anhedral quartz. Pumice fragments are moderately flattened, comprise 5 to 15 percent of the rock, and are devitrified to fine, botryoidal and granular masses so that the original pumice texture is rarely preserved (fig. 12).

Microscopic study of the pinnacles member reveals that, although sanidine appears euhedral in hand specimen, it usually appears anhedral or subhedral in thin section. The 0.05 mm to 3 mm long sanidine phenocrysts sometimes have a cellular texture and large quartz-filled embayments. Traces of anhedral quartz, altered biotite, amphibole, and pyroxene are seen in thin section. The biotite, amphibole,

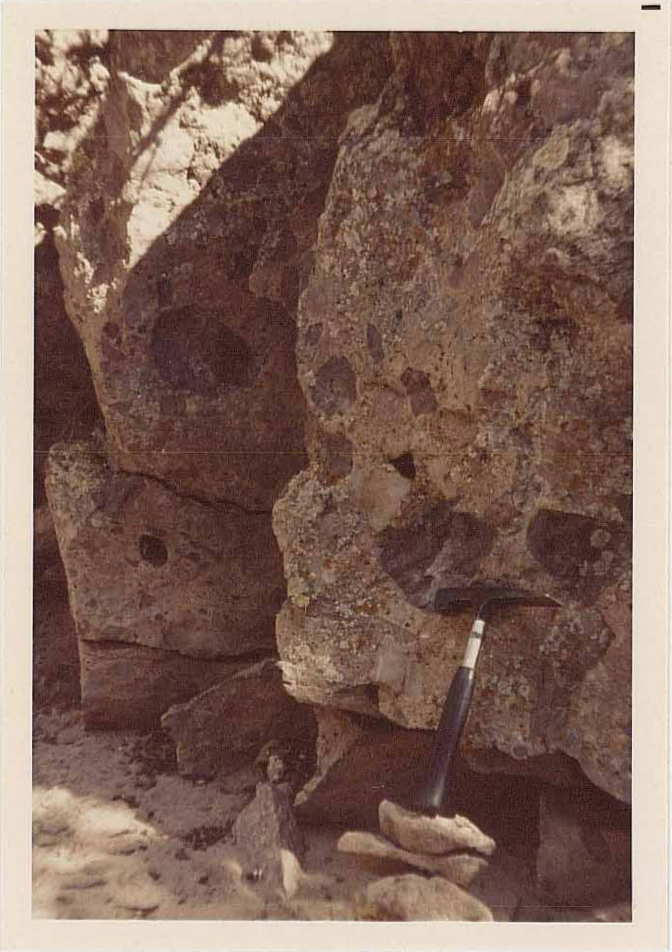


Figure 11. Lithic-rich basal portion of the pinnacles member of the A-L Peak Tuff. Clasts are dominantly comprised of the Hells Mesa Tuff and a banded rhyolite. Location is about 670 ft (240 m) southwest of Whiskey Well.

Figure 12. Partially compressed pumice fragments in pinnacles member of the A-L Peak Tuff about 930 ft (283 m) southwest of Whiskey Well.

and pyroxene are partly replaced by hematite-stained magnetite. One thin section from near the top of the unit contains about 1 percent anhedral magnetite as much as 0.5 mm in diameter. Axiolitic- and spherulitic-devitrified pumice fragments are present in thin sections from the lower half of the pinnacles member. The spherulites usually enclose irregular and bladed aggregates of cristobalite(?) and cellular sanidine. In contrast, pumice fragments from the upper half of the member lack spherulites and are devitrified to axiolites and interlocking arrays of sanidine and cristobalite(?). In the lower portion of the tuff, glass shards are strongly deformed to conform to the edges of phenocrysts and are devitrified (in part) to fine (0.05 mm or less) masses of sanidine and cristobalite(?). Thin sections from the moderately to poorly welded upper portion of the member generally show less shard distortion. The shards are partly devitrified to very fine (about 0.002 mm long), low-birefringent axiolites. The groundmass in sections from near the top of the unit is devitrified to 0.004 to 0.03 mm interlocking arrays of quartz and sanidine. Fine, hematite dust enhances the shard structure in most thin sections. Two lithic fragments seen in thin section were comprised of plagioclase and ferromagnesian minerals. The ferromagnesian minerals had been extensively replaced by magnetite and quartz.

Mafic Lavas and Sedimentary Rocks

Mafic lavas overlie the pinnacles member of the A-L Peak in two widely separated portions of the Gallinas Peak area. The lavas are exposed along the northeastern border of the map area, northeast of Jones Tanks, and in the southwest portion of the area, north of Antelope Flats. Minor exposures are also found southeast of Antelope Flats. The lack of continuous exposure of these lavas from Jones Tanks to Antelope Flats makes correlations impossible; however, petrographic study indicates that the flows are of similar composition.

Basalt of Jones Tanks

Flows of basaltic composition crop out along the piedmont escarpment in the northeastern portion of the thesis area. Here, the thin, erratic distribution and discontinuous nature of the lavas, with respect to the underlying A-L Peak Tuff, suggest that the lavas were deposited in channels cut into the older tuffs. At two localities northeast of Jones Tanks, the basalts separate the pinnacles member from the flow-banded member of the A-L Peak Tuff. Outcrops of these lavas are usually small exposures partly concealed by colluvium shed from the overlying piedmont gravels.

In fresh hand specimens, 2 to 3 percent hematitic pseudomorphs of olivine and pyroxene, and 1 to 2 percent green phenocrysts of pyroxene are set in a medium-gray (N 5) matrix. The phenocrysts average between 0.5 and 1.0 mm in length. Almond-shaped vesicles are present in some specimens.

Thin section analysis reveals that two types of phenocrysts and microlites of pyroxene are present: euhedral hypersthene, and subhedral clinopyroxene. Prismatic hypersthene phenocrysts, averaging about 0.6 mm in length, are altered to hematite and lesser amounts of minute (less than 0.002 mm), low-birefringent aggregates, and are rimmed by magnetite grains. Green phenocrysts of clinopyroxene, averaging approximately 0.2 mm in length, are about twice as abundant as hypersthene, and are usually embayed and cellular. Olivine euhedra and subhedra account for about 2 percent of the thin section examined, and are altered to hematite and 0.002 mm and less, low-birefringent aggregates.

An estimate of the groundmass composition is: 50 to 55 percent, 0.1 mm or smaller, labradorite laths (composition is about An60, maximum value out of 7 measurements, Michel-Levy method); approximately 30 percent green, 0.002 mm to 0.01 mm long, clinopyroxene microlites, about 1 percent yellow, 0.02 mm long, laths of hypersthene; and about 15 percent anhedral grains of magnetite. Many of the clinopyroxene microlites are enclosed by plagioclase;

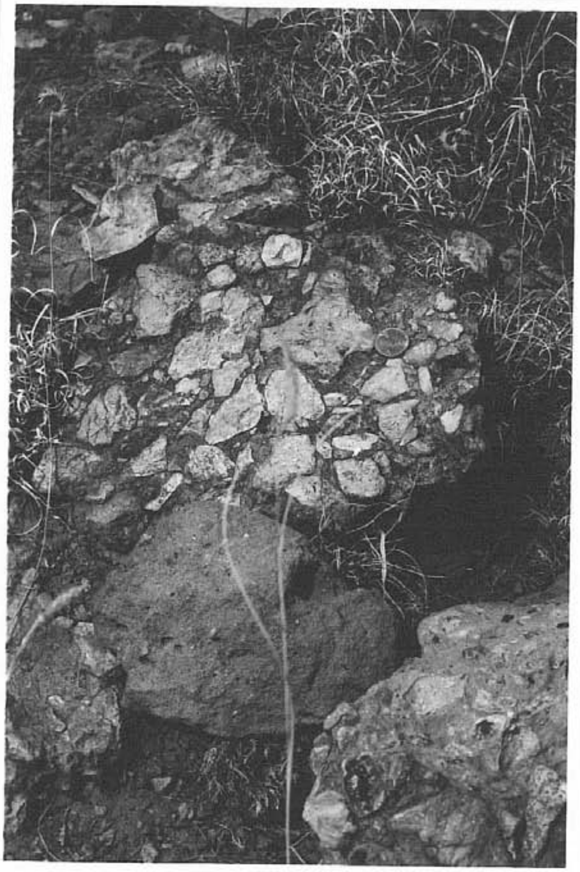
some of the magnetite may be an alteration product of olivine. Occasionally, small irregular carbonate patches replace the plagioclase.

Basalt and Sedimentary Rocks of Antelope Flats

Overlying the pinnacles member of the A-L Peak Tuff in the southwestern Gallinas Peak area is a thin sequence (about 180 ft, 55 m) of basalt flows and intercalated sedimentary rocks. Exposures are confined to small, slope-forming, rubbly outcrops both north and southeast of Antelope Flats. The lava flows consist of pale-brown (5 YR 5/2) to medium-gray (N 5) basalt flows which have from 5 to 20 percent, irregular- to almond-shaped vesicles as much as 20 mm long. The vesicles usually have a preferential orientation, and are sometimes filled with calcite. One vesicle lineation had a bearing of N 32° W after removing the regional dip of the flows. Hand samples of these flows sometimes contain several percent olivine and clinopyroxene phenocrysts, as much as 1 mm long, which are altered to hematite. Sparse phenocrysts of plagioclase are also seen in some hand samples.

Petrographic analysis of these lavas shows that from 7 to 10 percent, anhedral to euhedral clinopyroxene crystals are present. These crystals average between 0.05 and 1 mm in length, and are sometimes twinned. Anhedral to euhedral, 0.02 to 0.5 mm olivine phenocrysts account for between 1 and 5 percent of any given thin section. Some of the olivine is partially altered to, or encloses, magnetite. Portions of the olivine crystals contain patches of hematite along with a brown, opaque material, and low-birefringent, needle-like crystals (antigorite?). Out of two thin sections examined from these basalts, one contains about 15 percent, euhedral to subhedral (rarely anhedral), 0.5 to 1.3 mm plagioclase phenocrysts with randomly oriented, 0.02 to 0.2 mm groundmass plagioclase. A few of the plagioclase phenocrysts are normally zoned. A second thin section contains 70 to 80 percent, pilotaxitic plagioclase having a continuous range in size from about 0.05 to 0.5 mm. Plagioclase phenocryst and microcryst compositions indicate that these flows are probably basalts. In the thin section with both phenocryst and groundmass plagioclase, the groundmass plagioclase had a composition of about An58 (maximum value from 14 measurements, Michel-Levy method); the phenocryst plagioclase averaged An74 (average of two measurements, combined Carlsbad-albite twin method, range: An67 to An81). In the second thin section, plagioclase averaged An74 (average of two measurements, combined Carlsbad-albite twin method, range: An72 to An76). Each thin section contains from 3 to 5 percent magnetite anhedra in a glassy groundmass which turns brown in reflected light.

Intercalated with the basalts are sedimentary rocks which consist of poorly to well-indurated, medium- to thick-bedded sandstones and sandy conglomerates (fig. 13). These sedimentary rocks are poorly exposed, but some outcrops are found on hillslopes where colluvium and talus have been stripped away. The sandstones were not studied in detail, but estimates using a hand lens suggest they are fine- to medium-grained, and moderately to poorly sorted, immature litharenites to feldspathic litharenites. Some samples are possibly sublitharenites and lithic arkoses. The sandstones and conglomeratic sandstones contain lithic fragments which range from fine sand to cobble size (0.2 mm to about 90 mm). Lithic fragments, in order of abundance, include purple to black andesites(?); gray, silicified, flow-banded rhyolite; and red, silicified chips from the Abo Formation. The rhyolite fragments are similar to the rhyolite clasts described in the pinnacles member, and found by G.R. Osburn (1979, oral commun.) south of the thesis area. The sparse occurrence of the Abo clasts suggests that either a topographic high of the Abo existed locally during deposition of this sedimentary unit, or that the clasts are reworked clasts derived from an earlier period of erosion. Wilkinson (1974, p. 12) found the Abo Formation unconformably overlain by the Spears Formation south of Antelope Flats, in the vicinity of Tres Montosas. Provided that a topographic high of the Abo Formation still existed in the Tres Montosas area during deposition of these post-A-L Peak Tuff sedimentary rocks, that area could have been a source for these clasts.



igure 13. Sandy conglomerates and sandstones of the sedimentary rocks of Antelope Flats. Here, clasts are mostly banded rhyolite, but rock fragments of the Abo Formation are locally abundant. Photo taken about 0.6 mi (1.0 km) southwest of Whiskey Well.

Tuff of South Canyon

The tuff of South Canyon was named by Osburn (1978, p. 49) for a measured section of crystal-poor to moderately crystal-rich ash-flow tuffs located at the mouth of South Canyon in the Magdalena Mountains, about 26 mi (42 km) southeast of the Gallinas Peak area. A K-Ar age of 26.2 ± 1.0 m.y. was obtained on biotite from a sample of the same tuff from the Joyita Hills (Osburn, 1978, p. 49).

