THE GEOLOGY OF LA JOYITA HILLS, SOCORRO CO., N. M.

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THESIS

Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Geology
in the Graduate School of
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ABSTRACT OF THESIS

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La Joyita Hills is a complex series of horst blocks surrounding a Precambrian core. On the west, Pennsylvanian and Permian sediments overlie the Precambrian complex. On the east and south are a series of ash-flows and andesitic flows cut by east-west trending faults. There are some intrusive rocks occurring within fault zones.

Pennsylvanian sediments, 416 ft thick, are composed of the clastic Sandia Formation and the Madera Limestone. Resting unconformably on the Pennsylvanian sediments is the Bursum Formation of early Permian age. The Bursum Formation, 30 ft thick, is an arkose with a basal, limestone-granule conglomerate. The Bursum is conformably overlain by the Abo Formation. The Abo is a series of dark red, interbedded siltstone, mudstone, and shale and is gradationally and transgressionally overlain by the Meseta Blanca Sandstone Member of the Yeso Formation. The Yeso Formation, 1000 ft thick, contains four members: the Meseta Blanca Sandstone, the Torres, the Cañas Gypsum (not mappable), and the Joyita Sandstone. The units represent

a conformable sequence except where the Joyita Sandstone is disconformably underlain by the Torres in the northern part of the area. The Glorieta Sandstone, a massive, cliff-forming sandstone, 123 ft thick, gradationally and transgressionally overlies the Joyita Sandstone. The Glorieta is conformably overlain by the San Andres Limestone. The San Andres is a massive, cliff-forming limestone, 235 ft thick, unconformably overlain by the Dockum Group of Late Triassic age. The Dockum Group is a maroon, cross-bedded sandstone, 70 ft thick, unconformably overlain by the Baca Formation. The Mancos Shale-Mesa Verde undifferentiated consists of shale, sandstone and siltstone; and is erosionally unconformable with the Baca. The Baca Formation is a coarse conglomerate. The overlying Tertiary extrusive rocks are a series of ash-flows, water-laid tuffs and andesite (An_{25}-An_{50}) flows. The Santa Fe Group overlies all formations in the area. Intrusive rocks in the mapped area occur in fault zones and are mainly andesite (An_{22}-An_{43}) with a few rhyolites. Quaternary deposits consist of sand, gravel, and mud, which are loosely consolidated, with some recent stream channel and eolian deposits.

There are four main fault sets in the mapped area. The first set, N. 80° E., is probably related to early deformation, possibly during Precambrian time. The other sets are interrelated. The N. 10° W. set is the result of tension during the formation of the Rio Grande graben. The other sets, N. 48° W. and N. 32° E., are conjugate shears resulting from a possible compression in the north-south direction.

There is only minor lead, fluorite, and copper stockwork mineralization in the mapped area. Most of it was prospected at the turn of the century. However, there has been some recent prospecting for manganese in the San Andres Limestone.

CONTENTS

LIST OF FIGURES

FIGURE

LIST OF PLATES

PLATE

PLATE

INTRODUCTION

Physiography, Location and Accessibility

The name "La Joyita" is derived from the Spanish word "hoya" meaning arroyo or gully. La Joyita Hills, "Little Arroyo Hills," typifies the western half of the mapped area.

La Joyita Hills (Figure 1) are 15 air miles northeast of Socorro and adjacent to the east bank of the Rio Grande. The hills are bounded by the coordinates $34^{\circ}12'02''$ and $34^{\circ}18'30''$ north latitude, and $106^{\circ}52'30''$ and $106^{\circ}45'$ west longitude, and lie along the southern perimeter of the Sevilleta Land Grant. The mapped area is 3 miles east of Interstate Highway 25 and 8 miles south of N. M. State Highway 60 along N. M. State Highway 47.

The northern end of La Joyita Hills is accessible by travelling south on N. M. State Highway 47 until it ends at the town of La Joya. From there either of two dirt roads can be followed south 3 miles to La Joyita Hills. On the west, the principal roads are maintained by La Joya Game Refuge and are accessible with conventional vehicles. However, the relief and the ruggedness of the terrain lend themselves to four-wheel drive vehicles and a considerable

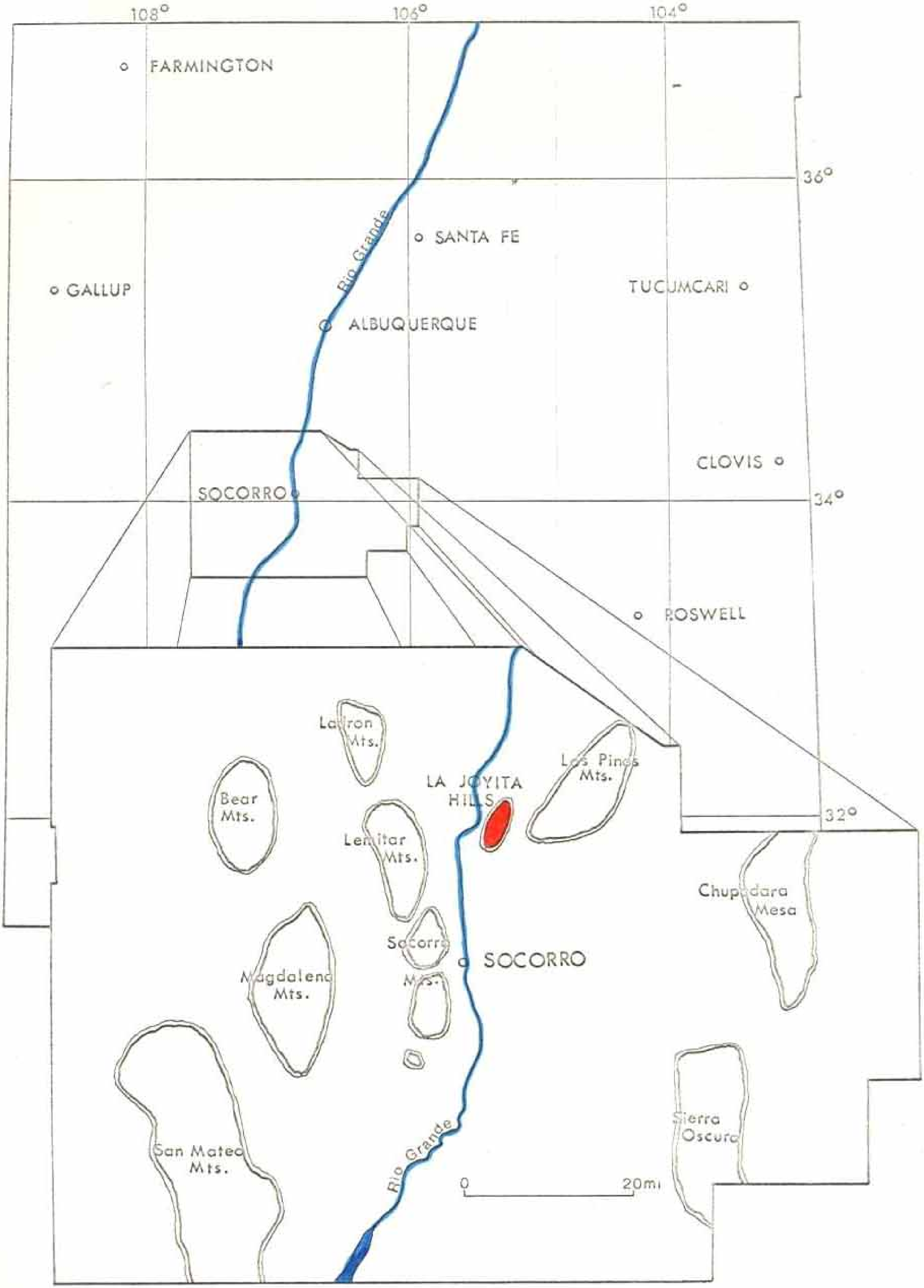


Figure 1: Index Map

part of the area can be reached only on foot. During the late 1950's, fluorite prospectors built roads into the central part of the mapped area. These roads, although clearly marked on the topographic sheets, are completely washed out. For the most part, the area can be reached at any time of the year with the exception of short periods of heavy rain or snow.

The mapped area is elongate, trends northeast-southwest, and is about 7½ miles long, covering an area of 60 square miles. The maximum elevation in the area is 5,300 ft and the minimum elevation is 4,700 ft with the average relief being no more than 250 ft. The western part of the area is dissected by gullies which drain directly into the Rio Grande. On the east and south, the topography is less rugged and not as notably dissected. The drainage in the east central part of the mapped area is to the south, draining through Rosa de Grande Arroyo or Arroyo Alamillo into the Rio Grande. The drainages on the south and east merge and follow Arroyo Alamillo into the Rio Grande. The drainages on the west flow through Central, Coal Mine, and Colorado canyons.

The fauna and flora of the area reflect typical desert environment. Reptiles are abundant, lizards being predominant along with a fewer number of snakes. Other animals that are present are jack rabbit, cottontail, ground squirrel, deer, badger, antelope, coyote, and several types of predatory and scavenger birds. The principal flora are creosote bush (Covillea glutinosa), mesquite (Prosopis), chollas, prickly pear, and barrel cacti. Also, there are several different varieties of grasses and wild flowers. In the arroyo bottoms, juniper trees, salt cedar, and other phreatophytes are present. The fauna and flora would be classified according to Merriam's Life Zone Concept (Baily, 1913), as Lower to Upper Sonoran.

The climate is semi-arid with temperatures ranging from 100°F in the day during the summer to 0°F at night in the winter. The area is subject to strong winds in spring and frequent summer thundershowers; rainfall is usually less than 8 inches per year.

Methods of Investigation

Field work was carried out from January to June 1970. Mapping was done on 1:24,000 topographic sheets in conjunction with 1:28,000 aerial photographs. Detailed mapping was done on 7½-minute quadrangle sheets enlarged to 1:8,000. Sections were measured using a Jacob staff, and clast sizes were recorded using Wentworth's classification (1922). Igneous rocks were named according to Streckeisen's classification (1967); and plagioclase determinations were made using the A-normal method and using Tobi's (1963) high temperature curves for anorthite composition.

Previous Investigations

Two Oil and Gas Maps have been published on this area, both under the supervision of Wilpolt (1946, 1951). The northern half of the area was mapped in 1946. The second map was published by Wilpolt and others in 1951. Both of these maps are on a scale of 1:63,360. Preliminary work was done on the Pennsylvania sections by Kottlowski (1960).

Herber (1963) mapped the Precambrian on a scale of 1:15,000 for his master's thesis at New Mexico Institute of Mining and Technology. Kottlowski and Stewart (1970) investigated and mapped the Pennsylvanian section in detail. Huber (1961) described the sedimentary petrogenesis of the Permian section for a master's thesis at the University of New Mexico.

Acknowledgments

The author would like to express his sincere appreciation to Dr. Lee Woodward, who gave continued guidance and direction in the writing of this thesis.

Special thanks are also extended to Dr. Albert Kudo for his help in identification of the volcanics, and Dr. Kelley for suggesting La Joyita Hills as a problem. Dr. Clay Smith was invaluable in lending his assistance and knowledge in the mapping of the area.

The author would also like to express his appreciation to the Roswell Geological Society and the New Mexico Geological Society for their financial assistance.

ROCK UNITS

General Statement

The rock units in this report range widely in composition and lithologic character. Ages from Precambrian to Recent are represented, and rock types range from metamorphic through volcanic (intrusive) and to sedimentary.

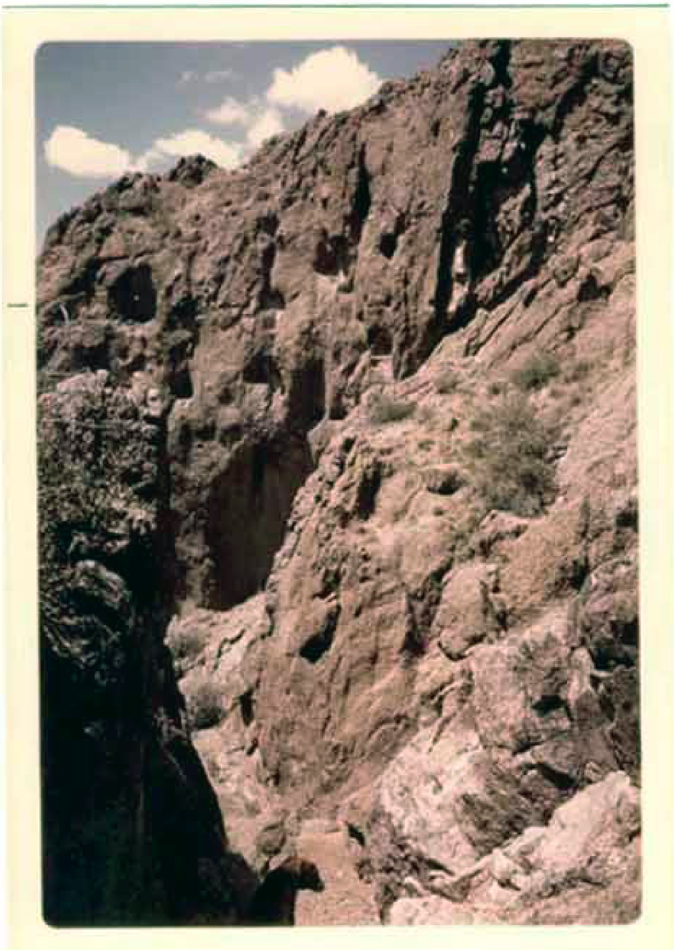
The Precambrian is composed primarily of gneiss. Precambrian rocks are overlain by a sedimentary sequence from Pennsylvanian to Eocene about 2175 ft thick; the Tertiary volcanic sequence is 3070 ft thick, and the overlying Santa Fe is of unknown thickness. The Pennsylvanian formations are mostly carbonates and shales of marine origin. The Permian rocks are transitional between marine and terrestrial, and the Triassic are of terrestrial origin. The Cretaceous is transitional, and the Tertiary is composed of clastics mixed with volcanics.

Precambrian

The Precambrian rocks were mapped by Herber (1963) as metamorphosed arenaceous, impure clacareous, or basic volcanic sediments (Plate 1).

