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GEOLOGY OF THE CENTRAL CHUPADERA MOUNTAINS

SOCORRO COUNTY, NEW MEXICO

by

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ABSTRACT

The Chupadera Mountains are a structurally and stratigraphically complex mountain range near Socorro, New Mexico. Rocks ranging from Precambrian to Quaternary are represented, but Tertiary volcanic and clastic sedimentary rocks are by far the most abundant. The Tertiary history begins at about 37-35 m.y. before present with the deposition of the Datil Group, a sequence of andesitic and latitic lava flows and volcaniclastic sedimentary rocks. At about 33 m.y., the Hells Mesa Tuff was erupted from the Socorro cauldron, a resurgent cauldron in excess of 15 mi (24 km) in diameter. Excellent exposures in the Chupadera Mountains document the Socorro cauldron from early in its development until it was completely covered by younger ash-flow tuffs. The record begins shortly after the eruption of the Hells Mesa Tuff began. At that point, the cauldron block had dropped an unknown distance and cauldron collapse breccias had begun to form. These breccias were formed contemporaneously with the cauldron-facies Hells Mesa Tuff and are intercalated in the cauldron-facies tuff. At the end of the Hells Mesa Tuff eruption, the lower sedimentary member of the Luis Lopez Formation began to be deposited contemporaneously with cauldron resurgence. The next members of the Luis Lopez Formation, the lower lava member and the basalt member are in the same stratigraphic

position. No evidence was found to indicate that the resurgence of the cauldron continued past the deposition of those units. The remaining units in the Luis Lopez Formation document a complex volcanic and sedimentary history for the Socorro cauldron which ended with the deposition of the La Jencia Tuff, a major ash-flow sheet, 33 m.y. ago. Following the La Jencia Tuff were the Lemitar Tuff and the South Canyon Tuff at 28 and 26 m.y., respectively. Basin-fill sedimentary rocks and the basalt flows intercalated in them are the youngest rocks in the area.

Down-to-the-west normal faults are the most common structural feature in the area. Down-to-the-east faults are present as well. The northern portion of the area has undergone rotational faulting and low-angle normal faults are common. Southward, the bedding dip decreases from about 70 degrees at the northern map boundary to about 10 to 20 degrees at the southern boundary. The dip is believed proportional to the amount of extension and thus it is assumed that the amount of extension also decreases southward. The topographic wall of the cauldron is exposed in the southern part of the map area, and the complex structure and rhyolite domes in, and north of, Nogal Canyon may be the surface manifestations of the ring fracture zone of the cauldron.

The Chupadera Mountains contain numerous manganese veins and breccia fillings collectively known as the Luis Lopez manganese district. Many of these bodies were mined at one time, but are uneconomic now. Metals other than manganese are found in the veins and have modest economic potential. The copper occurrences in the Precambrian rocks in the southern part of the map area are believed to have little potential. Two types of alteration were found: A regional potassium metasomatism which is limited to the northern part of the map area and a local alteration that is manifest by the destruction of the ferromagnesian minerals and the addition of hematite which imparts a red hue to the altered rocks. This alteration is also restricted to the northern part of the map area.

INTRODUCTION

LOCATION AND ACCESS

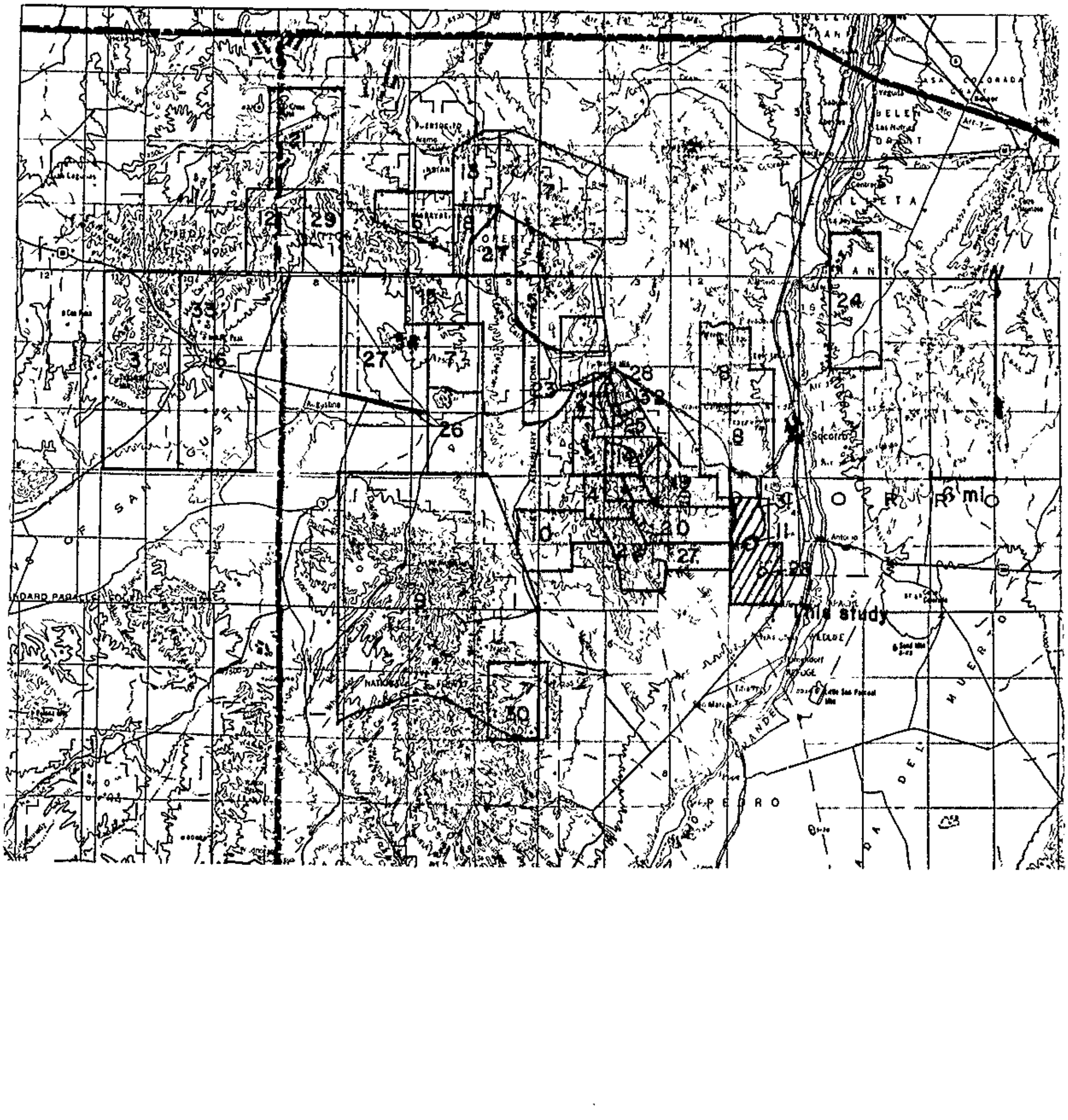
The area studied is located in the central Chupadera Mountains, Socorro County, New Mexico and includes about 42 mi^2 (110 km^2), the center of which is about 12 mi (14.4 km.) south-southwest of Socorro and 6 mi (7.2 km) west of San Antonio. Figure 1 shows the relationships of the thesis area to regional geographic and physiographic features as well as previous studies in the region. Figure 2 is a more detailed look at the geography, access, and previous studies in the Chupadera Mountains. All season, county-maintained roads provide access to the Chupadera Range from Socorro, San Antonio, and U.S. Highway 60. Access routes within the range are generally four-wheel-drive roads and trails. Figure 3 is a photograph taken near the north boundary of the study area looking south and shows the topography of the area.

OBJECTIVES

The primary objectives of this study are: 1) to extend the regional stratigraphic framework from the Magdalena and Socorro-Lemitar Mountains to the southern Chupadera Mountains; 2) to define, if possible, the southern boundary of the Socorro Cauldron; 3) to determine the extent of

Figure 1. Location map showing recent geologic studies of Tertiary volcanic rocks in the Socorro region. The numbers refer to the table below. The abbreviations used are; NMIMT-New Mexico Institute of Mining and Technology; NMBMMR-OF-New Mexico Bureau of Mines and Mineral Resources open-file report; USGS-U.S. Geological Survey; UNM-University of New Mexico; UTEP-University of Texas at El Paso; UTA-University of Texas at Austin; UA-University of Arizona; CU-University of Colorado; CSM-Colorado School of Mines; M.S.-Masters thesis; Ph.D.-Doctoral Dissertation; in prep-in preparation.

1-Allen, P.	1979	NMIMT (M.S.)
2-Blakestad, R.B.,Jr.	1977	CU (M.S.)
3-Bornhorst, T.J.	1976	UNM (M.S.)
4-Bowring,S.A.	1980	NMIMT (M.S.)
5-Brown, D.M.	1972	NMIMT (M.S.)
6-Cather, S.M.	1980	UTA (M.S.)
7-Chamberlin, R.M.	1974	NMIMT (M.S.)
8-Chamberlin, R.M,	1980	CSM (Ph.D.)
9-Deal, E.G.	1973	UNM (Ph.D.)
10-Donze, M.A.	1980	NMIMT (M.S.)
11-Gentile, A.L.	1957	NMIMT (M.S.)
12-Harrison, R.W.	1980	NMIMT (M.S.)
13-Jackson, R.A.	1979	NMBMMR-OF
14-Krewedl, D.A.	1974	UA (Ph.D.)
15-Laroche, T.M.	1981	NMIMT (M.S.)
16-Lopez, D.A.	1975	UNM (M.S.)
17-Massingill, G.E.	1978	UTEP (Ph.D.)
18-Mayerson, D.L.	1979	NMIMT (M.S.)
19-Osburn, G.R.	1978	NMIMT (M.S.)
20-Petty, D.M.	1979	NMIMT (M.S.)
21-Robinson, B.	1981	UTEP (Ph. D.)
22-Roth, S.J.	1980	NMIMT (M.S.)
23-Simon, D.B.	1973	NMIMT (M.S.)
24-Spradlin, E.J.	1976	UNM (M.S.)
25-Sumner, W.	1980	NMIMT (M.S.)
26-Wilkinson, W.H.,Jr.	1976	NMIMT (M.S.)
27-Osburn, G.R	1978-81	NMBMMR-OF
28-Kent, S.	1980	NMBMMR-OF
29-Coffin, G.	1981	NMIMT (M.S.)
30-Atwood,G.	in prep.	UNM (M.S.)
31-Miesch,A.T.	1956	NMBMMR Circular
32-Iovinetti, S.	1977	NMIMT (M.S.)
33-Lopez and Bornhorst	1979	USGS Map I-1098
34-Osburn and Laroche	1982	NMBMMR-OF



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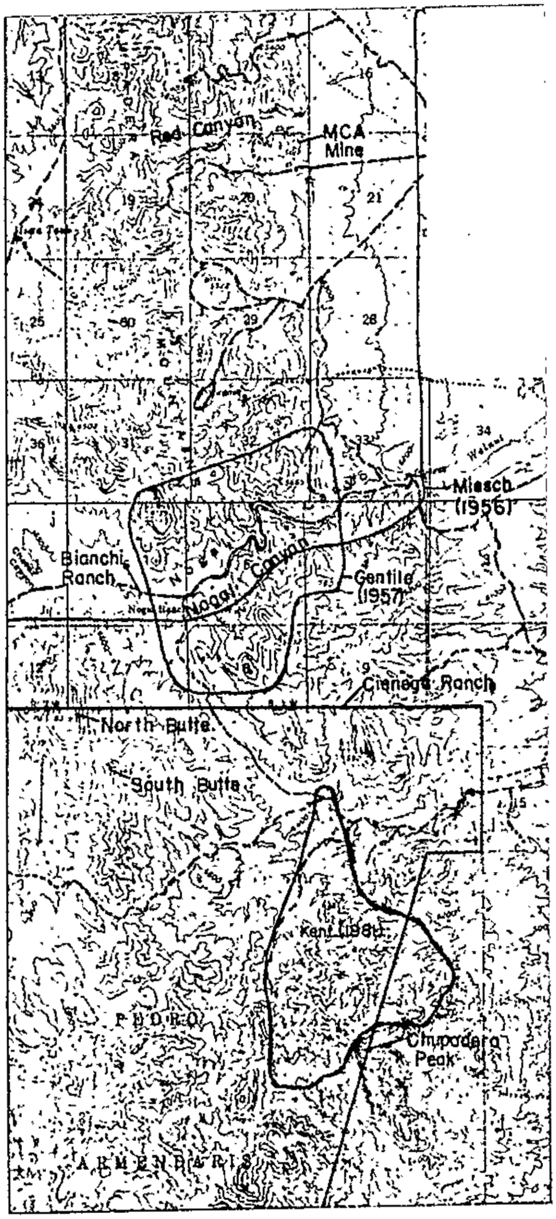


Figure 2. Previous geologic studies and geography within the study area. Dashed lines are roads.

Figure 3. View from near the north edge of the study area looking south.

domino-style faulting in the Chupadera mountains (chamberlin, 1980); and 4) to evaluate the mineral potential of the area.

METHODS OF INVESTIGATION

Detailed geologic mapping was done at a scale of 1:24,000 on a topographic base map consisting of parts of the Laborcita and San Antonio S.W. quadrangles of the U.S. Geological Survey's 7 1/2 minute series (Plate 1). Three sets of aerial photographs were used as an aid to the field work. One, a color set, at a scale of about 1:40,000 was flown by the New Mexico Bureau of Mines and Mineral Resources in 1969; the other sets are U.S. Geological Survey series GS-VCXM and GS-VCXM-S at a scale of about 1:24,000. The field work was done in the summer and fall of 1980. Eighty-seven thin sections were used to describe rock units and to verify correlations (see Plate 2 for location of the samples). All of the thin sections were stained with sodium cobaltinitrite to distinguish sanidine from quartz and to test for potassium metasomatism. The method described by Wilson and Sedora (1979) was used, but the etch times were increased from the recommended 1 1/2 seconds to 30 to 90 seconds. Forty-five thin sections were point counted on a Zeiss binocular microscope using a Swift automatic point counter. All of the thin sections were counted on a 1/3 by 2/3 mm grid, utilizing at least 2000 points except as noted (see Appendix 1). Petrographic rock names are after Travis (1955) and definitions will conform to the AGI Glossary of Geology except where noted. Ash-flow tuff terminology is after Ross and Smith (1961), Smith (1960a), and Smith (1960b). Many of the textural terms are from Williams, Turner and Gilbert (1954).

PREVIOUS WORK

One of the earliest mentions of the geology of the Chupadera Mountains was in a report on the Luis Lopez manganese district by E.H. Wells in 1918. He briefly described the geology and ore deposits of the northern Chupadera Mountains. Loughlin and Koschmann's (1942) map of the Magdalena Mountains shows the Chupadera Mountains consisting of Cretaceous and Tertiary volcanic rocks, Miocene and Pliocene sedimentary rocks, and Quaternary alluvium. During the 1950's, the New Mexico Bureau of Mines and Mineral Resources sponsored several studies in the area. A.T. Miesch (1957) mapped the geology from U.S. Highway 60 south to Nogal Canyon and H.L. Jicha (1956) gave a preliminary description of the geology, mineralogy, and ore deposits of the area. It was also during this time period that A.L. Gentile (1957) mapped about 6 mi^2 (15.5 km^2) in Nogal Canyon as part of an M.S. thesis at the New Mexico Institute of Mining and Technology. It should be noted that while some of Gentile's outcrop patterns are grossly similar to those of the present study, it is not possible to correlate map units. Difficulties in correlating with the present study arise because Gentile used hardness, secondary alteration, flow characteristics, and devitrification textures to separate stratigraphic units. Geologists now know that volcanic rocks must be separated into genetic units and that a single genetic unit may contain several texturally distinct rock types. In addition, different genetic units may, and often do, have texturally indistinguishable facies. Therefore, no direct correlations are made with Gentile's work. The map patterns of Miesch (1957) and Willard (unpublished mapping) generally correspond with the present work, but will not be referenced for similar reasons. At the time of his death in 1972, M.E. Willard was preparing a report on the geology and mineral deposits of the Luis Lopez manganese district for the New Mexico Bureau of Mines and Mineral Resources. The most recent mapping of the volcanic rocks was that of Chamberlin (1980). He mapped part of the Lemitar Mountains, all of Socorro Peak, and the extreme northern end of the Chupadera Mountains.

The Paleozoic section near Chupadera Peak has been investigated by F.E. Kottlowski (1960, 1963) and by A.K. Armstrong (1958, 1963). The Paleozoic section overlies a small block of Precambrian metasedimentary, metavolcanic, and granitoid plutonic rocks which have been mapped by Kottlowski (1960), Condie and Budding (1979), and by Kent (1980, NMBMMR open-file map).

The regional stratigraphic framework has developed over the last decade as part of the "Magdalena Project", a project of the New Mexico Bureau of Mines and Mineral Resources, directed by C.E. Chapin. Since 1972, some 25 theses and dissertations have been completed either as part of the project or in close cooperation with C.E. Chapin (see Figure 1). The present study is part of the "Magdalena Project". Chamberlin (1980) presents a concise history of the evolution of the regional stratigraphic framework. Osburn and Chapin (in press) have compiled a detailed stratigraphic chart of Cenozoic units in the northeastern Datil-Mogollon volcanic field.

ACKNOWLEDGMENTS

I thank Dr. Charles Chapin for his suggesting this project and for his support and guidance during the course of the work. I would also like to thank him and the New Mexico Bureau of Mines and Mineral Resources for the financial support for the study. I acknowledge and appreciate the discussions and suggestions with the other two members of my thesis committee: Dr. Allan Sanford and Dr. Clay T. Smith. I thank those two individuals for critically reading the original manuscript and suggesting changes which greatly improved the final product. Very special thanks go to Bob Osburn of the New Mexico Bureau of Mines and Mineral Resources for his thoughtful discussions and guidance throughout the course of this study. The black and white photographs in this report are a result of his skill with both a camera and darkroom. Other individuals have provided insight into problems encountered during the course of the study include Dr. Frank Kottlowski, Director of the New Mexico Bureau of Mines and Mineral Resources and Dr. Richard Chamberlin, geologist for the New Mexico Bureau of Mines and Mineral Resources. Access to the Cienega Ranch was kindly provided by Tenneco Oil Company and the Cienega Ranch, Slim Pond, Foreman. Access to other privately owned land in the Chupadera Mountains was provided by Smokey Pound, owner of the Pound Ranch.

I also thank my wife, Roberta, for her help and support during the course of this study because without that support, this study might never have been finished.

STRATIGRAPHY AND PETROGRAPHY

PRE-TERTIARY ROCKS

Precambrian rocks are exposed in the southeastern portion of the Chupadera Range (Plate 1). Kottlowski (1960) first reported the existence of these metamorphic and plutonic rocks. Condie and Budding (1979) revised Kottlowski's map in their memoir on the geology of the Precambrian of central and south-central New Mexico. In the spring of 1980, Sue Kent mapped the area at a scale of 1:12,000. Her work revealed the existence of granites, pelitic schists, metavolcanic rocks, feldspathic schists, quartz veins and pegmatites, and carbonatite dikes. Her map is on open file at the New Mexico Bureau of Mines and Mineral Resources and the reader is referred to her work for more detail on the area.

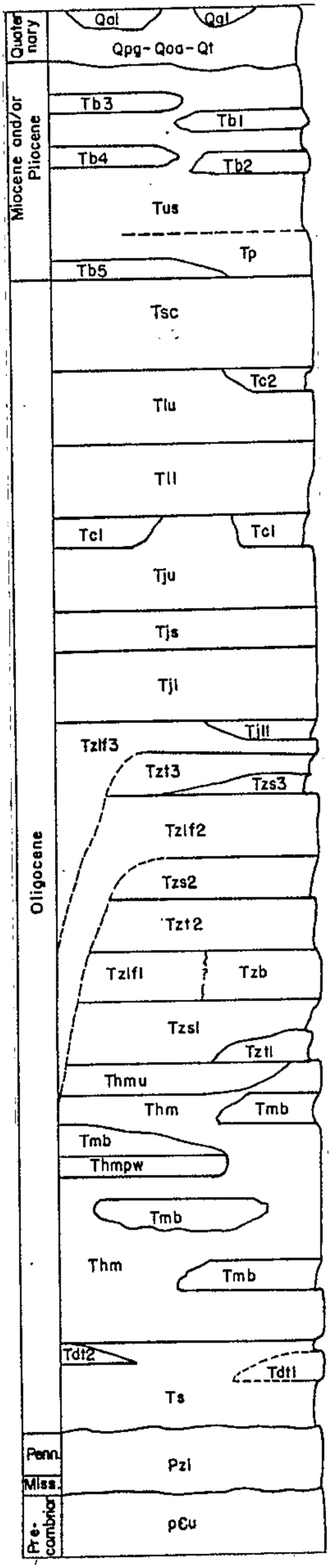
This block of Precambrian rocks is bounded on the west by a major down to the west fault which juxtaposes the La Jencia Tuff against the Precambrian rocks. To the southeast, the Precambrian rocks are unconformably overlain by Paleozoic and Tertiary rocks. Locally, the Paleozoic rocks are eroded through and rocks of the Oligocene Datil Group or the La Jencia Tuff rest directly on the Precambrian. To the northeast, the Precambrian rocks are truncated by the topographic wall of the Socorro cauldron along which cauldron-fill units overlie Precambrian rocks.

Overlying the Precambrian rocks on the south and east side of Chupadera Peak is a thin interval of Paleozoic rocks (Figure 4) consisting of several limestone horizons with thin interbedded shales and minor sandstones. Armstrong (1958) describes the lower part of this section as the Mississippian Caloso Formation which forms hogbacks on the east side of Chupadera Peak where, locally, it is intensely silicified. He found the unit to be 37 ft (11 m) thick including a basal, crossbedded, arkosic sandstone 5 ft (1.5 m) thick. Kottlowski (1960, 1963) reported 200 ft (61 m) of limestones south of Chupadera Peak that are Derryian in age and are probably part of the Sandia Formation (F.E. Kottlowski, 1981, oral comm.).

The contact between the Paleozoic rocks and the Precambrian rocks is a planar surface, suggesting a mature topography prior to the deposition of the Paleozoic rocks. The contact between the Tertiary and Paleozoic rocks, however is not so simple. The Oligocene Datil Group and La Jencia Tuff overlie the Paleozoic rocks with apparent angular unconformity. Prior to the deposition of the Datil Group, hills with considerable relief were formed in the limestone terrane and, locally, the limestones were eroded through and the Datil Group was deposited on Precambrian rocks. G.R. Osburn (1981, oral comm.) found that the Eocene Baca Formation in the northern Jornada Del Muerto

Figure 4. Stratigraphic column in the central Chupadera Mountains.

Qal-Quaternary alluvium
Qpg, Qoa, Qt-Quaternary
   piedmont slope deposits,
   older alluvium, talus.
Tus-Upper Santa Fe gravels
Tb1,Tb2, Tb3, Tb4, Tb5-Basalt
   flows intercalated in the
   upper Santa Fe gravels.
Tp-Popotosa Formation.
Tsc-South Canyon Tuff.
Tc2-Sedimentary rocks.
Lemitar Tuff
  Tlu-Upper Lemitar Tuff
  Tll-Lower Lemitar Tuff.
Tcl-Sedimentary rocks.
La Jencia Tuff
  Tju-Upper La Jencia Tuff.
  Tjs-Middle Member of the
      La Jencia Tuff.
  Tjl-Lower La Jencia Tuff.
  Tjll-Tuff of Chupadera Peak.
Luis Lopez Formation
  Tzlf3-Upper Lava Member.
  Tzt3-Upper tuff member.
  Tzs3-Upper sedimentary
       member.
  Tzlf2-Middle lava member.
  Tzs2-Middle sedimentary
       member.
  Tzt2-Middle tuff member.
  Tzlf1-Lower lava member.
  Tzb-Basalt member.
  Tzs1-Lower sedimentary
       member.
  Tzt1-lower tuff member.
Hells Mesa Tuff
  Thmu-Upper Hells Mesa Tuff.
  Thm-Hells Mesa Tuff.
  Thmpw-Poorly welded Hells
       Mesa Tuff.
  Tmb-Cauldron Collapse breccias.
Datil Group
  Tdt2-upper Datil Tuff.
  Tdt1-lower Datil Tuff.
  Ts-Spears Formation.
Pzl-Paleozoic undivided
pCu-Precambrian undivided.



contains clasts of lithologies similar to those in the Precambrian and Paleozoic terranes in the Chupadera Mountains. Transport directions in the area indicate that the source of the material was to the west. These bits of information suggest that the area around Chupadera Peak was high in Eocene time, possibly in response to Laramide uplift. Cather (1980) has postulated that Eardly's (1962) Sierra and Sandia uplifts were a continuous highland and that the Precambrian and Paleozoic rocks near Socorro were included in that uplift. This data is consistent with Epis and Chapin (1975) who postulate that an erosion surface of low relief was formed in the Eocene.

TERTIARY EXTRUSIVE AND SEDIMENTARY ROCKS

The Tertiary section in the Chupadera Mountains consists of both sedimentary and volcanic rocks (Figure 4). Appendix 1 presents point count data for 45 thin sections of volcanic rocks in the Tertiary section in the Chupadera Mountains and Appendix 2 lists the average crystal content and mineral ratios for the various units. The oldest Tertiary unit exposed is the Datil Group, consisting of Oligocene (33-37 my) volcaniclastic sedimentary rocks with interbedded ash-flow tuffs and lava flows. The Datil Group is usually overlain by outflow-facies Hells Mesa Tuff (33 my) in the northeastern Datil-Mogollon volcanic field;

however, in the Chupadera Mountains, no outflow facies Hells Mesa Tuff is present so the La Jencia Tuff (30 my) overlies the Datil Group. The Hells Mesa Tuff found in the area is cauldron facies tuff with no exposed base. Cauldron collapse breccias (Lipman, 1976) are commonly interbedded in the cauldron facies tuff. Overlying the Hells Mesa Tuff is the Luis Lopez Formation, the moat-fill sequence of the Socorro Cauldron. This unit consists of several ash-flow tuffs, lava flows, and sedimentary rock units. In the southeast part of the study area, the La Jencia Tuff overlies the Datil Group, farther north, it overlies the Luis Lopez Formation and the Datil Group is separated from the La Jencia Tuff by a thickness of rock in excess of 9,000 ft (2743 m). This profound unconformity was caused by the collapse and subsequent infilling of the Socorro Cauldron.

The Lemitar Tuff (28 m.y.) overlies a thin sedimentary unit that was probably derived from the uppermost La Jencia Tuff. The Lemitar Tuff is composed of two members and is locally overlain by a thin sedimentary unit derived from erosion of its poorly welded top. Overlying these units is the South Canyon Tuff (26 m.y.), the youngest major ash-flow tuff in the Chupadera Mountains. Upper Santa Fe Gravels overlie the South Canyon Tuff and consist of interbedded conglomerates, sandstones, and minor mudstones and mudflow deposits of Miocene and possible Pliocene age. Basalt flows are intercalated in the upper Santa Fe gravels at several levels. The mountain range is flanked on either side by piedmont deposits. Talus and colluvial material mantle many of the mountain slopes and alluvial deposits are found in the larger valley floors.

Datil Group (Ts, Tdt1, Tdt2)

The Datil Group is the oldest Tertiary unit exposed in the Chupadera Mountains (37 to 33 m.y.). It consists of volcaniclastic sedimentary rocks, lava flows, and ash-flow tuffs and is only found south of Chupadera Peak where it is as much as 450 ft (137.2 m) thick. It pinches out on the south side of Chupadera Peak. The Datil Group is the basal andesitic to latitic volcaniclastic apron of the northeastern Datil-Mogollon volcanic field (Chapin and others, 1978; Osburn and Chapin, in press). In this study, the Datil Group has been divided into three units; the Spears Formation, the lower Datil tuff, and the upper Datil tuff.

Sandstones, conglomerates, minor mudstones, and mudflow deposits (breccias) form the bulk of the Spears Formation in this area. The sedimentary rocks form low, rounded hills with poor exposures and are composed of clasts of andesitic to latitic lavas with fine-grained matrix material. The coarse clastic deposits are generally red to black in color, presumably reflecting the composition of the clasts and the matrix. The fine grained clastic deposits are red to buff in color.

Andesitic to latitic lavas are minor constituents of the Spears Formation, forming bold outcrops, rubble covered hillsides, and talus where they are present. Several thin tuffs are present in the area, but they are discontinuous units and are reworked tuffs rather than ash-flow deposits. Two tuffs, informally named the lower Datil tuff (Tdt1) and the upper Datil tuff (Tdt2) are probably ash-flow tuffs. They contain some pumice, are poorly to densely welded, and exhibit a eutaxitic texture typical of ash-flow tuffs. The lower Datil tuff is found only in a small area west of Chupadera Peak and consists of an aphanitic groundmass and 1 to 2 percent crystals (visual estimate) of which feldspar is the most common. Biotite and quartz are present in trace amounts only. This tuff is gray to pink and poorly welded with light-gray pumice. In outcrop, the lower Datil tuff is columnar jointed and is less than 100 ft (30.5 m) thick. The stratigraphic position of this unit is unclear, but is is probably about 300 ft (30.5 m) below the upper Datil tuff.

The upper Datil tuff is near the top of the Datil Group in the Chupadera Mountains and consists of a moderately crystal-rich, densely welded tuff between 50 and 100 ft (15 to 30 m) thick. Point counts show an average crystal content of about 19 percent. Sanidine comprises 18 to 19 percent of the rock with biotite present in amounts up to about 1 percent. Zircon, hornblende, and opaques are present as trace constituents and quartz and plagioclase are notably absent. Local pockets of lithic fragments are generally rare in this tuff. The color varies from dark red to white depending on the amount of alteration with darker colors resulting from the addition of hematite (possibly magnetite or manganese minerals) during alteration. Brecciation seems to accompany the alteration as the darkest areas are the most brecciated.

