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Geology of Puertecito Quadrangle, Socorro County, New Mexico

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Abstract

Puertecito quadrangle embraces a segment of the Colorado Plateau physiographic province adjacent to the northern and western margins of the Basin and Range province. The center of the area is approximately 21 miles north-northwest of Magdalena, New Mexico.

Mapped units include the Abo, Yeso, and San Andres formations, of Permian age; the Triassic Chinle formation; Cretaceous Dakota(?) sandstone, Mancos shale, and Mesaverde group; the Tertiary(?) Baca formation; Tertiary Datil volcanics, minor intrusives, and Santa Fe group; and Quaternary pediment-veneer gravels, spring deposits, landslides, and alluvium.

The late Miocene(?) Datil volcanics, exposed in the Bear Mountains and the eastern foothills of the Gallinas Mountains, are subdivided into three members: The lower, Spears member, consists of quartz latite tuff, agglomerate, breccia, and volcanic sandstone and conglomerate; the middle, Hells Mesa member, consists of semiwelded to welded rhyolite tuff; the upper, La Jara Peak member, consists of flows and flow breccias of basalt in the lower portions, and basaltic andesite in the upper part. The composition range in the La Jara Peak member is explained readily by fractionation in the magma chamber.

For the most part, dikes and sills of syenodiorite are intrusive only into Permian strata, whereas basaltic dikes, sills, and plugs are largely intrusive into post-Permian strata, including the upper portion of the late Miocene(?) volcanic sequence.

At least two periods of deformation took place in this quadrangle. The first orogeny, which occurred in late-Cretaceous or early-Tertiary time, consisted essentially of eastward directed compressional forces that resulted in the formation of the La Cruz anticline and the Sierra Lucero uplift. The basal portions of the Baca formation are interpreted as synorogenic, for they were folded with older beds during this deformation. The second orogeny took place in late-Miocene(?) time before the cessation of volcanism. Normal faulting, with a large horizontal component of movement, resulted from this deformation, which apparently was a product of a force couple directed in an east-southeast and west-northwest direction. Dike swarms trend about N. 10 W., parallel to the major trend of the faults, and were intruded during the early stages of faulting. The Santa Fe group, which overlies the Datil volcanics, has not been faulted or intruded in this area.

Detailed petrographic work is correlated with six chemical analyses that were made of the igneous rocks. The refractive indices of fused samples were plotted against the percentage of silica in the chemical analyses. These data indicate that the syenodiorite intrusions are not consanguineous with the extrusions and basaltic dikes. Application of

this silica-refractive-index curve to the volcanic rocks of the Gallinas Mountains suggests that they are chemically similar to those of the Bear Mountains.

Several stratigraphic sections were measured and are shown in the appendix.

Introduction

LOCATION AND PHYSIOGRAPHY

Puertecito quadrangle, in Socorro County, New Mexico, is bounded by latitudes 34°15' and 34°30' N. and longitudes 107°15' and 107°30' W. (fig. 1). It lies within the Datil section of the Colorado Plateau province adjacent to the north and west margins of the Mexican Highland section of the Basin and Range province. All but the sector north of the Rio Salado is within Cibola National Forest.

The quadrangle is named for the village of Puertecito in the north-central part of the area. No other settlement occurs in the quadrangle, and the nearest post office is in Magdalena, approximately 15 miles south of the southern border of the area.

A primitive desert road runs north from Magdalena through Puertecito to the settlement of Field. The arroyos flow torrentially when flash storms occur, bringing down large boulders from the mountains. A few wagon roads exist, but most are now traversable only on horseback. Four ranches have their headquarters within the quadrangle, at which good drinking water is available. The only other water safe to drink is found in springs in the mountains. Several Navajo families dwell in the northeastern portion of the area and make a meager living by raising a few sheep and cattle.

Relief within the area is only slightly greater than 2,000 feet. The crest of the Bear Mountains rises to at least 8,138 feet, whereas the Rio Salado valley, about 5 miles east of the eastern boundary of the quadrangle, has an altitude of 5,759 feet. Roughly three-fourths of the area is underlain by indurated sedimentary strata; the remaining one-fourth consists of volcanic rocks. The Bear Mountains range, most of which is included within the mapped area, is composed of volcanic rocks, which also form the foothills of the Gallinas Mountains in the southwest corner. Structurally the Bear Mountains are the east limb of a southward plunging syncline.

Two prominent volcanic necks, La Cruz Peak and La Jara Peak, are present in the central part of the quadrangle. La Cruz Peak rises about 800 feet above the floor of Jaralosa Canyon, and La Jara Peak stands an estimated 200 feet above the valley of Abbey Springs Canyon. Landslides of probable Quaternary age are present in the northern part of the area. They are almost entirely confined to the flanks of ridges capped by the Dakota(?) sandstone and underlain by easily eroded Chinle shale; small slides are found higher in the stratigraphic section, where less resistant beds are capped by more competent strata.

The area is drained by the Rio Salado and its tributaries. This large arroyo, which crosses the northern part of the area, is a major tributary of the Rio Grande to the east. Gullying is very common in the plains, especially those underlain by the Triassic "Red Beds." These gullies

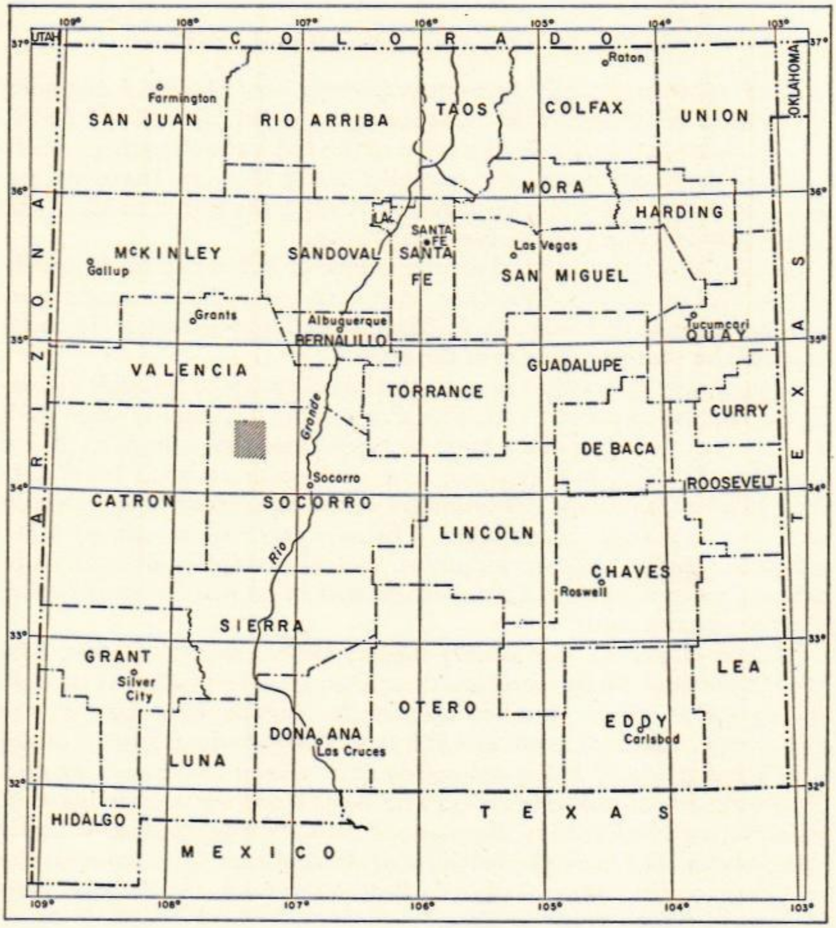


Figure 1

INDEX MAP OF NEW MEXICO SHOWING AREA INCLUDED IN THIS REPORT.

commonly attain depths of 8 to 10 feet and in places are less than 1 foot wide. Although all the streams are intermittent, here and there they have deposited as much as 15 to 20 feet of sediment. Many of the streams have been superimposed upon preexisting structures. Numerous gravel-capped remnants occurring at about the same elevation suggest an old erosion surface.

NATURE AND SCOPE OF INVESTIGATION

The mapping of this area represents a portion of a regional study of areas of essentially unknown geology, currently being undertaken by the New Mexico Bureau of Mines and Mineral Resources. The major problem was to determine and map the sequence of volcanic rocks in this portion of the Datil Plateau, and to determine their age. Moreover, very little was known concerning the structure of this region, for the detailed stratigraphy was lacking.

The field seasons of 1951 and 1952 were spent in mapping the quadrangle. The geology was mapped on aerial photographs with a scale of approximately 2 inches to 1 mile. A planimetric drainage map on a scale of 2 inches to 1 mile, prepared by the Soil Conservation Service, was used as a base map. A party under the leadership of R. H. Weber, of the New Mexico Bureau of Mines and Mineral Resources, made topographic profile traverses along the lines of the structural cross-sections.

PREVIOUS WORK

The work of others in the quadrangle has been primarily of a reconnaissance nature. In 1900, C. L. Herrick went through the northern part of the area in a reconnaissance survey that included over 12,000 square miles. His only comment (Herrick, 1900, p. 342) pertaining to the mapped area was that the Bear, Gallinas, and Datil Mountains are composed of trachyte and rhyolite intrusives. D. E. Winchester led a party in 1913 and 1914, mapping all of Puertecito quadrangle underlain by post-Paleozoic strata, as well as much of the area to the west. The results of this investigation were published in 1920. Winchester's study was concerned mainly with the Cretaceous coal-bearing strata; the Tertiary volcanic rocks were not studied in detail. Alamosa Creek, from which his report was entitled, is now designated as the Rio Salado.

E. H. Wells, in 1919, mapped structures in the Triassic "Red Beds" (his Puertecito formation) but worked mostly north of the Puertecito area. In 1928, N. H. Darton published his regional "Red Beds" study, which included his reconnaissance work in the area, as well as Winchester's previous work. The State geologic map, also compiled by Darton in 1928, shows the area essentially as mapped by Winchester.

The work of Kelley and Wood (1946) to the northeast, and the regional Upper Cretaceous stratigraphy of Pike (1947), particularly to the west and northwest, are valuable additions to a more thorough understanding of the geology of Puertecito quadrangle.

Stratigraphy

INTRODUCTION

The strata exposed in Puertecito quadrangle range in age from Permian to Quaternary. Table 1 shows the age and thickness of the units and Figure 2 is a generalized composite stratigraphic column.

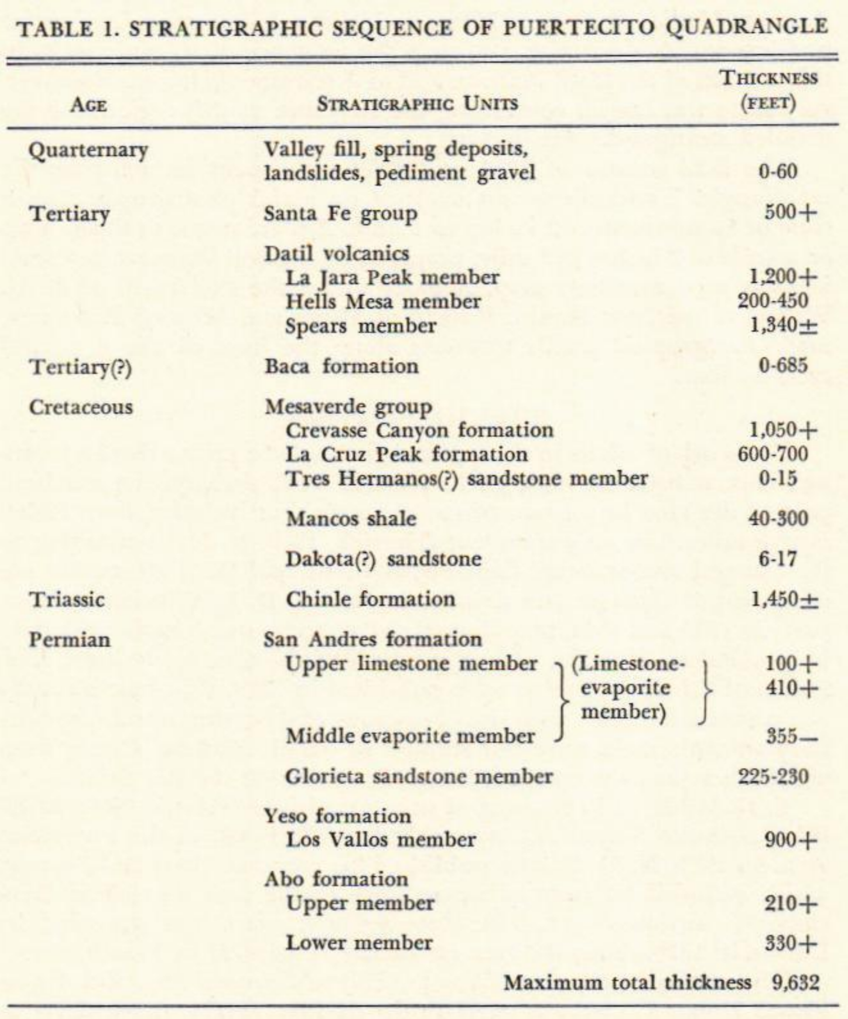


TABLE 1. STRATIGRAPHIC SEQUENCE OF PUERTECITO QUADRANGLE

Age	Stratigraphic Units	Thickness (feet)
Quarternary	Valley fill, spring deposits, landslides, pediment gravel	0-60
Tertiary	Santa Fe group	500+
	Datil volcanics	
	La Jara Peak member	1,200+
	Hells Mesa member	200-450
	Spears member	1,340±
Tertiary(?)	Baca formation	0-685
Cretaceous	Mesaverde group	
	Crevasse Canyon formation	1,050+
	La Cruz Peak formation	600-700
	Tres Hermanos(?) sandstone member	0-15
	Mancos shale	40-300
	Dakota(?) sandstone	6-17
Triassic	Chinle formation	1,450±
Permian	San Andres formation	
	Upper limestone member	100+
	(Limestone-evaporite member)	410+
	Middle evaporite member	355−
	Glorieta sandstone member	225-230
	Yeso formation	
	Los Vallos member	900+
	Abo formation	
	Upper member	210+
	Lower member	330+
	Maximum total thickness	9,632

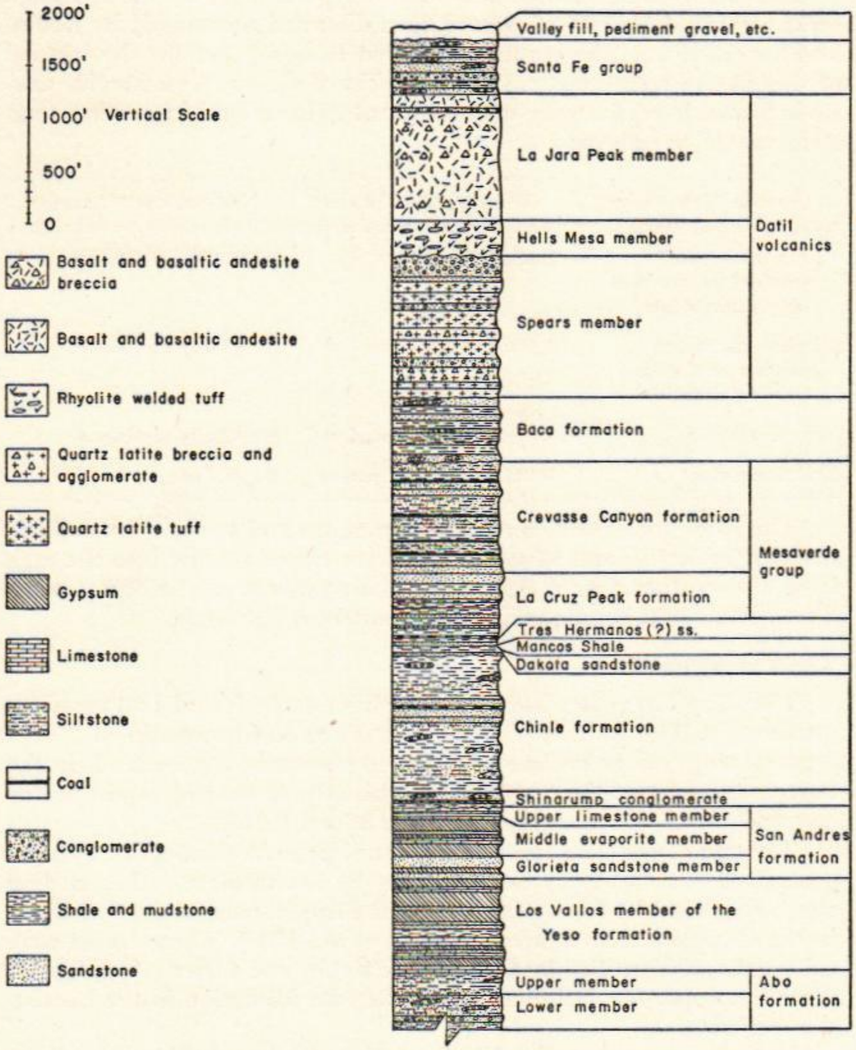


Figure 2

Generalized stratigraphic column.

PERMIAN

Strata of Permian age crop out in the northeastern corner of the area and cover approximately 25 square miles.

The nomenclature, correlatives, and type sections of the Permian rocks of central New Mexico have been discussed thoroughly by Kelley and Silver (1952). The reader is referred to this paper for the history of the present terminology. Permian rocks of central New Mexico and their probable equivalents in east-central Arizona and in northeastern Arizona are as follows:

CENTRAL NEW MEXICO	EAST-CENTRAL ARIZONA	NORTHEASTERN ARIZONA
Upper and middle members of the San Andres formation	Kaibab limestone	De Chelly sandstone
Glorieta sandstone member of the San Andres formation	Coconino sandstone	De Chelly sandstone
Yeso formation	Upper Supai formation	De Chelly sandstone
Abo formation	Middle Supai formation	Supai formation

The Abo, Yeso, and San Andres formations and associated members, mapped ~~by Kelley and Wood (1946), were traced readily into the area from the northeast~~ and, except for the members of the San Andres formation, could be mapped throughout the quadrangle.

ABO FORMATION

The Abo formation includes the oldest rocks found in Puertecito quadrangle. The unit, which has a south or southwest dip of 3 or 4 degrees, crops out as knobs and dissected cuestas in the lowlands in the northeast corner of the quadrangle. This area of outcrop separates the east and west Los Vallos of Kelley and Wood (1946).

The age of the Abo formation is considered Wolfcampian by most geologists, but the upper portions may be Leonardian. A Leonardian age is suggested by fossil plants from the upper part of the formation in the Chupadera Mesa area (Wilpolt et al., 1946). These fossils were collected and identified by C. **B.** Read. Kelley and Silver (1952, fig. 12) place the upper few hundred feet of the Abo formation in the Leonardian series.

In the mapped area, the Abo formation consists of thin- to medium-bedded dark-red to reddish-brown and grayish-yellow shale, shaly siltstone, and arkose, intercalated with lenses of limestone-pellet conglomerate. The lenticular character of the coarser grained detritus, as well as mud cracks and channeling, point to a continental origin of these strata. This interpretation is substantiated by the contained land plants and land vertebrates, as well as by additional sedimentary features observed in other areas (Wilpolt et al., 1946; Kelley and Wood, 1946; Wilpolt and Wanek, 1951; Kelley and Silver, 1952).