The Precambrian exposure is bounded on the east

Plate 1: Precambrian complex in the northern part of the mapped area.



by the East Joyita Fault and Tertiary volcanics; on the west by the Madera and Sandia Formations; on the north by an east-west-trending fault; and on the south by overlying Santa Fe Group.

The Precambrian is divided into 2 map units: (1) quartz-potash feldspar gneiss and (2) quartz-potash feldspar-biotite gneiss. Other rocks that are present, but not mappable on the scale used, are amphibolite schist, aplite, and epidosite. Fault zones are delineated by quartz-potash feldspar schist and quartz-potash feldspar-biotite schist developed within the gneissic units.

The contact between the quartz-potash feldspar gneiss and the quartz-potash feldspar-biotite gneiss is gradational. The terrane of the quartz-potash feldspar gneiss is characterized by low hills with little relief, and with west-draining arroyos. Unlike the quartz-potash feldspar gneiss, the quartz-potash feldspar-biotite gneiss presents a rugged terrane with a sharp, west-cutting drainage pattern, and relief up to 200 ft.

Foliation is the most obvious rock fabric feature associated with the Precambrian complex. Lineation and jointing are developed on a smaller scale.

Pennsylvanian System

The Pennsylvanian System was mapped and described by Kottlowski and Stewart (1970). The Pennsylvanian consists of the Sandia and the Madera Formations, which are a maximum of 416 ft thick. For a complete description and discussion of the Pennsylvanian section, see Kottlowski and Stewart (1970).

Sandia Formation

The Sandia Formation was first described by Herrick (1900) for rocks in the Sandia, Manzano, and San Andres Mountains.

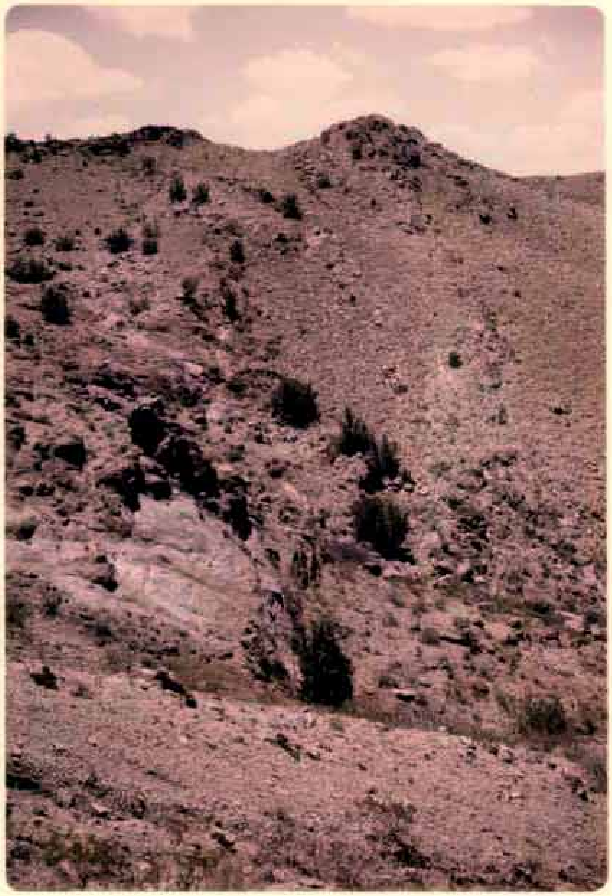
The Sandia Formation, 110 to 160 ft thick, consists of light-gray to brown quartzite overlain by argillaceous, fossiliferous limestone and dark-gray to black shale. There are some thin lenses of bone coal present in the shale. The basal contact is nonconformable with the Precambrian and the upper contact with the Madera is conformable to erosionally unconformable. The Sandia is slope-forming under cliffs of Madera Limestone. See Stratigraphic Column of the Sediments for details (Plate 2).

Madera Limestone

The Madera Limestone was named for rocks in the Sandia Mountains by Keyes (1903) (Plate 3).

The Madera Limestone consists of cherty, blocky, well bedded, fossiliferous, cuesta- and cliff-forming limestone, up to 250 ft thick. The upper contact with

Plate 1b: Precambrian complex in the southern part of the mapped area. View looking south near Rosa de Castillo arroyo.



STRATIGRAPHIC COLUMN OF THE SEDIMENTS

Plate 2

2273

Baca Formation: 60 ft thick, Tertiary alluvial mass, no volcanics, 45% San Andres Limestone and 50% Dockum Group.

2213

Dockum Group: 70 ft thick, a maroon, cross-bedded, imature (both texturally and compositionally), sandstone with some lenses of clay (fresh feldspar and quartz). Sand size is fine to coarse.

2143

San Andres Limestone:

massively bedded limestone, light gray, some silt, 30 ft thick.

karst colapse features, light grey, massive, fine-grained limestone, 45 ft thick.

light gray, fine-grained limestone, thicklybedded (beds less than 3 ft thick), 30 ft thick.

karst features, 20 ft thick.

light gray, thinly bedded limestone (beds 10 ft thick) 15 ft.

massive fossiliferous, light gray limestone (beds over 10 ft thick) fossils are mainly recalcified microfossils; texture

interbedded, red and grey siltstone and grey limestone; texture is that of a sponge, 30 ft thick.

1908

Glorieta Sandstone:

block, cliff-forming, well-bedded, fine-grained, well-silicified, sandstone, 90 ft thick

red and purple mudstone and very fine-grained sandstone, 18 ft thick, and slope-forming.

1785

blocky, well bedded, fine-grained, quartz sandstone, 15 ft thick.

Yeso Formation, Jovita Sandstone:

rhytnmic concentric color layering

white, yellow and [illegible], [illegible]bedded, very fine-grained, quartz sandstone, 60 ft thick

red, purple and yellow mudstone, 10 ft thick.

red mudstone grading up into red to pink fine sandstone with a little hematite staining, 80 ft thick.

red limy mudstone with some zones better indurated than others, 45 ft thick.

1595

Torres Member: ridge-forming, grey, sandy, limestone, 10 ft.

interbedded red and yellow siltstone and gray limestone, 40 ft thick.

sandy, coarse-grained, gray, very thinly bedded(less than 1 in) limestone, 30 ft thick.

red mudstone

white to gray limy mudstone interbedded with gray limestone, 25 ft thick.

red mudstone, 30 ft thick.

yellow siltstone 15 ft thick.

gray limestone with some gray siltstone, 10 ft thick.
white siltstone, 10 ft thick.

yellow cross-bedded mudstone and siltstone, 55 ft thick.

red mudstone, 55 ft thick.

gray to green silty limestone 5 ft thick.

red and yellow mudstone and siltstone 65 ft thick.

1125

cliff-forming, limy, greenish-gray claystone, 10 ft thick.

Meseta Blanca Sandstone:

jointing

white, very fine sandstone and siltstone, with surface coating of hematite, distinctly cross-bedded, 210 ft thick.

white to grey very fine sandstone and siltstone, slightly calcarious, crossbedded, 40 ft thick.

pinkish-yellow, ripple marked, slope-forming siltstone, 50 ft thick.

interbedded, red and yellow siltstone and mudstone, 50 ft thick.

785

Abo Formation:

red mudstone 30 ft thick.

interbedded siltstone, mudstone and arkose, red in color, 55 ft thick.

red interbedded siltstone and mudstone, 25 ft thick.

red, slightly calcarious shale, 15 ft thick.

interbedded (beds 5 ft thick), red siltstone with some pebbles and red mudstone, 10 ft thick.
red mudstone with some calcite veining, 20 ft thick.

massive, white, yellow and purple, cross-bedded siltstone, 20 ft thick.
red mudstone with some calcite inclusions 15 ft thick.
red, ridge-forming, siltstone, 5 ft thick.
red, mudstone with some calcite inclusions, 15 ft thick.
white, ridge forming cross-bedded siltstone, 5 ft thick.

red calcarious mudstone, 25 ft thick.

light pink to white, cross-bedded siltstone, ridge-forming, 25 ft thick.

red, cross-bedded calcarious, interbedded siltstone and mudstone, 80 ft thick.

440

Bursum Formation: reddish-brown, angular quartz-cobble arkose, with a basal, light green, crinoidal, limestone-granule conglomerate, 30 ft thick.

410

Madera Limestone: (see Kottlowski and Stewart, 1970; Coal Mine Canyon section for complete stratigraphic analysis) 250 ft thick.

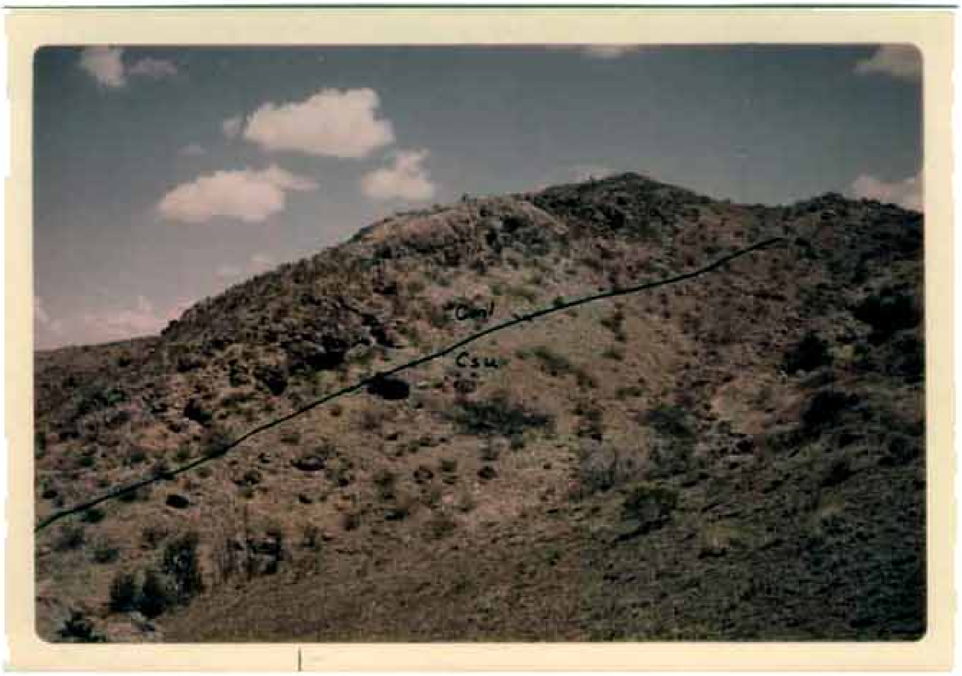
160

Sandia Formation: (see Kottlowski and Stewart, 1970; for complete stratigraphic analysis) 160 ft thick.

0

Precambrian: quartz—potassium feldspar gneiss

Plate 3: Contact between the Madera Limestone and the Sandia Formation. View northeast between Canoncito Colorado and Central Canyon.


Csu

the Bursum is an erosional unconformity. See Stratigraphic Column of the Sediments for details (Plate 2).

Permian System

The Permian System, 1635 ft thick, is represented by five formations: the Bursum Formation, the Abo Formation, the Yeso Formation, the Glorieta Sandstone, and the San Andres Limestone. These units include sediments containing arkose, mudstone, shale, siltstone, sandstone, and limestone.

Bursum Formation

The Bursum Formation was named by Wilpolt and other (1946) for rocks in Socorro County, New Mexico. The Bursum was mapped and described in detail by Kottlowski and Stewart (1970).

The Bursum Formation, 30 ft thick, is a reddish-brown, angular, quartz-cobble arkose, with a basal, light-green, crinoidal, limestone-granule conglomerate. The contact between the Bursum and underlying Madera Limestone is unconformable. Much of the sediment in the Bursum was derived from the Madera Formation, the Sandia Formation, and the Precambrian. The upper contact is gradational with the Abo Formation. The upper arkose in the Bursum is used as the contact between the Abo Formation and the Bursum

Formation. The Bursum forms small ridges and arroyos. See Stratigraphic Column of the Sediments for details (Plate 2).

Abo Formation

The Abo Formation was described by Lee and Girty (1909) with the type locality 2 miles west-northwest of the village of Abo, New Mexico.

The Abo Formation is a series of dark red, interbedded siltstones, mudstones, and shales, which is 345 ft thick (Plate 4a). It conformably overlies the Bursum Formation and is overlain gradationally and transgressionally by the Meseta Blanca Member of the Yeso Formation.

The basal contact with the Bursum is sharp and is marked by a greenish-red, calcite-cemented, pebble arkose at the top of the Bursum. The contact of the Abo with the overlying Yeso Formation is marked by an upward change to sandstone or mudstone which contains no fresh feldspar and by a color change from dark red to pink or yellow. Throughout the Abo Formation, the siltstones form ridges and cuestas and the shales and mudstones form slopes and strike valleys. The siltstone exhibits much cross-bedding and a few ripple marks. The mudstone and shale in the Abo have a tendency to deflect faults parallel to the strike of bedding and to deform plastically. See Stratigraphic Column of the Sediments for details (Plate 2).

Plate 4a: Abo dipping 40° W. in the northern part of the mapped area. Photograph shows Bursum and Yeso contacts with the Abo. View looking south along the Cañada Ancha.


Pb
Pa
Pa

Yeso Formation

The Yeso Formation was mapped and described by Lee and Girty (1909). They chose Mesa del Yeso, which is located in the southeast corner of the mapped area, as the type locality.

The Yeso consists of four members, three of which are mappable throughout the area, and the fourth, although it is present in the central and southern part, is not mappable on the present scale (Plate 4b). The lowest member in the Yeso, the Meseta Blanca Member, overlies and is in gradational contact with the Abo, and is overlain by the Torres Member. The Torres Member is overlain by the Cañas Gypsum Member in part of the area and elsewhere the Torres is overlain by the Joyita Sandstone Member. The Yeso Formation is transgressionally and gradationally overlain by the Glorieta Sandstone.

Meseta Blanca Sandstone Member

The Meseta Blanca Sandstone Member of the Yeso Formation was named by Wood and Northrop (1946) for sandstone near San Ysidro, New Mexico.

The Meseta Blanca Sandstone, 340 ft thick, is pink, yellow, and white (weathered), cliff- and ridge-forming siltstone and very fine-grained sandstone, with a minor mudstone at the base (Plate 5a). Distinctive features which

Plate 4b: Yeso section: Meseta Blanca Sandstone at the base, Torres Member in the middle and Joyita Sandstone at the top. View looking west, the Ladron Mts. in the background, between Central Canyon and Cañoncito Colorado.

