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TERTIARY VOLCANIC STRATIGRAPHY OF THE EASTERN TUSAS MOUNTAINS, SOUTHWEST OF THE SAN LUIS VALLEY, COLORADO-NEW MEXICO*

by

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INTRODUCTION

Tertiary rocks in the upland of the southeast part of the San Juan Mountains, Colorado, and the Tusas Mountains, New Mexico (fig. 1), southwest of the San Luis Valley, consist of effusive and pyroclastic volcanic rocks that alternate and interfinger with fluvially transported debris eroded from them. Locally, some fluvial beds consist entirely of material derived from Precambrian crystalline rocks. Volcanic rocks predominate near the large centers of eruption in southern Colorado (Lipman and Steven, 1970, fig. 1) but are generally subordinate to fluviatile sedimentary rocks in eastern Rio Arriba County, New Mexico. Along the eastern margin of the upland south of the San Luis Valley in New Mexico the top of the sequence is represented by widespread flows of basaltic lavas.

Many major units of the sequence were first delineated during extensive investigations of the San Juan volcanic field by Larsen and Cross (1956). Subsequent study by T. A. Steven and P. W. Lipman and their associates have resulted in better definition of the relations among interfingering volcanic units erupted from different centers, in establishing a chronology of events based on radiometric determinations of age that fits well with observed stratigraphic relations (Lipman and others, 1970) and in an improved understanding of the petrologic evolution of the rocks.

The units of the volcanic sequence established by Larsen and Cross in the southeastern San Juan Mountains in Colorado were traced southward by the author (Butler, 1946) and mapped in the eastern part of the Tusas Mountains, New Mexico, and along the western margin of the Taos Plateau.

This mapping resulted in an interpretation of the relation between the volcanic sequence and the Santa Fe Formation, as used by Bryan (1938), that differed from earlier interpretations by Atwood and Mather (1932) and Smith (1938) and forms the basis for the description of the Tertiary stratigraphy presented herein. The descriptions presented here are modified, however, to conform with the stratigraphy, nomenclature, and chronology as revised by P. W. Lipman and T. A. Steven and their associates (Lipman and Steven, 1970; Lipman and others, 1970), and with some results of work in New Mexico by Barker (1958), Bingler (1968), and Muehlberger (1968).

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OLDER ROCKS AND SURFACE BENEATH THE TERTIARY VOLCANIC SEQUENCE

The Tertiary rocks west of the southern part of the San Luis Valley rest with marked unconformity on older rocks. In Colorado, the older rocks are exposed only at the present southwest limit of the Tertiary volcanic sequence, but in New Mexico some parts of the basement were never completely covered by the Tertiary rocks, and other parts have been exhumed by subsequent erosion. In most of the area described in this report (fig. 2) the exposed basement consists of metamorphic and igneous rocks of Precambrian age. Near their present western limit in southern Colorado and in New Mexico the Tertiary rocks overlie unconformably the beveled edges of Mesozoic sedimentary rocks, which dip southwestward into the San Juan Basin (Larsen and Cross, 1956; Muehlberger, 1968).

The Precambrian terrane beneath the volcanic sequence in New Mexico represents the southeastern continuation of the Uncompaghre-Needle Mountain highlands of Colorado and, like them, was uplifted during Laramide orogeny. Prior to deposition of the Tertiary volcanic rocks erosion had removed any Paleozoic and Mesozoic rocks that may have once covered the older rocks and had sculptured a fairly rugged topography on them. The maximum relief of this topography approached 2,000 feet in the vicinity of T. 28 N., R. 8 E., and was 1,500 feet near the Rio de Los Pinos in the northwest part of the mapped area.

TERTIARY ROCKS

INTRODUCTION

The Tertiary rocks within the area shown on the accompanying geologic map (fig. 2) comprise seven formations (table 1) and several local bodies of volcanic rock that accumulated around individual vents. Some of the formations are composed largely of effusive and pyroclastic volcanic rocks and subordinately of interbedded clastic sedimentary rocks; some largely of clastic sedimentary

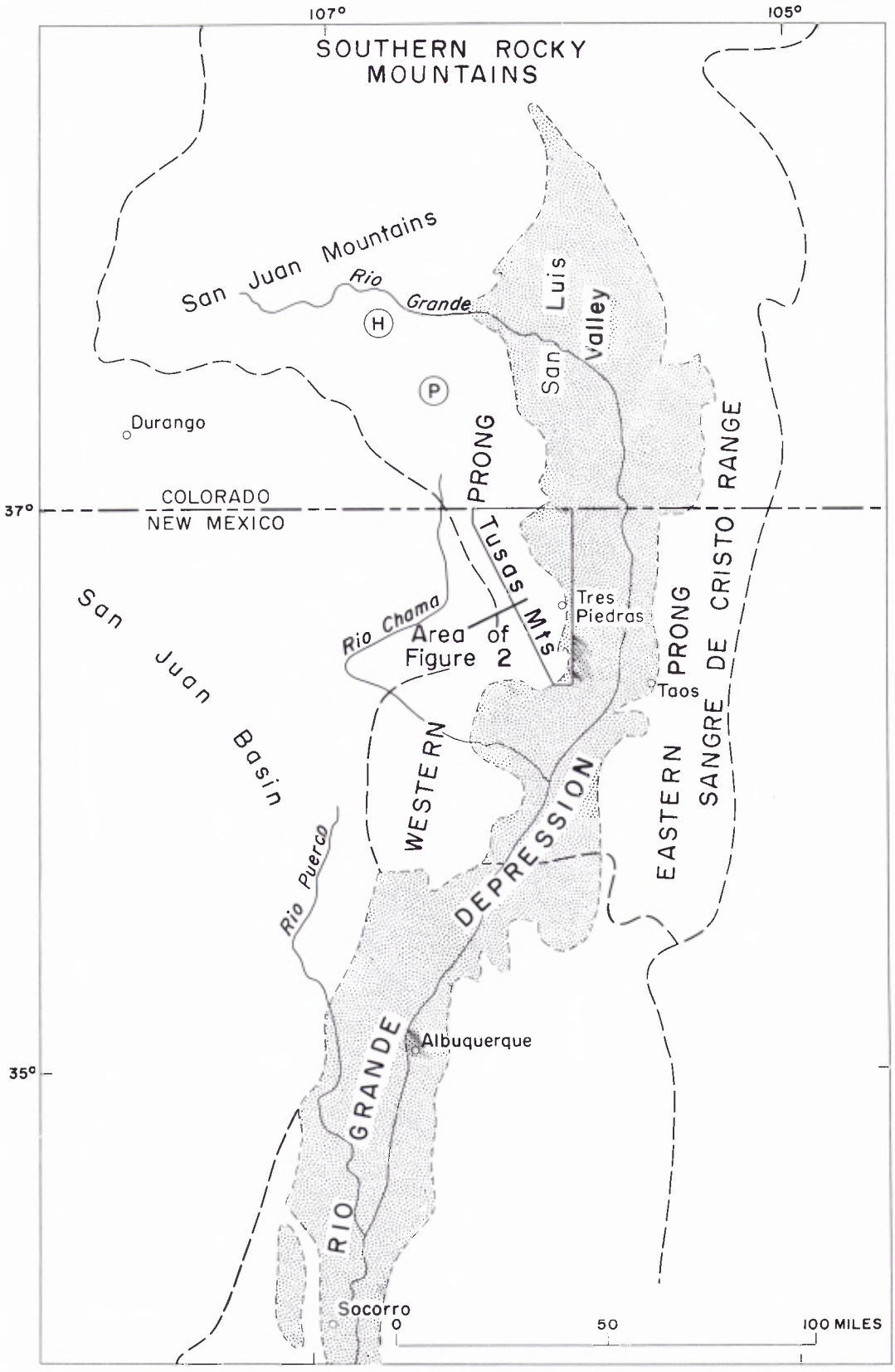


FIGURE 1.