Exposures of the tuff of South Canyon have been mapped in the Magdalena, Chupadera, and Lemitar Mountains the Joyita Hills, east of this thesis area, and on Lion Mountain, southwest of this study (G.R. Osburn, 1979, oral commun.). Similarities in crystal content, weathering characteristics, and welding suggest that the tuff of South Canyon is equivalent to Chamberlin's (1974, p. 41 to 45) middle and upper cooling units of the A-L Peak Formation in the western portion of the Council Rock area, just south of this study. In the Gallinas Peak area, the tuff of South Canyon, is a multiple-flow, simple cooling unit, and crops out in the southwest corner of the map area in two, low, south- to southwest-sloping ridges. These tuffs conformably overlie the basalt flows and sedimentary rocks of Antelope Flats and are conformably overlain by a thick sequence of andesites. An abrupt break in slope is present between a poorly indurated, crystal-poor, creamy-white to brownish zone at the top of the tuff of South Canyon and the overlying andesites.

A minimum thickness of 570 ft (174 m) and a maximum thickness of 965 ft (294 m) was estimated for the tuff of South Canyon from exposures in the southwest portion of the map area. Thin, discontinuous exposures of the tuff of South Canyon are found along the piedmont escarpment in the northeast portion of the map area. The outcrop pattern suggests that these tuffs were emplaced upon an irregular surface in the area northeast and southeast of Jones Tanks.

The tuff of South Canyon can be divided into two mappable members in the Gallinas Peak area: a crystal-poor lower member, and a thinner, moderately crystal-rich, upper member. The lower member is a platy-weathering, moderately to densely welded sequence of ash flows, and the upper member is a blocky-weathering, moderately to poorly welded sequence of ash flows (fig. 14). No cooling break was recognized between these members by the author.

Lower Member

The lower member of the tuff of South Canyon is estimated to have a minimum thickness of 355 ft (108 m), and a maximum thickness of 600 ft (183 m) in the southwest corner of the study area. A thin, vitric horizon, which sometimes has columnar jointing, is usually present at the base of the lower member of the tuff of South Canyon. This vitrophyre is usually medium dark gray (N 4), spotted with 1 to 2 mm, pink spherulites, and mottled with irregular, brown

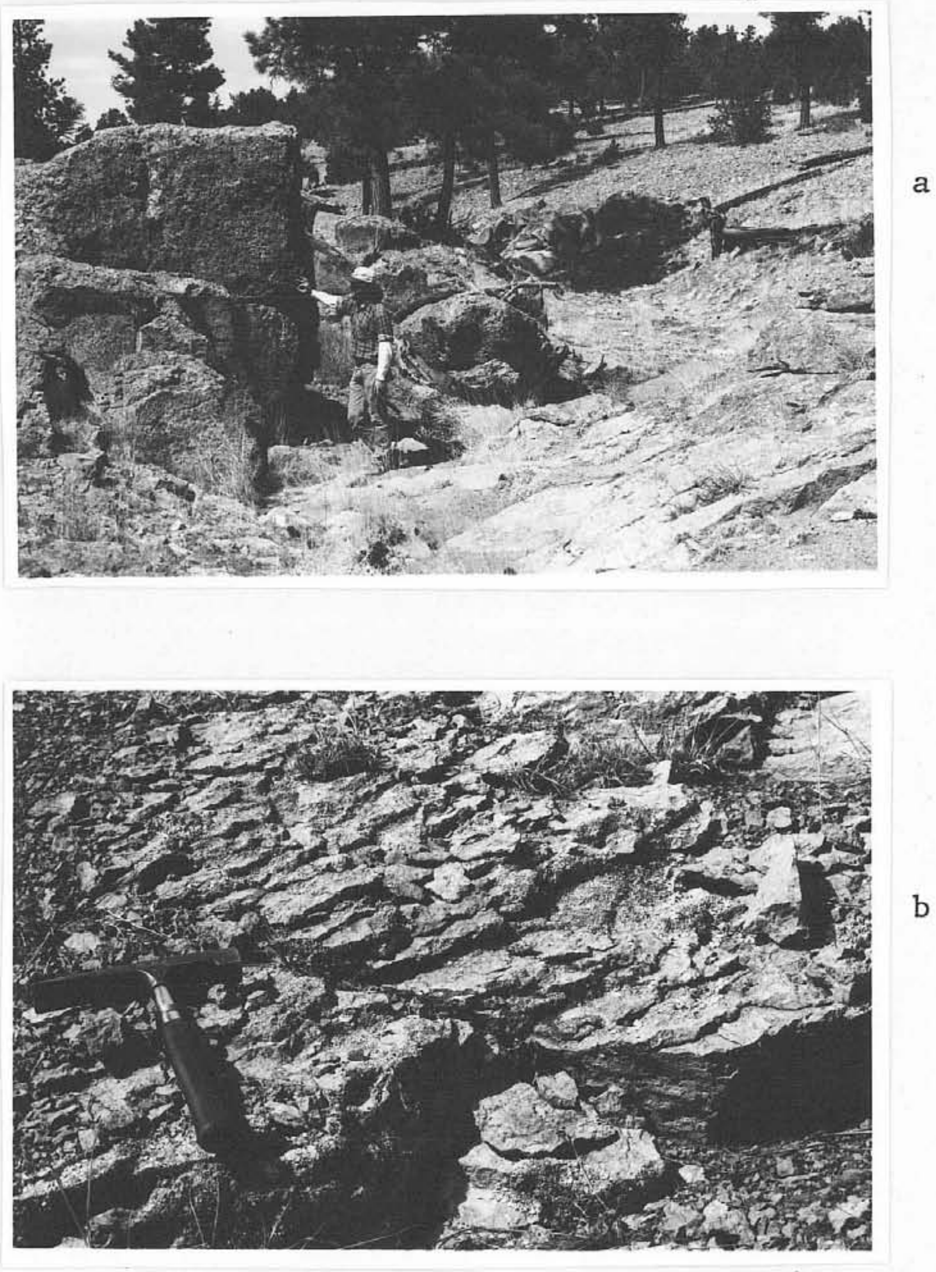


Figure 14. a. Blocky-weathering upper member of the tuff of South Canyon. Photograph taken about 0.4 mi (0.6 km) south of Antelope Flats.

b. Platy-weathering lower member of the tuff of South Canyon about 0.4 mi (0.6 km) northwest of Antelope Flats.

devitrified patches. A spherulitic, densely welded horizon was also found by Chamberlin (1974, p. 42) within 10 ft (3 m) of the base of his middle cooling unit. At some localities, the vitrophyre is pale brown (5 YR 5/2) and streaked with about 10 percent, black, glassy pumice fragments.

Hand specimens of the lower member are light brownish gray (5 YR 6/1) to light gray, and contain about equal amounts of sanidine and quartz. The quartz is usually 0.5 to 1 mm in longest dimension and anhedral to subhedral, while sanidine is usually 0.1 to 2 mm long and euhedral to subhedral. The quartz content increases in a roughly uniform fashion from the base (a trace of quartz) to the top (about 3 percent quartz) of the lower member. The sanidine also increases in abundance from about 1 percent at the base to about 2 percent at the top of the lower member. In thin section, some sanidine crystals are strongly embayed and some display Carlsbad twinning; quartz crystals also show varying degrees of embayment.

In thin sections from the densely welded base of the tuffs, axiolitic- and, less often, spherulitic-devitrified glass shards are arranged parallel to each other, and are appressed about corners of phenocrysts. Microscopic examination of the moderately welded middle and upper portions of the lower member reveals that axiolitic-devitrified glass shards slightly conform to corners of phenocrysts, and that glass bubbles are distorted to ellipses. The shards are separated by a fine hematitic dust. Creamy white, discoid pumice fragments are intensely flattened near the base of the section, but are less flattened in the rest of the lower member. Pumice varies from 2 to 5 percent of the rock. Devitrification products in the pumice are usually low-birefrigent axiolites, spherulites, and interlocking aggregates of sanidine and cristobalite(?). Traces of magnetite are present in thin sections from the lower member.

Upper Member

The upper member of the tuff of South Canyon, in the southwest corner of the study area, has a minimum estimated thickness of 215 ft (66 m); its maximum estimated thickness is about 365 ft (111 m). Fresh hand specimens from the upper member of the tuff of South Canyon are light gray (N 7) and contain approximately 6 to 9 percent, 0.5 to 2.5 mm, anhedral to euhedral sanidine. Four to ten percent quartz phenocrysts are also present, ranging from 0.5 to 3.0 mm in diameter; these crystals are euhedral to anhedral, and are often dipyramidal. The abundance of both sanidine and quartz increases upward in the upper member. Five to ten percent pumice fragments, less than 1 cm long near the base of the upper member, become larger and less compressed toward the top of the upper member.

In thin sections of the upper member, some sanidine phenocrysts are intensely fractured and have been partially plucked out during thin section preparation. Quartz phenocrysts sometimes show the rhombohedral outlines illustrated by Osburn (1978, p. 56). In those slides from the basal portion of the member, the compaction foliation is enhanced by the parallel arrangement of glass shards and pumice. Progressively upward in the tuff, shards become decreasingly parallel and show less axiolitic devitrification and more devitrification to minute (less than 0.02 mm), low-birefringent aggregates. In all thin sections, the glass shards rarely bend around phenocrysts or lithic fragments. Slightly compressed, spherulitic-devitrified pumice fragments are prevalent near the base of the upper member; upward in the section, the pumice fragments show increased devitrification to a polycrystalline mosaic of quartz and sanidine. The matrix of the tuff consists of interlocking aggregates of small (less than 0.05 mm) sanidine and quartz crystals set in a light-brown, opaque dust.

Traces of fresh plagioclase and pleochroic (reddish-brown to yellowish-brown) biotite are seen in thin sections throughout the tuff of South Canyon. Sparse, andesitic lithic fragments are also present; one lithic fragment from the middle portion of the tuff of South Canyon consisted of pyroxene phenocrysts rimmed by or completely replaced by magnetite (partially altered to hematite and limonite) in a matrix of plagioclase microlites.

Upper Andesite and Basaltic Andesite

Three small exposures of basaltic-andesite to andesite lavas are found overlying the tuff of South Canyon in the Gallinas Peak area. First, a thin (0 to possibly more than 100 ft, 30 m) basaltic-andesite lava flow is found near the eastern boundary of the study area, southeast of Jones Well. Outcrops of these mafic flows are poorly exposed; the nature of the lower contact is difficult to ascertain, and the top of the unit has been truncated by erosion prior to deposition of the overlying piedmont gravels. Bouldery float derived from these flows is often found along the piedmont escarpment southeast, east, and northeast ot Jones Well.

Megascopically, the basaltic andesites have about 10 percent irregular vesicles which are lined with botryoidal calcium carbonate, and are surrounded by a dark-gray (N 3), aphanitic matrix. Also seen are blocky to elongate, sub-parallel plagioclase phenocrysts averaging between 0.1 and 2 mm in length. The clear, glassy nature of most of these phenocrysts makes percentage estimates difficult in hand sample. A salmon-colored mineral, found in thin section to be pyroxene, is enclosed by some of the plagioclase.

Microscopically, pilotaxitic plagioclase phenocrysts have plagioclase microlites trachytically arranged about the phenocryst borders. The total amount of plagioclase is estimated to be between 20 and 25 percent of the rock. Glomeroporphyritic clots of plagioclase, clinopyroxene, orthopyroxene, and magnetite dot the thin section. Most of the plagioclase phenocrysts are normally zoned or have oscillatory zonation. Some of the plagioclase phenocrysts enclose worm-like intergrowths of clinoproxene, or enclose whole crystals of clinopyroxene or hypersthene. The plagioclase phenocrysts are subhedral to euhedral, and have a composition of about An61 (maximum value from 12 measurements, Michel-Levy method). Microlites of needle-like plagioclase, less than 0.1 mm long, have a composition of about An42 (maximum value from 10 measurements, Michel-Levy method). Phenocrysts of 0.25 to 0.7 mm long, subhedral to euhedral hypersthene account for about 1 percent of these basaltic andesites. The hypersthene sometimes encloses magnetite. Clinopyroxene phenocrysts are blocky to prismatic, 0.1 to 0.7 mm long, and comprise between 3 percent and 5 percent of the thin section examined. Anhedral to euhedral, 0.01 to 0.5 mm diameter magnetite crystals are present in amounts of about 5 percent. Edges of the magnetite crystals as well as cleavages and edges of clinopyroxene and orthopyroxene are altered to hematite and limonite. The matrix of these flows is a mixture of low-birefringent crystallites and gray glass. The crystallites are needle-shaped and less than 0.01 mm in length.