Psa
Psa
Pyj
Pyc
Pym

Plate 5a: Meseta Blanca Sandstone dipping 45° W. View looking south along Cañada Ancha.

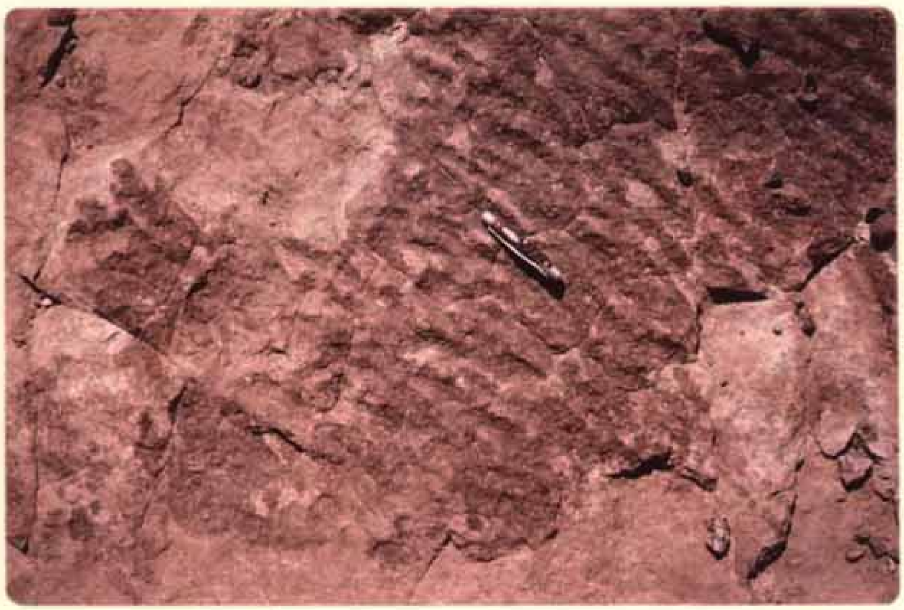
are found throughout the Meseta Blanca are ripple marks and cross-bedding (Plate 5b). It transgressionally and conformably overlies the Abo Formation. The base of the Meseta Blanca is defined as those mudstones or siltstones which do not contain fresh feldspar. Other characteristics of the basal Meseta Blanca are the upward change from dark red to pink and yellow and the absence of mudstone. The upper contact is below the first limy, cliff-forming mudstone that occurs upward in the section. See the Stratigraphic Column of the Sediments for a complete description (Plate 2).

Torres Member

The Torres Member of the Yeso Formation was described by Wilpolt and others (1946) for rocks occurring 2 miles east of the mapped area.

The Torres Member contains interbedded, red and buff siltstone and claystone; gypsiferous siltstone; and gray, ridge-forming limestone. Siltstone is more abundant at the base and limestone is predominant at the top, with limestone forming ridges and siltstone forming arroyos. The basal contact is sharp and conformable with the underlying Meseta Blanca Sandstone Member. The upper contact with the Cañas Gypsum Member is not well defined, but occurs below the gypsiferous siltstone. In the northern part of the mapped area the Joyita Sandstone Member lies

Plate 5b: Ripple marks in the Meseta Blanca Sandstone.



disconformably on the Torres Member. The uppermost limestone in the Torres is the contact between the Torres and the Joyita Sandstone. See the Stratigraphic Column of the Sediments for a complete description (Plate 2).

Cañas Gypsum Member

The Cañas Gypsum Member was described by Needham and Bates (1943) near Mesa del Yeso, 2 miles southeast of the southeast corner of the mapped area. It is absent in the northern part of the mapped area where the Joyita Sandstone Member directly overlies the Torres Member.

The Cañas Gypsum Member at its type locality is 155 ft of gypsum, but in the central part of the mapped area the Cañas occurs as white, gypsiferous, slope-forming, bedded (less than 6" thick), siltstone, not more than 5-10 ft thick (Plate 6). The basal contact is placed above the uppermost limestone of the Torres Member and the upper contact is placed below the lowest red mudstone in the Joyita Sandstone Member.

Joyita Sandstone Member

The Joyita Sandstone Member was named by Needham and Bates (1943) and designated as the upper member of the Yeso Formation. The type locality is in La Joyita Hills, Socorro County, New Mexico, 3 miles southeast of the mapped area.

Plate 6: Cañas Gypsum Member in the northwestern part of the mapped area. Contacts are shown between the Cañas and the Joyita. View looking west in Central Canyon.


Pyj
Pyc

Bright red mudstones interbedded with sandstone characterize the Joyita Sandstone throughout the area. It is underlain in the northern part of the mapped area by the Torres Member and is underlain by a thin remnant of the Cañas Gypsum Member in the central part of the mapped area. The Joyita Sandstone, 190 ft thick, is transitionally and gradationally overlain by the Glorieta Sandstone.

The basal part of the Joyita Sandstone Member is 45 ft of red, limy mudstone. This red mudstone grades upward into pink, fine-grained sandstone through an interval of 80 ft. Above is fine-grained, crossbedded, cliff-forming sandstone 65 ft thick. At the base of the Glorieta is a blocky, silicified, cliff-forming sandstone separating the Glorieta from the Joyita Sandstone. See Stratigraphic Column of the Sediments for more complete description (Plate 2).

Glorieta Sandstone

The Glorieta Sandstone was named by Keyes (1915) for a section at Glorieta Mesa, San Miguel County, New Mexico. Wilpolt and others (1946) and Wilpolt and others (1951) mapped it as the lower member of the San Andres Formation. However, the New Mexico Bureau of Mines and Mineral Resources recognizes the Glorieta Sandstone as a separate formation (Jicha and Balk, 1958).

The Glorieta Sandstone is a massive, cliff-forming, partially silicified, white to buff sandstone, 123 ft thick. It gradationally and transgressionally overlies the Joyita Sandstone Member of the Yeso Formation (Plate 7a). The base of the Glorieta is placed above the highest red mudstone of the Joyita Sandstone Member. The upper contact between the Glorieta Sandstone and the San Andres Limestone is sharp, although there are some "lenticular Glorieta-like sandstones" (Wilpolt and others, 1946), which represent a transitional phase in the lower San Andres Limestone.

The Glorieta has three informal members, in ascending order: (1) a slightly silicified, mineralogically pure, but texturally immature, cross-bedded quartz sandstone 15 ft thick; (2) 18 ft of Joyita Sandstone-like red and purple mudstone and very fine-grained cross-bedded sandstone; and (3) 90 ft of blocky, cliff-forming, well-bedded, silicified, fine-grained sandstone. The upper member contains local color banding and some rhythmic concentric color layering (Plate 7b) which are associated with goethite. Most of the sandstone contains angular quartz with a few grains of fresh biotite. See the Stratigraphic Column of the Sediments for detail (Plate 2).

San Andres Limestone

The San Andres Limestone was named by Lee and Girty (1909) for limestone in the San Andres Mountains. Wilpolt and others (1946) and Wilpolt and others (1951) mapped it as

Plate 7a: Contact between the Joyita Sandstone and the Glorieta Sandstone. View looking west in Central Canyon.

Plate 7b: Rhythmic concentric color layering in the Glorieta Sandstone. View looking west in Central Canyon.


Psg
Pyj

the middle member of the San Andres Formation. The New Mexico Bureau of Mines and Mineral Resources suggests that it is a separate formation (Jicha and Balk, 1958).

The San Andres Limestone is a massive, cliff-forming, silty, light-gray limestone which is 235 ft thick. The San Andres conformably overlies the Glorieta Sandstone (Plate 8) and is unconformably overlain by the Triassic Dockum Group. The base of the San Andres contains "lenticular Glorieta-like sandstones" (Wilpolt and others, 1946).

The San Andres is characterized by moderately well developed karst features. It is notably lacking in megafossils, but there are a few brachiopod, pelecypod, gastropod, crinoid, and scaphopod fragments present (Huber, 1961). Microfossils are present, but not easily identifiable due to recementation. Most of the formation is cliff-forming with a notable exception at the top which is a silty limestone weathering to low, rolling hills. See the Stratigraphic Column for a complete description (Plate 2).

Triassic System

The Triassic System is only locally present in the mapped area. It is confined to the Dockum Group of late Triassic age which is only 70 ft thick.

Dockum Group

The part of the Dockum Group in this area is best

Plate 8: Contact of the San Andres Limestone with the Glorieta Sandstone. View looking west in Central Canyon.


Ps
Psg

correlated with the Santa Rosa Formation. The Santa Rosa Formation was first described by Hager and Robitaille (1919) in eastern New Mexico. Wilpolt and others (1946) reported the Triassic in the mapped area as Dockum.

The Dockum Group is maroon, cross-bedded, immature (both compositionally and texturally) sandstone, which is 70 ft thick. It is unconformably overlain by the Baca Formation.

The basal contact between the Dockum and the San Andres is sharp. This is based more on the color of the Dockum than on the weathering characteristics of either formation. The Dockum Group forms low nonresistant hills and is easily eroded. See the Stratigraphic Column of the Sediments for a complete description (Plate 2).

Cretaceous System

The Cretaceous System consists of the Mancos Shale. Wilpolt and others (1946) also include the Mesa Verde Formation, but because of lack of evidence for the presence of this formation, it was mapped as Mancos--Mesa Verde undifferentiated.

Mancos-Mesa Verde Undifferentiated

The Mancos-Mesa Verde undifferentiated occurs only in the eastern part of the mapped area, and consists of buff to black shale and buff to brown sandstone and siltstone up to 700 ft thick. Most of it forms a flat surface, but there are a few outcrops which form resistant, isolated cuestas. The upper contact between the Mancos-Mesa Verde undifferentiated and the overlying Baca is an erosional unconformity.

Tertiary System

The Tertiary System is composed of four mappable rock units: (1) the Baca Formation, which is a nonvolcanic conglomerate; (2) Extrusive Rocks, which consist of ash- and lava-flows, and air-fall and water-laid tuffs; (3) the Santa Fe Group, which is a series of volcanic and sedimentary mud-flows and conglomerates; and (4) acidic and basic intrusive rocks. Tertiary rocks comprise more than 50 per cent of all rocks mapped and have been eroded from the west-central part of the mapped area.

Baca Formation

The Baca Formation was first described by Wilpolt and others (1946) as a coarse conglomerate in Baca Canyon near Bear Mountain in Socorro County, New Mexico.

The Baca Formation, 60 ft thick, is a coarse conglomerate composed of unsorted, boulder-size rocks derived from all earlier formations, but dominately San Andres Formation and Dockum Group. The basal contact is sharp and disconformable and it is unconformably overlain by Tertiary extrusive rocks. Topographically, the Baca Formation is represented by low hills, and is only slightly indurated, allowing it to be rapidly eroded. Its exposures are only locally present and are not conspicuous. See the Stratigraphic Column of the Sediments for detail (Plate 2).

Extrusive Rocks

The extrusive rocks were mapped by Wilpolt and others (1946) as undifferentiated Datil Formation. One of the key problems of the area was to map and to define the stratigraphy of and structure within these extrusions.

The units are a series of ash-flows, water-laid tuffs and flows, divided into 22 map units totaling more than 3070 ft in thickness. They are the predominant rock units in the southern and eastern part of the map area (Plate 9). The composition ranges from basalt to rhyolite, with rocks of intermediate composition, such as quartz-latite and andesite (An_{25}-An_{50}) most abundant.

The terrane of the volcanics is variable, but predictable. The acidic extrusives tend to be cliff-forming; the andesites and basalts are ridge- and slope-forming; and the water-laid tuffs and air-fall tuffs are arroyo-forming where they are unconsolidated, and ridge-forming where they are well indurated. The andesites have the most variable terrane of the extrusives, which may be due to the heterogeneity of the texture.

Plate 9: Volcanic flows and ash-flows in the southern part of the mapped area. View looking south, Rosa de Castillo Arroyo in the foreground. The ash-flows and flows shown in ascending order are: andesite flow Ta3, Trachyte ash flow Tt1, rhyolite ash-flow Tr2, and andesite flow Ta4.


Tr2
Ta4
Ta3

Stratigraphic Column of the Volcanics

Plate 10

Tb3: basalt flow, scoriaceous texture, brownish-black (fresh), weathers brown, undetermined thickness, crops out locally. Lower contact covered. Plagioclase (An_{60}), no upper contact exposed, probably in contact with the Santa Fe Formation.(see Plate 3).

Ta5: andesite flow, scoriaceous texture, black (fresh), weathers brown, calcite filling vugs, trachytic texture, holocrystalline, Plagioclase (An_{45}), olivine with reaction rims. Terrane: low hills. Thickness: 230 ft, may be incomplete, outcrop expressed as float (see Plate 23).

Tq3: quartz-latite ash flow, light gray, slightly welded, some calcite replacement, some pumice fragments up to 2 cm in diameter. Hypocrystalline, vitrophyric, ridge- and slope-forming, 130 ft thick, Plagioclase (An_{30}) (see Plate 24).

Tl5: latite ash flow, many basaltic fragments (see Ta4), flow texture, light brown, hypocrystalline, porphyritic, slope-forming, 130 ft thick (see Plate 24).

Tl4: latite vitrophyre, lava flow, black, porphyritic, slope- and arroyo-forming, 10 ft thick, thins to the south, some basalt fragments (Ta4), columnar joints developed on a small scale (½ cm in diameter), breaks easily along the columnar joints (see Plate 25).

Tl3: latite ash-flow, densely welded, glass shards, porphyritic, strong lineation, light brown, pumice fragments with some flattening, 25 ft thick, upper contact is sharp, basal contact grades into an air-fall tuff, plagioclase (An_{20}) (see Plate 25).

Air-fall and water-laid tuff: quartz-latite in composition; much randomly deposited pumice fragments, some displaying flattening and lineation; plagioclase (An_{19}); arroyo-forming; light buff, and 15 ft thick.

Ta4: a series of andesite flows and flow breccias; slope- and ridge-forming; brownish-black (unweathered), dark gray, dark brown, and dark red (weathered); scoriaceous texture, calcite fills vugs; plagioclase (An_{45}); trachytic texture, 390 ft thick (see Plate 26).

