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Geology of the Cebolla Quadrangle Rio Arriba County, New Mexico

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Abstract

The Cebolla quadrangle overlaps two physiographic provinces, the San Juan Basin and the Tusas Mountains. Westward-dipping Mesozoic rocks, Quaternary cinder cones and flow rock, and Quaternary gravel terraces occur in the Chama Basin of the San Juan Basin, which occupies the western half of the quadrangle. The Mesozoic rocks are assigned to the Triassic Chinle Formation, the Jurassic Entrada and Morrison Formations, and the Cretaceous Dakota Formation, Mancos and Mesaverde groups, and the Lewis Formation. In the upper 600 feet of shale of the Mancos Group and in the basal sandstone of the overlying Mesaverde Group, faunal and lithologic changes occur from normal marine to coal swamp environment, with a distinctive nearshore molluscan fauna in the upper 200 feet of the Mancos Group.

The eastern half of the Cebolla quadrangle, within the Tusas Mountains physiographic province, contains Precambrian and Mesozoic rocks unconformably overlain by eastward-dipping Cenozoic units. The Precambrian rocks are assigned to the Moppin Formation, Kiawa Mountain Formation, Burned Mountain Metarhyolite, and Maquinita Granodiorite. The Cenozoic rocks consist of 1300 feet of gravel and tuff assigned to the El Rito, Ritito, and Los Pinos Formations. Local sources for much of the gravel incorporated in these Cenozoic units have created considerable lithic variation in the Tusas Mountains. The Ritito Formation interfingers with the Conejos Quartz Latite of the San Juan Mountains to the north and with the lower part of the Abiquiu Tuff to the south. The Los Pinos Formation is correlated with the upper part of the Abiquiu Tuff and the basal part of the Santa Fe Formation, units recognizable in the Rio Grande valley of northern New Mexico.

Major folding and faulting occurred after deposition of the Precambrian Kiawa Mountain Formation, Cretaceous Lewis Formation, and Tertiary Los Pinos Formation. Folding of the entire Precambrian sequence created a series of anticlines and synclines, accompanied by rhyolite and granodiorite intrusions and regional metamorphism. Iron, gold, and copper have been mined from these rocks intermittently since 1881. Post-Lewis deformation, probably related to the Laramide orogeny, uplifted and folded the Mesozoic and older rocks. Post-Los Pinos block-faulting and tilting have imparted a regional east-northeast dip to the Cenozoic units. Outwash material and periglacial features associated with three periods of Pleistocene glaciation occur within the quadrangle Recent movement along the western edge of the Tusas Mountains has been accompanied by volcanic eruptions and associated flow rock. Slump and earthflow mass-wasting is typically associated with the Mancos and Mesaverde groups and

the El Rito and Ritito Formations. These slides cover wide areas and have disrupted the drainage in the headwaters of the westward-flowing, gravel-terraced streams draining into the Rio Chama.

Introduction

The Cebolla quadrangle overlaps the boundary of two physiographic provinces in north-central New Mexico. These are the Tusas Mountains, part of the southern Rocky Mountain province, and the San Juan Basin, part of the Colorado Plateau province. Cebolla is a fifteen-minute quadrangle about seventeen miles south of the Colorado—New Mexico state line (fig. 1). The western edge of the area approximately coincides with U.S. Highway 84, along both of which are the towns of Cebolla, Park View, and Tierra Amarilla, county seat of Rio Arriba County. The northern boundary of the quadrangle, at latitude 36 ° 45' N., is nearly coincident with the lower part of the Rio Brazos, a tributary of the Rio Chama. Its southern boundary, at latitude 36° 30' N., lies close to the Rito de Canjilon. The eastern boundary is longitude 106° 15' W.

The stratigraphy and geology of this area are of interest both from an economic and an academic viewpoint, because it is here that several economic provinces meet. In the Tusas Mountains, the western edge of the old Hopewell—Bromide gold, silver, and copper mining district abuts the eastern edge of the quadrangle. The easternmost lignite and bituminous Upper Cretaceous coal beds of the San Juan Basin extend into the western part of the quadrangle. The arm of the San Juan Basin that forms part of the quadrangle is called the Chama Basin, and it lies between the Tusas Mountains on the east and a monoclinal flexure on the west, stretching from the Nacimiento and San Pedro mountains north through the Archuleta anticlinorium (fig. 1). Immediately west of the map area, this flexure is reflected in the El Vado domes. Within the Chama Basin, the Mesozoic rocks do not dip consistently basinward (west) but show some reversals from local flexures (p1. 1).

This report describes various rock units that outcrop in the Cebolla quadrangle, as well as the geomorphology, structural geology, and economic geology. Different names for the Cenozoic units that crop out in areas north, east, and south of the Cebolla quadrangle were correlated with those of the quadrangle, lithologic and biostratigraphic units in the 1700-foot-thick Mancos Group were established, and the Mancos—Mesaverde contact was studied.

PREVIOUS WORK

Some of the earliest geologic work in this area was done by members of the Wheeler survey in 1873 and 1874. Professor J. J. Stevenson of the Wheeler survey described the Cretaceous rock units near Tierra Amarilla and the Brazos Box in 1873 (Wheeler, 1889). In 1874, both paleontologist Edwin D. Cope and

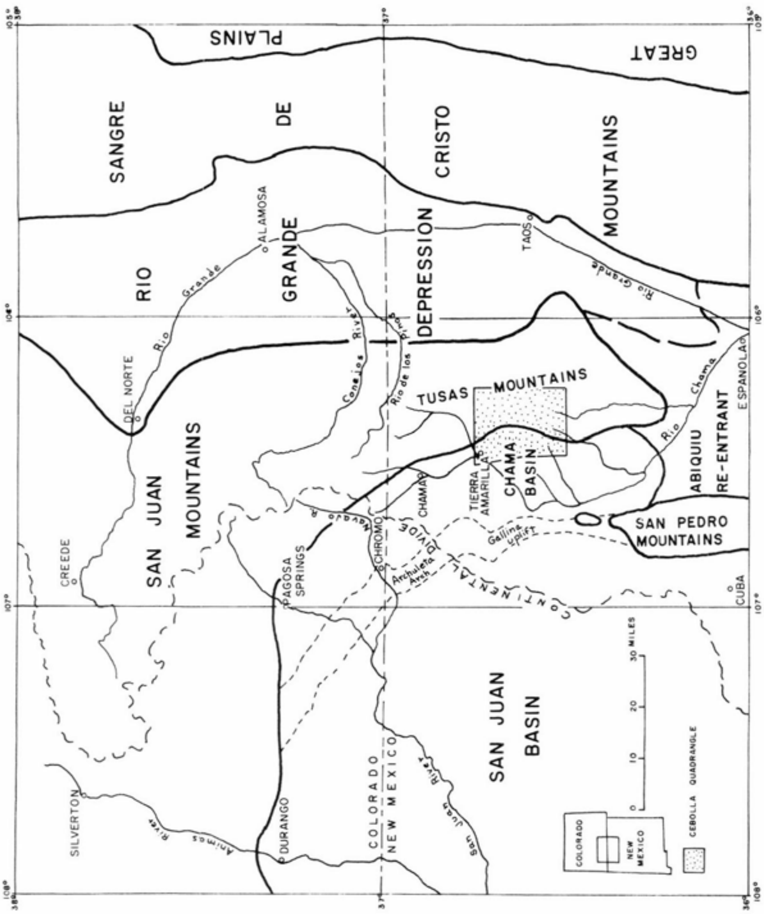

Figure 1

Major physiographic features in northern New Mexico and southern Colorado

G. M. Wheeler of the survey investigated the rocks cropping out around Tierra Amarilla (Wheeler). In the same year, Lieutenant G. S. Anderson made a study concerning the feasibility of constructing a wagon road from Fort Garland, Colorado, to Fort Wingate, New Mexico (Anderson, 1874). One of his survey lines cut east-west through the Cebolla quadrangle. He described in general terms the rocks and topographic features of this area.

In 1905, Lindgren and Graton made a reconnaissance study of the Hopewell—Bromide mining district and briefly discussed the Precambrian rocks (Lindgren and Graton, 1906). They followed this survey with a rather detailed account of the Hopewell and Bromide districts in 1910 (Lindgren, Graton, and Gordon, 1910).

Nelson H. Darton described the rocks in the Cebolla area (Darton, 1928), and Atwood and Mather referred to those in the Brazos Canyon and briefly described the glacial features of the area (Atwood and Mather, 1932).

A considerable amount of geologic work has been done in and around the Cebolla quadrangle since the early 1930's. Major mapping projects have been completed by Smith (1935,1936, and 1938), Butler (1946), Barker (1958), and Smith, Budding, and Pitrat (1961) in areas to the south and east. Dane (1948), Landis and Dane (1967), and Muehlberger (1960, 1967) mapped areas north and west. A number of theses and dissertations for the New Mexico Institute of Mining and Technology and the University of Texas also cover parts of some of these major areas (Adams, 1957; Trice, 1957 ; Longgood, 1960; St. John, 1960; and Davis, 1960). Bingler (1968) discussed the geology and mineral resources of Rio Arriba County.

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GEOGRAPHY

A north-trending escarpment nearly bisects the Cebolla quadrangle; west of it is the Chama Basin, east, the Tusas Mountains. East of the escarpment, the surface slopes gently eastward, with a few deep canyons carved into the sloping cuesta surface. On the west side of the escarpment, there is a precipitous drop to the level of the Chama valley (fig. 2).

In the southeastern quarter of the quadrangle, streams flow between a series of southward-trending, eastward-sloping ridges. The west sides of valleys like that of El Rito Creek are gentle slopes, whereas the east sides rise abruptly to the crest of the ridge and then descend with a rolling surface into the next stream valley. Most of the tributaries of streams like El Rito Creek flow down gentle slopes. Those that flow into the main streams from the east cut moderately deep, steep-walled canyons like Salvador and Hachita. The southeastern quarter of the quadrangle is drained by two major, spring-fed streams, the Rito de Canjilon and El Rito Creek, both of which empty into the Rio Chama.

The altitudes in this southeastern sector range from 10,913 feet at Canjilon Mountain, the highest point in the map area, to 8600 feet in the valley of El Rito Creek. The average altitude along the north-south escarpment, herein called the Canjilon escarpment, is 10,500 feet. The altitude range for this sector places it within the Transition and Canadian vegetation zones (Preston 1947).

About 80 per cent of the area is forested and consists mainly of western yellow pine, Douglas fir, lodgepole pine, spruce, and quaking aspen. Along the creeks, and especially in the source areas of the two main creeks, are open areas of gently rolling meadows that support primarily bunch grass. The southern half of the map area, with the exception of the extreme west side, is part of the Carson National Forest. Where the Canada de Chacon enters the El Rito valley, there is considerable slumping where beavers have constructed a maze of dams and considerably increased the area covered by water.

In the northeast quarter of the quadrangle, the Tusas Mountains are a

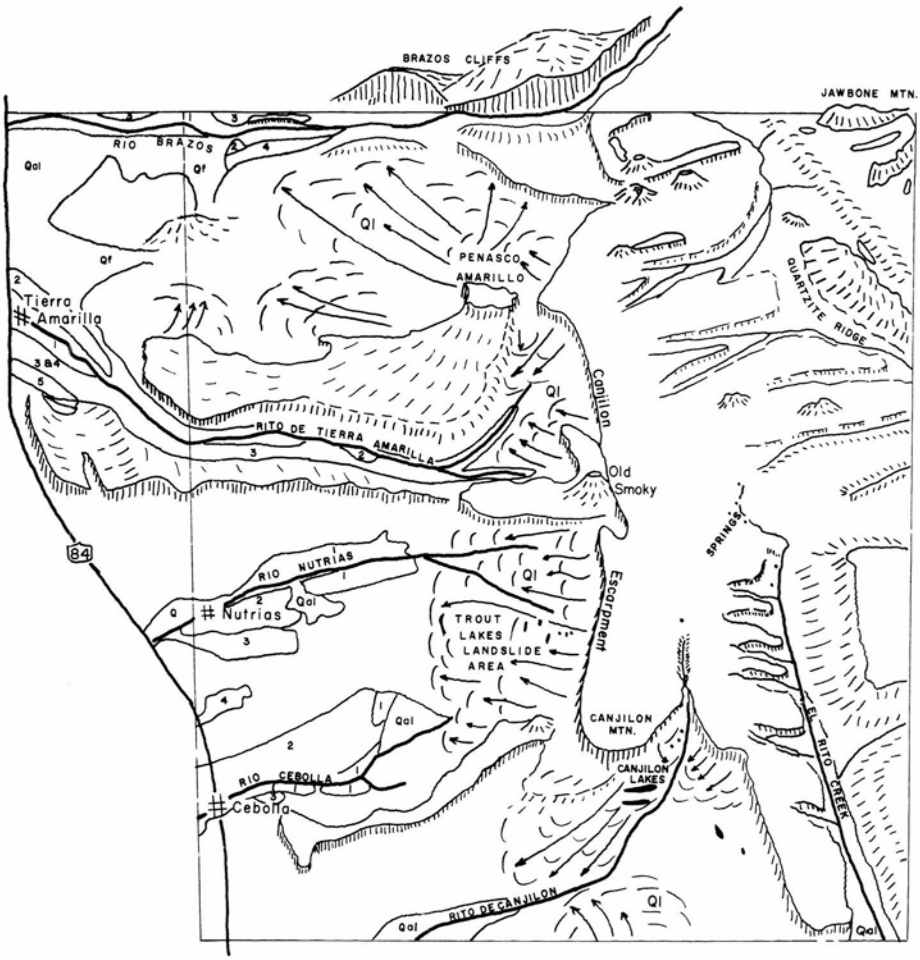


Figure 2

SCHEMATIC DIAGRAM SHOWING SOME OF THE MORE IMPORTANT GEOMORPHIC FEATURES IN THE CEBOLLA QUADRANGLE submaturely dissected, rolling highland about 40 per cent forested. The remaining 60 per cent is meadow covered predominantly with bunch grass. The rolling country is broken in many places by rugged, irregular ridges and isolated mountains of Precambrian rock where erosion and uplift have exposed them. The most spectacular of these features, the Brazos cliffs, culminates in peaks of 10,700 and 10,900 feet altitude along the north edge of the Rio Brazos Canyon just north of the Cebolla quadrangle (fig. 3). The deeply incised Rio Brazos rises in the mountainous highlands to the northeast. Along its course from the Tusas Mountains to its junction with the Rio Chama, it has carved a magnificent canyon (fig. 4). From the stream to the break at the top of these cliffs, the maximum relief is about 2200 feet. The Brazos Box, as this feature is called, contains some of the most spectacular scenery in the region. The western limit of the Tusas Mountains in the northeastern quarter of the Cebolla quadrangle is also delineated by the Canjilon escarpment, the relief along which diminishes toward the north until the escarpment abuts against the Brazos uplift.

The remainder of the map area lies between the escarpment and U.S. 84 and belongs to the Chama Basin physiographic area. Much of the area basinward from the Canjilon escarpment is covered by landslides. Canjilon Lakes, Trout Lakes, and numerous unnamed lakes that fill low spots on the slides were formed through the action of landslides, periglacial activity, and beavers. Of the several prominent features in this part of the basin, Penasco Amarillo, or Tierra Amarilla Mountain, is the most conspicuous. Cutting the western half of the quadrangle in an east-west direction is the scarp that separates the valley of the Rito de Tierra Amarilla (Nutritas Creek of older reports) from the valley of the Rio Nutrias. The western end of the scarp terminates in a synclinal mesa near U.S. 84.

At the center of the quadrangle, dominating the scene, is the beautifully symmetric volcanic cone, Old Smoky. This cone and that of Red Hill to the south lie along the north-south Canjilon escarpment.

Draining the western part of the quadrangle are five major streams; from south to north, the Rito de Canjilon, Rio Cebolla, Rio Nutrias, Rito de Tierra Amarilla (Nutritas), and the Rio Brazos. Major centers of habitation the villages of Cebolla, Nutrias, Tierra Amarilla, Park View, Ensenada, and Brazos dot the streams. The main occupation of the people of this area is raising sheep and cattle and crops of hay and alfalfa on the irrigated terraces of the streams. In this part of the Chama Basin, the altitudes range from 7300 feet along the western margin to 9000 feet at the base of the landslide material along the Canjilon escarpment, placing it in the Upper Sonoran and Transition vegetation zones of Preston. Forest covers 50 per cent of this part of the quadrangle the other 50 per cent containing scrub oak and land under cultivation.