Index map of south-central Colorado and north-central New Mexico showing locations of accompanying geologic maps, Figure 2 and of calderas mentioned in text; H, Mt. Hope; P, Platoro.

TABLE 1. TERTIARY ROCKS OF THE EASTERN PART OF THE TUSAS MOUNTAINS AND ADJOINING PART OF THE TAOS PLATEAU, NEW MEXICO

AGE	FORMATION AND MEMBER	DESCRIPTION	THICKNESS (FEET)[1]
Pliocene	Servilleta Formation	Flows of coarse-grained, porous, tholeiitic basalt and interbedded gravel	10-100
	Unconformity		
Pliocene and Miocene	Hinsdale Formation		
	Upper Basalt Member, (Dorado Basalt of Barker, 1958)	Flows of xenocrystic, quartz-bearing alkalic basalt and basaltic andesite in disconnected bodies	10-150
	Lower basalt member, (Cisneros Basalt of Barker, 1958)	Flows of fine-grained, slightly porphyritic, alkalic basalt in disconnected bodies	10-50
	Hypersthene Quartz Latite	Flows form San Antonio Peak and some other domes; relation to basalts uncertain	0-2000
	Rhyolite of No Agua Mountain	Dissected local mass of perlitic and spherulitic rhyolite	undetermined
	Unconformity		
Pliocene (?) and Miocene (?)	Santa Fe Formation as used by Smith (1938)	Fluvial and eolian sandstone in southeast part of area	0-900
Pliocene to Oligocene	Los Pinos Formation		
	Rhyolite Member	Sandstone, conglomerate, tuff, and flows or ash flows in which rhyolitic rock predominates	0-700
	Jarita Basalt Member of Barker (1958)	Flows of basalt of locally different characteristics in many disconnected bodies	10-100
	Undivided in northern part of area	Tuffaceous sandstone, conglomerate, and tuff, largely equivalent to two lower members in southern part of area	0-700
	Coarsely porphyritic Quartz Latite Member	Tuffaceous sandstone, conglomerate containing abundant clasts of coarsely porphyritic quartz latite, and tuff	0-600
	Quartz Latite-Andesite member	Breccia and conglomerate in which clasts of dark quartz latite or andesite predominate, tuff, and intrusive breccia	0-700
Uncertain	Ritito Conglomerate of Barker (1958)	Conglomerate of angular fragments of Precambrian rock. Present only in southwest part of area. Underlies rhyolite member of Los Pinos Formation, correlation otherwise uncertain	0-400
Oligocene	Tuff of Masonic Park	Ash-flow tuff of quartz latite, mostly welded	0-275
Oligocene	Treasure Mountain Tuff	Tuff, sandstone, conglomerate, and discontinuous welded ash-flow tuff near base. Absent south of center of T. 28 N., R. 8 E.	
	Unconformity		
Oligocene and older (?)	Conejos Formation	Breccia, flows, agglomerate, of varicolored andesite and quartz latite, tuff, tuffaceous sandstone, and conglomerate, crudely and irregularly bedded	0-1000

[1]The maximum thickness of different units are not superposed. Thus the total aggregate thickness at any one place is much less than the sum of individual maximums and may not be much in excess of 2,000 feet.

rocks and subordinately of effusive and pyroclastic material; and two composed mostly of basaltic lava. Their general relations are shown diagrammatically on Figure 3. As a group, these formations dip gently east-northeastward from the headwaters of the Rio de Los Pinos in Colorado and from the Tusas Mountains in New Mexico toward the San Luis Valley and Taos Plateau. In consequence of this dip and dissection by streams, the lower units are more widely present at the surface in the western part of the general upland, and successive younger units are more widely present in the eastern part.

Three other formations of Tertiary age are present mostly west and southwest of the area of the map and are only briefly mentioned here. Two of them—The Blanco Basin Formation (Larsen and Cross, 1956) and the El Rito Formation of Smith (1938)—are older than the volcanic sequence and consist of sandstone, arkose, and conglomerate composed largely of debris eroded from Precambrian rocks. The Blanco Basin Formation underlies the volcanic rocks discontinuously at their western margin in Colorado (Larsen and Cross 1956, p. 60-61) and northern New Mexico (Muehlberger, 1968, p. 3). The El Rito occupies a generally similar position from about latitude 36°49′ N. southward to the Chama River (Smith, 1938, p. 940). These formations are thought to be of Eocene age (Lipman and others, 1970; Bingler, 1968). The third of the three units—the Ritito Conglomerate of Barker (1958)—is a "conglomerate of gravel-size fragments of Precambrian rocks" that rests directly on the source rocks. Near its type locality in secs. 11 and 14, T. 27 N., R. 7 E., it underlies the topmost rhyolite member of the Los Pinos Formation and may be correlative either with rocks questionably equivalent to the Conejos Formation or with beds in the lowermost quartz latite-andesite member of the Los Pinos Formation (Barker, 1958, p. 43). Southwest of the area of the map with this report (fig. 3) beds of Ritito lithology are partly gradational to the underlying El Rito (Bingler, 1968, p. 33), but beds of generally similar lithology are also present locally in several formations of the volcanic sequence (Butler, 1946). Thus, away from the type locality all beds of Ritito lithology are not stratigraphic equivalents.