Tr2: rhyolite ash flow; brown (unweathered), dark red (weathered); Plagioclase (An_{25}); some basaltic rock fragments (Ta3); crystal-rich, strong flowage and lineation of pumice fragments, hypocrystalline, hyalopilitic; contact at base occurs at an unwelded zone 5 ft thick; unit is 90 ft thick; ridge-forming (see Plate 26).

unwelded zone

Tt1: trachyte ash flow, crystal poor, strongly welded, lineation due to collapsed pumice fragments; 70 ft thick; dark bluish-gray (weathered), tan (unweathered); cliff-forming; plagioclase (An_{17}); some Ta3 fragments (see Plate 27).

Ta3: a series of andesite flows containing flow breccias; many geodes of chalcedony and quartz; unit thins markedly and pinches out to the south; slope-forming; 245 ft thick; pilotaxitic texture; grayish-brown (weathered and unweathered), plagioclase (An_{45}) (see Plate 27).

Tw6: water-laid tuff; white; crystal-poor; pumiceous; valley-forming; 85 ft thick; basal contact is gradational; pinches out to the south.

Tl2: latite ash flow; slightly welded; pink to gray (unweathered), gray (weathered); lineation of weathered and flattened pumice fragments; crystal-poor; plagioclase (An_{20}) and some replacement plagioclase (An_{80}); 45 ft thick; cliff- and ridge-forming (see Plate 28).

Water-laid tuff: light pink; arroyo-forming; mostly pumice fragments; 15 ft thick.

Tr1: rhyolite-trachyte ash flow; welded; light gray to light pink; relatively crystal-poor; ridge-forming, but also forms talus slopes; Plagioclase (An_{26}); glass shards present; 115 ft thick.

Tw5: water-laid tuff; valley-forming; light buff to light gray; mostly pumice with fresh sanidine, quartz, and biotite; 145 ft thick.

Tq2: quartz-latite ash flow; most widely distributed of all the flows--occurs throughout the area; moderately welded; 25 ft thick in the south and up to 970 ft thick in the northwest; cliff-forming, although this feature is not well developed in some places due to the overlying, cliff-forming water-laid tuff; gray to dark gray; Plagioclase (An_{17}); glass shards; section measured in the south (see Plate 29).

Tw4: water-laid tuff; rhyolitic in composition, grades downward into Tq1; cliff-forming; light gray (unweathered), light buff (weathered); well bedded; 90 ft thick.

Tq1: quartz-latite ashflow; ridge-forming; reddish-brown (weathered), light brown (unweathered); plagioclase (An_{30}); knobby terrane; 95 ft thick; blocky; good lineation due to flattened pumice fragments (see Plate 29).

Water-laid tuff: 30 ft thick; rhyolitic in composition; grades into Tq1; slope forming; light pink.

Ta2: andesite flow containing some flow breccias on its perimeter; black (unweathered), dark gray, brown, or red weathered, especially in flow breccias; maximum thickness: 100 ft; plagioclase (An_{25}); much secondary quartz in nodules, pilotaxitic texture (see Plate 30).

Tl1: latite ash flow; 15 ft thick; crystal-poor; rock fragments present (Ta1?); moderately resistant; slightly welded glass shards; plagioclase (An_{10}); some flow structure; thins to the south; outcrops poor, often covered by float from Ta2 (see Plate 30).

Tw3: water-laid tuff; brownish-red; some bedding; fragments show some sorting; rhyolitic composition, with feldspar slightly rounded, and biotite with a bronze color; underlain by an unsorted, unbedded, water-laid tuff; thickness 35 ft; cliff-forming.

Tw2: water-laid tuff; 220 ft thick; light buff; not well consolidated; fine-grained; pumiceous; valley-forming.

Tb2: basalt-porphyry flow; 215 ft thick; cliff-forming; large plagioclase phenocrysts, some altered to green clay; porphyritic texture; brownish-gray (weathered and unweathered); plagioclase (An_{57}) (see Plate 31).

Tw1: water-laid tuff; 245 ft thick; pumiceous; thins and pinches out to the north.

Tb1: basalt flow; ridge-forming; localized outcrops; plagioclase (An_{25}) some zoned (An_{30}-An_{95}); intersertal texture; black (unweathered), dark gray (weathered); thickness at outcrop: 90 ft. (see Plate 31).

Ta1: andesite flow and flow breccias; 170 ft thick; gray (unweathered and weathered); interstitial texture; holocrystalline; plagioclase (An_{37}) (see Plate 32).

An extrusive andesite map unit usually consists of a series of individual flows, marked by flow breccias at the basal and upper contact as well as at the distal ends of the flow. Recognizing and mapping individual flows within these units is difficult because of float covering the contacts.

Many of the ash-flows contain lithic fragments of lower andesite units. Usually, the lithic fragments can be identified as to the unit from which they were derived by the mineralogy of the fragments.

The complete sequence of deposition of the extrusives is shown in the "Stratigraphic Column of Volcanics" (Plate 10). For modal analyses and photomicrographs of extrusive rocks refer to Table 2 and photomicrographs in the appendix.

Santa Fe Group

The Santa Fe Group was first described by Hayden (1869) as marls and conglomerates in the Rio Grande trough around Santa Fe, New Mexico.

The Santa Fe Group in the mapped area is a series of conglomerates and volcanic mud-flows. Most of the formation is well cemented and forms ledges and caves along its border in the northern part of the mapped area. The Santa Fe dips 5^{o} to the west throughout the area and is angularly unconformable on the Precambrian, Pennylvanian, Permian, Triassic, and Tertiary rocks. Its topographic expression is that of low, rolling hills dissected by west draining arroyos.

Intrusive Rocks

Intrusive rocks in the mapped area were included by Wilpolt and others (1946) with the Datil Formation or Quaternary Basalts. These intrusives are mapped and distinguished according to the rock type. These rocks are post-Santa Fe as they intrude the Santa Fe and older rocks.

Intrusives are mainly andesites (An_{22}-An_{43}), but there are a few basalts (An_{55}-An_{60}) and a few rhyolites in the northern part of the area (Plate 11). The andesites form dikes in fault zones along with small intrusives not more than 100 yd in diameter. Rhyolite forms small intrusions along the east fault contact between the Precambrian and the volcanics. Also, rhyolite forms very small stocks along fault zones in the northern part of the area. These rhyolite intrusions do not appear to be feeders to the extrusives because of their limited extent and their composition.

The rhyolite intrusions exhibit flow banding which controls the foliation; no glass shards are present. There are flattened gas bubbles in some of the stocks. The rocks are cliff-forming and there are some columnar joints.

For modal analyses of the intrusive rocks, see Table 2 in the appendix.

Plate 11: Intrusive rhyolite. Note the flow-banding which controls the foliation. View looking north, 1 mile east of the northern end of the Precambrian complex in Cañada Ancha.

Quaternary System

Quaternary deposits occur extensively throughout the eastern part of the mapped area. They are flat-lying deposits of red to yellow sand, gravel and mud, which are loosely consolidated; they constitute basin fill in the Valle del Ojo de la Parida and the Valle de la Joya. These deposits were derived from a combination of the Santa Fe Group sediments on the north, Tertiary volcanics on the west, and Permian sediments on the east.

Recent stream channels contain alluvium composed of reworked Tertiary and Quaternary sediments, and are mapped where extensive.

STRUCTURE

Regional Setting

La Joyita Hills is situated in the Mexican Highland Section of the Basin and Range Province (Fenneman, 1931), a province characterized by "disordered fault-block ranges with graben-like troughs" (Thornbury, 1967). La Joyita Hills (Figure 2), as used in this report, is structurally bounded by the Albuquerque basin on the north; by the Socorro constriction on the west; by the Los Pinos uplift on the east; and by a southward plunge beneath Santa Fe sediments south of Arroyo Alamillo.

La Joyita Hills consists of a series of horsts bordering the Rio Grande graben. The structural complexity of the mapped area is enhanced by the constriction of the Rio Grande graben at the San Acacia channel, which is developed to the west of the central mapped area. According to Kelley (1952), "La Joyita Hills is a low fold or anticlinal bend, which intervenes between the Jornada del Muerto and the Rio Grande depression, broken by a network of high-angle faults." The suggestion of right slip or right shift locally along the margins of the Rio Grande graben may be discernible in the N. 48° W. and the N. 32° E. fault sets that indicate north-south compression.

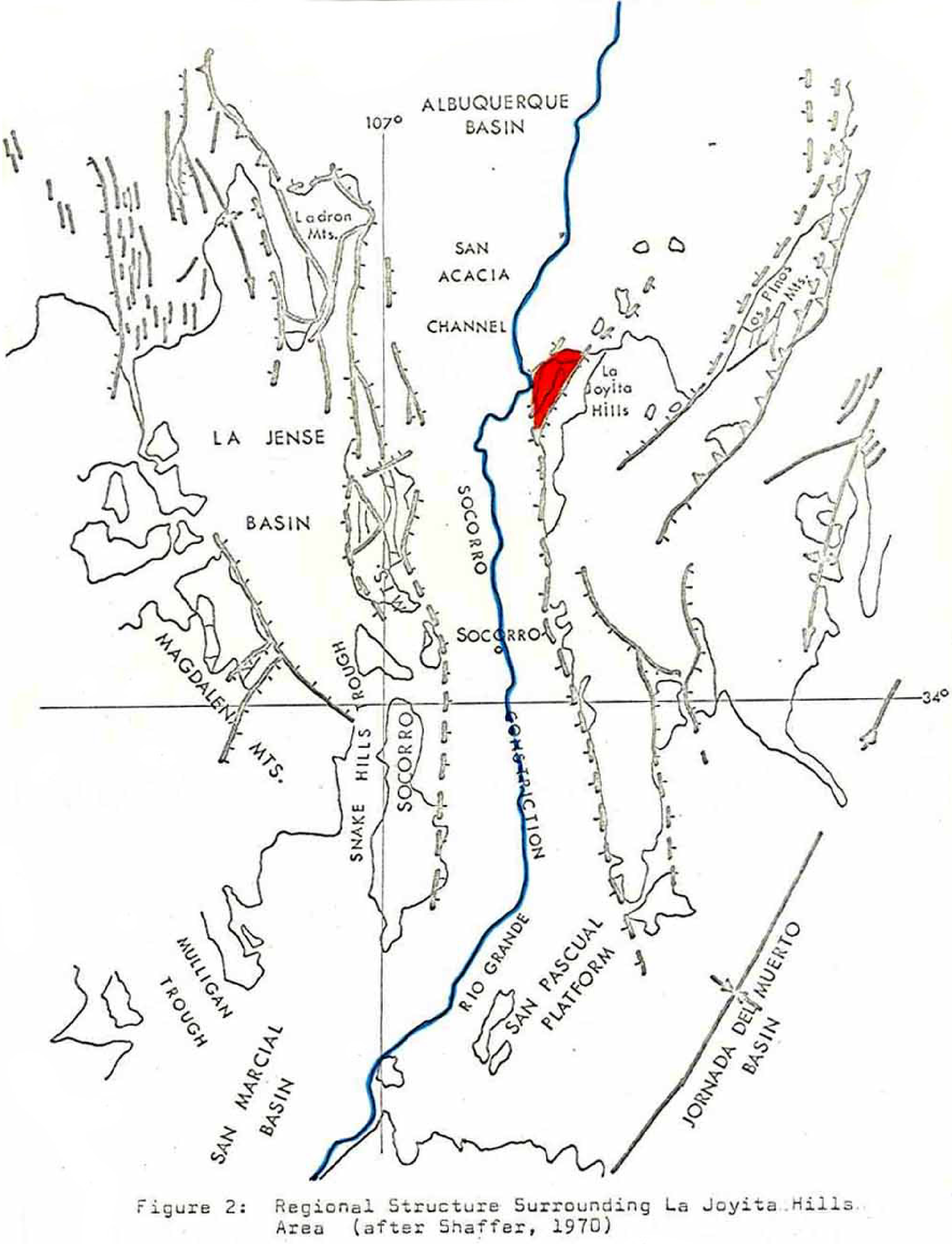


Figure 2: Regional Structure Surrounding La Joyita Hills Area (after Shaffer, 1970)

Precambrian Deformation

Geometry

The Precambrian structure is related to foliation and schistosity parallel to compositional layering in the gneiss. In the north, the foliation strikes north and dips 50° to 85° east. In the central part of the complex, the foliation strikes N. 35° E. and dips 60° to 82° southeast. In the south, the strike of the foliation progressively changes direction until it reaches an east-west direction, dipping 53° to 68° south.

There is a lack of evidence for folds within the complex, but there may have been some faulting. Movement may have occurred along the Rosa de Castillo fault at the southern end of the complex. Herber (1963) records several folds and a syncline within the Precambrian complex which are not evident when considering the foliation, schistosity, and lineation. Herber (1963) also recorded some compositional layering in the quartz-biotite-potash feldspar-gneiss, which he called "relic bedding," but it it not apparent without detailed petrographic analysis.

The lineation is generally in the same plane as the rake of the foliation.

History

The structural history of the Precambrian complex according to Herber (1963), pp. 33-34) is as follows (Figure 3):

> 1. Sedimentation: deposition of arenaceous, impure calcareous, or basic volcanic sediments. . . .
> 2. Regional metamorphism and deformation producing isoclinal folding which resulted in the formation of axial plane cleavage (foliation) and a b-lineation. . . . Simultaneous development of schistosity within axial plane cleavage.
> 3. Deformation (broad warping) which disrupted the structure pattern of the earlier regional deformation. . . .
> 4. Alkali feldspathization which may have occurred later than the regional deformation but earlier, during or later than the second deformation.
> 5. Jointing, which, because of its uniform orientation throughout the area, occurred later than either deformation.
> 6. Pegmatitization and probably the formation of aplite dikes.
> 7. Faulting and fracturing which may be temporally related to the jointing and pegmatitization or may be occurring at the present time.

The jointing, faulting, and pegmatitization were probably Tertiary events related to the formation of the Rio Grande graben. The Rosa de Castillo fault was probably the result of a tension couple during the Precambrian with renewed movement in the Tertiary.