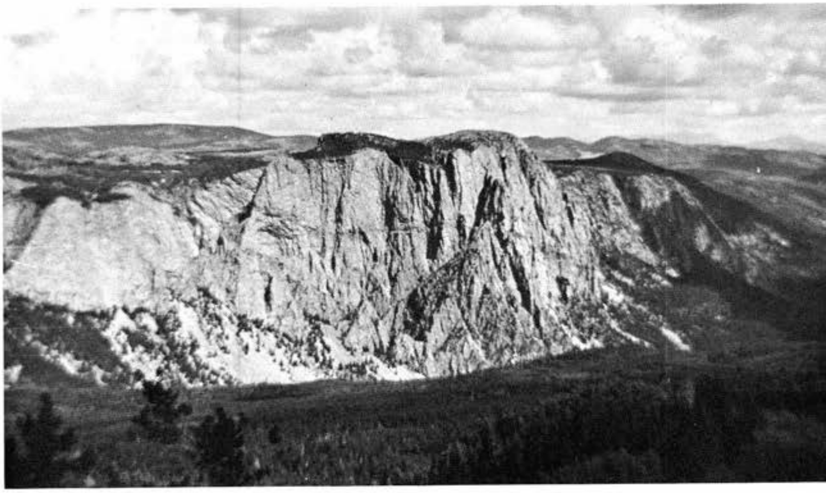


Figure 3
View looking north from Penasco Amarillo toward the Brazos Box and Brazos cliffs

Figure 4
A view east down into the Brazos Box

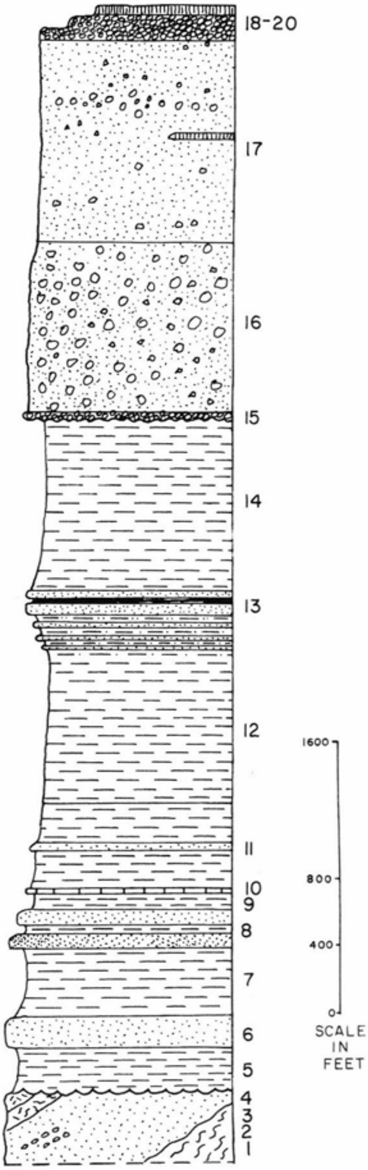
Stratigraphy

Precambrian metasedimentary and intrusive igneous rocks crop out in the northeastern and north-central parts of the quadrangle within the Tusas Mountains physiographic province. No Paleozoic rocks are exposed in the area, but Muehlberger (1967) has described an outcrop of Pennsylvanian strata about 2 miles north of the Cebolla quadrangle along Chavez Creek, which is along the western edge of the Brazos uplift.

Mesozoic rocks include parts of the Triassic, Jurassic, and Cretaceous systems. Figure 5 is a composite columnar section of the rocks exposed in the Cebolla quadrangle. The Triassic rocks are in the Chinle Formation and the Jurassic in the Entrada and Morrison Formations. Upper Cretaceous rocks are widely exposed in the Chama Basin and in the western half of the area; in ascending order, they compose the Dakota Formation, Mancos Group, Mesaverde Group, and the Lewis Formation. These rocks display a change from typical marine conditions through the transition zone into typical nonmarine conditions as the late Cretaceous sea made one of its regressions. The return of the sea to the transgressive phase is recorded by the typically marine Lewis Formation. The study of this transition zone as it progresses from the shale of the marine Mancos into the nonmarine sandstone of the Mesaverde is of major stratigraphic interest. For this study, I measured and described three fairly complete sections of the upper shale of the Mancos Group and the basal units of the Mesaverde Group, several smaller, less complete sections, and a section of the Dakota Formation (appendix).

Most of the eastern half of the quadrangle contains Cenozoic volcanic rocks exposed at the surface. Included in these units are a conglomerate of Precambrian fragments in an indurated tuff matrix, Precambrian and volcanic fragments in a loosely consolidated tuff matrix, volcanic fragments in both consolidated and unconsolidated tuff matrixes, tuff-cemented agglomerate, and layers of lava. These rocks, assigned to the El Rito, Ritito, Treasure Mountain and Los Pinos Formations, are genetically related to the great volcanic pile of the San Juan Mountains. Because some of this material was derived locally from volcanic and Precambrian rocks, whereas other material came from far away, the units do not display a great degree of uniformity over wide areas. This lack of uniformity has created stratigraphic and nomenclatorial problems, because geologists have proposed different terminologies in areas to the north, east, and south. These Cenozoic units form part of the tilted, east-dipping, western margin of the Tusas Mountains.

Quaternary rocks and features are abundantly displayed in all parts of the



SYSTEM	SERIES	GROUP	FORMATION	AVERAGE THICKNESS IN FEET	UNIT
QUATERNARY	HOLOCENE-PLEISTOCENE		ALLUVIUM		20
			TERRACES		19
			BASALT	50±	18
CENOZOIC	MIOCENE	FISHER	LOS PINOS	1200±	17
		POTOSI	RITITO	1000±	16
			EL RITO	60±	15
CRETACEOUS	UPPER CRETACEOUS		LEWIS	1000±	14
		MESAVERDE	CLIFF HOUSE MENEFEE POINT LOOKOUT	135±	13
		MANCOS	UPPER SHALE	1100±	12
			CARLILE	500±	11
			GREENHORN	30±	10
			GRANEROS	100±	9
			DAKOTA	225±	8
JUR			MORRISON	400±	7
			ENTRADA	200±	6
T			CHINLE	450±	5
P€			MAQUINITA	10,000±	4
			BURNED MOUNTAIN		3
			KIAWA MOUNTAIN		2
			MOPPIN		1

Figure 5

FORMATIONS EXPOSED IN THE CEBOLLA AREA

area. Among these are six volcanic cones and accompanying flows, solifluction lobes, stone stripes, landslides, river terraces, and alluvial fill. The relatively incompetent and unstable shale of the Mancos Group and overlying competent Mesaverde sandstone or younger Cenozoic rock has led to spectacular mass-wasting of a combination earthflow and slump type characteristic of the San Juan Mountains. This type of landsliding occurred all along the Canjilon escarpment, in places extending more than 5 miles in front of the escarpment. The five major streams, which flow west and empty into the Rio Chama, have built up an elaborate system of river terraces that may be partly related to Wisconsin glaciation.

MOPPIN FORMATION

A variety of rock types comprises the Moppin Formation in the Cebolla quadrangle. In decreasing order of abundance, it includes greenschist, muscovite-biotite schist, phyllite, and quartzite. According to Barker, who named this formation, the two major rock types in the adjoining Las Tablas quadrangle are greenschist and amphibolite. The light- to medium-green greenschist derives its color from chlorite and less abundant epidote and sericite, the sericite imparting a lustrous sheen to the surface of the greenschist. A high percentage of sericite (according to Barker) found in sulfide-bearing greenschists is probably of hydrothermal origin. His conclusion is further substantiated in the Cebolla quadrangle by the association of the sericite-rich greenschist with numerous quartz veins and the intrusive Burned Mountain Metarhyolite.

The quartz veins are abundant in the Moppin. Adjacent to these veins and to the Burned Mountain Metarhyolite are phyllites, bearing euhedral cubes of pyrite and minor amounts of other sulfides, probably introduced along with the hydrothermal action of the vein-producing solution and the metarhyolite intrusion. Abandoned mines and prospect pits are usually in or adjacent to quartz veins along the exposed outcrop of the Moppin Formation. The western part of the old Hopewell mining district includes this outcrop area. The zones that attracted major interest contained the hydrothermally altered sulfide-bearing rocks adjacent to the veins and to the metarhyolite intrusive masses.

The Moppin Formation crops out in the northeast quarter of the Cebolla quadrangle in secs. 26 and 36,T. 29 N., R. 6 E. and sec. 1, T. 28 N., R. 6 E. A belt from 0 to 200 feet wide is exposed along this rugged, fault-line scarp for about 1.5 miles. The top of the scarp is capped by Cenozoic beds, its base rests against Los Pinos Formation and alluvial fill of a branch of the Rio Vallecitos. The outcrop area lies along the west flank of the Hopewell anticline. Some of the best exposures appear in the canyons of northeast-trending tributaries, which cut into the scarp face.

The base of the Moppin Formation is not exposed in the Cebolla quadrangle, and its contact with the underlying unit is not known. The upper contact is likewise unknown, because the northwest-trending fault along which the Moppin crops out has placed this formation in an anomalous stratigraphic position. The exposed thickness of the Moppin in this area is estimated at 200 feet. Barker (p. 23) estimated a thickness of 1000 to 3000 feet in the adjacent Las Tablas quadrangle.

KIAWA MOUNTAIN FORMATION

Jawbone Conglomerate Member

Barker defined the Kiawa Mountain Formation for massive quartzite, which shows in excellent exposures on Kiawa Mountain in the Las Tablas quadrangle. The formation there has been divided into five members, the upper two of which, the Jawbone Conglomerate and an upper quartzite, crop out in the Cebolla quadrangle. Barker named the Jawbone Conglomerate Member for exposures on Jawbone Mountain in the extreme northeastern corner of the Cebolla quadrangle and the northwestern edge of the Las Tablas quadrangle. This Precambrian comglomerate, which forms Jawbone Mountain, rises several hundred feet through the gently eastward-dipping blanket of Cenozoic Los Pinos tuff and gravel. Jawbone Mountain is the surface expression of a northwest-plunging Precambrian syncline, herein called the Jawbone Mountain syncline. The mountain is bifurcated, with a northern and southern segment joined by a saddle in the axial trace of the syncline. West of the mountain smaller hills of Jawbone Conglomerate show through the Los Pinos Formation. Another outcrop area is along the upper Vallecitos fault scarp in sec. 1,T. 28N., R. 6 E., where about 80 feet of the conglomerate are exposed between the alluvium of the upper Rio Vallecitos and the Moppin Formation, topographically higher on the scarp.

The Jawbone Conglomerate is composed of quartz pebbles in a matrix of quartzite. The black, gray, and white pebbles, with a few pink ones, range in diameter from 2 to 30 mm, averaging 8 mm. In several isolated areas, the pebbles reach a diameter of 4 to 5 inches. Fairly well sorted and very well rounded, they are set in a matrix of gray to pinkish-gray quartzite, itself composed of coarse-grained quartz sand. Particularly along the axis of the Jawbone Mountain syncline, these pebbles depart from their normal suboval shape and show a marked degree of stretching. The tops and bottoms of beds can be determined by well-developed hematite banding and cross-bedding.

The thickness of the Jawbone Conglomerate Member on Jawbone Mountain ranges from 500 feet to several thousand feet. As neither the top nor the bottom of the member is exposed, the total thickness cannot be accurately determined. Along the fault scarp, the upper contact with the upper quartzite mermber of the Kiawa Mountain Formation is buried, but southeast along the strike of the conglomerate, it appears to finger out into the quartzite (Barker).

Upper Quartzite Member

The upper quartzite member of the Kiawa Mountain Formation is the most widely exposed and thickest of all the Precambrian units in the Cebolla quadrangle. It is exposed along the upper Rio Vallecitos valley in a long ridge that is a linear extension of Quartzite Peak to the southeast in Las Tablas quadrangle. The name *Quartzite Ridge* is herewith applied to this prominent topographic feature in secs. 35 and 36, T. 29 N., R. 6 E. and secs. 1, 2, and 3, T. 28 N., R. 6 E. Quartzite Ridge, which has a maximum relief above the upper Rio Vallecitos valley of 600 feet, is part of the northeast limb of the northwest-plunging Kiawa Mountain syncline. The extension of the ridge toward the northwest consists of a series of inliers surrounded by the Cenozoic Los Pinos Formation. To the north of and along Jarosa Creek several isolated peaks and outcrops constitute part of the southwest limb of the Kiawa Mountain syncline.

The most massive expression of the upper quartzite member occurs in the north-central part of the Cebolla quadrangle. At Brazos Box and Brazos cliffs, in a sheer canyon cut by the Rio Brazos, cliffs of quartzite rise to a height of 2200 feet (figs. 3 and 4).

Of the three major types of quartzite, the most abundant in the Cebolla quadrangle is massive, vitreous, and light purplish-gray. It is exposed primarily along Quartzite Ridge and in the Brazos Box; much of it is banded with hematite along the bedding planes. Some of the rock shows good cross-bedding, and on this basis, I determined structure in these Precambrian rocks. Scattered throughout this type of quartzite are zones of pebbly quartzite.

In thinsection, a sample of the purplish-gray quartzite from the south side of the Brazos Box contained 99 per cent quartz and 1 per cent mica. It is a holocrystalline, fine- to medium-grained, mature orthoquartzite, with granular texture and very tight packing of the recrystallized quartz grains. The median grain size is 0.2 mm, with an extreme range from 0.06 to 0.5 mm. The grains are equidimensional and subround.

The second major type, a grayish-pink, pebbly quartzite, is exposed mainly on the southwest limb of the Kiawa syncline. The grayish-pink, vitreous matrix contains grains of gray, pink, and white quartz that range in diameter from 1 to 2 mm. Biotite grains commonly occupy the poorly developed bedding planes.

The third major type is a closely banded, tightly folded, light grayish- pink quartzite. According to Barker, its red-brown and bluish-gray laminae are composed of hematite and kyanite. The laminae are closely spaced, 2 to 10 mm, and tightly folded into many microfolds, which may indicate slump folding. This kind of banding occurs in quartzites in the Brazos Box and is especially well developed in outcrops along the northern extension of Quartzite Ridge.

Because neither the top nor the bottom of this member is exposed and because consistent marker beds are lacking, the thickness can be only approximated. Barker estimated the upper quartzite member at 5000 to 10,000 feet thick, possibly thicker.

The upper quartzite member is the youngest Precambrian unit in the Cebolla area and is unconformably overlain by younger rock units ranging from the Triassic Chinle Formation through the Quaternary basaltic flow rocks and cinder cones. The great thickness of the member in the Brazos Box area and the thickness plus separation of the upper quartzite member from other Precambrian units by the upper Rio Vallecitos fault in the northeast area have made observation of the lower contact impossible on outcrop. The base, as defined by Barker, is the top of the amphibolite member.

BURNED MOUNTAIN META RHYOLITE

Just (1937) first named this unit the Vallecitos rhyolite; because this name was preoccupied, Barker renamed it the Burned Mountain Metarhyolite. It crops out in sec. 36, T. 29 N., R. 6 E. along the side walls of a canyon cut by a southwest-flowing tributary of the Rio Vallecitos.

The Burned Mountain metamorphosed rhyolite porphyry displays three color varieties in the Cebolla quadrangle: moderate orange pink, grayish orange pink, and pale purplish-pink. The aphanitic groundmass is a dense, holocrystalline aggregate of flesh to salmon-colored potassic feldspars, which, according to Barker, are microcline after original orthoclase or sanidine. The abundant relict phenocrysts, comprising 20 to 30 per cent of the rock volume, are well rounded, vitreous, gray to clear quartz and euhedral, tabular, orange-pink feldspar laths. Flow structure is displayed by a subparallel alignment of the phenocrysts.

The Burned Mountain Metarhyolite is in contact with the phyllite facies of the Moppin Formation. At the outcrop, the contact appears to be concordant. Barker observed, from numerous outcrops in the Las Tablas quadrangle, that the contact with its overlying and underlying strata is almost everywhere concordant.