Two other outcrops of mafic lava flows overlying the tuff of South Canyon in the Gallinas Peak area are present southeast of Antelope Flats. At the blow sand-obscured contact between these andesites and the tuff of South Canyon, the lavas are more resistant than the uppermost, poorly indurated tuffs. The top of these andesites is not found in in the study area. The lavas form low hills and have a platy weathering habit in the study area. Reconnaissance traverses south of the thesis area, toward Lion Mountain, indicate that these flows are quite extensive and grade upward into brown to black, blocky, vesicular andesites with large, tabular to needle-like plagioclase phenocrysts. Chamberlin (1974, p. 46-48) noticed a similar upward textural trend in his andesite of Landavaso Reservoir. Local vents for the andesites have been found southeast of Antelope Flats by Chamberlin (1974, p. 46), and south of Antelope Flats by G.R. Osburn (1979, oral commun.).

Fresh hand samples of the andesites are medium gray (N 5) and weather to brownish gray (5 YR 4/1). Aligned, subhedral to euhedral, tabular to blocky, milky plagioclase phenocrysts impart a foliation to these flows. The foliation dips from subvertical to subhorizontal. The plagioclase phenocrysts comprise from 5 to 15 percent of the platy andesites, and range from 0.1 to about 7 mm in length. One to two percent pyroxene and magnetite are seen in some hand samples.

In thin section, pilotaxitic plagioclase phenocrysts (about An31, maximum value from 16 measurements, Michel-Levy method) are cloudy and are often normally zoned. Felted microlites of plagioclase (about An32, maximum value from 6 measurements, Michel-Levy method), are from 0.01 to 0.6 mm long. Anhedra and subhedra of 0.01 to 0.2 mm clinopyroxene are largely altered to magnetite. Two phenocrysts of clinopyroxene were almost completely altered to magnetite and limonite. The original amount of clinopyroxene is estimated to be between 3 and 10 percent. One thin section examined contained 10 to 15 percent, anhedral to subhedral magnetite grains 0.005 to 0.5 mm in diameter. The same thin section contained 5 to 10 percent hematite as an alteration product of magnetite and as concentrations along flow laminae.

TERTIARY INTRUSIVE ROCKS

Intrusive rocks found in the Gallinas Peak area consist of propylitically altered mafic dikes and quartz latite dikes and plugs. The mafic dikes are more abundant and generally occur in two dike swarms in the northeastern and southeastern portions of the thesis area. Quartz latite intrusives are confined to the east-central and northeastern parts of the area. Modal compositions of the dikes are summarized in table 1; detailed petrographic descriptions are in the appendix. Each dike in the thesis area is slightly different compositionally from the others, making classification difficult. Those intrusives which contain phenocrysts of quartz, sanidine, and biotite are grouped as quartz latites; those intrusives which lack these minerals, or these minerals are xenocrystic as suggested by texture, are grouped as mafic dikes.

Two short mafic dikes are present in the Council Rock area, about 1.2 mi (1.9 km) south of McGee Spring (Chamberlin, 1974). These dikes, which Chamberlin (p. 50) referred to as lamprophyres, have similar textures and alteration as those described in this report. Mafic dikes are also present in the area mapped by Mayerson (1979), northeast of the Gallinas Peak area. Mayerson found biotite and apatite in these dikes - minerals that are not found in the mafic dikes of the northeastern Gallinas Peak area.

Table I. Approximate phenocryst percentages in intrusive rock samples from the Gallinas Peak area.

Sample/Location	Plagioclase		Sanidine	Quartz	Biotite	Amphibole/Pyroxene	Magnetite	Apatite	
	phenocryst	groundmass							
Td 456, 0.9 mi (1.4 km) N-NE of Jones Well	5% An_{61}	75-80% An_{64}	n.p.	n.p.	n.p.	3-5%	5%	n.p.	
Td 415, 0.6 mi (1.0 km) SW of Jones Well	n.p.	65-75% An_{39}	n.p.	tr	n.p.	7%	2%	n.p.	
Tmd 283, 0.3 mi (0.5 km) NW of McGee Spr.	n.p.	85-90% An_{42}	n.p.	tr	n.p.	7% phenocrysts 3% pyroxene (groundmass)	2%	tr	tr altered olvine phenocrysts
Td 298, 0.4 mi (0.6 km) SW of McGee Spr.	n.p.	50% (altered)	n.p.	n.p.	n.p.	40% pyroxene (groundmass)	5-7%	tr	
Td 317, 0.2 mi (0.3 km) S of McGee Spr.	n.p.	1% An_{56}	3%	1%	n.p.	9% phenocrysts 75-80% pyroxene (groundmass)	7%	tr	1% altered olivine phenocrysts
Td 296, 0.6 mi (1.0 km) SW of McGee Spr.	15-20% An_{42}	n.p.	n.p.	1% as alteration mineral	n.p.	2%	3%	tr	
Td 465a, 1.0 mi (1.6 km) N-NE of Jones Well	10-15% An_{59}	20%	1%	1-2%	tr	3-5%	2-3%	1%	
Td 383, 1.0 mi (1.6 km) SW of Jones Well	5% An_{49}	80% An_{30}	n.p.	7-10%	3-5%	tr	3%	tr	
Td 542, 0.4 mi (0.6 km) W-NW of Jones Well	5-7% An_{48}	80-85% An_{33}	n.p.	3-5%	3-5%	n.p.	2%	tr	
Td 549, 1.2 mi (1.9 km) N-NE of Jones Well	n.p.	80% An_{39}	2%	1-2%	tr	.5%	5-7%	tr	

n.p. = not present
tr = trace

Because the youngest unit cut by the mafic and felsic dikes is the tuff of Nipple Mountain, the dikes are inferred to be of Spears age.

Mafic Dikes

Mafic dikes of variable mineralogy (table 1) are found along the eastern boundary of the Gallinas Peak area. In general, the youngest stratigraphic unit intruded by these dikes is the lower member of the Spears Formation, although two short mafic dikes intrude the tuff of Nipple Mountain in the extreme southeastern portion of the study area.

The mafic dikes of the Gallinas Peak area are, in general, significantly altered to a mineral assemblage consisting primarily of chlorite and calcite. These dikes usually strike from about N 15° W to about N 5° E, but local northwest strikes and easterly strikes are present. Dips on the mafic dikes range from about 75° to the west to about 60° to the east. The dikes are usually discontinuous, sometimes in an en echelon fashion (fig. 15); the longest, continuous mafic dike crops out for about 800 ft (244 m). Mafic dikes in the thesis area range in thickness from about 2 ft to about 15 ft (0.6 to 5 m).

The mafic dikes vary in weathering habit; the same dike may form a wall-like exposure for part of its extent and be reduced to a small, rubbly mound at another

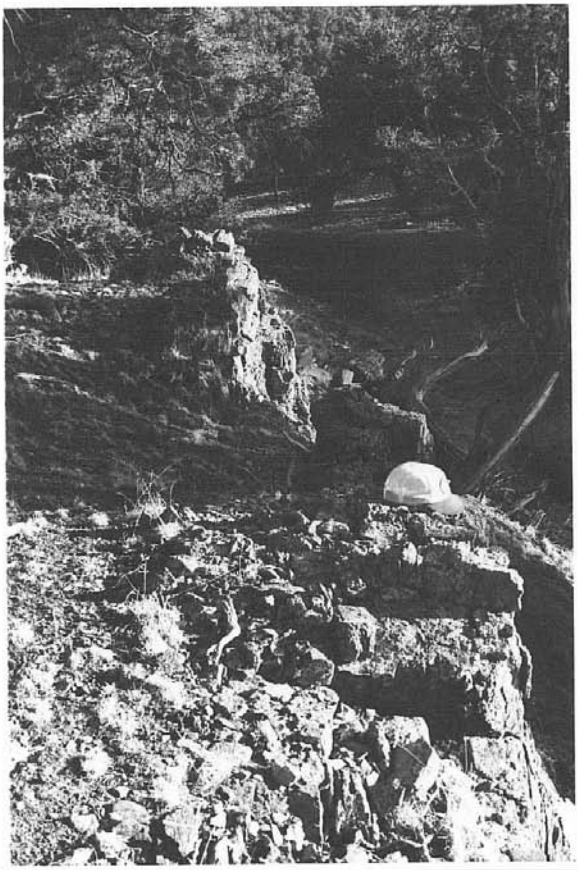


Figure 15. <u>En echelon</u> mafic dike trend in southeast portion of study area, about 0.3 mi (0.5 km) northwest of McGee Spring.

locality. Some mafic dikes have a platy fabric but most have a blocky, massive appearance in outcrop.

In hand sample, colors of the mafic dikes range from dark gray (N 4) to grayish olive (10 Y 4/2) on fresh surfaces and weather to various hues of brown. Texturally, the dikes are porphyritic-aphanitic with altered plagioclase being the dominant phenocryst and black, altered ferromagnesian phenocrysts, as much as 4 mm in size, subordinate in amount. The mafic dikes often contain from a trace to about 2 percent, rounded quartz as much as 7 mm in diameter.

Thin section analysis reveals that the mafic dikes have a variety of compositions and textures (table 1, and Appendix). Two thin sections examined from the northeastern Gallinas Peak area (Td 456 and Td 415) contain phenocrysts of plagioclase and altered ferromagnesian minerals set in an altered groundmass of chlorite and calcite. Trace amounts of quartz xenocrysts with undulose extinction are also present. Notably, these mafic dikes lack apatite in thin section, while other intrusives in the Gallinas Peak area consistently have a trace of apatite. Petrography of mafic dikes from the northeastern Gallinas Peak area is further described in the appendix.

Mafic dike samples from the southeastern Gallinas Peak area (Td 298 and Tmd 283, table 1 and Appendix) show similar alteration and textural variability as those mafic dikes from the northeastern Gallinas Peak area. The alteration of pyroxene and plagioclase in thin sections Td 298 and Tmd 283 is extensive, but their relative abundance and arrangement is suggestive of a relict intergranular texture. Typically, the rocks contain 10 percent or less ferromagnesian minerals which are altered to calcite, chlorite, and occasionally, quartz. A reaction rim of calcite, pyroxene, and a brown mineral is found on the traces of quartz xenocrysts that are present.

Approximately 950 ft (290 m) south of McGee Spring is a short mafic(?) dike (sample Td 317). This dike contains large prismatic sanidine xenocrysts(?) and rounded quartz xenocrysts in a subophitic array of labradorite and clinopyroxene. Other than the presence of the sanidine xenocrysts(?), this dike is similar to the mafic dikes previously described.

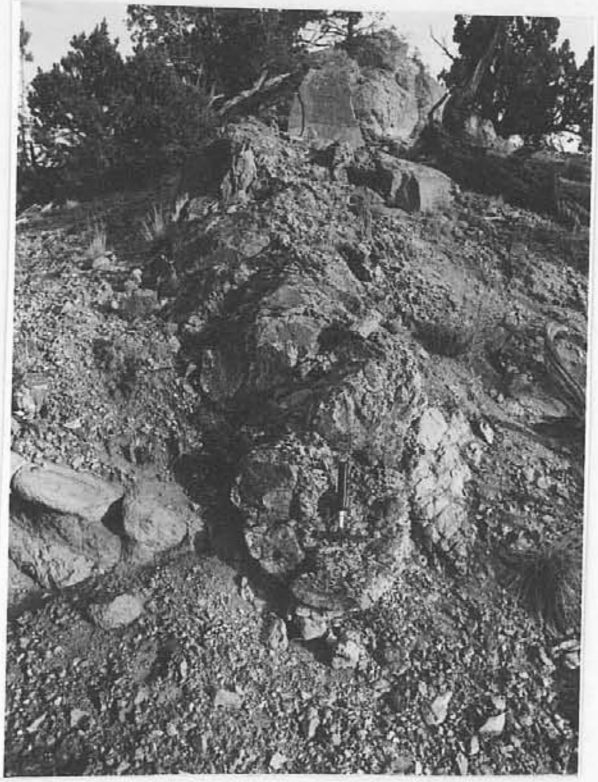
Sample Td 296 is altered in a different fashion from the mafic dikes described above. Megascopically, it is grayish yellow (5 Y 8/4) and dotted with hematite pseudomorphs after pyrite. The dike could only be traced a few meters, but several dikes, altered in a similar manner, crop out sporadically in the southeastern Gallinas Peak area, and are indicated as Td? on plate 1 (in pocket). Thin section study (Td 296, table 1 and Appendix) shows that the plagioclase phenocrysts are surprisingly fresh, although the groundmass has been replaced by small, low-birefringent crystals.

Quartz Latite Dikes and Plugs

Quartz latite intrusive rocks, present in the east-central and northeast corner of the map area, consist of three small plugs and several texturally distinct porphyritic dikes. Quartz latite dikes are present in the northeastern Gallinas Peak area, and a biotite-bearing dike occurs in the east-central Gallinas Peak area.