Paleotectonics Associated with the Wolfcamp Joyita Uplift

The Wolfcamp Joyita uplift, according to Kottlowski and Stewart (1970), was a major uplift centered in La Joyita Hills area and "is a well documented key to the widespread orogeny of late Virgilian and early Wolfcampian

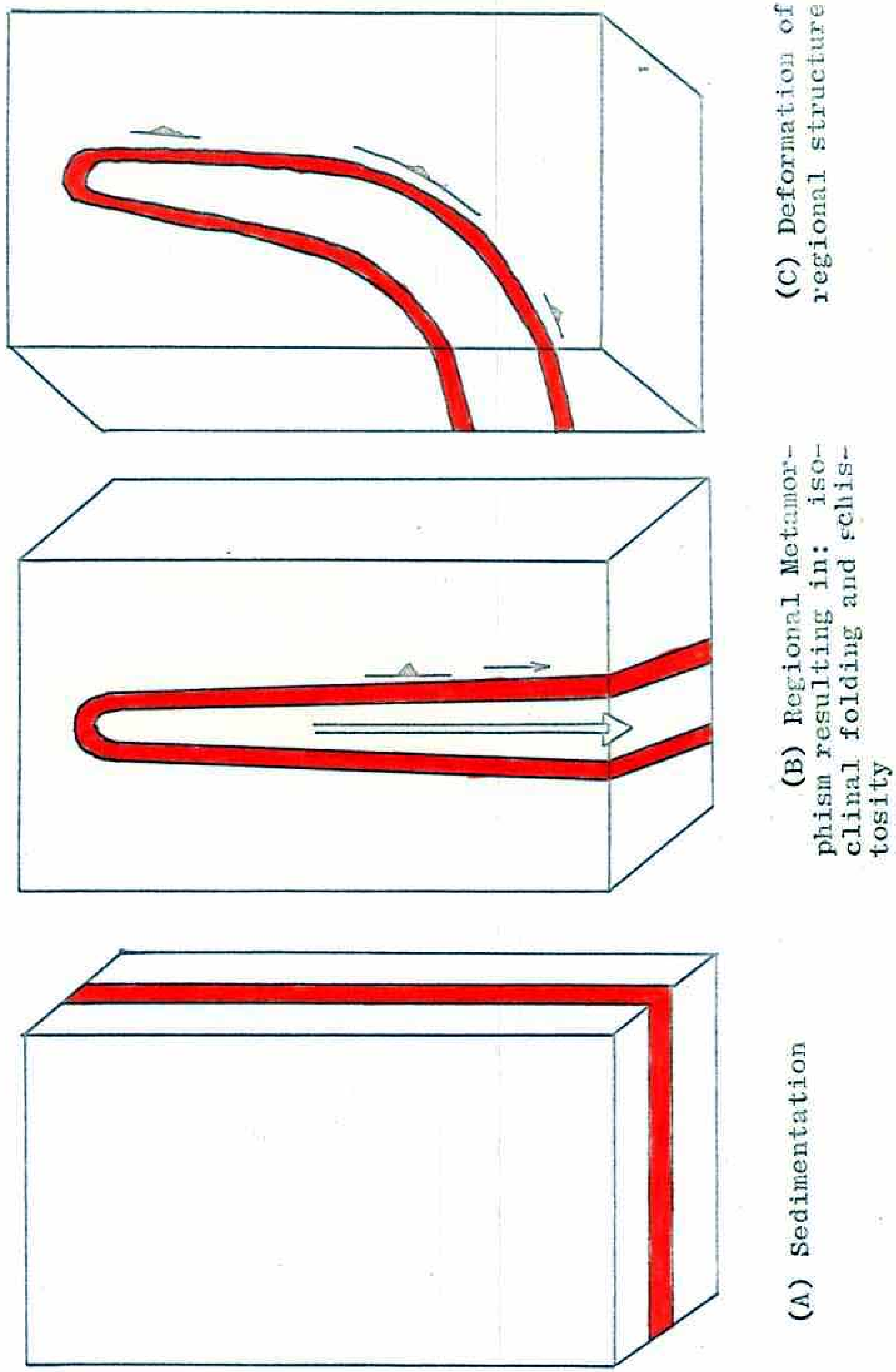


Figure 3: Precambrian Structural History (after Herber, 1963

time." The uplift is delineated by the deposition of the Bursum Formation of Wolfcamp age on top of the Madera Limestone of late Virgil age.

The Bursum is a terrestrial conglomerate, whereas the Madera is a marine limestone. The sediments of the Bursum grade upward from a nodular limestone to a fresh arkose with angular quartz cobbles through an interval of 30 ft indicating a rapid change in sedimentary environment. However, there is no angular discordance between the Virgil and the Wolfcamp in the mapped area. The Bursum facies wedge out to the south in the mapped area, but is present east of Socorro, New Mexico (Smith, C., personal communication). The northern extent of the uplift is not known due to truncation by the Tertiary Canada Ancha fault. According to Kottlowski and Stewart (1970, p. 30):

> In the southern part of the Joyita Hills, the small Joyita uplift rose above the early Wolfcampian seas, Pennsylvanian strata were truncated by erosion during this early Wolfcampian (and late Virgilian?) episode, and the basal Wolfcampian siliciclastics, the Bursum facies, were laid down across the various Pennsylvanian units. The wedgeout of the Bursum facies from north to south under the Abo facies in the area of study further supports the presence of the Early Wolfcampian Joyita uplift. Angular shards of quartz, and large fresh clasts of feldspar and granite gneiss attest to the nearness of the local uplift.

The uplift occurred over a relatively short period of time, which is indicated by the thin layer of sediments and the rapid change in composition of the sediments in the Bursum.

Paleotectonics of the Post-Leonard--Pre-Keuper Uplift

Post-Leonard--Pre-Keuper uplift is similar to the Wolfcamp uplift. The deposition of the Dockum Group, of Late Triassic age, which is a coarse-grained, immature, reddish sand, is angularly disconformable on the San Andres Formation. No associated faulting or folding occurred with this uplift.

The uplift was probably broad regional uplift, with the erosion of the upper member of the San Andres Formation, if it was present. This was followed by the deposition of sand and arkose of the Dockum in a high-energy environment and subsequent erosion of the Dockum. The center of this uplift is difficult to determine, because of the small areal exposure of the Dockum Group.

Tertiary Structure

Geometry

Tertiary structures in the mapped area consist of block-faults with some associated minor thrusts and a few drag folds. There are four main fault sets in the mapped area (see Figure 4). The oldest set is the one trending N. 80° E. The major fault in this set is the Rosa de Castillo fault. Later fault sets trend N. 10° W., N. 48° W.,

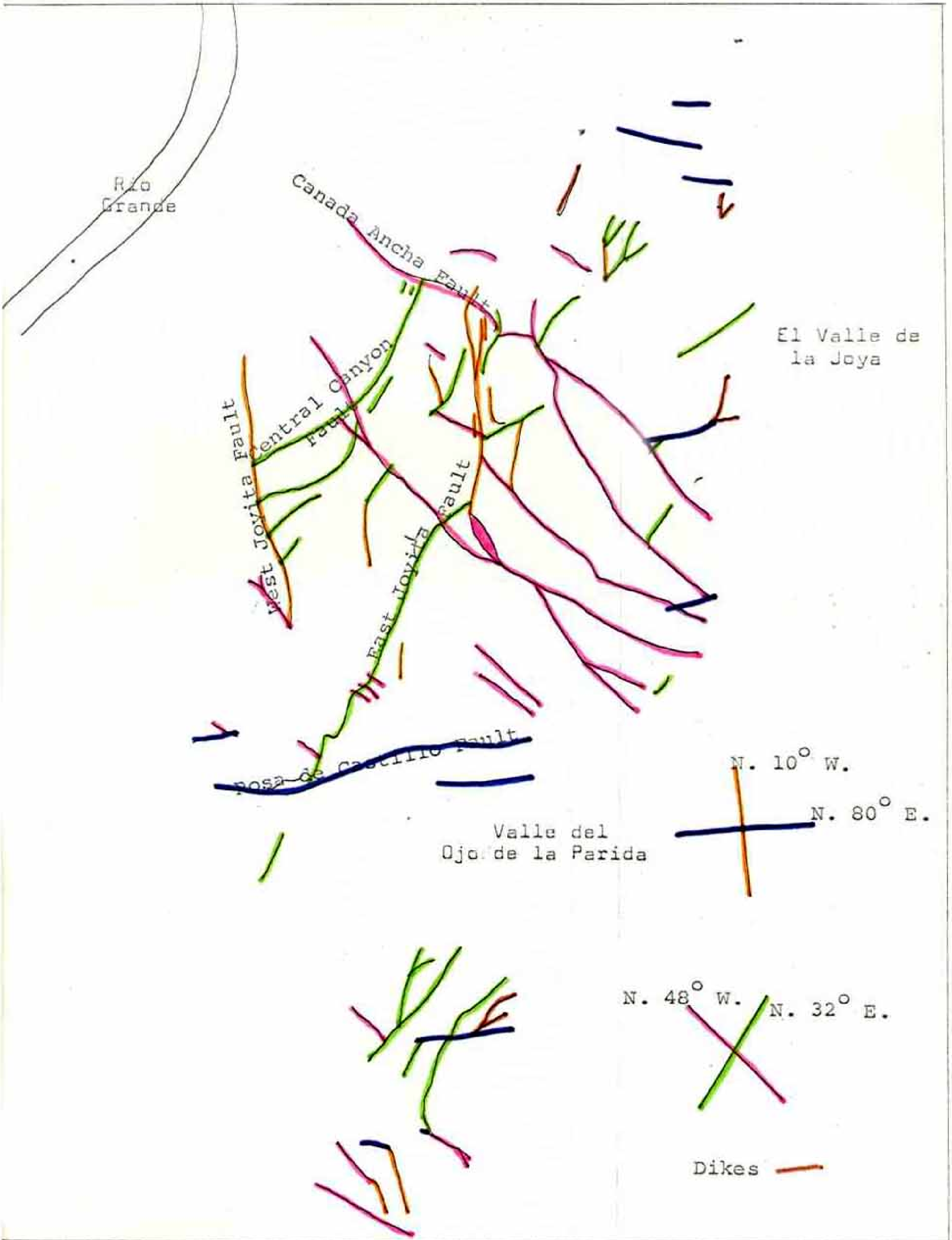


Figure 4: TERTIARY FAULT SYSTEMS

and N. 32° E. Most of the intrusives in the mapped area lie either in the fault zones or are parallel to one of the sets.

Rosa de Castillo Fault

The Rosa de Castillo fault is one of the more interesting faults in that it possibly began movement in the Precambrian and later experienced movement in the Tertiary. The fault in the Precambrian complex appears to be silicified and is difficult to identify.

Topographically, the Rose de Castillo fault forms an arroyo, which indicates its direction as it passes through the Precambrian complex. In the Tertiary volcanics the fault is more readily identified. Where the fault surface is present, it is difficult to determine the nature of the fault. From the outcrop and the map it appears to be a high-angle, normal fault with the south side down. The fault, as it is traced east, cuts through part of the volcanics, displaying apparent offset with the south side east. The fault zone is well silicified, but is usually covered. Andesite flow Ta3 is contorted, displaying erratic strikes and dips near the fault. Andesite flow Ta3 along with ash-flow Tq3, andesite flow Ta5, and basalt flow Tb3 are missing north of the fault. The easternmost part of the fault is filled by a manganese-rich andesite dike.

West Joyita Fault

The West Joyita fault, trending N. 10° W., is a normal fault dipping 30° to the west. Its surface is best exposed in the Cañoncito Colorado, where Tertiary Santa Fe Group is downthrown against early Tertiary volcanics (Plate 12). It is also exposed to the south where Santa Fe is downthrown against Permian rocks. The fault in Permian rocks is a silicified and brecciated zone not more than 10 ft wide with small drag folds on either side of the fault zone. The drag folds generally have an arc of circumference of less than 10 ft and a radius less than 20 ft.

The topographic expression of the West Joyita fault includes some small arroyos, but is not a major topographic feature itself. It is impossible to determine the net slip of this fault. The strike separation is about 1000 ft; the fault has 3315 ft of normal throw. Wilpolt and others (1946) interpret this fault as a thrust. Considering the relative ages of the sediments on either side of the fault surface, the angle and the direction of the fault surface, and the direction and sense of the drag folds, only normal movement has occurred in the area.

East Joyita Fault

The East Joyita fault, striking N. 10° W. in the

Plate 12: West Joyita fault: Santa Fe faulted down against Tertiary volcanics (Tq2). View looking northeast, fault trends N. 10° W. and dips toward viewer.


Tsf
Tq2

north and N. 32° E. in the south and dipping 80° to the east, has the most clearly exposed fault surfaces in the mapped area. The fault at the northeastern end of the Precambrian complex separates the Precambrian from the Pennsylvanian section (Plate 13a). The Precambrian fault surface is scratched and marked by slickensides that rake 42° south indicating the possible direction of movement (Plate 13b). The movement on this fault is normal, with some strike slip component. The fault zone is often filled with mylonite as can be seen in Plate 13a, but is usually covered. In the southern part of the fault, the fault zone has been intruded by a mineralized, flow-banded rhyolite and associated intrusive breccias.

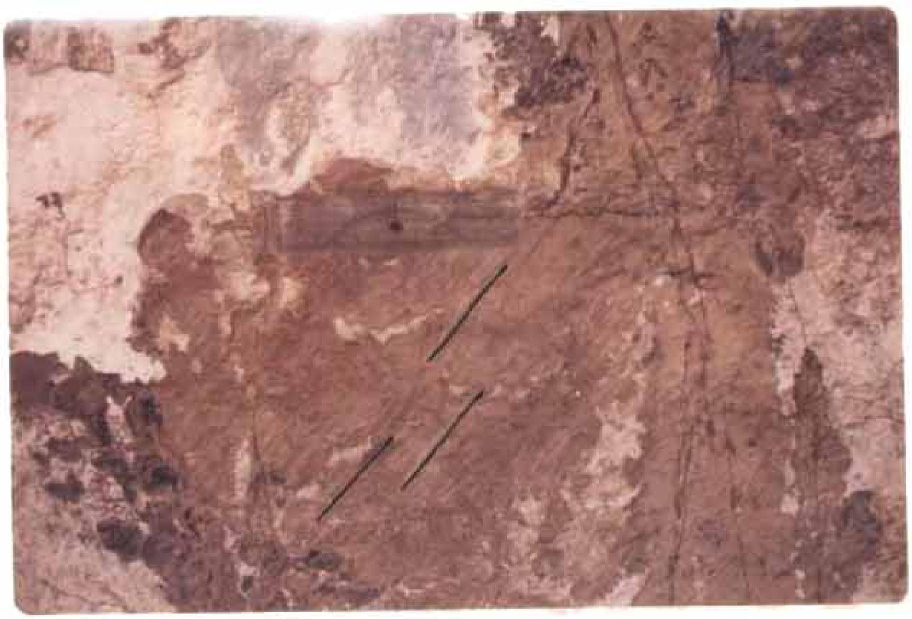
Topographically, the Precambrian block appears to be rising above the volcanic section with some recent fault scarps at its base. Near the fault the sediments and volcanics dip sharply to the east indicating a possible large scale drag fold or a small syncline.