MAQUINITA GRANODIORITE

This unit, named by Barker for exposures in Maquinita Canyon, is exposed in a single outcrop (sec. 30,T. 29 N., R. 7 E.) along the northeastern boundary of the Cebolla quadrangle. Close to the axis of the Hopewell anticline, it is a light gray to light pinkish-gray, granular, sheared, and foliated rock. Megascopic examination shows that this rock contains white and clear quartz, pink tabular feldspars, white striated feldspars, and knots of biotite. The biotite especially shows a weakly developed flow lineation. The gray color results from the presence of 10 to 15 per cent biotite. Amphibole and pyroxene are rare.

In the Cebolla quadrangle outcrop, the Maquinita Granodiorite is associated with the greenschist of the Moppin Formation. The contact is obscured in a small area of outcrop; Cenozoic LosPinos beds cover most of the adjacent area. The granodiorite, however, appears to be a dikelike intrusion into the green-schist. In the Las Tablas quadrangle, particularly in the area adjacent to the Cebolla quadrangle, the Moppin Formation has been invaded by many small dikes of granodiorite.

CHINLE FORMATION

Northrop and Wood (1946) subdivided the Chinle Formation in northern New Mexico into four units, which are well exposed near the Nacimiento Mountains and Ghost Ranch (14 miles south of the village of Cebolla). From lowest to highest, they are the Agua Zarca Sandstone Member, the Salitral Shale Tongue, the Poleo Sandstone Lentil, and an upper shale member. Colbert (1960) recently used the name *Petrified Forest Member* to designate the upper shale member. Because these four units are not everywhere distinguishable, other workers (Budding, Pitrat, and Smith, 1960) chose to divide the Chinle Formation into two members, a lower sandstone and an upper shale member, which are used herein for the Cebolla quadrangle.

The Chinle Formation crops out in two widely separated parts of the quadrangle. In the north-central part, it is exposed in two places: at the base of a Dakota hogback on the south side of the Rio Brazos under a debris-covered, forested slope and along the northern boundary on the north side of the Rio Brazos on a tree- covered slope, where it is largely obscured. In the southeastern part of the quadrangle in sec. 11, T. 26N., R. 6 E., the Chinle Formation is also exposed just north of the El Rito—Canjilon highway junction, where the outcrops form secondary ridges along the east and west slopes of El Rito Creek valley.

The thickest section of Triassic rock exposed in the report area, about 40 to 50 feet in discontinuous exposure, lies in El Rito valley The slope is covered by rubble from the eastward-dipping Ritito Formation of Cenozoic age, which rests on the Chinle. The Chinle consists of alternating beds of coarse- grained, calcite-hematite-cemented, pale red, quartz sandstone, pale red shale, and fine-grained sandstone. The coarse-grained, slightly friable sandstone forms poorly developed ridges that cannot be traced laterally for more than several hundred yards. This sandstone is thin-bedded, with beds from a few inches to (rarely) several feet thick. The quartz grains of this red sandstone are white, gray, brown, and black; between 1 and 2 mm in diameter; highly rounded; and fairly well sorted.

Along the Rio Brazos, fine-grained, hematite-cemented quartz sandstone and red siltstone are exposed. All the exposures here are poor because of debris and slumping from the topographically and stratigraphically higher formations. In areas to the south, Budding, Pitrat, and Smith estimated the thickness of the Triassic at 650 to 700 feet, and in the area to the north, Muehlberger et al. (1960) estimated its thickness at about 450 feet.

Although the precise contact was not seen, the upper Jurassic Entrada Formation overlies the Chinle Formation at the Dakota hogback location. The basal contact of the Chinle is not exposed. The Chinle in outcrops north of the Rio Brazos in the Brazos Box area rests unconformably on the upper quartzite member of the Kiawa Mountain Formation. In El Rito Creek section, neither the upper nor the lower contact of the Chinle is exposed. The basal part of the formation lies to the south, and the overlying Entrada is masked by landslides and alluvium along the valley of El Rito Creek. The stratigraphic position and lithologic composition of the Chinle beds resemble the upper shale member of Budding, Pitrat, and Smith or the Petrified Forest Member of Colbert. It is reasonable to conclude that the Triassic exposed here is a part of the upper shale member of the Chinle.

ENTRADA—TODILTO FORMATION

The Entrada Formation is poorly exposed in the Cebolla quadrangle. About 12 miles south of the village of C ebolla, along the edge of the San Juan Basin, the Chinle, Entrada, Todilto, Morrison, and Dakota Formations are well exposed at Echo Amphitheater. Here, the massive, cliff-forming Entrada Formation is about 300 feet thick. The east and northeast extensions of this outcrop belt show a progressive thinning in the direction of the Cebolla quadrangle. Budding, Pitrat, and Smith stated that the thickness of the Entrada Formation in the southwestern corner of the Magote Peak quadrangle is 200 feet; in the northeastern corner, it thins to 120 feet. The Magote Peak quadrangle joins the Cebolla on the south. A small part of this Entrada outcrop belt extends into the southeastern corner of the Cebolla area in sec. 10, T. 26 N., R. 6 E., where the Entrada may be still thinner, but because of poor outcrops the thickness is undetermined. The outcrop zone there is covered by slump and debris from the overlying Morrison, Dakota, and Ritito Formations. The Entrada does not constitute a cliff-forming unit in the Cebolla quadrangle as it does in areas both to the north and to the south.

A second area of equally poor exposures occurs along the Dakota hogback ridge immediately south of the Rio Brazos, where slump, slide, and forest cover all but a small part of the Entrada Formation. Where the Entrada is exposed, it consists of a white to yellowish-brown, well-rounded, well-sorted, fine-grained quartz sandstone. Approximate thicknesses of 100 feet in the southern outcrop zone and 200 feet in the northern outcrop zone are indicated.

The Entrada Formation is underlain by the upper shale member of the Chinle Formation and overlain by the Morrison Formation; the contacts are not exposed. The Todilto formation consists of shale and limestone, with massive beds of gypsum. The Todilto, which usually overlies the Entrada in the region to the south, does not appear in outcrops in the Cebolla quadrangle, but it has been recorded for a well drilled about three miles north of Nutrias in the Chama Basin. The Todilto there had a show of oil (Bieberman, 1960).

The thinning of the Entrada Formation toward the Precambrian of the Tusas Mountains seems in accord with the idea of Muehlberger et al. (1960) that there was a persistent high in this region throughout late Paleozoic and much of Mesozoic time. In the Brazos Peak quadrangle, the Pennsylvanian and Triassic units wedge out against the Precambrian.

MORRISON FORMATION

The claystone, shale, and silt stone of the upper Jurassic Morrison form gentle, rubble-covered slopes. Outcrops occur mainly where El Rito Creek has undercut banks and exposed fresh surfaces. Slope wash, slide deposits, and alluvial deposits cover most of the area where the Morrison Formation would crop out, but it does appear at several places in the valley of El Rito Creek and beneath the Dakota Sandstone on the hogback on the south side of the Rio Brazos. All the outcrops are small.

The Morrison Formation in northwestern New Mexico consists of multi-colored conglomerate, sandstone, siltstone, shale, and claystone. In the Cebolla quadrangle, it consists of pale greenish-yellow to pale olive siltstone, shale, and claystone, most of which are mottled with yellowish-brown limonite. The many other colors characteristic of the Morrison elsewhere are lacking.

The Morrison Formation on the northeast side of Cerro Pedernal, 27 miles southwest of Cebolla, is 1086 feet thick (Sears, 1953) and in the Gallina uplift, fifteen miles southwest of the village of Cebolla, 925 feet thick (Lookingbill, 1955). As one follows the Morrison across the Chama Basin to its outcrops along the southern and southeastern margins, the thickness in areas south of the Cebolla range from 575 to 675 feet (Budding, Pitrat, and Smith). In the Chama area, Adams estimated the thickness of the Morrison at 435 feet. A complete section of the Morrison is not exposed in the Cebolla quadrangle, but the estimated thickness is 400 feet.

Different authors have subdivided the alternating stream and flood plain materials of the Morrison into two, three, and four members in northern New Mexico. Because of the scarcity of outcrops in the Cebolla quadrangle, together with the lack of information concerning the contacts and thickness, it is not feasible to subdivide the formation here. On the basis of lithologic and color similarities, one can correlate the outcrops in the Cebolla area with the Brushy Basin Member described by Budding, Pitrat, and Smith. In the Chama region, this member consists mainly of claystone and sandstone that show predominantly orange near the base and green near the top. The stratigraphic position of the outcrops in the Cebolla area places them near the top of the Morrison.

Probably the Morrison in this area lies disconformably on the Entrada Formation and is overlain disconformably by the Dakota Formation The lower and upper contacts are poorly exposed. Arkell (1956) placed the Morrison in the Upper Jurassic Series (pre-Purbeckian).

DAKOTA FORMATION

Outcrops of the Dakota Formation (fig. 6) delineate the southern half of the Chama Basin. Where the outcropping Dakota is essentially horizontal, it forms some of the steepest cliffs in the area. Where it has been steeply tilted, it forms prominent ridges and hogbacks. On the west and south sides of the Chama Basin, the outcrop belt is wide and conspicuous. Along the east side of the basin and into the Cebolla quadrangle, the narrowed outcrop belt is covered in most places by younger formations. The most extensive Dakota outcrop in the Cebolla quadrangle appears in Magote Pass (fig. 6, no. 5), where the lower part forms cliffs but the upper part is covered by dense vegetation and debris from overlying formations. Two other outcrops occur along the eastern side of the basin where creeks have cut through the younger sedimentary and volcanic rocks (fig. 6, nos. 3 and 4). Only at the steep cliff of the Dakota outcrop along El Rito Creek (no. 4) is the formation well enough exposed to warrant measuring the section (fig. 7), though neither the top nor the base of the formation is

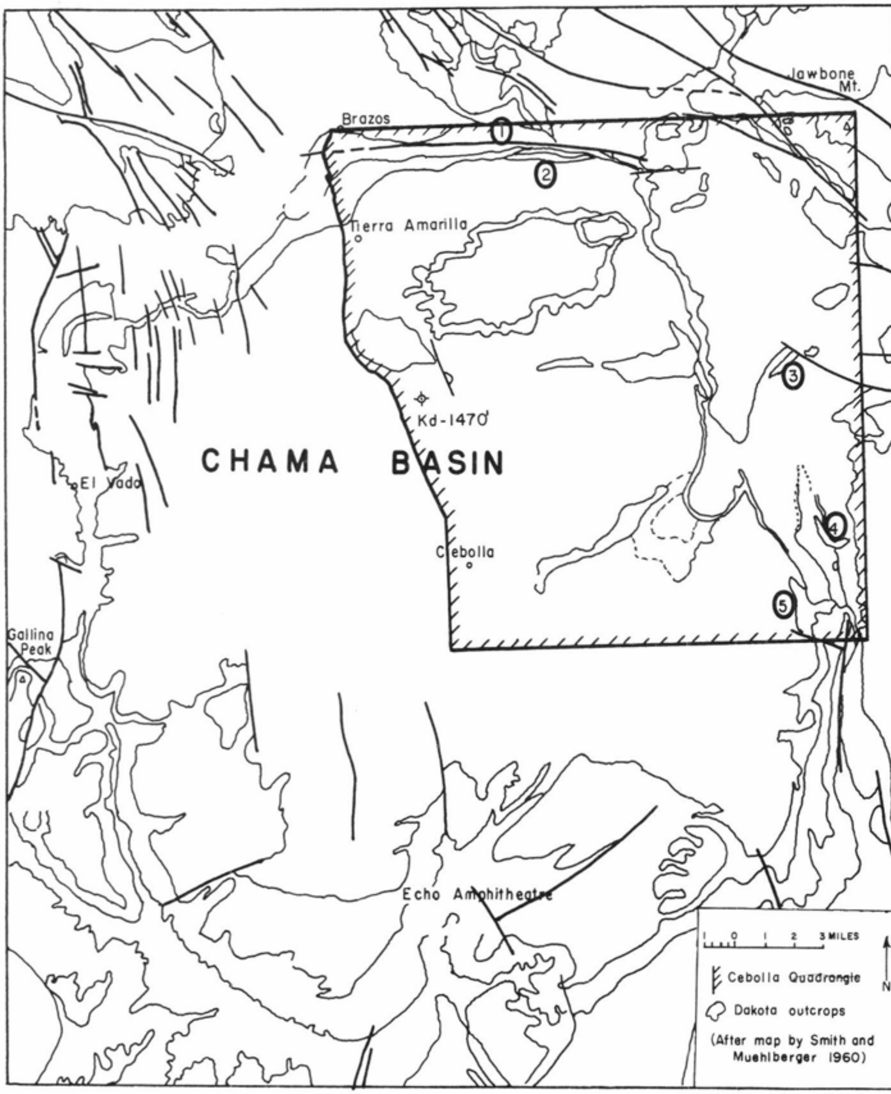


Figure 6

MAP SHOWING LOCATION OF DAKOTA OUTCROPS IN THE CHAMA BASIN

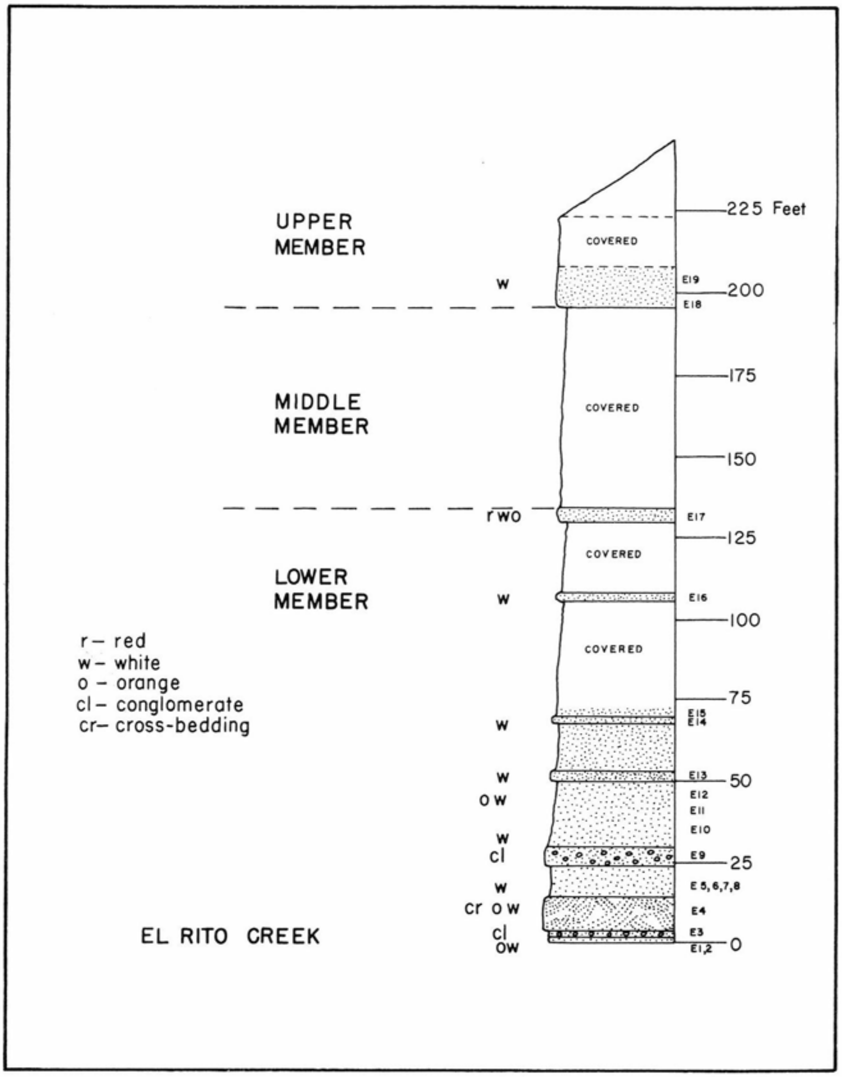


Figure 7
COLUMNAR SECTION OF THE DAKOTA FORMATION IN EL RITO CREEK VALLEY

exposed. Along the Rio Brazos (no. 2), the anomalous west strike of the Dakota is well displayed in a prominent hogback that reflects the west trend of the Brazos fault.