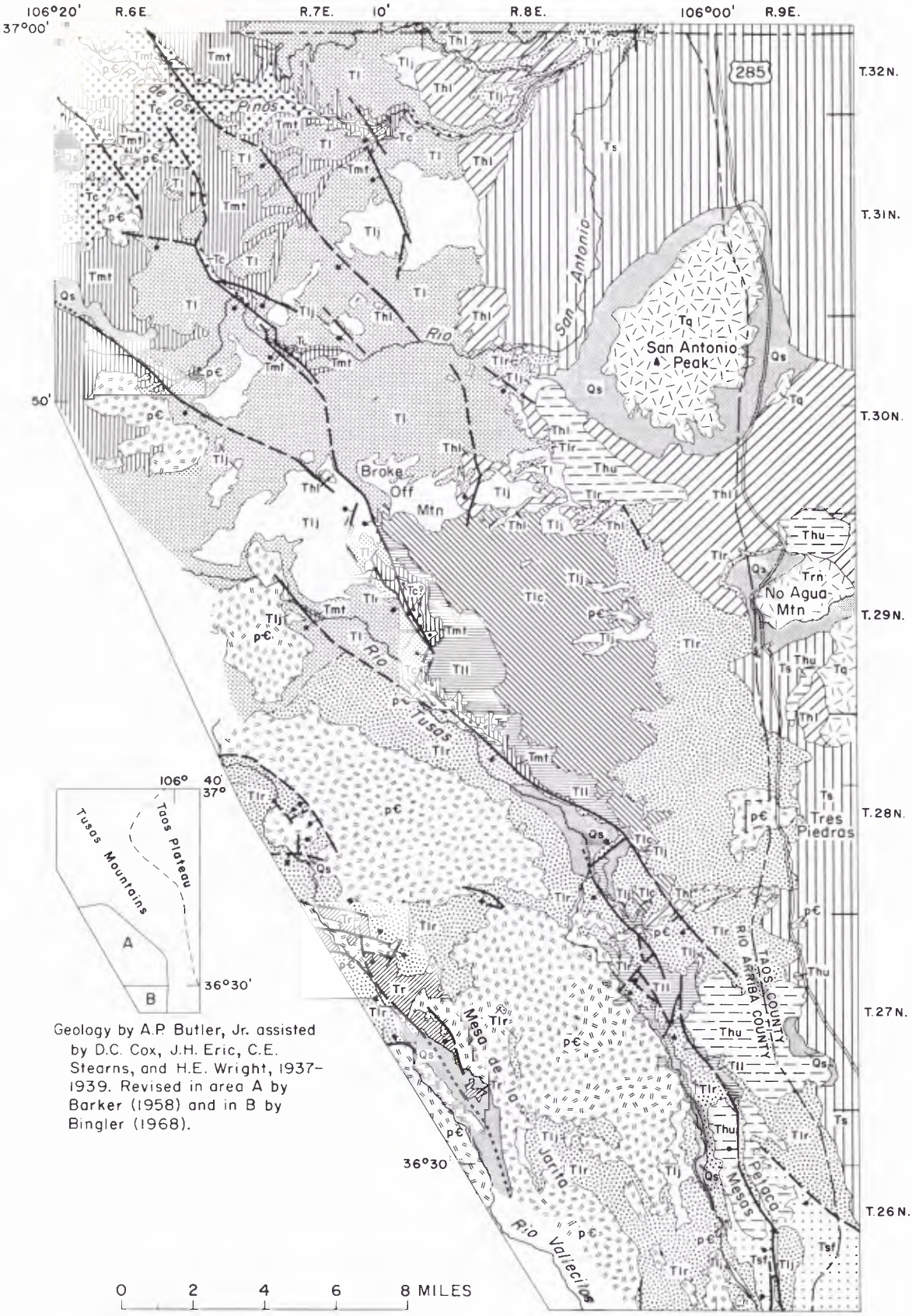
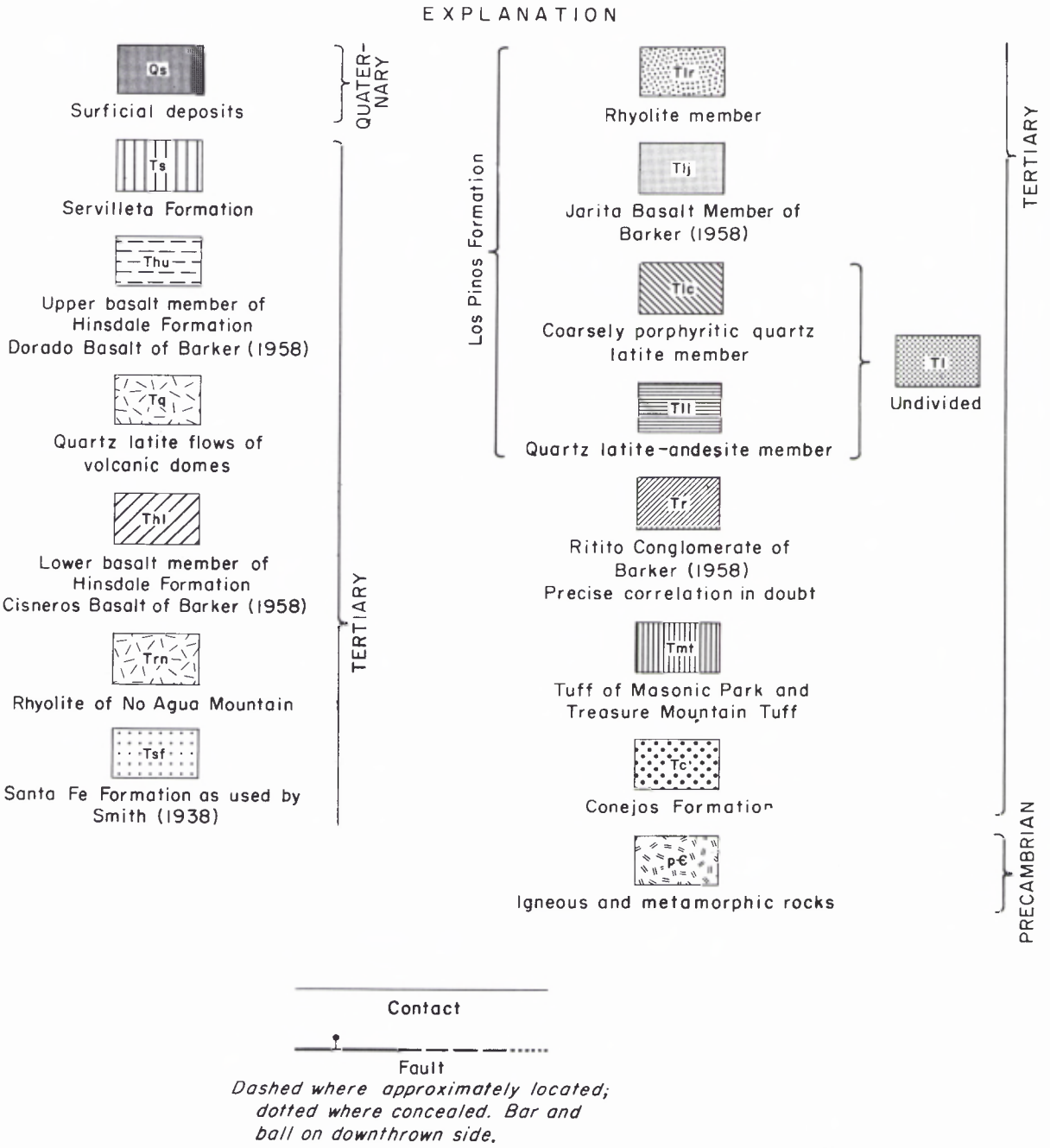


FIGURE 2.

Geologic map of the eastern part of the Tusas Mountains and western part of the Taos Plateau, Rio Arriba and Taos Counties, New Mexico.



CONEJOS FORMATION

The Conejos Formation, Conejos Quartz Latite of Larsen and Cross (1956), is the oldest unit of the volcanic sequence in the southern part of the San Juan Mountains, Colorado. It was named for its outcrops in the valley of the Conejos River, Colorado (Cross and Larsen, 1935), and comprises most of the "early intermediate lavas and breccias" (Lipman and others, 1970) in the southeast part of the volcanic field.

Within the map area (fig. 2) the Conejos Formation crops out mainly in the valley of the Rio de Los Pinos and its immediate tributaries and locally in the valley of the Rio San Antonio. Farthur south, in the northern part of the Rio Tusas Valley, rocks in scattered outcrops underneath the Treasure Mountain Tuff may be a distal facies of the Conejos Formation although their volcanic constituents are not typical. The formation underlies much of the upland west of the map area south to the canyon of the Rio Brazos (Muehlberger, 1968) and is well exposed at places along the narrow gauge railway north of the Rio de Los Pinos Valley.