Two quartz latite dikes, bearing phenocrysts of feldspar, an altered ferromagnesian mineral, and quartz, have been mapped in the northeastern corner of the Gallinas Peak area. The dikes intrude the Baca Formation, and where the terminus of one dike was observed, the dike abruptly ends in undisplaced bedding (fig. 16a). The dikes have a general northwest strike which locally deviates to a northerly or easterly strike. The dip of these dikes is usually close to vertical. The longest of these quartz latite dikes crops out continuously for about 880 ft (268 m). The maximum thickness of these dikes is about 65 ft (20 m). The dike rocks are well indurated and weather to resistant ridges 5 to 10 feet high (1.5 m to 3.0 m) as shown in figure 16b.

Megascopically, the quartz latite dikes of the northeastern Gallinas Peak area vary widely in phenocryst content and in color within the same outcrop. In fresh hand samples, the color ranges from medium dark gray (N 4), to light olive gray (5 Y 5/2). Weathered surfaces are mottled



a

b

Figure 16. a. Abrupt termination of quartz latite dike in undisplaced bedding of the Baca Formation.

b. Irregular outcrop pattern of same dike as in a; two hills in background are site of small, quartz latite plugs intruded into bleached sandstones of the Baca Formation. Photographs taken about 1.1 mi (1.8 km) north of Jones Well.

with shades of yellow and brown. Phenocryst content ranges from about 10 to 25 percent of the rock. Clear to chalky phenocrysts of plagioclase and sanidine average about 1 mm in length, but are as much as 7 mm long in some samples. Altered ferromagnesian minerals are also present. Phenocrysts of subhedral to rounded quartz, as much as 6 mm in diameter, account for about 1 to 2 percent of any given hand sample. A single thin section of these quartz latite dikes (Td 465a) is described in the appendix.

A north to northwest-trending quartz latite dike is present in portions of the east-central Gallinas Peak area. This dike is intruded into the lower Spears, and occupies a fault contact between the lower Spears, and the tuff of Nipple Mountain in the area 0.4 mi (0.6 km) northwest of Jones Well. The dike crops out in a discontinuous pattern for about 1.3 mi (2.1 km) and ranges in thickness from about 3 ft to about 16 ft (1 to 5 m); the maximum thickness is attained south of Jaralosa Creek. The dike usually weathers to a rubbly mound above the country rock.

Fresh hand samples of this quartz latite dike are dusky yellow to light olive gray (5 Y 6/4 to 5 Y 5/2) and weather to shades of yellow and brown. The texture of the dike is porphyritic-aphanitic with about 5 percent chalky, prismatic plagioclase phenocrysts averaging about 1 mm in length. Black biotite flakes, less than 1 mm long, make up between 3 and 5 percent of any given hand sample. Petrographic descriptions of this quartz latite dike (samples Td 383 and Td 542) are located in the appendix.

A similar quartz latite dike has been mapped by Chamberlin (1974, p. 52) in the area south of this study. Chamberlin's map shows a quartz latite dike along the same trend as the quartz latite dike in the east-central Gallinas Peak area. Chamberlin (p. 53) hypothesized that the quartz latite dike in the Council Rock area was related to the Gallinas Springs intrusive center, a Late Oligocene andesitic vent located about 2.7 mi (4.3 km) southwest of McGee Spring.

Three small, quartz latite plugs have been mapped in the northeast corner of the Gallinas Peak area (fig. 16b). These plugs intrude the Baca Formation with no visible disruption of bedding. The intrusives, all less than 180 ft (55m) in diameter, weather to rounded knobs rising about 20 ft (6 m) above the Baca Formation (fig. 16b).

In hand sample, chalky feldspars, averaging less than 0.5 mm are set in a greenish-gray (5 GY 6/1) groundmass. Altered ferromagnesian minerals and rounded quartz phenocrysts, as much as 1 cm in diameter, dot the matrix. A single thin section studied (Td 549) reveals that the plagioclase and the ferromagnesian minerals are at least partially replaced by chlorite, calcite, and clay. Quartz phenocrysts present are rimmed by calcite. Detailed petrographic description of Td 549 is found in the appendix.

Summary of Evidence of Inferred Intrusive

The occurrence of two major dike swarms, hematite staining, weak propylitic alteration of rock units, and the presence of an aeromagnetic high in the southeastern portion of the study area (fig. 17), all suggest a concealed stock beneath the eastern margin of the Gallinas Peak area. Epithermal quartz-carbonate veins, described in the economic geology section, further support this conclusion. The two dike swarms may provide the best field evidence of a concealed intrusive. In a similar tectonic setting as the Gallinas Peak area, Chamberlin (1974) and Wilkinson (1976) mapped latite dikes along radial and concentric faults associated with the Tres Montosas stock. The fact that felsic as well as mafic dikes occur in the two dike swarms also suggests a concealed intrusion. The correlation between mafic and felsic dikes with known intrusives has been demonstrated in the Magdalena area by Brown (1972), who found latitic and andesitic dikes associated with the Magdalena composite pluton.

Indirect evidence of doming over the postulated intrusive exists in the northeastern Gallinas Peak area. Here, abrupt thining of the lower Spears and younger Oligocene volcanic rocks, and the presence of numerous local

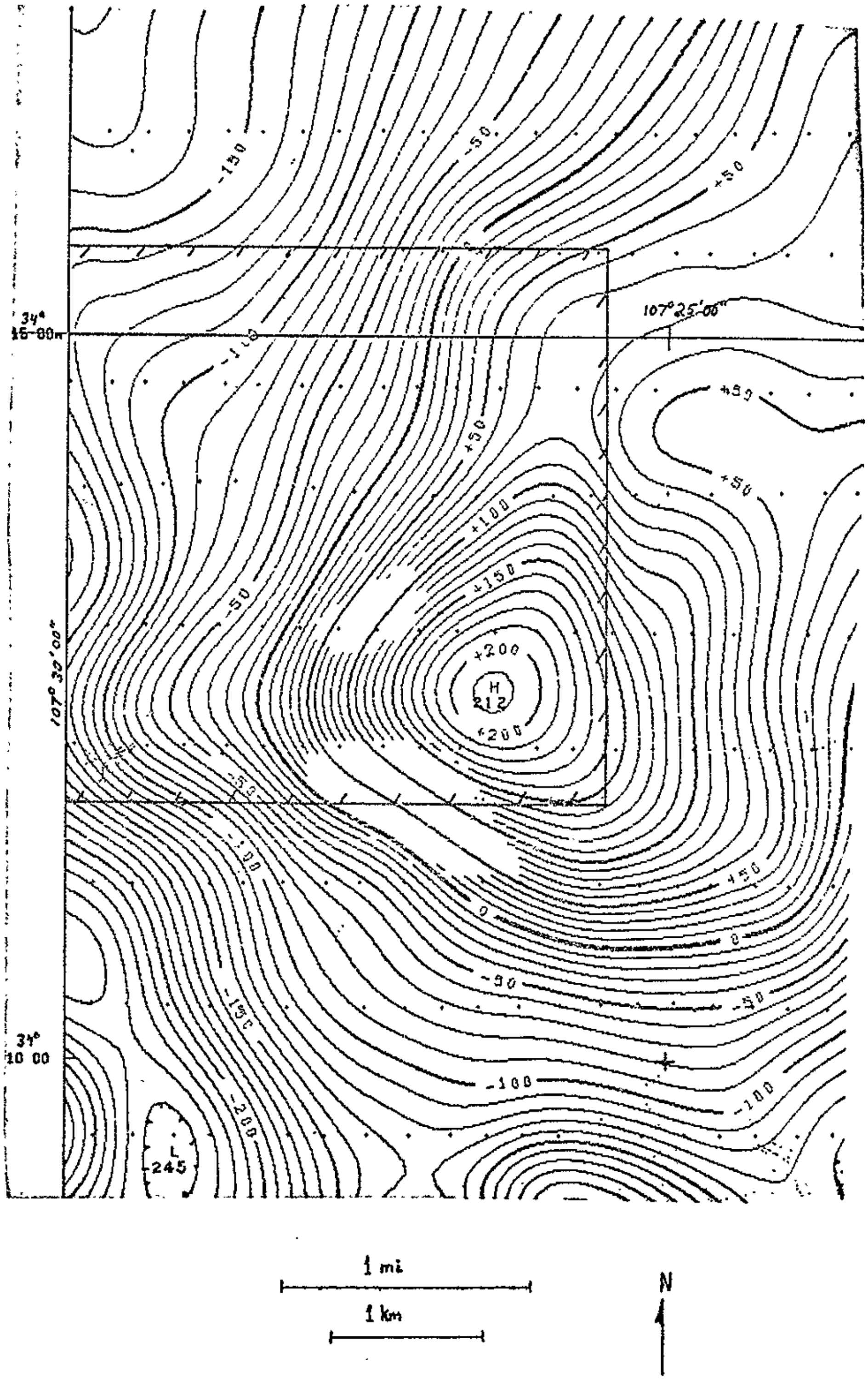


Figure 17. Residual magnetic intensity map showing magnetic high in eastern part of Gallinas Peak area (hachured). Contour interval is 10 gammas. (From U.S. Geological Survey Open-File Maps 247 and 271, southwest New Mexico, 1973.)

unconformities suggest the presence of significant paleo-topographic relief. Because of these thickness changes, a Spears age for the doming and thus intrusion, is inferred. This age is consistent with the fact that the youngest unit cut by dikes in the study area is the tuff of Nipple Mountain. Alternatively, the stratigraphic discontinuities listed above may be attributed to movement along a transverse structural zone of the Tijeras lineament as described in a following section on structure.

Chamberlin (1974) and Wilkinson (1976) have postulated several concealed stocks, distributed along a northerly trend, adjacent to the Mulligan Gulch graben (see Chamberlin°s fig. 16). In addition, Chamberlin suggested that the Gallinas Springs fault, a major fault which splits into two faults that continue into this study area, was of major importance in controlling the distribution of the postulated stocks. Chamberlin's hypothesis is supported by studies in the Magdalena area where Chapin and others (1974a) have suggested that early rift faults broke the roofs of Oligocene batholiths, promoting the emplacement of epizonal plutons in the Kelly mining district. The presence of the exposed and postulated intrusives along the Gallinas Springs fault suggests a possible similar situation to that in the Kelly district. In this study area, the presence of an aeromagnetic high, located along strike of one of the faults related to the Gallinas Springs fault, adds support to Chamberlin's fault control hypothesis.

MIOCENE DEPOSITS

Popotosa Formation

The Popotosa Formation was named by Denny (1940) who described areas of good exposure in Arroyo Popotosa on the east side of the Sierra Ladron. A detailed study of the Popotosa Formation is presented in a doctoral dissertation by Bruning (1973), who concluded that the Popotosa is the basal Santa Fe Group in the Socorro region. The Popotosa was deposited in a 40 mi- (64 km-) wide, rift-related trough, referred to as the Popotosa basin. Accumulation of detritus in the Popotosa basin began about 24 m.y. ago and continued to at least late-Miocene time (Bruning, 1973). The Gallinas Mountains and the Colorado Plateau, marking the west and northwest margin of the Popotosa basin, shed detritus into the basin throughout its history (Bruning, 1973). Other margins of the basin are less well documented. The Popotosa basin has now been broken into three parallel, 11 to 14 mi- (18 to 23 km-) wide basins which are separated by horsts associated with the Rio Grande rift (Bruning, 1973; Chapin and Seager, 1975).

Four minor exposures of the Popotosa Formation are present in the Gallinas Peak Area. Three of these exposures are found on the north side of McGee Canyon, east of McGee Spring; the fourth is in Jaralosa Canyon, north of Jones Well. All of these exposures are adjacent to the Mulligan

Gulch graben. In McGee Canyon, one outcrop of the Popotosa Formation lies adjacent to the Hells Mesa Tuff; in Jaralosa Canyon, the Popotosa Formation lies on the Baca Formation. Deposition of the Popotosa Formation on such units of diverse age suggests that, in the Gallinas Peak area, at least some rift-related faulting took place prior to Popotosa time.

The Popotosa Formation in the Gallinas Peak area has a sub-horizontal attitude and consists of conglomeratic mudstones and muddy sandstones. The unit contains a moderately to poorly sorted array of subangular lithic fragments. The clasts, predominantly andesite, A-L Peak Tuff(?), and Hells Mesa Tuff, range from about 3 mm to about 15 cm in longest dimension. The clasts are ususally set in a light-brown, calcite-cemented matrix of silt and clay.

PLIO-PLEISTOCENE DEPOSITS

Piedmont Gravels

Piedmont gravels cover a large portion of the east margin of the study area, where they form a surface which dips gently eastward into the Mulligan Gulch graben. This piedmont surface is dissected by tributaries of Jaralosa Creek on the west and north, and by Deep Well and McGee Canyons on the south. In the thesis area, the piedmont gravels are probably about 200 ft (61 m) thick and are generally above 7300 ft (2225 m) in elevation.

All rock types found in the Gallinas Peak area, primarily the Spears Formation, Hells Mesa Tuff, and A-L Peak Tuff, occur in the piedmont gravels. These clasts are angular to rounded blocks as much as 30 cm in largest diameter.