Cañada Ancha Fault

The Cañada Ancha fault trends N. 48° W., dips from 32° south to vertical. The fault zone is a silicified and calcified breccia zone up to 20 ft thick. It truncates the northern Precambrian, Pennsylvanian, and Permian rock units. The fault is complicated by the intersection of

Plate 13a: East Joyita fault southwest of Ojo del Padre. Exposure in prospect. View looking north.

Plate 13b: East Joyita Fault: slickensides and gouge on fault surface in Plate 13a showing possibl direction of latest movement.



the East Joyita fault along with minor thrusting from the northeast. The fault does not have associated drag folds such as accompany the East and West Joyita faults.

The topographic expression is generally arroyo-forming except where it has been covered by Santa Fe Formation and at the junction of the two fault zones where it is covered by talus or obscured by other faults. The strike separation is 2200 ft and the stratigraphic separation is 1600 ft.

Central Canyon Fault

The Central Canyon fault strikes N. 30° E. and dips 70° east to 55° west (Plate 14a). The fault extends from its intersection with the West Joyita fault to its intersection with the Cañada Ancha fault. The fault zone is clean with minor silicification, but the zone exhibits many small scale distortions of the mudstone in the Joyita Sandstone Member of the Yeso Formation (Plate 14b and 15a), along with some associated drag folds (Plate 15b).

This fault, along with others exhibiting the same orientation has little lateral or vertical separation. The fault often underlies arroyos trending N. 30° E. Vertical separation is 25 ft in Central Canyon. Tensional cracks produced by a fault parallel and 1500 ft east of central canyon fault show the extent of the movement. The horizontal extension across the fault is 30 ft (Plate 16).

Plate 14a: Central Canyon fault looking north. West side up.

Plate 14b: Small scale distortion in the Joyita Sandstone adjacent to Central Canyon Fault.

Plate 15a: Small scale distortion in the Joyita Sandstone adjacent to the Central Canyon fault. View looking north in Cañada Ancha.

Plate 15b: Central Canyon fault looking south: drag fold in the Torres Member.

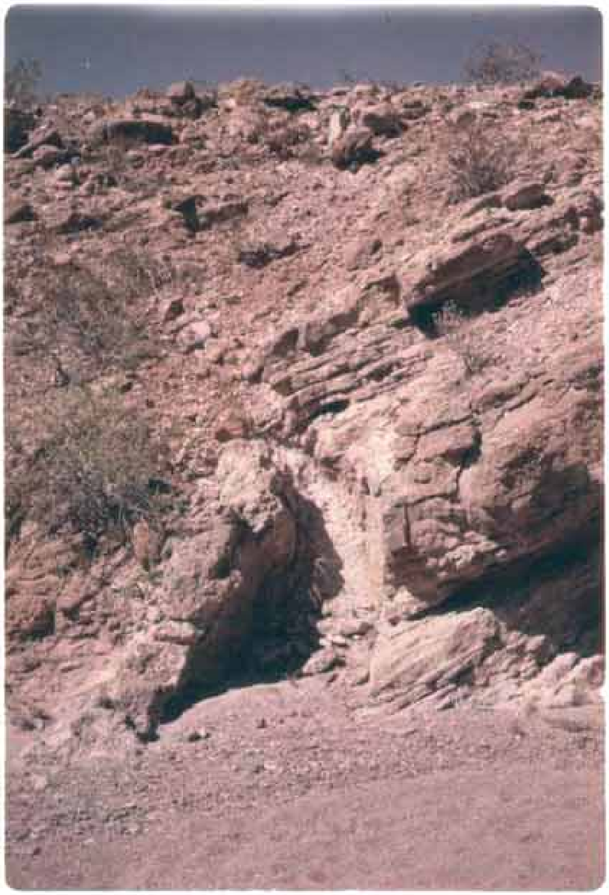


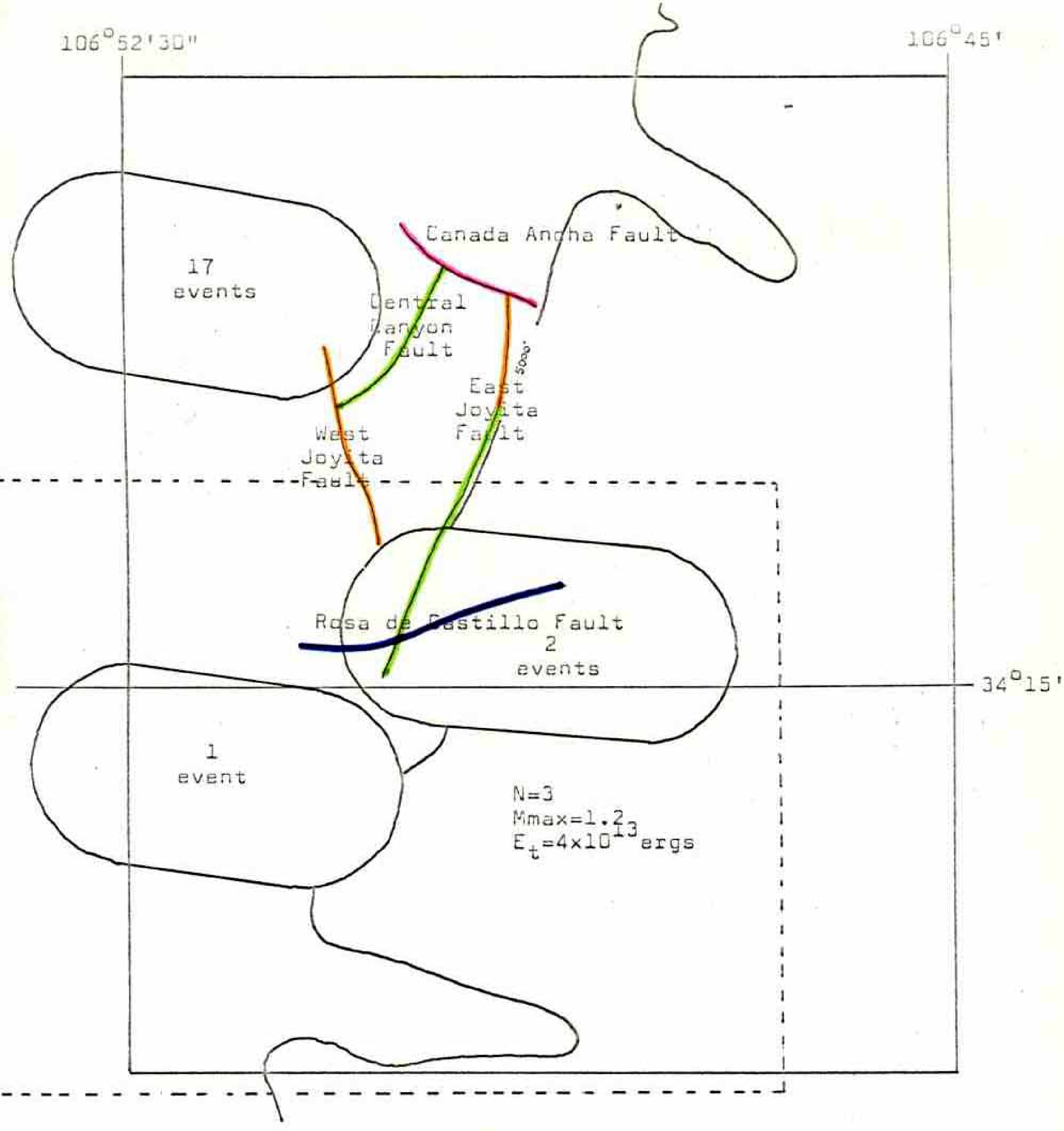
Plate 16: Tension fault near the Central Canyon fault. Horizontal extension across the fault is 30 ft. The beds that have been separated are part of Torres Member of the Yeso Formation. The view is looking southwest.

Mechanics

The fault set trending N. 80° E. is probably the oldest trend in the area dating back to Precambrian time. It resumed movement in the Tertiary. These faults are high-angle normal faults. This is best illustrated by the Rosa de Castillo fault.

The major fault set trends N. 10° W. and resulted from east-west tension during formation of the Rio Grande graben. The most prominent fault in this set is the West Joyita fault. There are two conjugate shear sets: (1) the N. 32° E. set with the Central Canyon fault being the most prominent fault and (2) the N. 48° W. set with the Cañada Ancha fault being the example. These conjugate shears are apparently of less magnitude than the N. 10° E. set and may be the result of a north-south compression or a force couple along the graben margin. This is indicated from small scale thrusts or reverse faults in the Cañada Ancha near the Precambrian contact. This also gives the suggestion of right slip or right shift along with buttressing at the San Acacia channel.

During 1969, Sanford (1970) recorded three microseismisms in the central mapped area with a total energy release of 4×10^{13} ergs with a maximum magnitude of any one microseismism being less than 1.2 on the Richter scale (Figure 5). The southern part of the East Joyita fault probably is responsible for these microseismisms. As



N is the number of microseismic events.
Mmax is the maximum magnitude of all the events within the dashed area.
E_t is the total energy released within the dashed area.

Figure 5: Map of Microseismic Events for 1969 in La Joyita Hills Area (after Sanford, 1970).

noted above, the southern end of the East Joyita fault contains recent fault scarps.

Looking at the regional geology, three of the fault sets are possibly reflected in a major structural feature: the Rio Grande graben, a tensional feature reflecting the N. 10° W. fault set with conjugate shears trending N. 48° W. and N. 32° E.

ECONOMIC GEOLOGY

La Joyita (Los Cañoncitos) district was discovered by Lon Jenkins at the Dewey Mine in 1895 (Howard, 1967) (Figure 6). The Bachelder-Everhart and La Joyita Prospects were discovered 10 years later, in 1905. The mineralization is hypogene containing galena with little gold or silver, but with some copper in a gangue of fluorite, barite, and quartz.

The Dewey Mine discovery shaft is about 400 ft deep and was sunk on a mineralized, quartz-rich aplite dike. Low-grade galena with some fluorite was all that was mined (Gordon and others, 1910). Johnston (1928) mentioned that there may be a possibility for fluorite exploration in the Dewey mine and La Joyita prospect.

La Joyita prospect consists of a tunnel 75 ft long and a shaft 25 ft deep. The discovery tunnel was started in rhyolite flow breccias in the East Joyita fault zone and was terminated in quartz-potassium feldspar-gneiss. The prospect contains some chalcopyrite and bornite with secondary malachite.

The Bachelder-Everhart prospect progressed the farthest toward actual production. A small mill built to concentrate the lead ore was not able to separate the galena

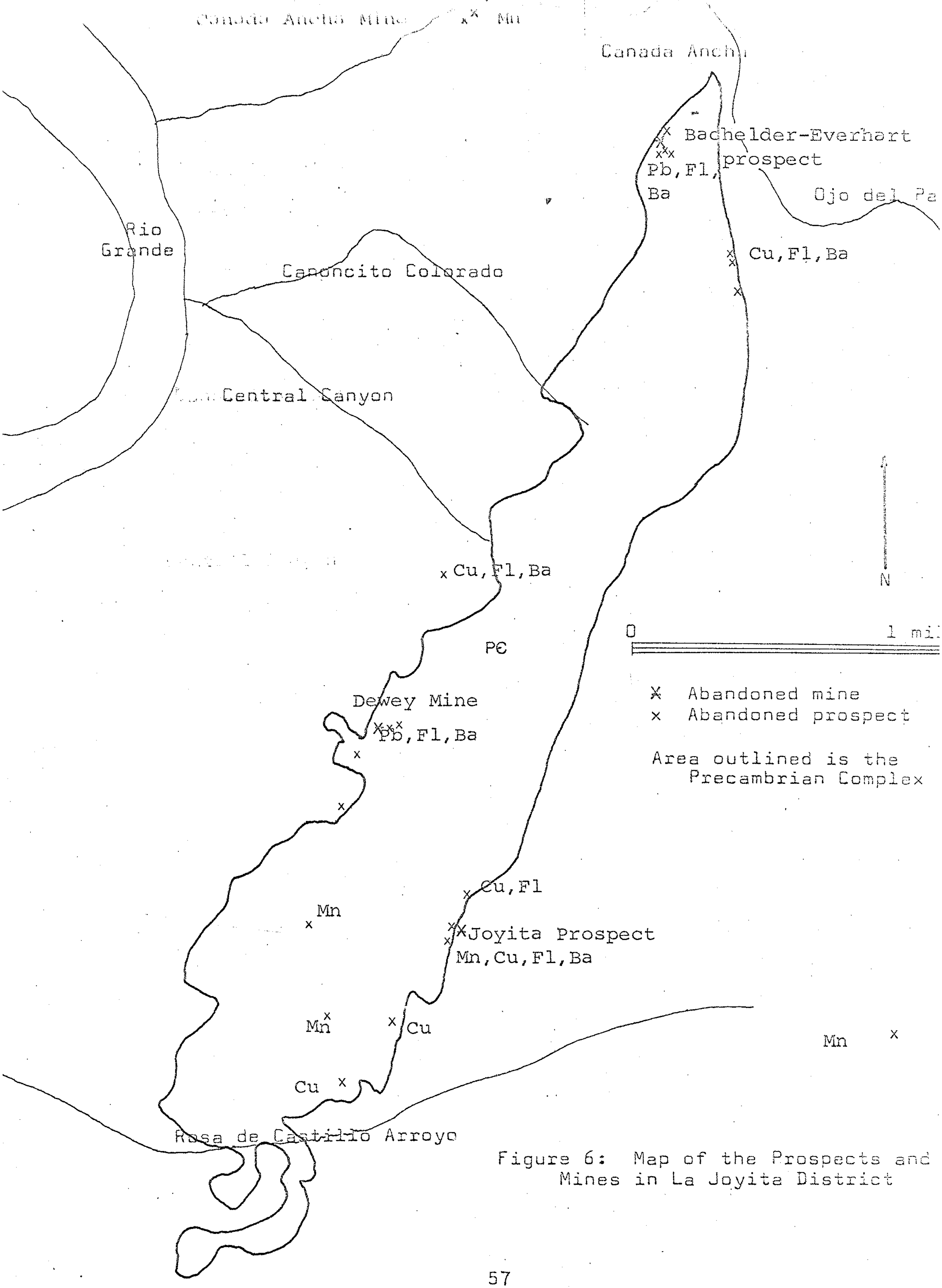


Figure 6: Map of the Prospects and Mines in La Joyita District

from the gangue and the prospect was abandoned (Howard, 1967).