The Conejos Formation within the map area is a rather chaotic assemblage of varicolored effusive and volcaniclastic rocks in which breccia predominates over flows, tuff-

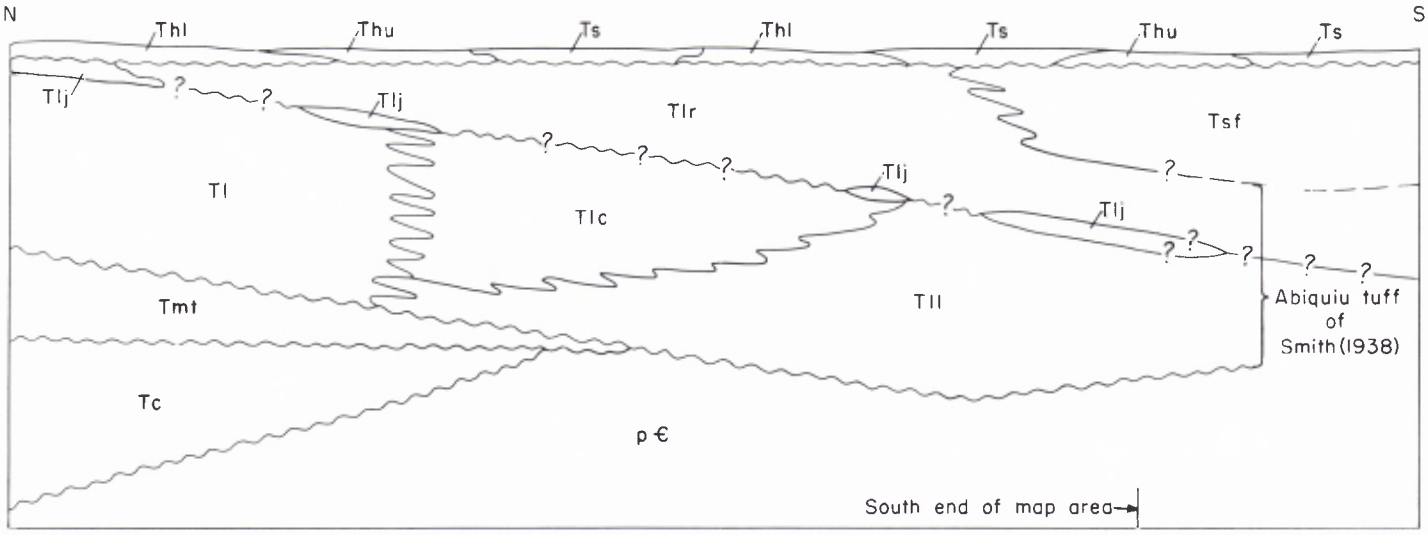


FIGURE 3.

Diagrammatic correlation chart showing the general stratigraphic relation of the Tertiary rocks from north to south along the east side of the Tusas Mountains, New Mexico. Ritito Conglomerate of Barker is omitted. See Figure 2 for explanation of symbols. Chart is not to scale.

breccia, agglomerate, tuff, tuffaceous arenite and conglomerate. Breccia and flows are generally more abundant in the upper part of the formation and other kinds of rock in the lower part. All lithologic types are interbedded in crude, irregular lenses of mostly local extent. Beds are generally massive, and those of one type pass laterally into or end abruptly against another type. Individual flows, which range from less than 10 to 50 feet in thickness, are traceable only from 1 to 2 miles. The coarsely clastic tuffaceous rocks weather to conspicuous pinnacles that can be observed from the railway line on the north side of the Rio de Los Pinos.

The rock of breccia, agglomerate, and flows is mainly dark-colored and is andesite to quartz latite in chemical composition (Lipman and others, 1970, p. 2331), but was considered to be petrographically mainly quartz latite by Larsen and Cross (1956, p. 97). Some of the rock is more felsic, and that of some flows is basaltic andesite. Most of the rocks are somewhat porphyritic and contain megascopically recognizable phenocrysts set in an aphanitic groundmass, but some dark rocks are fine grained and nonporphyritic. Plagioclase, dark-green pyroxene, and altered olivine are the commonly recognizable phenocrysts in gray and dark-green rocks; plagioclase and biotite are those in other lighter colored rocks.

Colors range from black to various shades of gray in mafic andesite and from gray or grayish green to grayish and reddish purple in more felsic rocks. Tuff is various pastel shades of pink and gray. It is more indurated than similar appearing tuff in the younger Los Pinos Formation.

The Conejos Formation is about 1,000 feet thick from the bottom of the Rio de Los Pinos Valley in the east center of R. 6 E., but the maximum thickness is not known because the base is not exposed and its top is an irregular surface. At places it wedges out against hills of Precambrian rock.

No vents for Conejos rocks are known in northern New Mexico and the rocks were probably erupted from volcanic centers in southern Colorado (see Lipman and others, 1970, fig. 1).

The age of the formation as determined by the potassium argon method is between 31 and 35 m.y. (Lipman and others, 1970, tables 1 and 2), or largely Early and Middle Oligocene, rather than Miocene as once thought (Larsen and Cross, 1956, table 18).

Treasure Mountain Tuff

Both the unit now called Treasure Mountain Tuff and the overlying unit now referred to as tuff of Masonic Park (Lipman and Steven, 1970) were included in the Treasure Mountain Rhyolite by Larsen and Cross (1956). The extension of their units into New Mexico was traced in the field by the writer (Butler, 1946) and they were distinguished in mapping, although they are combined on figure 2.

The Treasure Mountain Tuff crops out in a thin interval on the sides of valleys in part of the basin of the Rio de Los Pinos, in Rs. 6 and 7 E. in the basin of the Rio San Antonio, and east of the Rio Tusas south to the center of T. 28 N., R. 9 E. It also crops out more broadly in the upland in the northwest part and west of the map area.

The Treasure Mountain Tuff was deposited on an irregular surface of the Conejos Formation, which has a relief of as much as 300 feet in a few places, and also abuts against hills of Precambrian rocks, which rise above it.

In Colorado, three welded ash-flow sheets are recognized as formal members and some underlying and intervening welded and nonwelded ash flows and air-fall tuffs as in-

formal members of the Treasure Mountain Tuff (Lipman and Steven, 1970). All were erupted from the site of the Platoro caldera. At the state line and in New Mexico, however, only one welded ash-flow sheet is irregularly present at or close to the base. Its distribution is incompletely known, either because it is absent as a result of the relief of the underlying surface, or because it is concealed by colluvium. This ash flow consists of two parts where it is most complete: (1) a lower interval that grades vertically and horizontally from black vitrophyre into gray unwelded tuff, and (2) a more persistent upper dull-brown, aphanitic, porphyritic, firmly welded interval. Phenocrysts of plagioclase and biotite are more abundant in the upper part. The combined thickness of the two parts is at least 50 feet in some places. Its stratigraphic position relative to the units recognized in Colorado is not known.