The Datil Group in this area has no marker horizons that may be used to correlate to Datil exposures elsewhere in the region, however, the upper Datil tuff (Tdt2) may correlate with a tuff in the Datil Group in the north end of the Jornada Del Muerto, about 15 mi (24 km) east of the study area. That tuff is currently being studied by G.R. Osburn of the New Mexico Bureau of Mines and Mineral Resources. It is possible that the upper Datil tuff will correlate with the tuff of Datil Well described by Lopez (1975), Bornhorst (1976), Lopez and Bornhorst (1979), and Harrison (1980). Harrison (1980) reports that the tuff of Datil Well contains 18 to 22 percent sanidine, 1 to 2 percent clinopyroxene, 1 percent biotite, and trace amounts of quartz and plagioclase. Though the suggestion is made that the upper Datil tuff may correlate with the tuff of Datil Well, the lack of clinopyroxene and the distance to the first outcrop to the west (about 60 mi (100 km)) makes such a correlation tenuous at best.

Hells Mesa Tuff (Thm, Thmpw, Thmu, Tmb)

The Hells Mesa Tuff is a 33 m.y. old crystal-rich rhyolite tuff named for a mesa in the southern Bear Mountains (Tonking, 1957). It is generally a simple cooling unit of densely welded ash-flow tuff. The outflow sheet is usually less than 600 ft (183 m) thick, but the cauldron facies may reach several thousand feet (Chapin and others, 1978; Krewedl, 1974). No outflow facies Hells Mesa Tuff is present in the Chupadera Mountains the Hells Mesa Tuff is all cauldron facies tuff with intercalated cauldron collapse breccias (Tmb) (Lipman, 1976) that fill the Socorro cauldron. The total thickness of Hells Mesa in the study area is unknown, but a thickness in excess of 7,000 ft (2,134 m) is not unreasonable. The absence of marker horizons make thickness estimates unreliable. Chapin and others (1978) estimated that the Paleozoic rocks of the area have been downfaulted to depths of 4,000 to 12,000 ft (1,219 to 3,658 m) in the Socorro cauldron. This study indicates that the 12,000 ft (3,658 m) estimate might be the more realistic estimate.

This study has shown that the Socorro cauldron is the source of the Hells Mesa Tuff rather than the source of the Lemitar Tuff as suggested by Chamberlin (1980). In the Magdalena Mountains, Chapin and others (1978) propose that the source cauldron of the Hells Mesa Tuff be termed the North Baldy cauldron. It is recommended that the term

"North Baldy cauldron" be dropped in preference to the term "Socorro cauldron" since the cauldron is well exposed near the town of Socorro, New Mexico.

Chamberlin's (1980) Lemitar(?) Tuff is actually cauldron facies Hells Mesa Tuff and outflow facies Lemitar Tuff. His upper Lemitar Tuff correlates with the upper Hells Mesa tuff of this study and his lower Lemitar tuff will generally correlate with Hells Mesa Tuff in this study. It should be noted that north and west of Black Canyon, in the vicinity of the Tower Mine, Lemitar Tuff is present as outflow (Osburn, 1981, oral comm.). This indicates that the Lemitar Tuff was deposited in a depression, possibly the Sawmill Canyon cauldron. It is probable then that Black Canyon is the surface expression of the topographic margin of the Sawmill Canyon cauldron.

Several textural differences have been noted in the Hells Mesa tuff, but only three subdivisions have been made: 1)the "normal" crystal-rich, lithic-rich to lithic-poor Hells Mesa Tuff, 2) the upper Hells Mesa Tuff which is interbedded ash-flow and ash-fall tuffs, and 3) a poorly welded zone.

Hells Mesa Tuff (Thm)

The Hells Mesa Tuff consists of several thousand feet of densely welded tuff with intercalated cauldron collapse breccias. The tuff is crystal-rich (about 42 percent crystals), densely welded, and is generally light brown to light reddish brown depending on the degree of alteration (Figure 5). The crystal content averages about 11 percent quartz, 19 percent sanidine, 10 percent plagioclase, 1 percent biotite, and traces each of sphene, zircon, hornblende, and opaque minerals. The quartz forms very large, broken-to-euhedral, and locally embayed crystals. The plagioclase is generally somewhat altered and in some samples (11-10-5) is totally replaced by calcite and/or clay minerals and in other cases, by potassium feldspar. Devitrification textures include a granular groundmass, axiolites in shards, and rare spherulites. Vitrophyres are preserved locally.

The main variant in the Hells Mesa Tuff is the lithic content which varies from 0 to over 80 percent. That variation is one of the most difficult problems in mapping the area, as there is a gradation between lithic-rich tuff and matrix-rich cauldron collapse breccias (Figure 6a,b,c,and d). The two rock types were differentiated by two criteria; 1) welding, and 2) whether of not the rock is clast supported. The first criteria is obvious, a densely welded rock must have a very high tuff content to weld so it

Figure 5. Color variation in Hells Mesa Tuff due to alteration.

Figure 6a. Poorly indurated cauldron collapse breccias.

Figure 6b. Well indurated cauldron collapse breccias.

Figure 6c. Densely welded Hells Mesa Tuff (?). This exposure may be a cauldron collapse breccia.

Figure 6d. Densely welded, lithic rich Hells Mesa Tuff.

was termed a tuff, but a moderately or poorly welded rock may be either a tuff or a breccia. If the rock is obviously clast supported, or totally lacked a tuff matrix, it was called a breccia. The rocks that caused problems were those that were poorly to moderately welded and were not obviously clast supported. Lipman (1976) first described similar breccias from the San Juan Mountains in Colorado, but did not mention any criteria for distinguishing between lithic-rich tuffs and matrix-rich breccias. The problem is a lack of objective criteria with which to separate breccias from tuffs: no satisfactory answer has been found during this study.

Poorly Welded Hells Mesa Tuff (Thmpw)

The poorly welded Hells Mesa Tuff is only exposed about 1 mi (1.6 km) northwest of Bianchi Ranch. This zone in the Hells Mesa contains 1.5 percent quartz, 10 percent sanidine, 3 percent plagioclase, 0.3 percent biotite, and traces each of zircon, sphene, and opaque minerals. Glass shards are well preserved. The quartz phenocrysts are embayed and the plagioclase is intensely altered. This unit is poorly exposed and forms colluvium covered benches or is covered by talus on steeper slopes.

The reasons for the lack of welding are not understood. This tuff is associated with cauldron collapse breccias and it is possible that those breccias cooled the tuff enough to inhibit welding. It is also possible that the interval represents an hiatus in volcanism in which the top of the previous ash flows were not welded. Overlying this poorly welded zone is a zone that contains red "clots" similar to those in the upper Hells Mesa (Thmu). They may also represent an hiatus in volcanism (see the section on the upper Hells Mesa).

Upper Hells Mesa Tuff (Thmu)

The upper Hells Mesa Tuff is exposed along the eastern front of the Chupadera Mountains north of the MCA mine and below the lower lava member of the Luis Lopez Formation between the mine and Nogal Canyon. It consists of interbedded ash-flow tuffs and air-fall tuffs which are moderately to densely welded, as well as deposits that have been interpreted as co-ignimbrite, lag-fall deposits (Chamberlin, 1980)(Figure 7). This unit correlates with Chamberlin's (1980) upper cauldron facies tuff (Tlu). The reader is referred to his work for a complete description of these deposits.

The air-fall tuffs are usually very thin, fine-grained units that are often more resistant to erosion than the surrounding ash-flows. They consist of subequal amounts of crystals and ash and are not common in the study area. The ash-flow tuffs are similar to the "normal" Hells Mesa Tuff, but lack the lithic fragment of the lower unit and locally

Figure 7. Upper Hells Mesa Tuff. The thin bed by the hammer is an air-fall layer. Above that (to the right), is a co-ignimbrite, lag-fall deposit.

contain more pumice. As a result, they have a more pronounced foliation. The co-ignimbrite, lag-fall deposits (Wright and Walker, 1977) consist of ash-flow tuff with red "clots" of material that is mineralogically similar to the enclosing tuff. The "clots" are as much as 3 ft (1 m) in diameter, but are normally 2 to 10 in (5 to 25 cm) in diameter. The "clots" weather more readily than the surrounding tuff and form obvious depressions. Chamberlin (1980) explains these deposits as the result of periodic blocking of a vent by its own magma. This blockage would presumably allow pressure to rebuild and explosively remove the plug which was probably not completely solidified.

The lower contact of the upper member of the Hells Mesa Tuff is problematic. South of the MCA Mine, this unit is in fault contact with the "normal" Hells Mesa Tuff. However north of the mine, the unit is in apparent depositional contact with the "normal" Hells Mesa Tuff, but the actual contact is not well defined. The contact has been inferred along a topographic break that is about where the lithic-rich lower member loses its lithic fragments.

Cauldron Collapse Breccias (Tmb)

When a cauldron collapses due to voluminous and rapid eruption of ash-flow tuff, steep fractures are formed and the downward motion of the cauldron block is along those fractures, generally called ring fractures (Smith, 1960a,1960b; Ross and Smith, 1960; Smith and Bailey, 1968). As the cauldron block drops, material spalls off the surrounding cliffs which retreat by a combination of slumping, land-sliding, and erosion to form the topographic wall of the cauldron. The material that first spalls off the topographic wall would form deposits much like talus cones at the base of cliffs in mountainous regions. As the slope of the topographic wall retreats, the spalling material may form debris flows and rock avalanches. These mechanisms would allow the spalled material to travel far out into the cauldron. Very large blocks could be transported by sliding along a surface "lubricated" by hot, unwelded, fluidized ash-flow tuff. It is also possible that material coming off the topographic walls may partially block of disrupt segments of erupting ring fracture zones. It is within this framework that the most problematic of the rocks in the Chupadera Mountains, the cauldron collapse breccias, will be discussed.

Lipman (1976) first described cauldron collapse breccias in the San Juan Mountains of Colorado. He divided the breccias into two categories based on clast size: mesobreccias and megabreccias. Mesobreccias generally have clasts under 3 ft (1m) and megabreccias have clasts over 3 ft (1m). In the Chupadera Mountains, this classification is unsatisfactory as individual exposures may have clasts from fractions of an inch to several tens of feet in diameter. For this reason, these breccias will not be subdivided by clast size in this report.

The breccias consist of heterolithic, unsorted, rounded to angular clasts set in a matrix of ash-flow tuff and/ or a microbreccia of the clast material (Figures 6a, 6b). The size of the clasts varies from a fraction of an inch to thousands of feet in the long dimension (Figure 8). The breccias form discontinuous lenses intercalated in the Hells Mesa Tuff (Plate 1). They pinch and swell with no apparent pattern. The largest volume of the breccias is immediately north of Bianchi Ranch and the deposits become more scattered and disappear between Red Canyon and the north boundary of this study area. The clast lithologies are recognizable as rocks of the Datil Group and the Precambrian, both of which are exposed in the southern one-half of the study area. This suggests that the source of these breccias was the southern topographic wall of the Socorro cauldron.

Low in the Hells Mesa section, the breccias are not widespread and are composed of clasts that are generally less than 30 ft (9 m) in diameter. These breccias may have formed as talus deposits along the base of cliffs (Figure 28). Higher in the Hells Mesa section, the breccias are widespread and the maximum clast size is measured in thousands of feet. However, the normal size is measured in inches. These deposits probably formed from debris flows and rock avalanches. Still higher in the section, the

Figure 8. Rhyolite block in cauldron cauldron collapse breccias. The hammer (at the end of the arrow) is 30 in. (0.75 m) long.

breccias form small, discrete lenses.

Formation of the breccias is discussed in the cauldron development section and illustrated in Figures 28, 29, and 30. During initial stages of eruption, the breccias are formed at the base of cliffs and are restricted in their lateral extent. Few of the breccias are transported far into the cauldron (Figure 28). As the topographic wall of the cauldron retreats, the deposits form from debris flows and rock avalanches similar to those described by Hsu (1975). Debris flows formed as a result of the fluidization of the moving debris can move great distances in a very short time (Hsu, 1975). Fluidization effectively reduces the internal friction of the moving mass by a relative pressure increase inside the mass which tends to separate the particles. This is accomplished by entraining air in the mass during its initial fall or as it passes over irregular topography or an erupting ring fracture. It is also possible that as the debris flow moves over the ring fracture zone, the violence of the eruption may rip the flow apart, forming the lithic-rich tuffs and matrix-rich breccias that are so difficult to differentiate.

The largest blocks must slide rather than flow, possibly "lubricated" by a layer of newly erupted, hot, fluidized ash-flow tuff. A reasonably gentle slope seems requisite for this, as a steep slope would probably allow the blocks to be destroyed. As these blocks come to rest, the fractures in the base of the blocks are filled with tuff and possible "tracks" left by the moving blocks are destroyed. The highest breccias probably moved as debris flows but they are so distal and the topographic wall so gentle that the deposits tend to be thinner and the clasts smaller.

Luis Lopez Formation

The Luis Lopez Formation is the moat-fill sequence of the Socorro cauldron (Chamberlin, 1980). In the central Chupadera Mountains, the Luis Lopez Formation consists of ten members with a composite thickness of over 3,500 ft (1067 m) as measured from cross sections. This composite section may exaggerate the true thickness at any one locale. Chamberlin (1980) reports 15 members with a composite thickness of 4440 ft (1353 m) in the northern Chupadera Mountains and feels that the Luis Lopez Formation will probably not exceed 2625 ft (800 m) at any one place. This agrees well with the present study. The Luis Lopez Formation in this study area consists of three ash-flow tuffs, three sedimentary rock intervals, two rhyolite lava flows, one basalt flow, and one andesite flow (Figures 4 and 9, Plate 1). The lower tuff member is interbedded in the lower sedimentary member which overlies the Precambrian rocks and the Hells Mesa Tuff. Locally the lower tuff member rests directly on Precambrian rocks. The contact of the Luis Lopez Formation with the Precambrian rocks is

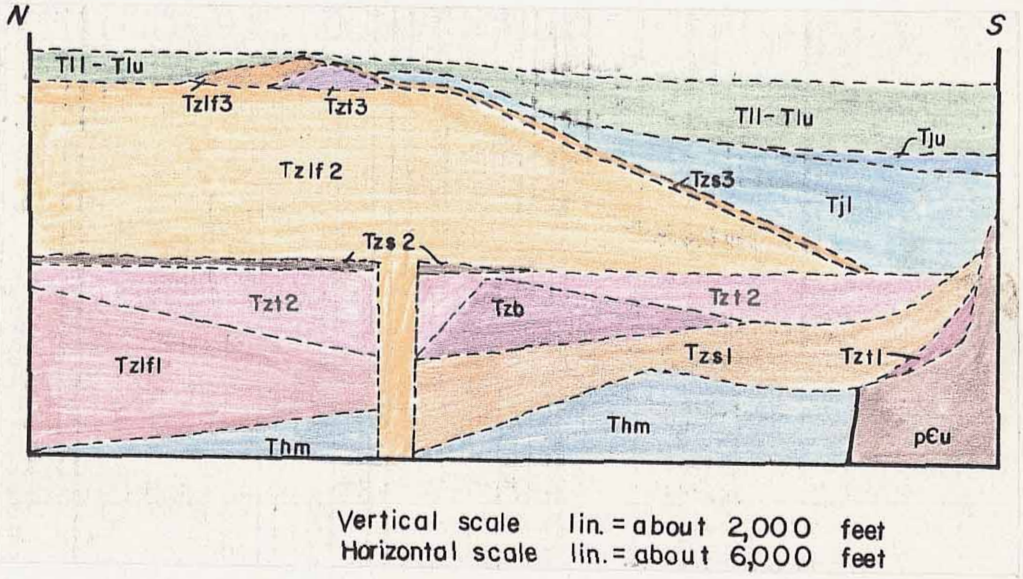


Figure 9. Generalized stratigraphic relationships in the Luis Lopez Formation. The symbols are the same as those on plate 1 and Figure 4.

an angular unconformity interpreted to be the topographic wall of the Socorro cauldron. The basalt member of the Luis Lopez Formation overlies the lower sedimentary member and in the southern part of the moat, underlies the middle tuff member which is the most laterally extensive of the moat-fill units. In the northern part of the moat, the middle tuff member overlies an andesite lava flow. The middle tuff member may correlate with Chamberlin's (1980) lower tuffs. The relationships between the sedimentary rocks and the basaltic lavas in the south and the andesitic lava to the north is unknown as the contact is never exposed. A thin unit consisting of coarse clastic sedimentary rocks and one or more andesitic lava flows overlies the middle tuff member. This middle sedimentary member is in turn overlain by the middle lava member, a thick, rhyolite dome and flow complex. The remaining units are a thin ash-flow tuff, a thin rhyolite lava, and a thin, discontinuous sedimentary rock interval. Each of these units overlie the middle lava member at various places.

Chamberlin (1980) reported that the Socorro cauldron is the source of the Lemitar Tuff. This study has shown, however, that the Socorro cauldron is the source of the Hells Mesa Tuff. This being the case, the Luis Lopez Formation is correlative with the unit of Hardy Ridge of Bowring (1980), Roth (1980), and Donze (1980). Bowring (1980) informally named a thick series of ash-flow tuffs, sedimentary rocks, and andesite lavas the unit of Hardy

Ridge for exposures in the Magdalena Mountains. His unit boundaries were later refined by Roth (1980). It is recommended here that the cauldron-fill sequence in the Socorro cauldron be named the Luis Lopez Formation and that the informal name, unit of Hardy Ridge, be dropped or used as a member of the Luis Lopez Formation.

Lower Tuff Member (Tztl)

This is the lowest tuff in the moat fill sequence of the Socorro cauldron. It is a poorly welded, white to red, lithic-rich, crystal-rich tuff containing about 8 percent quartz, 12 percent sanidine, 0.3 percent plagioclase, 2 percent biotite, 0.5 percent opaque minerals, and a trace of zircon. The unit contains several percent lithic fragments, of which Precambrian lithologies are the most common. Andesitic lithic fragments are a minor constituent in the unit. Grid twinning of some of the feldspars suggests that at least a portion of the feldspars are xenocrysts derived from Precambrian rocks. No shards were seen in thin section. The groundmass is granular and has an abundance of secondary calcite, probably the result of alteration.

The lower tuff member has a very restricted aerial extent. It is only found along the contact of the Tertiary units with the Precambrian on what is interpreted to be the topographic wall of the Socorro cauldron. The upper and lower contacts of the unit are gradational with the lower sedimentary member (Tzsl) and are difficult to define. The thickness of this unit is not precisely known. The foliation dips about 40 to 50 degrees to the east and assuming that the foliation represents the dip, the unit may be as much as 900 ft (275 m) thick. However, because of uncertainty in the dip and the probability of a number of small, normal faults exaggerating the section, the tuff is probably much thinner.

The origin of this tuff is unknown. No volcanic feature has been found that might be the source of the tuff. The abundance of quartz suggests that the tuff cannot be a tuff of the Datil Group that slid into the cauldron (G.R. Osburn, 1981, oral comm.). Quartz/sanidine ratios suggest that this tuff is a poorly welded phase of the Hells Mesa Tuff. Gradational contacts with the enclosing lower sedimentary member of the Luis Lopez Formation suggests that the units were deposited contemporaneously. If this tuff is correlative with the Hells Mesa Tuff, it was deposited on a bench on the topographic wall of the Socorro cauldron. This suggests that the processes that formed the lower sedimentary member are an extension of the processes that formed the cauldron collapse breccias (Tmb).

Lower Sedimentary Member (Tzsl)

The lower sedimentary member of the Luis Lopez Formation is composed of sandstones, conglomerates, mudflow deposits, and mudstones. It is apparent from outcrops that the unit had two source areas, one to the south, the other to the north. The southern source area was probably the topographic wall of the Socorro cauldron while the northern source was the resurgent dome of the cauldron. The unit shows a dramatic change of clast lithology from north to south and for this reason it is convenient to divide the unit into a southern and northern facies.

The southern facies of the lower sedimentary member of the Luis Lopez Formation fines upward, that is, it grades from unsorted mudflow deposits through conglomerates and sandstones to mudstones. This gradation is complex and is thought to be the result of degradation of the topographic wall of the Socorro cauldron. Early in the deposition of this unit, the wall was probably high, possibly measuring in hundreds of feet. As simultaneous erosion of the cauldron wall and filling of the cauldron proceed, finer clastic material would be deposited. The clasts in this part of the unit are primarily andesitic and may have been derived from rocks of the Datil Group which should have formed a portion of the cauldron wall.

The northern facies (exposed in Nogal Canyon) is characterized by fine-to coarse-grained sandstones, mudstones, and conglomerates. Transport directions are consistent with a source area to the north. The sandstones and mudstones alternate and, near the top of the section, conglomerates are intercalated in the unit. This coarsening upwards suggests episodic uplift of the resurgent dome during the deposition of this unit. The sandstones are composed of broken and unbroken, anhedral to euhedral crystals of quartz and feldspar in a very-fine-grained, tuffaceous matrix. This composition is consistent with derivation of this unit from the poorly welded top of the cauldron-facies Hells Mesa Tuff. The fine-grained sandstones and mudstones have a large tuffaceous component with various amounts of crystals. Colors in this northern facies vary from white to pale red, in contrast to the shades of purple, gray, and dark red in the southern facies. The facies change is accomplished over a strike length of a few miles and is centered near the north end of the Cienega Ranch. The base of the lower sedimentary member is only exposed where it is in contact with Precambrian rocks along the southern margin of the Socorro cauldron and in one place near the north end of the Cienega Ranch where it is in contact with the Hells Mesa Tuff. The unit pinches out against Precambrian rocks and this relationship is taken as evidence that the Precambrian rocks form part of the topographic wall of the Socorro cauldron. Other interpretations include: 1) the pinch out is in response to paleovalley control, and 2) the pinch out occurs along a paleo fault scarp. Where the lower sedimentary member is in contact with the Hells Mesa Tuff, the Hells Mesa appears to be high, possibly a ridge on top of the cauldron fill. The maximum thickness of the lower sedimentary member of the Luis Lopez Formation is more than 700 ft (213 m) as measured from cross sections.

Basalt Member (Tzb)

As much as 500 ft (152 m) of basalt or basaltic andesite overlie the lower sedimentary member or the Luis Lopez Formation. These mafic rocks form a dense, dark gray to black unit that comprises several flows. Iddingsite is present in amounts up to about 7 percent, possibly indicating a large primary olivine content (Deer and others, 1966). Local vesicular parts mark flow boundaries and are frequently altered, probably the result of deuteric processes. Locally, the unit has numerous white "spots" which may be devitrified glass (Osburn, 1981, oral comm.; Chamberlin, 1980). The source of this unit is unknown, but it is possible that the vents may be north of Nogal Canyon where small exposures of basalt surrounded by the middle tuff member may represent the top of a volcanic edifice.

Lower Lava Member (Tzlfl)

The lower lava member of the Luis Lopez Formation (Tzlfl) is red, white, or bluish depending on the degree of alteration. The rock is crystal poor and in outcrop resembles a rhyolite lava as it contains a trace of quartz, local autobreccias, flow folds, minor flow banding, and is locally very thick. The above features and the color suggest a more felsic rock than is indicated by its mineralogic composition. In thin section the rock has a pilotaxitic texture and contains 2-7 percent of pyroxene, a trace to 4 percent plagioclase, and a trace of biotite. The microlites in the groundmass are generally less than 0.004 in (0.1 mm) in length and the pyroxene phenocrysts are less than 0.02 in (0.5 mm) in diameter. Plagioclase reaches 0.1 in (2.5 mm) in length. Lithic fragments (xenoliths) are present locally and all show chilled margins. The xenoliths are less than 1 cm in diameter and are andesitic in composition. The presence of quartz in an andesite is anomalous, but the quartz may be either xenocrystic or a high pressure phase that did not completely resorb because of rapid ascent of the magma (Osburn, 1981, oral comm.).

The lower lava member forms rounded hills with abundant platy talus and few bold outcrops. The unit everywhere overlies the Hells Mesa Tuff and is overlain by the middle tuff member of the Luis Lopez Formation. The source of these lavas is unknown, but it may be to the north of the present exposures as the unit thins southward.

Middle Tuff Member (Tzt2)

The middle tuff member (Tzt2) is a variable sequence of interbedded ash-flow tuffs, mudflow deposits, water-lain tuffs, and mudstones. The water-lain tuffs and mudstones are restricted to the base of the unit and are only locally present. Unidentified plant fossils were collected from a 2-ft (0.6 m)-thick water-lain tuff in a small canyon in SE 1/4, NE 1/4, NW 1/4, sec.32, T.4 S., R.1 W. The mudflow deposits are generally low in the unit and are less important higher in the section. This suggests that the tuff covered topography and as that happened, the mudflows diminished. The middle tuff member varies from a minimum thickness of about 200 ft (61 m) to a maximum of more than 600 ft (183 m). The southernmost exposures show the unit pinching out against the lower sedimentary member, near the topographic wall of the cauldron. The unit seems to thin to the north, but it is faulted off before it pinches out.

The tuffs are lithic rich, crystal poor, and poorly welded. Pumice frequently forms a nebulous foliation and lithic fragments are andesitic with rare fragments of Hells Mesa Tuff. The crystal content of the ash-flow tuffs averages about 6 percent, but varies from about 12 percent down to about 2 percent. The unit averages about 1 percent quartz, 3 percent sanidine, 2 percent plagioclase , 0.2

percent biotite, and trace amounts of zircon and opaque minerals (Appendix 2). The ratios of the minerals to each other is as variable as the total crystal content which suggests that the unit had more than one source.

The mudflow deposits are composed of pebbles to boulders of andesite and minor amounts of Hells Mesa Tuff (Figure 10). These deposits are frequently clast supported which suggests that some of the deposits may be talus which was infiltrated by tuffaceous material (B. Hildebrant, 1980, oral comm.). The waterlain tuffs and mudstones at the base of the sequence are composed of fine-grained tuffaceous material with variable amounts of pumice.

Immediately below one thin mudflow deposit, a number of pipe-like bodies were found in an ash-flow tuff (Figure 11). These bodies are irregular in cross section, 3 to 5 in (7 to 12 cm) in the largest dimension, sinuous in shape and extend for several feet below the contact with the overlying mudflow deposit. They consist of lithic fragments and crystals with little ash sized material. Similar pipes have been described by Walker (1971,1972) and Roobol and Smith (i976) in tuffs (ignimbrites) from various parts of the world. These investigators postulate that these pipes form as a result of gases streaming upward shortly after deposition of the tuff and before it welded. Walker (1972) estimates that the gas streamed at 3 to 6 ft/sec (1 to 2 m/sec). This estimate is based on the terminal velocity of

Figure 10. Mudflow/debris flow deposits in the middle tuff member of the Luis Lopez Formation.

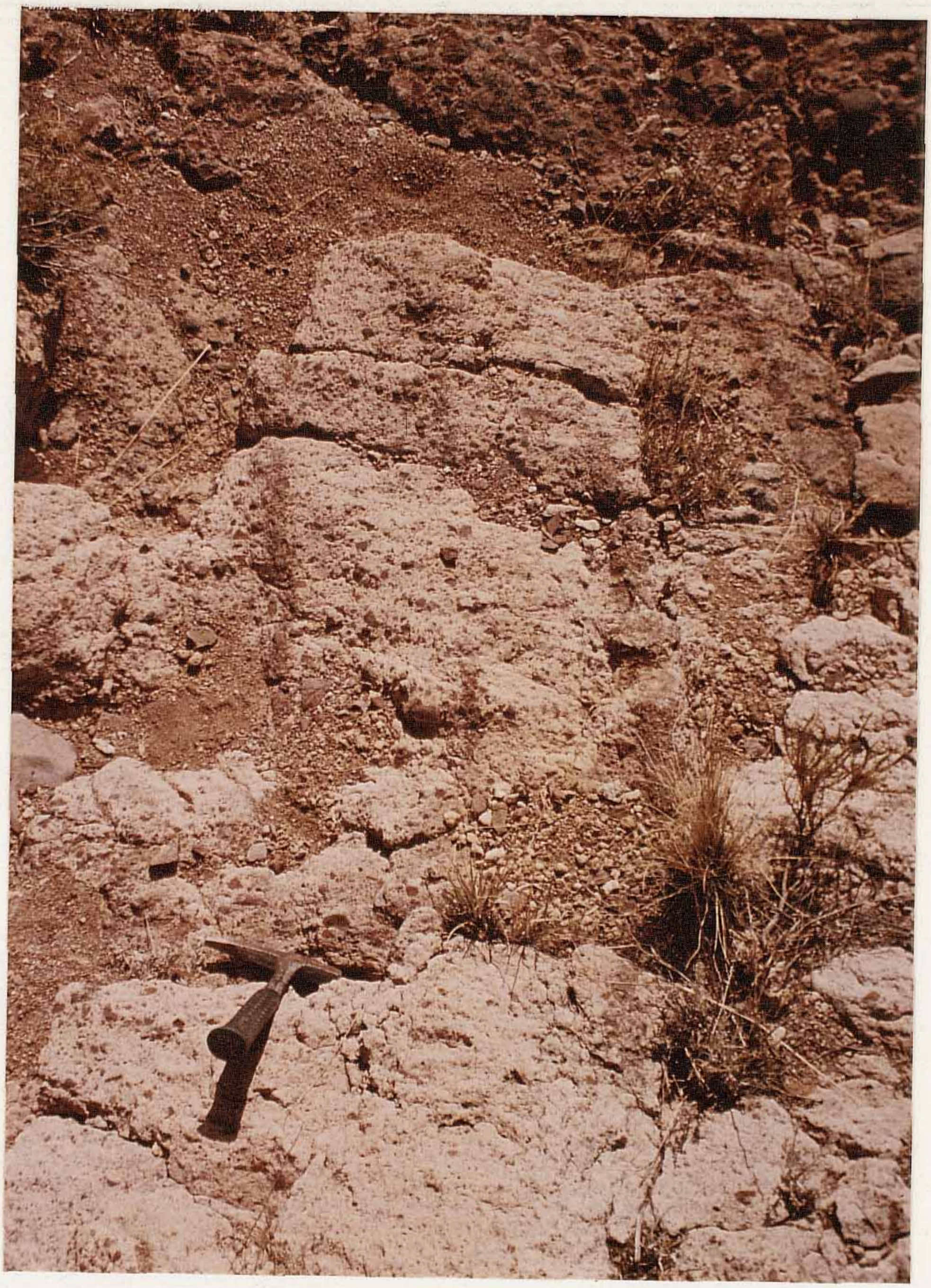


Figure 11. Fossil fumaroles in the middle tuff member of the Luis Lopez Formation. The dark red bands sub-parallel to the hammer handle are the fossil fumaroles.