On the basis of lithology, it is possible to map within the quadrangle an upper and a lower member of the Abo formation. The lower member consists of interbedded dark-grayish-red to reddish-brown arkosic shaly siltstone, shale, arkose, and lenses of limestone-pellet conglomerate. The grains generally are well cemented with silica and iron oxide, forming a tough, compact rock. Local zones of carbonate cement are found. Sorting is poor, and the grains are predominantly angular to subangular. Brown-gray limestone fragments in the conglomerate rarely exceed 1 inch in diameter and are subangular to subround. Some euhedral casts, apparently of halite crystals, occur in the finer grained material. The coarser strata, where present, generally cap knobs and cuestas. The base of the unit is not exposed. Northeast of the area, however, approximately 900 feet of the Abo formation rests with apparent conformity on the Red Tanks member of the Madera limestone of late Pennsylvanian age (Kelley and Wood, 1946). About 300 feet of the lower member was measured in the Puertecito area from the northeastern boundary to the contact with the upper member. However, the total thickness of this member probably approaches 700 feet. In many regions in central New Mexico, Abo beds rest with only slight disconformity, or are conformable, on the Magdalena group (mainly Madera formation), although some angular relations have been noted (Loughlin and Koschmann, 1942). In the Zuni uplift area, this unit overlies Precambrian rocks in many outcrops (Darton, 1928-a).

The upper member is about 200 feet thick and consists of grayish-yellow to light-reddish-brown thin- to medium-bedded very fine- to fine-grained feldspathic sandstone and siltstone. These rocks contain fairly well-sorted detritus that is subangular to subround and generally cemented by carbonate; silica cement predominates in the lower portions of the member. The upper member can be distinguished in the field from the underlying strata by its lighter color, by the fact that persistent beds are generally of finer texture, and by the presence of much carbonate cement. Transition from nonmarine to marine depositional conditions may be represented by the upper member of the Abo formation, which appears to be approaching the marine lithology of the Yeso formation.

YESO FORMATION

Kelley and Wood (1946) recognized two members of the Yeso formation, a lower member, the Meseta Blanca sandstone, consisting of tan-brown massive crossbedded quartzose sandstone, and an upper member, the Los Vallos, consisting of tan-brown sandstone, limestone, siltstone, and gypsum. Kelley and Wood found that southward within their area the Meseta Blanca sandstone member, which ranges in thickness from 0 to 250 feet, loses its identity and cannot be differentiated.

The Los Vallos member has been traced into the Puertecito area, where it crops out east of the Sierra Lucero escarpment, at the southern extension of the west Los Vallos of Kelley and Wood.

The Los Vallos member of the Yeso formation forms a belt west and southwest of the Abo outcrop in the northeastern part of the quadrangle. The dip is generally to the west and southwest, with minor variations in attitude in the southern part of the outcrop belt. The area of outcrop consists of undulating lowlands, with local relief rarely in excess of 50 feet. Two igneous masses have been mapped within Los Vallos beds which appear to represent a series of very closely spaced sills. These sills were intruded into predominantly gypsiferous beds of the upper part of the member. Dikes of generally northward trend intrude the sediments and the sills.

The Los Vallos member conformably overlies the Abo formation. The contact between the two units was drawn at the base of the first gray medium-bedded fine-grained limestone that overlies beds of typical Abo Ethology. There are no key beds in this lithologically heterogeneous unit. The outcrops are so limited that stratigraphic sections could not be measured accurately. Kelley and Wood (1946) had good exposures of this member along the Sierra Lucero to the north, where they measured 820 to 1,020 feet of strata. It is reasonable to expect more than 900 feet in the Puertecito area.

The dominant lithologies of the Los Vallos member are medium-gray to greenish-gray, thin- to medium-bedded fine-grained limestone; pink and grayish-yellow fine- to medium-grain quartzose sandstone, subgraywackes and siltstone; and white to light-greenish-gray granular gypsum. The member is more detrital toward its base and more gypsiferous in the upper portions. Individual gypsum beds reach an observed 25 feet in thickness.

SAN ANDRES FORMATION

Strata of the San Andres formation rest conformably on the Los Vallos member of the Yeso formation. They form the prominent eastward and northeastward facing escarpment of Sierra Lucero. In places this escarpment rises over 600 feet above the Yeso lowlands that form the floor of the west Los Vallos. With only minor exceptions, the entire outcrop occurs north of the Rio Salado.

The San Andres formation is divided for mapping purposes into two members in the south and three members in the north.

As in most of central New Mexico, the Glorieta sandstone (see Kelley and Silver, 1952, for derivation of name) forms the basal member. It consists of two massive, white to grayish-yellow, tangentially cross-bedded quartzose sandstone strata, separated by a gypsum or gypsiferous sandstone unit. The sandstone is very fine to fine grained, well sorted, and well cemented (predominantly with calcite). Quartz grains are sub-round with a high degree of sphericity.

The Glorieta sandstone member has a thickness of about 230 feet. It generally forms the basal part of the Sierra Lucero escarpment in the mapped area. Along the Sierra Lucero, north of the area, the Yeso formation forms the base, and the Shinarump conglomerate or basalt flows form the cap of the scarp. To the south, the contact with the Los Vallos member is gradational, with pink quartzose sandstones and clayey siltstones occurring above the gypsum that generally forms the topmost strata of the Los Vallos member to the north. The contact is placed above the uppermost siltstone bed, so that the basal part of the Glorieta sandstone member consists entirely of sandstone, which is pinkish at the base. The pinkish elastic beds that occur at the southernmost outcrop of the basal part of the Glorieta sandstone member may represent a portion of the Joyita sandstone member of the Yeso formation, as defined by Wilpolt et al., in the Joyita Hills (1946). Sills are common in the Glorieta sandstone member within the gypsum, at the gypsum-sandstone contacts, and particularly at the upper contact of the member.

Following the terminology used by Kelley and Wood (1946), to the north a middle evaporite member and an upper limestone member of the San Andres formation were mapped in the northern part of the area. The contact between the two members could not be discerned farther south, where the San Andres above the Glorieta sandstone member is referred to as the upper limestone-evaporite member, having characteristics of both the middle evaporite and upper limestone members.

The middle evaporite member consists primarily of white and greenish-gray granular gypsum, with subordinate amounts of greenish-gray to light-olive-gray thin- to medium-bedded limestone, and grayish-yellow, calcite-cemented quartzose sandstone of Glorieta type. Some of the gypsum is thinly banded in dark and light layers and contains inclusions of calcite euhedra. The limestone is generally either aphanitic or finely crystalline, with some sandy limestone strata containing subangular to subrounded silt to fine-grained sand of medium sphericity. This member, together with the underlying Glorieta sandstone member, constitutes most of the face of the Sierra Lucero escarpment within the quadrangle. The measured thickness of this member is about 350 feet, with individual gypsum strata as much as 40 feet thick. Sills as thick as 50 feet are common throughout the member, particularly in the gypsum and at gypsum-sandstone and gypsum-limestone contacts.

Within the mapped area, the upper limestone member, approximately 100 feet thick, is conformable on the middle evaporite member and generally forms the long westward dip slope of the Sierra Lucero. These beds consist of grayish-green to medium-dark-gray fine-grained limestone, sandy limestone, and limestone breccia. Lesser amounts of gray to grayish-yellow very fine-grained quartzose sandstone and subgraywacke, and very light-gray gypsum are also present in the section.

Prior to Shinarump deposition, a young karst topography was developed on the surface of the upper limestone member. Much of the limestone breccia appears to be solution breccia, blocks and fragments of which have collapsed into the sinkholes and caverns of this karst topography (fig. 3). This post-San Andres erosion feature is observed best under the two southern travertine-capped mesas, where the contact with the overlying Triassic is very undulating. Elsewhere at the contact, Triassic "Red Beds," together with limestone breccia, fill solution cavities within the limestone. Read (1950) reports a relief of 100 feet on the San Andres formation in other parts of New Mexico.

In a few exposures to the south, particularly in sec. 1, T. 2 N., R. 5 W., the upper 15 to 20 feet of the San Andres formation consists of grayish-yellow to yellowish-orange medium-bedded fine-grained sandstone, intercalated with tan to gray calcareous shale and mediumdark-gray aphanitic limestone. These beds may represent the upper member of the San Andres formation as mapped by Wilpolt et al. (1946, 1951) east of the Rio Grande depression.

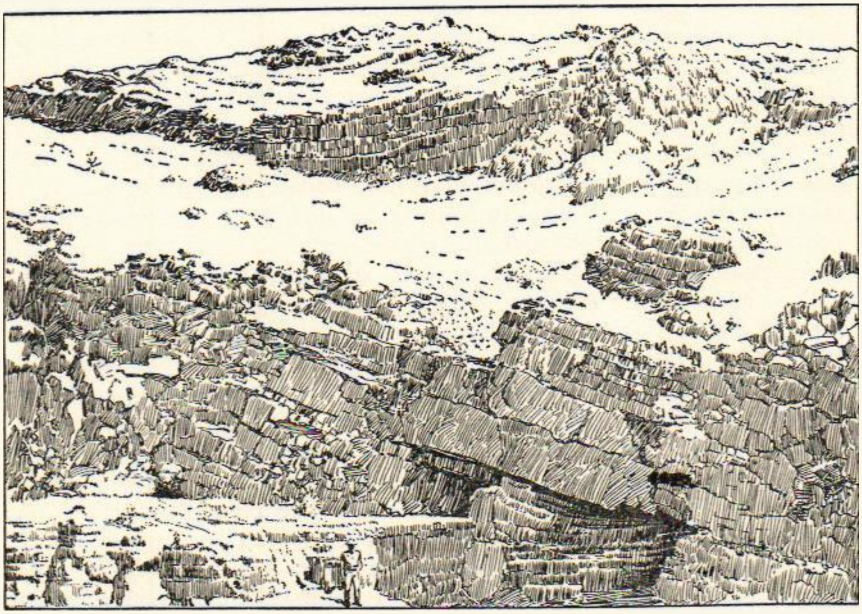


Figure 3

COLLAPSE IN SAN ANDRES LIMESTONE.

PALEOGEOGRAPHY

The Abo formation represents nonmarine deposition following the southward withdrawal of the Pennsylvanian seas of Virgil time. The source for the detritus was probably to the north and northeast in the active ancestral Rocky Mountains, with perhaps some contribution from the less active Zuni uplift to the northeast. The conditions of deposition are interpreted by Read (1950) as floodplain and deltaic. This interpretation is also held by the writer, who visualizes meandering streams with fairly wide floodplains depositing most of the material in a lowland area. The coarser beds of the Abo formation are believed to be the deposits of the migrating streams, and the finer grained detritus to represent floodplain deposition. The decrease in grain size toward the top of the section is accompanied also by better sorting and rounder grains. It is suggested that these deposits accumulated under conditions transitional into the restricted marine environment of the Yeso formation, when the source area was low, and the depositional area was being invaded by the seas.

The Yeso and San Andres formations were deposited in fluctuating seas. The Meseta Blanca sandstone member of the Yeso formation is interpreted by Wilpolt et al. (1946, 1951) as a transgressive-sea deposit. Restricted marine environments were present throughout much of Los Vallos and San Andres time, as evidenced by the large thickness of gypsiferous strata. Migrating bar and/or beach deposits are represented by the Glorieta sandstone member and the numerous quartzose sandstone beds within the Yeso formation and the San Andres formation. Read (1950) suggests that the position of migrating bars and beaches of the type represented by the Glorieta sandstone may well have accounted for the restriction necessary for the formation of evaporite beds in the Los Vallos member and the San Andres formation.

It has been mentioned above that the lithology of the basal part of the Glorieta sandstone in the southern part of the mapped area is similar to that of the Yeso formation. Wilpolt and Wanek (1951) found that the Yeso formation thickens southward. Intertonguing to the south would account for the grading of the Glorieta into strata of Yeso-type lithology. A similar interpretation may account also for the gypsum within the Glorieta sandstone member, which may be equivalent to part of the Yeso formation or upper portions of the San Andres formation. In the Puertecito area, the gypsum probably is related to the San Andres formation, for it becomes more clastic to the south. Wilpolt and Wanek (1951) found the opposite relation, in that their middle Glorieta sandstone was comprised of soft Yeso-like clastics to the north and gypsum to the south (fig. 4).

Thicknesses of measured sections in surrounding areas indicate that the marine Permian thins to the north, northwest, west, and east, and thickens to the southeast and immediate northeast, but thins again

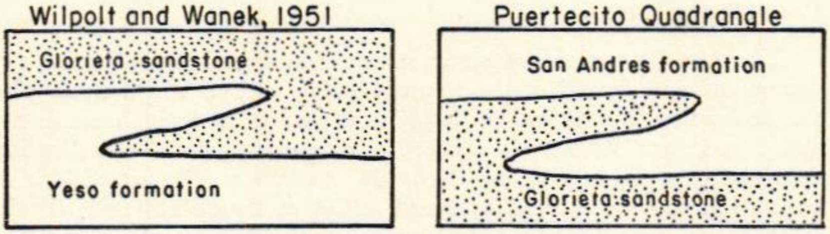


Figure 4

SCHEMATIC DIAGRAM SHOWING POSSIBLE SOURCES OF GYPSUM IN THE GLORIETA SANDSTONE.

northeast of the Lucero area (Dayton, 1928-a; Kelley and Wood, 1946; Wilpolt et al., 1946; Wilpolt and Wanek, 1951; Kelley and Silver, 1952).

After the San Andres seas withdrew, subaerial erosion apparently occurred on a terrain of low relief. The emergence of the area after San Andres deposition was accompanied by little orogeny or tilting. Instead, broad epeirogenic movements were responsible for the withdrawal of the sea.

TRIASSIC

A thick sequence of Triassic "Red Beds" disconformably overlies the San Andres formation. These beds crop out in a lowland belt that extends west, southwest, and south along the lower part of the gentle dip slope of the San Andres formation in the Sierra Lucero. Three remnant exposures occur within the San Andres belt, two of which are capped by Recent travertine. To the north, this Triassic belt is as much as 5 miles wide, with the strata trending north-south and dipping gently westward. The belt swings southeast parallel to the San Andres formation, assuming an east-west strike, and its outcrop width is reduced to less than 2 miles near the eastern boundary of the quadrangle. Structures, particularly faults, are very difficult to follow within this unit north of La Jara Peak, inasmuch as the north-south fault trend parallels the strike of this uniform sequence. The poor outcrops presented by this predominantly shaly unit also hinder deciphering of structures.

The "Red Beds" contain a coarse basal portion that is correlated here with the Shinarump conglomerate of the Lucero uplift area (Kelley and Wood, 1946). In the Lucero area, the Shinarump conglomerate is overlain by basalts that form the cap of the Sierra Lucero. Further work north of Puertecito quadrangle is needed to ascertain the validity of this correlation. G. H. Wood visited the writer in the field and agreed that the Shinarump conglomerate as mapped in the Lucero uplift area is present in the mapped area, and that the upper contact with the Chinle formation probably cannot be mapped (personal communication, 1952). Therefore, the complete red-bed unit is mapped as the Chinle formation (TrC).

The Chinle formation is of Upper Triassic age, and the Shinarump conglomerate in central New Mexico also is considered to be Upper Triassic. The nearest strata of questionable early-Triassic age occur in the Zuni uplift, 55 miles to the northwest, where Moenkopi(?) beds may be present.

The Chinle formation consists of continental grayish-red, grayishred-purple, light-green, and light- to dark-reddish-brown shale, mud-stone, and siltstone, intercalated with thin- to medium-bedded very fine- to medium-grained feldspathic sandstone and impure arkose. Lenticular beds of limestone pebble conglomerate occur throughout the section, and red and black quartzite pebble-conglomerate lenses are present near the base. The detrital grains are generally poorly sorted, sub-angular, and of intermediate sphericity. Some of the feldspathic sandstones in which sorting is good, and roundness and sphericity are intermediate to good, approach quartzose sandstones in composition. Nearly all the strata effervesce strongly with HC1, producing a hematitic froth. Crossbedding is common in the sandstones, and petrified wood is particularly abundant in the shales and siltstones.

This sequence may be divided into four subunits which, however, were not mapped because of the gradational character of the contacts. In ascending order these subunits are as follows:

(4) Upper siltstone-shale unit similar to 2.
(3) Upper sandstone unit containing some intercalated sandstones and limestone pebble-conglomerate lenses.
(2) Lower siltstone-shale unit, with minor intercalated sandstones and limestone pebble-conglomerate lenses.
(1) Lower sandstone unit—the Shinarump conglomerate.

The lower sandstone unit is believed to be the equivalent of the Shinarump conglomerate. A detailed section of the basal 250 feet of the Shinarump and Chinle formations was measured under the large travertine-capped mesa in sec. 31, T. 3 N., R. 4 W. (see appendix). The lower 150 feet, composed mainly of sandstone, probably represents the Shinarump conglomerate, and the upper 100 feet of shales and silt-stones are basal Chinle strata. Although the Shinarump conglomerate is coarser than most of the Chinle formation in the Puertecito and Lucero areas, it is not similar to the Shinarump conglomerates of western New Mexico and Arizona.

The lower siltstone-shale unit is lithologically similar to the upper siltstone-shale unit but maintains a more constant thickness of about 300 feet throughout the mapped area.

The upper sandstone unit forms a prominent cuesta or series of disconnected cuestas within the large Chinle valley, which is underlain by the less resistant shales. Three parallel sandstone cuestas are locally present, particularly south of the Rio Salado. Some of the sandstones that comprise this unit are fairly "clean" and approach the quartzose type in composition. The thickness of the unit is about 200 feet. The base is designated on the geologic map (pl. 1) by a dotted line. This sandstone unit probably correlates with the middle conglomeratic sandstone unit in the Zuni uplift area, but the basal beds need not correlate in time with the base of the unit in the Zuni Mountains.

The upper siltstone-shale unit is thickest at the northern border, where it attains a thickness of 800 feet. This unit thins considerably southeastward, so that near the eastern border its thickness is less than 200 feet. The Correo sandstone member of Kelley and Wood (1946) is not represented in the Puertecito area; if ever deposited, it was removed subsequently before deposition of the Dakota(?) sandstone.

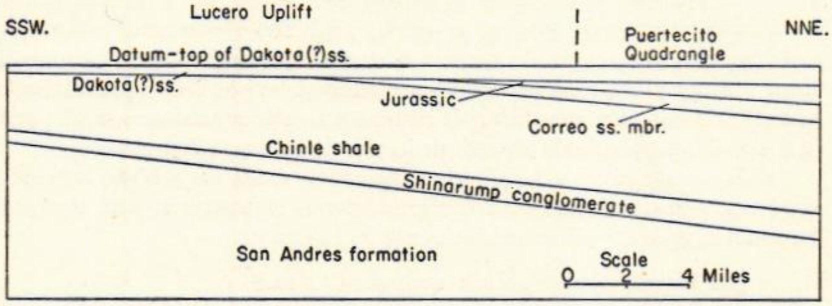


Figure 5

Schematic diagram illustrating Mesozoic relationships in the Puertecito and Lucero uplift areas at the end of deposition of the Dakota(?) sandstone. Vertical scale exaggerated.