The rest of the Treasure Mountain Tuff consists of interbedded nonwelded ash-flow and air-fall tuff, tuffaceous sandstone, and conglomerate. In the northern part of the area, tuff generally predominates in the lower part of the formation; fluviatile deposits in the upper part. Much of the tuff is buff, but some is pink and some is dark gray. It consists of crystal fragments, mainly plagioclase and biotite, in a matrix of devitrified glass shards. Fragments of pumice are common in some beds.

The fluviatile rocks consist of buff to gray tuffaceous sandstone and lenticular beds of conglomerate. Some boulders in the conglomerate are as much as 3.5 feet in diameter, and large boulders fill some channels cut into fine-grained beds, as can be seen in railway cuts near the east side of sec. 29, T. 32 N., R. 7 E. Dark-colored rocks predominate among clasts in the conglomerate beds and may have been derived from the lower lavas related to the Platoro caldera (Lipman and Steven, 1970, p. C23) and less distant high-standing parts of the Conejos Formation.

The Treasure Mountain Tuff is about 250 feet thick on the north side of the Rio de Los Pinos and about 60 feet near the southern limit of its outcrop in T. 28 N., R. 8 E.

Tuff of Masonic Park

The tuff of Masonic Park is an ash-flow sheet that is mostly welded. It rests with apparent conformity on and is essentially coextensive with the underlying Treasure Mountain Tuff southward as far as the most northerly large tributary of the Rio Tusas in sec. 24, T. 29 N., R. 7 E. The main welded part of the sheet is the most distinctive of the Tertiary rocks in the map area. It is a gray to purple-gray and locally reddish rock that tends to weather into platy tablets which are recognizable in hillside float even where the tuff is not exposed. In places it stands as a cliff. The welded tuff is fine-grained fragmental to aphanitic and generally porphyritic rock. Plagioclase and biotite are the common phenocrysts and sparse green pyroxene is generally present. At many places the lowest part of the sheet is pink to buff nonwelded tuff about 10 feet thick.

The tuff of Masonic Park is about 100 feet thick in the southeast corner of T. 32 N., R. 7 E. It thins westward and southward from there and is only about 15 feet thick in the western part of the map area and in the northern part of the Rio Tusas Valley.

The tuff was erupted from the Mount Hope caldera and has an age of 28.2 m.y. (Lipman and others, 1970).

Los Pinos Formation

The Los Pinos Formation, formerly Los Pinos Gravel (Atwood and Mather, 1932), was named for exposures in the canyon of the Rio de Los Pinos. It is the most continuous and widespread of the Tertiary formations within the map area. It is present north of the Rio de Los Pinos eastward from the west part of R. 7 E. and underlies much of the broad belt that extends southeast from the southeast part of T. 31 N., R. 6 E. beyond the south edge of the map. Along part of the west side of the belt, the formation pinches out against the highland of Precambrian rocks, but it extends west of the map area to the rim of the Brazos Canyon (Muehlberger, 1968) and into much of the upper drainage area of the Rio Vallecitos (Barker, 1958, pl. 1). It declines eastward with the general dip of the rocks and is covered by flows of younger basalt everywhere in about the eastern third of the area. The formation extends northward many miles along the eastern flank of the San Juan Mountains in Colorado (Larsen and Cross, 1956). South of the map area, rocks that are equivalent to parts of the Los Pinos Formation constitute much of the Abiquiu Tuff of Smith (1938, p. 944).

The Los Pinos Formation rests with apparent conformity on the tuff of Masonic Park in the north half of the area and unconformably on Precambrian rocks or nearly conformably on the Ritito Conglomerate of Barker (1958) in much of the south half, except in Tps. 28 and 29 N., R. 8 E., where it rests on Treasure Mountain Tuff.

The Los Pinos Formation comprises a varied assortment of lithologies that includes widespread beds of fluvial, partly tuffaceous sandstone and conglomerate, air-fall and fluvially reworked tuff, welded ash-flow tuffs several square miles in extent, small masses of intrusive rock, and an interval of discontinuous but widespread basalt flows, which may belong in the Hinsdale Formation, but for convenience are here described as a unit of the Los Pinos.

South of Broke Off Mountain, mostly in and east of the valley of the Rio Tusas, the predominantly clastic part of the Los Pinos Formation is divisible into three local members. These are distinguished by the kinds of rock that occur as clasts in conglomerate and fragments in pyroclastic breccia and as flows. North of Broke Off Mountain, the kinds of rock in conglomerate are mixed and the two lower members recognized farther south cannot be distinguished. The bulk of the formation that underlies the basalt unit in this part of the area is undivided but corresponds generally to the lower two clastic members farther south.

From near the middle of the Petaca Mesas southward, the upper part of the top clastic member partly underlies and partly interfingers with arkosic sandstone and sandstone that are continuous with the Santa Fe Formation as used by Smith (1938).

Undivided part of the formation

The undivided part of the Los Pinos Formation consists of sandstone, tuffaceous sandstone, conglomerate, and

some pyroclastic tuff. Tuff is more common near the bottom than near the top and a relatively persistent zone of conglomerate occurs about 100 feet below the top.

The tuffs are felsic, buff, light gray, and creamy white. They are composed of angular mineral grains in a fragmental matrix of partly devitrified glass. Some contain uniformly distributed angular pebbles.

Conglomerate, in beds 1-10 feet thick, forms only a small portion of the formation, but cobbles and boulders litter most of the slopes underlain by it. Pebbles and cobbles less than 4 inches in diameter are most common, but some boulders are as much as 4 feet in diameter. They are mostly volcanic rocks of felsitic to intermediate composition. Dark-colored andesite-like rocks are distributed throughout but are particularly abundant in angular conglomerate near the base, which in this respect resembles that in the lowest member farther south. Other conspicuous clasts are gray to maroon coarsely porphyritic felsite containing phenocrysts of feldspar as much as 1.5 centimeters long. Many other less distinctive types are also present.

Quartz Latite-Andesite Member

The lowest clastic member of the formation, the Biscara Member of Barker (1958), is characterized by the abundance of fragments of generally dark-colored quartz latite or andesite in beds of conglomerate and breccia. In general, the member is present mainly on lower valley slopes east of the Rio Tusas, and only locally west of the river in T. 27 N. Within the area, it disappears under younger units south of that township, but Smith's (1938) description of the Abiquiu Tuff suggests that part of that formation may correspond to this member.

The combination of lithologies in the Quartz Latite-Andesite Member is much like that in the undivided part of the Los Pinos Formation, but tuff is more abundant. The member also includes bedded breccia of volcanic rocks, conglomerate composed of fragments of Precambrian rocks, and dikes and small pipes of volcanic breccia that are too small to show at the scale of the map.

Breccia of dark-colored quartz latite locally cliff-forming in Tps. 28 and 29 N., R. 8 E., and conglomerate of similar rock form much of the upper part of the member. Gray to blue-gray aphanitic rhyolite occurs as local bodies of breccia and as pebbles in conglomerate near the middle of the member.

Fragments of Precambrian rocks form masses of rubble and beds of conglomerate close to and locally some distance above the base.

The quartz latite or andesite of the breccia and conglomerate is light gray-green to maroonish gray and black, generally finely crystalline to aphanitic, and porphyritic. Plagioclase and shiny black hornblende are the common phenocrysts. Rusty iddingsite and biotite occur in some of the rock, and pyroxene is a phenocryst in some bodies of intrusive rock.