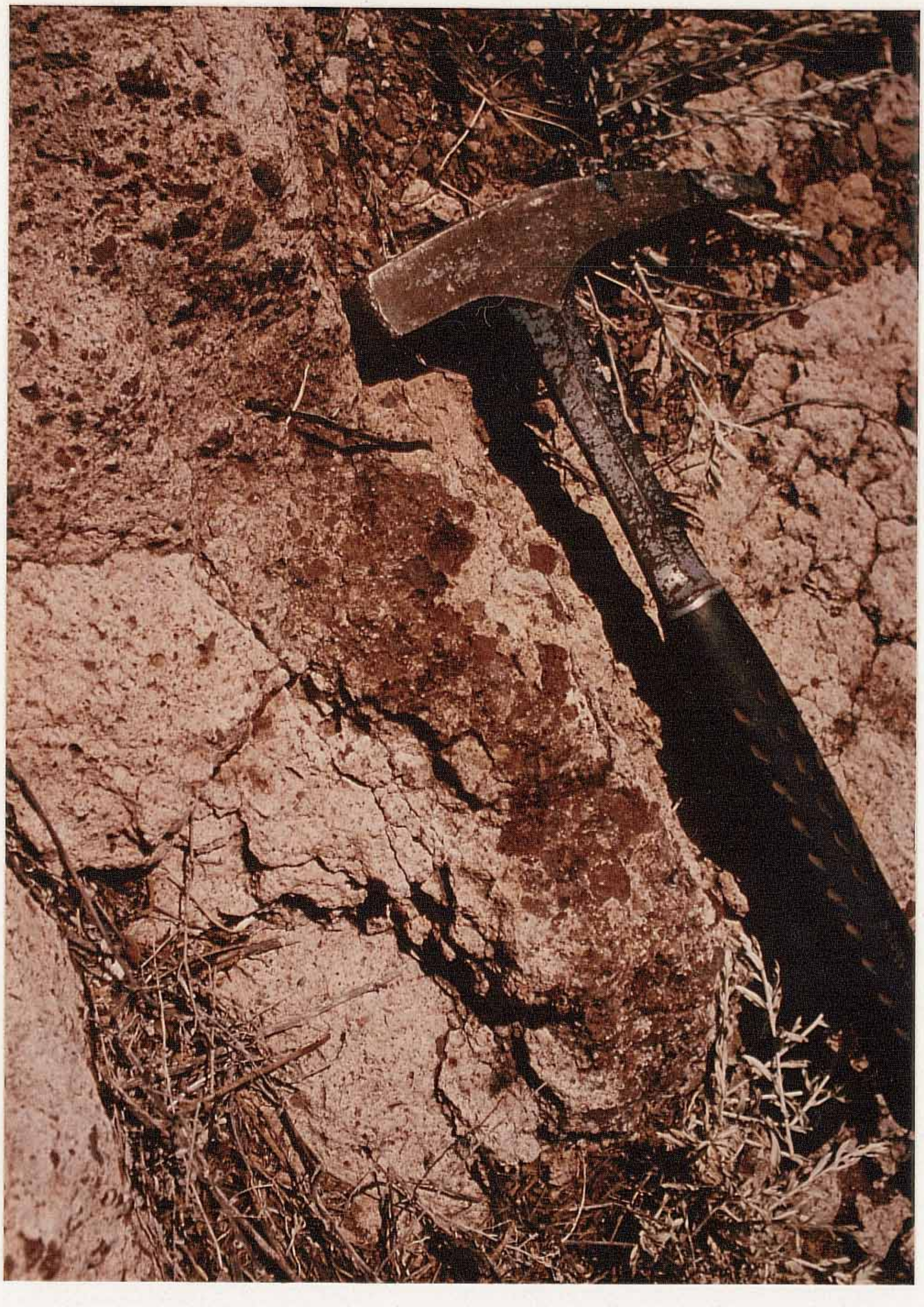


Figure 11. Fossil fumaroles in the middle tuff member of the Luis Lopez Formation. This is a close-up view of the pipes. Note the lack of fine material in the pipe.

the smallest particles found in the pipes.

Middle Sedimentary Member (Tzs2)

The middle sedimentary member of the Luis Lopez Formation consists of conglomerates, sandstones, breccias, and minor andesitic lavas. The andesitic lavas are composed of about 15 to 20 percent plagioclase, 2 to 5 percent pyroxene, and 1 to 3 percent hornblende. The plagioclase is intensely altered and is locally replaced by secondary calcite and clay minerals. Some crystals show sieve texture. Hornblende is altered to opaque minerals and is also replaced by calcite as is much of the groundmass. The breccias are probably autobreccias associated with the lava flows. The color of these andesites is maroon as is the color of the associated sedimentary rocks. The groundmass is murky with opaque minerals, possibly hematite, which may give the maroon color.

The sedimentary rocks are composed of clasts of andesite, tuff, rhyolite lava, and subrounded to euhedral quartz. Scour-and-fill structures are common and few horizons continue unbroken for any distance. These clastic sedimentary rocks are well indurated and are cemented with calcite. Fine-grained clastic sedimentary rocks are notably absent.

The clastic sedimentary rocks envelop the andesite flows which have eroded tops and may have been eroded through in places. The lower contact of the middle sedimentary member is reasonably smooth at the northernmost exposures, but just north of Nogal Canyon, this unit is exposed as disconnected channel fill sediments filling channels cut into the underlying middle tuff member of the Luis Lopez Formation. South of Nogal Canyon, the middle sedimentary member is white to buff with rare red horizons and is highly tuffaceous. This suggests a different source area for these southern rocks.

Middle Lava Member (Tzlf2)

The middle lava member of the Luis Lopez Formation forms a large dome-flow complex centered near Nogal Canyon. Short, stubby flows that may be as much as 1800 ft (549 m) thick extend for short distances north and south of the dome. The southern flow pinches out near the topographic wall of the Socorro cauldron and the northern flow is faulted off before it can pinch out so its extent is unknown.

This dome and flow sequence overlies the middle sedimentary member of the Luis Lopez Formation and is overlain by the upper members of the Luis Lopez Formation as well as the La Jencia Tuff and the Lemitar Tuff. The La Jencia Tuff pinches out against the dome and the Lemitar thins dramatically, indicating that it is pinching out. However, that pinch out is not exposed.

The rock of the middle lava member is generally brown, but is frequently altered to lighter colors. The base of the unit frequently is white and waxy in appearance, possibly the result of deuteric alteration. A similar style of alteration is present at the top of the unit where it is overlain by the upper tuff member. The texture of the rock varies from vitric to lithoidal over very short distances. The bulk of the unit shows a granular groundmass with sparse phenocrysts. Black, fresh to perlitic vitrophyre is common as are spherulites, which are found throughout the unit. The spherulites are generally found on flow planes, but are not restricted to those planes. Spherulites in the vitrophyres are often randomly scattered or may coalesce to form dense, lithic masses (Figure 12).

The phenocryst mineralogy averages about 1 percent sanidine, 3 percent plagioclase (about An 26, a-normal method), 0.7 percent biotite, 0.2 percent hornblende, and a trade each of sphene and opaques (Appendix 1 and 2). Much of the plagioclase and hornblende is altered and the plagioclase shows sieve texture. No quartz was noted in any of the thin sections from this unit. In hand sample, very sparse, large (0.2 to 0.4 in (5-10 mm)) phenocrysts of plagioclase are obvious (one or two per sample).

Figure 12. Coalescing spherulites on the upper lava member of the Luis Lopez Formation.

A single exposure of a rhyolite lava on the western map boundary (on the boundary of T.4 S and T.5 S) has been mapped as middle lava member, but it should be noted that the phenocryst content differs somewhat from other rocks of this unit. The textures are very similar, but this exposure contains 3 percent crystals with 2 percent sanidine, 0.8 percent plagioclase, 0.3 percent biotite, and traces each of quartz, mafic minerals, and zircon (Appendix 2). The lava in this exposure overlies the Hells Mesa Tuff and is intensely altered and brecciated. The mineralogical differences and the stratigraphic position suggest that this exposure is not correlative with the middle lava member of the Luis Lopez Formation, but no other correlation is known for this part of the Chupadera Mountains.

Upper Tuff Member (Tzt3)

The upper tuff member of the Luis Lopez Formation (Tzt3) is exposed only in Nogal Canyon (sec.5, T.5 S., R.1 W.). It is 50 to 70 ft (15-21 m) thick, overlies the middle lava member (Tzlf2), and underlies the upper lava member (Tzlf3). The tuff is poorly welded, lithic-rich to lithic-poor, white to pink, pumiceous, and crystal-poor. Plagioclase (about An 29) constitutes about 2 percent of the rock and quartz and biotite are present in trace quantities. The lithic fragments are rhyolite to andesite in composition with some perlite fragments.

The base of the unit is an intensely crossbedded, tuffaceous, sedimentary interval 10 to 30 ft (3 to 9 m) thick that consists of sandstones and pebble conglomerates. Many of the conglomerates are composed of pumice pebbles in a very fine-grained, tuffaceous matrix. The sandstones are similar, but lack the pumice pebbles. This interval is probably correlative, in part, to the upper sedimentary member (Tzs3).

The tuff is probably closely related to the overlying lava and may represent the products of the initial vent-clearing eruptions of a rhyolitic volcano. Lithic fragments of rhyolite lava similar to the upper lava member are found in the tuff and may be unvesiculated magma.

Upper Lava Member (Tzlf3)

The upper lava member is the uppermost lava in the Luis Lopez Formation and is found only near the mouth of Nogal Canyon (sec.32,33, T.4 S, R.1 W; sec.5, T.5 S, R.1 W). It consists of an aphanitic, vitric to lithic groundmass containing about 2 to 3 percent phenocrysts. The phenocrysts are about 2 percent plagioclase, a trace to one percent sanidine, and a trace each of biotite and opaque minerals. Numerous spherulites are found along flow banding planes and may coalesce to form dense, lithoidal masses (Figure 12). North of Nogal Canon, this unit has three distinct subdivisions: 1) a basal breccia, 2) an intermediate vitrophyre, and 3) an upper lithic zone. The basal breccia consists of perlitic rhyolite blocks in a fine-grained, rhyolitic breccia filling. This part of the unit is possibly a vent breccia (C.E. Chapin, 1981, oral comm.). The intermediate vitrophyre is probably the basal part of the lava flow or the edge of a dome. It is black with varying amounts of red-brown spherulites. The upper lithic zone is brownish-gray in color, flow banded, and contains numerous spherulites. Flow banding forms a crude semi-circle with dips toward the center of the circle. This and the breccia at the base of the unit and the tuff just south of Nogal Canyon suggest that this lava is at or near the source vent. It is not possible to determine whether or not the unit is a lava flow or a dome from the exposures in the study area.

Upper Sedimentary Member (Tzs3)

The upper sedimentary member of the Luis Lopez Formation consists of conglomerates, sandstones, and mudstones which generally have a tuffaceous character. The unit is discontinuous and may in part correlate with the base of the upper tuff member. The exposures in NE 1/4, SE 1/4, SW 1/4, sec.5, T.5 S, R.1 W are a clast supported pebble to cobble conglomerate. The unit overlies the middle lava member (Tzlf2) and underlies the La Jencia Tuff. The conglomerate is quite distinct as it consists of rounded to subrounded clasts with little matrix. It is possible that this unit is a channel deposit in the bottom of a paleovalley. The overlying La Jencia Tuff incorporated pieces of this conglomerate near its base to form distinct inclusions in the densely welded tuff.

Other exposures generally show the "normal" tan to white, tuffaceous, thinnly bedded character of the unit. Just south of Nogal Canyon, the unit is sandstone with intercalated mudstones. The sandstones are crossbedded in a manner similar to the base of the upper tuff member. The unit is found only along the top of the middle lava member and is probably derived in large part from that unit.

La Jencia Tuff (Tjll, Tjl, Tjr, Tju)

The La Jencia Tuff generally consists of two members which are crystal poor, densely welded, rhyolite ash-flow tuffs (Chapin and others, 1978) separated by a thin interval of basaltic andesite lavas and/or volcaniclastic sedimentary rocks. The tuff was originally named the A-L Peak Tuff for exposures on A-L Peak in the San Mateo Mountains (Deal and Rhodes, 1976; Chapin and others, 1978). It has recently been renamed the La Jencia Tuff for exposures in the ranges bounding the La Jencia Basin (Osburn and Chapin, in prep.). In the Chupadera Mountains, four members of the La Jencia Tuff have been defined. The upper (Tju) and lower(Tjl) members are present and are separated by the discontinuous middle member (Tjs) which is distinctive because of its reddish color and the presence of dark gray to black pumice which are locally both foliated and lineated. A thin, discontinuous sedimentary rock interval locally overlies the middle member and is included with the middle member. The tuff of Chupadera Peak (Tjll) is considered a fourth member of the La Jencia tuff and is confined to paleovalleys below the lower member. Overlying the La Jencia Tuff is a thin, discontinuous, tuffaceous sedimentary rock interval (Tcl) consisting of conglomerates, sandstones, and mudstones probably derived from the top of the La Jencia Tuff. Tcl is in turn overlain by the Lemitar Tuff. The northernmost exposures of the La Jencia Tuff in the study area are just south of Nogal Canyon where the unit is 50 to 70 ft (15 to 21 m) thick and pinches out northward (Figure 13). A maximum thickness of the La Jencia Tuff in the study area is about 1700 ft (518 m) of which 1200 ft (365 m) is lower member, 100 ft (30 m) of Tjs, and about 400 ft (122 m) is the upper member. These thicknesses are taken from cross sections. In the southeast corner of the study area, the lower member pinches out and the upper member is only 70 to 100 ft (21 to 30 m) thick, suggesting that hills with considerable relief existed prior to deposition of the tuff. To the north, the upper member pinches out near the northern boundary of the Cienega Ranch. The source cauldrons for the La Jencia Tuff are thought to be both the Sawmill Canyon and the Magdalena Cauldrons (Bowring, 1980; Osburn, 1981, oral

Figure 13. Typical exposures of the La Jencia and Lemitar Tuffs. The symbols are the same as those in Figure 4 and on Plate 1.

comm.) in the Magdalena Mountains.

Tuff of Chupadera Peak (Tjll)

The Tuff of Chupadera Peak is a poorly welded, crystal-poor, lithic-rich tuff containing about 0.2 percent quartz, 2.5 percent sanidine, 1.3 percent plagioclase, 0.1 percent biotite, and a trace each of zircon, sphene, and hornblende (Appendix 1 and 2). The unit is only exposed on Chupadera Peak and in an arroyo on the extreme west edge of the map area, about 0.25 mi (0.4 km) north of the southern map boundary. On Chupadera Peak, intensely altered andesitic lithic fragments are common. The exposures on the extreme west margin of the map area contain relatively unaltered lithic fragments of andesite and of a rock very similar to the Hells Mesa Tuff. The tuff of Chupadera Peak is found only south of the topographic wall of the Socorro cauldron, where it overlies the Datil Group and is overlain by lower La Jencia Tuff. On Chupadera Peak, this unit appears to fill a paleovalley. This topographic control may explain the lack of widespread exposures.

Lower La Jencia Tuff (Tjl)

The lower La Jencia Tuff is a densely welded, flow-banded, flow-folded ash-flow tuff (Figure 14). The lithic fragment content is variable and may control the

Figure 14. Flow-banding in the lower La Jencia Tuff.

amount and degree of flow banding, that is, the higher the lithic content, the less the rock is flow banded. Both primary and secondary flow folds (Chapin and Lowell, 1979) are present (Figure 15).

The lower La Jencia tuff contains about 0.1 percent quartz, 3.4 percent sanidine, and a trace each of biotite, zircon, sphene, hornblende, and opaque minerals (Appendix 1 and 2). Secondary calcite is a common alteration product. A vitrophyre is locally found at the base of this unit. The color of the lower La Jencia tuff is generally shades of red, but lighter colors are produced by alteration. The top of the unit is often white, possibly due to bleaching by vapor phase alteration.

The lower La Jencia Tuff is widely exposed in the southern one half of the study area where it attains a thickness of over 1200 ft (366 m). The unit exhibits rapid lateral and vertical changes in lithic content and flow banding. The base of the unit is generally flow-banded; the top of the unit locally contains as much as 10 percent lithic fragments and is not flow banded. From Chupadera Peak southward, the basal 100 to 200 ft (30 to 60 m) of the unit shows abundant lithophysae and glass shards are preserved locally. These variations may represent different "lobes" of ash-flow tuff that were erupted from different areas of, or depths in, the source cauldron.

Figure 15. Secondary flow folds in the lower La Jencia Tuff.

Lineated pumice fragments are frequently seen on foliation planes (Figure 16) and are believed to have formed during deposition of the tuff. (They are primary lineations according to the nomenclature of Chapin and Lowell, 1978). Such lineations generally have an east-west to southeast-northwest orientation which suggests that the tuff flowed to the east-southeast (assuming that the source was the Sawmill Canyon cauldron). Flow directions inferred from asymmetric primary flow folds tend to confirm this suggestion, however, in the extreme south-central part of the map area, flow lineations show an east-northeasterly trend. The flow directions in this area are unknown as no primary flow folds were found and the lineation only provides the flow axis. Secondary flow folds in this southern area show flow in a southeasterly direction, perpendicular to the primary flow lineation. Similar relations were found in an area south of South Butte, but the direction of flow was to the northeast. This data suggests that a highland existed along the western boundary of the study area prior to the deposition of the La Jencia Tuff (Figure 17). No remnant of that high has been found which suggests that it was buried by the La Jencia Tuff. The rapid thickening of the La Jencia Tuff in the northeast corner of the Cienega Ranch suggests that topography existed prior to the deposition of the tuff. In this case, the thickening is the result of the filling of depressions related to the Socorro cauldron (Figure 37).

Figure 16. Lineated pumice in the lower La Jencia Tuff.

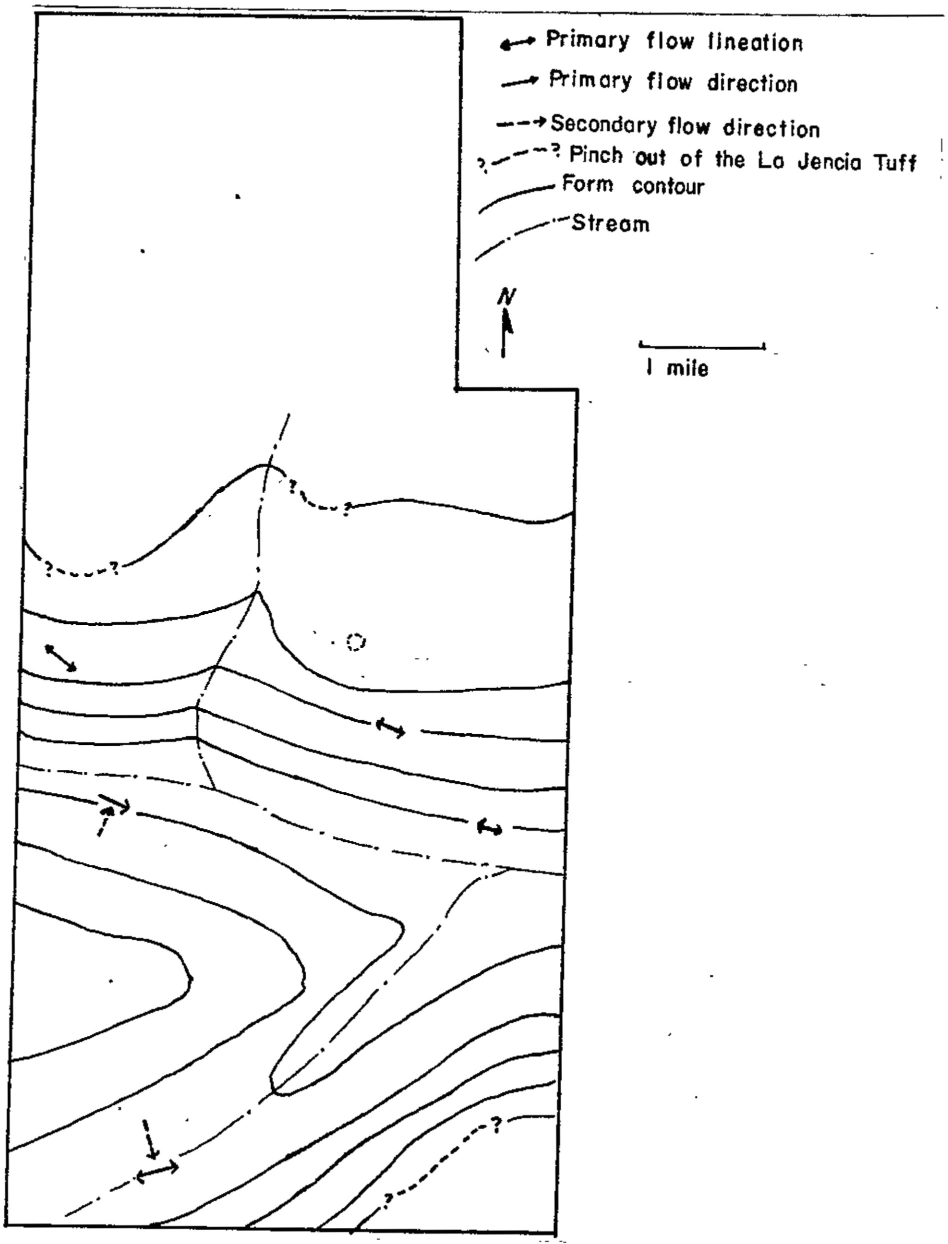


Figure 17. Possible configuration of the paleovalleys in the southern Chupadera Mountains prior to the deposition of the La Jencia Tuff.

Middle La Jencia Tuff (Tjs)

The top of the lower La Jencia Tuff is generally marked by a distinctive red to maroon tuff containing dark gray to black, flattened, and locally lineated pumice. This tuff separates the lower and upper members of the La Jencia Tuff and is informally termed the middle member of the La Jencia Tuff. This middle member was not noted where the upper member was absent. The tuff contains 0.28 percent quartz, 2.32 percent sanidine, and a trace each of plagioclase, biotite, zircon, and opaque minerals (Appendix 1 and 2). The dark gray to black pumice is invariably flattened (foliated) and locally lineated. These characteristics combine to make this tuff a distinctive marker horizon in the La Jencia Tuff. The unit is up to 100 ft (30 m) thick, but normally is only 10 to 20 ft (3 to 6 m) thick.

The source of the middle member of the La Jencia Tuff is problematic. The color and dark pumice suggest that the middle member is more mafic than a rhyolite, and suggests a separate source for this tuff or a vertically zoned magma chamber. A different source vent is difficult to reconcile with the lack of a welding break between this unit and the lower La Jencia Tuff. Vertically zoned magma chambers have been described and are well documented (Hildreth, 1979; Chamberlin,1980), making it the more attractive model.

A thin, discontinuous sedimentary rock interval has been included with this tuff. This unit is a thinly bedded, locally crossbedded, white to buff, tuffaceous interval comprising sandstones and pebble conglomerates. It overlies the tuff described above and underlies the upper La Jencia Tuff.

Upper La Jencia Tuff (Tju)

The upper La Jencia Tuff can be divided into at least two sub-units. The lower sub-unit is a massive, gray, very crystal-poor tuff that contains little pumice. It is densely welded and the rare pumice fragments are generally quite flat. It is discontinuous and does not exceed 50 ft (15 m) in thickness. It may have been deposited only in paleo-valleys formed by differential compaction of the underlying La Jencia Tuff. A lithophysal zone is locally present at varying distances up from the base of this sub-unit(Figure 18). The lithophysae show a size gradation from 1 to 2 in. (2.5 to 5 cm) near the base to 0.25 to 0.5 in. (6 to 12 mm) near the top of the zone.

Overlying the lower sub-unit is a volumetrically more important sub-unit that contains abundant pumice, most of which is not completely collapsed and shows sucrose interiors possibly due to vapor phase mineralization (Chamberlin, 1981, oral comm.; Osburn, 1981, oral comm.). This sub-unit is the "normal" upper La Jencia Tuff and

Figure 18. Lithophysae in the upper La Jencia Tuff. Note the size gradation from top to bottom of the photograph. The hammer is 30 in. long.

contains about 0.25 percent quartz, 2.5 percent sanidine, and a trace each of biotite and zircon (Appendix 2). The rock is generally light gray, similar to the lower sub-unit, but may be shades of red or gray depending on the degree of alteration. A spherulite zone is present just above the base of this unit in the northeast corner of the Cienega Ranch.

A possible third sub-unit overlies the other units of the upper La Jencia Tuff in sec.13, T.4 S, R.2 W. This unit is very similar to the lowest sub-unit, but it has a very restricted extent and may be a pumice poor variety of the previously described upper sub-unit.

The upper La Jencia Tuff is as much as 400 ft (122 m) thick, but pinches out south of Nogal Canyon and nearly pinches out in the southeast corner of the study area. The fact that it does not uniformly cover the lower member suggests that as the lower member welded and compacted, depressions mimicking the underlying topography were created and the upper member filled those depressions. The lower sub-unit of the upper La Jencia Tuff may only be exposed in paleo-valleys created in this way.

Tcl

A thin, discontinuous sedimentary rock interval frequently separates the La Jencia Tuff from the Lemitar Tuff. The unit consists of white, tuffaceous sandstones and pebble conglomerates probably derived from the top of the La Jencia Tuff.

Lemitar Tuff (Tll, Tlu)

The Lemitar Tuff was named by Chamberlin (1980) for exposures in the Lemitar Mountains. The name supercedes other names such as "tuff of Allen Well" (Brown, 1971; Simon, 1973; Blakestad,1976; Spradlin, 1976) and the "tuff of La Jencia Creek" (Brown, 1971; Simon, 1973). The Lemitar Tuff is a complexly zoned, simple cooling unit which is divided into an upper and lower member which in turn are divided into several sub-units. Osburn (1978) and Chamberlin (1980) describe the petrography of this tuff in detail.

The Lemitar Tuff overlies the La Jencia Tuff and is overlain by the South Canyon Tuff (Figure 13). Thin sedimentary rock intervals (Tc1, Tc2) are locally found above and below the Lemitar Tuff. The maximum thickness of the Lemitar Tuff is in excess of 600 ft (183 m). On the east flank of the Chupadera Mountains, where Nogal Canyon exits the mountains, the Lemitar Tuff thins and may pinch out against the rhyolite domes of the Luis Lopez Formation. The unit thins and nearly pinches out in the extreme southeast corner of the study area. The thickness in the remainder of the study area seems to be reasonably constant.

Chamberlin (1980) stated that the Socorro cauldron was the source of the Lemitar Tuff. This study has shown that the Socorro cauldron is the source of the Hells Mesa Tuff. Osburn and others (in prep.) found exposures in the Torreon Springs area to the west of this study area that also suggest that Chamberlin's (1980) interpretation was incorrect. The source of the Lemitar Tuff is believed to be in the northern San Mateo Mountains (G.R. Osburn, 1981, oral comm.; Donze, 1980; Deal, 1973).

Lower Lemitar Tuff (Tll)

The lower Lemitar Tuff is divided into two sub-units in this study area; a poorly welded base and a densely welded top. Both sub-units are mapped together and are as much as 500 ft (152 m) thick. The poorly welded base has a variable thickness and comprises as much as 50 percent of the unit. It is poorly exposed and the lower contact with the La Jencia Tuff is often difficult to locate precisely. The poorly welded base is colored shades of white, pink, and gray. It contains an average of about 6 percent crystals including about 1.7 percent quartz, 4 percent sanidine, 0.5 percent plagioclase, 0.2 percent biotite and traces of zircon and sphene (Appendix 1 and 2). The plagioclase composition is about An 22 (a-normal method). The pores of this sub-unit are often filled with chalcedony; devitrification textures include axiolites and rare spherulites.

The upper sub-unit of the lower Lemitar Tuff is crystal poor, white to pale red to gray, and densely welded. Bold outcrops are rare and the rubbly weathering of this unit makes finding a hand sample difficult at times. This rock contains about 1.5 percent quartz, 6.6 percent sanidine, 0.5 percent plagioclase, and traces of hornblende, opaque minerals, zircon, and sphene. Devitrification textures include axiolites in glass shards, rare spherulites, and commonly a granular groundmass. Sanidine and quartz phenocrysts vary from broken to euhedral and quartz is sometimes embayed. The rare lithic fragments are andesitic in composition. The top of this sub-unit grades into the overlying upper Lemitar Tuff.