Mayerson (1979) mapped extensive piedmont gravels to the northeast of the Gallinas Mountains and hypothesized that these gravels were formed by coalescing alluvial fans derived from the Gallinas Mountains. This is probably also the case for the piedmont gravels of the Gallinas Peak area, which are continuous with the piedmont gravels of Mayerson's area; however, the gravels are now separated from the present Gallinas Mountain front by a broad erosional valley.

QUATERNARY DEPOSITS

Talus, Colluvium, and Landslide Deposits

Colluvial deposits and talus were mapped in the Gallinas Peak area only where such debris obscured contacts. The author found, as did Chamberlin (1974), that the basal contacts of the cliff-forming Hells Mesa Tuff and tuff of Nipple Mountain were the primary sites of such deposits.

Landslide and slump blocks of the Hells Mesa Tuff are present at the head of Three Log Spring Canyon and on the east side of Gallinas Peak. Nearly vertical slopes, and the rubbly upper surfaces of the upper Spears andesites probably contributed to the instability of the overlying Hells Mesa Tuff in areas of slumping.

Alluvium

Recent stream gravels and sand deposited in the larger drainages are grouped as alluvium in this study. Mappable deposits of alluvium in the Gallinas Peak area are present in the head of Three Log Spring Canyon and in the tributaries and main channels of McGee, Deep Well and Jaralosa Canyons. Present stream deposits are a mixture of locally-derived boulders, cobbles, pebbles, and sand.

Older alluvium may be present in the flat, gently sloping meadows adjacent to the main channel of Jaralosa

Creek. These meadows, mantled by soil and eolian sand, are about 5 to 10 ft (1.5 to 3 m) above the present stream channel, and could represent older, elevated alluvial deposits of Jaralosa Creek.

Eolian Sand

Light-brown, wind-blown sand mantles many topographic lows and thinly veneers a few higher elevations in the Gallinas Peak area. The sands are most extensive, and probably thickest, at the west margin of the thesis area, adjacent to the Plains of San Augustin. Barchan dunes, clearly discernable on aerial photographs, but ambiguous at ground level, indicate prevailing winds from the southwest. Assuming a similar wind direction throughout Holocene time, the source of the eolian sands was probably the Plains of San Augustin. A pluvial lake occupied the Plains of San Augustin during Wisconsin time and desiccation and deflation of the lake basin provided enormous quantities of sand in post-Wisconsin time (Chapin and others, 1978c).

At lower elevations, thick stands of Ponderosa pines generally grow only on the eolian sand, in arroyos, or on shaded canyon slopes. In the eolian deposits, the present water table is probably perched within the sands overlying the less permable volcanic units, thus allowing for lusher tree growth.

STRUCTURE

Regional Structure

A three-stage tectonic model for the evolution of the Cordilleran foreland in the Arizona-New Mexico-Colorado region during the Cenozoic has been outlined by Chapin (1974b). Initially, during the Laramide orogeny, an east-northeast directed compressional stress field uplifted and formed the southern Rocky Mountains. As the Laramide orogeny closed, it was followed by a neutral stress field of significant duration; this stress field was in turn followed by an east-west oriented tensional stress field which induced rifting and basin and range faulting (Chapin, 1974b; Chapin and Seager, 1975).

Structural flaws in the continental lithosphere were instrumental in dictating structural trends associated with the Rio Grande rift (Chapin and others, 1974b; Chapin and others, 1978a,b; Chapin, 1978). Such a structural flaw is the northeast-trending Morenci lineament, along which the San Augustin rift opened as a bifurcation of the Rio Grande rift (Chapin, 1971b; Chapin and others, 1978a,b). A transverse shear zone of the Morenci lineament is characterized in the Socorro-Magdalena area by opposing structural symmetries across the lineament (Chapin and others, 1978a,b,c). Shear zones such as this influenced tectonic style, the distribution of volcanic centers, and the distribution of present-day magma bodies (Chapin and others, 1978a,b,c).

A second lineament, the Tijeras lineament, has been documented northeast of the study area and may have had some influence on the structure of the Gallinas Peak area. Although less well documented than the Morenci lineament, the northeast-trending Tijeras lineament possibly represents a basement fault of Precambrian ancestry. In a study of the economic mineral potential of the Riley-Puertecito area, Chapin and others (1979) have reported that late-Cretaceous sedimentation was strongly influenced by differential vertical movements across the Tijeras lineament. Work northeast of this study by Mayerson (1979) attributed thickness variations and local unconformities in the Oligocene volcanic section to transverse structural zones associated with the Tijeras lineament.

The Mulligan Gulch graben is a north-trending, early rift structure which separates the Gallinas Range from the Bear Mountains to the east of the study area. The depth of the graben shallows southward across the Morenci lineament, south of this study area (Chapin and others, 1978a,b).

Local Structure

A fault map of the Gallinas Peak area, showing distribution of faults in the study area, is shown in plate

2 (in pocket). This map shows that north-trending rift faults dominate the structural pattern of the Gallinas Peak area and that transverse normal faults are less common in the study area. No structural evidence of compressional (Laramide) deformation was encountered in the Gallinas Peak area; however, folding attributable to the effects of fault drag or vertical tectonics was recognized.

North-Trending Faults

The structural pattern of the Gallinas Peak area is dominated by north-trending extensional faults. The frequency of these faults increases from west to east in the study area, reflecting the tectonic importance of the Rio Grande rift. The extensional faults have a distinct northerly trend, but vary locally from about N 20° W to about N 10° E. Such variances in trend are common in rift-related structures (Freund, 1978).

The youngest units displaced by north-trending faults are basaltic-andesite flows which overlie the tuff of South Canyon in the northeast portion of the study area. Some north-trending faults in the area probably developed during depostion of the lower member of the Spears Formation. In the northeast portion of the Gallinas Peak area the lower Spears thins abruptly, in an eastward direction, across two, down-to-the-west faults. Additionally, mafic dikes, thought to be of middle Spears age, are emplaced along these two faults. Some north-trending faults have been intruded by mafic and felsic dikes; however, not all dikes were emplaced along a recognizable stratigraphic displacement.

The maximum stratigraphic throw on a north-trending fault occurs in the southeast portion of the area. Here, about 1475 ft (449 m) of down-to-the-west displacement results in a structurally high block of lower Spears Formation juxtaposed against Hells Mesa Tuff.

East-west cross sections (plate 1) show that the major north-trending faults in the Gallinas Peak area generally alternate from down to the east to down to the west. This has formed a series of broad, alternating horsts and grabens, east to west, across the thesis area.

A definite genetic relationship exists between the north-trending faults and extension of the Rio Grande rift (and the Mulligan Gulch graben). However, another possible mechanism for some minor north-trending faults is tensional breakup over the arched portion of the eastern Gallinas Peak area. Mechanisms which could explain the arching of the eastern portion of the study area are discussed in a following section on folding.

Transverse Faults

Transverse normal faults are less well developed than the north-trending normal faults in the Gallinas Peak area. About a dozen transverse faults have been mapped in the study area; of these only two were traceable for more than 2000 ft (610 m). Of the two longer faults, one trends west-northwest across the north-central portion of the study area, and the other transects the south-central portion of the area along a northeast trend. Each of the two longest transverse faults apparently dies out toward the center of the map area; here, displacement is probably taken up by the north-trending faults of the central Gallinas Peak area. This suggests that these transverse faults may be contemporaneous with the north-trending normal faults. Additionally, several other transverse faults take on a northerly trend over part of their length, further suggesting contemporaneity and a genetic tie with the Rio Grande rift system.

Some possible mechanisms of formation of the transverse faults are:

1) These faults are related to a broad uplift of the Gallinas Peak area, forming a conjugate fault pattern with the north-trending faults across the crest of a broad, northerly elongate dome.

2) The two extensive, down-to-the-north faults may reflect *en echelon* movement along the northeast-trending Tijeras lineament. Evidence of structural discontinuities related to the Tijeras lineament has been described by Mayerson (1979) for the region just northeast of the

Gallinas Peak area. Mayerson suggested that deflection of the Mulligan Gulch graben in a right-lateral sense could be attributed to basement fault zones of the Tijeras lineament. A crude northeast-trending cutoff of the piedmont gravels in the northeast Gallinas Peak area, abrupt thinning of Oligocene volcanic rocks to the northeast, and the presence of abundant, local unconformities in the northeast corner of the study area all support structural discontinuities related to the Tijeras lineament.

3) The transverse faulting may be a reflection of movement of the Colorado Plateau to the northwest, away from its southeast corner; this has been proposed by Chapin (1971b) as a possible mechanism for the formation of the San Augustin rift, south of the study area. The formation of a minor sag between the Gallinas Range and the Colorado Plateau may have thus resulted in the transverse fault pattern.

4) The transverse faults could merely reflect local stress perturbations in a regional, east-west extensional stress field. These faults could thus represent an inherent feature of rift faulting in the Gallinas Peak area.

Folding

The general westward tilt of the Gallinas Peak area, away from the Mulligan Gulch graben, is a common feature of fault blocks bordering the Rio Grande rift (Chapin, 1971b). This westward tilt is reversed on the east margin of the study area where pervasive eastward dip into the Mulligan Gulch graben is found. This monoclinal flexure extends from the Abbe Spring area on the north (Mayerson, 1979) to Cat Mountain on the south (Wilkinson, 1976).

Separate mechanisms for the formation of the graben-bounding monocline have been examined by Chamberlin (1974) and by Mayerson (1979). Chamberlin proposed that intrusion of a northerly elongate pluton and concomitant upthrusting, reactivating basement faults adjacent to the Mulligan Gulch graben, resulted in a monoclinal flexure. The obvious linearity of inferred stocks in the Gallinas Peak area and Council Rock area along with the Tres Montosas stock, support a larger, parent intrusive at depth, adjacent to the Mulligan Gulch graben (see Chamberlin, 1974, fig. 16). Chamberlin argued that strata would be more apt to break than to fold under a tensile stress and concluded that active upthrusting would be a more realistic mechanism to produce a monocline. Mayerson (1979) discounted Chamberlin's magmatic intrusion hypothesis and concluded that, based on the close spatial association of the monoclinal hinge with the fault system of the Mulligan Gulch graben, fault drag was the cause of the flexure. Because of the arching of strata (see cross-sections, Plate 1) over an inferred intrusive in the Gallinas peak area, an intrusive-related upthrusting may also have formed the monoclinal flexure (or at least enhanced the effects of drag in this area of the graben).

An alternative to Mayerson's and Chamberlin's hypotheses for the formation of the monocline is possible diapiric intrusion of Mesozoic shale sequences and Paleozoic evaporite horizons into the structurally weak zones adjacent to the Mulligan Gulch graben. Diapiric intrusion of shale has been hypothesized in the Española basin by Lisenbee (1976) to explain small, elongate, dome-like structures adjacent to a regional fault system. These structures are underlain by anomalous thicknesses of Cretaceous shale. Lisenbee suggested that natural gas mixed with the shales and contributed to their bouyant rise. A similar situation may exist in the Gallinas Peak area; here isostatic rise of Permian evaporite sequences along the border fault system of the Mulligan Gulch graben could have produced a vertical stress resulting in a monoclinal warp above the diapiric structure. This situation would not preclude a pluton at depth, and it is possible that such an intrusion could have provided a thermal source necessary to increase the plasticity of Paleozoic and Mesozoic evaporite and shale sequences.

Cross-sections in the northeastern portion of the thesis area show anticlinal folding of the Spears and Baca Formations where these strata dip toward adjacent, north-trending faults (see cross-section A-A', Plate 1). Because these flexures lack adjacent synclines, a mechanism other than active compression may have caused the folding in the northeast portion of the study area. Mayerson (1979) has suggested reverse drag as a possible mechanism of folding in the post-Laramide formations of the Corkscrew Canyon--Abbe Spring area, northeast of this study. By assuming that fault planes dip less steeply at depth and that displacement is relatively large (greater than 100 ft; 30 m), large gaps between the downthrown blocks and upthrown block will form. Hamblin (1965), in his study of reverse drag in normal faults on the Colorado Plateau, has shown that the downthrown blocks of normal faults can compensate for spatial gaps by tilting of strata of the downthrown block, toward the fault plane, resulting in reverse drag. It is concluded that, in the Gallinas Peak area, reverse drag is responsible for the anticlinal folds in the Spears and Baca Formations.

ECONOMIC GEOLOGY

The Gallinas Peak area is located about 17 mi (27 km) northwest of the Kelly mining district, one of the largest zinc-lead-copper districts in New Mexico. In that district, rich zinc-lead-copper orebodies were formed in Paleozoic limestones adjacent to stocks intruded along the structural margin of the Magdalena cauldron (Blakestad, 1978; Chapin and others, 1978c).