Coarsely Porphyritic Quartz Latite Member

The coarsely porphyritic Quartz Latite Member, Esquibel Member of Barker (1958), is characterized by the kind of rock most abundant in the conglomerate beds in it. Otherwise it is much like the undivided part of the Los Pinos Formation, with which it may be in large part correlative.

The member is confined largely to the highland east of the Rio Tusas from Broke Off Mountain southward to the northwest corner of T. 27 N., R. 8 E., where it pinches out between the underlying and overlying clastic members. It is also present, but not mapped separately, west of the Rio Tusas in T. 29 N., R. 7 E. (Barker, 1958, pl. 1). To the east it dips under the overlying Rhyolite Member.

The rock of the most abundant clasts in the conglomerate beds is coarsely porphyritic quartz latite in which phenocrysts of feldspar as much as 8 mm long, and subordinate biotite and hornblende are set in a gray to purple-pink groundmass. Unusually large boulders of this rock 4-9 feet in diameter, near the top of the member in sec. 30, T. 28 N., R. 9 E., suggest the proximity of a bedrock source that is not exposed. The lower part of the member is transitional to the underlying Quartz Latite-Andesite Member, and at places clasts of Precambrian rocks and arkosic sandstone predominate in the top 25 feet.

Jarita Basalt Member of Barker (1958)

Widespread but discontinuous flows of basalt that rest mainly on older parts of the Los Pinos Formation, and locally on Precambrian rock, constitute the Jarita Basalt Member of Barker (1958), a name adopted from Butler (1946). For convenience herein, these flows are included with the Los Pinos Formation because of their stratigraphic position in New Mexico, but they may be equivalent to older parts of the Hinsdale Formation in Colorado, where some basalt in that formation intertongues with the Los Pinos Formation as mapped by Larsen and Cross (1956, pl. 1) and by P. W. Lipman (oral commun., 1971).

In the northern part of the area, basalt of this member caps Broke Off Mountain and other inclined mesas on the divides between the Rio San Antonio and the Rio Tusas and between the Rio San Antonio and Rio de Los Pinos. To the south, disconnected bodies of the basalt are present on the east slope of the mountains, in the valley of the Rio Tusas and locally on its eastern slopes, and on part of the west rim of the Mesa de La Jarita. At different places the flows rest on Precambrian rocks or conglomerate of fragments derived therefrom, on the two older clastic members, and, north of Broke Off Mountain, on the undivided part of the Los Pinos Formation. On the lower slopes east of Broke Off Mountain and in much of the valley of the Rio Tusas, the Jarita Basalt Member is overlain by the Rhyolite Member.

The basalt on mesas in the north part of the area consists of two megascopically slightly different varieties. The more widespread, and upper one where both are present, is fine grained and only slightly porphyritic, has considerable intergranular pore space and phenocrysts of rusty iddingsite after olivine, and locally contains amygdules of chalcedony. The other variety contains phenocrysts of only slightly altered olivine, phenocrysts of pyroxene in some flows, and veinlets and amygdules of calcite, and lacks intergranular pores.

Basalt in and near the valley of the Rio Tusas in the southern part of the area differs from that of the northern mesas in various megascopic details. Some flows are characterized by moldy-appearing pale-green or yellow-green spots, possibly a superficial alteration of plagioclase. Many have intergranular pores and sparse inconspicuous phenocrysts of hypersthene but lack the rusty altered olivine of the northern porous basalt. Non-porous rock in other flows has phenocrysts of rusty, altered olivine and, generally, of plagioclase. In a few flows, a dark-green pyroxene is the principal phenocryst and olivine is inconspicuous.

The Jarita Basalt Member is 100 feet thick on the north side of the Rio de Los Pinos and east of the Rio Trusas south of the Petaca Mesas. Elsewhere it is thinner.

Rhyolite Member

The top member of the Los Pinos Formation, the Cordito Member of Barker (1958), is characterized by rhyolitic rock that makes up the predominant fragments in the conglomerate and occurs as local flows or welded ash flows and a few small intrusive bodies.

The Rhyolite Member is most continuous on the eastern slope of the highland area south from Broke Off Mountain beyond the limit of mapping but extends west, as mapped by Barker (1958, pl. 1), into the basin of the Rio Vallecitos. On the sides of the canyon of the Rio de Los Pinos, sandy tuff above the Jarita Basalt Member and under the Hinsdale and Servilleta formations is also included in it.

The member consists predominantly of fluvially deposited beds that range from mudstone to conglomerate and subordinately of beds of tuff and lava or ash flows. Much of the member is poorly consolidated and exposures are generally confined to some indurated beds of conglomerate and to parts of some lava or ash flows.

North of the Petaca mesas the common clasts in the conglomerate consist of white, brownish-red, blue, and gray porphyritic rhyolite, and a blue slightly porphyritic variety. Quartz is an abundant phenocryst in all but the blue variety. Sanadine and sodic plagioclase phenocrysts are present in all varieties. The more phenocryst-rich rock occurs as a 70-foot thick flow, possibly an ash-flow tuff, and as tuff in the north-central part of T. 27 N., R. 8 E., and as a flow in the Rio Tusas Valley.

In the vicinity of and southward from the Petaca mesas, the predominant clasts in the conglomerate beds consist of coarsely porphyritic rock in which abundant phenocrysts of feldspar are accompanied by some biotite and hornblende and sparse quartz. Rock of this type occurs as a flow east of the Petaca mesas.

A third variety of somewhat glassy purple-pink porphyritic rhyolite, which lacks sanadine phenocrysts, forms a massive to brecciated flow in the Tusas Valley and in the valley east of the Petaca mesas, where it is 150 feet stratigraphically below the coarsely porphyritic flow. It also occurs in a few small dikes and plugs in the west-central part of T. 26 N., R. 9 E.

Southward from the middle of the Petaca mesas conglomerate beds are less abundant than farther north, and interbedded friable tuffaceous arkose and sandstone are more abundant. Upward in the section east of the Rio Tusas, volcanic components diminish to disappearance, and the rocks are arkose and sandstone like those of the Santa Fe Formation as used by Smith (1938).

Thickness

From the south side of Broke Off Mountain northward to the Rio de Los Pinos, the Los Pinos Formation is between 600 and 700 feet thick to the top of the Jarita Basalt Member. In the northern part of T. 28 N., R. 9 E., the formation is between 1,300 and 1,400 feet thick below the eroded top of the Rhyolite Member. It thins out completely against hills of Precambrian rock, especially those west of the Rio Tusas.

Origin and age

The fluvially deposited rocks that make up the larger part of the Los Pinos Formation consist largely of material of volcanic origin and very subordinately of materials eroded from Precambrian rocks. A large part of the fluviatile beds probably represents a clastic facies spread as an apron around centers of nearly contemporaneous volcanic eruption. The components of the undivided part of the formation may have come from varied sources including the younger lavas erupted from vents east of the Platoro caldera (Lipman and Steven, 1970). South from the northern part of the Tusas Valley, the coarser components in the fluviatile beds change in type systematically upward through the different members. The clasts in conglomerate beds of the Lower Quartz Latite-Andesite Member and the Upper Rhyolite Member have counterparts in associated eruptive and intrusive rocks. The largest boulders in the coarsely porphyritic member are near the center of the map area. These features suggest that the components of these members came from local centers of eruption rather than from those that supplied the undivided part of the formation farther north. Such centers may be largely concealed, for the known bodies of intrusive rocks appear too small to represent vents that supplied all the volcanic material of these units.