There are small manganese prospects in the intrusive rocks and in the San Andres Formation. The only one that shows evidence of production was the Cañada Ancha Mine (?). This mine appears to have been prospected in the late 1950's as the timbers are new and there is fresh ore on the loading docks.

Herber (1963) states M. Radcliffe had reported the occurrence of beryl in Precambrian pegmatites. Herber (1963) was not able to locate any beryl in any of the pegmatites that he examined using heavy mineral separation techniques.

Lasky (1932) thought that mineralization occurred contemporaneously with Tertiary faulting. The fact that all mineralization in the mapped area occurs within Tertiary fault zones corroborates this view. La Joyita district has no recent ore production, but it has been well prospected as can be seen in Figure 6. Present day prospecting has been limited to re-examination of these prospects for possible fluorite or manganese deposits.

APPENDIX

MODAL ANALYSES

Modal analyses of intrusive and extrusive Tertiary rocks are presented in this appendix. Herber (1963) gives complete petrographic analyses of the Precambrian rocks and Huber (1961) gives complete analyses of the Permian sedimentary rocks. Plagioclase determinations were made using the a-normal method and using Tobi's (1963) high-temperature curves for anorthite composition. Rock nomenclature is based on Streckeisen's (1967) work.

Seventy-four thin sections of twenty extrusive ash-flows and flows and numerous intrusives were studied. The intrusive rocks include three types: basalt, andesite, and rhyolite.

The following tables give modal analyses of 36 thin sections which are followed by photomicrographs.

Table 1

MODAL ANALYSES OF THIN SECTIONS, EXTRUSIVE ROCKS

Flow	An%	Plag	qtz	biot.	cl-pyro	orth-pyr	sanid	Oliv.
Tb3	60	70			10	10		
Ta5	45	80						15
Tq3	30	15	15	--			10	
T15	20	10	--					
T14	--	5	5					
T13	20	5	5	--				
Ta4	45	80	--					10
Tr2	25	15	5	10			25	
Ttl	17	3					7	
Ta3	45	80			15			
T12	20	25						
Trl	26	--					10	
Tq2	17	30	25	--			10	
Tql	30	30	15	5				
Ta2	25	75	20					5
T11	30	15		10			5	
Tb2	57	60			5			
Tb1	55	40			5			
Tal	37	85						

Table 2

MODAL ANALYSES OF THIN SECTIONS, INTRUSIVE ROCKS

Intrusion	An%	plag.	qtz.	biot.	cl-pyro.	orth-pyro.	sanid.	oliv.
1r	22	5	10	--			35	
2r	23	5	30	--			20	
3r	16	25	20	5			5	
4r	22	10	25	5			10	
1a	30	40						
2a	22	60			--			
3a	43	65		--				
4a	43	65			5			
5a	34	70		--				
6a	30	80		--				
7a	30	70		--				
8a	20	75						
9a	33	90						
1b	59	85						
2b	55	70						20
3b	60	60			20			
4b	55	80						

Photomicrographs of Extrusive Rocks

Plate 17

A.

Tb3: basalt. Mostly plagioclase (An_{60}), with some ortho- and clino-pyroxenes (Cl). Crossed nicols.

B.

Ta5: andesite. Mostly plagioclase (An_{45}) with some olivine phenocrysts (Ol). Note trachytic texture. Crossed nicols.

Plate 18

A.

Tq3: quartz-latite. Plagioclase (An_{30}) (P), anhedral quartz (Qtz), sanidine (S), and a single crystal of sphene (Sp). Crossed nicols.

B.

T15: latite. Plagioclase (An_{20}) (P) phenocrysts surrounded by pumice fragments. Crossed nicols.

Plate 19

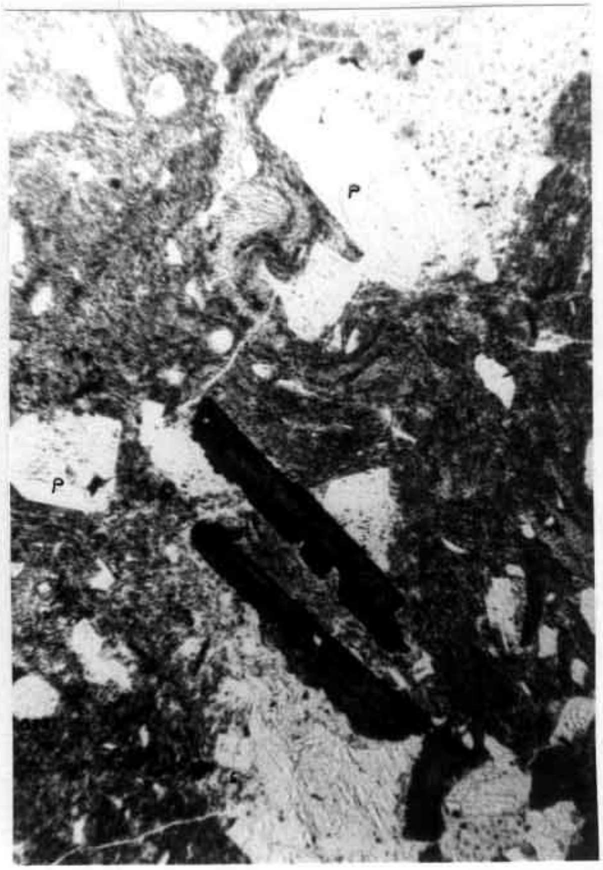
A.

T14: latite vitrophyre. Plagioclase (P) (An_{33}), quartz (Qtz). Note flow banding. Plain light.

B.

T13: latite. Biotite (B), plagioclase (An_{20}) (P), and quartz (Qtz). Note densely welded glass shards and flowage. Plain light.

Plate 20



A.

Ta4: andesite. Plagioclase (An_{45}) (P) and olivine (Ol). Crossed nicols.

B.

Tr2: Rhyolite. Biotite (B), plagioclase (An_{25}) (P), sanidine (S), and quartz (Qtz). Plain light.

Plate 21

A.

Ttl: trachyte. Sanidine (S) and plagioclase (An_{17}) (P). Crossed nicols.

B.

Ta3: andesite. Plagioclase (An_{45}) (P) and clinopyroxene (Cl). Plain light.

Plate 22

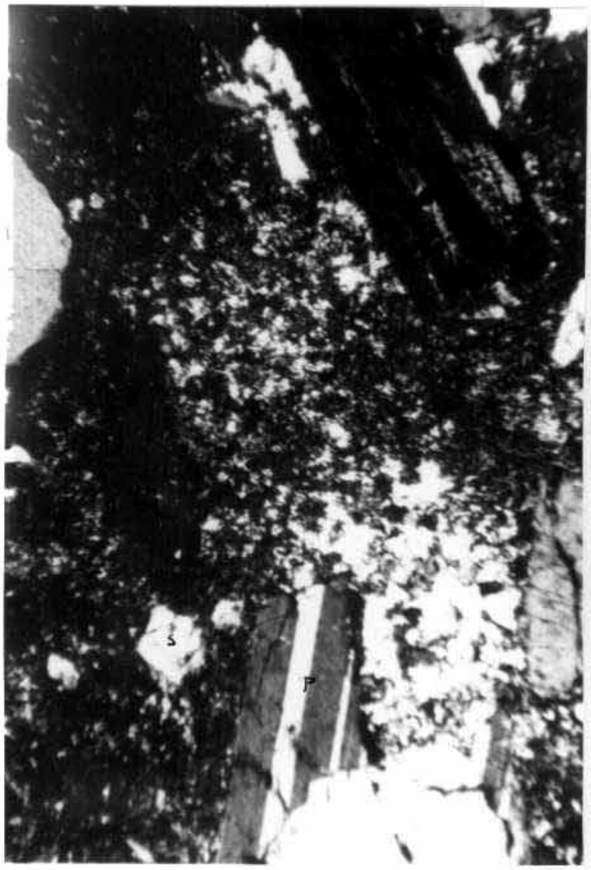
A.

T12: latite. Plagioclase (An_{20}) (P). Note flow texture. Crossed nicols.

B.

T12: note welded glass shards and flow texture Plain light.

Plate 23



A.

Tq2: quartz-latite. Biotite (B), quartz (Qtz), plagioclase (P) (An_{17}), and sanidine (S). Crossed nicols.

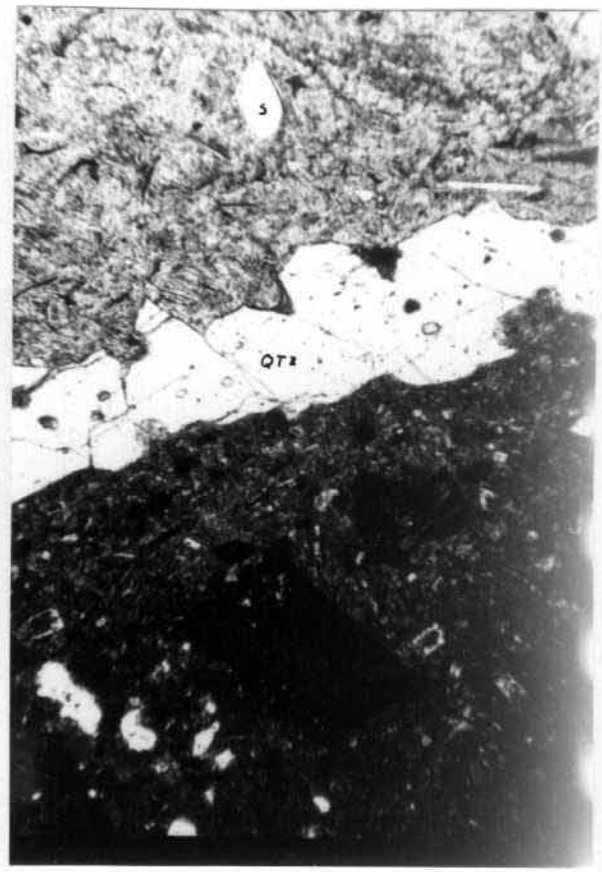
B.

Tql: quartz-latite. Plagioclase (An_{30}) and pumice fragments. Crossed nicols.

Plate 24

A.

Ta2: andesite. Mostly plagioclase (An_{25}) (P) and secondary quartz (Qtz). Crossed nicols.



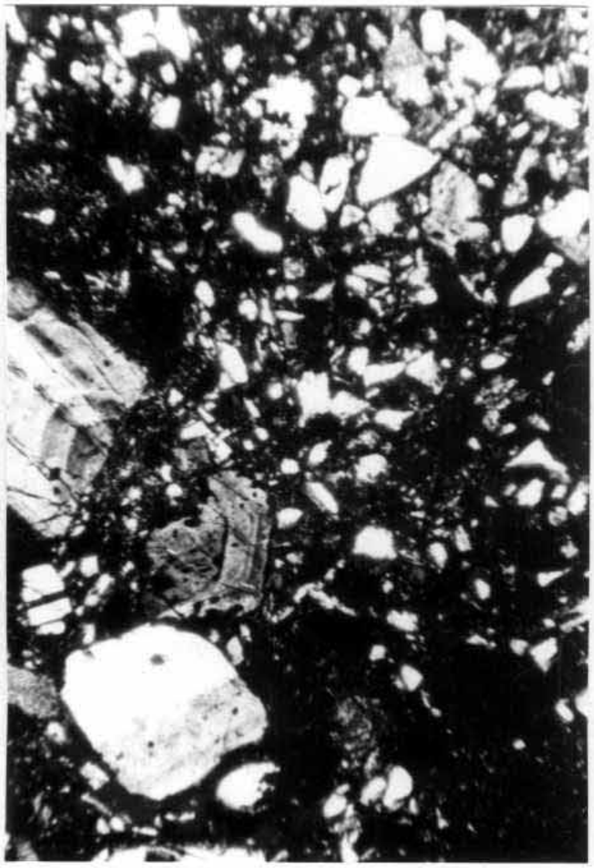
B.

Tl1: latite. Sanidine (S), plagioclase (An_{30}) (P) and andesite fragments (A). Note glass shards. Crossed nicols.

Plate 25

A.

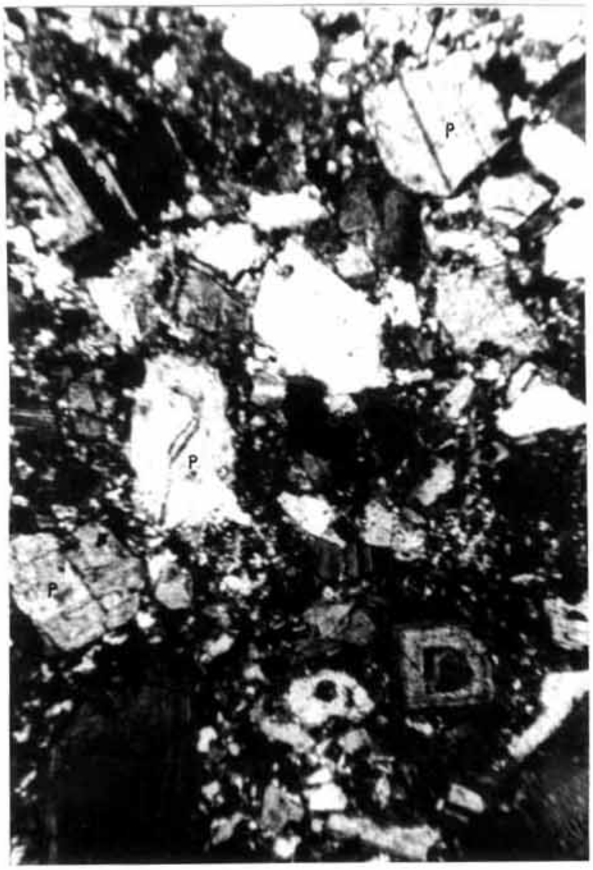
Tb2: basalt porphyry. Plagioclase (An_{57}) and clinopyroxene (C1). Note large phenocryst of plagioclase. Crossed nicols.