Two much smaller mining districts, the Council Rock district and the Cat Mountain district, are located from 4 to 11 mi (6 to 18 km) south of the Gallinas Peak area. Lasky (1932) has reported that lead-carbonate veins of the Council Rock district were worked in the 1880's for their silver content. Some of the ore from that district reportedly averaged as much as 250 dollars per ton (Chamberlin, 1974). The Cat Mountain district was worked, around the turn of the century, for gold at the intersection of quartz veins (Wilkinson, 1976). The sixty prospect, adjacent to the Cat Mountain district, produced about 356 tons of disseminated silver, copper, and lead ore (Wilkinson, 1976).

In the Gallinas Peak area, prospecting has generally been confined to the eastern two thirds of the area and consists of small pits and shallow shafts along faults or adjacent to dikes. No production of ore from these workings is known from the thesis area.

Alteration

Alteration in the Gallinas Peak area is most intense along the area's eastern margin (plate 2). Three types of alteration, affecting the Spears Formation, Hells Mesa Tuff, and dikes, are recognized. These are weak propylitization, hematite staining, and minor silicification. Epithermal veins of quartz, calcite, and minor veinlets of pyrite are also present.

Propylitization

The effects of propylitization are best developed in the lower Spears Formation and portions of the Hells Mesa Tuff in the southeastern Gallinas Peak area. Thin sections show that mafic minerals and groundmass constituents of these units, when altered, have been partially to completely replaced by chlorite, calcite, and sparse epidote. Additionally, clay minerals are often seen as an alteration product of groundmass minerals. Veinlets of quartz and calcite are sometimes found in thin sections of propylitically altered units. Weak propylitization is also evident in some mafic and quartz latite dikes of the eastern portion of the thesis area. Chlorite replacement of phenocrysts and groundmass constituents often imparts an olive-green color to the altered dikes. Thin sections reveal that the chlorite is often accompanied by calcite and clay minerals, but epidote is notably absent in the altered dikes. For a more complete description of these alteration textures the reader is refered to petrographic descriptions of the Spears Formation, Hells Mesa Tuff, and dikes.

Hematite Staining

Hematite staining, sometimes accompanied by silicification, most commonly affects the tuff of Nipple Mountain in the eastern portion of the Gallinas Peak area. One area of particularly intense hematite staining of this tuff is found adjacent to Jaralosa Creek, about 0.6 mi (1.0 km) east of Sawmill Well. Here the tuff of Nipple Mountain is stained bright orange where it crops out adjacent to the intersection of two faults. The orange color is probably caused by surface oxidation of pyrite; just north of this outcrop euhedral holes, from which hematitically altered pyrite cubes have been leached, were seen in rubbly float from the tuff of Nipple Mountain.

Hematite staining is sometimes found in the lower member of the Spears Formation and in the Hell Mesa Tuff in the east central and southeastern portions of the thesis area. In these units the staining, accompanied by hydrothermal bleaching, imparts varied hues of yellow and orange to altered outcrops. This type of alteration in the lower Spears is often confined to within a few feet of sheared outcrops, or along dike margins. Here, the hematite staining is probably associated with both the migration of hydrothermal fluids along faults and the emplacement of dikes.

Silicification and Veining

Two areas of extensive silicification of the tuff of Nipple Mountain are found in the study area. One such area is on a ridge that is bounded by a north-trending fault just east of Jones Tanks. Presumably, the fault acted as a conduit for silica-bearing fluids. A second area of silicification, present as quartz and opaline silica veining, occurs in the tuff of Nipple Mountain in the southeast to east-central portion of the study area. In this area, the silicified tuff is closely jointed and sheared adjacent to faults, and some joint surfaces are coated with iron oxide; locally the tuff appears hydrothermally bleached.

Quartz-calcite veins, as much as 5 ft (1.5 m) wide, are present along faults in the north-central and eastern Gallinas Peak area (plate 2). In some places, the veining is along shear zones of unknown displacement and cannot be traced more than a few feet along strike. In these veins, euhedral rhombs of calcite, as large as 3 in. (7.6 cm) on a side, are often dark gray to black, and are sometimes associated with chalcedony or fine-grained quartz. Wilkinson (1976) concluded that black coloration in calcite veins of the Tres Montosas area was caused by inclusions of manganese and iron oxides; he speculated that the inclusions of manganese oxides may carry minor silver values in the Cat Mountain district. Some of the quartz-calcite veins in the Gallinas Peak area have been prospected on a small scale. It is not known whether these veins were prospected for manganese or for their possible silver content.

Pyrite cubes, as much as 2 mm on a side, were found coating surfaces of intensely hydrothermally altered rocks of the lower Spears Formation in a waste dump south of McGee Spring. A vertical shaft, located next to the waste dump, may have been as much as 30 ft (9.1 m) deep, judging from the size of the dump. Some rocks in the waste dump are intensely brecciated, cemented with silica, bleached, and variously stained with red, orange, and black iron oxides. Quartz crystals, as much as 0.5 in. (1.3 cm) in length fill larger open spaces in some rocks of the waste dump. This area of alteration in the lower Spears is probably related to intrusion of an adjacent, mafic(?) dike (hematite staining and bleaching are often found on dike margins in the study area). This site was the only occurrence of fresh pyrite found in the thesis area. However, euhedral holes, formed by leaching of hematitically altered pyrite in altered tuff of Nipple Mountain, were found in the extreme north-central portion of the thesis area.

Base and Precious Metals

The presence of an inferred intrusion in the eastern Gallinas Peak area presents the possibility of epithermal replacement bodies in favorable horizons at depth. Chapin and others (1974a) have found that mineralization in the Magdalena area is associated with epizonal stocks where the Kelly Limestone (Mississippian) has produced large quantities of zinc, lead, and silver ore in the Kelly mining district. The depth to the Kelly Limestone in the Gallinas Peak area is estimated to be between 7,170 ft (2185 m) and 8,295 ft (2528 m) assuming the following thicknesses:

0-1125 ft (343 m) Spears Formation
515 ft (157 m) Baca Formation
2920 ft (890 m) Mesozoic rocks (from Mayerson, 1979)
2535 ft (773 m) Permian rocks (from Tonking, 1957)
1200 ft (366 m) Pennsylvanian rocks (from Siemers, 1973)

Similarly, the depth to possible replacement deposits in Permian limestones would be between 4560 ft (1390 m) and 3435 ft (1047 m).

Chamberlin (1974) has estimated the depth to an inferred pluton in the Council Rock district to be within 2000 ft (610 m) of the surface based on surficial exposure of the Tres Montosas stock and doming over the inferred intrusive. However, estimating depth to the postulated pluton in the Gallinas Peak area is difficult. Intense hematite staining, numerous exposed dikes, and epithermal quartz-carbonate veins probably indicate that the intrusive is at a moderately shallow depth. In fact, doming could have brought the intrusive to within 2000 ft (610 m) of the surface. Because dikes are most abundant in the northeast and southeast portions of the area, the intrusive could be closest to the surface in these areas.

The lower Spears Formation in the eastern portion of the Gallinas Peak area may be a viable exploration target. The intense hydrothermal alteration of the Spears Formation suggests that this andesitic to latitic unit may have been sufficiently reactive to form base metal or precious metal deposits at shallow and, perhaps economically minable depths. Southwest east of this study, near Magdalena, Simon (1973) has found silver mineralization associated with reactive, vesicular, mafic lavas of the Silver Peak area (the La Jara Peak basaltic andesite).

Uranium

The Baca Formation, which crops out only in the northeast corner of the thesis area, has historically been the primary target for uranium exploration in the region around the Gallinas Peak area (Chapin and others, 1979). The Baca Formation has been divided into three members by Potter (1970), Massingill (1979), and Cather (1980). In the Riley-Puertecito area, it is the middle member which is most favorable to uranium mineralization because of its thickness, lateral extent, permeability, bleached nature, and abundant carbonaceous fragments (Chapin and others, 1979). In the Gallinas Peak area, the Baca Formation is also bleached a light-gray to light-yellow color and contains local carbonaceous trash. The bleached nature of the Baca Formation, along with some anomalous radioactivity present in outcrops along Jaralosa Creek, indicates that the unit has probably been a conduit for mineralizing solutions in the study area. Mineralization in the Baca Formation occurs just north of this study where Anonymous (1959) has noted uranium associated with carbonaceous materials of the Baca Formation.

Because the Baca Formation dips southward and westward under the volcanic units of the Gallinas Peak area its uranium potential could be enhanced; Chapin and others (1979, p. 27) suggest that the key to exploration of the Baca Formation is to find areas where the middle member has been downfaulted and protected from leaching. Tertiary volcanic cover in the thesis area could have also protected the Baca Formation from leaching and the unit is possibly mineralized where it is concealed.

Documented occurrences of uranium mineralization near the study area include the Hook prospect, about 3 mi (5 km) northeast of the Gallinas Peak area (Anonymous, 1959; Mayerson, 1979),and disseminated uranium in Baca channel sandstones along Jaralosa Creek (Anonymous, 1959). However, no prospects were seen in the Baca Formation in the Gallinas Peak area.

Coal

A modest amount of coal has been mined from the upper portion of the Crevasse Canyon at the Hot Spot mine, about 4 mi (6 km) northeast of the Gallinas Peak area (Mayerson, 1979). Although no mining of coal has been done in the Gallinas Peak area, minor coal beds, a few feet thick, crop out in the extreme northeast portion of the area. Exposures of the Crevasse Canyon are limited in the study area, making the resource potential difficult to determine. Should the Crevasse Canyon found in the northeastern Gallinas Peak area continue west and south beneath Tertiary cover, a significant amount of coal may be present in the thesis area. However, large depths to coal horizons would make strip mining uneconomic. Studies concerning the Crevasse Canyon near the Gallinas Peak area by Chapin and others (1979) and Mayerson (1979) have indicated that the coal beds of the upper portion of the Crevasse Canyon grade rapidly into organic shales both laterally and vertically. This discontinuity of the upper coal beds demeans their resource potential except where the beds are readily strippable. The coal beds of the lower Crevasse canyon are more laterally continuous (Chapin and others, 1979), but depths to these coal horizons in the Gallinas Peak area are probably prohibitive for mining.

CONCLUSIONS

The following conclusions regarding the stratigraphy, structure, and economic potential of the Gallinas Peak area can be made from this study.

Stratigraphy

Oligocene volcanic rocks and less voluminous, interbedded sedimentary rocks cover most of the Gallinas Peak area. A minor amount of prevolcanic Eocene and Cretaceous sedimentary rocks are exposed in the extreme northeast portion of the study area, where they dip gently south and west beneath the volcanic units.

The tuff of Granite Mountain, a quartz-latite ash-flow tuff which is characteristically near the top of the Spears Formation elsewhere in the Socorro-Magdalena area is not present in the Gallinas Peak area. Replacing the tuff of Granite Mountain in most of the Gallinas Peak area is a thick (greater than 300-ft, 91-m) sequence of basaltic andesites which may reflect a buried shield volcano near the west margin of the study area. These flows pinch out toward the northwest and northeast margins of the study area. Because of this abrupt thickness change and probable uplift and erosion during Spears time, the Hells Mesa Tuff unconformably overlies the tuff of Nipple Mountain in the northwest and northeast portions of the study area.

The tuff of Lemitar Mountains, a regionally extensive ash-flow tuff that is normally between the A-L Peak Tuff and the tuff of South Canyon, is not present in the Gallinas Peak area. In place of the tuff of Lemitar Mountains in the study area is a thin sequence of basalts and sedimentary rocks. The tuff of South Canyon in the southwestern Gallinas Peak area is anomalously thick and may reflect development of considerable topography in this area prior to emplacement of the tuff.

A concealed, Spears-age intrusive is postulated to have been emplaced along north-trending faults bounding the Mulligan Gulch graben in the Gallinas Peak area. Evidence supporting a concealed intrusive is: 1) the presence of an aeromagnetic high in the southeast portion of the study area; 2) the presence of mafic and felsic dikes in the northeast and southeast portion of the study area; 3) locally intense hydrothermal alteration of the Spears Formation, and weak propylitization of dikes; and 4) the presence of epithermal quartz-calcite veins. It is possible that doming of the eastern margin of the thesis area may have brought the intrusive to within 2000 ft (610 m) of the surface.

Structure

The Gallinas Peak area consists of several blocks which gently dip southwest; this regional dip is away from the Colorado Plateau and the Rio Grande Rift, to the north and east of the study area, respectively. The structurally highest portions of the area are on the east margin where the units have been arched over an inferred intrusive. The eastern boundary of the area marks the western border of the Rio Grande Rift; along this boundary, strata dip steeply eastward into the Mulligan Gulch Graben.

North-trending rift faults are the most common structures in the Gallinas Peak area; here they form a series of horsts and grabens across the range. These faults increase in frequency and amount of displacement eastward, toward the west edge of the Mulligan Gulch graben. Some north-trending faults probably developed during lower Spears time.