PALEOGEOGRAPHY

There is no evidence that Triassic beds older than those represented by the Shinarump conglomerate ever were deposited in the mapped area. As mentioned earlier, the contact with the San Andres formation contains depressions filled with "Red Beds" of Shinarump lithology. However, Moenkopi-equivalent strata may have been deposited and subsequently removed, together with some of the Permian beds, in middle Triassic time. The irregularity of the Paleozoic-Mesozoic contact here and in other parts of central New Mexico indicates that gentle denudation, rather than aggradation, prevailed before the deposition of the Shinarump conglomerate.

The conditions of deposition of the Triassic "Red Beds" sequence are interpreted as similar to those that existed during the deposition of the Permian Abo formation. Floodplain sedimentation over a relatively flat surface is represented by the finer grained strata, whereas the lenticular conglomerates and crossbedded sandstones are indicative of channel or alluvial-fan deposition.

The "clean" sandstones of the upper sandstone unit may have been derived from older "clean" sands of Glorieta or Meseta Blanca source areas. A minor contamination from other source materials would be necessary to produce sands of the type found in the upper sandstone unit. The abundance of subrounded limestone pebbles in the conglomerates suggests a Paleozoic source, possibly Permian and/or Pennsylvanian, for much of the material.

It is not known whether the southeastward thinning of the upper siltstone-shale unit is depositional or due to the later erosion. Regional analyses favor the latter hypothesis. The Jurassic rocks, which in the Lucero area overlie the Correo sandstone member of the Chinle formation, coarsen and finally pinch out southward, and are not present in the Puertecito area. The Correo sandstone member of the Chinle formation is also absent in the mapped area, and it is not known if it ever was deposited. That deposition ceased and erosion commenced earlier in the south is supported, however, by the relationships in the Jurassic rocks to the north. It is concluded that erosion processes were effective for a longer period of time in the south than in the north.

CRETACEOUS

Marine and nonmarine beds of late-Cretaceous age crop out in an essentially northwestward trending belt across the north-central part of the area. These strata generally form a series of parallel cuestas or ridges of resistant medium-grained quartzose sandstone and subgraywacke, interbedded with less competent shale, siltstone, and sandy shale that form the intervening valleys.

DAKOTA(?) SANDSTONE

The oldest Cretaceous unit in the mapped area, the Dakota(?) sandstone, rests unconformably on the Chinle formation with very slight angularity. This sandstone lies on the Morrison formation north of the quadrangle and overlaps progressively older beds southward. As mentioned above, the Chinle formation underlying the Dakota(?) sandstone in the north is younger than the Chinle beds on which the Dakota formation rests to the southeast.

The Dakota(?) sandstone consists of light-gray to grayish-yellow medium-grained sandstone well cemented with silica and/or calcite. The grains are subround to round, and the sphericity and sorting are good. Tangential crossbedding is common within the massively bedded unit. The crossbedding is accentuated where abundant dark heavy minerals are present. Conglomeratic lenses composed of pebbles of quartzite, quartz, and partially decomposed chert in a quartz-sand matrix are common; some carbonized wood fragments are also present. The Dakota(?) sandstone ranges in thickness from 6 to 17 feet within the area.

Erosion of the incompetent Chinle shales has undercut ridges capped by the Dakota sandstone, and blocks of the sandstone have fractured and slid down the steep slope. Sliding of the blocks is indicated by attitude in the landslide blocks, which is always much steeper than the regional dip of the bedrock. A unit consisting of landslide debris of Dakota and Chinle beds has been mapped. Similar landslide phenomena also involve other Cretaceous beds where relatively incompetent shales and siltstones are capped by resistant sandstones.

MANGOS SHALE AND MESAVERDE GROUP

The Mancos shale and the Mesaverde group form the remainder of the Cretaceous sediments in the mapped area. Much difficulty is encountered in attempting to differentiate mappable units from this thick and extensive series of shale, siltstone, sandstone, and coal. Study of these rocks reveals that they represent strand-line deposits of the migratory late-Cretaceous sea. There are few "clean" shale units in the section. Intertonguing is locally very pronounced, and detailed planetable mapping on a larger scale should yield abundant data concerning inter-tonguing of strand-line deposits of this type.

The Cretaceous sedimentary rocks in Puertecito quadrangle were mapped by Winchester as the Miguel formation but also include equivalents of his Chamiso formation (Crevasse Canyon formation).

Lee (1915), using Winchester's unpublished data, subdivided the Cretaceous rocks into the Mancos shale (Winchester's Miguel formation) and the Mesaverde(?) formation (Winchester's Chamiso formation). He states (1915, p. 44):

> The Mancos, which elsewhere is almost exclusively a marine shale, here [the Datil Mountains] consists of sandstone and shale in nearly equal proportion and contains several beds of coal in the upper part.

He concludes (1915, p. 45) that the Datil Mountain area was very near

> ...the western continental land mass of Cretaceous time [, and that] ... Near-shore deposits, including coal, began to accumulate in the Datil Mountain region early in Colorado time while marine shale was accumulating farther north.

The coal beds which Lee assigned to the upper part of the Mancos are included with Mesaverde strata in this report.

In his regional "Red Beds" study, Darton (1928-a, p. 124) refers to Winchester's work (1920) and states that the Miguel formation

> . . . represents, in whole or in part, the Mancos shale, but [that] the position of the upper limit of the Mancos formation is not ascertained.

Darton suggests that the basal two persistent sandstone beds of the Miguel formation may represent the Tres Hermanos sandstone member of Lee (1915) and mentions (1928-a, p. 132) that the overlying Chamiso formation

> . . . is believed to be a nonmarine representative of the Mesaverde formation and probably also to include the upper part of the Mancos shale.

Pike (1947), in a regional study of the intertonguing relations of the Mancos and Mesaverde formations, correlated members and tongues from Mesa Verde National Park, in southern Colorado, southward to the section exposed at D-Cross Mountain, in T. 3 N., Rs. 8 and 9 W. He reported that the Miguel formation, contrary to Lee (1915) and Darton (1928-a), contains both Mancos and Mesaverde equivalents. The ManсosMesaverde contact presents a perplexing problem to the east, as it does in the D-Cross Mountain section, for near-shore conditions have been responsible for the deposition of much sand within the shales of the Mancos formation.

A brief description of the subdivisions of the Cretaceous which were mapped in the present study follows. Detailed lithologic descriptions are given with the selected measured sections in the appendix.

The Mancos shale consists of 40 to 300 feet of black to gray calcareous and noncalcareous shales. Large (as much as 2 feet in diameter) septated limestone concretions and thin limestone lenses are commonly present. The minimum thickness recorded within the mapped area is in the northwest and north-central portions; here the Mancos shale is restricted to the strata beneath the Tres Hermanos(?) sandstone. Thicker sections were measured in the south-central and east-central parts of the quadrangle, where the Tres Hermanos(?) sandstone member is absent.

The Tres Hermanos(?) sandstone member is assigned tentatively to the Mesaverde group, but it may be more closely related to the Dakota(?) sandstone. It is a massive soft grayish-yellow quartzose sandstone, generally quite feldspathic, ranging in thickness from 0 to 15 feet. It commonly forms a second ridge or cuesta above the Dakota(?) sandstone. The contact with the Mancos shale is gradational in that thin sandstone beds are interbedded in the shale and become progressively thicker and more abundant as one ascends the section. Near the top of this transitional zone, shale is present only as thin stringers. The contact on the map is drawn at the top of the last shale bed. Similar gradational contacts occur throughout all the Cretaceous strata, and all contacts have been drawn at the top of the last thin bed of the dominant underlying lihologic type. The Tres Hermanos(?) sandstone member apparently pinches out to the south in secs. 4 and 8, T. 2 N., R. 5 W., for it has not been found southeast of these localities.

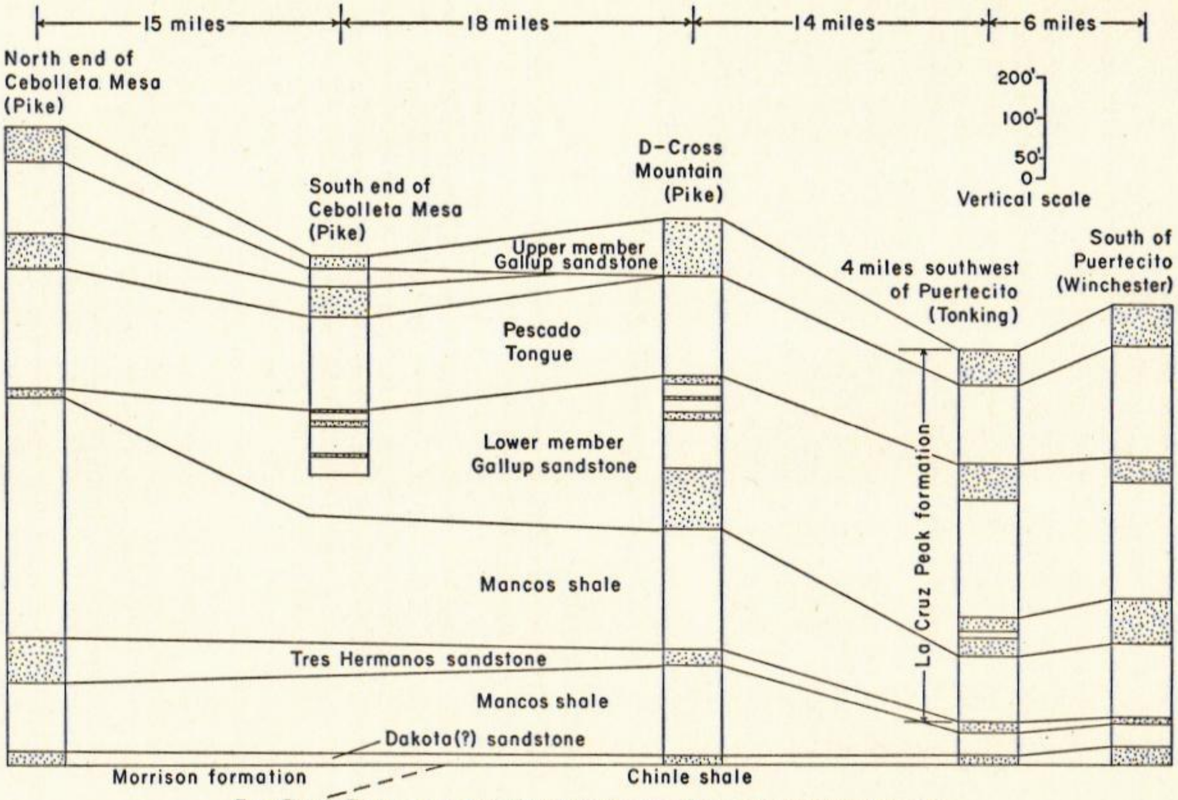
A sequence of olive-gray to bluish-gray marine shales, sandy shales, and gray to yellow crossbedded quartose sandstones and subgraywackes rests conformably on the Tres Hermanos(?) sandstone member in the west and on the Mancos shale in the east. This unit is here given the local name La Cruz Peak formation of the Mesaverde group, after La Cruz Peak in secs. 13 and 24, T. 2 N., R. 6 W. Its possible equivalents are discussed below. Attempts to map individual shale or sandstone beds within this formation were unsuccessful except locally in the west. Exposures are generally poor, particularly those of the basal 100 feet that overlies the Tres Hermanos(?) sandstone member. Most of this covered portion probably consists of shaly strata.

The La Cruz Peak formation is over 600 feet thick. It includes, in the western half of the region, three persistent massive grayish-yellow sandstone beds which contain abundant *Halymenites.* The top of the member is placed at the top of the Gallego sandstone of Winchester (1920), which varies from 0 to 80 feet in thickness. This massive sandstone is the most definitely marine in the mapped area. The ledge-forming Gallego sandstone, which contains a 1.5- to 2-foot oyster bed a few feet from its top, crops out continuously in the west but is faulted out in sec. 6, T. 1 N., R. 5 W., and has not been observed to the east. Because this prominent sandstone is not present in the eastern half of the area, the upper contact of the La Cruz Peak formation is drawn at the top of marine beds which are generally 75 to 125 feet below coal beds of the overlying Crevasse Canyon formation.

The Crevasse Canyon formation consists of grayish-yellow and grayish-olive sandstone and sandy shale, dark-gray to black carbonaceous shale, and coal beds. These rocks conformably overlie the La Cruz Peak formation. In addition to cropping out in the central portions of the area, this member is exposed by faulting in the eastern half of R. 6 W., in the southern part of the mapped area, north and south of the New Mexico base line. These beds suggest nonmarine and littoral conditions of deposition landward from the open sea to the northeast. Floral remains collected by Winchester (1920) and identified by Knowlton indicate a Montanan age, whereas invertebrates were assigned to the Coloradan by Stanton. Approximately 1,050 feet of strata comprising this member was measured.

Figure 6 is an attempt to apply the tonguing and member relationships that Pike (1947) found to the west and northwest to sections measured by Winchester (col. 5) and the writer's La Cruz Peak formation (col. 4). Once these are established, thickness variations may readily be seen as the shore and source area to the southwest are approached. The most interesting relationship shown in Figure 9 is the progressive decrease in the thickness of the Mancos shale from the north end of Cebolleta Mesa (col. 1) to Winchester's section south of Puertecito (col. 5). Lithologically the formation becomes more sandy southeastward, as does the Pescado tongue of the Mancos formation, particularly the

Figure 6



LA CRUZ PEAK FORMATION: TERMINOLOGY AND CORRELATIONS.

upper portions. The Tres Hermanos(?) sandstone member thins progressively in the same direction and probably pinches out. The lower part of the Gallup member in column 3 (fig. 9) apparently is represented by 323 feet of strata in column 4. In the mapped area (col. 4), this sequence of beds consists of basal and upper units of essentially massive sandstone, between which is a thick covered zone; in the west, the Rio Salado valley is cut into this covered portion of the section.

The Pescado tongue of the Mancos shale may be represented by 137 feet of strata in column 4 (fig. 6) and by 177 feet of beds in column 5. Winchester's section may have been measured where a small local embayment occurred during Pescado time, or the writer's section may represent a submerged seaward projection of the mainland into the Pescado sea, or slower deposition. This tongue overlies the upper massive sandstone of the lower part of the Gallup member and is gradational into the overlying upper part of the Gallup member. In column 4, the lower 67 feet of the Pescado tongue is covered and presumed to be shaly, whereas the upper 70 feet consists essentially of shaly sandstone and siltstone.

Pike (1947) noted a correlation between the upper part of the Gallup member and the Gallego sandstone of Winchester (1920).

PALEOGEOGRAPHY

Pike (1947) suggested that the Tres Hermanos sandstone member may be a tongue of the Dakota(?) sandstone or a tongue of Mesaverde sandstone, but he had no information to substantiate this suggestion. The present writer has found it impossible to distinguish this member south of sec. 8, T. 2 N., R. 5 W., and southeast of sec. 4, T. 2 N., R. 5 W. The field relations in the mapped area, as well as measured sections presented by Pike, indicate that this member pinches out or abruptly changes facies to the south. No available evidence is known which suggests that this member is part of the Dakota(?) sandstone or part of the lower Mesaverde to the south and southwest. Therefore, it is still unknown whether this sandstone is a part of the Dakota(?) sandstone or the Mesaverde formation. It may be seen in Figure 6 that at the northern end of Cebolleta Mesa (col. 1), the Tres Hermanos sandstone member is 75 feet thick, whereas only 25 feet occurs at D-Cross Mountain (col. 3). Not more than 15 feet of the Tres Hermanos(?) sandstone member occurs in the Puertecito area.

It is reasonable to suggest that this sandstone pinches out to the south, for it is a marine unit and very similar to the Dalton member of the Crevasse Canyon formation, which farther north, pinches out to the south. That it may be a peninsular deposit, as Spieker (1949) has suggested for the Ferron sandstone tongue in the Mancos formation of Utah, is also a possibility.

The history of this region during Mancos and Mesaverde deposition is interpreted as follows: The Tres Hermanos(?) sandstone originated as a bar, rather than a beach, in the Mancos sea. Land lay to the southwest. This bar was migratory and was submerged finally by a rise in sea level. Following deposition of more Mancos offshore sediments, which in this region was very near the shore line, several other strand-line features became prominent. A possible beach or bar is represented by the lowest sandstone of the La Cruz Peak formation; this was a regressive feature that was built out northeastward as the sea retreated. Landward of this strand-line feature, sands and silts, with some clay and minor carbonaceous material, were deposited. The Mancos sea returned to deposit the Pescado tongue. The noticeable increase in coarseness toward the top of this tongue indicates the initiation of another northeastward regression. The upper sandstone of the La Cruz Peak formation (Winchester's Gallego sandstone) represents the regressive sand body that followed the deposition of the Pescado tongue, and brought to a close marine deposition in the Puertecito area. The land by this time had been reduced to low terrain and shed only fine-grained detritus. Locally, coal swamps and lagoons prevailed; the deposits formed in this environment are represented by the Crevasse Canyon formation.

TERTIARY(?)

BACA FORMATION

The Baca formation disconformably overlies the Mesaverde group and is overlain by the Datil volcanics. Extensive exposures occur near the Hook and Spears ranches, and north of the Gallinas Mountains. These outcrops overlap the Crevasse Canyon formation of the Mesaverde group. Local outcrops in T. 2 N., R. 5 W., mainly overlie the La Cruz Peak formation of the Mesaverde group. The Baca formation, ranging from 0 to approximately 700 feet in thickness, consists of paleyellow-brown to pale-red-purple medium- to coarse-grained sandstone and conglomerate, intercalated with reddish-brown and grayish-redpurple mudstone and shale, and rare beds of green shale. The sandstones are largely impure arkoses, although arkoses and "salt and pepper" subgraywackes occur. Silicified tree trunks and branches as much as 1.5 feet in diameter are fairly abundant in the basal coarse sandstones, and many "woody" twigs are preserved in semiplastic clay and silt beds. Crossbedding and mud-pellet intraformational conglomerates occur sporadically, and mud cracks were found in one outcrop of the finer grained detritus.

Pebbles, cobbles, and boulders of quartzite, quartz, limestone, granite, and pegmatite, as much as one foot in diameter, occur in the conglomerate beds and aid in tracing the formation in areas of poor outcrop. The pegmatite, granite, quartzite, and quartz fragments probably were derived from Precambrian rock, and the limestone may be from a Pennsylvanian or Permian source. Much of the red material undoubtedly has been derived from the "Red Beds" of the Triassic and Permian.

Some outcrops of the basal portion of the Baca formation are lithologically similar to parts of the Mesaverde group and may have been derived from these underlying strata. Lee (1915) believes that much of the Mesaverde group was continuous over this region and northward. If this interpretation is correct, the Cretaceous beds would be the first beds eroded following uplift that occurred before Baca deposition. The stratigraphic relationships between pebble and boulder types are not systematic so as to match an inverted stratigraphic section. Instead, an admixture of materials from several lithologic source areas is indicated. The sources for these deposits probably lay several tens of miles away, for the fragments in the conglomerates are well rounded and have a high degree of sphericity.

The Baca formation, as mentioned above, overlies the Crevasse Canyon and La Cruz Peak formations of the Mesaverde group. In secs. 16, 17, 20, and 21, T. 2 N., R. 5 W., the Baca formation is folded with the La Cruz Peak formation in a syncline that forms a topographic valley. An unknown amount of time elapsed between the deposition of the two units, in order to account for the deep pre-Baca erosion. This synclinal valley existed before deposition of the Datil volcanics, for a tongue of the basal member of the Datil volcanics rests in the synclinal valley with marked angularity on the Baca formation and the La Cruz Peak formation. The Baca formation in this exposure probably was synorogenic and older than the Baca beds that truncate Mesaverde strata in other areas (Wilpolt et al., 1946). The Baca formation in the remainder of the mapped area may also be synorogenic, for its attitude is very similar to that of the underlying Crevasse Canyon formation. However, an erosional surface separates Baca beds from the Mesaverde group, the Baca overlying two different formations of the Mesaverde group.