Upper Lemitar Tuff (Tlu)

The upper Lemitar Tuff is conveniently divided into three sub-units (zones)in the study area: a lower crystal-rich, quartz-poor zone, an intermediate, crystal-rich, quartz-rich, densely welded zone, and an upper, crystal-rich, quartz-rich, poorly welded zone.

The lower, quartz poor zone is a foliated, dark-reddish-brown, crystal-rich (31 percent phenocrysts), densely welded tuff containing about 0.6 percent quartz, 20 percent sanidine, 9 percent plagioclase, 1 percent biotite, and 0.5 percent opaque minerals with a trace of zircon (Appendix 2). In outcrop, the zone typically forms a low cliff 10 to 50 ft (3 to 15 m) high and is easily recognized from a distance (Figure 13).

The quartz-poor zone grades into the quartz-rich, pale-red, densely welded, crystal-rich, intermediate zone. This zone contains about 46 percent crystals which include 13 percent quartz, 22 percent sanidine, 9 percent plagioclase, 2 percent biotite, and 0.5 percent opaque minerals in a densely welded groundmass (Appendix 2). The quartz phenocrysts are very large, as much as 0.2 to 0.25 in. (5 to 7 mm) across and the sanidine phenocrysts may approach that size, but are generally smaller. Secondary calcite is locally common and small patches of the groundmass appear to be replaced by secondary potassium feldspar. This zone is poorly exposed and in most places it has been eroded off the quartz-poor zone.

The intermediate zone grades into the upper, poorly welded zone and with that transition comes decreases in quartz (to 10 percent), plagioclase (to 5 percent), and biotite (to 0.8 percent) and an increase in sanidine (to 27 percent). The total phenocryst content drops to about 43 percent, but that drop is viewed as insignificant. Few other changes occur between the upper and intermediate zones. The upper zone is rarely preserved and where it is, slightly more resistant horizons form ledges, low cliffs, and spires.

Tc2

This unit is a sedimentary rock interval that locally separates the Lemitar Tuff and the South Canyon Tuff. It consists of fine-grained, tuffaceous sedimentary rocks that may be air-fall tuffs rather than fluvial sedimentary rocks. The unit is poorly exposed and is restricted to the contact between the Lemitar and South Canyon Tuffs immediately south of Nogal Canyon.

South Canyon Tuff (Tśc)

The youngest major ash-flow tuff in the study area is the South Canyon Tuff which is about 26 m.y. old. Osburn (1978) named this tuff for a type section at the mouth of South Canyon in the eastern Magdalena Mountains. The south Canyon Tuff is a simple cooling unit of high silica rhyolite that is mineralogically and texturally zoned (Osburn, 1978; Chamberlin, 1980). The South Canyon Tuff is generally mapped as a single unit, but can be divided into two members: a lower, poorly to densely welded, crystal-poor member and an upper, densely welded, moderately crystal-rich member (Chamberlin, 1980). In the Chupadera Mountains, it is not clear that the upper member is present, as only float of the unit is found.

The South Canyon Tuff in the study area consists of a poorly welded base with a moderately welded top that is only locally densely welded. The poorly welded base contains about 0.25 percent quartz, 1.4 percent sanidine, 0.2 percent plagioclase, and a trace each of biotite and opaque minerals (Appendix 1 and 2). The moderately welded top contains about 6 percent quartz, 6 percent sanidine, 0.5 percent plagioclase, and a trace each of biotite and opaque minerals (Appendix 2). This sequence fits only the lower member of the South Canyon Tuff (Osburn, 1978). The South Canyon Tuff is exposed only where it has been downfaulted against a more resistant unit or where it is faulted to a level near the present base level; and for this reason, it is not a widespread unit in the study area.

TERTIARY INTRUSIVES

Intrusive rocks in the Chupadera Mountains include felsic to intermediate stock-like bodies and andesite dikes. The ages of these rocks are problematic and in general, only a maximum age can be postulated.

Felsic to Intermediate intrusives (Tif,Tix,Tid,Tir)

Four Tertiary intrusives (Tif,Tix,Tid,Tir) are found in the northwest portion of the area (sec. 18,19, T.4 S., R.1 W.; sec. 23, T.4 S., R.2 W.; Plate 1) where they intrude cauldron facies Hells Mesa Tuff and the Luis Lopez

Formation. The larger of these intrusives (Tif) is a porphyritic, grayish- pink to pale-red , quartz latitic rock. Point counts show the average composition of this unit to be about 3 percent quartz, 3 percent sanidine, 11 percent plagioclase, 3 percent biotite, and a trace each of sphene, zircon, unidentified opaque minerals, and intensely altered green hornblende set in an aphanitic groundmass (Appendix 1 and 2). The sanidine content between the two thin sections differed radically; one thin section had 1 percent sanidine, the other had 4.9 percent sanidine. The amount of other phenocrysts in the thin section is about the same. The reason for the difference in the sanidine content is unknown.

The texture of the rock is quite distinct; sanidine phenocrysts as much as 7 mm in length are conspicuous and comprise about 1 percent of the rock. In thin section, these sanidine crystals are actually composed of several small sanidine phenocrysts with smaller included plagioclase crystals. Plagioclase is frequently glomeroporphyritic and has a composition of about An 24-33 (Michel-Levy method, 6 grains). Quartz is rounded to subhedral, commonly exhibiting embayed grain margins.

Four scattered exposures of Tif were found. These exposures approximate a square about 0.25 mi (0.4 km) on a side. For this reason, it is suggested that the exposures represent a series of cupolas on the top of a larger intrusive body at depth. A dike of similar rock extends eastward from the largest exposure of Tdl and dips about 60 degrees to the south. It shows obvious flow banding which is not always parallel to the strike and dip of the dike. Though a physical connection cannot be proven, the dike is assumed to be connected to the other bodies. Locally, the cupolas are somewhat bleached and altered and manganese mineralization commonly fills breccia zones along fault and shear zones.

Tix is located about one-fourth mile north of Tif and consists of two phases. The first phase has an aphanitic groundmass containing a trace to one percent phenocrysts of sanidine and a trace of quartz. No plagioclase was noted; however, numerous holes in the thin section have outlines suggesting that are the result of the removal of a feldspar, possibly plagioclase. The groundmass is a mosaic of very small, unidentified crystals. This phase of Tix is intensely brecciated near its margins. These breccias are anealed and filled with material similar to the breccia fragments, which suggests that the breccia was formed contemporaneous with emplacement of the intrusive.

The second phase of Tix has a phenocryst mineralogy similar to the first phase. The primary difference in the two phases is the texture of the groundmass. The second phase has a pilotaxitic texture compared to a granular texture in the first phase and has a peculiar banded appearance with medium-dark gray bands in a grayish-red rock. The origin of these bands is not understood. The nature of the contact between the two phases is not known. It appears as a very straight line and may be either a fault or an intrusive contact. The second phase is texturally similar to the lower lava (Tzlfl) in the Luis Lopez Formation and it is possible that there is a genetic link between the two units.

Dikes with mineralogy and textures similar to the first phase described above (Tix) are found trending east-west along the northern boundary of the study area. The color of these dikes depends on the degree of alteration and varies from red to white. The source of the dikes must be Tix but, as seen in Plate 1, the dikes never come into direct contact with the main intrusive. The dikes are generally almost vertical, but may dip steeply southward. They are everywhere altered and generally bleached. In thin section, about one percent of the rock consists of holes that may have developed due to the removal of plagioclase (?).

The third intrusive (Tir) is located in the SE 1/4, sec.29, T.4 S, R.1 W. Two similar exposures were found along a down to the west fault and are believed to be part of the same intrusive as they are separated by only a few hundred feet. The rock consists of phenocrysts of generally euhedral quartz (3 percent), sanidine (22 percent), and biotite (1 percent) set in an aphanitic, granular-to-spherulitic groundmass. Trace amounts of zircon are present. Plagioclase appears to have been removed by alteration. Clay minerals and secondary calcite are the main alteration products.

The rock strongly resembles the Hells Mesa Tuff for which it is readily mistaken. The euhedral crystals and the spherulitic groundmass suggest that the rock is an intrusive rather than an ash-flow tuff. The spherulitic groundmass further suggests that this rock was a hypabyssal intrusive and that it cooled rapidly (Walton and others, 1980). This intrusive intrudes into the middle tuff member of the Luis Lopez Formation and is therefore much younger than the Hells Mesa Tuff.

Andesite Dikes (Tand1, Tand2, Tand3)

Four andesite dikes were found in the study area. Two of those dikes were mapped as Tand1 and are located in the southwest corner of the study area. These dikes strike northwesterly and are 2500 to 3000 ft (762 to 914m) long and about 20 ft (6 m) wide. Tand2 is about 0.5 mi (0.8 km) northeast of Tand1. It is exposed for only about 600 ft (183 m) and is 10 to 20 ft (3 to 6 m) wide. Tand3 is located in the S 1/2, sec.29, T.4 S, R.1 W. It is about 2700 ft (823 m) long and 10 to 30 ft (3 to 10 m) wide. Possible continuations of this dike are about 600 ft (183 m) east of the main dike and 3000 ft (914 m) southwest of the main dike. If these exposures are part of the dike, then the total strike length in excess of 6500 ft (1981 m).

All the dikes have a pilotaxitic texture, but Tand2 is the coarsest grained and contains plagioclase and biotite phenocrysts that the other dikes do not have. Tand2 contains about 5 percent biotite, 5 to 7 percent pyroxene, and a few clay-filled holes that were probably plagioclase crystals prior to alteration. This dike is black and only mildly altered. Tand1 and Tand2 are very similar in appearance and mineralogy. These dikes are dark green in outcrop and are intensely fractured. They contain about 2 percent pyroxene in a groundmass of plagioclase microlites. Calcite and clay minerals have partially replaced the microlites. The pyroxenes in these dikes are tiny, birefringent dots in thin section. Iron staining along the fractures suggests that iron was added during alteration.

The age of these dikes in problematic; Tand1 and Tand2 both cut upper La Jencia Tuff and Tand2 cuts the very lowest part of the Lemitar Tuff indicating that the dikes are younger than the lower Lemitar. Tand3 cuts the middle lava member of the Luis Lopez Formation, but it turns and follows structures that cut the Luis Lopez Formation, indicating that the dike is younger than the moat-fill of the Socorro cauldron.

MIOCENE AND PLIOCENE DEPOSITS

Popotosa Formation (Tp)

The Popotosa Formation (Denny,1940; Bruning, 1973; Chamberlin, 1980) is restricted to the extreme northwest corner of the study area. These deposits are interpreted to be bolson deposits (Chamberlin,1980; Osburn and others, in prep.). They consist of red, well-indurated, heterolithic conglomerates, sandstones, and possible mudflow deposits. The thickness of this unit is unknown, but it is at least several hundred feet with no exposed base. The sandstones and conglomerates show scour-and-fill structures and crossbedding. One transport direction suggests southerly transport, but the poor quality of the data makes the direction suspect. This unit may correlate with parts of the upper Santa Fe Gravels described below.

Upper Santa Fe Gravels (Tus)

The central Chupadera Mountains are flanked by coarse clastic deposits that may be more that 2000 ft (610 m) thick. They were probably covered by these deposits prior to the most recent episodes of rifting. Gravels of the upper Santa Fe Group (Tus) are heterolithic, coarse, clastic sedimentary rocks with minor mudstones showing a general fining-upward trend. The base of the sequence consists of very coarse deposits, which may be of mudflow origin, and boulder conglomerates which are poorly indurated and dip about 20 to 25 degrees to the east. The dip decreases upward and is nearly horizontal on North Butte. These deposits have been interpreted as fanglomerates (Osburn, in prep.) and are thought to be correlative with parts of the Popotosa Formation (Denny, 1940) and the Sierra Ladrones Formation (Machette, 1978). Absence of an angular unconformity between the two units (Machette, 1978) makes separating them very difficult; consequently the deposits were mapped as upper Santa Fe gravels and no attempt was made to separate them.

The gravels of the upper Santa Fe Group are tan to pale red and are poorly indurated. The lack of induration generally causes the unit to form low, rounded hills with poor exposures. In Nogal Canyon, however, the unit forms cliffs as much as 100 ft (30 m) high. Transport directions from two areas near the opposite ends of Nogal Canyon suggest a southerly transport for this material. However, these transport directions are from very limited exposures and are poor quality data.

The lower contact of these gravels is an erosional unconformity along which the gravels rest on nearly all of the previously deposited Tertiary and pre-Tertiary rocks. Locally, hills were developed on the unconformity and were then buried. Excellent examples of these hills can be seen along the west edge of the study area (Figure 19 and 20). Another excellent example of the topography on this unconformity is in the northeast corner of the Cienega Ranch. Here, pre-Santa Fe erosion exposed the lower sedimentary member of the Luis Lopez Formation. Topographic relief was in excess of 1000 ft (305 m) before the valley was filled with gravel.

Several basalt intervals are interbedded in the upper Santa Fe Group and will be described later. Three of these basalts (Tb1, Tb2, and Tb4) may correlate with each other and with Chamberlin's (1980) basalt of Bear Canyon. If this correlation could be confirmed, the upper Santa Fe gravels in the Chupadera Mountains would then be correlative with the Popotosa Formation (Chamberlin, 1981).

Basalt Flows (Tb1, Tb2, Tb3, Tb4, Tb5)

Several dark gray to black basalt flows are intercalated in the upper Santa Fe Group. The oldest of these flows, Tb5, is a basalt filling a channel cut in the South Canyon Tuff at the base of the upper Santa Fe Group. This basalt probably correlates with the basalt of Madera Canyon (Osburn and others, 1981). The rock is microvesicular and contains a trace of iddingsite which may indicate that olivine was a primary constituent of the rock (Deer and others, 1966). Most of the vesicles are now filled with calcite.

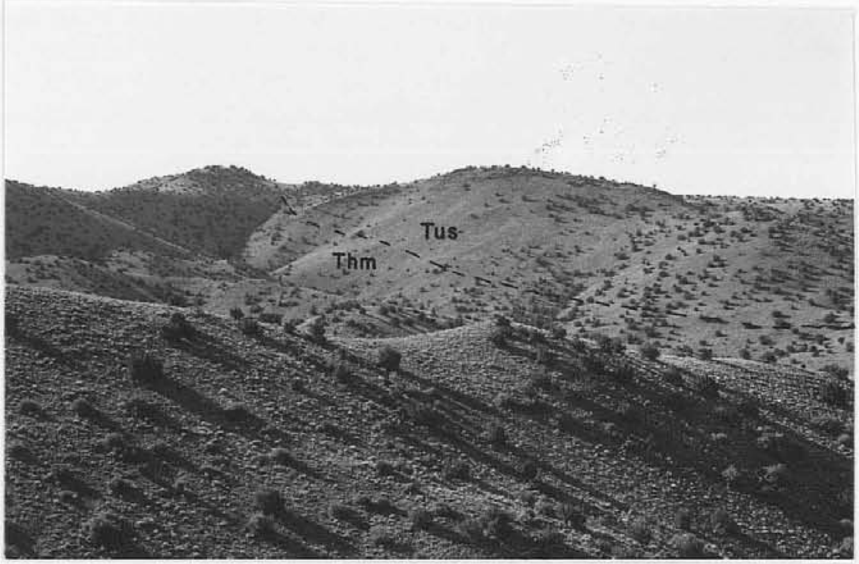


Figure 19. View looking south from Madera windmill, south of Red Canyon. The dashed lines show paleotopography at the base of the upper Santa Fe gravels. The symbols are the same as those on Figure 4 and Plate 1.

Figure 20. View of North and South Buttes from the west. The dashed lines show paleotopography along the unconformity at the base of the upper Santa Fe gravels. The symbols are the same as those on Figure 4 and Plate 1.

Four other basalt units (Tb1, Tb2, Tb3, Tb4) are intercalated in the upper Santa Fe Group. As many as three of these units may be correlative, but correlation is difficult as the basalts are isolated from each other and are altered. The degree of alteration varies greatly with location. For instance, Tb3 and Tb4 on North Butte are locally unaltered but, calcite generally fills the vesicles and travertine veins are common; however, only locally is the texture and color of the rock affected. In contrast, Tb1 on the east flank of the Chupadera Mountains may be shades of brown, green, and gray over much of its strike length and hand-specimen textures are obscured.

Contact metamorphic effects of the flows is restricted to the few inches of sedimentary material immediately below the flow. The sedimentary rocks are frequently dark red and slightly more indurated than the material a few inches below the flow. Clastic dikes are common along the base of the flows.

Tb1 is exposed sporadically along the eastern front of the Chupadera Mountains. This basalt is black where it is fresh, but it is frequently altered to lighter colors. In hand sample, small amounts of iddingsite may indicate that olivine was a primary constituent of the rock. This unit is a composite of several flows and as a result, the rock varies from a dense, massive basalt near the centers of the flows to highly vesicular basalt at the flow boundaries.

The maximum thickness of Tbl is just north of Nogal Canyon where it may be as much as 300 ft (91 m) thick. The unit thins to the north and south, but it is faulted off and buried by piedmont deposits. About 0.5 mi (0.8 km) north of Nogal Canyon, Tbl is crisscrossed by veins and veinlets of travertine and calcite. Minor amounts of jasperoid and manganese oxides are present in some of the veins. Alteration in this area is intense and the original color of the rock is generally obscured. Vesicles are filled with calcite and possible zeolites. Large plagioclase microlites are frequently altered to calcite and clay minerals; celadonite(?) is a common alteration product. This basalt may correlate with Tb4 and/or Tb2, but that correlation is tenuous.

Tb2 is a thin, discontinuous unit exposed only in secs.13 and 24, T.4 S, R.2 W. The discontinuous nature of Tb2 suggests that it may have filled channels in the upper Santa Fe Gravels; alternatively, it may have been eroded through after deposition. This basalt is deeply weathered and generally altered. Low, rubbly outcrops are common, as are spheroidally weathered blocks. Shades of red, purple, and black are common depending on the degree of alteration. Secondary calcite is ubiquitous which makes dating the rock difficult. It may correlate with Chamberlin's (1980) basalt of Bear Canyon (Osburn, 1981, oral comm.).

Tb3 caps North Butte (Figure 20) and South Butte as well as the butte about a mile north of North Butte (Figure 19). This basalt correlates with the basalt of Broken Tank (Osburn and others, 1982) and was described by them as a microvesicular, subophitic to ophitic basalt. It appears to be the youngest igneous rock in the study area but it has not been dated. Travertine veins as much as 12 in. (29 cm) wide cross-cutting this basalt are very common and sometimes show alteration halos.

Tb4 forms the low cliff below the top of North Butte (Figure 20). It may correlate with Tb1, Tb2, and/or Chamberlin's (1980) basalt of Bear Canyon. It is composed of at least one and probably two flows which show vesiculated tops and massive cores. In most cases, the flow is altered and fresh material is difficult to obtain. Calcite and possibly zeolites commonly fill vesicles and iddingsite may indicate that olivine was a primary constituent of the rock. The unit is black where fresh, but alters to shades of gray. Travertine veins cut the unit and are as much as 12 in. (29 cm) wide.

QUATERNARY UNITS

Piedmont Gravels (Qpg)

These deposits consist of coarse conglomerates and sandstones derived from the existing mountains and are probably of Quaternary age. However, it is possible that some of the deposits are late Tertiary in age. They form gently sloping terraces on both flanks of the Chupadera Mountains and are formed by coalescing alluvial fans. The thickness of the deposits is unknown, but arroyos incised into the piedmont gravels east of the study area expose about 50 ft of gravel and the base is not exposed. Piedmont gravels along the east side of the Chupadera Range form a broad geomorphic surface that slopes gently toward the Rio Grande. Several terrace levels are seen in the arroyos cut into this surface, but the terraces are obscured along the mountain front and were not mapped.

Older Alluvium (Qoa)

Older alluvium consists of coarse alluvial deposits that are younger than the piedmont deposits and older than the presently active stream channels. Older alluvium includes paleosoils, several of which are present in the older alluvium along Nogal Canyon. The maximum thickness of older alluvium is in excess of 15 ft (5 m). Some colluvial material is invariably included in this unit.

Talus and Colluvium (Qt)

Talus and colluvial material mantle most of the slopes in the Chupadera Mountains. These deposits were mapped only where they obscured geologic relationships.

Alluvium (Qal)

Alluvium consists of silt- to boulder-sized sediments that may move with each storm in the region. It is found in most arroyos, but is mapped only where it obscurs underlying geologic relationships.

STRUCTURAL GEOLOGY

REGIONAL STRUCTURE

The Chupadera Mountains area has been involved in several periods of tectonism. It is situated in the Rio Grande rift, an intracratonic, continental rift superimposed on a previously deformed terrane (Chapin and Seager, 1975). Deformation during the Paleozoic (Ancestral Rocky Mountains) and during the Late-Cretaceous to middle Eocene (Laramide Orogeny) has been documented (Figure 21) (Chapin and Seager, 1975; Cather, 1980; Chamberlin, 1980).

Little is known of the Paleozoic highlands, but the Laramide highland is well documented (Eardly, 1962; Cather, 1980). It was worn down by erosion nearly as fast as it rose and the detritus filled adjacent basins (Chapin and Seager, 1975; Chapin and others, 1974; Cather, 1980). Erosion quickly planed a surface of generally low relief (Epis and Chapin, 1975) as the compressional forces died in the late Eocene. Local highlands were preserved on this surface. One such area is near Chupadera Peak where relatively high relief (several hundred and possibly a thousand feet) was preserved. The early Oligocene Datil Group was deposited on this surface. This group is the basal, andesitic to latitic volcaniclastic apron common to ash-flow tuff fields (Chapin and others, 1975, 1978;

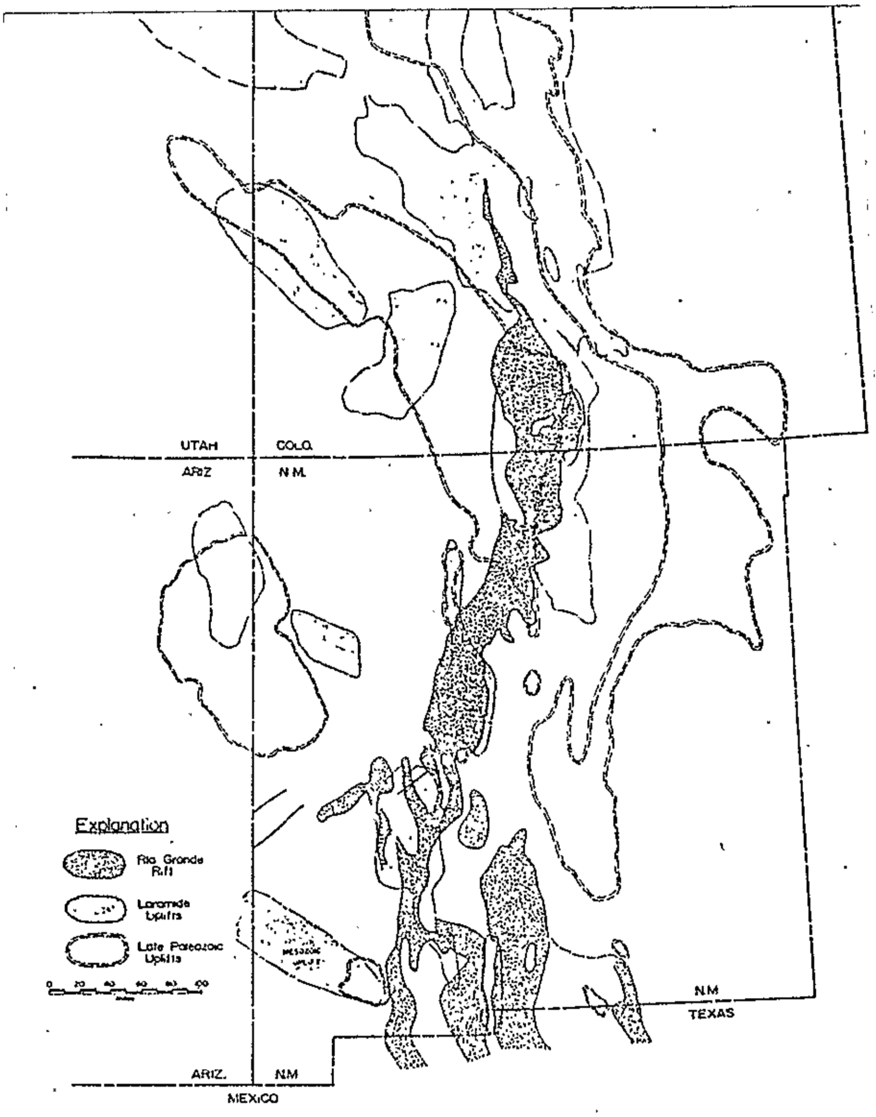


Figure 21. Laramide and Paleozoic uplifts overprinted by structures related to the Rio Grande rift (after Chapin and Seager, 1978).

Chapin, 1980, oral comm.). At about 33 m.y. ago, the Hells Mesa Tuff was erupted and shortly after that, (about 30 m.y. ago) the Rio Grande rift began to open (Chapin, 1978, 1979; Chamberlin, 1978, 1980). The Rio Grande rift splits New Mexico in two and extends well into Colorado. Chapin (1978, 1979) has divided the rift into three segments; a northern segment, a central segment, and a southern segment (Figure 22). The southern segment extends from Socorro south to El Paso and includes the area of the present study. This segment has undergone the greatest extension of any of the segments. Near Socorro, the rift bifurcates with the San Agustin rift following the Morenci lineament to the southwest (Chapin, 1978, 1979). The Morenci lineament is one of a series of northeast trending lineaments that are surface manifestations of deep seated, possibly Precambrian, flaws in the lithosphere (Figure 22). As the Rio Grande rift opened, it broke en echelon across these flaws and the basins and ranges on either side have opposing symmetries (Chapin, 1978, 1979; Chapin and others, 1978). In the Socorro area, the Morenci lineament is referred to as the transverse shear zone (Chapin and others, 1978). North of that zone, beds dip to the west; south of the zone, the beds dip to the east (Chamberlin, 1978, 1980; this study). This zone, then, is acting as an incipient transform fault and the opposite rotation of beds requires that the underlying lithosphere is sheared. The surface expression of the zone is a zone of jostled blocks a mile or more wide

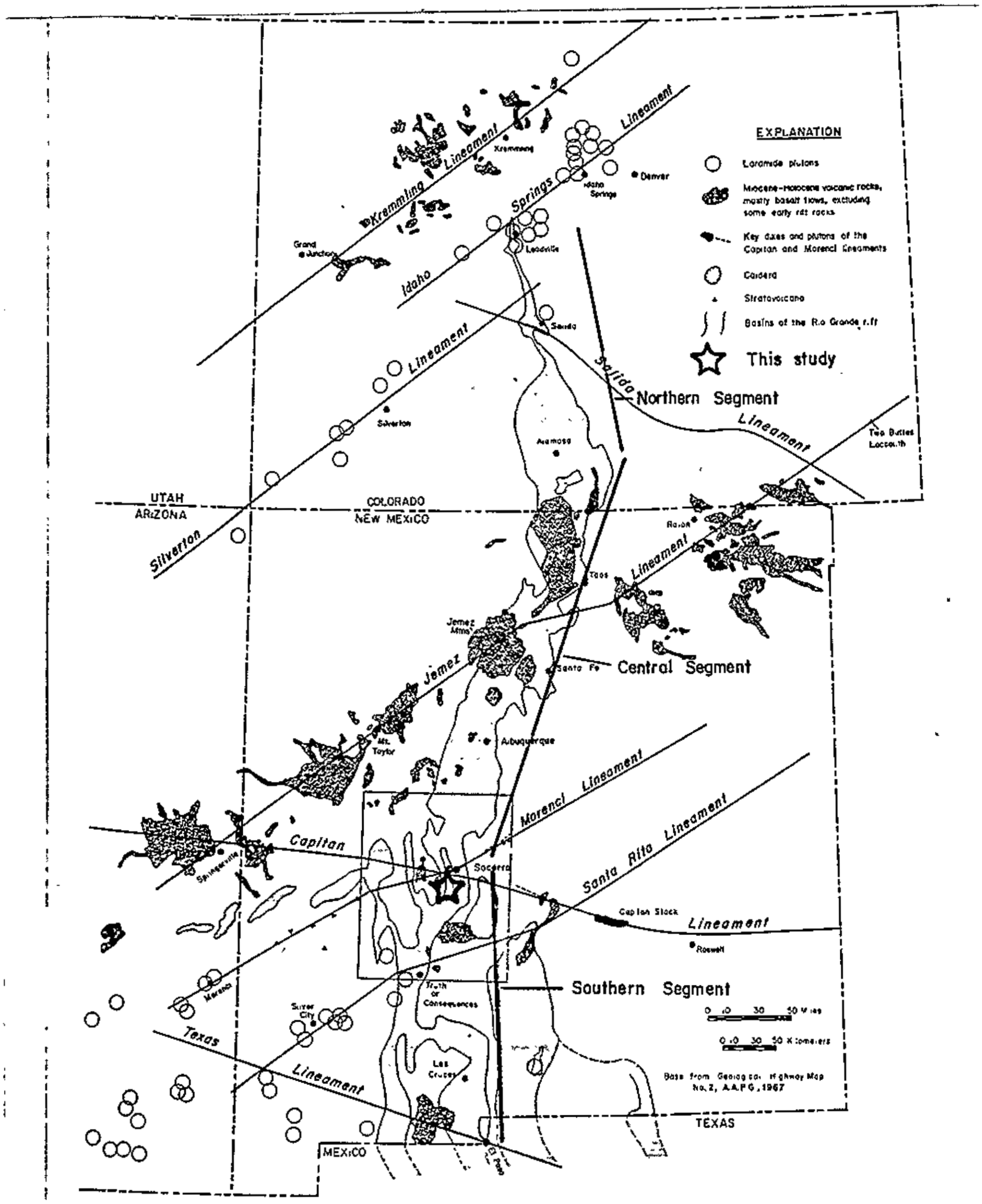


Figure 22. Major structural features in the Rio Grande Rift (after Chapin and others, 1978).