Transverse normal faults, probably contemporaneous with north-trending faults, are minor in comparison with north-trending faults. The transverse faults have several possible origins: 1) they may represent a conjugate fault pattern related to doming of the Gallinas Peak area over a postulated intrusive; 2) they may be a reflection of a basement fault zone related to the Tijeras lineament; 3) these faults could be related to differential movement of the Colorado Plateau to the northwest, away from the Gallinas Peak area; and 4) the transverse faults may merely represent a deviant fault trend local to the Gallinas Peak area and not directly attributable to regional structures.

Structural evidence of movement related to the northeast-trending Tijeras lineament in the northeastern Gallinas Peak area is the presence of structurally high blocks exposing pre-volcanic units. These blocks may be related to uplift associated with a basement fault zone. Other evidence which supports structural discontinuities related to the Tijeras lineament are the abrupt thinning of volcanic units to the northeast, and the presence of numerous, local unconformities in the northeast portion of the Gallinas Peak area. Alternatively, these structural features may be related to doming over an intrusive or an evaporite diapir in the eastern Gallinas Peak area.

A monoclinal flexure, adjacent to the Mulligan Gulch graben is present on the east margin of the study area. This flexure extends from Abbe Spring on the north to Cat Mountain on the south. The monocline may be attributed to 1) upthrusting associated with the emplacement of a northerly elongate intrusion adjacent to the Mulligan Gulch graben; 2) fault drag related to the fault system bounding the graben; or 3) possible diapiric intrusion of Mesozoic shale sequences and/or Paleozoic evaporite horizons.

Alteration and Mineralization

Alteration is best developed in the eastern portion of the Gallinas Peak area where it consists of weak propylitization of the Spears Formation, the Hells Mesa

Tuff, and mafic and felsic dikes. Silicification of the tuff of Nipple Mountain is also common adjacent to faults. Hydrothermal effects of bleaching and hematite staining in the lower Spears Formation, the tuff of Nipple Mountain, and the Hells Mesa Tuff are also found in the eastern portion of the study area. Here, hematite staining is often found in sheared outcrops and adjacent to dikes. Manganiferous calcite veins with microcrystalline quartz, emplaced along faults in the central and eastern portions of the study area, probably represent low-temperature epithermal veining related to intrusive activity at depth. Fresh pyrite has been found as a minor constitiuent of a hydrothermally altered outcrop adjacent to a dike in the southeast portion of the study area but may have been formerly present in all hematite-stained areas.

An inferred, concealed intrusive in the eastern portion of the study area may have resulted in replacement orebodies in Paleozoic limestones similar to those orebodies of the Magdalena district. However, depths to favorable replacement horizons are probably uneconomic. An alternative exploration target of low to moderate favorability in the Gallinas Peak area is the Spears Formation which is andesitic to latitic in composition and may be sufficiently reactive to host shallow base or precious metals deposits adjacent to the inferred intrusive. Dike swarms in the northeast and southeast portions of the thesis area suggest that depth to the intrusive would be least in these areas.

The Baca Formation is a host for uranium mineralization along Jaralosa Creek just northeast of the study area. The bleached nature of the Baca Formation in the study area, along with minor radioactivity anomalies present in outcrops along Jaralosa Creek, indicate that the Baca acted as a passageway for mineralizing solutions. The Baca may have increased uranium potential in areas where it dips gently beneath younger volcanic strata and may have been protected from leaching.

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APPENDIX

Td 456 - Mafic Dike

Thin section Td 456 contains about 5 percent phenocrysts of subhedral to euhedral plagioclase which averages about 1 mm in length. These feldspars have slight normal zonation and a composition of about An61 (maximum value from 11 measurements, Michel-Levy method). Chlorite and calcite replace some of the plagioclase. Chlorite and calcite pseudomorphs of amphibole and (possibly) pyroxene, enclosing minor amounts of magnetite, comprise from 3 to 5 percent of the thin section. Euhedral to anhedral, 0.01 to 0.1 mm magnetite grains account for about 5 percent of the thin section. The groundmass consists of slightly normally zoned labradorite (about An64, maximum value from 9 measurements, Michel-Levy method) averaging less than 0.5 mm, and 5 to 10 percent patches of chlorite and calcite. The groundmass plagioclase is randomly oriented except for a slight tendency to parallel borders of adjacent phenocrysts.

Td 415 - Mafic Dike

A second thin section examined from a mafic dike in the northeastern Gallinas Peak area (Td 415) contains 65 to 75 percent, 0.04 to 0.4 mm plagioclase (about An39, maximum value from 11 measurements, Michel-Levy method), and about 2 percent magnetite anhedra. The 7 percent ferromagnesian phenocrysts present in this thin section are altered in the same fashion as those of the previous thin section. Interstitial material, comprising about 20 percent of the thin section, is replaced by patches of chlorite and calcite. The thin section contains about 2 percent 0.01 to 0.1 mm anhedral magnetite. Several 0.5 mm, hematitic pseudomorphs of pyrite are present along with polycrystalline quartz and calcite veinlets. Angular to rounded, polycrystalline clots of quartz with undulose to straight extinction are present in trace amounts.

Tmd 283 - Mafic Dike

This dike shows similar alteration to that of Td 456 and Td 415. Ferromagnesian phenocrysts in dike Tmd 283 are often replaced by calcite, chlorite, lesser amounts of quartz, and, occasionally, magnetite. Some of the ferromagnesian crystals contain hematitally altered olivine or pyroxene grains. A trace of rounded quartz xenocrysts are present in Tmd 283. These crystals have minor calcite veinlets and are surrounded in part, by a very low birefringent, brown mineral of fibrous habit. Calcite and minor, anhedral clinopyroxene also rim the quartz. Sample Tmd 283 contains about 85 to 90 percent, 0.07 to 0.4 mm, trachytically arranged andesine (about An42, maximum value from 10 measurements, Michel-Levy method). A relict intergranular texture is indicated by traces of birefringence in hematitically altered olivine or pyroxene microcrysts (about 3 percent), averaging less than 0.05 mm in size, and by portions of the groundmass which have been replaced by chlorite, clay, calcite, and quartz. About 2 percent magnetite crystals, averaging less than 0.05 mm are also present. Euhedral apatite, as much as 0.13 mm long, is present in trace amounts.

Td 298 - Mafic Dike

Sample Td 298 contains between 2 and 5 percent altered ferromagnesian(?) crystals 3 or 4 mm in size. These crystals are rounded in shape, replaced with calcite, and rimmed by subparallel plagioclase needles and intergranular chlorite (after clinopyroxene). Some ferromagnesian crystals are subhedral (possibly clinopyroxene) and replaced by calcite. Sparse, altered plagioclase phenocrysts are also present. The groundmass consists of about 50 percent, 0.05 to 0.6 mm plagioclase needles which are altered to chlorite, clay, and calcite. The groundmass also contains about 40 percent intergranular clinopyroxene(?) largely replaced by chlorite. From 5 to 7 percent, anhedral to euhedral magnetite crystals dot the matrix. Traces of euhedral apatite, averaging about 0.01 mm in size, is present in trace amounts.

Td 317 - Mafic(?) Dike

Sample Td 317 contains about 5 percent xenocrysts(?) of sanidine and quartz. The sanidine, as much as 3 cm long, are prismatic with rounded termini. The 1 or 2 percent quartz xenocrysts present are rounded, comminuted masses with cracks occupied by masses of calcite and chlorite. This dike sample contains about 10 percent pseudomorphs of clinopyroxene, amphibole, and lesser olivine, averaging about 0.5 mm (range is about 0.15 to 2.8 mm) in length. Some of these pseudomorphs have inclusions of magnetite, all are comprised of calcite, and contain lesser amounts of chlorite and occasionally, quartz. Texturally, the groundmass is subophitic; traces of plagioclase crystals, as much as 0.5 mm long, are surrounded by about 75 to 80 percent prismatic clinopyroxene crystals. The blocky to prismatic plagioclase has a composition of about An56 (maximum value from 7 measurements, Michel-Levy method) and averages less than 0.5 mm. The clinopyroxene is sometimes replaced by chlorite, illite, and minor quartz and calcite. The sanidine phenocrysts show minor perthitic exsolution and sparse alteration to calcite and chlorite. Albitic plagioclase is intergrown with, and rims the sanidine. Euhedral to anhedral magnetite grains, averaging about 0.03 mm, are present in amounts of about 7 percent. A trace of euhedral apatite, as much as 0.3 mm, is also present.

Td 296 - Mafic Dike

Td 296 contains about 15 to 20 percent phenocrysts of euhedral to subhedral, 0.08 to 1.3 mm plagioclase, which are clouded by alteration to clay. About 2 percent, hematitic pseudomorphs of pyrite, and about 1 percent patches of polycrystalline quartz are present. The quartz is sometimes strongly undulose and occurs as veinlets and as radiating aggregates. Several glomeroporphyritic clots of plagioclase and a hematitically altered ferromagnesian mineral, probably clinopyroxene, are present. Magnetite, as euhedral to anhedral crystals, accounts for about 3 percent of the thin section. Trace amounts of apatite, ranging from 0.06 to 0.5 mm in size, are also present. The matrix is an altered, felty mass of low-birefringent microlites, and a hematitcally and chloritically altered ferromagnesian mineral, less than 0.1 mm in length.

Td 465a - Quartz Latite Dike

Sample Td 465a contains about 10 to 15 percent, subhedral to euhedral plagioclase phenocrysts. These crystals average about 1.1 mm in length and have a composition of about An59 (maxiumum value from 10 measurements, Michel-Levy method). Chlorite and calcite pseudomorphs of euhedral to subhedral amphibole, 0.1 to 3.0 mm long account for between 3 and 5 percent of the thin section. One to two percent quartz crystals with slightly undulose extinction sometimes have small embayments. Subhedral to euhedral sanidine, altered in part to illite, accounts for about 1 percent of the thin section. One sanidine crystal partially envelopes a plagioclase crystal. Biotite crystals, present in trace amounts, are sometimes enclosed by amphibole relics. Two to three percent magnetite crystals, averaging less than 0.1 mm, are also occasionally enclosed by the amphibole. About 1 percent apatite crystals are present as 0.02 to 0.04 mm euhedra. The groundmass consists of plagioclase laths, less than 0.5 mm long, set in a brown, aphanitic matrix.

Td 383 and Td 542 - Quartz Latite Dike

These two two thin sections of a quartz latite dike found in the east-central Gallinas Peak area are remarkably similar and are therefore described together. Each slide contains about 5 percent altered, euhedral plagioclase phenocrysts and from 3 to 5 percent biotite phenocrysts set in an equigranular matrix of plagioclase with interstitial quartz and minor biotite. Plagioclase phenocrysts (about An49, maximum value from 16 measurements, Michel-Levy method) average about 1 mm, are sometimes normally zoned, and are partially altered to clay with lesser amounts of calcite and chlorite. In one thin section (Td 383), many of the plagioclase phenocrysts had been partially plucked out during the thin section process. The groundmass plagioclase ranges from trachytic to randomly oriented and has a composition of about An33 (maximum value from 14 measurements, Michel-Levy method). Pleochroic reddish-brown to light-yellow biotite is anhedral to euhedral in shape and averages less than 1 mm in length. Interstitial quartz crystals, some with slightly undulatory extinction, comprise from 3 to 5 percent of the thin sections examined. Two to three percent magnetite anhedra, as much as 0.3 mm in diameter are also present. Traces of euhedral to subhedral apatite range from about 0.1 to 0.7 mm in size. Most of the finer groundmass constituents have been replaced by chlorite. A glomeroporphyritic clot of altered pyroxene and/or amphibole with biotite and apatite was seen in thin section Td 383. The pyroxene and/or amphibole is extensively replaced by hematite, calcite and chlorite.

Td 549 - Quartz Latite Plug

Sample Td 549 contains about 80 percent plagioclase crystals which average less than 0.5 mm. These subhedral to anhedral crystals have a composition of about An39 (maximum value from 16 measurements, Michel-Levy method) and are arranged in a pilotaxitic array. The plagioclase is partially altered to chlorite, calcite, and clay. Phenocrysts of an altered ferromagnesian mineral, as much as 1.1 mm in size, make up about 5 percent of the thin section. These crystals have been completely replaced by chlorite, hematite, and quartz; some have shapes diagnostic of amphibole, others may be relict pyroxene. One to two percent quartz crystals occur as interstitial grains and, less often, as well-rounded phenocrysts with slightly undulose extinction. The quartz phenocrysts are rimmed by calcite. Anhedral sanidine crystals, altered in part to illite, average less than 0.5 mm in size and make up about 2 percent of the thin section. Traces of biotite, plechroic from reddish brown to very light brown, average about 0.05 mm in length. Magnetite anhedra, present in amounts of 5 to 7 percent, sometimes occur as inclusions within the ferromagnesian minerals and the plagioclase. Traces of euhedral apatite dot the thin section. The groundmass is altered to irregular masses of calcite and chlorite.