The Los Pinos Formation was deposited subsequent to emplacement of the tuff of Masonic Park, which has an age of 28.2 m.y. Bingler, (1968, p. 36) reported that a sample of welded ash-flow tuff from the Rhyolite Member west of the Rio Tusas in T. 26 N., R. 9 E. yielded a potassium argon age of 25.9 ± 1.8 m.y. The part of the formation bracketed by these ages is mostly Late Oligocene. Some beds in the southeast part of the area which are in the Rhyolite Member but which appear to be transitional into the Santa Fe Formation, may be considerably younger.

Santa Fe Formation

Rocks that are continuous with the Santa Fe Formation as used by Smith (1938) are confined to the southeastern corner of the map area. The lower boundary of the formation is gradational with the top of the Rhyolite Member of the Los Pinos Formation, and the lower beds interfinger with and appear to overlap northward onto that member.

This same kind of transition zone also marks the boundary between the Abiquiu Tuff and the Santa Fe Formation immediately south of the area of the map (Smith, 1938).

The Santa Fe Formation consists chiefly of light-buff, thin- to thick-bedded, clean to silty sandstone. Some beds near the base are brownish red. High-angle, possibly eolian, crossbedding that extends across layers 10-20 feet thick is a characteristic of some beds.

The position of the rocks of the Santa Fe Formation in this area relative to the stratigraphy in its main area of outcrop farther south in the Rio Grande Valley has not been clearly determined. However, the interval with large-scale crossbedding may correspond to similar strata in a member near the top of the Tesuque Formation as used by Galusha and Blick (1971), to which they assign an Early Pliocene age.

Rhyolite of No Agua Mountain

No Agua Mountain is the eroded remnant of a local mass of rhyolite that was extruded after all, or nearly all, of the uppermost member of the Los Pinos Formation had been deposited and before eruption of the Lower Basalt Member of the Hinsdale Formation, which is younger than all of the Los Pinos Formation and is described below. The rhyolite consists mostly of finely flow layered spherulitic pitchstone and granules of obsidian set in a webwork mesh of glass. It has a fission track age of 4.8 m.y. (Lipman and others, 1970, p. 2346). Sand and gravel derived from the mountain are exposed under the Lower Basalt of the Hinsdale Formation in a cut on U.S. Highway 285 about 1 mile north of the base of the mountains.

Hinsdale Formation

The Hinsdale Formation (Lipman and others, 1970), formerly a part of the Hinsdale Volcanic Series (Larsen and Cross, 1956), is a bimodal association of rather local bodies of rhyolite and more extensive sheets of alkali olivine basalt. On the east flank of the Tusas Mountains and near the west edge of the Taos Plateau the formation comprises two basaltic members.

Lower Basalt Member, Cisneros Basalt of Barker (1958)

The Lower Basalt Member, the Cisneros Basalt of Barker (1958), of the Hinsdale Formation in the area of the map, consists of disconnected bodies in the northeast part of the area and some isolated bodies in the south part of T. 28 N., R. 9 E. and north part of T. 27 N., R. 9 E. It rests with a slight but distinct angular unconformity on all members of the Los Pinos Formation except the lowest. It partly fills shallow valleys eroded in the Jarita Member east of Broke Off Mountain and in the Upper Rhyolite Member south of Tres Piedras.

On the lower east slope of Broke Off Mountain, the basalt is dark gray, maroon streaked, very fine grained, nonporous, and carries sparse phenocrysts of relatively fresh irridescent olivine. Other flows, particularly some in the southern part of the area and at places north of the Rio de Los Pinos, are more porphyritic and contain phenocrysts of plagioclase, as well as olivine, and some are slightly porous. The plagioclase in the groundmass is generally finer grained than that in most flows of the Jarita Member of the Los Pinos Formation and Servilleta Formation.

Upper Basalt Member, Dorado Basalt of Barker (1958)

The Upper Basalt Member, the Dorado Basalt of Barker (1958), includes the flows that cap the Petaca Mesas and a mesa north of them and several other separated bodies of quartz-bearing basalt southwest of San Antonio Peak and north and south of No Agua Mountain. In some areas north of No Agua Mountain, this basalt member is included with the Lower Basalt Member on the map.

The southern bodies of the Upper Basalt Member (Dorado Basalt) are unconformable on the Quartz Latite-Andesite and Rhyolite members of the Los Pinos Formation and the Santa Fe Formation. They were erupted after erosion had obliterated the topographic effect of post-Los Pinos movement on a fault that bisects the Petaca mesas. Some of the northern bodies of quartz-bearing basalt rest on the slightly eroded Lower Basalt Member (Cisneros Basalt). All bodies of the Upper Basalt Member (Dorado Basalt) contain quartz xenocrysts, and some in the northern part of the area also contain xenocrysts of sodic plagioclase. Rock in the southern bodies is fine grained, nonporphyritic to porphyritic, finely to coarsely vesicular; that of the northern bodies is conspicuously porphyritic. Plagioclase and sparse olivine are phenocrysts in porphyritic rock.

In T. 27 N., R. 9 E., the Upper Basalt Member (Dorado Basalt) is at least 150 feet thick; elsewhere its maximum thickness is not known, and at the edge of individual flows it thins to about 10 feet.

Source vents of the Dorado and related quartz basalts are more numerous than those of any other volcanic rock in the area. They include remnants of cinder cones southwest and south of San Antonio Peak, on the south rim of a depression about 6 miles southeast of the peak, and a cone on the east side of Petaca Mesa.

Age

In the San Juan Mountains, Colorado, basalts of the Hinsdale Formation have ages that range from about 23 m.y. for a body north of Summitville, Colorado, to about 5 m.y. for the average of a dike and flow high on Los Mogotes (Lipman and others, 1970, table 5), about 5 miles north of the map (fig. 2) with this report. The ages of the basalt members of the Hinsdale Formation within the area of the geologic map probably are close to the younger limit of the range. Some of the Lower Member (Cisneros Basalt) north of the Rio de Los Pinos may have come from Los Mogotes, and another body of this basalt, as mentioned above, overlies gravel derived from rhyolite of No Agua Mountain which has a fission track age of 4.8 m.y. (Lipman and others, 1970, p. 2346). The volcanic rocks of the Hinsdale Formation near the east margin of the mountains and west edge of the Taos Plateau in New Mexico appear to have been erupted in a brief time span near the close of Hinsdale volcanism, but radiometric ages of some bodies of basalt are still undetermined.

Quartz Latite Flows of Volcanic Domes

San Antonio Peak and several other domal mountains of the Taos Plateau are constructed largely of two varieties of hypersthene-bearing quartz latite. The more abundant rock on San Antonio Peak is various shades of gray, aphanitic, sparsely porphyritic, and partly vesicular. The other is black, glassy, and breaks with a good conchoidal fracture.

The age of the rock of San Antonio Peak relative to that of basalts of the Hinsdale Formation is unclear, as the contact is obscured by alluvium or slope wash. On rather tenuous evidence it is thought to be younger than the Lower Basalt Member of the Hinsdale (Cisneros Basalt).