The Dakota Formation is mainly a fine- to coarse-grained, pale orange-white, conglomeratic, cross-bedded, chert-bearing, quartz sandstone with an interbed of gray, carbonaceous, silty shale. In El Rito Creek section (fig. 7), the Dakota consists of three lithologic units: a basal sandstone member, a middle, covered shale member, and an upper sandstone member. The lower and upper sandstone members form small cliffs, whereas the middle shale member forms a steep slope. The basal contact is not exposed. At the base of the exposed lower member, from El to E3 (fig. 7), the sandstone is medium-grained, conglomeratic, grayish-orange, and thin-bedded and contains well-rounded, white and gray chert and quartz pebbles. This conglomerate characteristically lies at the base of the Dakota throughout the Chama Basin. The pale orange color comes from zones and specks of limonite. The sandstone of some of the more prominent ledges of the lower member displays well-developed, though random, cross-bedding. The rest of the sandstone in the lower member, with the exception of conglomeratic unit E9, is very fine- to medium-grained, pale orange, limonite-stained, well-rounded, and porous. Some of it has good parallel bedding. In the units from E 1 0 to E17, inclusive, the sandstone is speckled with black carbonaceous flecks, another characteristic feature of the Dakota in this area.

The middle member appears as a steep rubble- and debris-covered slope that resembles the slope of silty, gray, carbonaceous shale in other outcrops. The uppermost outcropping ledge-forming sandstone (units E18 and 19) comprises the upper member of the Dakota and is pale orange to white, massive, fine-grained, and quartzitic. The upper contact is concealed under the overlying Ritito Formation.

Four units (E2, E9, E14, and E18) of the Dakota measured section that seemed megascopically representative of the over-all section furnished samples for thinsections (fig. 7). The number in parentheses following each unit number below is the label number of the thinsection; for example, unit 9 (3 5D-M-3).

Unit E2 (35D-M-1), near the base of the exposed Dakota section in El Rito Creek valley, is a medium-grained, immature, orthoquartzite. The composite quartz grains that constitute 93 per cent of this rock are fairly well rounded and most have partly rounded authigenic overgrowths. The porosity has been reduced by the overgrowths and the clay and limonite cement.

Unit E9 (35D-M-3) is the most prominent ledge-forming conglomeratic unit in the measured section. The rock is coarse-grained to conglomeratic, sub-mature, chert-bearing orthoquartzite. The quartz types, totaling 61 per cent, comprise mainly plutonic quartz and vein quartz, with a small per cent of chalcedonic quartz that shows imperfect spherulitic structure. Fairly well-rounded chert pebbles that range from coarse-grained sand size to 1.5 inches in diameter compose about 9 per cent of the rock. Chert that feathers around chert and quartz grains or appears as loose filling composes about 30 per cent. Porosity is almost absent because of the chert and vein-quartz cement.

Unit E14 (35D-M -7) is a silty, fine-grained, cherty, submature, orthoquartzite with a scattered assortment of grain sizes from clay size to 0.5 mm; most of the grains are the silt fraction size. The larger quartz grains show good rounding, whereas the smaller ones are angular. The rock is poorly cemented with clay, chert, ilmenite, and leucoxene and is very porous. Minor amounts of mica, chert pebbles, and carbonaceous material are present.

Unit E18 (35D-M-10) is a fine-grained, immature, orthoquartzite. The grains are smaller than those of most of the other units and show greater angularity. In this rock, microcline feldspar comprises less than one per cent of the total constituents, but in the thinsections examined, microcline occurred only in beds of the upper sandstone member of the Dakota Formation. Besides quartz, 5 to 10 per cent of the sample is composed of silt and clay cement. Chert is present but not so prominently as in the lower part of the formation. The grains of quartz, chert, and feldspar are all fresh; they show little or no alteration.

Thinsections of samples from other Dakota outcrops permit comparison with those from the El Rito Creek measured section. A thinsection from the Rio Brazos outcrop (fig. 6, no. 2) shows sandstone of the upper member that resembles unit E18 of the El Rito section in both mineralogy and cement. The rock of two thinsections from the east-central Dakota outcrop (fig. 6, no. 3) resembles the sandstone of the upper part of the lower member at the measured section, that of three thinsections from the Magote Pass outcrop belt (fig. 6, no. 5), the sandstone of the lower member at the measured section. Especially well displayed in the Magote Pass rock is the conglomeratic fraction of the lower member. This rock is a conglomeratic, chalcedonic, submature, chert-pebble orthoquartzite. The chert grains constitute 45 per cent, quartz 30 per cent, and chalcedony 25 per cent of the rock. A small amount of vein quartz shows good comb structure. The rock is fairly uniform with large chert pebbles, 2 to 5 mm, surrounded by smaller quartz grains 1/16 to 1/3 mm, and both tightly cemented with featherlike chalcedonic cement. The pebbles appear in zones. A definite bimodal distribution shows gravel-fraction chert and smaller fraction quartz The quartz and chert grains are subrounded to well rounded.

The thickest exposed section of the Dakota Formation in the Cebolla quadrangle is 225 feet in El Rito Creek section. The formation is divided into three members: lower sandstone, 130 feet; middle shale, 60 feet; and upper sandstone, 35 feet. This threefold division of the Dakota agrees with the findings of Budding, Pitrat, and Smith in areas south of the Cebolla quadrangle and of Muehlberger et al. in areas to the north.

The lower and upper contacts of the Dakota are vague. In El Rito Creek valley, half a mile south of the Dakota measured section, green Morrison claystone crops out. A landslide and alluvium conceal the contact. Above the upper member of the Dakota of the Rio Brazos hogback is the black Graneros Shale of the Mancos Group. The contact zones are not visible. Muehlberger (1960) stated that the Dakota has a gradational contact with the Graneros. Dane (1960) mentioned the striking similarity between the basal Dakota and the underlying Morrison. Color is the major basis of division. The Dakota with its pale orange, buff, and yellowish-brown contrasts with the greenish and white sandstone and conglomerate of the upper Morrison. At locations 3 and 4 (fig. 6), the Dakota is partly conformably overlain by the Mancos and partly unconformably overlain by El Rito Formation. It appears (Muehlberger, 1960) that the Dakota rests on Precambrian in places in the Tusas Mountains, indicating that perhaps some of these Precambrian highs were in existence when the Dakota sea advanced across this region. There may have been some sort of barrier separating this area from the Dakota of northeastern New Mexico (Dane, 1960).

Early workers in the area, like Wheeler, assigned the Dakota around Tierra Amarilla to the Lower Cretaceous Series. In the Cebolla quadrangle, no one has found identifiable fossils in the Dakota, although there are plant impressions, "borings," and much carbonaceous material. In the Brazos Peak quadrangle, there are some unidentifiable pelecypod casts (Muehlberger, 1960). Dane (1960) believed that the age of the Dakota on the eastern side of the San Juan Basin is Late Cretaceous and that the formation is possibly younger than the Dakota in northeastern New Mexico and southeastern Colorado. Other workers, such as Brown (1950), have assigned a Late Cretaceous age to the Dakota in southwestern Colorado.

The material that makes up the sandstone of the Dakota Formation in the Cebolla quadrangle comes from a reworked sedimentary source. The quartz, chert grains, and pebbles display a high degree of rounding. The rounded, reworked overgrowths on some of the rounded quartz grains indicate several cycles of reworking.

Dane (1960) suggested multiple sources for the Dakota in the San Juan Basin. The upper and lower sandstone members of the Dakota along the eastern side of the San Juan Basin thin toward the southwest, whereas some sand units on the south side of the basin thin to the north. The unconformity between the Precambrian and the Dakota in the Tusas Mountains indicates Precambrian highs that may have acted as local sources.

Some authors have postulated a fluvial environment of deposition for part of the Dakota (Pike, 1947) and flood plain, swamp, and lagoon for the rest, excepting the uppermost beds, which are littoral. The fluvial environment is not corroborated in the eastern part of the San Juan Basin, for the Dakota lacks typical channel fillings and conspicuous lenses (Dane, 1960). Most authors envision the Dakota as a transgressive, dominantly lagoonal deposit left during the widespread invasion of the Late Cretaceous sea into the Rocky Mountain area (Sears, Hunt, and Henricks, 1941; Pike). Young (1960) explained how these sediments could have accumulated. He visualized a repeated history of large subsidence and quick transgression of the sea westward, followed by a slow regression during which the bulk of the sediment was deposited. With each large subsidence, the sea transgressed farther to the west, leaving an over-all record of westward transgression.

MANCOS GROUP

For the dark and light gray shale, sandstone, and limestone, which are so well exposed in the Mancos Valley, Colorado, Whitman Cross (Cross and Purington, 1899) proposed the name *Mancos* The town of Mancos lies in the heart of the valley only a few miles from Mesa Verde National Park. Since the unit was established, it has been recognized in Colorado, New Mexico, Arizona, Utah, and Wyoming.

Some writers use the term *Mancos Formation;* others call it *Mancos Shale;* still others subdivide it into formations. The Mancos Group includes all the Upper Cretaceous strata between the Dakota Formation and the Mesaverde Group. In the Cebolla quadrangle, this is slightly more than 1700 feet of predominantly gray shale. Historically, this interval has been designated as Cretaceous No. 2, No. 3, and part of No. 4, or as the Fort Benton, Niobrara, and Fort Pierre subgroups of the Colorado group (Stevenson, 1881). Dane (1948) partly replaced these subgroup names, which were carried from the original type localities of Meek and Hayden along the Missouri River into the Front Range, with names of units from Colorado. In the northeastern part of the San Juan Basin and the Cebolla area, he introduced four names, from lowest to highest, the Graneros shale, Greenhorn limestone, Carlile shale, and the Niobrara calcareous shale, leaving an upper shale member unnamed (fig. 8). These formations are not recognized in the southern and western parts of the San Juan Basin.

The Mancos Group is a wedge-shaped accumulation, thinner in the western and southwestern parts of the San Juan Basin than in the eastern and northern parts. In the western and southern parts of the San Juan Basin, complex intertonguing between the Mancos and the overlying Mesaverde demonstrates that this region lay near the edge of the Mancos sea. This general region also represents the maximum extent of the Mancos sea. A series of major and minor regressions and minor transgressions gradually resulted in an eastward and

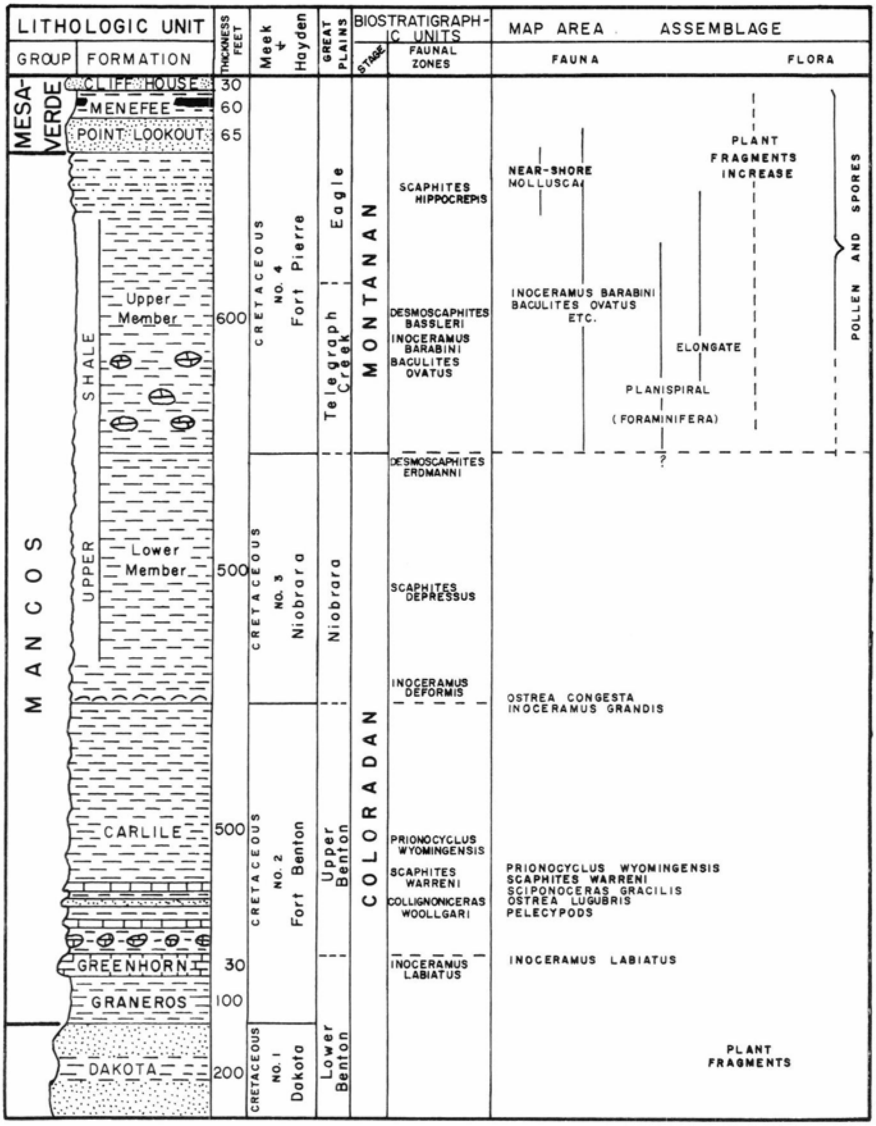


Figure 8

COMPOSITE COLUMNAR SECTION OF THE MANCOS AND MESAVERDE GROUPS IN THE TIERRA AMARILLA AREA northward advance from the south and west until the Mesaverde finally covered the earlier Mancos deposits.

Yet for some time, the shoreline of the regressing Mancos sea was far enough to the west that many of the early, minor, complex transgressions and regressions did not get recorded in the Cebolla area, where the marine Mancos continued to accumulate. Not until the second major regression of the Mancos sea in early Campanian time (Weimer, 1960) did the shoreline, and with it the Mesaverde lithotope, invade the Cebolla area (fig. 9). In the western and southwestern parts of the San Juan Basin, where the Mesaverde began its eastward and northward advance in late Turonian time, the Mancos marine shale is relatively thin, measuring about 80 feet in Apache County, Arizona (O'Brien, 1956), 550 feet at Salakhai Mesa, Arizona (Gregory, 1917), and 725 feet near Gallup, New Mexico (Sears, Hunt, and Hendricks). This contrasts with 2000 feet at Telluride, Colorado (Reeside, 1924), 2000 feet in the Cebolla area, and 6000 feet in western Colorado (Pike). Reeside (1924) stated that the base of the Mesaverde rises 1200 feet stratigraphically in a west-to-east direction in a distance of 100 miles.

The Mancos Group is the most widespread stratigraphic unit in the Cebolla quadrangle. It is exposed over the western half to two thirds of the map area. Topographically, it forms the low rounded hills and stream valleys in the eastern part of the Chama Basin. It underlies the more resistant cliff-forming sandstone of the Mesaverde and conglomerate of the El Rito. The thickness of the Mancos, as calculated from measured sections and interpretation of the log of Continental Oil Company's Perfecto Esquibel No. 1 well, is 2016 feet. This well was drilled just east of U.S. 84 on the north side of the Rio Nutrias, about in the center of the Chama Basin. Because of limited exposures resulting from mass-wasting and alluvial cover, the formations of the Mancos Group have not been individually differentiated on the geologic map.

Graneros Shale

The Graneros Shale, the basal formation of the Mancos Group, occupies the stratigraphic interval between the underlying Dakota Formation and the overlying Greenhorn Limestone (fig. 8). This thin-bedded, black to gray shale is recognized in northern New Mexico and eastern and southwestern Colorado; it was named by G. K. Gilbert (1896) for exposures along Graneros Creek near Walsenberg, Colorado.