This thesis is accepted on behalf of the faculty of the Institute by the following committee:

Charles E. Chapin
Adviser

Clay T. Smith

A. J. Budding

12/20/1980
Date

Bureau OF 128

PLATE 1

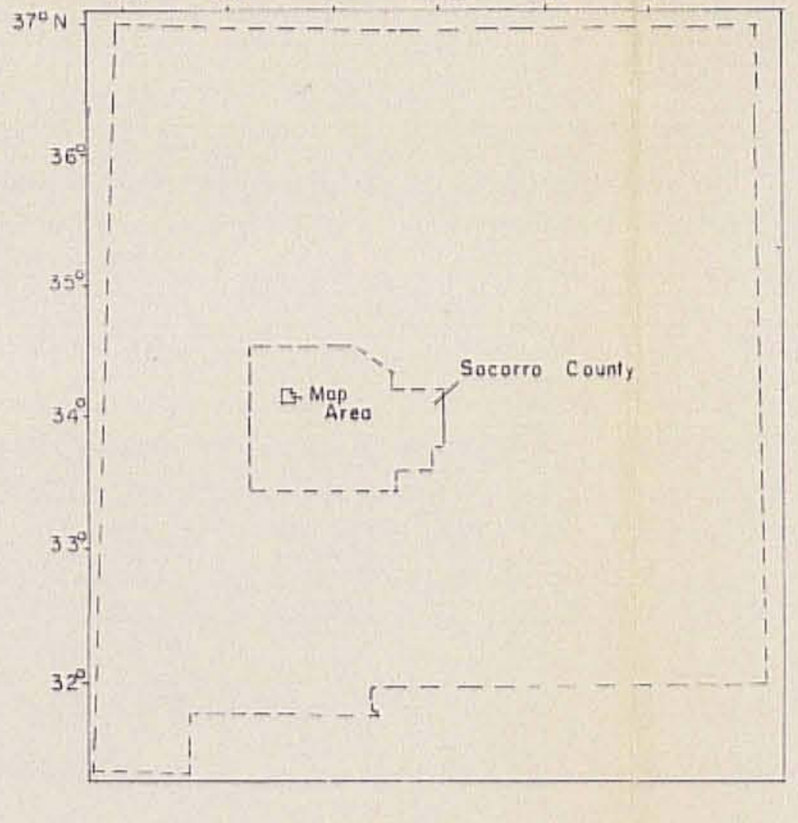
GEOLOGIC MAP AND SECTIONS OF THE GALLINAS PEAK AREA,
SOCORRO COUNTY, NEW MEXICO

by

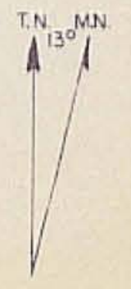
T. MATTHEW LAROCHE

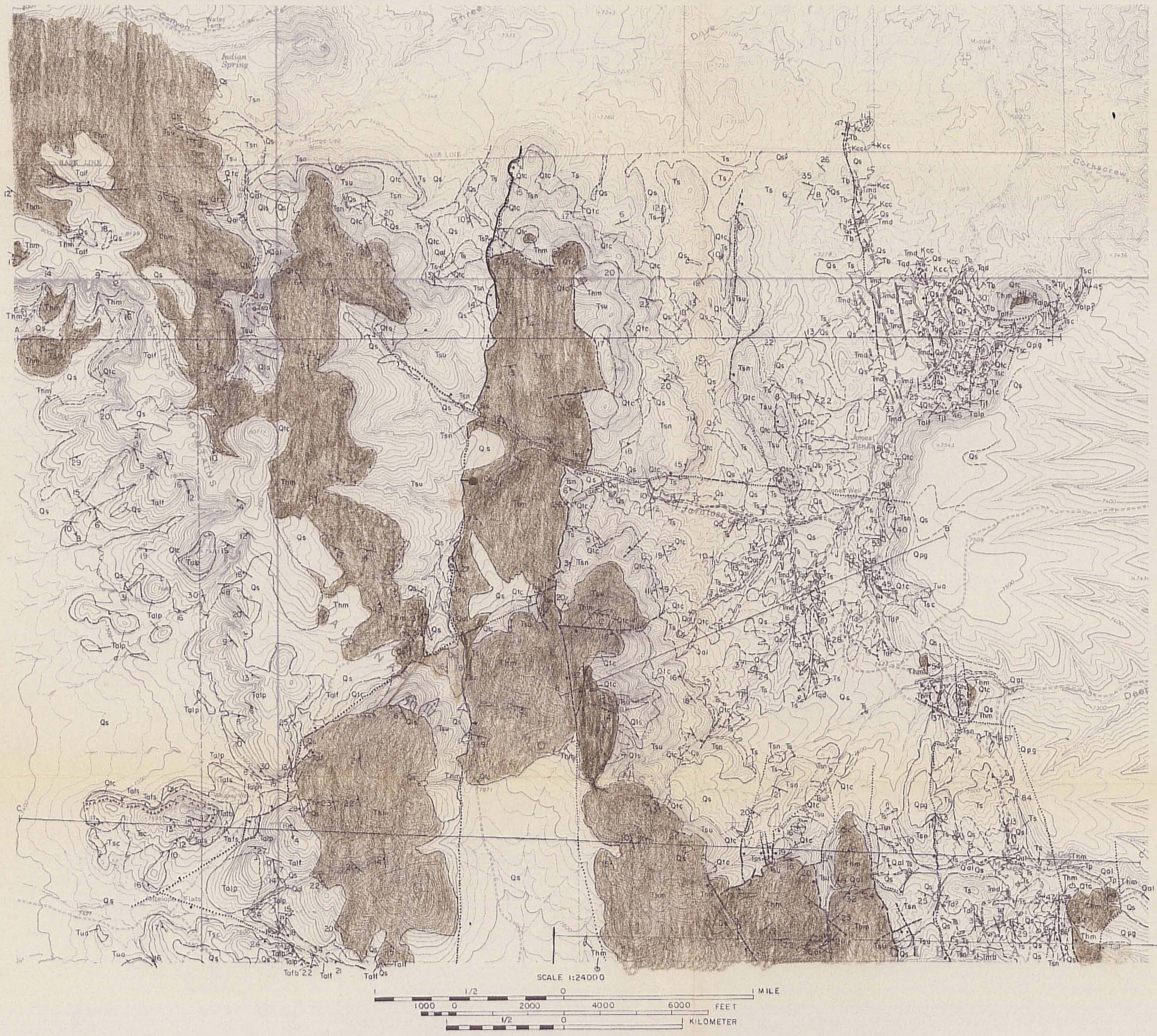
1980

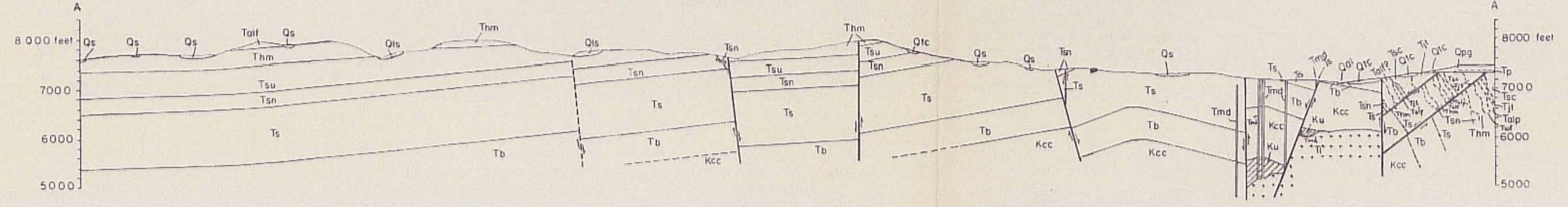
OF 128 1 of 2

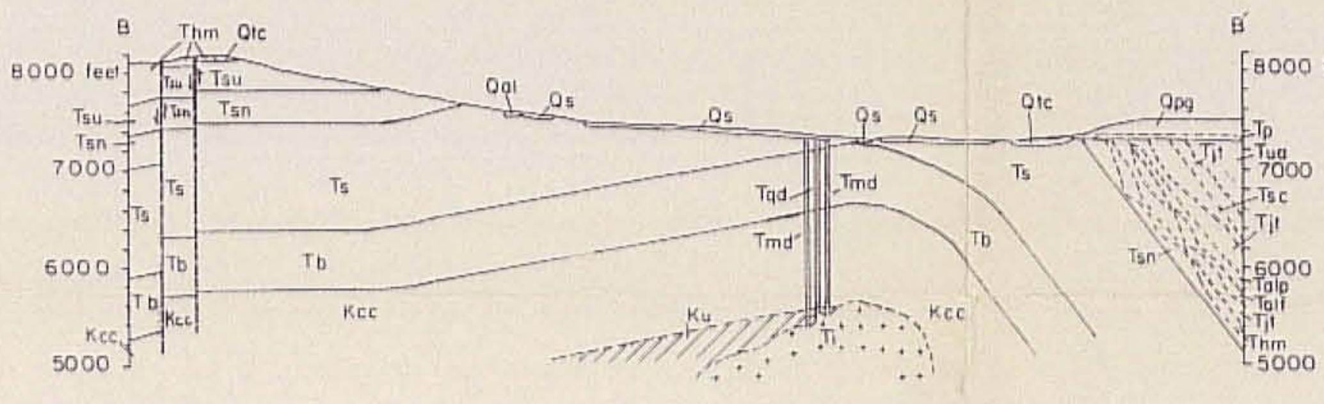


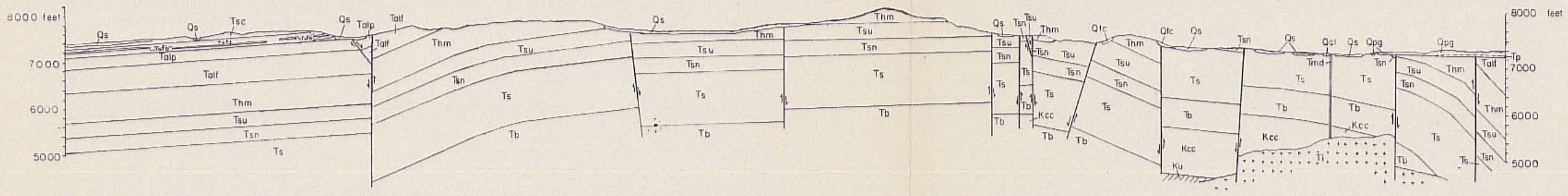
NEW MEXICO











EXPLANATION

QUATERNARY

Qal — Alluvium

Qs — Eolian sand

Qls — Landslide

Qtc — Talus and colluvium

PLIO-PLEISTOCENE

Qpg — Piedmont gravels

MIOCENE

Tp — Popotosa Formation

OLIGOCENE

Tua — Upper andesite and basaltic andesite

Tsc — Tuff of South Canyon
v: basal vitrophyre

Tafs, Tafb — Basalt and sedimentary rocks of Antelope Flats
Tafb: basalt flows
Tafs: sedimentary rocks

Tjt — Basalt of Jones Tanks

Talp, Talf — A-L Peak Tuff
Talp: pinnacles member, L: lithic-rich base, ⋯: basal sedimentary horizon
Talf: flow-banded and gray-massive members

Thm — Hells Mesa Tuff
v: basal vitrophyre

Tsu, Tsn, Ts — Spears Formation
Tsu: lavas and epiclastic rocks
Tsn: tuff of Nipple Mountain
Ts: lower member

Tqd, Tmd, Td ?, Ti — Dikes, plugs, and inferred stock
Tqd: quartz latite dike or plug
Tmd: mafic dike
Td?: intensely altered dike (?)
Ti: inferred stock (shown on cross sections only)

EOCENE

Tb — Baca Formation

CRETACEOUS

Kcc — Crevasse Canyon Formation

Ku — Cretaceous undifferentiated (shown on cross sections only)

Contact
Dashed where approximately located, short dashed where inferred

Fault
Dashed where approximately located, short dashed where inferred, dotted where concealed
Bar and ball on downthrown side

57
Strike and dip of bedding

7
Strike and dip of compaction foliation (dips commonly steeper in ash-flow tuffs than indicated by contacts between units)

8
Strike and dip of contact

8
Trend and plunge of flow lineation

128

PLATE 2

MAJOR STRUCTURES, INTRUSIVE ROCKS, AND ALTERATION OF THE GALLINAS PEAK AREA, SOCORRO COUNTY, NEW MEXICO

by

T. MATTHEW LAROCHE

1980

EXPLANATION

800

Fault
Dashed where approximately located,
short dashed where inferred,
dotted where concealed
Bar and ball on downthrown side
(Faults with possible early-Oligocene movement
shown with hachures on downthrown side)
Number indicates, in feet, approximate stratigraphic throw

Tqd Tmd Td?

Dikes and plugs
Tqd: Quartz latite dike or plug
Tmd: Mafic dike
Td?: Intensely altered dike (?)

Hydrothermal alteration

Quartz–carbonate vein

⊠

Shaft or inclined tunnel

×
Prospect

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