The Baca formation was named by Wilpolt (Wilpolt et al., 1946) for Baca Canyon in secs. 4, 5, 8, and 9, T. 1 N., R. 4 W., where Winchester (1920) measured his type section of the Datil formation. Wilpolt selected the bottom 684 feet (694 feet, Wilpolt) of Winchester's section of the Datil formation (1920, p. 10) and made this the type section of the Baca formation.' He then extended the name to beds in the Carthage coal-field area (about 40 miles southeast of the Bear Mountains), which were lithologically similar to the Baca formation and in the same stratigraphic position. To these beds in the Carthage area he tentatively assigned a middle Eocene age, on the basis of a fossil mammal tooth collected near the base of the formation by Gardner (1910) and identified by Gidley as possibly *Palaeosyops* of Bridgerian age. Moreover, Wilpolt (Wilpolt et al., 1946) suggested that beds in the Elephant Butte dam area (about 60 miles south of Carthage) of "identical" lithology and in the same stratigraphic position are correlative with the Baca

1. It is unfortunate that this type Baca section contains 365 feet of cover. More continuously exposed sections occur west of the Bear Mountains.

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formation in the Carthage area. *Triceratops* remains found in these beds by Lee (1917) are believed by Wilpolt to have been "exhumed" from the Cretaceous and redeposited. The possibility of correlation with the Galisteo formation in the Galisteo basin to the north was also considered by Lee.

Kelley and Silver (1952), who give a much more comprehensive review of Wilpolt's work, do not believe that the Baca formation at Carthage is equivalent to, or lithologically "identical" with, the Elephant Butte exposures. They conclude (1952, p. 119):

> Although some similarity of environment and provenances is indicated for the two formations, we believe that, owing to differences in thickness, lithology, and faunal content, and in view of the complete separation of the areas, it is better to assign an independent name to the beds at Elephant Butte ...

They named these beds the McRae formation and tentatively assigned to them a late Cretaceous to Eocene age (1952, fig. 14, p. 114).

The nature of the basal contact with the Cretaceous rocks varies from area to area. Kelley and Silver (1952, p. 115) report that contacts between their McRae formation and the Mesaverde formation may be transitional, disconformable, or sharp. The writer finds Baca folded with the Mesaverde group, as well as resting disconformably on these strata. In several outcrops, the basal few tens of feet of Baca beds are similar lithologically to Mesaverde strata. Approximately 100 miles northeast of the Elephant Butte area, in the Sierra Blanca coal field, the upper part of the Mesaverde group is interbedded with a sequence of conglomeratic red-beds similar to the Baca formation (M. W. Bodine, personal communication, 1952).

The writer contends that the Baca, McRae, Raton, and Galisteo formations represent genetically related, although isolated, deposits. Lithologic and thickness variations are primarily due to differences of provenance and depositional environment. Variation in factors such as the depth and size of the basin, climate, drainage within the basin, rate of subsidence versus rate of uplift, transporting power of streams, type of material being shed by the source area, distance between basin and source, etc., produced local differences in the total aspect of the deposit. It is reasonable to expect that these depostis may be of different ages in different basins. If the basins were formed contemporaneously, the chance would be slight that they all trapped detritus at the same time and at the same rate. Because some basins were formed and filled before others, varied relationships with underlying strata would be expected.

Because these different combinations of controlling factors will yield diverse deposits within a similar tectonic framework, beds of late Cretaceous age may occur in a basin that is only a few tens of miles from a basin containing lithologically similar deposits of Paleocene or Eocene age. Conversely, two isolated basins may contain beds of an identical age that were derived from totally different rock types, and thus may be lithologically dissimilar. The names assigned to these beds are not important if one recognizes the complexities inherent in these isolated intermontane basin deposits, which are, nevertheless, genetically related to a general tectonic framework. Local names for these deposits probably will lead to less confusion.

TERTIARY

DATIL FORMATION[2]

The Baca formation is overlain by a great thickness of volcanic rocks named the Datil formation after the Datil Mountains 20 to 25 miles west of the Bear Mountains (Winchester, 1920). In the type locality, at the north end of the Bear Mountains, there is 1,824 feet of ". . . tuffs, rhyolites, conglomerates, and sandstones . . ." (Winchester, 1920, p. 9).[3] However, Winchester failed to measure a complete section, for above his uppermost 120 feet of "quartz rhyolite," there is at least 150 feet of vitric and welded rhyolite tuff, and a minimum of 1,200 feet of basalt and basaltic andesite lava flows. Winchester, moreover, mapped about 500 feet of the Popotosa-Santa Fe unit as Datil formation, but did not include it in his measured section. As mentioned earlier, the bottom 684 feet of his section is now the Baca formation (Wilpolt, 1946).

The Datil formation crops out in the Bear, Gallinas, and Datil Mountains. In the mapped area, it rests on strata of Cretaceous age, as well as overlying the Baca formation. To the south, in the Magdalena mining district, Loughlin and Koschmann (1942) report a thick sequence of volcanic rocks, some of which may correlate with the Datil formation, that rest unconformably on Pennsylvanian and Permian strata.

In this report, the term Datil formation is retained, and it has been divided into three mappable lithologic units in the Bear Mountains. These units are carried into the eastern Gallinas Mountains within the quadrangle's southwestern boundary. Reconnaissance with E. Callaghan and D. Givens, the latter at present mapping the Gallinas Mountains, showed the practicability of maintaining these units throughout the Gallinas Mountains. However, thickness variation within the individual units in the two ranges is great.

The three subunits are here termed members. In ascending order they consist of: (1) The Spears member, comprised of quartz latite tuffs and volcanic-rich detrital rocks, (2) the Hells Mesa member, composed of vitric rhyolite tuffs, most of which are welded, and (3) the La Jara Peak member, made up of basalt and basaltic andesite flows. Mapping

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2. According to Wilpolt (1946), this section was measured in secs. 4, 5, 8, and 9, T. 1 N., R. 4 W.

3. E. Callaghan has suggested that this unit more appropriately may be called the Datil volcanics.

westward may reveal that these units are more widespread than now suspected, and the rocks of the Datil formation may require a group rank.

The Datil formation has not yielded any identifiable fossils; thus its age is unknown. It is younger than the Baca formation and older than all but the basal portions of the Santa Fe group, which in the mapped area may include beds equivalent to the Popotosa formation. If the Baca formation extends into the Eocene, the Datil rocks are post-Eocene in age. The Santa Fe group is considered by most geologists to be late Miocene and younger in age. The La Jara Peak member is found intercalated with basal Santa Fe beds in the Bear Mountains; hence this part of the Datil formation is of the same age as these strata of the Santa Fe group.

Pelecypod shells and casts were found in a silicified sandstone intercalated with the La Jara Peak member, in sec. 12, T. 1 N., R. 5 W. The shells suggest that standing bodies of water were present in the area toward the close of Datil deposition, possibly the result of stream damming by lava flows. It is doubtful that any large streams were present at this time that could have supported this fauna.

Spears Member

A series of grayish-purple to reddish-brown quartz latite tuffs, tuff breccias, agglomerates, flow breccias, and volcanic sediments disconformably overlies the Baca formation with local angularity. This unit is exposed continuously along the northern and eastern flanks of the Bear Mountains. Isolated outcrops occur near Abbey Spring, some of which could not be mapped on the scale used. Extensive exposures occur throughout T. 1 N., R. 6 W., near the Hook ranch headquarters, and westward into the foothills of the Gallinas Mountains. Beds in the eastern exposures all dip into the Bear Mountains. Attitudes in outcrops in T. 1 N., R. 6 W., are gently undulating, except near the southwestern margin of the area, where these beds dip towards the Gallinas Mountains.

The Spears member of the Datil formation is named for the Guy Spears ranch in sec. 8, T. 1 N., R. 4 W. The type section was measured approximately 1 mile south of the ranch headquarters, where a complete section is exposed. Here, the Spears member rests with apparent conformity on the Baca formation. Three-fourths of the distance up Hells Mesa, this quartz latite unit is overlain disconformably by the Hells Mesa member.[4]

The section at Hells Mesa contains nearly 1,350 feet of volcanic material. The lower 1,000 feet consists of a monotonous sequence of medium-gray to grayish-purple fine- to thick-bedded tuffaceous sand-

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[4] This member would correspond to the 1,020 feet of strata below the "quartz rhyolite" of Winchester's section, which overlies the 684 feet of Baca separated by Wilpolt et al. (1946).

stones, conglomerates, flow breccias, and agglomerates, with intercalated thin beds of silt and clay. The tuffaceous sandstones are fine to coarse grained, whereas the tuffaceous conglomerates and agglomerates contain subrounded quartz latite boulders as much as 2 feet in diameter. Volcanic sandstones and conglomerates of similar color are interbedded with the tuffaceous strata in beds 3 to 20 feet thick. Crossbedding in the volcanic sandstones suggests reworking of original pyroclastic material. Basaltic dikes are common within the member in the Bear Mountains area.

Some of the finer grained volcanic conglomerates immediately overlie very thin tuffaceous(?) claystone or siltstone beds, and contain subrounded pebbles of these siltstones and claystones. These intraformational conglomerates suggest that some of the tuff beds were deposited in local bodies of water. The succession of rock types may represent graded bedding. Scouring by storms disrupted and "churned up" the finer sediments. Pellets of this material then were incorporated in the overlying volcanic sandstone.

Above the lower 1,000 to 1,025 feet of medium-gray to grayish-purple strata at Hells Mesa is a conspicuous, but local, 18-foot bed of white vitric rhyolite tuff, overlain by 300 feet of reddish-brown volcanic conglomerates and sandstones. The conglomerates contain beds of latitic boulders as large as 1.5 feet in diameter, intercalated with conglomerates containing pebble- and cobble-sized debris. The finer grained conglomerate is represented best in the top-most 50 feet of the section. These volcanic conglomerates probably represent alluvial-fan deposition.

A prominent discontinuous ledge of igneous rock occurs within the member in sec. 5, T. 1 N., R. 4 W., secs. 31 and 32, T. 2 N., R. 4 W., and sec. 36, T. 1 N., R. 5 W., at the northern end of the Bear Mountains. This ledge, which is mapped separately, is 30 feet thick and about 200 feet below the top of the member. The upper contact of this ledge with overlying grayish-green tuffs was not observed, owing to heavy talus cover. The rock is a medium-gray vesicular porphyritic aphanite containing large phenocrysts of pyroxene and plagioclase, and smaller phenocrysts of altered olivine. It is related petrogenetically to the later basalt and basaltic andesite flows of the La Jara Peak member and is believed to represent a sill that was intruded along a plane of weakness from a fissure that fed the La Jara Peak member to the surface.

In sec. 21, T. 2 N., R. 5 W., an angular unconformity is present between the Baca formation and the Spears member. The Baca formation here is interpreted as a synorogenic deposit that was infolded with the La Cruz Peak formation of the Mesaverde group during the Laramide orogeny. This synclinal structure was eroded into a topographic trough subsequent to the orogeny, owing to the fact that the Baca beds were less resistant than the underlying Mesaverde strata. Therefore, a topographic depression was present when the latitic material was being deposited, and a tongue thereof extended into the trough. Subsequent erosion has removed much of the Spears member from the depression, but the topographic syncline is still preserved because of the relative incompetence of the later beds.

The Spears member in T. 1 N., R. 6 W., is similar to that described in the Bear Mountains, with the exception that it contains more flow breccia. Large included fragments of grayish-green aphanitic limestone, light-brown medium- to coarse-grained quartzitic sandstone, and red siltstone, as much as 20 feet long, are abundant in the flow breccia. The included blocks represent Permian, Triassic, and/or the Baca formation rock types. Excellent exposures of the flow breccia occur along Dove Spring and Indian Spring Canyons. Both here and in the Bear Mountains the flow breccias are more resistant than the other rocks of this area.

Springs are common at the contact of the Spears member and the overlying rhyolite of the Hells Mesa member. The upper conglomerates of the Spears member apparently are good aquifers; where capped by the impervious rhyolite, springs occur in outcrops of the contact. The springs at the Hook and Chavez (Abbey Springs) ranches are located along this contact.

A 3-foot medium-gray basic dike containing iddingsite and hematite phenocrysts cuts the Spears formation in the W½ sec. 27, T. 2 N., R. 5 W. The dike is jointed both parallel and perpendicular to its walls and has chilled margins. This dike, which crops out over a distance of less than 100 feet and trends essentially north-south, is interpreted as a "feeder" for the lavas of the La Jara Peak member but is included with the Spears member on the map.

Hells Mesa Member

The Hells Mesa member of the Datil formation consists of tuffaceous rhyolitic material. It disconformably overlies the Spears member and crops out in bold palisades that form the marginal cliffs of the Bear and eastern Gallinas Mountains. The outcrop is almost continuous in the eastern and northern Bear Mountains but is not present in parts of sea. 8 and 17, T. 1 N., R. 4 W. At the latter locality, the Spears member is in fault contact with the La Jara Peak member of the Datil formation. To the north, the Hells Mesa member is offset in many places by normal faults. Scattered exposures in the vicinity of Abbey Springs dip toward the mountains, as do the northern and eastern outcrops. The inclination is steeper on the west flank of the Bear Mountains. Exposures (not shown on the map) occur at the contact of the Santa Fe and Baca formations, in sea. 18 and 19, T. 1 N., R. 5 W., and at the contact of the Santa Fe formation and Spears member, in sea. 13 and 24, T. 1 N., R. 6 W. The outermost high peaks of the Gallinas Mountains, in sea. 4, 5, and 6, T. 1 S., R. 6 W., and sea. 31 and 32, T. 1 N., R. 6 W., also consist of this material.

The member is named for the conspicuous peak in secs. 17 and 20, T. 1 N., R. 4 W., popularly called Hells Mesa. The peak is capped by approximately 250 feet of rhyolite. About 75 feet from the top, there is an iddingsite-rich basalt or basaltic andesite unit. This unit, which is 8 to 10 feet thick, is overlain by pink rhyolite tuff and rests on gray-white tuff. The basaltic rock is interpreted as a sill genetically related to the sill in the Spears member and is thus related also to the basalt and basaltic andesite flows of the La Jara Peak member. The sill is well exposed in one of the deep canyons in sec. 8, T. 1 N., R. 4 W., where it pinches out to the northeast. A similar sill was mapped near Abbey Springs.

The Hells Mesa member is about 250 feet thick in the northern Bear Mountains but is approximately twice as thick southward along the eastern mountain front. In the Gallinas Mountains, about 0.5 mile west of the quadrangle, more than 600 feet of rhyolite was measured, but this is not a complete section of the member. Reconnaissance observations indicate that this member may be more than 2,000 feet thick in the Gallinas Mountains.

The basal half of the section in the eastern and northern Bear Mountains consists largely of welded rhyolite tuff. The color ranges from pink below, to white or light-gray higher in the section. A conspicuous copper-colored euhedral biotite is characteristic of these beds and is also present in the lower part of the Gallinas Mountains section. The upper half of the member consists of white to light-gray welded rhyolite tuffs capped by about 25 feet of pink tuff. Most of the welded tuffs exhibit a foliation that dips parallel to the stratification, caused by collapse and elongation of silicified pumice vesicles.

In the Gallinas Mountains, the rhyolite observed within the mapped area consists of a basal white welded tuff that caps the easternmost knobs or peaks. Toward the interior of the range, the white basal tuff is overlain by a thick pink sequence of similar composition, which forms a higher series of peaks. These two rhyolites easily could be mapped separately, on the basis of color, as two subunits within the Hells Mesa member. Higher in the section and beyond the quadrangle, the Hells Mesa member is softer and consists of white welded tuff and semiwelded pumiceous crystal tuff, containing abundant lithic pebbles. Near the top of the section, several miles west of the area, there is an intercalated vesicular iddingsite-rich basaltic andesite unit about 50 feet thick.

La Jam Peak Member

This upper member of the Datil formation consists of the basalt and porphyritic basaltic andesite that conformably overlie the Hells Mesa member. Three volcanic sandstone and conglomerate beds of Santa Fe lithology are intercalated in the uppermost part of the member.

The high central area of the Bear Mountains is composed of this member. Local outcrops occur also near Abbey Springs. The attitude of the La Jara Peak member is basinal, dipping toward the mountains similarly to the rest of the Datil formation. Owing to the deep canyons and talus cover, no single flow or flow unit can be traced any great distance; hence the number of flow units is unknown. As many as 18 oxidized and vesicular flow-unit tops have been observed on single traverses through the mountains from east to west, but faulting may have caused repetition.

The member is named for the volcanic neck, La Jara Peak, in sea. 11 and 14, T. 2 N., R. 5 W., about 2.5 miles north of the Bear Mountains.

The flows are dark- to medium-gray aphanophyres, which are in part red, oxidized, and scoriaceous. The lower part of the member has a distinctive red speckled appearance, owing to the presence of phenocrysts of hematite and iddingsite. Secondary calcite, quartz, and rare zeolites fill or partially fill the amygdules. Horizontal sheeting is common, giving the rock a stratified appearance. Crude columnar jointing has developed in the more massive outcrops. Essentially vertical non-polygonal joints are present. These are filled locally with gray crystalline calcite; individual cleavage rhombs attain lengths of as much as 2 inches. Flow breccias, as well as block flows (aa type), are abundant throughout the section.

The type section for the La Jara Peak member was measured in the northern Bear Mountains, in secs. 27 and 34, T. 2 N., R. 5 W., 3 to 3.5 miles south-southwest of La Jara Peak. Owing to possible structural complications, the measured sections may be inaccurate. The thickness measured along structure cross-section D-D' is about 2,500 feet; this is considered to be the maximum thickness for the unit. The type section contains 1,175 feet of lava and 25 feet of intercalated volcanic conglomerate and sandstone. Talus and soil obscure much of the upper portions of the section. Other detrital beds may be present above the ones recorded, for three such beds were observed at several localities in the mountains to the southeast. These intercalated volcanic conglomerate and sandstone beds, which are lithologically similar to the overlying Santa Fe group, support the conclusion that intermittent extrusion and sedimentation characterize the close of the Datil period of volcanism. The lavas grade from dark-gray basalt at the base to medium-gray basaltic andesite at the top of the section. Red hematite phenocrysts are present, decreasing in quantity higher in the section. Several red oxidized vesicular layers are present.

Flow breccias are particularly well developed in the La Jara Peak member in Carrizozo Canyon, near the contact with the Santa Fe group, and intercalation of the two units is also well exposed. These conglomerates and sandstones of the Santa Fe facies are about 20 feet thick; in their basal several feet they contain subrounded boulders of the La

Jara Peak member as much as 8 inches in diameter. Above the basal portion, the Santa Fe beds contain finer conglomeratic and sandy material derived from all members of the Datil formation. The succeeding flow of basaltic andesite "churned up" the top of the gravels as it moved into place, resulting in an irregular contact. The basal 2 or 3 feet of the flow consists of subrounded scoriaceous basaltic andesite boulders in a conglomeratic and sandy matrix. Many subrounded xenoliths of conglomeratic sandstone are present. The middle portion of the flow consists of "sheet lava," and the upper few feet is litho-logically similar to the basal portion. But here the detritus, which later deposited over the cracked and brecciated surface, filled the open spaces between the lava fragments. Hence the contact between gravel and lava is gradational. Downdip, some flow-front breccias are present, which also include much detrital material. Commonly the vesicular boulders at the tops and fronts of the interbedded flows are fractured, presumably by contraction upon cooling, and these fractures are filled with silt. A typical vesicular boulder from these parts of a flow will contain a fine network of siltstone.