Servilleta Formation

The Servilleta Formation is the youngest unit of the Tertiary sequence in the map area. It is part of the fill of the Rio Grande depression as described by Bryan (1938) rather than a part of the mountain sequence. The western edge of the formation coincides with much of the boundary between the depression and the upland to the west. The contact between the Servilleta Formation and underlying rocks is a slight but distinct unconformity that is suggested largely by the way the basalt flows in it lap on various older rocks at different places. The unconformity can be seen on the southeast rim of the canyon of the Rio de Los Pinos in T. 32 N., R. 8 E. and in a shallow valley west of U.S. Highway 285 about 5.5 miles south of Tres Piedras (fig. 4). The formation is inferred to be younger than the rock of San Antonio Peak, but that relation is not clear.

Flows of basalt that extend from the vicinity of Antonito, Colorado, 5 miles north of the state line, southward 20 miles beyond the limit of the map and underlie much of the Taos Plateau (see Upson, this guidebook, fig. 5) are the most distinctive feature of the formation. Lenticular beds of sand and gravel intertongue with the basalt, but are mostly poorly exposed except in excavations and in the canyon of the Rio Grande, 15 miles east of the area. The fluvial beds, like the basalt, are unconformable on the Los Pinos Formation and on the Santa Fe Formation as used by Smith (1938) and Bryan (1938) and are younger than rocks included in the Santa Fe Group as used by Galusha and Blick (1971). They accumulated in response to relatively late downwarping of the Rio Grande depression and are related in time and position but not in provenance to the basalt.

Basalt of the Servilleta Formation is at least 100 feet thick along part of the course of the Rio San Antonio and about 40 feet thick at places on its west margin in T. 26 N., R. 9 E. Elsewhere within the area its thickness is less than 40 feet or mostly indeterminate. The formation thickens eastward to at least 500 feet along the canyon of the Rio Grande.

Most of the basalt is medium to dark gray, medium to coarse rather even grained, mostly nonporphyritic, and has abundant intergranular pore space, or as Lipman (1969) has mentioned, a diktytaxitic texture. Plagioclase, and olivine, and in some specimens pyroxene, are distinguishable megascopically. The relatively coarse, even grain and porosity of the groundmass are the features by which this basalt generally can be distinguished from the older basalts.

The basalt of the Servilleta Formation is an olivine theoleiite (Aoki, 1967*, and Lipman, 1969) and differs somewhat in chemical composition as well as megascopically from basalt in the Hinsdale Formation. It contains considerably less K_2O, P_2O_5, Sr, Rb, Pb, V, and Th; slightly less Na_2O and TiO_2; and little more Al_2O_3, MgO, and total Fe than alkali olivine basalt of the Hinsdale Formation (Lipman, 1969, p. 1349).

Basalt flows of the Servilleta Formation exposed in the canyon of the Rio Grande northwest of Taos have ages of 3.6 to 4.5 m.y. (Ozima and others, 1967). These are compatible with the stratigraphic position of the formation.

Unlike the effusive and volcaniclastic rocks of the older Tertiary formations, which were spread as vent and clastic apron facies around various volcanic centers, the Servilleta Formation accumulated in an asymmetric, subsiding basin of the Rio Grande depression. The subsidence was induced or accompanied by rifting. Lipman (1969) postulated that the difference in tectonic setting and difference in composition between the tholeiitic basalt of the depression and alkali basalt of the bordering highlands are

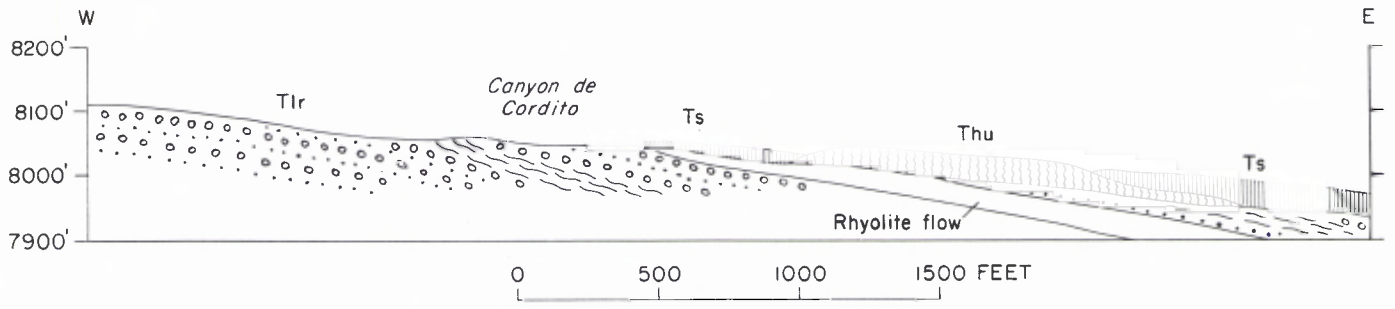


FIGURE 4.

Cross section in the southern part of secs. 10 and 11, T. 27 N., R. 9 E. showing Upper Basalt Member of the Hinsdale Formation (Thu), Dorado Basalt of Barker (1958) resting unconformably on the Rhyolite Member of the Los Pinos Formation (Tlr) and basalt of the Servilleta Formation (Ts) unconformable on both older units.

* Aoki refers to the basalt as "Taos basalts."

both related to shallower depth of magma generation under the depression than under the highlands.

STRUCTURE OF THE TERTIARY ROCKS

The Tertiary rocks of the area are mildly deformed by gentle eastward tilting, and most of the units are displaced by normal faults. The Los Pinos Formation and underlying formations commonly dip from 4° to 6°, younger formations mostly less than 3°. North of the latitude of Tres Piedras the strike of the beds is mostly between N. 15° W. and N. 30° W., but at places is east of north. South from there the strike is more northerly.

Several normal faults divide the rocks of the area into tilted blocks that are elongated in a north-northwesterly direction and have relatively steep west slopes and gentle east slopes. North of the Rio San Antonio there are five principal blocks, but south of it, owing to dying out of some faults and merging of others, there are only three.

The principal faults strike north-northwesterly, are downthrown mostly on their southwest sides, and are arranged partly en echelon or connected by northerly to northeasterly striking subsidiary faults in such a way that a more southerly fault is southwest of a more northerly one.

The maximum displacement on a single fault is about 1,200 feet in T. 28 N., R. 6 E., but elsewhere it is mostly less than 500 feet and diminishes to 0 at points where the faults die out.

CONCLUDING REMARKS

Study of the stratigraphy of the Tertiary rocks in the area of the Tusas Mountains reported on here has resulted in showing: (1) that the Los Pinos Formation is largely a product of waning phases of mid-Tertiary volcanism in the southeast extension of the San Juan Mountains; (2) that much of the Los Pinos Formation and the Abiquiu Tuff of Smith are equivalents, a relation further substantiated by Bingler (1968); and (3) that the Los Pinos Formation is mostly older than but also partly contemporaneous with the Santa Fe Formation as used by Smith (1938) rather than younger as once thought (Atwood and Mather, 1932). In addition the Servilleta Formation was recognized as a separate unit more closely related to events that affected the Rio Grande depression than to volcanism in the San Juan field.

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