(Chapin and others, 1978). Extension along the rift has been active since about 30 m.y. and is presently active as indicated by high heat flow, modern uplift, magma bodies at depth, geophysical evidence for anomalous crust and upper mantle beneath the rift and by the number of fault scarps cutting Pleistocene piedmont slopes, (Chapin, 1978, 1979).

LOCAL STRUCTURAL GEOLOGY

The structural geology of the central Chupadera Mountains is very complex and includes down-to-the-west normal faults, down-to-the-east normal faults, low-angle normal faults, horsts and grabens, drag folds, and cauldron structures. Plate 2 shows the major structural features in the study area. These features are related to extension along the Rio Grande rift and to the development of the Socorro and Sawmill Canyon cauldrons.

Faulting is dominantly down-to-the-west normal faulting. These faults strike north-northwest in the northern two-thirds of the study area; in the southern one-third of the study area, the largest faults (Plate 2) strike northeast and curve north and then north-northwest. The fault planes dip from 20 degrees to about 90 degrees. Two groups of faults are present. One group consists of faults with dips between 30 to 50 degrees, the other group consists of faults with dips between 60 and 90 degrees. If these groups are real, they suggest that the lower angle faults are earlier than the higher angle faults and that they were involved in rotational faulting similar to Chamberlin's (1978, 1980 and Morton and Black, 1975) "domino" style faulting in the Lemitar Mountains. It may also suggest that these faults were active during Chamberlin's (1978) earliest period of extension (29 to 20 m.y.). These low-angle normal faults generally exhibit a sinuous trace and rarely have a consistent topographic expression.

The second group of faults, those with dips of 60 to 90 degrees, have topographically consistent traces and may be younger than the first group. These faults have not undergone much rotation and may have been active during Chamberlin's (1978) last period of extension. The tilting and faulting of the Santa Fe Group indicates that Chamberlin's (1978) third period of extension (12 to 7 m.y.) affected the Chupadera Mountains. Stratigraphic separation along these faults is as much as 3500 ft (1067 m) (estimated); the mapped faults generally must have more than 400 to 500 ft (122 to 152 m) of separation to be distinguishable.

Down-to-the-east faults are also common in the area (Plate 2). These faults dip 60 to 90 degrees and like the down-to-the-west faults, are of differing ages. Most of these faults may be related to Chamberlin's last period of extension as they cut rocks of the Santa Fe Group. Others, such as the fault immediately east of Bianchi Ranch dip 60 to 80 degrees to the west rather than to the east. This gives the appearance of a reverse fault, but it is really a normal fault that has been rotated. It probably was originally a high-angle normal fault and dipped to the east. These down-to-the-east faults are occasionally difficult to recognize as they dip at about the same angle as the bedding and tend to thicken strata rather than offset strata.

Infrequently, small grabens are formed. These features are rare and are mentioned because they preserve strata very high in the section. One such graben is immediately north of North Butte and preserves the South Canyon Tuff. Drag along the east boundary fault of this graben produced a syncline. An anticline formed in a similar manner is exposed in the north-central part of the Cienega Ranch (Plate 2).

A structurally problematic area is located in the northeast corner of the Cienega Ranch. Here, it is difficult to explain the emplacement of a large block of La Jencia Tuff surrounded by upper Santa Fe gravels. Cross section E-E′ (Plate 1) shows one interpretation of the structure that is consistent with surface data. The fault on the west side of the block dips only 29 degrees. This interpretation, however, allows no variation from the geometry shown and no subsurface data is available to confirm the geometry. C.E. Chapin (1981, oral comm.)

suggested that the block might be a very large slump block that slid about 0.25 to 0.5 mi (0.4 to 0.8 km) to the east. This hypothesis gains support from the remarkable resemblance of the block to the embayment in the volcanics to the west.

Near Chupadera Peak, one or two east-northeast-trending faults have been inferred beneath the La Jencia Tuff. These faults cut the Paleozoic and Precambrian rocks in the area. Several modes of formation are possible for these faults which have locally downdropped and rotated the Paleozoic of the area. It is possible that these faults formed by one of the following means 1) slumping toward the Socorro cauldron during the Hells Mesa eruption, 2) fracturing during the tumnescence that may have preceded the Hells Mesa Tuff eruption, and 3) the faults are Laramide age features formed during the Laramide orogeny. None of the possible modes of formation is favored by this study.

CAULDRON STRUCTURES

A segment of the Socorro cauldron is exposed in the Chupadera Mountains (Figure 23). This segment includes part of the topographic wall of the cauldron, the moat and moat fill of the cauldron, and possibly part of the resurgent dome of the cauldron. Figure 24 is a generalized geologic map of the study area and shows the cauldron related rocks. Cauldron collapse breccias are thought to have been derived

Figure 23. Relationship of this study area to cauldrons, the transverse shear zone, and regional geography of the Socorro area. The cauldrons are as follows: 1) Socorro cauldron, 2) Sawmill Canyon cauldron, and 3) Magdalena cauldron. After Osburn and Chapin (in prep.).

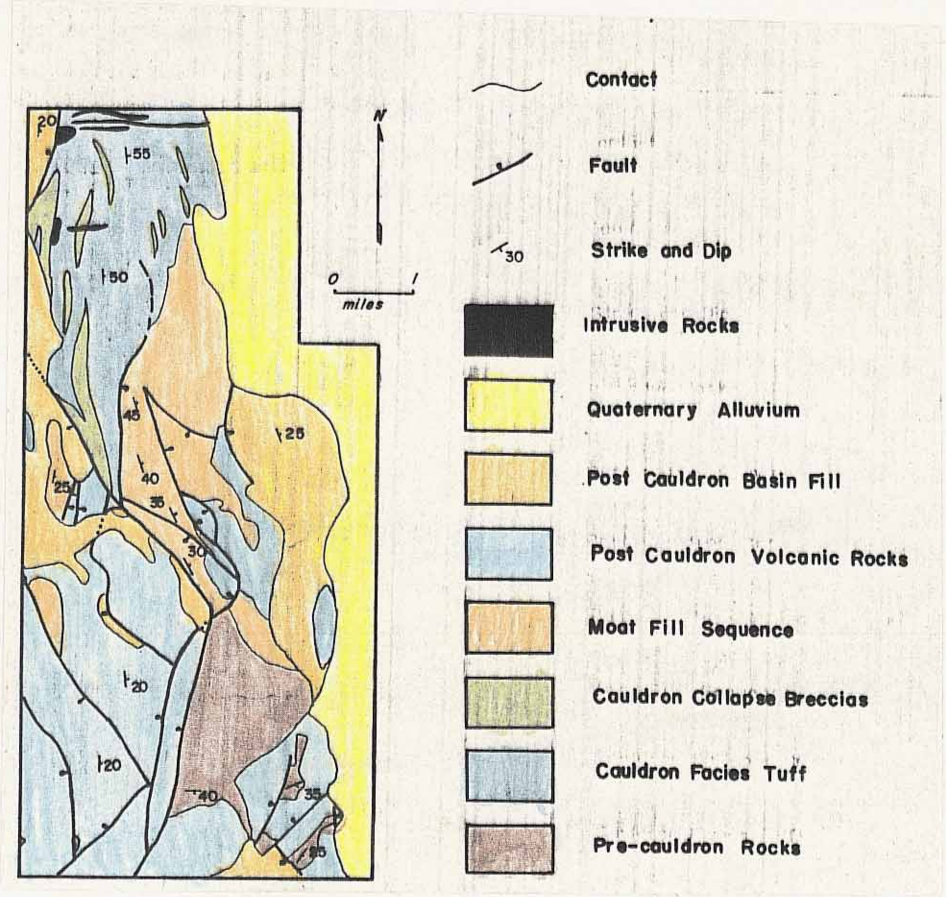


Figure 24. Chupadera Mountains showing the cauldron related rocks.

from the topographic wall of the cauldron (Lipman, 1976; this study) during the collapse of the cauldron. These breccias are very coarse, heterolithic deposits consisting of clasts of lithologies that are older than the enclosing Hells Mesa Tuff. Several thousand feet of cauldron-facies tuff is exposed in the northern one-half of the study area. That thickness suggests an even greater amount of collapse because the tuff compacted as it welded. The location of the ring fracture zone along which the cauldron block subsided is not exposed in the study area; however the location of the rhyolite domes in the Luis Lopez Formation suggests that the zone is near Nogal Canyon and the geometry of the Luis Lopez Formation suggests that the ring fracture zone parallels Nogal Canyon.

The topographic rim of the cauldron is just north of Chupadera Peak. It is not possible to locate it precicely, but it is within about 0.5 mi (0.8 km) of the peak. Between the topographic rim and the ring fracture zone is an area known as the topographic wall of the cauldron. In the Socorro cauldron, this wall is located in the northern part of the Cienega Ranch (Figure 25). This feature is an erosional unconformity cut into the pre-Tertiary and Datil Group rocks. Above this unconformity are heterolithic mudflow deposits, conglomerates, sandstones, and mudstones that contain lithologies obviously derived from the underlying rocks. A tuff near the base of the wall (Tztl) probably correlates with the Hells Mesa Tuff which suggests

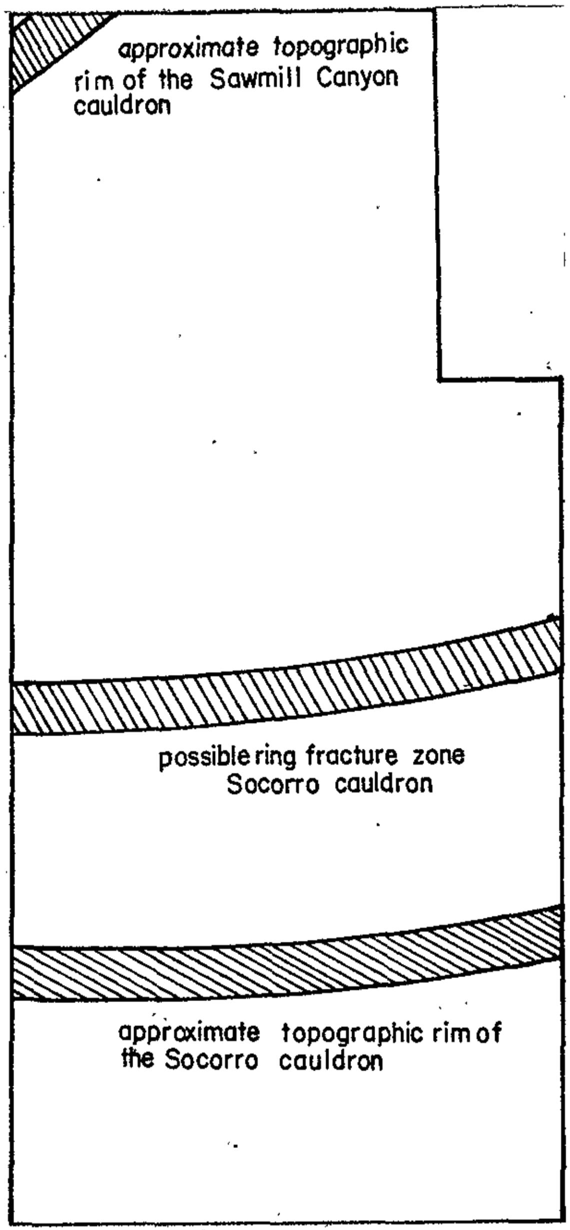


Figure 25. Approximate locations of major cauldron features in the central Chupadera Mountains relative to the study area.

that the Hells Mesa was deposited on a bench cut into the topographic wall of the cauldron (Figure 30).

SLUMP AND LANDSLIDE FEATURES

The basalt flows intercalated in the upper Santa Fe gravels frequently show offsets that are interpreted as slump features. The stratigraphic separation is usually a few feet to tens of feet and the block that moved may exhibit very different attitudes than the "parent" outcrop. Toreva blocks are uncommon as sliding is more common than slumping.

CAULDRON DEVELOPMENT

The Socorro cauldron is a well-defined, probably resurgent, cauldron of mid-Oligocene age. The cauldron is about 15 mi (25 km) in diameter and is the source of the Hells Mesa Tuff (Figure 23). Exposures in the Chupadera Mountains allow us to document the evolution of the cauldron from shortly after it began to collapse until it was completely filled by younger ash-flow tuffs. To document the cauldron, is is first necessary to investigate the geologic history immediately preceding the eruption of the Hells Mesa Tuff.

The Laramide orogeny of Late Cretaceous-Early Tertiary age uplifted a long, linear mountain belt which would have included all of the present day Chupadera Mountains. This uplift, Cather's (1980) Sierra-Sandia uplift (after Eardly, 1962), produced detritus that filled several basins flanking this highland (Cather, 1980). That the Chupadera Mountains were part of that highland has been postulated by Osburn (1981, oral comm.) and by this study.

The Datil Group was deposited in early Oligocene time and is a basal, andesitic volcaniclastic apron such as are commonly found beneath ash-flow tuff fields (Chapin and others, 1978, Chapin, 1980, oral comm.). The Datil Group was deposited on a regional erosion surface (Epis and

Chapin, 1975) that generally had low relief, but locally had highlands remaining from the Laramide orogeny. The Chupadera Peak area was one such high. The Datil Group pinches out on Chupadera Peak, suggesting local relief of several hundred feet. (The Datil Group is more than 1500 ft (457 m) thick (Chapin and others, 1978) and if the upper Datil tuff correlates with the tuff of Datil Well, the upper part of the Datil Group is exposed. This makes it difficult to argue that erosion prior to the eruption of the Hells Mesa Tuff reduced the Datil Group to a thin remnant of the original thickness. An added note is that the Paleozoic section on Chupadera Peak has relief of 200 to 300 ft (61 to 91 m) recorded on the unconformity with the overlying Datil Group.

The eruption of the Hells Mesa Tuff ended the deposition of the Datil Group , but the events immediately prior to the eruption are not clear. Smith and Bailey (1968) postulate that regional tumnescence precedes ash-flow tuff eruptions (Figure 26). Ross and Smith (1960) and Smith and Bailey (1968) further postulate that ash-flow tuffs erupt from circular fissure vents (ring fractures) above the magma chamber. The cauldron is then formed as a circular block, the cauldron block, subsides into the evacuating magma chamber (Figure 27).

The record of the eruption of the Hells Mesa Tuff and the subsidence of the Socorro cauldron begins shortly after subsidence began (Figure 28). At this point, the cauldron block has dropped an unknown distance and cauldron collapse breccias (Lipman, 1976) began to form. As the cauldron block dropped farther, more collapse breccias were formed and were enveloped by the ash-flow tuff that was simultaneously erupting (Figure 29). At this point, a significant depression had formed. It was only partially filled with cauldron facies tuff and cauldron collapse breccias. As the cauldron facies tuff is deposited, it compacts and welds, substantially reducing the volume within the cauldron. Near the end of the eruption, cauldron collapse breccias were formed, but they were not as voluminous as those lower in the cauldron (Figure 30). Interbedded air-fall and ash-flow tuffs, as well as co-ignimbrite, lag-fall deposits (Wright and Walker, 1977) were deposited on top of the cauldron facies Hells Mesa (Chamberlin, 1980; this study). These deposits suggest that the waning stages of volcanism were intermittent, explosive eruptions. the magma lacked sufficient gas pressure for continuous eruption and the magma chamber was periodically repressurized as a result of blockage of the vent by unvesiculated magma. This unvesiculated magma was explosively removed from the vent and was included in the resulting tuffs as large blocks (the co-ignimbrite, lag-fall deposits). Field evidence suggests that a bench was formed on the topographic wall of the cauldron and the bench was partially covered by the cauldron facies tuff (Figure 30).

It is interesting to note that no outflow facies tuff is found in the Chupadera Mountains (Osburn, 1981, oral comm.; this study). This suggests that the area was high during the eruption and that no Hells Mesa Tuff was deposited on that highland or, if it was, it was quickly eroded.

Since the cauldron was not completely filled by the cauldron facies tuff and cauldron collapse breccias, it immediately began to fill with clastic sediments, local ash-flow tuffs, and lava domes and flows. This cauldron fill is collectively called the Luis Lopez Formation (Chamberlin, 1980, this study). It has ten members, each of which will be discussed briefly in chronological sequence.

The Socorro cauldron began to resurge, forming a moat, soon after the end of the eruption of the Hells Mesa Tuff. The lower sedimentary member of the Luis Lopez Formation was deposited in the moat as the moat formed. (Figure 31). The lower sedimentary member of the Luis Lopez Formation has been divided into a southern and northern facies. The southern facies was derived from the topographic wall of the cauldron. This facies consists of conglomerates, sandstones, mudflow deposits, and minor mudstones. The mudflow deposits and coarse conglomerates are low in the section and suggest a high energy environment and rapid deposition. The finer-grained sedimentary rocks higher in the section suggest that slopes became more gentle as the basin filled. The northern facies interfingers with the southern facies and is composed of crystal-rich, tuffaceous sandstones and mudstones which were probably derived from the poorly welded top of the cauldron-facies Hells Mesa Tuff. Several coarse conglomerates near the top of the northern facies suggest that the cauldron was beginning to resurge. These conglomerates are the only evidence found in the Chupadera Mountains that the Socorro Cauldron did, in fact, resurge. A crystal rich, poorly welded tuff (lower tuff member of the Luis Lopez Formation) is exposed at the base of the sedimentary member of the Luis Lopez Formation. The phenocryst content and mineral ratios (Appendix 2) suggest that this tuff is correlative with the Hells Mesa Tuff and was probably deposited on a bench formed by the retreat of the cauldron walls during the waning stages of the Hells Mesa eruption.

The lower lava member is a thick andesitic lava that was deposited prior to most of the resurgence of the cauldron (Figure 32). The lateral and temporal equivalent of the lower lava member is the lower basalt member which overlies and locally interfingers with the lower sedimentary member (Figure 33). The basalt member of the Luis Lopez Formation is overlain by the middle tuff member of the Luis Lopez Formation (Figure 34). The middle tuff member is composed of interbedded ash-flow tuffs, mudflow deposits, and minor clastic sediments. This member pinches out near the topographic wall of the cauldron and appears to be pinching out on the lower lava member to the north. The source of these deposits is unknown, but since these tuffs appear to be equivalent to Chamberlin's (1980) tuffs to the north of this study area, the source may be in that area or in a portion of the cauldron that is not exposed. The middle sedimentary member overlies the middle tuff member of the Luis Lopez Formation and consists of coarse clastic sedimentary rocks and minor andesite lavas. The clastic material is dominantly andesitic, the source of which is unknown (This unit is not shown on the schematics as it is only 15 to 50 ft (5 to 15 m). The middle lava member is a thick rhyolite dome and flow complex overlying the the middle sedimentary member (Figure 35). The complex is centered near Nogal Canyon (Plate 1) and may be the surface manifestation of the ring fracture zone.

A minor rhyolite dome (the upper lava member) was emplaced on the top of the middle lava member (Figure 36). A thin tuff (upper tuff member) and a thin, discontinuous sedimentary rock interval (upper sedimentary member) record a period of erosion and explosive volcanism that preceded the dome building episode. This dome building episode (the upper lava member of the Luis Lopez Formation) is the last volcanic activity directly associated with the Socorro cauldron in the central Chupadera Mountains.

Figure 37 depicts the last stage of the moat filling. The La Jencia Tuff was erupted from the Sawmill Canyon and the Magdalena cauldrons in the Magdalena Mountains and filled the last vestige of the moat of the Socorro cauldron. The La Jencia Tuff and the overlying Lemitar Tuff both pinch out against the dome and flow complex of the middle and the upper lava members of the Luis Lopez Formation.

G.R. Osburn (1981, oral comm.) noted that no lacustrine sedimentary rocks are present in the Luis Lopez Formation. This suggests that the moat was breached. Figure 17 shows a possible location of that breach, but there are other possible locations as most of the Socorro cauldron is covered by younger volcanic and sedimentary rocks.

Figures 26 to 38 portray the evolution of the Socorro Cauldron from its postulated beginnings to the end of cauldron related volcanism and until it was covered by younger volcanic rocks. These figures are schematic and show the various units and processes in a relative way only. The various events are portrayed in chronologic order and a few of the minor units are omitted for clarity. due to the lack of information on the early history of the cauldron , Figures 26 and 27 are after Smith and Bailey (1968). Also note that there is no time scale in this sequence as few absolute ages can be determined. Note that the symbols used on these figures corresponds to those used in Figure 4 and on Plate 1.

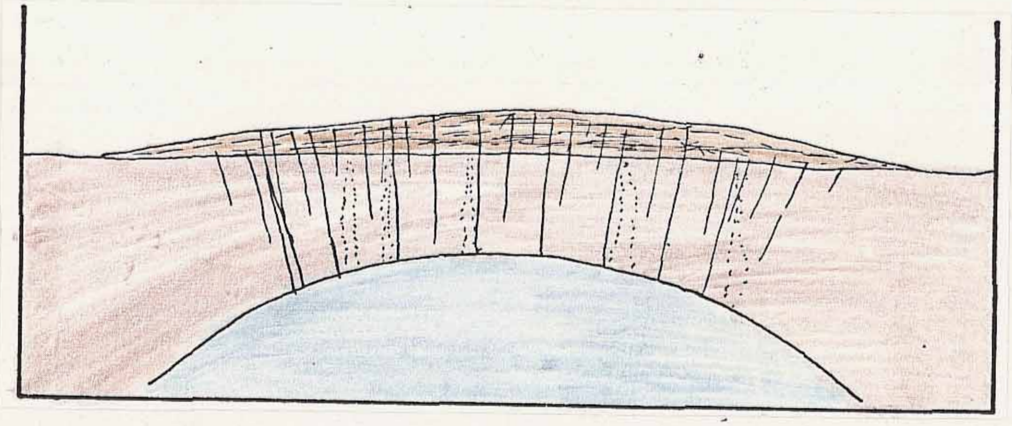


Figure 26. Regional tumnescence and fracturing over a magma chamber prior to a major ash-flow tuff eruption (after Smith and Bailey, 1968).

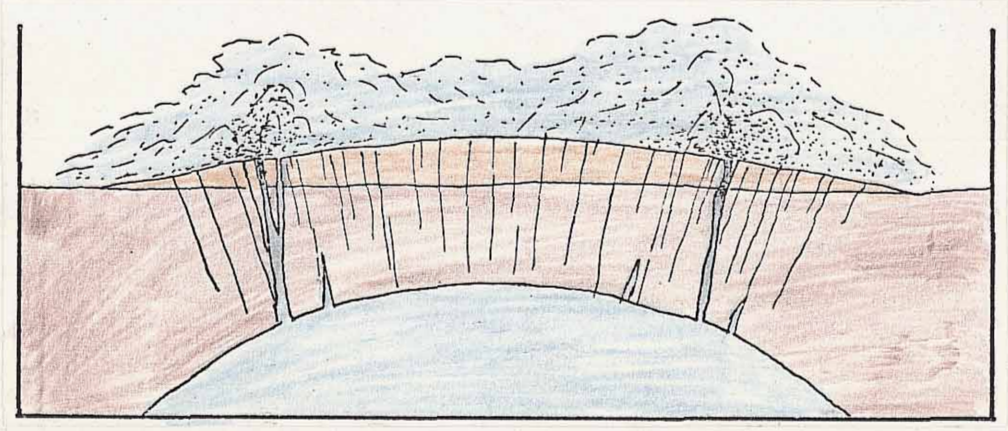


Figure 27. Ring fracture zones open and the ash-flow tuff eruption begins. The cauldron block will begin to subside at this point (after Smith and Bailey, 1968).

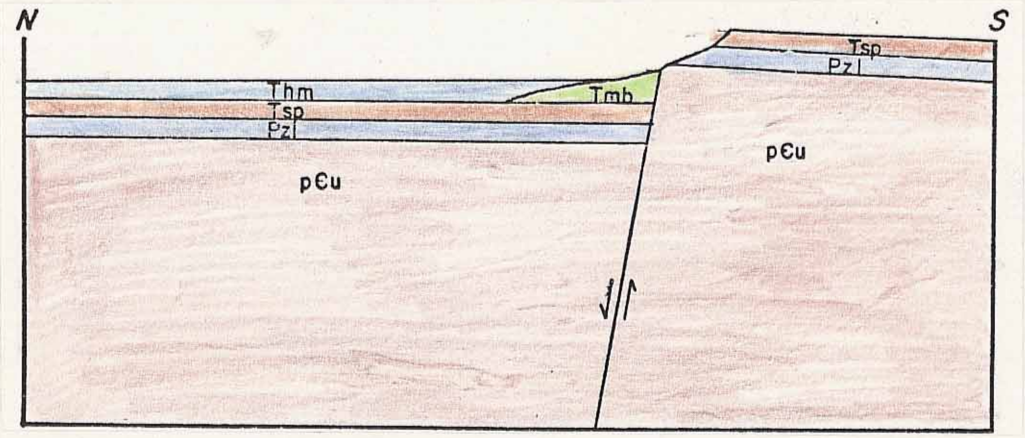


Figure 28. As the eruption continues, cauldron facies tuff (Thm) is deposited and cauldron collapse breccias (Tmb) begin to form.

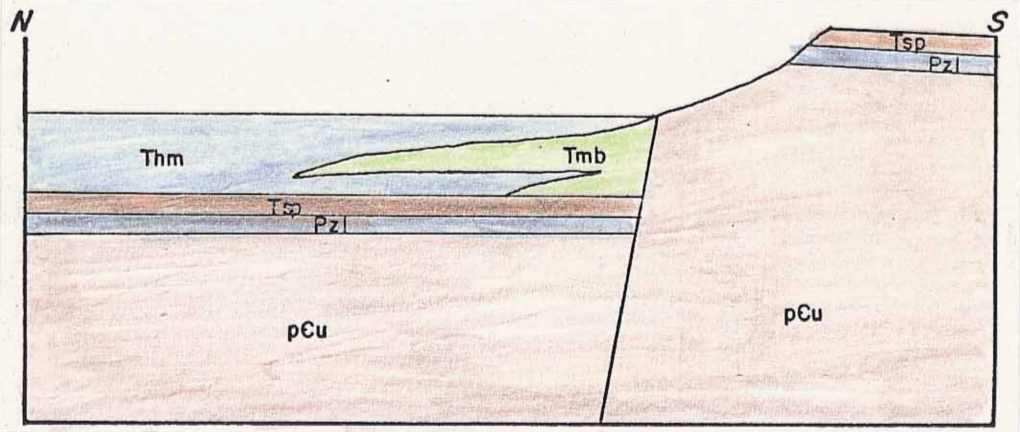


Figure 29. At approximately the midpoint of the eruption, the cauldron contains abundant cauldron facies tuff and cauldron collapse breccias. Note that the cauldron wall has Retreated a considerable distance from its original position.

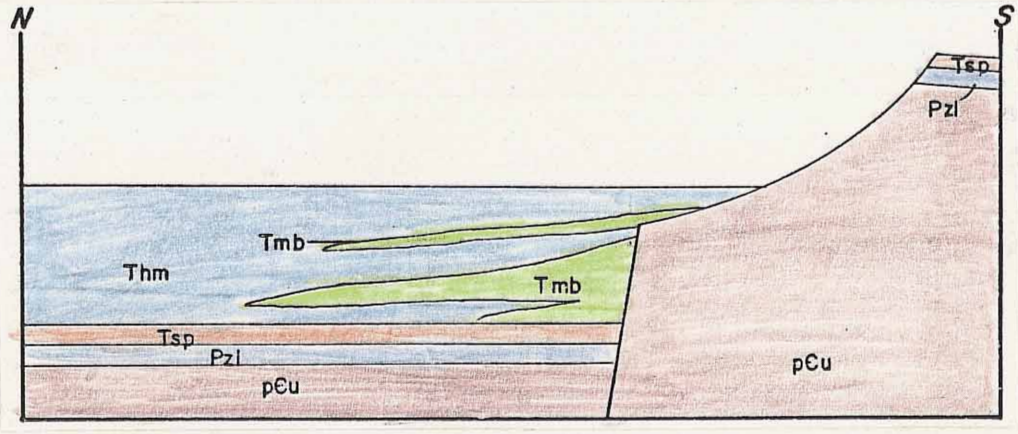


Figure 30. Hypothetical cross section of the Socorro cauldron at the end of the Hells Mesa Tuff eruption. Note the relatively gentle slope of the cauldron wall.

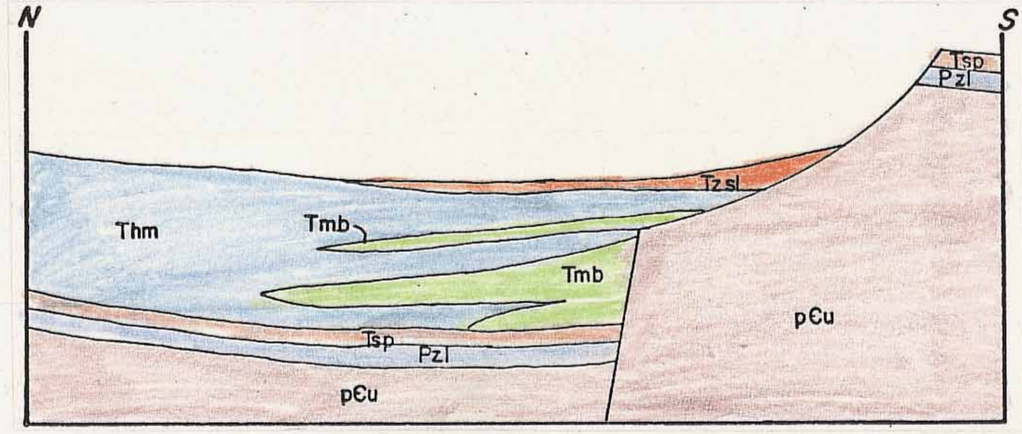


Figure 31. The Socorro cauldron begins to resurge and the lower sedimentary member of the Luis Lopez Formation is deposited. The southern facies was derived from the topographic wall of the cauldron and the northern facies was derived from the resurgent dome of the cauldron.