Fissile and calcareous, the Graneros Shale can be recognized only where one finds the overlying Greenhorn Limestone because of the lithologic similarity of the Carlile and the Graneros. The Graneros in the Cebolla area is about 100 feet

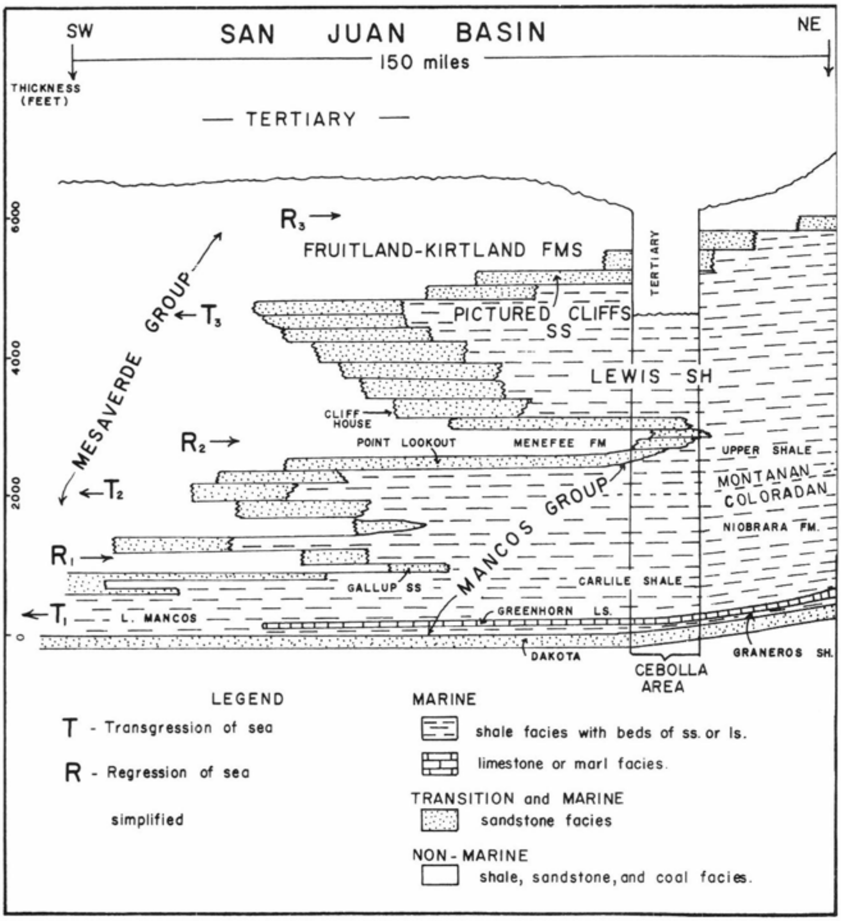


Figure 9

Diagrammatic representation of the major Upper Cretaceous transgressions and regressions in the San Juan Basin and their relationship to the Cebolla area thick. Although it reaches an interpreted thickness of 134 feet (Dane, 1960) in the Perfecto Esquibel No. 1 well, north of the village of Nutrias near the structural center of the Chama Basin this probably represents a maximum for the Cebolla area. The basal third of the Graneros is sandy shale with numerous calcareous concretions. The shale immediately beneath the GreenhornGraneros contact has several thin bentonite interbeds.

The Graneros is poorly exposed in the Cebolla area. The narrow outcrop belt consists of rounded grass- and tree-covered hills; only adjacent to the projecting overlying or underlying units is the shale exposed, and then only a few feet of it. The belt is contiguous with that of the underlying Dakota Formation in the extreme southeast, east, and north-central parts of the Cebolla area.

The conformable contact between the Dakota Formation and the Graneros Shale consists of a transition from sandstone to shaly sandstone to arenaceous shale. The upper boundary of the Graneros is also conformable and is placed at the first occurrence of the Greenhorn Limestone. The fauna of the Graneros Shale in western Colorado is equivalent to the early Benton fauna in the early Coloradan stage in the Rocky Mountain area (Reeside, 1925). The characteristic index fossils of this zone are *Exogyra columbella* and *Gryphaea newberryi,* neither of which has been found in the outcrops in the Cebolla area.

Greenhorn Formation

G. K. Gilbert gave the name *Greenhorn* to an alternating 20- to 60-foot sequence of gray shaly limestone and limy shale, typically displayed along Greenhorn Creek south of Pueblo, Colorado. This formation has since been recognized in northern New Mexico, eastern and southwestern Colorado, and on the Great Plains. The Greenhorn Formation of the Mancos Group lies stratigraphic ally between the Graneros and Carlile Formations (fig. 8).

The Greenhorn Formation in the Cebolla area consists of alternating thin beds of shaly, platy limestone and limy shale with less numerous thin bentonite interbeds. Beds of white to very pale orange limestone range from less than an inch to several feet thick. Characteristically, this limestone weathers into chips and flakes that extend some distance below the surface of the outcrop, masking the underlying gray calcareous shale. The shale members are thicker in this area than the limestone members; the total thickness of the formation ranges between 20 and 30 feet. On the weathered surface, the very pale orange limestone and the light gray shale contrast strikingly with the underlying black and gray Graneros and the overlying brownish-black Carlile. The lower and upper contact of the Greenhorn is placed at the lowest and highest occurrences of the thin- bedded limestone layers. These lithologic and color characteristics are extremely useful in mapping; if it were not for the Greenhorn Formation it would be difficult to separate the underlying Graneros Shale from the overlying Carlile shale. Thinsection analysis shows that the limestone is a biomicrite with minor inclusions of muscovite and carbonaceous material. Very abundant in the platy limestone are impressions of *lnoceramus labiatus* Schlotheim.

The Greenhorn with its alternating layers of shale and thin bedded limestone does not form a prominent topographic feature. The limestone layers do, however, form secondary ridges that one can recognize on close observation The characteristic lime chips strewn on the surface and downslope aid in the limestone identification and location. The Greenhorn crops out in the Cebolla area in three widely separated places: in the saddle between the north flank of Penasco Amarillo and the prominent Dakota hogback along the Rio Brazos, where a dense forest cover coupled with landslide debris reduces the exposure; along El Rito Creek, where the outcrop is likewise poor because of alluvial deposits and mass-wasting; and in Cano Canyon in the southeastern part of the area, where the best outcrop exposes about 20 feet of fossiliferous shaly limestone.

The lower and upper contacts of the Greenhorn, with the Graneros and Carlile, respectively, are conformable, but detailed study of the contacts is not feasible because of the poor outcrops. The gradational contacts make exact determination of the limits of the formation difficult. Dane (1960) suggested the possible use of characteristic underlying and overlying bentonite beds.

The age of the Greenhorn Limestone is based on the abundant fossil, *Incoceramus labiatus* Reeside (1924) correlated this fossil with the lower part of the Turonian Stage in Europe and with the lower part of the Coloradan Stage of the Western Interior and Rocky Mountain Region.

Carlile Formation

G. K. Gilbert defined the Carlile Formation of the Mancos Group. His formation is predominantly shale and well exposed at Carlile Springs, 21 miles west of Pueblo, Colorado. Before Gilbert named the Carlile, workers in north-central New Mexico had used the expanded Fort Benton subgroup of Cretaceous No. 2, which Meek proposed for the Cretaceous rocks outcropping along the Missouri River (Stevenson). Some geologists treat the Carlile in the Cebolla region as a member of the Mancos Formation.

Only the basal half of the Carlile Formation is well enough exposed to permit extensive study; the upper part is poorly exposed because the younger Mancos shale is involved in slump and earthflow mass-wasting and has partly covered and masked the upper Carlile. The thickness of the Carlile varies considerably.

Dane (1960) interpreted it as 805 feet in the Perfecto Esquibel No. 1 well. Yet, north, south, and west of this well, the estimate of thickness ranges from 400 to 600 feet. Dane (1948) believed the great variance resulted from differences in original deposition, not truncation. The Carlile is about 500 feet thick in its best exposure in the Cebolla area along Cano Canyon, where the underlying Greenhorn Limestone and about 240 feet of the Carlile Formation are exposed.

A three-part lithologic division of the Carlile is recognized in this region. The lower member is a medium gray to black, platy, fissile shale, lithologically and texturally like the Graneros. The basal shale of the Carlile and the Graneros shale could not be distinguished from each other if the intervening Greenhorn Limestone were missing. Thin beds of bentonite lie near the base of the formation.

About 125 feet above the base of the Carlile and extending upward for another 100 feet is the middle unit, probably referable to the Juana Lopez Sandstone Member, a good mappable unit farther to the west, but it lacks good definition in the Cebolla area. The middle unit consists of zones of septarian concretions in the first 40 feet, above which are brown to black shale, grayish-orange thin beds of slabby limestone, and fine-grained, very pale orange sandstone. These highly fossiliferous beds contain the best defined biostratigraphic zone in the Cebolla area. The oblate concretions, averaging about a foot in diameter and grayish-yellow with pale brown septa, constitute a distinctive marker bed in the Carlile of northern New Mexico. Lee (1912) described the concretion (septaria) zone in the Rio Puerco field and listed other papers that recognized the same distinctive zone. In a measured section at Pagosa Springs, Colorado, Rankin (1944) described its association with the Juana Lopez Sandstone Member of the Carlile Formation.

The poorly exposed upper member of the Carlile Formation, about 250 feet thick, consists of light brown to yellowish gray fissile shale.

The best exposures of the Carlile occur along Cano Canyon. Other good outcrops are southeast and south of the prominent mesa-top syncline that delineates the axis of the Chama syncline just south of Tierra Amarilla, to the west and east of U.S. 84, northeast near the junction of Chavez Creek and the Rio Brazos, and along the southern edge of the Cebolla quadrangle north of the junction of the Canada Fuertes and Rito de Canjilon. In these outcrops, the Carlile appears as small valleys and low rounded hills that consist of the highly fossiliferous, brownish-weathering shale, grayish orange limestone, and fine-grained sandstone of the Juana Lopez Member. The valleys are cut mainly in the medium gray, platy, fissile shale of the lower member.

The conformable lower contact of the Carlile Formation is the distinctive top of the Greenhorn Limestone. The less distinct upper contact is a matter subject to a great number of opinions. In the Cebolla area, it has been placed at the first occurrence of a thin layer, averaging less than an inch thick, consisting of ***Ostrea congesta*** shells tightly packed and cemented to large ***Inoceramus*** prisms. Where there are several such layers, as in the eastern part of the San Juan Basin, other workers have placed the top of the Carlile at the base of the lowest layer. Although the layer or assemblages of layers are thin they are persistent and easy to recognize. Associated with this marker bed are two more subtle changes. The brown-black sandy shale of the upper member of the Carlile grades into the overlying ash-gray, very calcareous shale of the Niobrara equivalent. There is also a biostratigraphic change from the Benton fauna to the Niobrara fauna, characterized by ***Ostrea congesta.*** This biostratigraphic break occurs approximately 100 feet above the Juana Lopez Sandstone Member.

The sparingly fossiliferous lower and upper members of the Carlile in the Cebolla area yield a characteristic Benton fauna. The abundantly fossiliferous middle member is the most distinctive biostratigraphic unit in the Cebolla area. In the Cano Canyon and Chavez Creek areas, it has yielded ***Gryphaea*** cf. ***G. newberryi*** Stanton, ***Inoceramus dimidius*** White, ***Ostrea lugubris*** Conrad, ***Prionocyclus wyomingensis*** Meek, ***Scaphites warren!*** Meek and Hayden, ***Ptychodus*** sp., ***Crassatellites*** sp., ***Col/ignoniceras wool/gari*** (Mantell), ***Scipo-noceras gracilis*** (Shumard), and numerous fish scales. This fauna is correlative with Reeside's (1924) third zone, Carlile fauna, in the Mancos of western Colorado and adjacent areas. The ***Scaphites warreni*** zone is one of the best defined and most fossiliferous in the Mancos of north New Mexico; it includes several of Cobban's (1951) seven faunal zones in the Carlile. Reeside (1925) indicated that the age of the ***Scaphites warren!*** biostratigraphic zone is upper Turonian. These characteristic, middle Carlile fossils, especially the most abundant ***Scaphites warren!*** and ***Prionocyclus wyomingensis,*** are in the browntogray, platy, concretionary, arenaceous limestone that is probably the Juana Lopez Member in the Cebolla area. This biostratigraphic unit is recognized by Katich (1956), Repenning and Page (1956), Dane and Bachman (1957), Young (1960), and others in different parts of the Colorado Plateau region.

Upper Shales

The upper 1000 to 1100 feet of the Mancos Group do not lend themselves to subdivision into formational units, partly because of extensive landsliding and forest cover. This unnamed unit consists of calcareous, arenaceous, soft, platy, fissile shale containing sandstone and limestone interbeds and highly fossiliferous limestone concretions. On the basis of gross over-all lithic difference, one can subdivide this predominantly shale unit into two vague members, here called the upper member and the lower member; their contact is gradational.

The base of the upper shale is placed at the lowest occurrence of the zone of ***Ostrea congesta.*** With the occurrence of this persistent zone, there is a change from the light brown, somewhat arenaceous, shale of the Carlile to the gray calcareous shale of the lower member of the upper shale. Although calcareous in the lower part, the shale grades upward into sandy shale that closely resembles the shale of the upper member. Dane (1960) stated that the contact between the upper and lower members is vague and that the two members can be identified only by the change in over-all lithic characteristics.

The upper member is the best exposed unit of the Mancos in the Cebolla area. Its stratigraphic position below the capping Mesaverde sandstone affords it protection from excessive cover by surficial deposits. Sections were sampled of this interval near El Vado Dam, Penasco B. M. 8148, Salazar Road, and several smaller sections along Rito de Tierra Amar ill a.

Near the base of the upper member, about 600 feet below the Mesaverde, the shale is dark gray, carboniferous, and slightly calcareous, with paper-thin laminae. It weathers light gray and much of it is limonite-stained. In the float at the base of this upper member are many scattered ***lnoceramus*** prisms. Between 400 and 250 feet below the Mesaverde contact, many chunks and crystals of gypsum are scattered on the surface and occur in numerous fractures in the shale. Also near the base of the upper member in the dark gray shale are zones of yellowish-orange to gray, arenaceous, concretionary limestone. The concretions contain vein calcite filling and their diameters range from less than 1 foot to 3 feet. Many are richly fossiliferous, containing mainly ***lnoceramus*** and ***Baculites.*** The number of individuals of ***Baculites*** in some concretions is almost great enough to constitute a coquina; some writers have called this "the cephalopod concretion zone." A thinsection (34A-S3-10) of the limestone of one of these concretions, S4 in the Salazar Road section, revealed it to be a chert- and feldspar-bearing biointramicrite.

Toward the Mesaverde contact, the shale becomes more sandy, and in the upper 200 feet, there is an alternation of gray marine, sandy shale and grayish-yellow, fine-grained, littoral marine sandstone. Many of the sandstone beds have a salt-and-pepper mottled appearance that results from the increasing carbonaceous content. A thinsection of bed S16 of the Salazar Road section about 30 feet below the contact with the Mesaverde, shows a very fine-grained immature, feldspathic subgraywacke. At several places, there is a thin zone of predominantly molluscan, nearshore fossils in several sandstone beds from 25 to 100 feet below the base of the Mesaverde. Arenaceous foraminifers, locally abundant, are present in a zone 100 to 400 feet below the Mesaverde contact; calcareous foraminifers, however, are scarce. The upper contact of the upper shale is placed at the base of the first massive sandstone of the Mesaverde; this contact is gradational and conformable.

The Mancos Group crops out over much of the western two thirds of the map area, occupying most of the watershed of the Rito de Canjilon,Rio Cebolla, Rio Nutrias, and Rito de Tierra Amarilla. The upper shale underlies most of this area.

The upper shale weathers rapidly; deep erosional gullies are especially common in the valley of the Rio Nutrias. In the southwestern corner of the area and along the southern flank of the Mancos ridge, which separates the Rito de Tierra Amarilla valley from the Rio Nutrias valley weathering has produced badlands with rounded hills of yellowish-gray weathered shale and gullies of dark shale. The upper part of this resistant Mancos ridge weathers light yellow-brown, while the lower part remains gray to black. The same weathering characteristics are seen in other hills of the upper shale. These hills are more resistant to weathering and are more yellowish-brown, mainly because they contain more arenaceous beds than the underlying part of the formation. The uppermost part of the upper member is resistant; its fairly massive sandstone beds form small cliffs. The thin limestone and concretionary layers also form lesser ridges and ledges.

Where capped by the Mesaverde, the upper member is well exposed, but its slopes are covered with weathered rock waste. In the greater part of the area underlain by the upper shale, the original attitude has been obscured by numerous slump and earth-flow movements. Several of the areas involved in mass-wasting cover more than 2 square miles each, with typical hummocky topography. The lower member, because it is stratigraphically farther removed from the protective Mesaverde cap, has fewer good outcrops and is less accessible for study.