The basaltic dikes that are so characteristic of the area intrude beds of the La Jara Peak member. These dikes have not been mapped because traceable outcrops thereof are rare. Outcrops of dikes in the southern Bear Mountains were truncated by the same erosion that affected the La Jara Peak member. If the age of the Datil formation, particularly the La Jara Peak member, were known, the age of the intrusions could be determined more accurately, for the Santa Fe beds are not intruded by these dikes. Apparently the dikes were intruded near the end of the La Jara Peak eruptive episode.

INTRUSIVE ROCKS

The igneous rocks which intrude all strata from the Yeso formation through the Datil formation are represented by sills, dikes, plugs, and volcanic necks. Many dikes and sills are not represented on the map (pl. 1) because of scale limitations.

On the basis of their field occurrence, these rocks may be separated conveniently into two groups: (1) basalt, most of which is intrusive into post-Permian strata, and (2) syenodiorite, emplaced principally in the Yeso and San Andres formations.

The intrusive rocks within the post-Permian portion of the section consist of greenish-gray, olive-gray, and medium-dark-gray basic aphanites and aphanophyres. Phenocrysts in the latter type consist of olivine, hornblende, pyroxene, and biotite. Most of the rocks are deeply weathered, particularly those in dikes and plugs. Weathering produces spheroidal forms of grayish-green and reddish-brown color. Columnar jointing, vertical in sills and perpendicular to the walls in dikes, is common. Inclusions are plentiful, ranging in size from slabs of shale 30 feet long and 2 feet thick to subrounded quartz xenocrysts 2 millimeters in diameter. Chilled border fades are discernible within the igneous bodies, except in those masses that are aphanitic throughout their entire thickness.

Dikes 2 to 30 feet thick and plugs 50 to 200 feet in diameter stand out in bold relief above the less competent stratified rocks and are noted easily on aerial photographs as prominent spines and knobs. The dikes intrude beds as young as the upper La Jara Peak member. In these youngest beds, the dikes do not stand out as prominent features, owing to the similarity in competency of the two rock types. The prevailing north-northwest trend of the dikes, and parallelism with most of the faulting,—easily seen on the geologic map (p1. 1)—are discussed in the section on structure. Some dikes and faults converge along strike (sec. 12, T. 1 N., R. 6 W.).

Contacts between intrusive rock and host are sharp, and metasomatic effects on the wall rocks are slight. The principal effect of the intrusions on the host is the development of a zone of induration, which rarely exceeds 6 inches in thickness adjacent to dikes, but which is several times thicker at the upper contact of some sills. An extremely hard grayish-yellow baked siltstone, with conchoidal fracture, occurs at the contacts of the La Cruz Peak formation with a sill, in sec. 19, T. 2 N., R. 4 W. The baked zone is about 3 feet thick, and the base is stratigraphically within 10 feet of underlying coal beds which have been coalified. The sill is about 30 feet thick, has very fine-grained chilled borders, and is cut by a dike of similar composition, which is slightly chilled against the coarser grained sill.

The sills generally are intruded into the most incompetent strata in the section, or along sedimentary contacts. Coal and shale are hosts for many sills, as are sandstone-shale contacts. In several instances, dikes pass into sills, and these sills at places have dikelike apophyses that extend into the overlying strata. Some sills are not completely concordant along their entire outcrop but follow a particular horizon for some distance and then transgress gradually into another position stratigraphically near the first.

Two volcanic necks of dark-gray vesicular aphanitic basalt form prominent landmarks in the Puertecito area. La Jara Peak, 1 mile east-northeast of the Armijo ranch headquarters, rises an estimated 200 feet above the Abbey Springs arroyo bed. It has pierced the Dakota sandstone, which forms a partial collar around the neck. Many small faults, possibly related to the emplacement of the neck, are distributed between the ranch headquarters and the peak. Spinose dikes project in a north-northwest direction from its base. The other neck, La Cruz Peak, in secs. 13 and 24, T. 2 N., R. 6 W., stands an estimated 800 feet above the valley of the Jaralosa arroyo. This neck is enclosed by the Upper Cretaceous La Cruz Peak formation and was emplaced along the axis of the La Cruz anticline. Essentially northward trending dikes like those associated with La Jara Peak project from its base.

The igneous rocks that intrude the Yeso and San Andres formations are speckled greenish-gray, white, and black aphanophyric and phaneritic syenodiorite. Weathering has been more extreme, the grain size is coarser, and the fresh color is much lighter in the syenodiorite than in the basaltic intrusions (type 1).

Syenodiorite sills are abundant within gypsiferous beds and at contacts of limestone and/or sandstone and gypsum. They are common at the upper contact of the Glorieta sandstone member, but the steepness of relief makes their mapping impracticable. Two areas within the Yeso outcrop are colored solidly on the geologic map (pl. 1) but do not represent single igneous masses. Attitudes are determinable in a few outcrops, which indicate a series of closely spaced sills separated by thin layers of Yeso sediments. Dikes of similar composition trend essentially northward throughout the Yeso and San Andres formations. In one outcrop, a finer grained dike cuts the northern sill mass.

Contacts of sills with most of the sediments are sharp. In contrast, the contacts with beds of gypsum are irregular and undulating, with apophyses or stringers of sill material sinuously extending into the gypsum. At some contacts, the gypsum has been recrystallized to a coarser grain within a few feet of the contact. No evidence was found of inversion of the gypsum to anhydrite as a result of heating and recrystallization.

SANTA FE GROUP

A series of poorly sorted volcanic-rich siltstone, sandstone, and conglomerate occurs interbedded with and overlying the La Jara Peak member of the Datil formation. These rocks have been designated arbitrarily as the Santa Fe group. Although they may be part of the Popotosa formation (Denny, 1940), no distinctive lithologic difference between the Santa Fe and the Popotosa has been described by Denny. A minimum thickness of 500 feet is assigned to these strata. The basal beds were deposited at the same time that the last few flows of the La Jara Peak member of the Datil formation were extruded, whereas the rest of the formation is younger than the Datil formation. The age of the Santa Fe group is late Miocene to Pliocene according to Wood (1941), and the Popotosa formation is considered by Denny (1940) to be of late-Miocene(?) age.

The formation crops out west of the main Bear Mountains divide in the headwater area of Abbey Springs Canyon. In addition to being interbedded with late La Jara Peak member flows, the Santa Fe formation rests unconformably on the Datil and older formations. The attitude of the formation is largely undulatory. The steepest recorded dips, 8 to 9 degrees, are near the eastern contact with the underlying La Jara Peak member and may be depositional to a large extent.

The Santa Fe group is fairly well cemented with calcite and ranges from pink to light brown, pink and pale red predominating. The coarser components consist mainly of subangular pebbles, cobbles, and boulders, as much as 2 feet in diameter, derived from all the members of the Datil formation. Channel and scour features are common, and crossbedding is pronounced. Distribution, poor sorting, and thickness variations of coarse debris suggest a fanglomerate. A few outcrops contain thin-bedded clayey siltstones, which may represent local lake deposits. No faults or dikes have been observed in the Santa Fe group.

An excellent exposure of this formation occurs in sec. 23, T. 1 N., R. 5 W., where gully erosion and slumping have exposed a 250- to 300-foot section. Here pinkish-tan sandstones and siltstones are well bedded, with occasional intercalated conglomeratic lenses.

QUATERNARY

GRAVEL DEPOSITS

Unconsolidated pediment-capping gravels, composed primarily of volcanic pebbles, cobbles, and boulders from the Datil formation, occur throughout the area. The most extensive isolated deposits unconformably overlie the Baca formation in Tps. 1 and 2 N., R. 6 W. A large isolated exposure truncates the La Cruz Peak formation of the Mesaverde group near the southern half of the Puertecito fault; it was de-

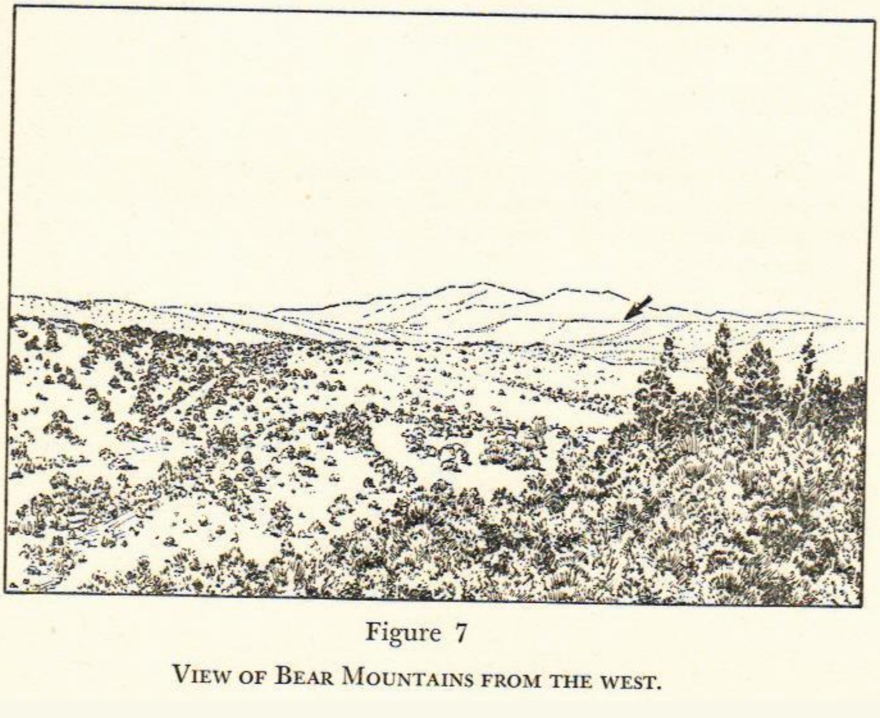

Figure 7

VIEW OF BEAR MOUNTAINS FROM THE WEST.

posited subsequent to the faulting. Most of these isolated deposits are approximately horizontal and occur at essentially the same altitude. It is believed that they are remnants of a once continuous extensive surface that was inclined 1 or 2 degrees northward (fig. 7). The large gravel area in the south-central part of the quadrangle slopes gently southward, whereas similar gravels east of the Bear Mountains dip eastward away from the mountain front. These eastern pediment gravels are younger than the other surface-capping detritus, for they are being formed today. A few gravel deposits occur along the Rio Salado at a lower level than the pediment-capping material and are considered to be terrace gravels.

SPRING DEPOSITS

Recent spring deposits cap the three mesas in sea. 30 and 31, T. 3 N., R. 4 W., and sec. 25, T. 3 N., R. 5 W. These horizontal beds overlie with angular unconformity the Triassic "Red Beds" and the Permian San Andres formation. At the present time, all the springs are inactive. The maximum thickness of these deposits, 60 feet, caps the largest (southern) mesa. The basal deposit is a conglomerate composed of limestone and Datil detritus, cemented by travertine; this basal conglomerate may be a pediment gravel older than the spring deposition. The remainder of the unit is composed of travertine, which locally is exceptionally hard and contains botryoidal and colloform structures. Included quartz sand grains are common.

LANDSLIDES

Landslides that form extensive aprons around ridges capped by resistant strata are mapped separately. Landsliding is most prominent in areas where the competent Dakota(?) sandstone forms ridges or cuestas overlying the relatively incompetent Chinle shale. Similar slides are present within the La Cruz Peak formation of the Mesaverde group, where resistant sandstone caps less resistant siltstone and shale. Some of the individual landslide blocks are more than 100 feet long. All blocks dip more steeply than the rock that is in place.

ALLUVIUM

Valley fill, local sand-dune areas, and the more deeply weathered areas are mapped as alluvium. The large amount of alluvium to the north, with the exception of the Rio Salado valley and its tributaries, consists of locally derived material.

Structure

The principal structural features in the area are normal faults which have produced horsts, grabens, and tilted blocks.[5] Gentle compressional features, in the form of open folds, are broken by the later normal faulting. Dips are rarely in excess of 25 degrees, and no overturned beds were found.

The structural elements within the mapped area may be divided conveniently into two groups, each representing separate orogenies. The first major episode of crustal buckling occurred in late-Cretaceous or early-Tertiary time, whereas the latest major deformation is late Tertiary in age.

LATE-CRETACEOUS OR EARLY-TERTIARY STRUCTURES

Two major compressional structural features are present in the mapped area. One of these, the folded and faulted Lucero uplift, is continuous to the north and northeast into the area mapped by Kelley and Wood in 1946. Darton (1928-a) believed that the Sierra Lucero consists of a large gentle homocline dipping to the west. Kelley and Wood (1946) find that the Sierra Lucero actually is the western limb of a large arch, the steeper eastern limb having been much modified by thrusting. Along this sinuous zone, termed the Comanche thrust belt, the stratigraphic displacement is at least several thousand feet. The southwestern sector of this arch is exposed in the Permian tract in the northeast portion of the Puertecito area. The entire quadrangle, however, may be considered to be located on the southwestern limb of this great southward plunging arch. As mentioned earlier, most strata on the northern border strike northward and have westerly dips. As these beds are traced southward, the general trend swings eastward out of the area, or under the cover of Tertiary beds (see cross-section A-A').

The second major flexure that apparently belongs to this orogeny is the La Cruz anticline (Winchester, 1920). The fold interrupts the regional homoclinal west to southwest dip of the sedimentary units. The axis plunges south-southeast at about 20 degrees. Although the trend of the axis is roughly N. 20 W., it is sinuous in detail. The fold is asymmetrical, with steeper dips generally present on the northeast limb. The western limb is readily traceable because of good outcrops of the ledge-forming upper member of the Gallup sandstone (Gallego sandstone).

A marginal basin occurs directly northeast of La Cruz Peak. Here the upper member of the Gallup sandstone is exposed in a circular

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[5] It was found advisable to map only those faults with more than 50 feet of throw. Fractures with smaller displacements are so numerous as to obscure important geologic relationship on the map scale used. In general, the larger fault blocks have been broken up by smaller fractures which are not indicated on the map.

platterlike outcrop dipping basinally under the coal-bearing Dilcolower Gibson member (see cross-section A-A').

A subsidiary syncline occurs on the eastern limb of the La Cruz anticline, east of the Puertecito fault, in T. 2 N., R. 5 W.; its trend is essentially parallel to the major structure. Later movement along the Puertecito fault may have rotated the fold axis slightly. Included in this syncline are beds of the Baca formation, which are folded as intensely as the adjacent Mesaverde strata.

Smaller scale flexures are present in the Cretaceous tracts, particularly southeast of La Jara Peak, in T. 2 N., R. 5 W., in the Los Vallos member of the Yeso formation to the northeast.

LATE-TERTIARY STRUCTURES

The late-Tertiary orogeny produced much normal faulting. Contiguous steplike tilted blocks, horsts, and grabens are the resultant structural features. The faulting involves beds as old as Permian and as young as early Tertiary. Most of the faults are of the transverse type, with some strike-slip movement. The strike-slip movement along the faults is indicated by the bed offsets seen in plan section, as well as by the inclination of slickensides. None of the slickensides observed in the area has a vertical pitch; a pitch of 45 degrees or less is common. The dips of the few fault planes that could be measured are essentially vertical.

The trend of the faulting, with few exceptions, is north-northwest; this trend parallels that of the numerous dikes. The merging of many dikes and faults along the strike, as well as penecontemporaneous faulting and dike emplacement, are additional evidence of a genetic relationship between the dikes and faults. Some faulting actually occurred shortly after emplacement of the dikes and sills, for in a few places the latter features are offset by faults; elsewhere intrusion and faulting were contemporaneous.

The maximum vertical displacement along the faults seldom exceeds 500 feet. The Hells Mesa fault is the largest fault in the quadrangle; it can be traced about 15 miles in a general northward direction. The displacement is greatest at the south, where the throw is of the order of 500 to 600 feet, and the horizontal displacement exceeds 1 mile. Strata of the upper Spears member of the Datil formation are in juxtaposition with the lower part of the La Jara Peak member of the same formation. The northern part of this fault is shown in cross-section A-A'. Cross-sections D-D' and E-E' show the southern portions of this fault. The Chavezito fault trends northwestward, oblique to the predominant trend of the faulting. Fault breccia is abundant along the trace of this fracture and in places has completely cut out the La Cruz Peak formation, which indicates a throw of approximately 600 feet. The remaining faults, with throws of 50 to 300 feet, include the Puertecito and Castello faults of Winchester (1920).

Mineralogy and Petrology

METHOD OF STUDY

The megascopic and microscopic features of the igneous rocks of the Puertecito area were studied systematically. First, hand specimens were examined under a hand lens and a binocular microscope, and the visible mineralogy was recorded. Crushes (-120-mesh) then were prepared and separated magnetically with a Frantz Isodynamic Separator, Model L-1 (S. G. Frantz & Co., New York), at 0.6 amperes. Mounts were prepared in a commercial mounting medium of 1.55 ± 0.02 refractive index studied under a petrographic microscope. Over 65 thinsections of the igneous rocks of the area were examined microscopically. An additional group of 11 welded-tuff specimens collected by R. A. Christman from the Iron Springs district, in southwest Utah, and 7 San Juan volcanic specimens collected by E. S. Larsen were studied for purposes of comparison. Several rock slices were etched with hydrofluoric acid fumes and stained with sodium cobaltinitrite to determine the potash feldspar content, following the method described by Chayes (1952).

All optic-angle measurements were made on a 5-axis universal stage and are accurate to ±1 degree. Indices of refraction were determined under sodium vapor light by the immersion method and are accurate to ±0.001.

The color terms used in describing the rocks were obtained from the Rock Color Chart, published in 1948 and distributed by the National Research Council.

Modal analyses were made by measuring individual grain diameters with a mechanical stage. The length of the traverses is at least 100 times greater than the longest dimension of the largest grain.

Thirteen representative specimens, including the 6 specimens that were chemically analyzed, were ground finer than —200 mesh and fused in a carbon arc, as described by Mathews (1951). Indices of the glasses obtained were determined and are reproducible to 0.0015.

Three polished sections of basalt and basaltic andesite from the La Jara Peak member were prepared, and an examination was made of the metallic minerals.

Norms for the chemical analyses were calculated according to the C. I. P. W. system.

SPEARS MEMBER

The volcanic rocks of the Spears member of the Datil formation consist of gray, grayish-green, grayish-red, brownish-gray, grayish-redpurple, pale-red-purple, and pale-red quartz latite flow breccias, agglomerates, volcanic conglomerates and sandstones, and tuffs. Sizes of this material range from boulders greater than 1 foot in diameter to thin ash beds of silt and clay.