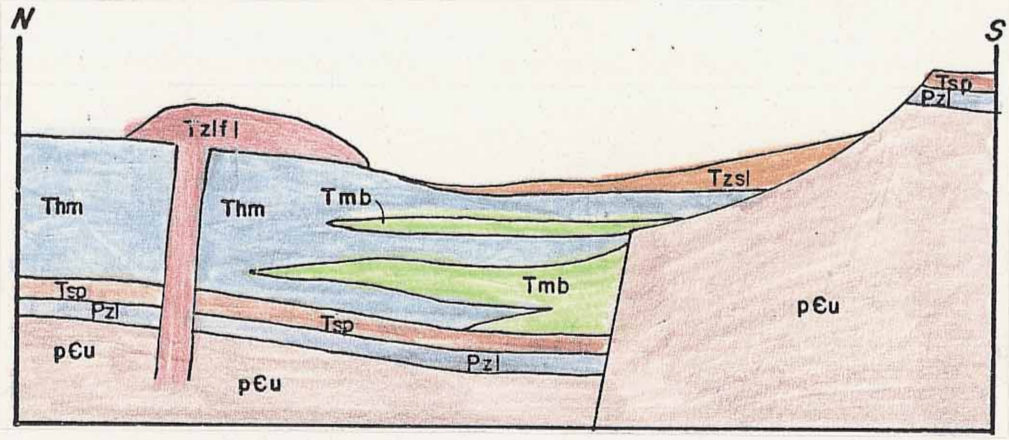


Figure 32. Resurgence has stopped, but sedimentation and volcanism continue with continued deposition of the Lower sedimentary member and extrusion of the lower lava member of the Luis Lopez Formation.

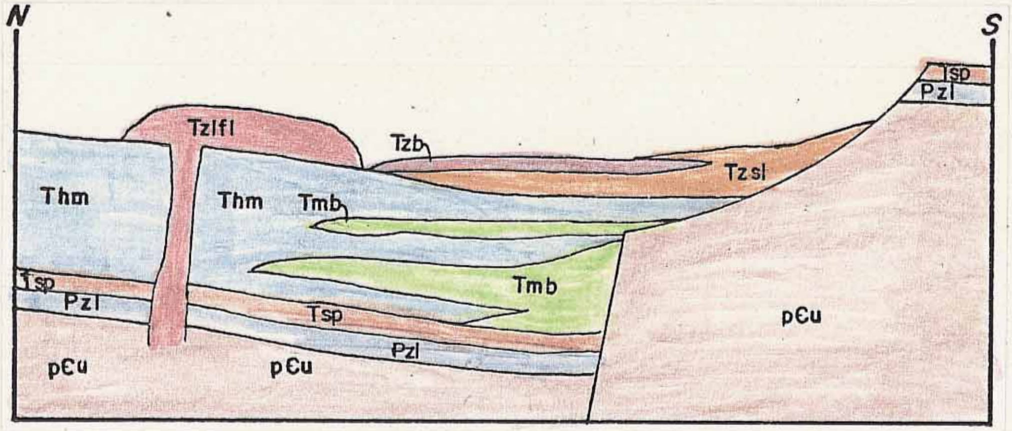


Figure 33. The basalt member of the Luis Lopez Formation is deposited and interfingers with the lower sedimentary member near the southern edge of the cauldron.

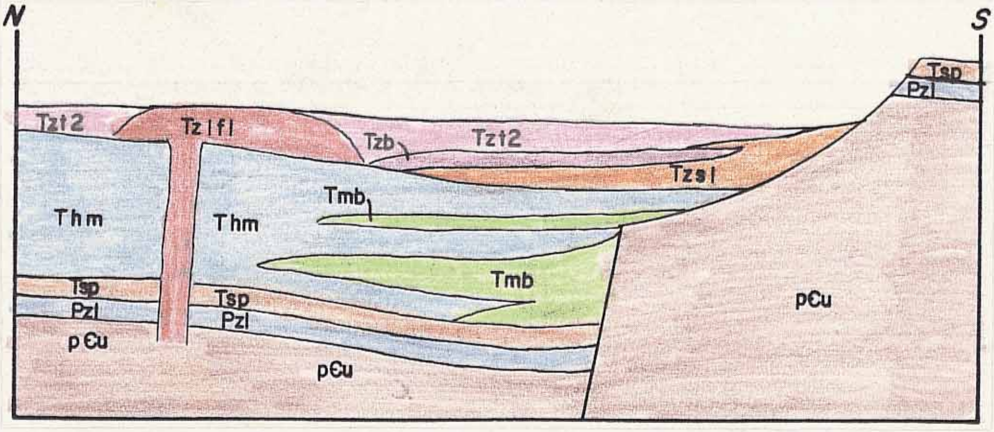


Figure 34. The deposition of the lower sedimentary member was terminated by the deposition of the middle tuff member of the Luis Lopez Formation. The source of this tuff is unknown.

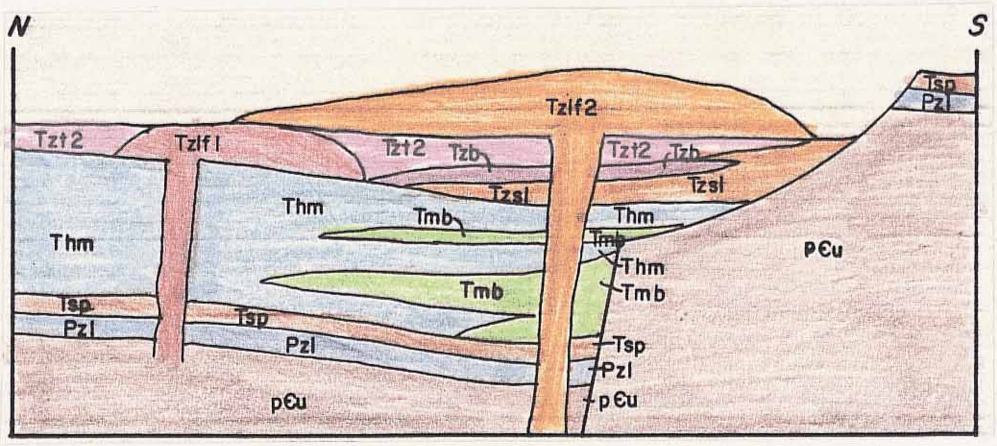


Figure 35. The middle lava member of the Luis Lopez Formation forms a thick dome and short, stubby flows.

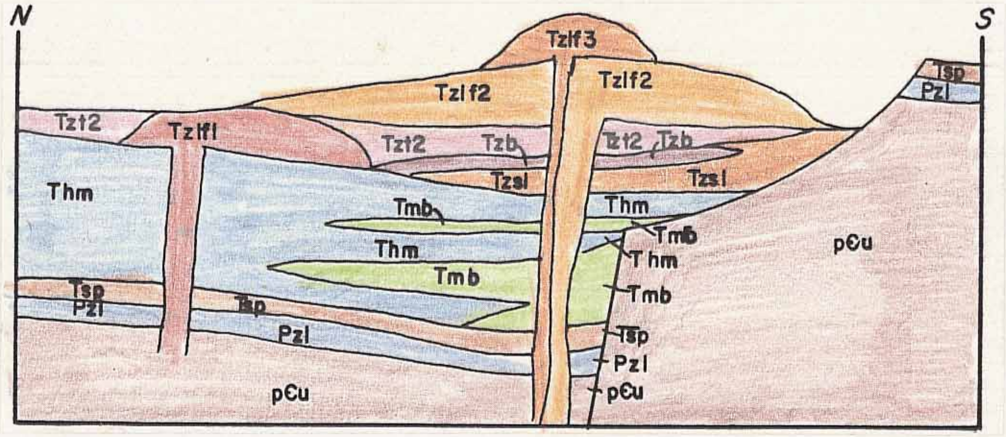


Figure 36. The upper lava member of the Luis Lopez Formation is a rhyolite dome emplaced on the middle lava member. This eruption was preceded by a period of explosive volcanism.

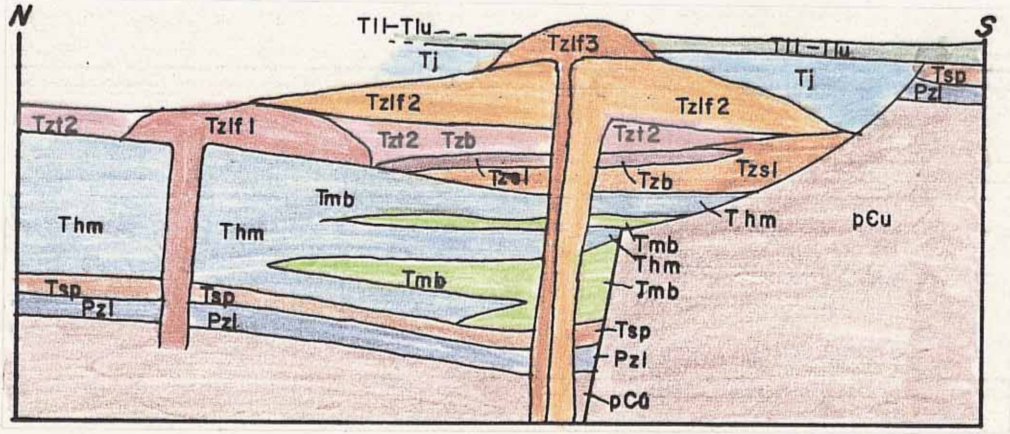


Figure 37. The cauldron is finaly filled by the La Jencia Tuff, a 30 m.y. old major ash-flow tuff that is as much as 1,700 ft (518 m) thick. the La Jencia Tuff is overlain by the Lemitar Tuff and both tuffs pinch out against the domes formed by the upper and middle lava members of the Luis Lopez Formation.

ECONOMIC GEOLOGY AND ALTERATION

ECONOMIC GEOLOGY

The economic potential of the central Chupadera Mountains is discussed in two sections; metals and industrial materials. The metallic deposits include manganese and copper; the industrial materials include perlite, sand and gravel, and riprap material.

Metals

The manganese deposits in this study area are part of the Luis Lopez manganese district. Plate 2 shows most of the manganese occurrences in the study area. The greatest density of manganese occurrences is north of the MCA mine. A decrease in the number of manganese occurrences is noticeable between the MCA mine and Nogal Canyon. South of Nogal Canyon, little manganese occurs. The controls of manganese distribution are not understood and were not investigated in this study.

The descriptions of the manganese deposits presented here are the result of cursory investigations; for more details, the reader is referred to the work of Jicha (1956) and Miesch (1956). Additional information is available in Willard (1971) and in an unpublished manuscript that M.E. Willard was preparing at the time of his death in 1972.

The manganese deposits consist of various oxides of manganese in veins and breccia fillings (Figure 38). The veins are generally less than 6 in. (15 cm) wide and are rare in the study area. M.E. Willard (unpub. data) found that some of the manganese occurrences contain as much as 3.3 ppm silver, 20 percent lead, 19 percent zinc, 0.13 percent copper, 0.7 percent cobalt, 0.2 percent molybdenum, 1.7 percent tungsten, and 0.02 troy oz/ton gold. These values, however, are not common and during the course of this study, only manganese minerals were seen. The common mode of occurrence is as breccia fillings with accompanying white and black calcite. The breccias are as much as several tens of feet wide and may extend for several hundred feet along strike. The breccias vary from very fine to very coarse breccias and many of the coarse breccias have abundant open spaces (Figure 39). Many of these breccias have been re-brecciated so that manganese oxides occur as breccia fragments in breccias cemented by calcite. The structures that formed the breccias are usually faults and shear zones that show little displacement. The larger structures are generally unmineralized; small structures seem to have brecciated more intensely than the larger structures. At the MCA mine, this generalization may not hold true. No displacement can be shown on the structures at the MCA mine, but north of the mine, the fault appears to have at least a few hundred feet of displacement. The other exception to the above generalization is the quartz vein in

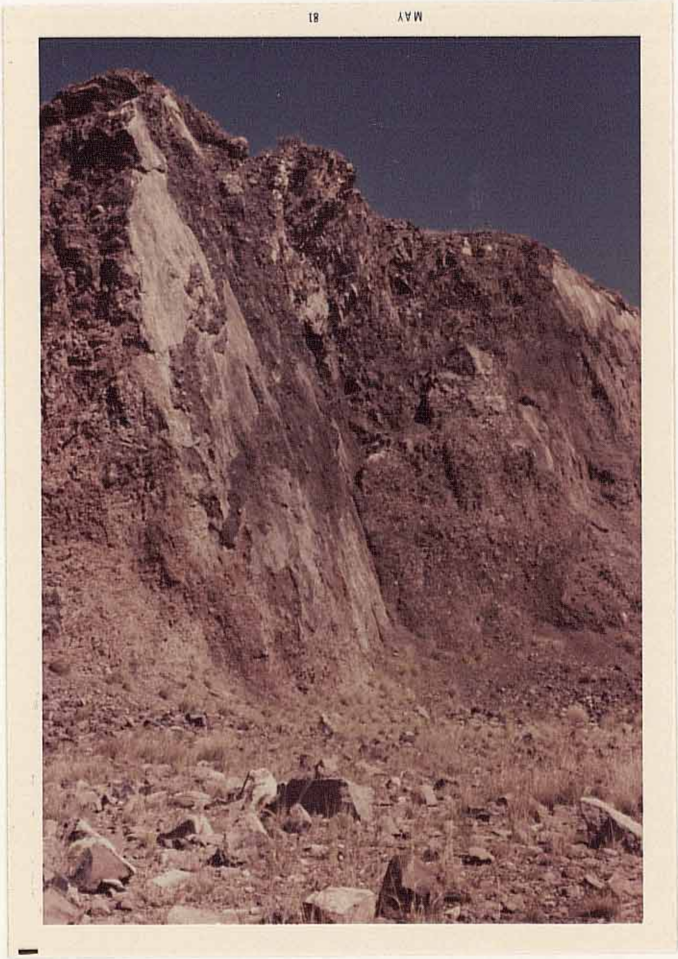


Figure 38. Brecciation in the MCA Mine.

Figure 39. Breccia manganese ore with open space from the MCA mine. This ore is typical of that in the southern Luis Lopez district.

NW 1/4, sec.31, T.4 S., R.1 W. This quartz vein has a strike length of several thousand feet and is as much as 30 ft (9 m) wide. It consists of white to black microcrystalline quartz with various amounts of white and black calcite and manganese oxides. The quartz vein clearly predates the manganese mineralization and probably predates most, if not all, of the associated calcite. This vein is filling a down-to-the-east normal fault that is presently dipping to the west at 60 to 80 degrees. This gives the appearance of a reverse fault, but the fault has actually been rotated from a near-vertical, easterly, dip as a result of domino style extension in the area.

The MCA mine consists of three large open pit workings (Figure 40) and several smaller cuts; it appears to be the only mine in the study area to have had significant production. Minor production may have come from several workings to the south and west of the MCA.

Minor copper showings are present in the Precambrian rocks in the southern one-third of the study area. These occurrences were briefly visited and little is known of them. The copper occurs as copper carbonates and minor sulfides filling fractures. The reader is referred to the mapping done by S. Kent (New Mexico Bureau of Mines and Mineral Open-file map) for more detail on the geology of the area and the location of the occurrences.

Figure 40. View of the main pit at the MCA mine. Note the slickensided fault surfaces.

Industrial materials

Perlite is common in the study area and is generally found in the middle and upper lava members of the Luis Lopez Formation. Plate 2 shows the perlite occurrences that have been explored with bulldozer trenches. The perlite was found to have too many impurities in the form of spherulites and phenocrysts to be economic at this time (C.T. Smith, 1981, oral comm.).

The sand, gravel, and riprap material come from alluvial deposits and from mine dumps in the area.

ALTERATION

Most of the units in the study area have been affected by local alteration. Much of this alteration is at the base and top of units and is probably deuteric alteration in lavas and vapor-phase alteration in tuffs. These types of alteration are characterized by local bleaching and/or silicification of the affected rocks. Since this alteration type is local, it will not be described further.

Osburn (1978) and Chapin and others (1978, 1980) describe a regional potassium metasomatism that is very widespread in the Socorro area and affects all the units in the region. D'Andrea (1981) studied the potassium metasomatism of the ash-flow tuffs and the mafic flows in the Socorro area and found the following geochemical trends.

First, the tuffs and mafic flows show an increase of K_2O and Rb and a decrease of Na_2O and CaO. K_2O can increase from normal values of 4 to 6 percent to as much as 12 percent. Since potassium feldspar contains the most potassium of any common mineral and it only has about 16 percent potassium, it is assumed that the highly metasomatized rocks have a groundmass of nearly pure potassium feldspar (Osburn, 1981, oral comm.). Na_2O drops from normal values of 3 to 5 percent to as low as 1 percent or less, presumably the result of the destruction of plagioclase feldspar in the rock.

Secondly, the mafic flows show decreases in MgO, FeO, and Sr. These decreases may be due to the destruction of biotite and other ferromagnesian minerals in the rocks. In the metasomatized rocks, few ferromagnesian minerals are seen, but it is not known whether their destruction is due to the potassium metasomatism or to some other alteration process.

Thirdly, MnO may decrease in the crystal-poor ash-flow tuffs, but this relationship can not be positively demonstrated from the data available.

The fourth geochemical trend defined by D'Andrea is that the stronger increases and decreases of elements were seen in the crystal-rich tuffs. This trend is believed to be the result of the destruction of the plagioclase feldspar phenocrysts in these crystal-rich rocks.

The petrography of these rocks show 1) alteration of the groundmass to unidentified secondary minerals, 2) reddening of the groundmass, 3) alteration of plagioclase phenocrysts, 4) alteration of the sanidine in advanced stages of alteration, and 5) alteration of the ferromagnesian minerals (D'Andrea, 1981). The groundmass alters to unidentified minerals that stain yellow with sodium cobaltinitrite, indicating that they contain a large percentage of potassium. The alteration of the groundmass is accomplished with little effect to the texture of the rock. The reddening of the groundmass is generally a subtle effect and is not a reliable indicator of this alteration in the study area. The plagioclase phenocrysts show many stages of destruction, the most common is the replacement of the plagioclase with unidentified, chalky white clay minerals. In the most advanced stages of the alteration, however, the plagioclase may be completely destroyed and replaced by a potassium feldspar. The sanidine phenocrysts may be somewhat altered in the most advanced stages of the alteration, but they are generally stable during potassium metasomatism as are the quartz phenocrysts. In many samples, the ferromagnesian minerals are destroyed, but it is not clear that they were affected by the potassium metasomatism and not by some other type of alteration.

This alteration is regional in scale and affects much of the Magdalena and Socorro-Lemitar Mountains (Chapin and others, 1978). The southern boundary of the alteration is in the northern part of this study area, north of Nogal Canyon (D'Andrea, 1981; this study). The boundary has not been precisely defined as it appears to be a broad, irregular zone. Near the boundary, the alteration is sporadic with many altered areas apparently detached from the main altered zone.

The source of this alteration is unknown, but Chapin and others (1980) suggest that the alteration may be a response to a metamorphic core complex beneath the altered area. This core complex is suggested by the coincidence of anomalous extension (30-100 percent), domino style faulting, anomalous reddening and induration of the basin fill sediments, a drastic change in the seismic reflection character, and an aeromagnetic quiet zone (Chapin and others 1980). These data suggest a long-lived (about 10m.y.) period of crustal mobilization that may be caused by the formation of a metamorphic core complex. A similar style alteration has been described by Ratte and Steven (1967) in the San Juan Mountains of Colorado and by Agron and Bentor (1981) in the Sinai-Negev Desert. As with the Socorro potassium metasomatism, no source of the altering fluids is known.

A reddish alteration affecting only cauldron facies Hells Mesa Tuff and the included cauldron collapse breccias was mapped (Plate 1). In thin section, this alteration is manifest by destruction of biotite, partial alteration of both sanidine and plagioclase, and addition of hematite. The red color may be due to oxidation of pyrite, but the lack of pseudomorphs after pyrite does not support that idea.

The rocks affected by this alteration occur in the north west corner of the study area and are restricted to the cauldron-facies Hells Mesa Tuff and cauldron collapse breccias included in it. The alteration imparts a reddish hue to the rocks that varies from pale pink to bright red. The outline of the altered area is elongate north-south, parallel to the strike direction of the tuff in this area. The north-south axis is about 3 mi (5 km) long and the east-west axis is as much as 1.25 mi (2 km) long. The contact of the altered with the unaltered rock is generally gradational over a few feet to a few tens of feet, but may locally be sharp.

Two intrusives are found near the red altered area, but appear to be unrelated to the red alteration. The alteration appears to postdate the intrusives, but those relations are not certain. The proximity of this alteration to the best manganese mineralization in the Luis Lopez manganese district suggests a genetic relationship. The rocks hosting the manganese veins and breccia zones, however, are generally unaltered. This lack of alteration seems to preclude any relationship between the red alteration and the manganese mineralization.

SUMMARY AND CONCLUSIONS

This study has contributed to the understanding of the geology of the northwest corner of the Datil-Mogollon volcanic field and to the understanding of cauldron evolution. These contributions are divided into Stratigraphic, Structural, Cauldron, and Economic Geology and alteration sections which are detailed below.

STRATIGRAPHY

The rocks in the study area are dominantly Tertiary volcanic and clastic sedimentary rocks with a small block of Precambrian and Paleozoic rocks exposed near Chupadera Peak. The Datil Group generally overlies the pre-Tertiary rocks and forms the basal breccia sheet for the Datil-Mogollon volcanic field. The Hells Mesa Tuff was erupted from the Socorro cauldron 33 m.y. ago and that eruption marked the end of Datil Group deposition. The end of the Hells Mesa eruption marked the beginning of deposition of the lower sedimentary member of the Luis Lopez Formation, the moat fill sequence in the Socorro cauldron. At about the same time, the resurgent dome of the cauldron began to form and continued until the eruption of the basalt and lower lava members of the Luis Lopez Formation. The bulk of the Luis Lopez Formation was erupted after the end of resurgence and nearly filled the moat. The moat was finally filled and the Socorro cauldron covered by the La Jencia Tuff 30 m.y. ago.

Following the La Jencia Tuff were the Lemitar Tuff and the South Canyon Tuff. The deposition of the upper Santa Fe Group with its intercalated basalt flows mark the end of the Tertiary history in the Chupadera Mountains. Events and processes of special note are as follows.

1) The Datil Group nearly pinches out on Chupadera Peak. That information suggests that the Precambrian and Paleozoic rocks formed a highland in the Oligocene. Evidence suggests that the highland was formed during the Laramide orogeny since the Eocene Baca Formation in the north end of the Jornada Del Muerto contains clasts that are similar to the pre-Tertiary lithologies found in the Chupadera Mountains. Transport directions are consistent with the interpretation that the clasts were derived from the Chupadera Mountains.

2) Cauldron collapse breccias are common in the cauldron-facies Hells Mesa Tuff. These breccias formed as the topographic wall of the cauldron retreated. The processes involved in the formation of these breccias are believed to be mudflows, debris flows, and rock avalanches. The terminology of Lipman (1976) was not applicable to the breccias in the Socorro cauldron. Since the the breccias form during the eruption of the ash-flow tuff, they are mixed with the tuff and frequently, it is impossible to distinguish between lithic-rich ash-flow tuff and tuff-rich breccias. No entirely satisfactory criteria were

established to distinguish between those rock types.

3) The Hells Mesa Tuff rather than the Lemitar tuff (Chamberlin, 1980) was erupted from the Socorro cauldron. This conclusion is based on the stratigraphy of the area. The outflow-facies Lemitar Tuff overlies the La Jencia Tuff which overlies the Luis Lopez Formation which is the moat-fill for the Socorro cauldron which, therefore, cannot be the source of the Lemitar Tuff. This re-interpretation makes it necessary to clarify the name of the moat fill units of the Socorro cauldron. Bowring (1980) called the equivalent unit the unit of Hardy Ridge and Chamberlin (1980) called it the Luis Lopez Formation. This study has adopted the terminology of Chamberlin and recommends the name Luis Lopez Formation. The name is derived from the Luis Lopez manganese district, located in the northern Chupadera Mountains, a few miles west of the town of Luis Lopez.

4) The Luis Lopez Formation is a sequence of interbedded ash-flow tuffs, lava flows and domes, and clastic sedimentary rocks with a composite thickness of over 4000 ft (1200 m). This unit is the moat-fill unit of the Socorro cauldron and in this study area consists of 10 members; 3 ash-flow tuffs, 3 clastic sedimentary rock units, 2 rhyolite dome and flow units, 1 andesite flow unit, and one basalt flow unit. The Luis Lopez Formation laps onto both the topographic wall and the resurgent dome of the

cauldron.

5) The La Jencia Tuff is locally more than 1,700 ft (518 m) thick in the southern Chupadera Mountains. The thickness of the unit was controlled, during deposition, by topography. A generalized picture of the topography can be obtained by careful mapping of the primary and secondary flow structures.

STRUCTURE

The Tertiary rocks in the Chupadera Mountains generally dip easterly at 10 to 80 degrees. The dip decreases from north to south within the study area and this change is attributed to a southerly decrease in the amount of extension in the area. The steeply dipping northern half of the area has undergone domino style faulting similar to the faulting described just north of this area by Chamberlin (1980). Two groups of down-to-the-west normal faults were defined, one group dips 30 to 60 degrees, the other group dips at 60 to 90 degrees. These groups suggest two periods of faulting, the first of which was during Chamberlin's (1980) early period of extension. The second period would be in one of Chamberlin's (1980) later periods of extension and would have rotated the earlier fault planes.

Down-to-the-east faults show the same age relations as the down-to-the-west faults described above. Locally grabens are formed when young faults with opposing senses of motion are near each other. Locally, drag folds are found along the normal faults in the area.

CAULDRON EVOLUTION

A portion of the topographic wall of the Socorro cauldron is exposed in the study area. That wall marks the southern limit of the Luis Lopez Formation, the moat-fill unit of the Socorro cauldron. The Luis Lopez Formation records the post eruptive history of the Socorro cauldron. A portion of the eruptive history of the cauldron is recorded in the cauldron-facies Hells Mesa Tuff and in the intercalated cauldron collapse-breccias. The cauldron collapse breccias were formed during the eruption by mud and debris flows and by rock avalanches. At the end of the eruption, the lower sedimentary member of the Luis Lopez Formation was deposited. The cauldron resurgence occurred at this time and no evidence of resurgence was found that postdated the lower sedimentary member. The other members of the Luis Lopez Formation record the volcanic and sedimentary history of the moat of the Socorro cauldron. The cauldron was finally filled by the La Jencia Tuff, a major ash-flow sheet.

ECONOMIC GEOLOGY AND ALTERATION

The economic potential of the central Chupadera Mountains is restricted to metals associated with the manganese veins and industrial materials. Silver, lead, and tungsten are sometimes associated with the veins (M.E. Willard, unpublished data) and represent an interesting exploration target. Industrial materials, such as sand and gravel, are currently being produced from the mine tailings in the area. The copper shows in the Precambrian rocks in the southern half of the area have very limited potential as does the perlite which has too many phenocrysts and spherulites to be economic.

Two types of hydrothermal alteration were distinguished in the study area; a regional potassium metasomatism and a local alteration manifest by reddening of the affected rock and by the destruction of the biotite. Both alteration types affect the northern portion of the area. The potassium metasomatism is sporadic, but the other alteration is pervasive. The source of the fluids for both types of alteration is unknown.

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APPENDIX 1

Appendix 1 contains point-count data from 45 thin sections from within the central Chupadera Mountains. Point counting was done on a Zeiss binocular microscope fitted with a Swift automatic point counter. The minerals counted are quartz (Q), sanidine (S), plagioclase (P), biotite (B), hornblende (H), pyroxene (Py), sphene (Sp), zircon (Z), and opaque minerals (O). The ratio presents the number of points counted over the percentage of mineral in the rock. That percentage is arrived at by dividing the number of points of the mineral counted over the total number of points (usually 2000). The sum of the reported percentages is not 100 as a percentage was not calculated for the groundmass. The dashes indicate that the mineral was not seen in that thin section and "tr" indicates that the mineral was seen in the thin section, but no points were counted for that mineral.

The unit designations are those used for the geologic map (Plate 1) and the sample numbers refer to the number of the thin section on file at the New Mexico Bureau of Mines and Mineral Resources.