The upper contact of the upper shale with the topographically prominent Mesaverde Group is well exposed in most of the Cebolla area. Massive cliffs of the Point Lookout Formation grade downward into the sandy shale and the thin to fairly thick beds of massive sandstone in the top of the upper member of the upper shale. This contact between the Mancos and the Mesaverde is placed at the bottom of the lowest, massive, cliff-forming sandstone of the Mesaverde Group. Young (1957), in his work on the Book Cliffs of Colorado and Utah, described the cycles of the upper Mancos and the Star Point Sandstone and the Blackhawk Formation. The cyclothem consists of a basal marine shale followed by a littoral marine sandstone, then a lagoonal deposit, and a coal bed that completes the cycle. The Mesaverde—Mancos contact zone in the Cebolla area displays the same cyclic pattern. Below the massive sandstone at the base of the Mesaverde is an alternation of marine shale and littoral marine sandstone characteristic of both regions. According to Young, this shifting of environmental zones is in response to pulses of basin subsidence. A complete cycle is rare, although all the units of the typical cyclothem are exposed in the Cebolla area.

The upper member of the upper shale contains a fauna correlative with the "Telegraph Creek fauna" and "Eagle fauna" of the Montana stage or lower Campanian stage of the European section. This change in faunas marks one of the best biostratigraphic boundaries in the San Juan Basin. The change from the "Niobrara fauna" to the "Telegraph Creek fauna" also marks the change from the Coloradan to the Montanan stages of the Rocky Mountain area.

The cyclic or gradational sedimentologic change between the upper part of the Mancos and the lower part of the Mesaverde was studied in four measured sections. Three occur along the Rito de Tierra Amarilla; the fourth, a reference section, southwest of El Vado Dam.

In early Campanian time, the second major regression of the Upper Cretaceous sea brought with it into the Cebolla area the sandy marine-to-continental Mesaverde lithotope (fig. 9). The change from the marine shale of the Mancos to the massive Point Lookout Sandstone of the Mesaverde was accompanied by an alternation of marine shale and littoral marine sandstone.

Paleontologic study of the upper member of the upper shale disclosed two ecologically different molluscan zones, the lower a normal marine fauna, the upper a nearshore, littoral marine-brackish molluscan fauna. Pollen, spores, and plant fragments increase as the Mesaverde boundary is approached. A predominantly arenaceous suite of coiled and elongate foraminifera extends from the normal marine fauna in the upper member to within 25 to 100 feet below the near shore zone.

In a zone approximately 200 to 500 feet below the base of the Mesaverde is a normal marine molluscan fauna. It is quite sparse in kind but not in quantity. The age of the most characteristic species, *Baculites ovatus haresi* Reeside, *Inoceramus barabini* Morton, and *Inoceramus sagensis* Owen is Montanan. They occur sparingly in the fissile, dark-gray shale at the base of the upper member. These fossils, however, are spectacularly abundant in some of the zones of sandy, pale brown, limestone concretions, 2 to 3 feet in diameter and common in the basal shale, that weather yellowish-orange; they are so filled with *Baculites* that authors have called the beds containing the concretions "the Cephalopod zone." Many of the limestone concretions are severely fractured and filled with vein calcite. The center of some *Baculites* individuals are geodes filled or partly filled with well- developed scalenohedral calcite crystals. The fossils in some of the concretions are crushed and distorted; in others, they are normal.

These concretionary zones and other thin lenticular and nodular calcareous zones at the base of the upper member are sandy limestones, whereas the upper part of this member comprises calcareous sandstone. The accompanying shale also becomes progressively more sandy nearer the Mesaverde contact. With the increase in sand goes an increase in carbonaceous content; the profusion of normal marine macrofossils decreases until there are none at all.

The number of pollen and spores recovered from the upper member of the upper shale in the Cebolla area was disappointing, and no zonation similar to that by Sarmiento (1957) in the Book Cliffs was made. Foraminifers are fairly abundant from the base of the upper member to within 100 to 200 feet of the Mesaverde contact. Their distribution throughout this zone is spotty; in some units, they are relatively abundant, in others scarce, and in still others absent. About 80 per cent of all the foraminifers recovered are arenaceous forms. All the genera are placed into two broad categories, elongate and coiled. The elongate category includes uniserial and biserial types as well as those that coil in the youthful stage and uncoil in the adult stage. The most characteristic elongate genera are *Bigenerina, Spiroplectammina,* and *Ammobaculoides.* The coiled forms are *mainly Haplophragmo ides* and *Trochamminoides.* Because of the scarcity of any type, zonation is not practicable on a specific or generic level, but the two categories, elongate and coiled, show a definite trend. At the base of the upper member, both coiled and elongate forms are present. In the more sandy beds higher in the section, the elongate forms are more abundant. As the gradational Mesaverde boundary is approached, there is a reduction of coiled types and an increase in elongate forms. This trend has not been checked in enough areas to see whether useful zones can be established on this basis.

Particularly well displayed in the upper 200 feet of the Mancos is a cyclic sequence of alternating sandy marine shale and littoral marine sandstone, which reflects recurrent movement in the basin. Several of the layers of littoral marine sandstone yield a predominantly molluscan, shallow, neritic, nearshore fauna in several outcrop areas. Beds of yellowish-brown to buff, very fine grained sandstone are equivalent to the "Transitional" and "Marine" environment of Weimer. The environment of the littoral sandstone was intermediate between the marine environment, with its deeper neritic and shallower neritic (offshore marine) subenvironments, and the nonmarine swamp and lagoon environment. These fossiliferous beds are also equivalent to unit 2 of the typical Mancos cyclothem described by Young (1957): "Unit 4. Coal, Unit 3 Lagoonal, Unit 2. Littoral marine, Unit 1. Marine shale." The nearshore marine sandstone beds grade upward into a nonmarine lagoonal deposit. To the southwest, the source of the sediment of this continental transgression, the nearshore marine sandstone, probably also grades into the landward lagoonal unit. The cephalopod-concretion zone that lies stratigraphically several hundred feet below the zone of nearshore marine sandstone was deposited in the shallower neritic (offshore marine) part of the marine environment.

The near shore fossiliferous, very fine-grained, moderate yellowish brown to light olive-gray sandstones are petrographically immature, feldspathic, sub-graywackes characteristic of this environment. Inclusions of carbonaceous material and clay pebbles are common. The limonite-stained fossiliferous beds are generally several feet thick. In the more massive outcrops, however, the fossils occupy only a thin zone. Cone-in-cone structure is associated with some of the fossiliferous beds.

In an outcrop 1.25 miles west of the junction of Rito de Agua Fria and the Rito de Tierra Amarilla, the molluscan shells are so abundant and so closely packed that they form a quasicoquina. It appears that this particular accumulation represents a partly drifted, rather than an indigenous-habitat, assemblage. Here together are the fresh-water pelecypod *Unio;* the brackish-water forms *Ostrea, Goniabasis,* and *Pyrgulifera;* and the shallow-marine, neritic, nearshore forms *Tellina, Turbonilla, Cyprimeria, Cardium, Margarites, Cymbophora* and *Lunatia.*

In the Salazar Road section, the Penasco section, and the El Vado section, the density of fossil forms is considerably less and the mixing of elements from these three environments is not so marked. In those three sections, the nearshore sand- dwelling *Cardium, Cymbophora,* and *Lunatia* are most conspicuous. These are normal marine forms. In all sections, fish scales, fish vertebrae, and shark teeth are numerous. Locally, oysters are abundant, particularly in the Rito de Agua Fria section, where perhaps this occurrence may mark fresh water intrusion into the shallow neritic environment, which could account for the mixing of the marine-, brackish-, and fresh-water forms. The only representative from the offshore marine environment found in this horizon is *Scaphites* cf. *S. hippocrepis,* a form characteristic of the "Eagle fauna" that places this near-shore fauna in the lower part of the Campanian Stage (Reeside, 1924). The arenaceous foraminifers present in much of the upper member of the upper shale of the Mancos Group are not associated with the nearshore molluscan fauna.

Meek (1876), White (1883), and Stanton and Hatcher (1905) have studied the transitional marine and nonmarine invertebrate faunas of the late Cretaceous Judith River beds of Montana, which are younger than the forms in the Cebolla area. Yen (1954) described the nonmarine fauna of the Cenomanian Bear River Formation of Montana; it and the fauna of the Cebolla area show many similar features.

MESAVERDE GROUP

Point Lookout Sandstone

In the Cebolla area, three formations of the type locality, Point Lookout Sandstone, Menefee Formation, and Cliff House Sandstone, are recognized. The Mesaverde Group forms cliffs in the Cebolla area. In the less densely vegetated western half of the map area, the Mesaverde outcrop is more prominent than that of other cliff-forming units in more vegetated areas. The basal Point Lookout Sandstone is the most conspicuous of the three formations. This unit averages 70 feet in thickness and consists of fine-grained, massive- bedded sandstone. It appears as steep cliffs overhanging the weaker, underlying, Mancos Shale. Its best outcrop is 3.5 miles south of Tierra Amarilla, where it and the Menefee Formation cap part of the west limb of the Chama syncline. Here, the Point Lookout Sandstone overlies approximately 400 feet of exposed upper shale of the Mancos. The cliffs of the Point Lookout are visible for many miles. Here, also, the axis and both flanks of the Chama syncline are delineated by the capping Mesaverde Group, particularly by the Point Lookout Sandstone and the Menefee Formation. The Mesaverde Group also rings the mountain Penasco Amarillo, east of Tierra Amarilla, where the outcrop is partly covered by the younger Lewis, El Rito, and Ritito Formations, as well as by a thick forest. The Mesaverde, however, is well exposed along the southwest flank of this mountain north of the Rito de Tierra Amarilla, where the carbonaceous shale, sandstone, and coal beds of the Menefee Formation are best displayed. Coal is mined from the Menefee Formation in this area. Along the southwest flank of Penasco Amarillo is the only outcrop of the thin-bedded, poorly exposed Cliff House Sandstone.

A much smaller outcrop of the Point Lookout Sandstone and the Menefee Formation, just south of Canjilon Mountain in the south central part of the Cebolla quadrangle, for the most part underlies the eastward-dipping El Rito Conglomerate and Ritito Formation, which cap Canjilon Mountain.

The Point Lookout consists of a massive, very fine- to medium-grained, light olive-gray, gray, and buff, friable sandstone. The lower half is light olive-gray in almost all outcrop areas; it grades upward into gray and yellowish-brown sandstone. The light olive sandstone is friable and displays a characteristically pitted, vuggy, weathered surface in most outcrop areas. In several of the outcrops, a thin, resistant ledge of orange, limonite-stained sandstone occurs at approximately the level of transition from the olive to gray or buff sandstone.

Thinsections from the Point Lookout Sandstone in the Salazar Road section show a fine-grained, immature to submature, cherty, feldspathic, subgray-wacke, or, according to Williams, Turner, and Gilbert (1958), a subfeldspathic lithic arenite. A thinsection (35D-134A) of the Point Lookout Sandstone from the outcrop west of Canjilon Lakes shows a medium-grained, limonitic, immature, feldspathic subgraywacke. Thus, lithologically, the Point Lookout Sandstone differs considerably from the sandstone of the Dakota, which is composed predominantly of coarser- grained orthoquartzite.

In the upper part of the Point Lookout Sandstone, especially in the outcrop area west of Canjilon Lakes and along the north flank of Penasco Amarillo, abundant limonite-stained, musketball concretions occur. More resistant than the enclosing yellowish-brown to pale orange sandstone, these concretions weather out locally littering the surface. Most are spherical or sub spherical, but some odd-shaped forms result from the fusion of one or more of the more or less normal forms. The upper surface of the Point Lookout on the west limb of the Chama syncline displays well-developed mudcracks and west-striking symmetrical ripple marks. Also in the upper part of the Point Lookout are well-developed, northeast-dipping cross beds.

The contact of the Point Lookout Sandstone and the upper shale of the Mancos is gradational, so much so that the base of the Point Lookout is arbitrarily defined as the base of the lower massive bed of sandstone The basal Point Lookout Sandstone is light olive-gray. It has the same composition and color as the thinner sandstone beds in the upper shale. The change from the Point Lookout Sandstone to the basal shale of the Menefee Formation is abrupt and easily defined.

Menefee Formation

Just as the Point Lookout Sandstone thins into the Cebolla area from the west and south, so does the Menefee Formation. Dane (1948) described the middle Mesaverde (his Gibson coal) in the eastern part of the San Juan Basin southwest of the Cebolla area as 250 feet thick, thinning to 80 to 130 feet near Monero, about 22 miles northwest of Tierra Amarilla. The middle Mesaverde Menfee Formation in the Cebolla area, between 20 and 60 feet thick also demonstrates thinning in this direction.

The Menefee is a heterogeneous formation consisting of a mixture of coal; carbonaceous gray, black, and purple siltstone; shale; claystone; and fine- to medium-grained, thin- to massive-bedded, friable, white-to-gray corss-bedded leaf-bearing, fucoid-bearing (?) sandstone. The Menefee represents the non-marine lagoonal and coal units of the typical Upper Cretaceous cyclothem of Young(1957).

In several areas of the Cebolla quadrangle, two coal beds are separated by a massive, pale orange, fine-grained sandstone that, in the Penasco section is 14 feet thick. At two places in the quadrangle, coal has been mined from the lower of the two beds; the upper bed is too thin and contains too many shale partings to warrant mining. Subbituminous to bituminous, coal in the lower bed has an aggregate thickness of 5.5 feet in the Penasco area and about the same thickness at the Dandee mine, 3.7 miles southeast of Tierra Amarilla. Several thin shale partings occur in this lower bed of coal.

The upper coal bed, P55, in the Penasco section ranges in thickness from 6 inches to slightly more than 1 foot and is split in places by wedgelike shale partings. Both the lower and upper coal beds contain abundant droplets of resin on the surface and a high percentage of sulfur. The coal exhibits the characteristic bituminous blocky fracture. The shale immediately above and below the coal seams contains abundant plant fragments. More than a third of the total Menefee Formation consists of white to gray, cross-bedded sandstone. Besides the massive sandstone that separates the two coal beds, the formation contains several layers of sandstone 1 to 4 feet thick. At the base of unit T13 of the Tierra Amarilla Creek section, the surface of the sandstone immediately above the coal is covered with tubular, branching sand casts 1 to 2 inches wide and up to several feet long that resemble what Lesquereux (in Hayden, 1878) described as *Halymenites striatus*

Petrographic analysis of one of the thin sandstone beds in the Menefee, S32 of the Salazar Road section shows a tightly packed, fine grained, submature, mud pellet, feldspathic subgraywacke containing a small amount of ilmenite and leucoxene cement. These sandstone beds form resistant ridges that are especially prominent because of the weaker overlying and underlying shale and coal. The argillaceous beds of the Menefee consist of olive-gray siltstone, brownish-black shale, and olive-gray claystone. All contain abundant carbonaceous material and plant impressions.

The contacts between the coal beds and the overlying and underlying shale and claystone are gradational. Some of the shale contains stringers of coaly material and becomes more carbonaceous near the coal bed In the Menefee Formation, there is usually an abrupt contact between an underlying shale or claystone and overlying sandstone, but the contact between the sandstone and an overlying shale or claystone is gradational.

Cliff House Sandstone

The uppermost formation of the Mesaverde Group, the Cliff House Sandstone, is usually thin or absent in the Cebolla area. It reaches a maximum thickness of about 30 feet in the vicinity of the Dandee mine. A very fine-grained, pale orange, thin-bedded sandstone, it contains numerous worm burrows. Its thin beds and debris from the overlying Lewis Shale help to obscure it and make determination of its actual thickness difficult. It has an abundance of limonite cement.

The transition from Menefee to basal Cliff House Sandstone is abrupt. The upper contact of the Cliff House Sandstone and the overlying Lewis Shale is gradational, much like the contact of the Point Lookout Sandstone and the upper shale of the Mancos. The Cliff House—Lewis contact is arbitrarily placed at the top of the last massive sandstone bed.

LEWIS SHALE

The Lewis Shale in the Cebolla area ranges to approximately 1500 feet in thickness. Predominantly a dark-gray to light olive-gray calcareous shale, its basal part contains thin beds of sandstone lithologically similar to the underlying Cliff House Sandstone of the Mesaverde Group. Between 50 and 100 feet above the base of the Lewis are a number of very pale orange, septarian-limestone concretions from 1 to 5 feet in diameter. The average concretion, about 3 feet in diameter, has some septa fillings as much as 1 inch thick on the outside surface; the fillings have many large crystals.