Mineralogically the rocks are quite uniform, being composed mainly of plagioclase, sanidine, and hornblende crystals in a siliceous cryptocrystalline groundmass. Quartz, biotite, magnetite, and apatite occur subordinately in most specimens, and hematite is present in the reddish rocks. Clinopyroxene occurs in tuff specimens near the top of the member. Porphyritic lithic fragments, apparently andesitic in composition, are abundant in the tuffs. Very little glass is present, although devitrification products may occur in the groundmass. Introduced interstitial calcite is present in varying amounts, some of which exhibits cleavage that passes through engulfed quartz and feldspar grains. Alteration includes kaolinization and sericitization of the feldspars, and the formation of magnetite rims on biotite and hornblende. Chlorite is uncommon.

Sanidine occurs as subangular and subhedral crystals mostly 0.3 to 1 millimeter long, although some are as long as.8 millimeters. Carlsbad twinning is common on (010), and the extinction is not always sharp. Optical data indicate that the orthoclase content in these sanidine crystals is 62 (± 10) percent.

Plagioclase is generally more abundant than sanidine and averages 0.1 to 0.7 millimeter in length. It is largely oligoclase, with a negative optic angle and estimated 2V of 80° to 90°. Crystals twinned on the Carlsbad and peridine laws are also abundant. Zoning is pronounced, especially in untwinned grains, and higher indices indicate more calcic cores.

Oxyhornblende and green hornblende are present. Strongly pleochroic oxyhornblende (Roger's lamprobolite, 1940) occurs as individual crystals, which reach a maximum length of 1.5 millimeters. Most grains have dark borders of magnetite, and some have been changed completely to magnetite. Green hornblende is present in somewhat larger amounts than the oxyhornblende. It is less pleochroic than the red-brown variety and shows varying degrees of alteration to magnetite.

Monodinic pyroxene is present in several of the tuffs and consists of subhedral pale-green augite crystals as much as 0.4 millimeter in length. No exsolution lamellae were observed, but twinning on (100) is common.

Bright red-brown biotite [6] occurs in many of the tuffs as subhedral to euhedral hexagons. Pleochroism is moderate to strong. The optic angle is very small, and in many grains the interference figure appears uniaxial. Darker borders of more iron-rich biotite and magnetite surround most of these grains.

The 18-foot white bed (see p. 56) near the top of the member is a vitric rhyolite tuff. The rock is estimated to contain about 95 percent groundmass, which is composed of glass and devitrified aggregates. Individual shards are still discernible, and crystallites are present. Most shards are composed largely of extremely fine-grained tridymite(?) or

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6. This variety of biotite has been termed oxybiotite by Kuno (Hay, 1952).

chalcedony(?). Secondary partial spherulites have developed within many of the shards. These spherulites are enclosed by a rim of chlorite(?) or celadonite(?). Angular subhedral crystals comprise an estimated 3 or 4 percent of the rock, and the remaining 1 to 2 percent consists of porphyritic lithic fragments. The large majority of the crystals are sanidine and generally less than 1 millimeter long. The remaining crystals are quartz, oxyhornblende, green hornblende, and clinopyroxene. Apatite needles occur in some of the sanidine crystals.

Crushed samples contain many murky-brown grains in the nonmagnetic fraction. These grains apparently represent shards that are coated with bentonitic clay.

The mode of the Spears member (volume percent) is as follows:

Sanidine	8.4
Oligoclase	8.7
Oxyhornblende	2.5
Green hornblende	3.9
Quartz	0.5
Groundmass	65.4*
Rock fragments	9.7
Iron oxides	0.9
Total	100.0

*Consists of a fine-grained aggregate of chalcedony, quartz, calcite, feldspar, hornblende, biotite, and magnetite.

The effectiveness of wind as a sorting agent is well illustrated in several tuffs. In many slices, subangular quartz and feldspar grains show little variation in size. This sorting is interpreted as caused by differential settling velocities dependent upon size and density of airborne grains, similar to aqueous graded bedding. Some tuffs, however, apparently were water laid.

HELLS MESA MEMBER

The Hells Mesa member consists of white, light-gray, pale-red, grayish-pink, light-brownish-gray, and grayish-orange-pink semiwelded and welded rhyolite tuff. In the Bear Mountains the upper part of the member is finer grained and contains more groundmass relative to crystals than the lower portions. Crystals account for less than 5 percent of the total rock volume in the upper portions, and over 40 percent in the lower 50 feet of the member. In the Gallinas Mountains, the white and light-gray tuffs contain a larger proportion of groundmass and are finer grained than the pale-red and grayish-pink rhyolite.

Quartz, feldspar, and euhedral copper-colored biotite crystals, 0.5 to 3 millimeters in length, readily can be identified megascopically in a very fine-grained groundmass. The groundmass is ashy or pumiceous in the upper portions of the member in both the Bear and Gallinas Mountains. Collapsed pumice vesicles, which have been partly or completely silicified, give a foliated appearance to the rock in most outcrops. Brown, green, and gray lithic fragments are present throughout the section and represent more basic porphyritic igneous rocks.

The major mineral constituents of this member are sanidine, quartz, and plagioclase crystals in a glassy to cryptocrystalline, partly devitrified, groundmass, which generally shows varying degrees of bogen structure. Oxyhornblende and red-brown biotite are varietal; accessory apatite and magnetite are present in many silces. Feathery chalcedonic quartz and mosaic quartz line and fill collapsed *vesicles.* Generally the rock is extremely fresh, and only traces of alteration products are found. Hornblende and biotite have iron-rich borders, and the feldspars show incipient kaolinization.

Two varieties of feldspar occur in these tuffs. Sanidine is present in all specimens examined, and plagioclase occurs in a large majority of them. The sanidine crystals are generally subhedral and range from 0.05 to 3 millimeters in length, with the average being 0.1 to 0.5 millimeter. They are generally fresh and may have sharp or undulose extinction. Many crystals have much variation, even within a single slice; this may be due to variable amounts of the albite molecule present in solid solution. The range of 2V measurements is from (—) 22.5° to (—) 42.8°. The most common readings of 30° to 34° may reflect as much as 55 percent albite in solid solution.

As mentioned above, most of the specimens from the Bear Mountains contain plagioclase, whereas this is present without exception in all specimens examined from the Gallinas Mountains. The grain size varies within the limits of the sanidine, but on the average the plagioclase is larger. Extinction angles on Carlsbad and albite twins indicate an oligoclase composition. The majority of the optic angles are negative, but a few are positive and may represent more sodic compositions. Pericline and Manebach twinning occur also, and zoning with more calcic cores is common. The larger plagioclase crystals are the most altered of the feldspars.

Quartz is always present as extremely fresh but fractured angular crystals ranging from 0.02 to 3 millimeters in length (average is 0.5 to 2 millimeters). Many crystals contain numerous embayments and holes filled with groundmass glass and exhibit slightly undulose extinction. Those grains that are less sinuous in outline generally have pinpoint extinction. Collapsed vesicles are lined with feathery chalcedonic quartz and are filled partly or completely with vein quartz. In the larger cavities, aggregates of mosaic quartz and sanidine commonly comprise the filling.

Various degrees of devitrification are exhibited by the groundmass glass, which generally consists of a very fine-grained, submicroscopic crystalline aggregate. Crystallites (trichites and scopulites) and partial spherulites occur in some specimens but are not abundant. Shard outlines commonly can be observed *even where* devitrification has been complete. If the intensity of the light source is diminished, and the microscope tube raised or lowered out of focus, relic shard outlines are seen in the devitrified groundmasses. Bent biotite crystals commonly are associated with a flow structure around feldspar and quartz crystals; this relationship apparently is caused by differential compaction and flattening of the material in a horizontal plane.

Subrounded porphyritic lithic fragments as much as one-half inch in diameter are common, and oxyhornblende is generally present. Small amounts of augite and apatite have been observed in some slices. Red-brown biotite is abundant in the lower portions of the section in the Bear Mountains.

Two types of clinopyroxene, one colorless and the other pale green, were noted in a slice of rhyolite tuff from the Gallinas Mountains, several miles west of the quadrangle.

The Rosiwal analyses of the chemically analyzed specimen (181-2) and a specimen from the base of the member at Hells Mesa (181-1a) are as follows (volume percent):

	181-2	181-1a
Sanidine	15.4	21.5
Quartz	8.7	6.4
Oligoclase	5.8	10.3
Oxyhornblende	1.0	2.6
Red-brown biotite	0.2	0.1
Rock fragments	0.7	-
Iron oxides	0.2	0.4
Groundmass	68.0	58.7
Totals	100.0	100.0

This study gives little insight into the mechanism of emplacement of these semiwelded and welded tuffs.

A minimum temperature at the time of emplacement of the tuff can be assigned from the occurrence of red-brown biotite and oxyhornblende. Ordinary biotite upon heating in air becomes red brown between 400° and 500°C (Kozu et al., 1927). Therefore, a minimum temperature of emplacement of 500°C may be assigned. Moreover, Kozu et al. (1927, 1928) and Barnes (1930) found that by heating green hornblende in a nonreducing environment at one atmosphere of pressure, a transformation to oxyhornblende occured near 750°C. It follows that after consideration of transformation temperature variations caused by gases, the minimum temperature at the time of emplacement of the tuff was 750°C. Gilbert (1938) found green hornblende in the Bishop tuff but oxyhornblende (basaltic hornblende) in two granitic xenoliths. He concluded (p. 1856):

> . . . the temperature of emplacement could not have veen very much higher than 750° C. for, if it had been, all the hornblende should have been converted to the basaltic variety.

This conclusion would indicate that the temperature of emplacement of the Hells Mesa tuff was distinctly higher than the temperature at the time the Bishop tuff was emplaced. However, Gilbert neglected to mention that oxyhornblende is transformed into the green variety in a reducing environment. It is reasonable to suggest that reduction, capable of transforming oxyhornblende to green hornblende, could take place during the cooling of a partly consolidated rock that had lost most of its gases and had effectively sealed itself off from the atmosphere.

The different degrees of welding within the member do not appear to correlate with the weight or thickness of the overlying strata. Variations in temperature of emplacement and different cooling histories are apparently responsible for the welding variations that occur throughout the member.

LA JARA PEAK MEMBER

The La Jara Peak member consists of a series of gray, brownish-gray, and greenish-gray porphyritic basalt and basaltic andesite lava flows. Scoriaceous red oxidized flow tops and basal flow breccias are present throughout the unit. The flows range from dense aphanitic porphyries to scoriaceous types. Phenocrysts of iddingsite, pyroxene, hematite, and rare hornblende are megascopically visible. Disseminated amygdules are filled with quartz and calcite, and rarely with a zeolite and cristobalite.

The major minerals are plagioclase, clinopyroxene, iddingsite, and hematite. Small amounts of oxyhornblende, olivine, apatite, and magnetite are also present. Serpentine, hydrous mica, and chlorite occur as alteration minerals. Late quartz, calcite, cristobalite, and/or analcime(?) are found as amygdule fillings. Plagioclase feldspar and clinopyroxene occur as small groundmass crystals and microlites (<0.05 millimeter) trachytically arranged around phenocrysts of clinopyroxene and olivine. In some instances, the texture is felty or pilotaxitic without any preferred orientation to the microlite laths. Magnetite, iddingsite, and hematite microlites are also present in the groundmass. Carlsbad, albite, and Carlsbad-albite twins are common among these splintery-terminated plagioclase laths. The fineness of these aggregates precludes any definite composition determinations. However, extinction-angle measurements and immersion indices suggest a sodic andesine composition for all groundmass plagioclase. The plagioclase of the basal portion is more anorthitic than in the topmost flows, although the range of composition may be less than 5 percent anorthite. Potash feldspar has not been found, but a few zoned plagioclase phenocrysts, 0.1 to 0.6 millimeter in length, are present in some slices. These plagioclase crystals apparently are xenocrysts, for they are partly resorbed or corroded and extremely clouded with kaolin.

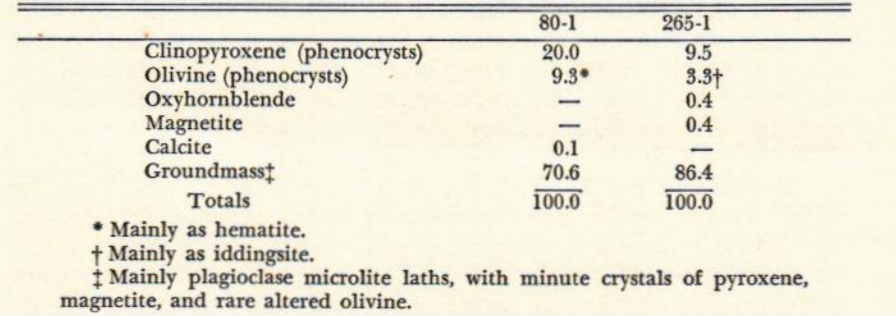
The microscopic data indicate that olivine did not crystallize under equilibrium conditions. Some clinopyroxene contains cores of olivine.

The borders and cracks in these olivine cores may be iddingsitized. Apparently olivine crystallized first and was unstable in its environment. Reaction took place between the larger olivine crystals and the liquid, and pyroxene was formed. This reaction did not go to completion, for cores of olivine remain. Subsequent deuteric alteration of the olivine has produced partial iddingsite pseudomorphs. Smaller euhedral to subhedral olivine crystals, not associated with pyroxene, may represent a second generation of olivine crystallization. Iddingsite has not replaced the olivine completely in most grains but forms rims or borders around it and fills sinuous veinlets through the core. The core, which may be serpentinized, and the iddingsite are in optical continuity. Optical properties of the iddingsite vary greatly and are difficult to measure, owing to the extreme coloration and pleochroism of the mineral.

Most of the iddingsite in the lower portions of the member has been altered completely or partially to red hematite, with preservation of the euhedral crystal form of the original olivine. The upper units of the La Jara member contain very few hematite pseudomorphs.

Bowlingite has been identified as an alteration mineral of olivine, and a yellow mineral, with morphology and optical properties similar to antigorite, has been observed. According to H. H. Hess (personal communication), similar yellow minerals contain a few percent ferric iron. Pale-green chlorite is often an alteration product of the antigoritelike mineral.

The modes for the basal (80-1) and upper (265-1) flows of the member are as follows (in volume percent):



	80-1	265-1
Clinopyroxene (phenocrysts)	20.0	9.5
Olivine (phenocrysts)	9.3*	3.3†
Oxyhornblende	—	0.4
Magnetite	—	0.4
Calcite	0.1	—
Groundmass‡	70.6	86.4
Totals	100.0	100.0

* Mainly as hematite.

† Mainly as iddingsite.

‡ Mainly plagioclase microlite laths, with minute crystals of pyroxene, magnetite, and rare altered olivine.

The modes show that the amount of olivine is several times more abundant at the base than at the top of the member.

The pyroxene, which occurs as phenocrysts 0.2 to 1.5 millimeters in length and as minute groundmass crystals, is monoclinic. Carlsbad-like twinning is common in basal sections, and a few grains have hourglass extinction. Few recognizable exsolution lamellae are found, but several of the larger phenocrysts (about 3 millimeters long) are zoned with dark-green cores (more diopsidic). At the base of the member, the indices of refraction of the dinopyroxene are: Nx = 1.670, N_y = 1.675(?), and

N. = 1.700. An equivalent mineral in the uppermost flow has slightly higher refractive indices: Nx = 1.685 and Nz = 1.717. These pyroxenes appear best to fit the properties of salite. This identification also is supported by the fact that a diopside-hedenbergite pyroxene may be expected to accompany olivine during magmatic crystallization. Moreover, the pyroxene in the lavas of this member is too iron-rich to be called diopside and too calcium-rich to be included with the augites. The increase in the refractive indices of the salite toward the top of the section indicates an increase in iron in this direction (Hess, 1941).

Magnetite is the fourth most abundant mineral, occurring as distinct subhedra and euhedra 0.05 to 1.2 millimeters long, as inclusions in pyroxene, and as minute "dust" throughout the lavas. Oxyhornblende often is altered partially or completely to magnetite.

Accessory apatite is present mainly as needles and prisms in the plagioclase and pyroxene. Cristobalite forms blebs that partly fill cavities, and calcite and quartz amygdules are common. Analcime(?) fills some amygdules. This mineral is isotropic and has a refringence of 1.487. Hydrous micas cloud some of the plagioclase.

The medium-gray sill in the upper one-third of the Spears member is slightly vesicular and is much coarser grained than the flows of the La Jara Peak member. This sill is composed of large (6 millimeters long) clinopyroxene and altered plagioclase phenocrysts in a felty or trachytic groundmass of plagioclase, pyroxene, and magnetite. The plagioclase phenocrysts, twinned on the Carlsbad, albite, and Manebach laws, have more intensely kaolinized edges than cores. Smaller (1 to 2 millimeters long) phenocrysts of iddingsite, hematite, and fresh plagioclase are also present. Amygdules are filled mainly with mosaic quartz. An unknown mineral that resembles orthopyroxene occurs closely associated with the clinopyroxene phenocrysts. It is colorless and has moderate relief, negative elongation, striations parallel to the elongation, parallel extinction, a large positive optic angle, and refringences greater than balsam.

The dike in sec. 27, T. 2 N., R. 5 W., resembles flows from the middle part of the La Jara Peak member and is undoubtedly a feeder. The groundmass is very fine grained (pilotaxitic) and contains abundant carbonate. Clinopyroxene and altered olivine phenocrysts are plentiful. The olivine now consists of partial pseudomorphs of hematite, iddingsite, and bowlingite in optical continuity with olivine cores.

INTRUSIVE ROCKS

Before the mineralogy and petrology of the intrusive rocks is discussed, it is necessary to mention a few observations concerning the freshness of these rocks. All degrees of alteration are found in these intrusions in the field. Those specimens that appeared fresh megascopically were found under the miscroscope to be altered. Chemical analyses were made only on the freshest samples, but even *these* had undergone a substantial amount of alteration. Interpretation of original mineralogical and chemical content is, therefore, necessary in the classification of these rocks. Little can be done modally with the aphanitic basalts.

As mentioned above, the igneous rocks that mainly intrude post-Paleozoic strata consist of greenish-gray, olive-gray, and medium- to dark-gray aphanites and aphanophyres. Subhedral to euhedral phenocrysts of hornblende, altered olivine, augite, and biotite are present megascopically in the aphanophyres. The hornblende occurs as slender needles as much as 10 millimeters in length; several triplets have been noted. The other phenocrysts seldom exceed 5 millimeters in length. Augite is common in all rocks either as phenocrysts or groundmass microlites. Olivine, hornblende, and biotite phenocrysts generally do not coexist in the same rock. Xenocrysts of quartz and feldspar commonly are present.

The groundmass consists of microcrystalline felty to trachytic aggregates of plagioclase, pyroxene, iron oxides, chlorite, and calcite. Biotite and slender needles and prisms of apatite are common. The plagioclase, which comprises an estimated 70 percent of the groundmass, consists largely of subhedral microlite laths less than 0.05 millimeter in length. These laths are twinned on the Carlsbad and albite laws. They are of medium andesine composition, and alteration to white mica is common. Much of the calcite has been derived from this andesine.

The monoclinic pyroxene, which occurs as subhedral to euhedral phenocrysts and groundmass microlites, is augitic. The optic angle is positive, the average 2V = 56°, and Z'Ac varies from 41° to 43°. Twinning on (100) is common, but neither zoning nor exsolution lamellae are present. All stages of calcitization of the pyroxene have been observed.