B.

Tb1: basalt. Plagioclase (An_{55}), some zoned (An_{30}-An_{70}). Crossed nicols.

Plate 26



Tal: andesite. Plagioclase An_{37}) (P), some zoned.

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This thesis, directed and approved by the candidate's committee, has been accepted by the Graduate Committee of The University of New Mexico in partial fulfillment of the requirements for the degree of

Master of Science

THE GEOLOGY OF LA JOYITA HILLS,
SOCORRO CO., N. M.

Title

Ward W. Arendt

Candidate

Geology

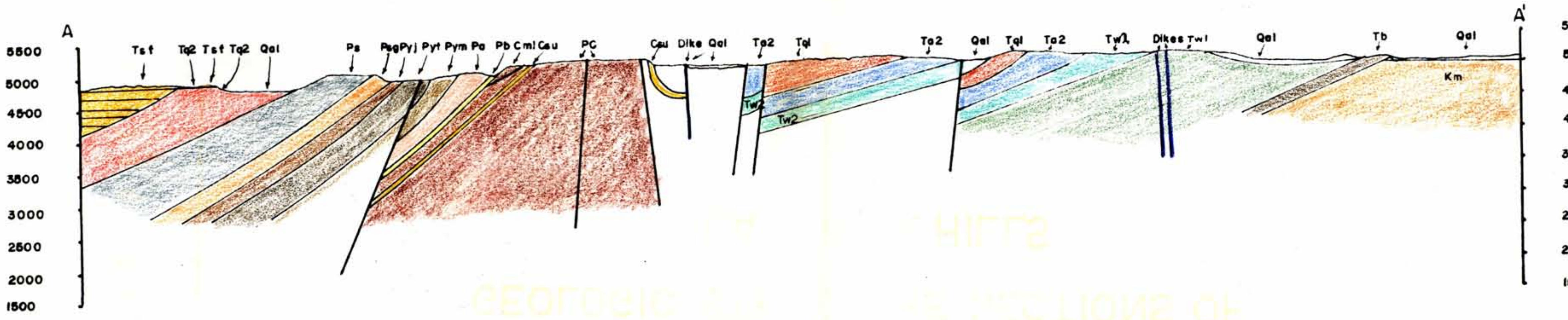
Department

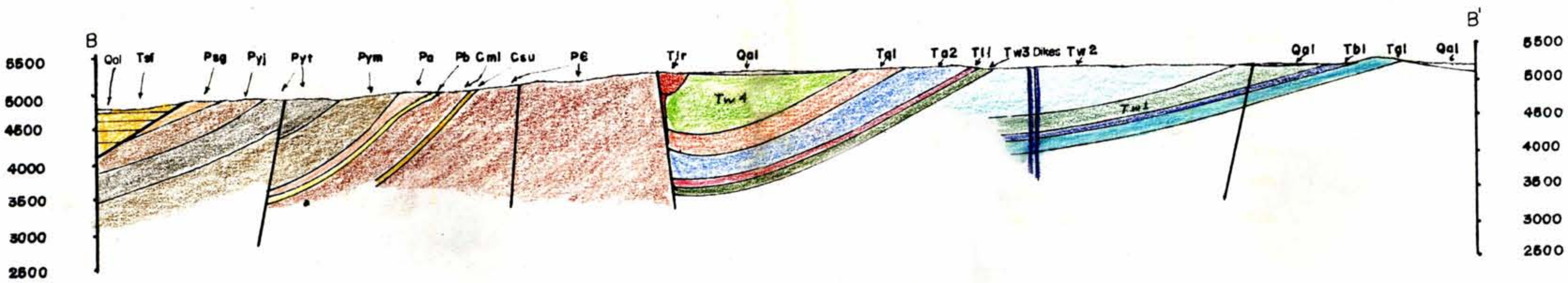
Dean

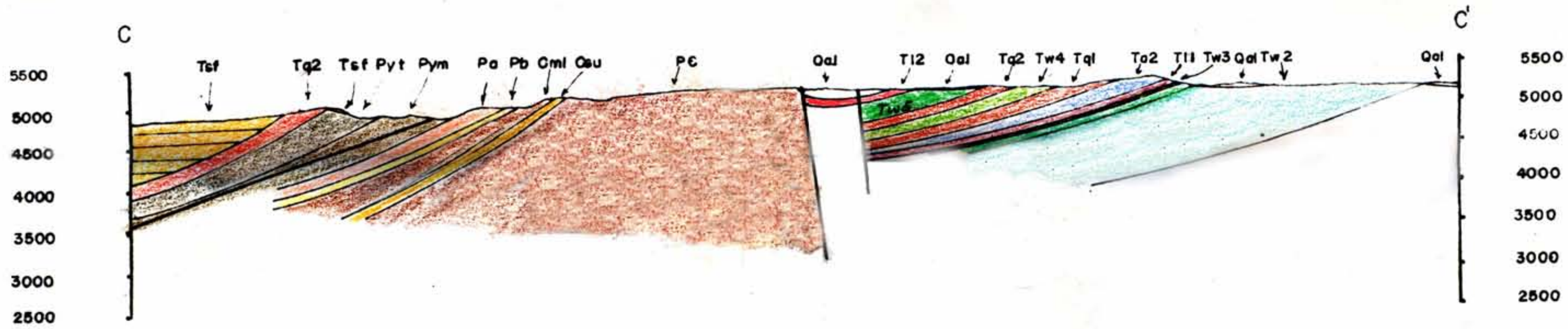
Date

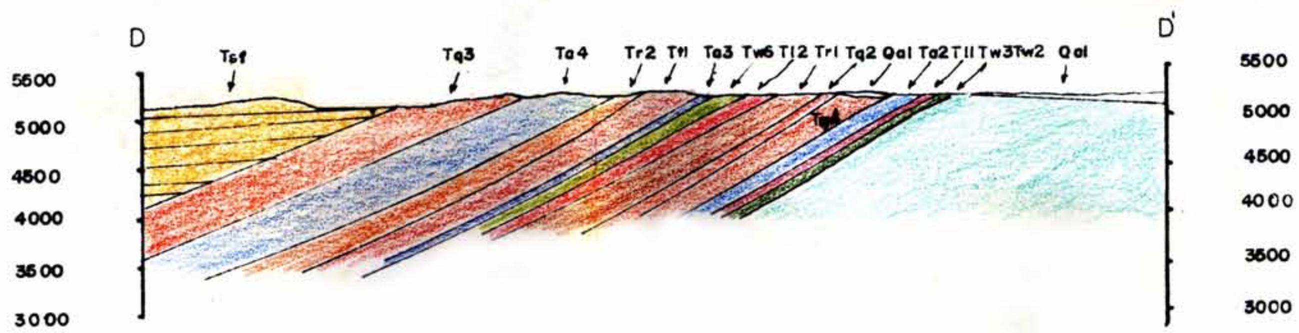
Committee

Chairman









GEOLOGIC STRUCTURE SECTIONS OF LA JOYITA HILLS

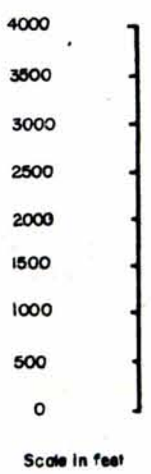
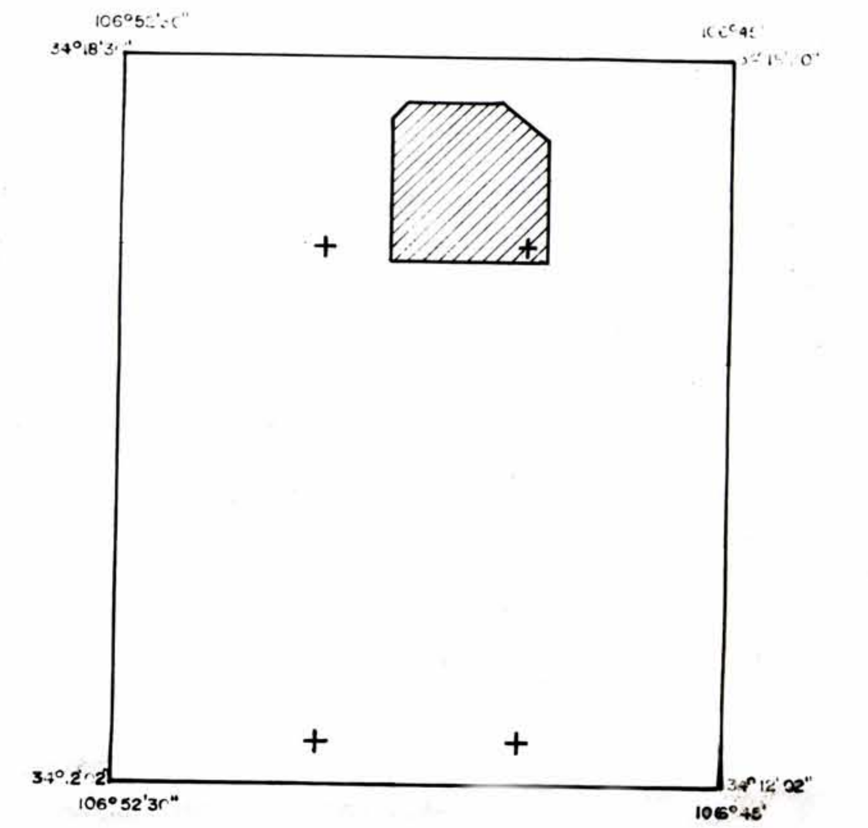


PLATE 27

GEOLOGIC AP OF THE NORTHERN PART
F LA JOYITA HILLS

WARD W. ARENDT, 1971

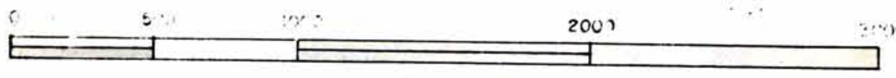
PLATE 28



Enlarged area of the Geologic Map of La Joyita Hills

Approximate mean declination 1970

SCALE: 1:8000



Symbols same as on Plate 29

GEOLOGIC MAP OF LA JOYITA HILLS

WARD W. ARENDT, 1971

PLATE 29

EXPLANTION

ROCK UNITS

QUATERNARY

- Qs — Stream channel fill and eolian deposits
- Qal — Alluvium

TERTIARY

- Tir — Rhyolitic intrusives
- Tia — Andesitic intrusives
- Tib — Basaltic intrusives
- Tsf — Santa Fe Group: volcanic and sedimentary mudflows and boulder conglomerates
- Tb3 — Basalt flow
- Ta5 — Andesite flow
- Tq3, Tl5, Tl4, Tl3 — Tq3: quartz latite ash-flow; Tl5: latite ash-flow; Tl4: latite vitrophyre flow; Tl3: latite ash-flow
- Ta4 — Andesite flow and flow breccia
- Tr2 — Rhyolite ash-flow
- Tt1 — Trachyte ash-flow
- Ta3 — Andesite flow and flow breccia
- Tw6 — Water-laid tuff
- Tl2 — Latite ash-flow
- Trt — Rhyolite-trachyte ash-flow
- Tw5 — Water-laid tuff
- Tq2 — Quartz-latite ash-flow
- Tw4 — Water-laid tuff
- Tq1 — Quartz-latite ash-flow
- Ta2 — Andesite flow and flow breccia
- Tl1 — Latite ash-flow
- Tw3 — Water-laid tuff
- Tw2 — Water-laid tuff
- Tb2 — Basalt porphyry flow
- Tw1 — Water-laid tuff
- Tb1 — Basalt flow
- Ta1 — Andesite flow
- Tb — Baca Formation

CRETACEOUS

- Km — Mancos-Mesa Verde undifferentiated

TRIASSIC

- Tdoc — Dockum Group: maroon, cross-bedded, immature sandstone

PERMIAN

- Ps — San Andres Limestone: massive, cliff-forming, silty, light-gray limestone
- Psg — Glorieta Sandstone: massive, cliff-forming, partially silicified, white to buff sandstone
- Pyj, Pyt, Pym — Yeso Formation: Joyita Sandstone (bright red mudstone interbedded with sandstone), Torres Member (interbedded red and buff siltstone, claystone, gypsiferous siltstone, and gray ridge-forming limestone), and Meseta Blanca Sandstone (pink, yellow, and white, cliff- and ridge-forming siltstone and very fine-grained sandstone)
- Pa — Abo Formation: dark red, interbedded siltstone, mudstone, and shale
- Pb — Bursum Formation: reddish-brown, quartz-cobble conglomerate

PENNSYLVANIAN

- Cml — Madera Limestone
- Csu — Sandia Formation

PRECAMBRIAN

- PC2 — Quartz-potassium feldspar-gneiss
- PC1 — Quartz-potassium feldspar-biotite-gneiss

SYMBOLS

- Geologic boundaries: dashed where approximate, dotted where concealed
- Fault: U/D indicating relative movement; dotted where concealed, dashed where approximate
- Low angle thrust fault
- 35 — Strike and dip of beds
- Horizontal beds
- 60 — Strike and dip of foliation
- Adit
- Abandoned mine or prospect
- Land grant boundary
- Unimproved dirt roads
- Structure section
- Measured section

12½°

True North — Magnetic North

Approximate mean declination, 1971

SCALE 1:24000

1 ½ 0 1 Mile

1000 0 1000 2000 3000 4000 5000 6000 7000 Feet

Contour interval 40 feet

Datum is mean sea level

Base adapted from U.S.G.S. La Joya and Mesa del Yeso Quadrangles