The Lewis Shale makes up most of the upper part of Penasco Amarillo Mountain east of Tierra Amarilla; only the peak is capped by younger formations. This is the best outcrop of the Lewis in the quadrangle. Another outcrop between Red Hill and Canjilon Mountain is covered by mass-wasting. Because of its extreme fissility, the Lewis Shale is incompetent, and like the Mancos, it is involved in the slump and earth-flow mass-wasting found abundantly in the western half of the map area. This mass-wasting of the Lewis Shale has masked much of the outcrop of the underlying Mesaverde Group; it makes determination of attitude impossible, or at best questionable in many places. Because of inadequate knowledge of dip and strike, the maximum thickness of the Lewis is only approximated.

Above the massive sandstone beds in the basal Lewis are thinner sandy beds that become progressively thinner upward and disappear before the lower concretion zone is reached. In the Cebolla area, the Pictured CliffsSandstone, which elsewhere overlies the Lewis, has been removed by post-Lewis erosion At Penasco Amarillo, the Lewis is overlain with angular unconformity by the Cenozoic El Rito Conglomerate. The same relationship exists at Canjilon Mountain.

Fossils appear at several levels in the Lewis Shale but are more abundant in the shale of the concretion zone. Some of the large septarian concretions contain a few fossils. The two main forms of the Lewis fauna in the Cebolla area are *lnoceramus barabini* and *Baculites ovatus* Reeside (1924) stated that the fauna in a general way is equivalent to part of the middle and upper "Pierre fauna" of the Montanan Stage

EL RITO FORMATION

El Rito Formation is the basal unit of the Cenozoic sequence that characteristically occurs in the San Juan Mountain physiographic province part of the

Cebolla quadrangle. This formation crops out nearly continuously from Cano Canyon past Canjilon Mountain to a Quaternary cinder cone about midway between Cano Canyon and the Brazos Box (figs. 2 and 10). Along this escarpment, El Rito Formation is firmly cemented and is characterized by cliffs up to 100 feet high. Where it is less well-cemented, the cliffs are not so pronounced. The western edge of the outcropping El Rito Formation forms part of the cap of Penasco Amarillo Mountain and exhibits nearly vertical cliffs 65 to 85 feet high (fig. 11). On the north-side of Penasco Amarillo, differential erosion in the more poorly consolidated parts of the formation has produced picturesque pinnacles with caps of larger boulders and cobbles.

El Rito Creek has cut through the overlying Ritito Formation to expose El Rito and older formations in the southeastern part of the Cebolla quadrangle. From the tributary canyons of Hachita and Canada de Chacon, El Rito Formation crops out intermittently along El Rito Creek north for about three miles to where the overlying Ritito Formation has not yet been breached. Another good outcrop of El Rito Formation lies along a logging road in Canada Escondida along the eastern edge of the Cebolla quadrangle. El Rito Formation also crops out along the fault zone in the northeastern corner of the Cebolla quadrangle, where the outcrop pattern is discontinuous, being interrupted by major and minor faults. In the vicinity of Peterson's Cow Camp, an 85-foot section is exposed. El Rito Formation also caps part of the Brazos Cliffs on the north and south sides of the Rio Brazos in the Brazos Box area.

In the southern part of the Cebolla quadrangle from the headwaters of the Rio Nutrias southward, El Rito Formation consists of a loosely consolidated to well-indurated quartzite-bearing conglomerate. It resembles the type El Rito in its over-all aspect but differs in respect to color and cementation. The well-rounded to subrounded conglomerate is made up almost completely of gray and pink cobble-sized quartzite fragments held together by clay and silt-sized quartz cement.

The characteristic red of El Rito Formation in the type locality changes southeastward and northwestward to a duller shade of red; in the Cebolla area, the color ranges from pale orange to pink to red. According to Smith (1938), this color comes from weathering under tropical conditions. Budding, Pitrat, and Smith (1960) suggest that the source of the red silt and clay matrix is the underlying Triassic and Permian redbeds. Further evidence supporting this idea is found in the Cebolla area. Wherever El Rito Formation crops out near older redbeds—such as the outcrops along the Brazos Box, El Rito has a red matrix. Where El Rito overlies the Cretaceous, the formation bears a yellowish tint characteristic of the sand in the Upper Cretaceous. Along the Canjilon escarpment, the formation ranges in thickness from 0 to 75 feet and has a yellowish matrix.

Figure 10

VIEW NORTH ALONG THE CANJILON ESCARPMENT TOWARD THE QUATERNARY CINDER CONE NEAR THE HEADWATERS OF THE RIO NUTRIAS

Figure 11

NORTH VIEW OF THE CLIFFS PRODUCED BY EL RITO FORMATION NEAR THE TOP OF PENASCO AMARILLA MOUNTAIN

Exposures of El Rito along the upthrown side of the northwest-striking fault in T. 29 N., R. 6 E. present a different picture. Along this trend, the formation is a well-cemented breccia composed of pebbles, granules, and cobbles of Precambrian quartzite, schist, gneiss, and metarhyolite. The inclusion of these other metamorphic-rock fragments and the angularity of the fragments serve to set this outcrop apart from the others. Outcrops of Precambrian metamorphic rocks of this type in the vicinity of this facies of El Rito probably served as a local source. The angularity of some of the more easily weathered metamorphic-rock fragments seems to indicate a nearby source and rapid deposition.

Between El Rito Formation and the underlying rocks, which range in age from Precambrian to Late Cretaceous, is a profound, angular unconformity. El Rito Formation like the younger Cenozoic formations, has a general northeasterly dip of 3 to 6 degrees. The underlying Mancos and Mesaverde groups in the vicinity of Canjilon Mountain dip to the west, although the exact relationship of this angular unconformity is obscured by landslides in which the incompetent shale of the Mancos has given away, carrying with it large blocks of El Rito. In the northeastern outcrop area along the fault zone and in the vicinity of the Brazos Box, El Rito nonconformably overlies Precambrian quartzite and metavolcanic rock.

The Ritito Formation disconformably overlies El Rito Formation in all outcrop areas. It has a regional northeasterly dip of 3 to 6 degrees. Only where erosion has removed the overlying Ritito is El Rito exposed. The contact between these two formations topographically is sharp. El Rito produces prominent cliffs, whereas the Ritito, which is poorly indurated, produces gentle slopes (fig. 11).

El Rito Formation of Smith (1938) is extended into the Cebolla quadrangle to include the basal Cenozoic conglomeratic formation. The two primary reasons for this are reconaissance correlation with the type locality and lithologic similarity. El Rito Formation in the type locality is typically brick red, but in the majority of outcrops in the Cebolla area, it is gray yellowish-orange, and pale pink.

On the undulating surface created by pre-El Rito erosion, the conglomerate is believed to have accumulated as alluvial fan deposits. The undulating pre-El Rito erosion surface is demonstrated by the variance in thickness of this formation from 0 to 200 feet in the Cebolla area. The roundness of the Precambrian quartzite boulders, pebbles, and cobbles seems to indicate several periods of reworking. The Precambrian formations cropping out in the Cebolla and adjacent areas contain rocks similar to that found in El Rito Formation and may have served as local source areas.

The angularity of fragments in areas like the northeast corner, the inclusion of some material that weathers rapidly, the textural immaturity of the finer grained deposits, and the matrix material all indicate a nearby source. All these factors plus the varied composition seem to indicate local multiple source areas. Smith (1938) believed that the breccia represents indurated regolith and talus and the conglomeratic part a torrential stream deposit. Figure 12 demonstrates the relationships and correlations of the Cenozoic units in the Cebolla area with the Cenozoic units in areas north, east, and south. Mapping by Muehlberger (1960) in the Brazos Peak quadrangle north of the Cebolla quadrangle has demonstrated an interfingering relationship of the Blanco Basin Formation with El Rito Formation. At least part of the Ritito Formation described by Barker is laterally continuous with El Rito Formation. In the Canada Escondida, the conglomerate outcrop displays all the characteristics of El Rito Formation; this outcrop extends into the Las Tablas quadrangle.

No fossils have been recovered from the El Rito Formation. Working with the also unfossiliferous Blanco Basin Formation in southern Colorado, Larsen and Cross (1956) have assigned it to the Oligocene (?) on the basis of the age of overlying formations. Subsequent work by Van Houten (1957) has led him to consider the Telluride Conglomerate and Blanco Basin Formation as upper Paleocene and lower Eocene. Petrographic comparison between the Blanco Basin and the "Wasatch" of the eastern San Juan Basin has led Muehlberger to believe that these formations are possible correlatives (1960).

RITITO FORMATION

The major outcrops of the Ritito Formation lie in the southeastern quarter of the Cebolla area, where they form the cap of the north-trending escarpment that divides El Rito and Vallecitos drainage basins from the Rio Nutrias, Rito de Tierra Amarilla, and Rito de Canjilon drainage basins (fig. 2). The formation forms a dip slope cover from the western edge of the escarpment to the eastern border of the Cebolla area. El Rito Creek makes the only notable breach in this dip slope. An erosional remnant of the escarpment caps Penasco Amarillo Mountain. The Ritito Formation also crops out along the upthrown side of the Vallecitos fault zone and along the Brazos fault in the northeastern part of the area.

The gentle slope of the unconsolidated or poorly consolidated Ritito in contrast to the cliffs of the El Rito allows one to easily distinguish the contact between these formations in the field. The Ritito Formation dips 3° to 6° northeastward. This is essentially the same dip as the overlying and underlying beds of the other Cenozoic formations.

The Ritito in its type area consists of pebbles and boulders of quartzite, metarhyolite, and minor amphibolite in a usually weakly cemented matrix of

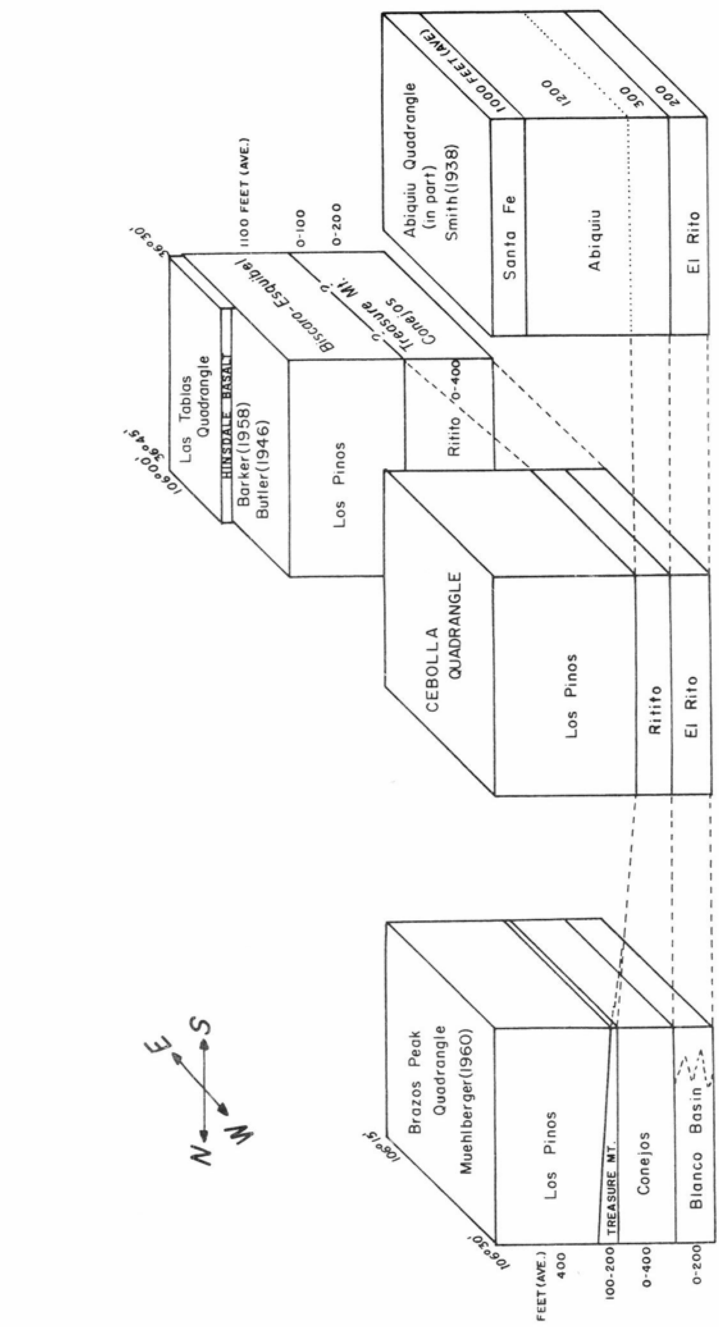


Figure 12

Schematic diagram showing the relationship of the Cenozoic formations in the Cebolla quadrangle with adjacent areas quartz grains. The pebbles and boulders in the conglomerate are rounded to subrounded, as are the grains of the matrix. The greatest thickenss in Las Tablas quadrangle reported by Barker is 400 feet on the east side of Ritito Creek and in Canada Escondida.

The Ritito Formation crops out near the northern edge of the Cebolla quadrangle and extends south into the Abiquiu quadrangle. It is a poorly indurated to unconsolidated conglomerate. About 90 per cent of the sand-to boulder-sized, subangular to rounded fragments is milky, banded, purplish quartzite. The matrix is white sand and yellowish-brown tuff. Most of the fragments are pebble-sized. The pebbles appear to have derived from source areas within or near the Cebolla quadrangle, perhaps from Tusas, Kiawa, and Brazos Precambrian ridges. The Ritito in the Cebolla quadrangle reaches a maximum thickness of 400 feet in the vicinity of Canjilon Mountain. Elsewhere, it has been reduced by erosion.

In the northeast quarter of the Cebolla quadrangle, the Ritito is disconformably overlain by Los Pinos Formation. The Treasure Mountain Formation, which overlies the Conejos Quartz Latite and separates it from Los Pinos Formation in the area north of the Cebolla quadrangle, is represented by a single small outcrop of welded rhyolite along the Canjilon escarpment southeast of Trout Lakes. The position of the Treasure Mountain Formation overlying the Ritito gives strength to the conclusion that the Ritito and the Conejos are correlative and facies of each other.

North of the Cebolla quadrangle, the contact between the Conejos and Los Pinos Formations would be difficult or impossible to place were it not for the distinctive intervening Treasure Mountain Formation. In this area, Los Pinos and Conejos Formations are conglomerates of volcanic fragments imbedded in a tuffaceous matrix. The Treasure Mountain Formation is absent over most of the Cebolla area, but the Ritito Formation in the area, mainly a conglomerate of Precambrian quartzite pebbles, contrasts markedly with the overlying Los Pinos, which is dominantly a volcanic-clast conglomerate. The change in lithology marks the contact between these units in the Cebolla area.

The volcanic-clast conglomerate with a tuffaceous matrix, named the Conejos Quartz Latite at its type locality in Colorado, extends into northern New Mexico about to the northern edge of the Cebolla quadrangle. Just north of the Brazos Box and east of Brazos Peak, the volcanic-clast conglomerate of the Conejos and. Treasure Mountain Formations interfingers with the Precambrian clast conglomerate of the Ritito Formation (Muehlberger, 1960).

The Ritito correlates with the basal part of the Conejos as recognized by Muehlberger (1957) in the Chama area. Muehlberger recognized two formations in the Conejos: a basal formation, a loosely consolidated conglomerate with mainly cobble-sized pebbles of granite and metamorphic rock, and an upper formation, a poorly sorted breccia and agglomerate consisting mainly of quartz latite.

In the Chama valley in the Abiquiu 30 minute quadrangle immediately south of the Cebolla, Smith (1938) reported a poorly stratified, arkosic, Precambrian clast-conglomerate in the basal 300 feet of the Abiquiu Tuff (fig. 12). This conglomerate rests on El Rito Formation and is stratigraphically and lithologically correlative with the Ritito Formation of the Cebolla quadrangle.

TREASURE MOUNTAIN RHYOLITE

The formation in its type locality in Colorado consists of flow rock, welded tuff, rhyolitic tuff, and rhyolitic quartz latite. Tuff makes up more than half of the material. Trice recognized three members in the Treasure Mountain Rhyolite in the Brazos Peak quadrangle, from oldest to youngest, the Toltec andesite member, the Lagunitas clastic member, and the Osier Mountain welded tuff member.