Hornblende is uncommon, although a hornblende porphyry dike intrusive into the Baca formation is exposed in sec. 23, T. 1 N., R. 6 W. Subrounded-to rounded quartz xenocrysts stand out on weathered surfaces of this porphyry--and and have mafic reaction rims. Under the microscope, various stages of resorption of the quartz were observed. Rounded quartz grains without mafic borders occur in the same slice with grains that have thin coronas of clinopyroxene. Clusters of many small individual pyroxene crystals are interpreted as indicative of complete reaction. Similar quartz inclusions are common in other dikes and sills. Several extremely altered turbid grains of feldspar in thinsections of this hornblende porphyry are also interpreted as xenocrysts. The quartz and feldspar xenocrysts could have come from the feldspathic strata of the Baca or from older formations.

Anhedral to subhedral crystals of biotite are common in the ground-mass, and subhedral to euhedral biotite phenocrysts are present in a few sills and dikes, particularly near the Chavez ranch headquarters. Commonly the biotite has dark grain borders, and magnetite inclusions are present.

Olivine occurs as phenocrysts in a few of the darker dikes, where it shows alteration to bowlingite and antigorite(?).

Vein quartz and chalcedony are present as late interstitial and amygdule-filling minerals. Calcite is common and may be associated with the vein quartz. Partial chloritization of groundmass biotite is general. Apatite is present in all slices as stout prisms and slender needles. Magnetite invariably is present and may constitute over 5 percent of the rock.

The intrusions that were emplaced mainly in pre-Mesozoic rocks consist of speckled green, black, gray, and white microphanerites and aphanophyres. Biotite phenocrysts are conspicuous in a light-gray or greenish-gray groundmass. Flow structure is well developed in some specimens by alinement of biotite flakes. Calcite is abundant as interstitial material and as subhedral to euhedral crystals. The rock is termed a biotite syenodiorite.

Microscopically these rocks are found to be extremely altered. The hypautomorphic granular texture is arranged in an intersertal structural pattern. Commonly the feldspar occurs as anhedral to euhedral laths, 1 to 1.5 millimeters in length (maximum length, 3.5 millimeters), and is altered always to sericite and clinozoisite. Some calcite has formed at the expense of the feldspar. Carlsbad and rare albite twins are preserved, and some microcline twinning is suggested. The composition of the feldspar could not be determined, but extinction-angle measurements on Carlsbad and albite twins indicate that it is oligoclase. Application of sodium cobaltinitrite to slices that were etched in hydrofluoric acid fumes stains much of the feldspar canary yellow. Thus the presence of potash feldspar is recognized (Chayes, 1952).

The pyroxene is altered completely to chlorite, calcite, and magnetite. Some of the calcite is subhedral and apparently pseudomorphous after pyroxene. Quartz is associated commonly with interstitial anhedral calcite. Apatite needles and prisms, as long as 1 millimeter, cut feldspar and biotite crystals. Part of the biotite may have been derived from pyroxene. Biotite phenocrysts generallya are partly-chloritized and are as much as 2.5 millimeters in length.

The mineral composition, as determined by a mechanical-stage count, is as follows (volume percent):

	430-3-b
Feldspar	64.1
Calcite	17.8
Biotite	7.4
Chlorite	4.8
Iron oxides	4.2
Quartz	1.2
Apatite	0.5
Total	100.0

Because these intrusions differ texturally, mineralogically, and chemically from the basaltic intrusions, these two series of intrusive rocks appear not to be consanguineous.

Chemical Data

Six chemical analyses of igneous rocks from the Puertecito area were made by H. B. Wiik, of Helsinki, Finland. The analyses and norms are as follows:

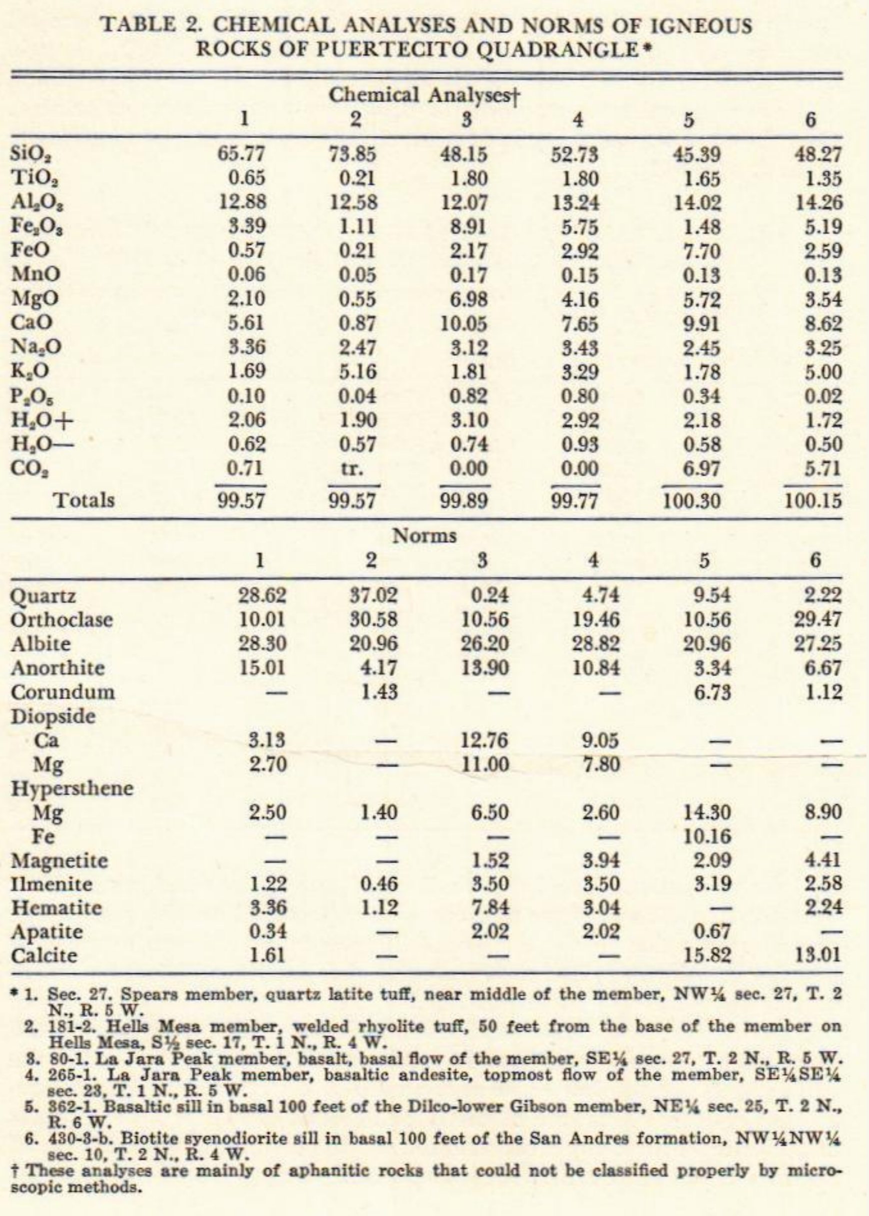


TABLE 2. CHEMICAL ANALYSES AND NORMS OF IGNEOUS ROCKS OF PUERTECITO QUADRANGLE*

	Chemical Analyses†					
	1	2	3	4	5	6
SiO_2	65.77	73.85	48.15	52.73	45.39	48.27
TiO_2	0.65	0.21	1.80	1.80	1.65	1.35
Al_2O_3	12.88	12.58	12.07	13.24	14.02	14.26
Fe_2O_3	3.39	1.11	8.91	5.75	1.48	5.19
FeO	0.57	0.21	2.17	2.92	7.70	2.59
MnO	0.06	0.05	0.17	0.15	0.13	0.13
MgO	2.10	0.55	6.98	4.16	5.72	3.54
CaO	5.61	0.87	10.05	7.65	9.91	8.62
Na_2O	3.36	2.47	3.12	3.43	2.45	3.25
K_2O	1.69	5.16	1.81	3.29	1.78	5.00
P_2O_5	0.10	0.04	0.82	0.80	0.34	0.02
H_2O+	2.06	1.90	3.10	2.92	2.18	1.72
H_2O-	0.62	0.57	0.74	0.93	0.58	0.50
CO_2	0.71	tr.	0.00	0.00	6.97	5.71
Totals	99.57	99.57	99.89	99.77	100.30	100.15

	Norms					
	1	2	3	4	5	6
Quartz	28.62	37.02	0.24	4.74	9.54	2.22
Orthoclase	10.01	30.58	10.56	19.46	10.56	29.47
Albite	28.30	20.96	26.20	28.82	20.96	27.25
Anorthite	15.01	4.17	13.90	10.84	3.34	6.67
Corundum	—	1.43	—	—	6.73	1.12
Diopside						
Ca	3.13	—	12.76	9.05	—	—
Mg	2.70	—	11.00	7.80	—	—
Hypersthene						
Mg	2.50	1.40	6.50	2.60	14.30	8.90
Fe	—	—	—	—	10.16	—
Magnetite	—	—	1.52	3.94	2.09	4.41
Ilmenite	1.22	0.46	3.50	3.50	3.19	2.58
Hematite	3.36	1.12	7.84	3.04	—	2.24
Apatite	0.34	—	2.02	2.02	0.67	—
Calcite	1.61	—	—	—	15.82	13.01

* 1. Sec. 27. Spears member, quartz latite tuff, near middle of the member, NW¼ sec. 27, T. 2 N., R. 5 W.
2. 181-2. Hells Mesa member, welded rhyolite tuff, 50 feet from the base of the member on Hells Mesa, S½ sec. 17, T. 1 N., R. 4 W.
3. 80-1. La Jara Peak member, basalt, basal flow of the member, SE¼ sec. 27, T. 2 N., R. 5 W.
4. 265-1. La Jara Peak member, basaltic andesite, topmost flow of the member, SE¼SE¼ sec. 23, T. 1 N., R. 5 W.
5. 362-1. Basaltic sill in basal 100 feet of the Dilco-lower Gibson member, NE¼ sec. 25, T. 2 N., R. 6 W.
6. 430-3-b. Biotite syenodiorite sill in basal 100 feet of the San Andres formation, NW¼NW¼ sec. 10, T. 2 N., R. 4 W.

† These analyses are mainly of aphanitic rocks that could not be classified properly by microscopic methods.

The norms of the La Jara Peak member (col. 3 and 4) do not show olivine, which is present, however, in the mode in an altered condition. This discrepancy is caused by the high Fe_20_3:FeO ratio in the chemical analyses, due to the hematite and iddingsite pseudomorphs, which results in an apparent excess of silica. More accurate norms, in the sense of approaching the modal minerals, are given below (table 3). These norms were determined by recalculating all the iron in the two chemical analyses as FeO, using Ossan's conversion factor of 0.9 Fe_20_3. A ratio of Fe_20_3:FeO for the average basalt was obtained from Daly (1933), and the proportionate amounts for these two analyses were calculated. Ossan's factor was used again to convert FeO back to this proportionate amount of Fe_20_3.

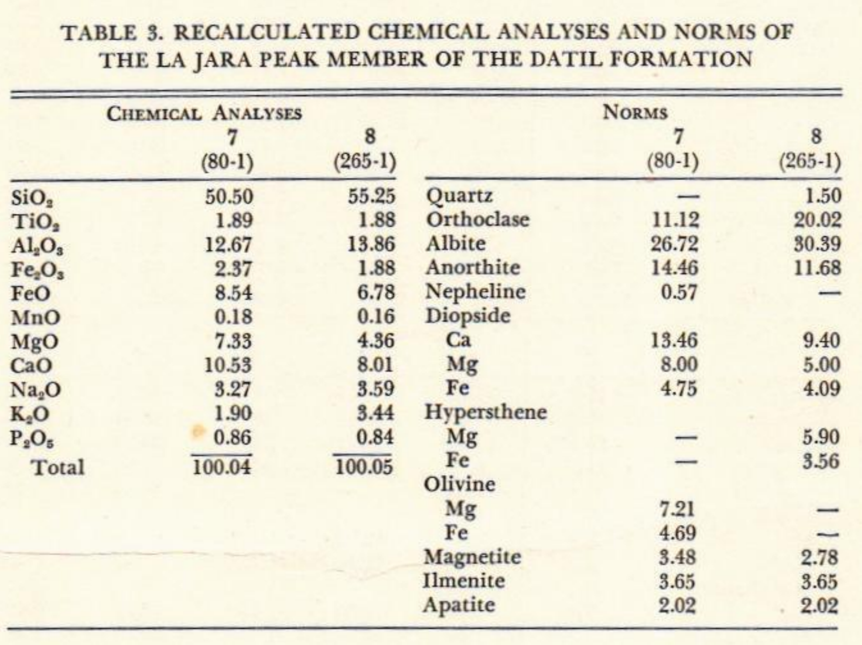


TABLE 3. RECALCULATED CHEMICAL ANALYSES AND NORMS OF THE LA JARA PEAK MEMBER OF THE DATIL FORMATION

	CHEMICAL ANALYSES			NORMS	
	7 (80-1)	8 (265-1)		7 (80-1)	8 (265-1)
SiO_2	50.50	55.25	Quartz	—	1.50
TiO_2	1.89	1.88	Orthoclase	11.12	20.02
Al_2O_3	12.67	13.86	Albite	26.72	30.39
Fe_2O_3	2.37	1.88	Anorthite	14.46	11.68
FeO	8.54	6.78	Nepheline	0.57	—
MnO	0.18	0.16	Diopside		
MgO	7.33	4.36	Ca	13.46	9.40
CaO	10.53	8.01	Mg	8.00	5.00
Na_2O	3.27	3.59	Fe	4.75	4.09
K_2O	1.90	3.44	Hypersthene		
P_2O_5	0.86	0.84	Mg	—	5.90
Total	100.04	100.05	Fe	—	3.56
			Olivine		
			Mg	7.21	—
			Fe	4.69	—
			Magnetite	3.48	2.78
			Ilmenite	3.65	3.65
			Apatite	2.02	2.02

The two intrusive rocks (table 2, col. 5 and 6) are much altered but were the freshest specimens that could be collected. The high percentage of carbon dioxide in the analyses, 5.17 percent in column 6 and 6.97 percent in column 5, had to be calculated as calcite, which required so much lime that very little was left for the anorthite molecule. Hence the normative plagioclase composition is too sodic, and substantial amounts of corundum appear in both norms. In these two rocks, the silica values are too low to be representative of the fresh rock, particularly of column 6, because of the large amount of calcite in both rocks and biotite in the sample represented by this column. Recalculation of norms was not successful, as it is impossible to ascertain the amount of silica which the carbonate represents. Moreover, the amount of MgO, and possibly iron, was diminished, whereas unknown quantities of potash and soda may have been introduced during the calcitization. Recalculation, however, of these two norms to 100 percent, omitting the CO_2 content, gives a plagioclase ratio of An_{50} for column 5 and An_{26} for column 6; these ratios are in fair agreement with the modal composition.

The chemical changes from the base (table 2, col. 3) to the top (col. 4) of the La Jara Peak member are as follows: (1) increase in $Si0_2$ from 48.15 percent to 52.73 percent; (2) increase in Na_20 K_20 and $A1_20_3$; and (3) decrease in CaO, MgO, and FeO Fe_20_3. Moreover, there is an increase of soda in both the normative and modal plagioclase, an increase in the amount of iron in the pyroxene, and a decrease in the percentage of olivine. These chemical and mineralogical changes may be explained readily by fractional crystallization and suggest that the entire member was extruded from the same magma body. Petrogenetically related flows that represent fractionation within the magma chamber are common in the literature. An interesting comparison may be made between the changes in the La Jara Peak member and the progressive chemical changes recorded by Wilcox (1951) for the Paricutin lavas.

Wilcox found that $Si0_2$ had increased from 54.7 percent in 1943 to 59.0 percent in 1950; $Na_20 + K_20$ showed a progressive increase, whereas Fe_20_3 FeO, CaO, $A1_20_3$, and MgO decreased. There was also a decrease in the quantity of olivine.

The parallelism of the progressive chemical and mineralogical changes within these two lava sequences is remarkably complete, with the exception of the alumina. Wilcox concludes that gravitative differentiation can account adequately for these changes.

Three polished sections from the basal (table 2, col. 3), middle, and upper (col. 4) portions of the La Jara Peak member were studied under the microscope, but no visible evidence was found for the 3.50 percent of normative ilmenite. Some ilmenite is likely in solid solution with magnetite, but no exsolution lamellae or blebs are present in the magnetite.

The chemical variations in the igneous rocks of the Puertecito area are given in Table 2. These analyses show clearly the dissimilar chemical compositions of the basal basalt of the La Jara Peak member (col. 3) and the intrusive biotite syenodiorite (col. 6). The variation diagram, Figure 8, illustrates progressive changes in the oxides of rocks believed to be consanguineous or genetically related to the same parent magma body; that is, exclusive of the biotite syenodiorite.

A study of the chemical analyses and variation diagram suggests a few generalizations concerning the igneous rocks of the Puertecito area: (1) All rocks contain relatively large amounts of alkalis; soda is fairly constant. The largest amount (8.25 percent) and the least amount (4.23

percent) are present in the two altered intrusive samples. (2) None of the norms as originally calculated contains olivine, which, however, is present in an altered condition in the basic rocks. The only feldspathoid recognized, analcime(?), at a few places partly fills amygdules in the La Jara Peak member. Thus all rocks chemically are saturated with respect to silica. (3) The four extrusive rocks are relatively low in alumina and contain more ferric than ferrous iron.