Unit	Sample Number	Q	S	P	B	H	Py	Sp	Z	O	Total Points
Tdt2	8-6-2	---	375 18.75	---	11 0.55	tr	---	---	tr	tr	2000
Tdt2	1-9-7	---	366 18.3	---	8 0.4	---	---	---	tr	11 0.55	2000
Thm	11-10-5	177 8.75	427 21.35	231 11.55	18 0.9	---	---	---	---	16 0.8	2000
Thm	10-6-2	294 14.7	359 17.95	206 10.3	29 1.45	---	---	3 0.15	---	14 0.7	2000
Thm	10-6-6	210 10.5	340 17	180 9	20 1	---	---	tr	tr	9 0.45	2000
Thmpw	10-6-3	32 1.6	128 6.4	62 3.1	13 0.65	---	---	tr	tr	5 0.25	2000
Thmpw	10-6-4	27 1.35	259 12.95	60 3	16 0.8	---	---	tr	tr	4 0.2	2000
Tzt1	6-26-1	155 7.75	249 12.45	5 0.25	43 2.15	---	---	---	tr	9 0.45	2000
Tzt2	TE-2	38 2.6	78 5.3	53 3.6	8 0.55	---	---	---	---	6 0.4	1479
Tzt2	TE-13	2 0.1	23 1.15	4 0.2	2 0.1	---	---	---	tr	4 0.2	2000
Tzt2	TE-15	30 1.5	76 3.8	34 1.7	3 0.15	---	---	---	tr	---	2000
Tzt2	TE-32	12 0.6	38 1.9	30 1.5	2 0.1	---	---	---	---	---	2000
Tzt2	1-5-2	---	19 0.95	68 3.4	3 0.15	---	---	---	tr	---	2000

Unit	Sample Number	Q	S	P	B	H	PY	Sp	Z	O	Total Points
Tzlf2	TE-20	---	14 0.7	62 3.1	17 0.85	13 0.65	---	tr	tr	3 0.15	2000
Tzlf2	TE-39	---	15 0.75	57 2.85	12 0.6	1 0.05	---	---	tr	4 0.2	2000
Tzlf2	6-19-1	---	18 0.9	81 4.05	17 0.85	---	---	---	tr	---	2000
Tzlf2	6-20-1	---	19 0.95	43 2.15	19 0.95	6 0.3	---	---	---	1 0.05	2000
Tzlf2	6-20-2	---	34 1.7	77 3.83	9 0.45	5 0.25	---	---	tr	---	2000
Tzlf2	TE-5	---	41 2.05	72 3.6	8 0.4	5 0.25	---	---	tr	8 0.2	2000
Tzlf2	10-8-2	tr	42 2.1	15 0.75	5 0.25	tr	---	---	tr	---	2000
Tall	7-24-3	4 0.2	49 2.45	26 1.3	2 0.1	tr	---	tr	tr	---	2000
Tjl	TE-41	1 0.05	107 5.35	35 1.75	13 0.65	6 0.3	---	---	tr	1 0.05	2000
Tjl	TE-42	1 0.05	26 1.3	1 0.05	1 0.05	2 0.1	---	---	tr	---	2000
Tjl	TE-43	1 0.05	55 2.75	---	---	---	---	tr	tr	1 0.05	2000
Tjl	6-19-3	13 0.65	14 0.7	---	1 0.05	---	---	---	---	---	2000
Tjl	8-6-1	---	114 5.7	---	---	tr	---	---	---	2 0.1	2000

Unit	Sample Number	Q	S	P	B	H	Py	Sp	Z	O	Total Points
Tjl	1-9-3	---	$\frac{110}{5.5}$	---	$\frac{1}{0.05}$	---	---	tr	tr	---	2000
Tjl	1-9-4	---	$\frac{94}{4.7}$	---	---	---	---	tr	---	$\frac{3}{0.15}$	2000
Tjs	7-18-2	$\frac{4}{0.2}$	$\frac{74}{3.7}$	$\frac{5}{0.25}$	$\frac{5}{0.25}$	---	---	---	tr	$\frac{3}{0.15}$	2000
Tjs	1-13-27	$\frac{7}{0.35}$	$\frac{65}{3.25}$	tr	---	---	---	---	tr	---	2000
Tju	1-13-30	$\frac{1}{0.05}$	$\frac{4}{0.2}$	---	$\frac{1}{0.05}$	---	---	---	---	---	2000
Tju	1-13-32	$\frac{2}{0.1}$	$\frac{57}{2.75}$	---	$\frac{1}{0.05}$	---	---	---	tr	---	2000
Tll	6-23-1	$\frac{36}{1.8}$	$\frac{63}{3.15}$	$\frac{8}{0.4}$	$\frac{4}{0.2}$	---	---	---	tr	---	2000
Tll	12-22-8	$\frac{31}{1.55}$	$\frac{93}{4.65}$	$\frac{11}{0.55}$	$\frac{5}{0.25}$	---	---	---	$\frac{2}{0.1}$	---	2000
Tll	TE-45	$\frac{22}{1.1}$	$\frac{115}{5.75}$	$\frac{4}{0.2}$	$\frac{4}{0.2}$	---	---	$\frac{2}{0.1}$	tr	$\frac{2}{0.1}$	2000
Tll	TE-46	$\frac{24}{1.2}$	$\frac{117}{5.85}$	$\frac{11}{0.55}$	$\frac{5}{0.25}$	tr	---	tr	tr	---	2000
Tll	1-13-15	$\frac{45}{2.25}$	$\frac{163}{8.15}$	$\frac{13}{0.65}$	$\frac{6}{0.3}$	---	---	$\frac{2}{0.1}$	tr	$\frac{6}{0.3}$	2000
Tlu	1-13-16	$\frac{12}{0.6}$	$\frac{403}{20.15}$	$\frac{184}{9.2}$	$\frac{18}{0.9}$	---	---	---	tr	$\frac{9}{0.45}$	2000
Tlu	1-13-17	$\frac{267}{13.35}$	$\frac{435}{21.75}$	$\frac{172}{8.6}$	$\frac{43}{2.15}$	---	---	---	---	$\frac{9}{0.45}$	2000

Unit	Sample Number	Q	S	P	B	H	Py	Sp	Z	O	Total Points
Tlu	1-13-19	199 9.95	540 27	99 4.95	16 0.8	---	tr	---	---	4 0.2	2000
Tsc	TE-9	112 5.6	114 5.7	10 0.5	2 0.1	---	---	---	---	2 0.1	2000
Tsc	1-13-20	5 0.25	27 1.35	3 0.15	1 0.05	---	---	---	---	2 0.1	2000
Tir	TE-47	270 13.5	447 22.35	---	27 1.35	---	---	---	tr	7 0.35	2000
Tif	10-24-1	52 2.6	20 1	227 11.35	65 3.25	---	---	tr	---	---	2000
Tif	10-24-3	67 3.35	97 4.85	230 11.5	65 3.25	tr	---	tr	tr	---	2000

Appendix 2

Average phenocryst content and ratios of rock units in the central Chupadera Mountains. Quartz (Q), sanidine (S), plagioclase (P), and biotite (B) content is reported as percentages. Trace minerals are reported if seen in thin section (see footnotes for abbreviations). Mineral ratios (Q/S, Q/P, P/S) are aids to correlation and are dimensionless. The total phenocryst content is also an aid to correlation. Most of the data is from point counts (Appendix 1), but data from visual estimates is included for completion.

Tuffs	Q	S	P	B	Tr. Mins.	Mafic Mins.	Q/S	Q/P	P/S	Total Phenocrysts
Tdt2	---	18.5	---	0.5	Z	H,O	---	---	---	19
Thm	11.35	18.77	10.28	1.12	Z,S	O	0.6	1.1	0.55	42.02
Thmpw	1.48	9.68	3.1	0.33	Z,S	O	0.15	0.48	0.32	14.59
Tzt1	7.75	12.45	0.25	2.15	Z	O	0.6	31	0.02	23.05
Tzt2	1.2	2.78	1.75	0.2	Z	O	0.43	0.69	0.63	5.93
Tzt3*	tr	---	2	tr	---	---	---	---	---	2
Tjll	0.2	2.45	1.3	0.1	Z,S	H	0.08	0.15	0.53	4.05
Tjl	0.13	3.4	---	tr	Z,S	H,O	0.04	---	---	3.64
Tjs	0.28	2.32	tr	tr	Z	O	0.12	---	---	4.1
Tju	0.25	2.5	---	tr	Z	---	0.1	---	---	2.75
Tll[1]	1.68	3.9	0.48	0.22	Z,S	--	0.43	4.4	0.12	6.33
Tll[2]	1.52	6.58	0.47	0.25	Z,S	H,O	0.22	3.23	0.07	8.97
Tlu[3]	0.6	20.15	9.2	0.99	Z	O	0.03	0.07	0.46	31.3
Tlu[4]	11.65	24.4	6.8	1.5	---	P,O	0.48	1.7	0.3	44.6

Tuffs (cont.)	Q	S	P	B	Tr. Mins.	Mafic Mins.	Q/S	Q/P	P/S	Total Phenocrysts
Tsc[5]	0.25	1.35	0.15	tr	---	0	0.2	1.7	0.1	1.75
Tsc[6]	5.6	5.7	0.5	tr	---	0	0.98	11.2	0.09	11.8
Lavas										
Tzlf1*	tr	---	4	tr	Z,S	5%P	---	---	---	5-9
Tzlf2	---	1.2	3.3	0.68	Z,S	H,O	---	---	2.75	5.4
Tzlf3*	---	1	2	tr	Z,S	0	---	---	2	3
Intrusives										
Tif	2.98	2.93	11.43	3.25	Z,S	H	1	0.26	3.9	20.6
Tir	13.5	22	tr	1.35	Z	0	0.6	---	---	37.2
Tix	---	---	---	---	---	---	---	---	---	0

---

* Visual estimates
1 Poorly welded base
2 Densely welded top
3 Quartz-poor zone
4 Quartz-rich zone

5 Poorly welded base
6 Densely welded top
Z Zircon
S Sphene
H Hornblende

O Opaque minerals
P Pyroxene
tr Trace amounts only
--- mineral not noted
or ratio not real

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

Adviser

Clay T. Smith

Allan R. Sanford

4/1/82

Date

F 141

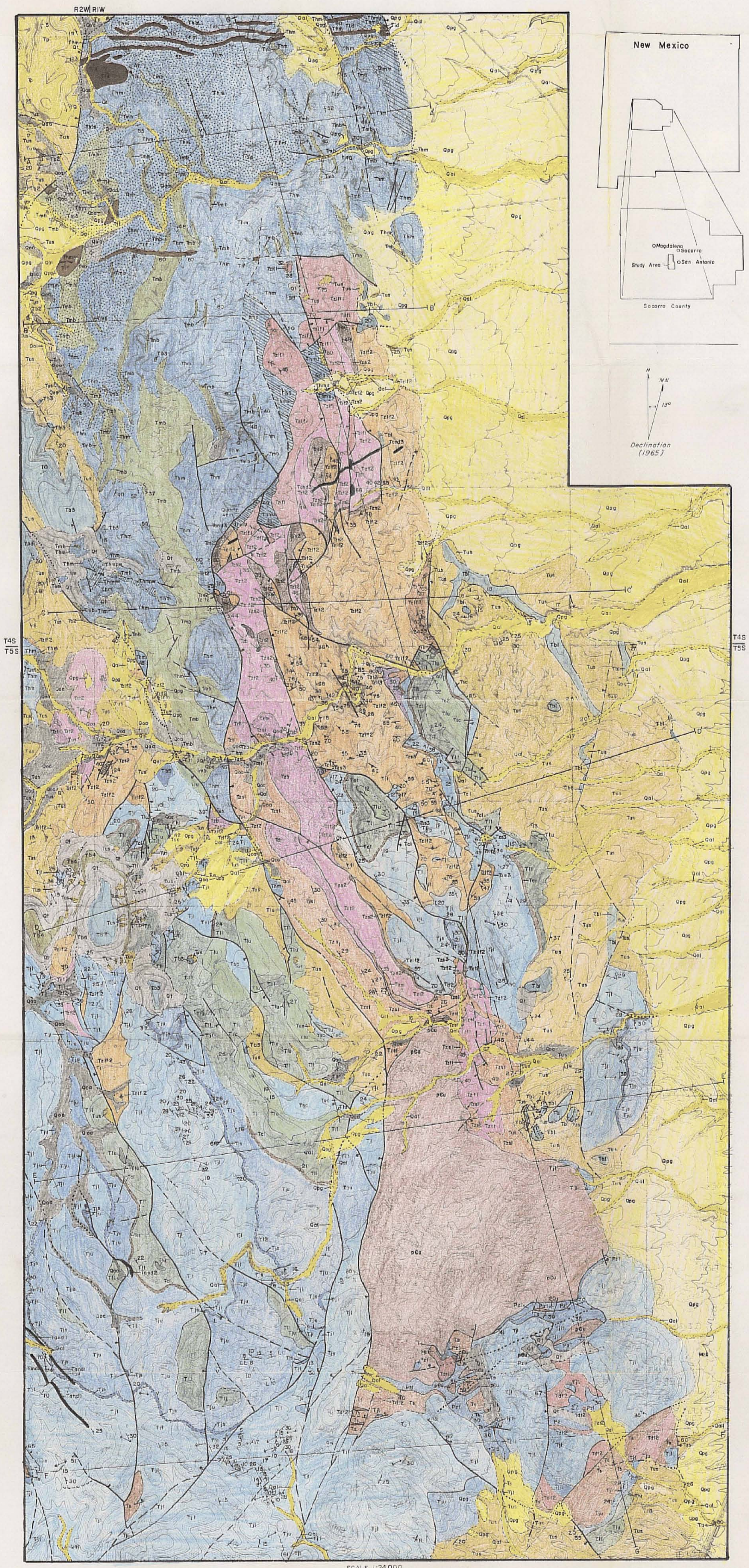
GEOLOGY OF THE CENTRAL CHUPADERA MOUNTAINS

SOCORRO COUNTY, NEW MEXICO

by

Ted Eggleston

1981



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1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

EXPLANATION

LAYERED ROCKS

Qal	Quaternary alluvium.
Qt	Quaternary talus. Includes some colluvial material.
Qoa	Older Quaternary alluvium. Forms terraces above Qal and contains paleo-soil horizons.
Qpg	Quaternary piedmont deposits. Usually conglomerates with minor sandstones and mudstones.
Tbl	Basalt flow. Black to gray basalt depending on alteration. Comprises several flows.
Tb2	Basalt flow. Discontinuous exposures in the northwest corner of map. May correlate with Tb4 and the Bear Canyon Basalt of Chamberlin (1980).
Tb3	Basalt flow. Caps butte southwest of Bianchi Ranch.
Tb4	Basalt flow. Lower basalt on butte southwest of Bianchi Ranch. May correlate with Tbl and/or Tb2.
Tb5	Basalt flow. Fills channels cut into South Canyon Tuff. Locally spread over South Canyon and not restricted to channels. Probably correlates with the Madera Canyon Basalt of Osburn (in preparation).
Tus	Upper Santa Fe gravels. Conglomerates, sandstones, and minor mudstones, and mudflow deposits. Tan to pale-red, poorly indurated bolson deposits. Correlates in part with both the Popotosa Formation and the Sierra Ladrones Formation.
Tp	Popotosa Formation. Bright-red and well-indurated fanglomerates found only in the extreme northwest corner of map.

South Canyon Tuff (about 26 m.y. old)

Tsc	South Canyon Tuff. Generally crystal-poor, white, poorly welded tuff. Crystal content increases near the top of the unit.
Tc2	Discontinuous, tuffaceous conglomerates, sandstones, and mudstones probably derived from the upper Lemitar Tuff.

Lemitar Tuff (about 28m.y. old)

Tlu	Upper Lemitar Tuff. Crystal-rich, dense to moderately welded tuff with a poorly welded top. Consists of three zones: a lower quartz-poor zone, an intermediate quartz-rich zone, and an upper poorly welded, quartz-rich zone that is not always preserved.
Tll	Lower Lemitar Tuff. Crystal-poor, white to pale-red, densely welded tuff with a poorly welded base. Generally forms low, rubbly outcrops.
Tcl	Tuffaceous conglomerates, sandstones, and mudstones probably derived from the top of the La Jencia Tuff.

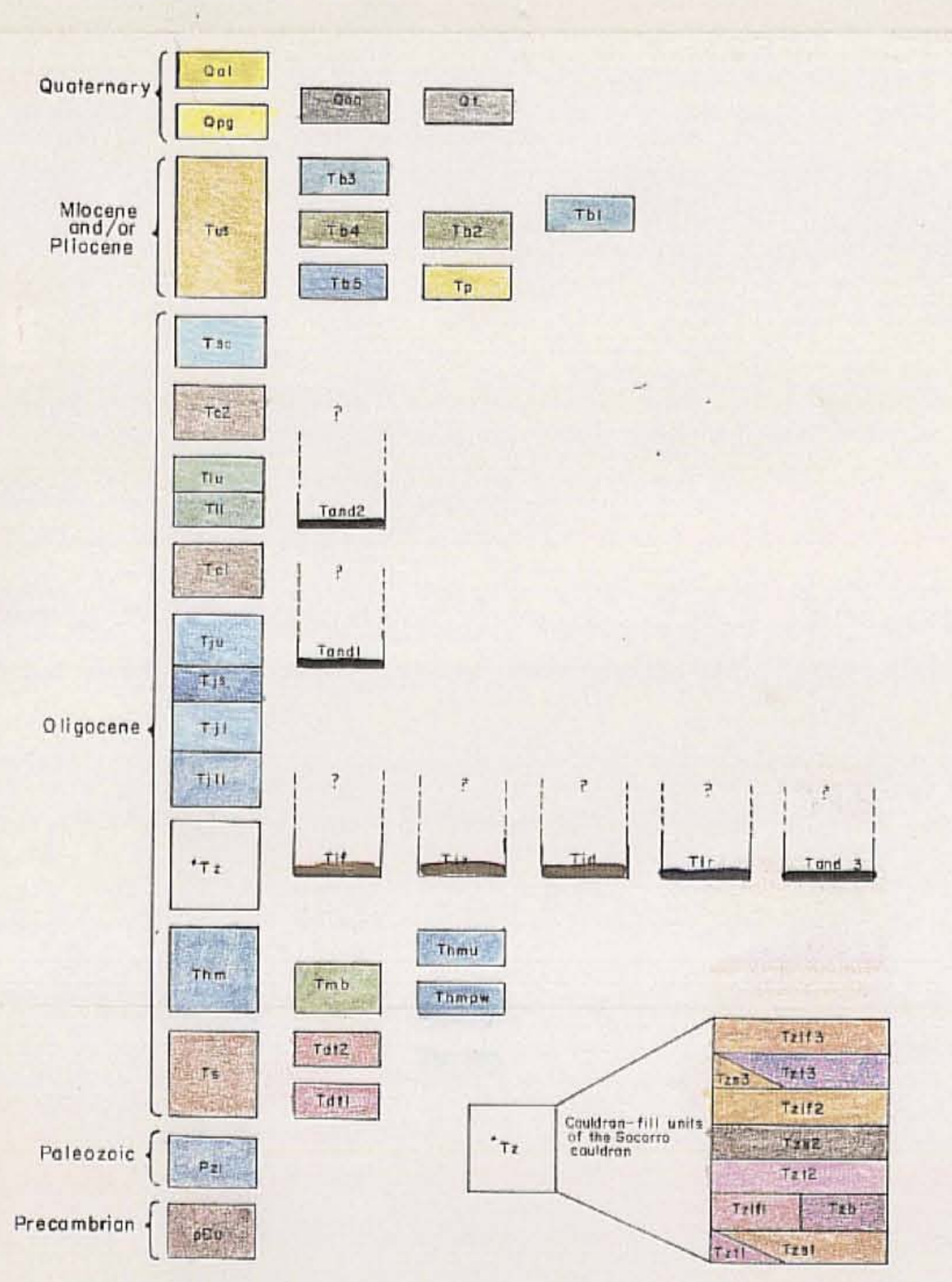
La Jencia Tuff (about 30 m.y. old)

Tju	Upper La Jencia Tuff. Densely welded, gray to pale red tuff. Color depends on the type and degree of alteration. Lithophysal zone near base; vapor phase minerals common.
Tjs	Ash-flow tuff and sedimentary rock interval between Tju and Tjl. Red to maroon tuff containing dark-gray to black pumice that are foliated and locally lineated. Includes a thin sedimentary rock interval overlying the red tuff.
Tjl	Lower La Jencia Tuff. Flowbanded and flow-folded, crystal-poor, lithic-poor to lithic-rich tuff that is various shades of red and gray depending on the degree of alteration.
Tjll	Poorly welded ash-flow tuff below Tjl. Lithic-rich, crystal-poor tuff probably related to Tjl.

Luis Lopez Formation

Tzs3	Upper Sedimentary member. Crossbedded, tuffaceous conglomerates, sandstones, and mudstones possibly correlative with the base of Tzt3.
Tzlf3	Upper lava member. Rhyolite lava consisting of three sub-units: a basal vent breccia, an intemediate vitrophyre, and an upper lithoidal zone. Red-brown spherulites are common. Lower two sub-units are not present.
Tzt3	Upper ash-flow tuff member. Poorly welded, lithic-rich to lithic-poor, white tuff only 50 to 70 feet thick. Base is a crossbedded sandstone with minor pebble conglomerate.
Tzlf2	Middle lava member. Brown where fresh, but commonly altered to lighter colors. Crystal poor, commonly spherulitic, flowbanded, and locally vitric.
Tzs2	Middle sedimentary member. Conglomerates, breccias, sandstones, and minor andesite lavas. Thin andesite lavas underlain and overlain by clastic sedimentary rocks. Generally bright red, but may be buff to gray.
Tzt2	Middle tuff member. Mainly ash-flow tuffs and mudflow deposits with thin, basal waterlain tuff and clastic sedimentary rock intervals. Consists of several thin, white, poorly welded, lithic-rich ash-flow tuffs with intercalated mudflow deposits and possibly talus.
Tzb	Basalt member. Black to dark gray basalt (basaltic andesite?). Relatively unaltered, but iddingsite suggests a primary olivine content.
Tzlfl	Lower lava member. Red, white, or bluish depending on degree of alteration. Flowbanded and flow-folded. May contain up to 7percent pyroxene and a trace of quartz. Textures indicate that the unit is probably an andesite.
Tzsl	Lower sedimentary member. Moat-fill sediments as much as 700 feet thick. Two facies present: a southern facies derived from the topographic wall of the Socorro cauldron and a northern facies derived from the resurgent dome of the cauldron. The southern facies consists of conglomerates, sandstones, mudstones, and mudflow deposits obviously derived from a source area rich in andesite and Precambrian lithologies. The northern facies consists of sandstones and mudstones with large amounts of crystals and tuffaceous material possibly derived from the resurgent dome. The top of the southern facies contains several conglomerate intervals that may suggest episodic uplift of the resurgent dome.
Tztl	Lower tuff member. Crystal-rich, poorly welded ash-flow tuff containing abundant lithic fragments mostly of Precambrian lithologies.

CORRELATION OF MAP UNITS



Hells Mesa Tuff (about 33 m.y. old)

Thmu	Upper Hells Mesa Tuff. Interbedded ash-flow and ash-fall tuffs. Ash-fall deposits seem finer grained than the ash-flow deposits. Red "clots" of Thm are conspicuous in some of the ash-flow deposits.
Thmpw	Poorly welded Hells Mesa Tuff. Similar to Thm, but poorly welded and white. Found only in limited exposures north of Bianchi Ranch.
Thm	Hells Mesa Tuff. Crystal-rich, lithic-rich to lithic-poor, densely welded ash-flow tuff. Color varies from gray to bright red depending on type and degree of alteration.
Tmb	Cauldron collapse breccias. Intercalated in Thm, these breccias are the result of spalling of the wall of the cauldron during eruption. Distinction between lithic-rich Thm and these breccias is difficult at times.

Datil Group (about 33-37 m.y. old)

Tdt2	Ash-flow tuff. A distinctive tuff near the top of the Datil Group in this area. Composed of about 18percent sanidine and 1 percent biotite. Densely welded, pumice-poor tuff that may correlate with the tuff of Datil Well.
Ts	Spears Formation. Volcaniclastic sedimentary rocks with intercalated tuffs and andesitic to latitic lavas.
Tdt1	Thin, crystal-poor, lithic-poor tuff.

Paleozoic Rocks

Pzl	Undivided Paleozoic limestones, shales, and sandstones. The Mississippian Caloso and Pennsylvanian Sandia Formations are present.

Precambrian Rocks

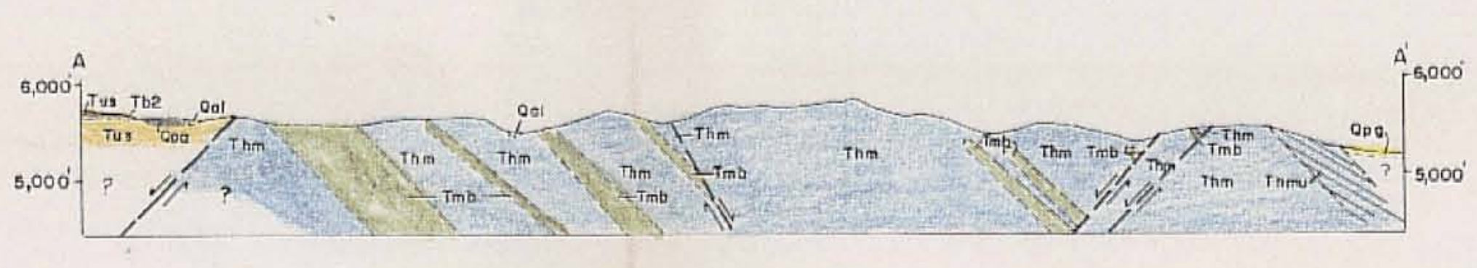
p€u	Undivided Precambrian schists, gneisses, and granitoid plutonic rocks.

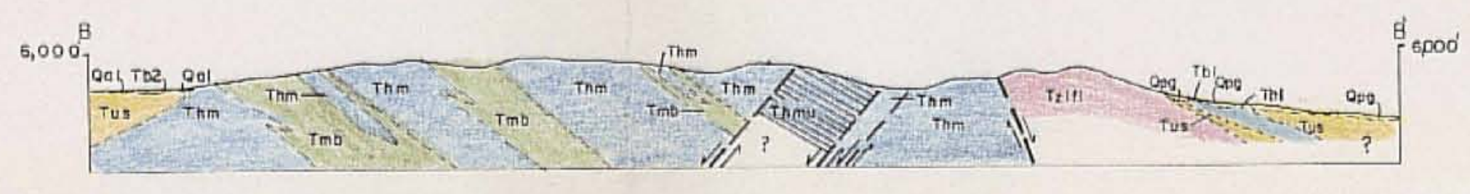
INTRUSIVE ROCKS

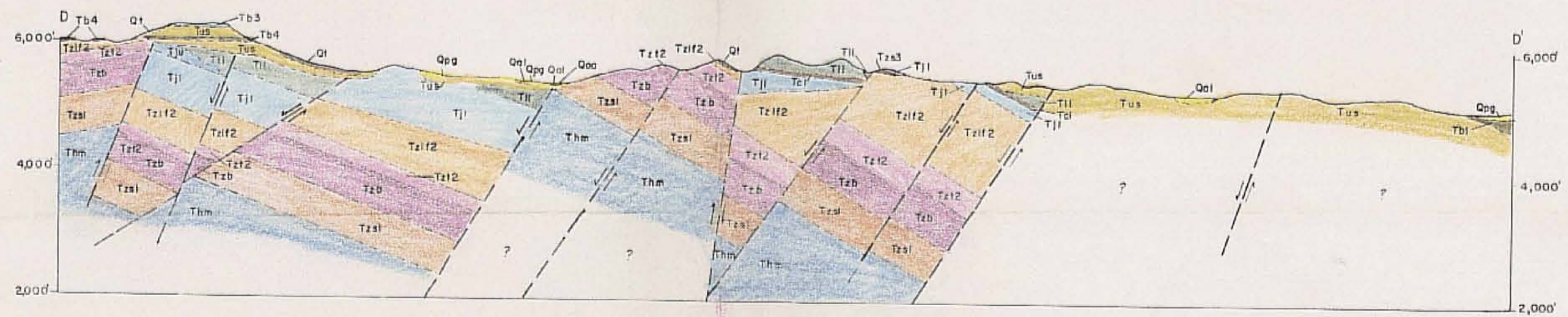
Tand1	Andesite dike. Gray to green, fine-grained andesite.
Tand2	Andesite dike. Coarse-grained, black andesite (possibly basalt).
Tand3	Andesite dike. Similar to Tand 1.
Tif	Felsic intrusive. Moderate crystal content. Large sanidine crystals (up to 1 cm) are distinctive.
Tix	Intermediate intrusive. Two-phase intrusive that is locally altered, brecciated, and silicified.
Tid	Intermediate dike rocks similar to Tix. Intensely altered.
Tir	Felsic intrusive. Very crystal-rich, spherulitic intrusive.