All specimens that were chemically analyzed, plus seven additional specimens, were fused in a carbon arc, as described by Mathews (1951). Complete fusion generally took place in less than 5 seconds. It was difficult to obtain good glass from the more acidic rocks. Indices of the

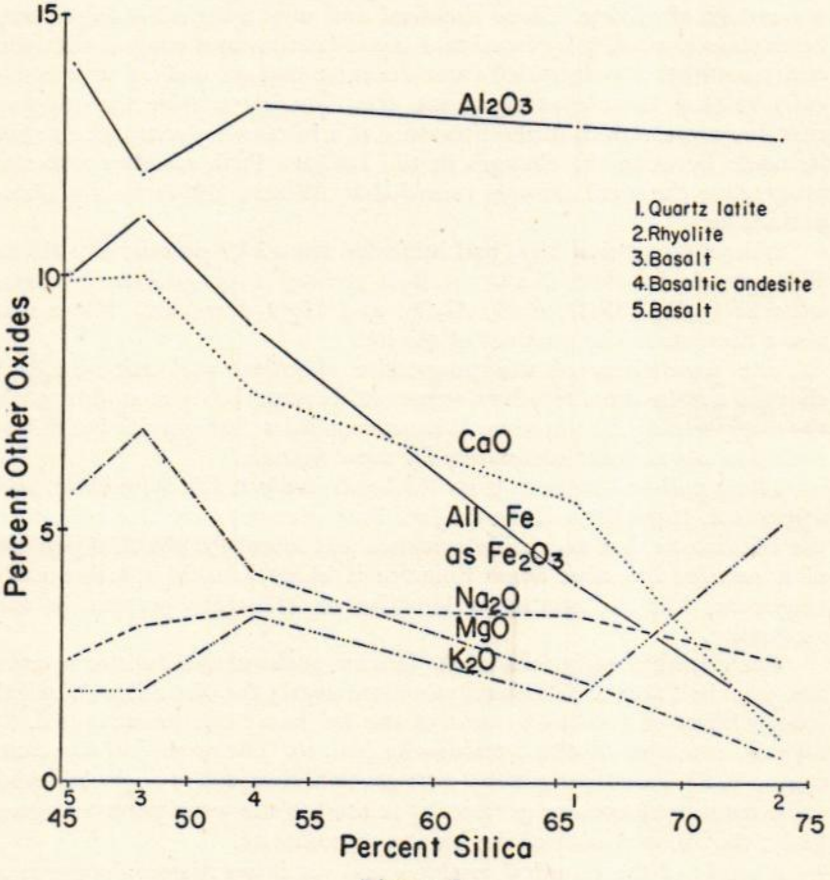


Figure 8

VARIATION DIAGRAM OF THE IGNEOUS ROCKS OF PUERTECITO QUADRANGLE (EXCLUDING THE SYENODIORITE).

glasses were determined by the immersion method under sodium vapor light and were found to be reproducible to ±0.0015. Following Mathews (1951), these indices then were plotted against the silica percentage obtained from the chemical analyses (table 2). Figure 9 shows the resulting "silica refractive index" curve, which is nearly a straight line when the biotite syenodiorite (table 2, col. 6) is omitted. More chemical analyses are needed to determine this curve more accurately. The maximum deviation of the extrusive rocks from this mean curve is 0.5 percent in silica content and 0.002 in index. The basaltic sill (362-1; table 2, col. 5) falls slightly off the curve (3.1 percent deficiency in silica or 0.012 in index), but this is an altered specimen. However, a dike rock (361-1) within 1,000 feet of 362-1, which is petrographically similar, would fall on the curve within the limit of deviation for the extrusive rocks, if its silica percentage were the same as that of 362-1. The analyzed biotite syenodiorite (table 2, col. 6) is chemically and mineralogically dissimilar to the five other chemically analyzed specimens, and falls well off (greater than 10 percent in silica content) this mean curve determined

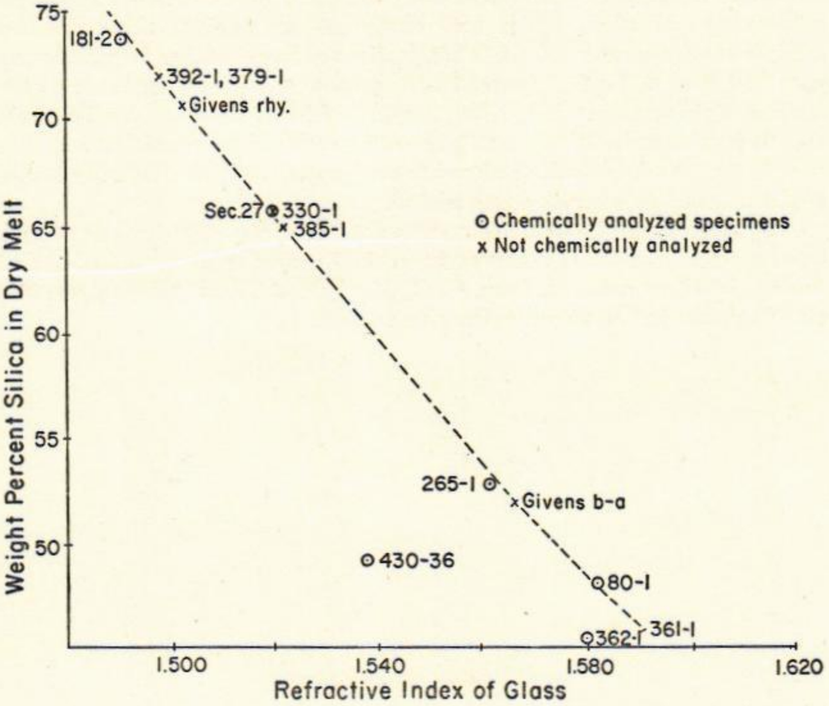


Figure 9

SILICA REFRACTIVE-INDEX CURVE OF THE IGNEOUS ROCKS OF PUERTECITO QUADRANGLE.

mainly by the four extrusive specimens. Although the syenodiorite is very much altered, these data suggest that it is not related petrogenetically to the other igneous rocks of the area.

Four samples of volcanic rock from the Gallinas Mountains were fused, and the indices of their glasses plotted on this curve. It readily is seen that the expected silica percentages vary little from those of the Bear Mountains volcanic rocks.

Mathews (1951) has shown that glasses of rocks from different igneous suites or "petrographic provinces," containing the same percentage of silica, may have very different indices of refraction. Conversely, glasses of rocks of diverse genesis may have the same refractive index but may differ by over 10 percent in silica content. It is thus apparent (Mathews, 1951, p. 92):

> . . . that the proportion of any one constituent, . . . does not alone determine the refractive index of the glass, but instead each constituent contributes according to its abundance and to its specific properties.

In an attempt to determine the constituents besides silica that contribute to the refractive index of the glass, plots were made of the weight percentages of nine oxides and combinations against the refractive indices of the glasses of the chemically analyzed rocks. It was found that "all iron as Fe_20_3" increases progressively with an increase of the indices of refraction: CaO, $Ti0_2$, MgO, and MnO show less well-defined trends in the same direction. The other oxides and combinations are widely scattered, including alumina and potash, which Mathews found could be used to express composition.

It is concluded from these results that the refractive indices of artificial glasses from the igneous rocks of the Puertecito area are influenced mainly by silica content. Iron, CaO, MgO, MnO, and TiO_2 apparently exert a lesser influence on refractive indices.

Appendix

STRATIGRAPHIC SECTIONS

UNIT No.	DESCRIPTION	THICKNESS (feet)
BACA FORMATION		
	(Sec. 13, T. 1 N., R. 6 W., and sec. 18, T. 1 N., R. 5 W.)	
	Santa Fe Group above	
25	Sandstone and conglomerate, thin- to thick-bedded, crossbedded, grayish-purple; sandstone, coarse-grained; abundant petrified wood and reddish-purple and green shale pellets; conglomerate, quartzite pebbles, and cobbles	85
24	Sandstone, medium-bedded, crossbedded, grayish-yellow, fine-grained; calcareous cement; lenses of reddish-purple and green shale; shale pellets	59
23	Cover	32
22	Sandstone, medium-bedded, crossbedded, white to grayish-yellow; weathered pale yellowish brown; fine-grained, subangular, feldspathic; calcareous cement; abundant grayish-green shale pellets	52
21	Sandstone, laminated to thin-bedded and crossbedded, pinkish-gray; weathered light gray; very fine- to fine-grained, subangular, feldspathic; calcareous cement	36
20	Siltstone, laminated to thin-bedded, dusky-red, micaceous and hematitic; calcareous cement	5
19	Sandstone, thin- to medium-bedded, crossbedded, pale-yellowish-brown ("salt and pepper"), fine- to medium-grained, angular, feldspathic; calcareous cement; stringers and pellets of reddish-brown and grayish-green mudstone	22
18	Silty shale, thin-bedded and fissile, reddish-brown, micaceous, hematitic	15
17	Sandstone, medium-bedded, grayish-orange (pale-red near top), medium-grained, angular, feldspathic; calcareous cement; abundant greenish-gray mudstone stringers and pellets near base	30
16	Silty sandstone, laminated to medium-bedded, silty to fine-grained; finer grained material thinner bedded; hematitic, micaceous, and feldspathic; subangular; calcareous cement	35
15	Mudstone, thin-bedded, reddish-brown, micaceous and hematitic	4
14	Sandstone, thin- to medium-bedded, pale-red-purple, fine- to medium-grained, feldspathic, subangular	15
13	Mudstone, like 15	12
12	Sandstone, massive and crossbedded, pale-red, fine-grained; calcareous cement; near middle, 5-foot bed of thin-bedded grayish-purple fine-grained sandstone	55
11	Sandstone, thin-bedded, grayish-purple, fine- to medium-grained, angular, feldspathic; interbedded layers of reddish-brown siltstone	50
10	Sandstone, thick-bedded to massive, "salt and pepper," medium- to coarse-grained, angular, feldspathic; calcareous cement; few interbeds of reddish-brown siltstone	34

UNIT No.	DESCRIPTION	THICKNESS (feet)
9	Silty shale, laminated to thin-bedded, reddish-brown, micaceous, hematitic	18
8	Sandstone, one bed; pale-red-purple; weathered pale yellowish brown; medium-grained, angular, feldspathic; calcareous cement	6
7	Conglomerate, lenticular, reddish-purple; medium- to coarse-grained sandstone matrix; subangular to subrounded fragments of quartzite, limestone, and granite as much as 6 inches in diameter	1
6	Silty shale, laminated to thin-bedded, pale-red, micaceous, hematitic; calcareous cement	15
5	Sandstone, thin-bedded, crossbedded, grayish-red, fine-grained, angular, feldspathic; calcareous cement	7
4	Sandstone, medium-bedded, yellowish-gray, coarse-grained, angular, feldspathic; calcareous cement; abundant round discoidal fine- to medium-grained sandstone concretions as much as 1 foot in diameter; calcareous cement	17
3	Sandstone, one bed; crossbedded, yellowish-gray, fine- to medium-grained, subangular, feldspathic; calcareous cement	3
2	Sandstone, thin- to medium-bedded, "salt and pepper"; weathered pale yellowish brown; medium-grained, subangular; calcareous cement; sandstone concretions and mudstone pellets	15
1	Covered; probably thin-bedded, greenish-gray siltstone	7
	Total Baca formation	630
	Crevasse Canyon formation	

SPEARS MEMBER
(Secs. 8, 9, 16, and 17, T. 1 N., R. 4 W.)

	Hells Mesa member above	
3	Reddish-brown volcanic conglomerate and sandstone; fragments subangular to subround, as much as 1.5 feet in diameter	297
2	White vitric rhyolite tuff	18
1	Gray and grayish-purple quartz latite tuffs, breccias, agglomerates, interbedded with 3- to 20-foot beds of volcanic conglomerate and crossbedded volcanic sandstone; numerous irregular thin beds of siltstone and claystone	1,025
	Total Spears member	1,340
	Baca formation below	

HELLS MESA MEMBER
(Sec. 31, T. 2 N., R. 4 W.)

	La Jara Peak member above	
3	Very light-gray welded rhyolite tuff; abundant collapsed and silicified pumice vesicles	175
2	White welded rhyolite tuff; crystals of quartz and feldspar comprise about 15 percent of the rock; copper-colored biotite hexagons conspicuous	65
1	Pink welded rhyolite tuff; like 2	49
	Total Hells Mesa member	289
	Spears member below	

Unit No.	Description	Thickness (feet)
LA JARA PEAK MEMBER		
(Sec. 27, T. 2 N., R. 5 W.)		
	Santa Fe group above	
3	Medium-gray iddingsite basaltic andesite porphyry; poorly exposed; sheeted	190
2	Grayish-yellow sandstone and conglomerate; rhyolite, quartz latite, basalt, and basaltic andesite (Santa Fe group lithology)	25
1	Dark-gray to medium-gray porphyritic basalt and basaltic andesite; phenocrysts of hematite, iddingsite, and pyroxene; abundant flow breccia and red oxidized scoriaceous layers; sheeted	990
	Total La Jara Peak member	1,205
	Hells Mesa member below	
GLORIETA SANDSTONE MEMBER		
(Sec. 30, T. 3 N., R. 4 W.)		
	Limestone evaporite member above	
10	Sill, syenodiorite	14
9	Sandstone, massive, crossbedded, grayish-yellow, very fine-grained; subrounded grains approach a sphere; excellent mineral and size sorting; moderately porous; calcareous and siliceous cement; quartzose sandstone	14
8	Sill, syenodiorite	8
7	Sandstone, like 9	40
6	Sill, syenodiorite	4
5	Sandstone, like 9; several 2-foot gypsum beds in upper two-thirds	95
4	Gypsum, banded, very light-gray, granular; abundant thin gypsiferous sandstone stringers	21
3	Sill, syenodiorite	4
2	Gypsum, like 4	4
1	Sandstone, like 9	51
	Total Glorieta sandstone member (excluding sills)	255
	Los Vallos member below	
MIDDLE EVAPORITE MEMBER		
(Sec. 13, T. 3 N., R. 5 W.)		
	Upper limestone member above	
10	Gypsum, banded dark and light layers; white to light-greenish-gray; included calcite crystals; partly covered	40
9	Limestone, thin- to medium-bedded, light-olive-gray, finely crystalline; some beds contain subangular to subround quartz grains of silt to very fine-grained sand size	39
8	Gypsum, like 10; contains several 1- to 5-foot beds of olive-gray limestone and gypsiferous sandstone	112
7	Sill, syenodiorite	2
6	Limestone, thin- to medium-bedded, greenish-gray, aphanitic	18
5	Sill, syenodiorite	16
4	Limestone, thin-bedded, greenish-gray, aphanitic	4

UNIT No.	DESCRIPTION	THICKNESS (feet)
3	Gypsum, like 10	3
2	Sill, syenodiorite	2
1	Gypsum, like 10; contains numerous 6-inch to 3-foot beds of sandstone and limestone	140
	Total middle evaporite member (excluding sills)	376
	Sill and Glorieta sandstone below	

CREVASSE CANYON FORMATION
(Secs. 9 and 16, T. 2 N., R. 6 W.)

UNIT No.	DESCRIPTION	THICKNESS (feet)
	Baca formation above	
12	Sandstone, medium-bedded, yellowish-gray	8
11	Sandstone, siltstone, shale, and coal; siltstone and shale, olive-gray, carbonaceous; coal beds as much as 2 feet thick; sandstone, fine- to coarse-grained, angular; poorly exposed	281
10	Sandstone, massive, yellowish-gray, very fine- to fine-grained, subangular	27
9	Sandstone, siltstone, shale, and coal, like 11; gradational contacts; poorly exposed	516
8	Sandstone, thin-bedded, yellowish-gray, fine-grained	5
7	Cover, probably shale and siltstone	17
6	Shale, dark-gray, carbonaceous	8
5	Shale, gray, carbonaceous; ironstone concretions as much as 6 inches long	10
4	Sandstone, medium-bedded, yellowish-gray, subangular	12
3	Siltstone, thin-bedded, grayish-brown, carbonaceous, clayey; wood fragments	8
2	Sandstone, thin- to thick-bedded, yellowish-gray, fine-grained, subangular; calcareous cement	72
1	Sandstone, like 2	88
	Total Crevasse Canyon formation	1,052
	La Cruz Peak formation below	

TRIASSIC
(Under mesa, sec. 31, T. 3 N., R. 4 W.)

UNIT No.	DESCRIPTION	THICKNESS (feet)
	Travertine-cemented conglomerate above	
14	Siltstone and shale, laminated to thin-bedded, grayish-red to reddish-brown, hematitic; calcareous cement	100
13	Sandstone, one bed; grayish-pink, fine- to medium-grained, subangular, feldspathic; calcareous cement (top of Shinarump conglomerate?)	2
12	Siltstone and shale, like 14	9
11	Conglomerate, lenticular; limestone pebbles, subangular to subround; poorly sorted matrix, grayish-red to dark-reddish-brown	2
10	Siltstone and shale, like 14; several 2- to 6-inch sandstone layers	43
9	Sandstone, thin- to medium-bedded, crossbedded, grayish-red-purple, fine- to medium-grained, subangular, feldspathic; calcareous cement; lenses of limestone pebble conglomerate	19

UNIT No.	DESCRIPTION	THICKNESS (feet)
8	Siltstone and shale, like 14	11
7	Conglomerate, like 11	9
6	Sandstone, one bed; like 13	3
5	Siltstone and shale, like 14; stringers of light-blue-green claystone	10
4	Sandstone, like 9	23
3	Siltstone and shale, like 14	15
2	Sandstone, one bed, like 13	3
1	Siltstone and shale, like 14	2
	Total Triassic	251
	San Andres formation below	

LA CRUZ PEAK FORMATION

(Sec. 34, T. 3 N., R. 6 W., and secs. 3, 4, and 9, T. 2 N., R. 6 W.)

	Crevasse Canyon formation	
13	Sandstone, thin-bedded, yellowish-gray, fine-grained, subangular; calcareous cement; brown 1.5-foot pelecypod-bearing silty sandstone at base	6
12	Sandstone, massive, yellowish-gray, fine-grained, subangular to subround; calcareous cement; gradational contact with underlying bed	54
11	Sandstone, thin-bedded, medium-dark-gray, very fine-grained, clayey, subangular to subround; calcareous cement; layers of calcareous concretions as large as 3 feet in diameter	15
10	Sandstone, massive, yellowish-gray, fine-grained	8
9	Sandstone, like 11	47
8	Cover, probably siltstone or silty shale	67
7	Sandstone, thin- to thick-bedded, grayish-yellow to pale-yellowish-brown; basal part, fine-grained sandstone, subangular to subround, fairly well-sorted, calcareous cement; top few feet, siltstone, gradation into underlying sandstone, noncalcareous	61
6	Cover, probably siltstone or silty shale; Rio Salado valley	196
5	Sandstone, massive and crossbedded, grayish-yellow, subangular to subround; calcareous cement; *Halymenites* throughout; pelecypod-bearing beds; stringers and pellets of grayish-green claystone	26
4	Cover, probably siltstone or silty shale	11
3	Sandstone, like 13, very fine-grained	20
2	Sandstone or siltstone, thin-bedded, light-gray, subangular to subround; calcareous cement; clayey	9
1	Cover, probably siltstone or silty shale	115
	Total La Cruz Peak formation	635
	Tres Hermanos(?) sandstone member below	

BACA FORMATION

(Secs. 1 and 2, T. 1 S., R. 6 W.)

	Spears member above	
22	Mudstone, thin-bedded, pale-red; several 2- to 3-foot beds of reddish-purple sandstone	37

UNIT No.	DESCRIPTION	THICKNESS (feet)
21	Sandstone, medium-bedded, crossbedded, grayish-red, medium- to coarse-grained, angular; calcareous cement; abundant reddish-brown mudstone pellets; numerous 1- to 3-foot mudstone beds	137
20	Mudstone, pale-red, hematitic, micaceous; two 2-foot sandstone beds	13
19	Sandstone, medium-bedded, crossbedded, pale-yellowish-brown, fine- to medium-grained, subangular, feldspathic; calcareous cement; pellets and lenses of calcareous greenish-gray and reddish-brown mudstone	50
18	Silty shale, thin-bedded, reddish-brown, hematitic, micaceous; three 4-foot pale-yellowish-brown sandstone beds	32
17	Sandstone, medium-bedded, crossbedded, pale-yellowish-brown, medium-grained, angular to subangular; calcareous cement	37
16	Silty shale, thin-bedded, reddish-brown, hematitic, micaceous	9
15	Sandstone, like 17	13
14	Silty shale, like 16	29
13	Sandstone, thin-bedded, purplish-gray-pink, medium-grained, angular, feldspathic; calcareous cement	6
12	Silty shale, like 16	7
11	Sandstone, like 13	2
10	Silty shale, like 16	6
9	Sandstone, like 17	17
8	Silty shale, like 16, greenish-gray toward top	17
7	Sandstone, like 17	11
6	Silty shale, like 16	12
5	Sandstone, like 17	20
4	Silty shale, like 16	4
3	Sandstone, one bed, like 17	1
2	Silty shale, like 16	2
1	Sandstone, thin- to medium-bedded, crossbedded, grayish-yellow to pale-yellowish-brown, medium- to coarse-grained, subangular; conglomerate lenses, with subangular fragments of limestone and quartzite as much as 1 foot in diameter; abundant grayish-green shale beds and pellets	155
	Total Baca formation	617

Crevasse Canyon formation below

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