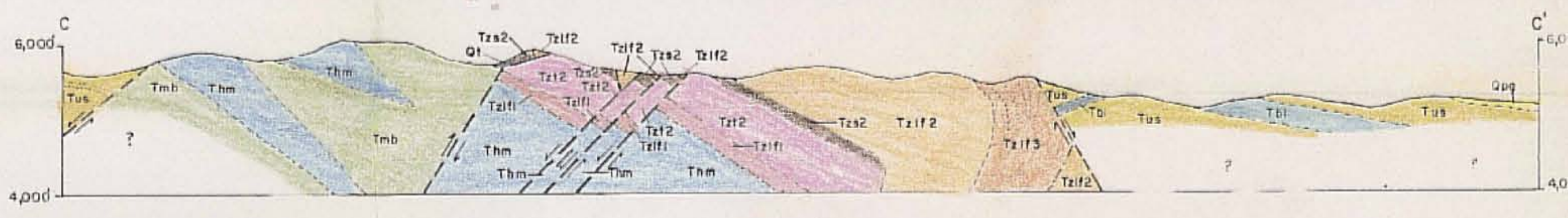
SYMBOLS

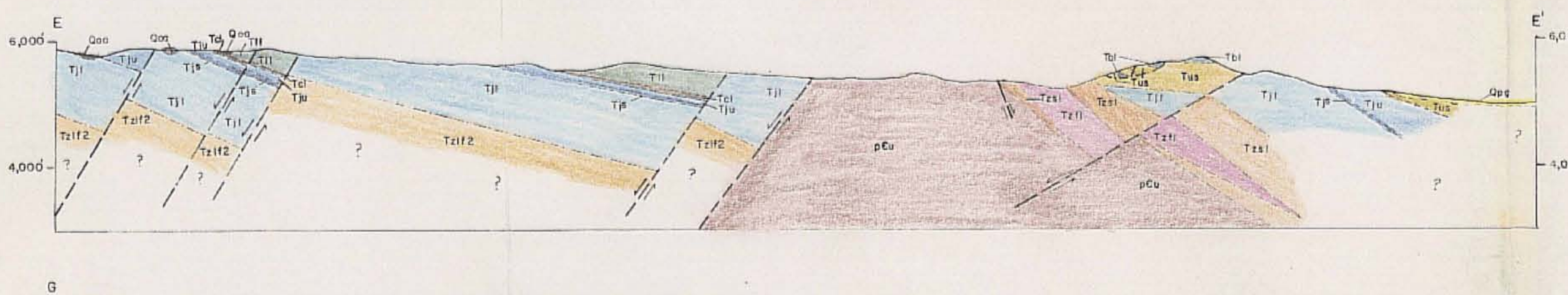
30	contact; dashed where approximate; dotted where concealed, showing dip
	speculative contact; bedding or flowbanding (on cross sections)
50	fault; dashed where approximate; dotted where concealed; showing dip and lineation of slickensides; ball on downthrown side.
40	slump; shear zone, showing dip
45 ⊕	strike and dip of beds, horizontal beds
65	strike and dip of flowbanding, vertical flowbanding
→	sediment transport direction
	flow lineation, flow direction from flow-folds
→	plunge direction of flow-folds
A —— A'	line of cross section
LL; VV	lithophysal zone; vitrophyre (in ash-flow tuffs)
	red altered Hells Mesa Tuff

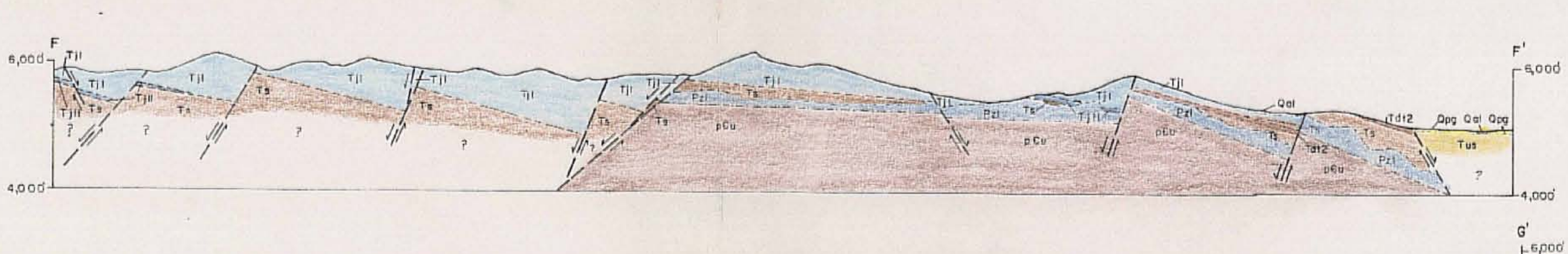












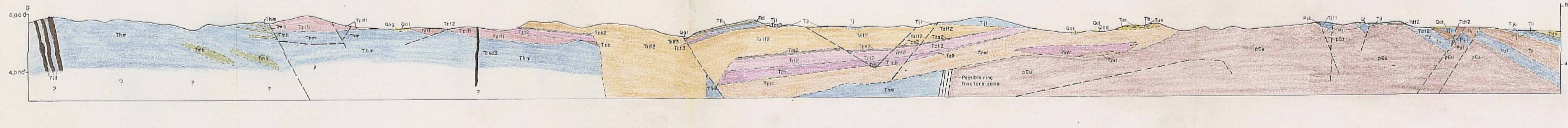


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PLATE 1

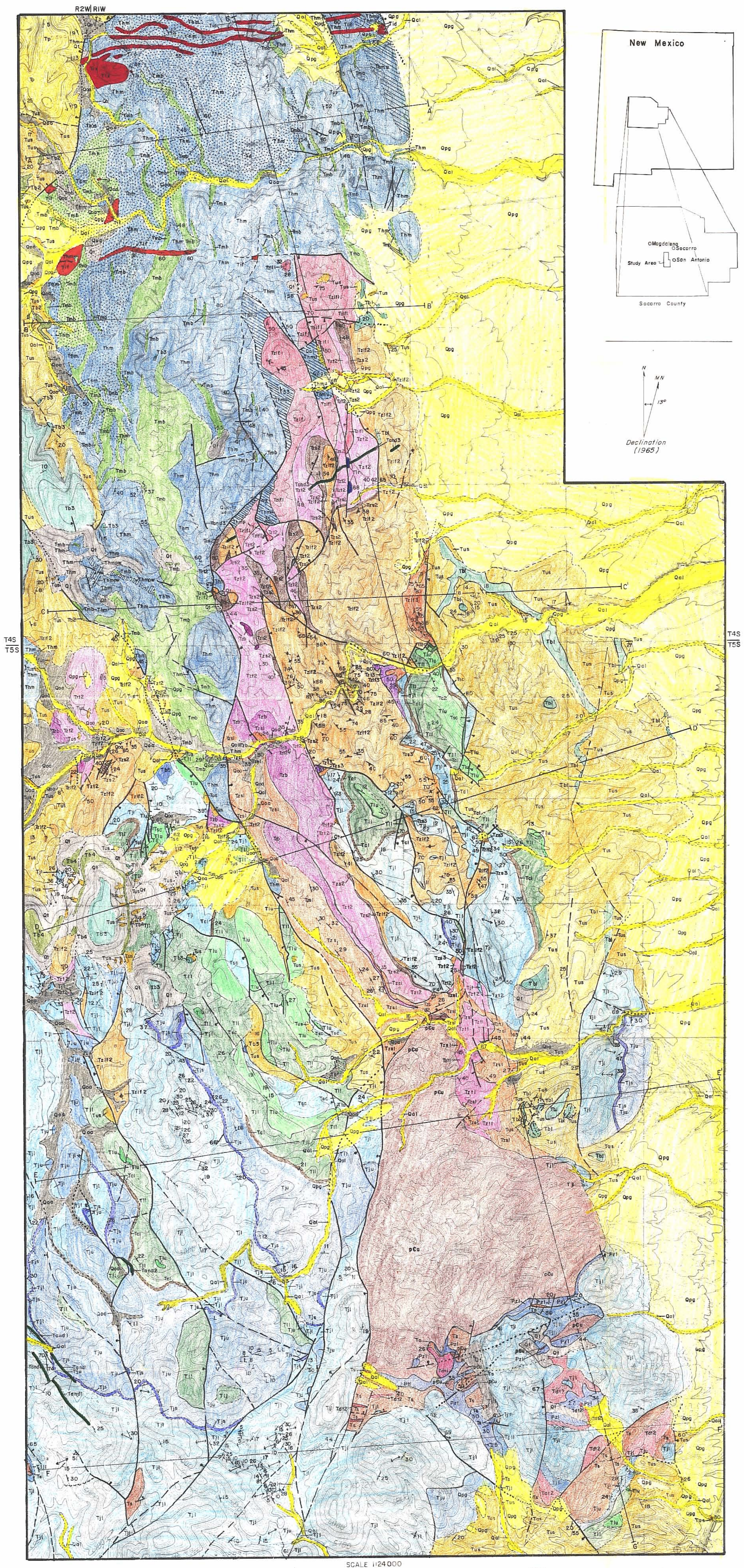
GEOLOGY OF THE CENTRAL CHUPADERA MOUNTAINS

SOCORRO COUNTY, NEW MEXICO

by

Ted Eggleston

1981



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1 .5 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET

DATUM IS MEAN SEA LEVEL

Declination (1965)

EXPLANATION

LAYERED ROCKS

Qal	Quaternary alluvium.
Qt	Quaternary talus. Includes some colluvial material.
Qoa	Older Quaternary alluvium. Forms terraces above Qal and contains paleo-soil horizons.
Qpg	Quaternary piedmont deposits. Usually conglomerates with minor sandstones and mudstones.
Tb1	Basalt flow. Black to gray basalt depending on alteration. Comprises several flows.
Tb2	Basalt flow. Discontinuous exposures in the northwest corner of map. May correlate with Tb4 and the Bear Canyon Basalt of Chamberlin (1980).
Tb3	Basalt flow. Caps butte southwest of Bianchi Ranch.
Tb4	Basalt flow. Lower basalt on butte southwest of Bianchi Ranch. May correlate with Tb1 and/or Tb2.
Tb5	Basalt flow. Fills channels cut into South Canyon Tuff. Locally spread over South Canyon and not restricted to channels. Probably correlates with the Madera Canyon Basalt of Osburn (in preparation).
Tus	Upper Santa Fe gravels. Conglomerates, sandstones, and minor mudstones, and mudflow deposits. Tan to pale-red, poorly indurated bolson deposits. Correlates in part with both the Popotosa Formation and the Sierra Ladrones Formation.
Tp	Popotosa Formation. Bright-red and well-indurated fanglomerates found only in the extreme northwest corner of map.

South Canyon Tuff (about 26 m.y. old)

Tsc	South Canyon Tuff. Generally crystal-poor, white, poorly welded tuff. Crystal content increases near the top of the unit.
Tc2	Discontinuous, tuffaceous conglomerates, sandstones, and mudstones probably derived from the upper Lemitar Tuff.

Lemitar Tuff (about 28 m.y. old)

Tlu	Upper Lemitar Tuff. Crystal-rich, dense to moderately welded tuff with a poorly welded top. Consists of three zones: a lower quartz-poor zone, an intermediate quartz-rich zone, and an upper poorly welded, quartz-rich zone that is not always preserved.
Tll	Lower Lemitar Tuff. Crystal-poor, white to pale-red, densely welded tuff with a poorly welded base. Generally forms low, rubbly outcrops.
Tc1	Tuffaceous conglomerates, sandstones, and mudstones probably derived from the top of the La Jencia Tuff.

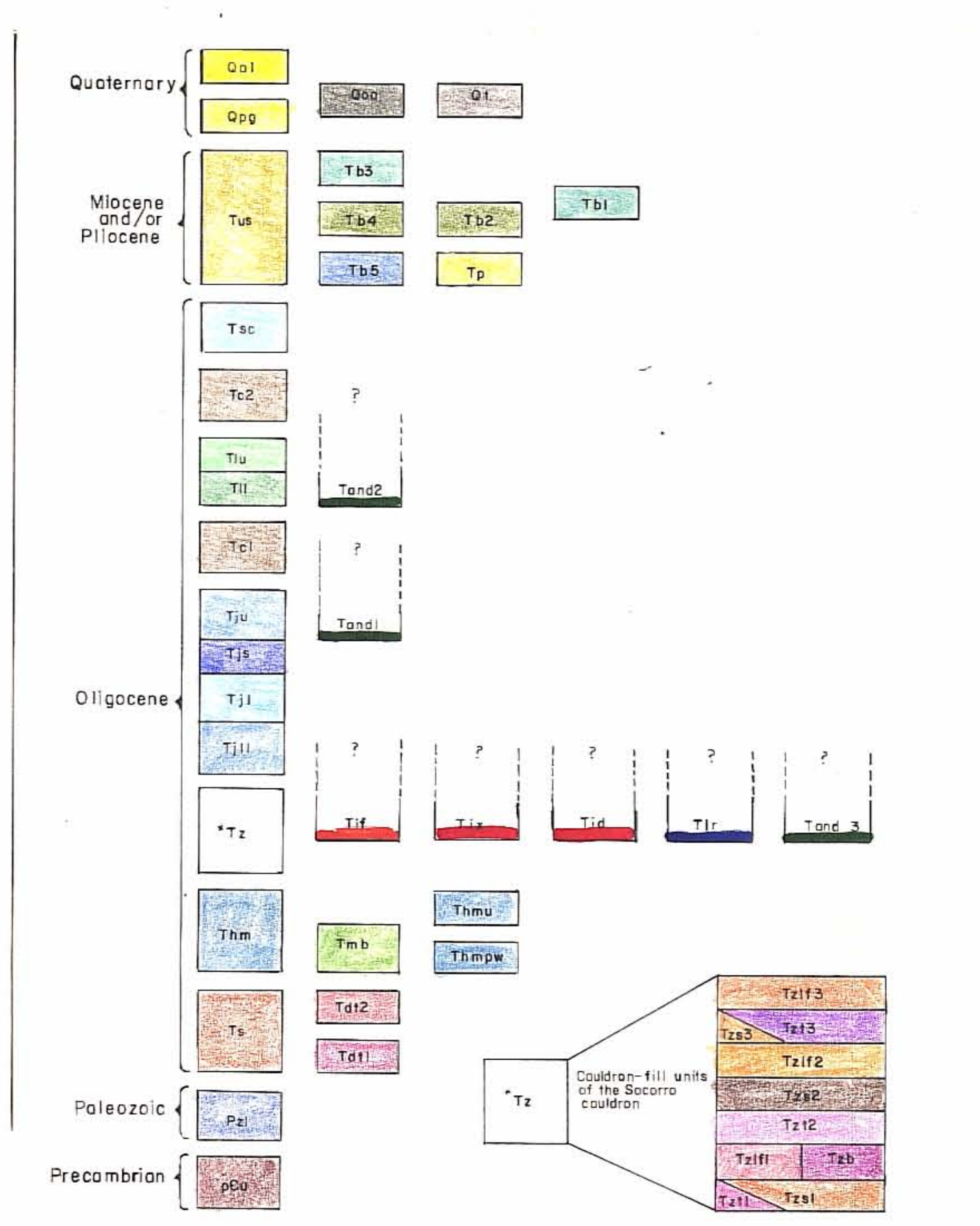
La Jencia Tuff (about 30 m.y. old)

Tju	Upper La Jencia Tuff. Densely welded, gray to pale red tuff. Color depends on the type and degree of alteration. Lithophysal zone near base; vapor phase minerals common.
Tjs	Ash-flow tuff and sedimentary rock interval between Tju and Tjl. Red to maroon tuff containing dark-gray to black pumice that are foliated and locally lineated. Includes a thin sedimentary rock interval overlying the red tuff.
Tjl	Lower La Jencia Tuff. Flowbanded and flow-folded, crystal-poor, lithic-poor to lithic-rich tuff that is various shades of red and gray depending on the degree of alteration.
Tjll	Poorly welded ash-flow tuff below Tjl. Lithic-rich, crystal-poor tuff probably related to Tjl.

Luis Lopez Formation

Tzs3	Upper Sedimentary member. Crossbedded, tuffaceous conglomerates, sandstones, and mudstones possibly correlative with the base of Tzt3.
Tzlf3	Upper lava member. Rhyolite lava consisting of three sub-units: a basal vent breccia, an intemediate vitrophyre, and an upper lithoidal zone. Red-brown spherulites are common. Lower two sub-units are not present.
Tzt3	Upper ash-flow tuff member. Poorly welded, lithic-rich to lithic-poor, white tuff only 50 to 70 feet thick. Base is a crossbedded sandstone with minor pebble conglomerate.
Tzlf2	Middle lava member. Brown where fresh, but commonly altered to lighter colors. Crystal poor, commonly spherulitic, flowbanded, and locally vitric.
Tzs2	Middle sedimentary member. Conglomerates, breccias, sandstones, and minor andesite lavas. Thin andesite lavas underlain and overlain by clastic sedimentary rocks. Generally bright red, but may be buff to gray.
Tzt2	Middle tuff member. Mainly ash-flow tuffs and mudflow deposits with thin, basal waterlain tuff and clastic sedimentary rock intervals. Consists of several thin, white, poorly welded, lithic-rich ash-flow tuffs with intercalated mudflow deposits and possibly talus.
Tzb	Basalt member. Black to dark gray basalt (basaltic andesite?). Relatively unaltered, but iddingsite suggests a primary olivine content.
Tzlf1	Lower lava member. Red, white, or bluish depending on degree of alteration. Flowbanded and flow-folded. May contain up to 7 percent pyroxene and a trace of quartz. Textures indicate that the unit is probably an andesite.
Tzs1	Lower sedimentary member. Moat-fill sediments as much as 700 feet thick. Two facies present: a southern facies derived from the topographic wall of the Socorro cauldron and a northern facies derived from the resurgent dome of the cauldron. The southern facies consists of conglomerates, sandstones, mudstones, and mudflow deposits obviously derived from a source area rich in andesite and Precambrian lithologies. The northern facies consists of sandstones and mudstones with large amounts of crystals and tuffaceous material possibly derived from the resurgent dome. The top of the southern facies contains several conglomerate intervals that may suggest episodic uplift of the resurgent dome.
Tzt1	Lower tuff member. Crystal-rich, poorly welded ash-flow tuff containing abundant lithic fragments mostly of Precambrian lithologies.

CORRELATION OF MAP UNITS



Hells Mesa Tuff (about 33 m.y. old)

Thmu	Upper Hells Mesa Tuff. Interbedded ash-flow and ash-fall tuffs. Ash-fall deposits seem finer grained than the ash-flow deposits. Red "clots" of Thm are conspicuous in some of the ash-flow deposits.
Thmpw	Poorly welded Hells Mesa Tuff. Similar to Thm, but poorly welded and white. Found only in limited exposures north of Bianchi Ranch.
Thm	Hells Mesa Tuff. Crystal-rich, lithic-rich to lithic-poor, densely welded ash-flow tuff. Color varies from gray to bright red depending on type and degree of alteration.
Tmb	Cauldron collapse breccias. Intercalated in Thm, these breccias are the result of spalling of the wall of the cauldron during eruption. Distinction between lithic-rich Thm and these breccias is difficult at times.

Datil Group (about 33-37 m.y. old)

Tdt2	Ash-flow tuff. A distinctive tuff near the top of the Datil Group in this area. Composed of about 18 percent sanidine and 1 percent biotite. Densely welded, pumice-poor tuff that may correlate with the tuff of Datil Well.
Ts	Spears Formation. Volcaniclastic sedimentary rocks with intercalated tuffs and andesitic to latitic lavas.
Tdt1	Thin, crystal-poor, lithic-poor tuff.

Paleozoic Rocks

Pzl	Undivided Paleozoic limestones, shales, and sandstones. The Mississippian Caloso and Pennsylvanian Sandia Formations are present.

Precambrian Rocks

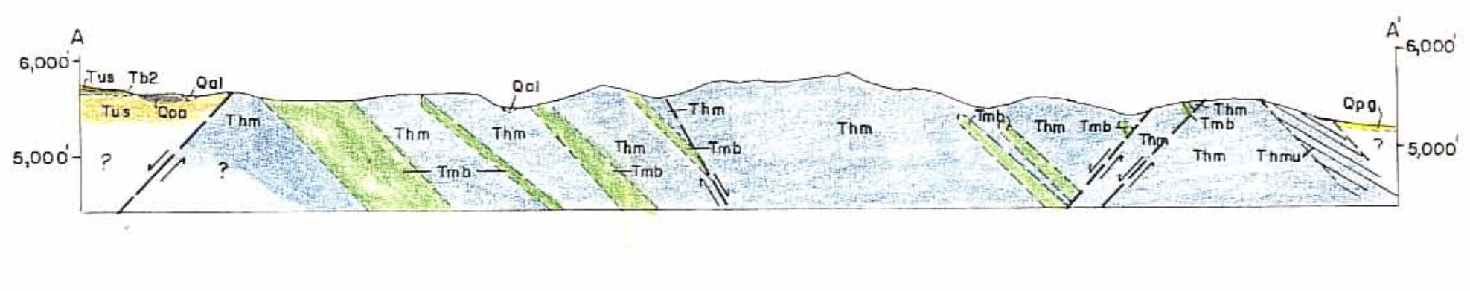
p€u	Undivided. Precambrian schists, gneisses, and granitoid plutonic rocks.

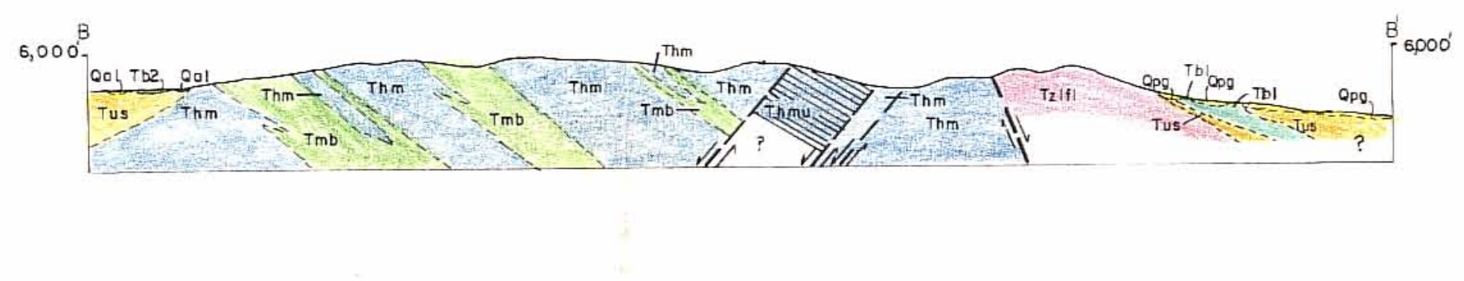
INTRUSIVE ROCKS

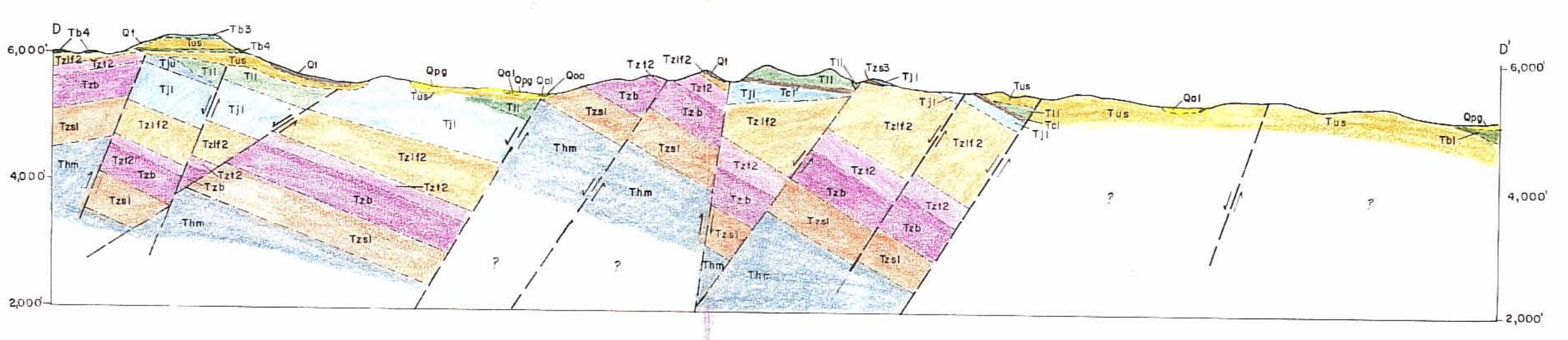
Tand1	Andesite dike. Gray to green, fine-grained andesite.
Tand2	Andesite dike. Coarse-grained, black andesite (possibly basalt).
Tand3	Andesite dike. Similar to Tand 1.
Tif	Felsic intrusive. Moderate crystal content. Large sanidine crystals (up to 1 cm) are distinctive.
Tix	Intermediate intrusive. Two-phase intrusive that is locally altered, brecciated, and silicified.
Tid	Intermediate dike rocks similar to Tix. Intensely altered.
Tir	Felsic intrusive. Very crystal-rich, spherulitic intrusive.

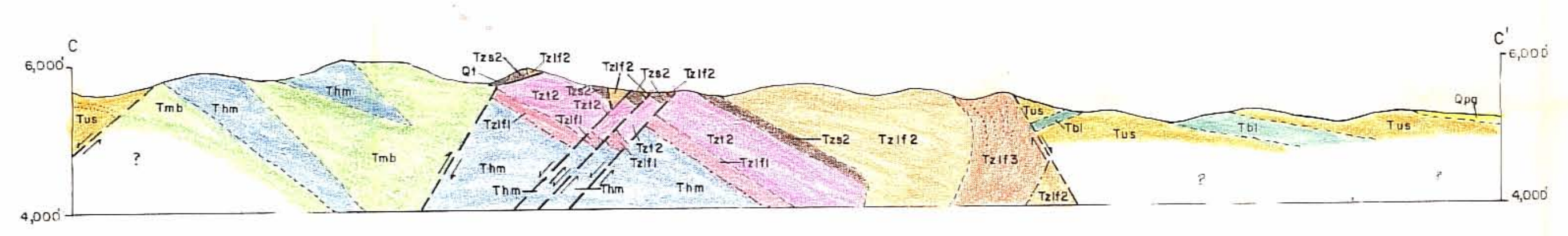
SYMBOLS

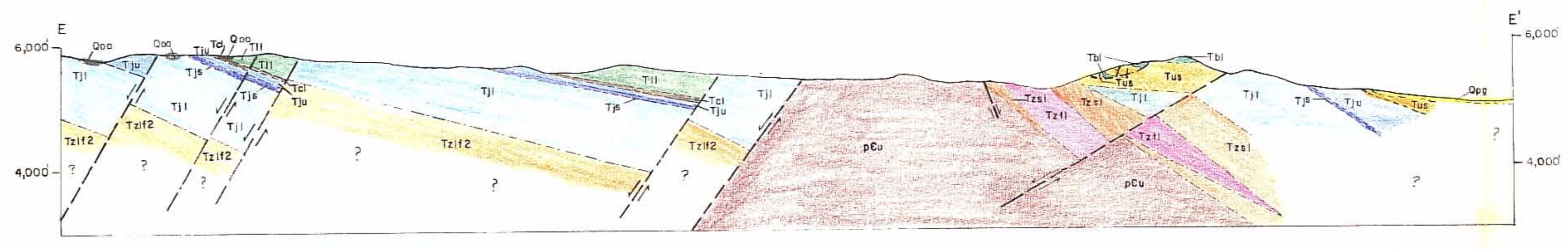
30	contact; dashed where approximate; dotted where concealed, showing dip
	speculative contact; bedding or flowbanding (on cross sections)
50	fault; dashed where approximate; dotted where concealed; showing dip and lineation of slickensides; ball on downthrown side.
40	slump; shear zone, showing dip
45 ⊕	strike and dip of beds, horizontal beds
85	strike and dip of flowbanding, vertical flowbanding
→	sediment transport direction
	flow lineation, flow direction from flow-folds
→	plunge direction of flow-folds
A —— A'	line of cross section
LL ; VV	lithophysal zone; vitrophyre (in ash-flow tuffs)
░	red altered Hells Mesa Tuff

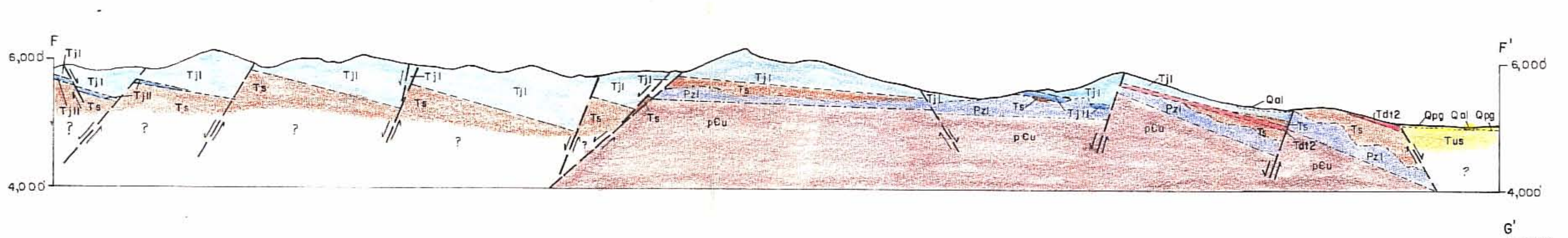


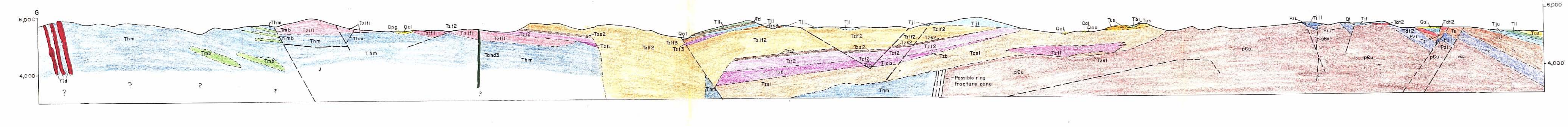












OF 141

STRUCTURAL GEOLOGY, MINERAL OCCURRENCES, AND SAMPLE LOCATIONS
CENTRAL CHUPADERA MOUNTAINS, SOCORRO COUNTY, NEW MEXICO

by

Ted Eggleston

1981

▲ Sample location, underlined where point count data is available.

m Manganese occurrence.

P Perlite occurrence.

500 45 Fault, showing dip of fault plane and direction of plunge of slickensides. Dashed where approximately located or inferred, dotted where concealed. Hachures on downthrown side. Stratigraphic separation in feet.

70 Dike with dip.

Drag features, anticline, syncline.

OPEN FILE REPORT 141

PLATE 2

PLATE 2