A single isolated outcrop of the Treasure Mountain Rhyolite in the Cebolla quadrangle along the Canjilon escarpment about a mile and three quarters north of Canjilon Mountain forms part of the escarpment cap. This outcrop may well mark the southwesternmost extent of the Treasure Mountain volcanic pile and may be correlative with the upper part of the Lagunitas clastic member and part of the Osier Mountain welded tuff member of Trice.

The Treasure Mountain Rhyolite consists of about 10 feet of shaly tuff and an interbed of welded tuff in the Canjilon escarpment outcrop. Above and below the welded tuff are several feet of pale bedded tuff. The rhyolitic tuffs contain about the same minerals as the welded tuff; they are shaly and thin-bedded and partly altered to bentonite.

The middle interbed of welded tuff, 4 to 5 feet thick, is grayish red-purple, vitreous, and aphanitic and exhibits a flow texture containing parallel-bedded crystals and crystal fragments. Small tabular fragments of black obsidian up to a millimeter long parallel the crystals of feldspar and biotite. Abundant phenocrysts account for about 30 per cent of the volume.

In thinsection, the groundmass of the welded tuff consists of flattened glass shards and dust in which the pore space has been eliminated. These shards, which make up about 70 per cent of the rock, are tightly welded and exhibit fluidal texture. The phenocrysts consist mainly of sanidine, quartz, oligoclase, and biotite. The diameter of the sanidine, quartz, and oligoclase crystals ranges between 1 and 2 mm, whereas that of the euhedral biotite crystals is generally less than 1 mm.

LOS PINOS FORMATION

The youngest Cenozoic unit in the Cebolla quadrangle, Los Pinos Formation, consists of poorly to well-sorted sandstone, poorly to well-cemented conglomerate, tuffaceous graywacke, and local lava. The type locality of Los Pinos Formation is on Los Pinos River in the Tusas—Tres Piedras area (Butler). Butler recognized and named four members of the formation, from oldest to youngest, the Biscara, Esquibel, Jarita Basalt, and Cordito. In the Cebolla quadrangle, only the Jarita Basalt Member was mapped; the bulk of the formation was mapped as Los Pinos undivided.

Los Pinos Formation occupies most of the northeastern quarter of the Cebolla quadrangle. Dipping from 3 to 6 degrees east and northeast, the formation is exposed continuously from the northern part of the Canjilon escarpment to the Vallecitos fault east of Quartzite Ridge. The only breaks in this layer occur where several Precambrian hills project above the general level of Los Pinos surface. East of the Vallecitos fault, the formation is again exposed in the vicinity of Jawbone Mountain in the northeast corner of the quadrangle. There are other outcrops along the southeastern boundary of the area.

The topographic expression of Los Pinos Formation ranges from ledges of firmly consolidated conglomerate through poorly consolidated gravel-strewn slopes to gentle slopes of unconsolidated sand and tuff. The surface of the hills is covered in many places with pebbles and cobbles that have weathered out of the conglomeratic layers. This gravelly appearance was, in part, the reason that Atwood and Mather called the formation *Los Pinos Gravel.* The beds of conglomerate and breccia are not extensive vertically or laterally and do not make up the major part of the formation. The clasts of the conglomerate range from granule through boulder size; the larger ones display better rounding than the smaller; the matrix is sand, mainly tuffaceous graywacke or tuff.

About 95 per cent of the clasts is fragments of volcanic rock, the most common of which are rhyolite, rhyodacite, and andesite. The dominant colors are white, red, blue, gray, and purple. Gray and black basaltic rocks comprise a smaller percentage of the clasts, many of which are porphyritic with phenocrysts up to several centimeters in their long dimension. Some of the clasts, derived from metamorphic rocks, consist of quartzite, schist, phyllite, and gneiss, in order of abundance.

Thinsection analysis of the matrix of two conglomeratic layers in Los Pinos Formation showed them to be graywacke. A thinsection of a poorly consolidated layer with numerous lenses of conglomerate from near the base of the formation (fig. 13) showed a volcanic, pebbly, immature, feldspathic, lithic

Figure 13
OUTCROP OF LOWER LOS PINOS CONGLOMERATE NEAR THE HEADWATERS OF JAROSA CREEK

graywacke containing abundant angular laths of feldspar that make up more than 10 per cent of the rock. Even more abundant are the angular to rounded fragments of volcanic rocks. Smaller composite quartz gains, which contain abundant rutile needles along with biotite and less abundant hornblende, form the matrix.

Another thinsection from an indurated conglomerate stratigraphically above the Jarita Basalt Member from an outcrop about half a mile west of Quartzite Ridge showed a pebbly, immature, calcite-cemented, feldspathic lithic graywacke. Feldspar laths make up more than 10 per cent of the slide. Metamorphic-rock fragments, partly schist and stretched composite quartz grains, are also abundant. Abundant fragments of volcanic rock are rich in small feldspar laths. Chert pebbles are common. All these occur in a matrix of sparry calcite and small quartz and biotite crystals.

Less than half the formation consists of tuff. Some of the tuff is fairly well consolidated and forms steep-walled outcrops, but much more is poorly consolidated and forms low, rounded hills. Most of it studied in thinsection is rhyolitic crystal tuff containing broken crystals of quartz and plagioclase with crystals of biotite in a matrix of quartz and glass fragments. In these gray, buff, and white felsic crystal tuffs, the mineral grains far outnumber the fragmental matrix.

This mixture of siltstone, sandstone, conglomerate, and tuff of fluvial and pyroclastic origins possesses all degress of bedding from no apparent bedding to well-developed thin-bedding and cross-bedding. The outcrops are discontinuous and commonly occur on the undercut bank of streams. The best section is along Jarosa Creek half a mile from the eastern edge of the Cebolla quadrangle where about 50 feet of conglomerate and tuff are exposed. This is probably equivalent to the Cordito Member of Barker and of Butler. The basal 12 feet are conglomeratic with large cobble-sized fragments, whereas the remainder is tuffaceous sandstone with pea-sized gravel.

Los Pinos Formation disconformably overlies the Ritito. The magnitude of the hiatus is probably small. At Quartzite Ridge, it nonconformably overlies part of the Precambrian ridge. Abundant angular clast fragments shed from the ridge into the adjacent upper Los Pinos conglomerate. Throughout most of the northeast quarter of the Cebolla quadrangle, Los Pinos Formation is the youngest one exposed. In areas east and north, Los Pinos is disconformably overlain by Hinsdale basalt and latite. Locally, four small Quaternary cinder cones and their associated lavas disconformably overlie the formation.

Los Pinos Formation thickens southward from Colorado, where its maximum thickness reaches 500 feet (Larsen and Cross, 1956), to more than 2000 feet south of the Cebolla quadrangle in the Magote Peak quadrangle (Budding, Pitrat, and Smith). This heterogeneous formation of fluvial sand and gravel, lava, and pyroclastic ejecta shows better bedding and sorting in New Mexico than in Colorado. The conglomerate and breccia beds are discontinuous and highly lenticular and have a small lateral distribution The beds are more conglomeratic in northern New Mexico than in the Magote Peak quadrangle immediately to the south. Some of the layers of Precambrian clast-breccia are of local origin, whereas most of the pyroclastic material came from slightly more distant sources, perhaps from the Taos Plateau or the San Luis Valley as Butler suggested.

Figure 12 shows the postulated correlation between the Cebolla and adjacent areas. From evidence near Petaca, Butler indicated that part of Los Pinos is older than the Santa Fe Formation. Parts of the Santa Fe have been dated from vertebrate fossil remains as upper Miocene and lower Pliocene, according to Wright (1946). This might indicate a Miocene age for Los Pinos. If at least part of the upper Los Pinos is equivalent to the lower part of the Santa Fe Formation, it would seem to indicate that the Abiquiu Formation of Smith in the quadrangle to the south is contemporaneous with the Ritito Formation and most of Los Pinos Formation of the Cebolla quadrangle. An intraformational rhyolite tuff collected by Bingler west of Petaca yielded a potassium—argon age of 25.9 [±1.8] million years.

Jarita Basalt Member

Several discontinuous flows of olivine basalt appear at about the same stratigraphic level within the undivided Los Pinos. Lithologically and stratigraphically these are similar to Butler's Jarita Basalt Member of Los Pinos Formation, named for outcrops at Mesa de la Jarita east of Vallecitos in Las Tablas quadrangle. Butler further recognized three divisions of the basalt, a northern variety, a central variety, and a southern variety, and further subdivided the northern variety into two kinds: Type A is fine- to very fine-grained, slightly porphyritic, moderately vesicular, with phenocrysts of rusty iddingstite, and amygdules of chalcedony in some layers. Type B is fine-grained and has more abundant phenocrysts of olivine with less alteration, as well as veinlets and amygdules of calcite in some layers.

Both types A and B of the northern variety occur within the Cebolla area. About three and a quarter miles west of the eastern edge of the quadrangle, a logging road to Hooker's sawmill cuts through an outcrop of Jarita Basalt, there formed by four flows, each leaving a layer about 10 feet thick It is overlain and underlain by white tuff. The basal layer is similar to type B of Butler and contains abundant phenocrysts of olivine that have not been extensively altered to iddingsite and amygdules of calcite. The overlying layers correspond to Butler's type A. They are also olivine basalt and moderately vesicular; some of the vesicles contain opalized fillings. In thinsection, the basalt shows numerous plagioclase laths and exhibits intergranular texture with the interstices filled with abundant phenocrysts of olivine extensively altered to red-brown iddingsite.

Other isolated flow remnants occur within Los Pinos between Jarosa Creek and Quartzite Ridge and on both sides of the Kiawa Mountain synclinal axis.

The Jarita Basalt Member, although now discontinuous, probably was more widespread at the time of its formation, and probably some post-Jarita erosion occurred before Los Pino s deposition continued.

BRAZOS BASALT

Brazos Basalt is a new name given to six cinder cones and their associated lava that are best displayed in the canyon of the Rio Brazos and along the tributary streams and highland areas adjacent to the river. This is the youngest formation in the Cebolla quadrangle, with the exception of alluvial material. The lava and the cones may postdate Pleistocene glacial activity. Flows not related to the existing cones and lava have been differentiated.

Generally the cones rise from 190 to 600 feet above their bases and show little erosion, retaining their original symmetrical shape. Near the summits of the cones, the cinders, bombs, ash, and scoriaceous material rest at an angle of about 30 degrees. The sides of the cones and their craters support scattered stands of pine trees and sparse grass. The cones and flows are designated Qb_1 through Qb_6 for the purpose of mapping, identification, and description.

The cones and lava lie along the Canjilon escarpment, which marks the eastern edge of the Chama Basin and the western edge of the San Juan Mountains. Three cones are clustered at the headwaters of Encinado Creek in the northeastern part of the Cebolla quadrangle. This is also where the Brazos fault intersects the Canjilon escarpment. Some of the lava from these volcanoes entered the Rio Brazos; presumably, the extensive lava on which the village of Ensenada is built and which approaches the village of Park View came from cone Qb_1. This correlation is based on the index of refraction of fused samples from the lava at different places (table 1). A breached cone, Qb_1, is the oldest of the three at the headwaters of Encinado Creek. A remnant of its lava or lava of a closely related flow is south of Corkin's and Brazos lodges at the mouth of the Brazos Box, where the basalt is 48 feet thick and displays crude columnar jointing in the lower 18 feet.

The tongues of basalt, which appear to have been extruded from near the base of the cinder cones, are of the as type, with angular blocks up to 5 feet in diameter. The basalt appears fresh with little weathering or consolidation of its angular blocks. The front of the basalt left by the northeastward-trending-flow from cone Qb_2 rises rapidly to 30 feet in thickness; the basalt layer is about 1 mile long and 750 feet wide. The largest of the cinder cones, "Old Smoky" (Qb_5) lies on the Canjilon escarpment about midway between Brazos Box on the north and Canjilon Mountain on the south (fig. 14). This peak rises 600 feet above the surrounding area. The lava of one large flow from it partly caps the divide between the Rito de Tierra Amarilla and the Rio Nutrias. It reaches approximately 4000 feet in its greatest width and extends westward about 5 miles. The cone rests on an east-west lineament that may be fault-controlled, for it parallels the Brazos fault.

Megascopically, the lava of the different flows of the Brazos Basalt are similar. They are typically medium gray, fine-grained, nonporphyritic, slightly to very vesicular. The small grains cannot be identified in a hand sample. The coarser grained Jarita Basalt contains abundant iddingsite, which is absent or nearly absent from the Brazos Basalt.

Microscopically, the Brazos Basalt shows intergranular texture with microlithic plagioclase laths, olivine that is mostly euhedral and fresh, and iron in random orientation. The olivine is conspicuous and abundant enough to call this rock olivine basalt. Cone Qb_2, however, has little olivine compared to the other flows.

The Brazos flows comprise the youngest stratigraphic unit in the Cebolla area, except for alluvial stream terraces, fans, and landslides. The flows unconformably overlie rocks from the Precambrian Kiawa Mountain Formation to the Cenozoic Los Pinos Formation and the oldest alluvial stream terraces. A thin, highly productive soil zone has developed on the flow underlying the village of Ensenada in the lower Brazos valley. However, most of the flows show little or no alteration and appear very fresh.

The Brazos flows were recent. Pleistocene glaciation indelibly marked the Cebolla area. Several flows, especially from cone Qb 2 , demonstrate the relative age of the Brazos Basalt. Two flows from the base of this cone flowed northward into the Brazos Box and encircled a high hill of Kiawa Mountain quartzite. Around the base of the hill is a quartzite talus and rock stream presumably derived during and after Pleistocene glaciation by intense periglacial activity. The flows from cone Qb_2 overrode the quartzite talus; therefore, the basalt is younger than the talus. The flows were postglacial, if the talus accumulated primarily during the period of glacial activity.

Another measurement of the relative age of the Brazos flows derives from the study of stream terraces. Noncyclic, nonpaired alluvial terraces are well developed along the westward-flowing steams draining into the Rio Chama. The basalt fraction is absent from the older terrace gravel along the Rio Brazos, Rito de Tierra Amarilla, and Rio Nutrias. All the younger terraces contain a basalt fraction similar in composition to that of the Brazos Basalt. Probably the flows occurred after the Rio Chama and its tributaries had started to develop their elaborate system of terraces.

Figure 14

VIEW EAST OF QB_5 "OLD SMOKEY" AT THE CENTER OF THE QUADRANGLE

TABLE 1. INDEXES OF REFRACTION OF FUSED SAMPLES OF CENOZOIC AND QUATERNARY LAVA FROM THE CEBOLLA AND BRAZOS PEAK QUADRANGLES, NEW MEXICO

Sample	Index (±)
Cone Qb_1	1.615
Cone Qb_2	1.575
Cone Qb_3	1.595
Cone Qb_4	1.560
Cone Qb_5 ("Old Smoky")	1.575
Cone Qb_6 (Red Hill)	1.565
Ensenada flow at U.S. 84	1.610
Jarita Basalt	1.581
Jarita Basalt	1.600
Treasure Mountain lava	1.504
Qb north side of Brazos Box	1.5815

Structural Geology

CHAMA BASIN

The Chama Basin, platform, sag, structural terrace, or embayment, as Kelly (1950,1955) and Muehlberger (1960) have referred to it, is a segment of the San Juan Basin. It is separated from the latter by a monoclinal flexure that starts as the high Nacimiento—San Pedro uplift on the southwestern edge of the Chama Basin (fig. 15). The flexure continuation to the north of this western boundary of the Chama Basin comprises the much more subdued French Mesa and Gallina uplifts. North of the Gallina uplift, the continuation of this flexure has been called the Archuleta anticlinorium (Muehlberger, 1960), which consists of a number of small folds and faults much diminished in elevation from the Gallina uplift. About 10 miles west of Nutrias and southwest of Tierra Amarilla are the north and south El Vado domes. These are fairly characteristic of the small folds that make up this part of the rim of the Chama Basin,

The Chama Basin is itself divided into a northern and a southern segment by the Brazos fault (fig. 15), a narrow zone of dislocation extending from the Brazos uplift in the northern part of the Cebolla quadrangle to the Horse Lake anticline in the Archuleta anticlinorium, some thirty miles west. The folds and faults of the Chama Basin and Archuleta anticlinorium south of this fault trend mainly northward; north of this fault, they trend northwest.

Figure 16 shows the major structural elements in the Cebolla area. The Chama Basin in the quadrangle consists of two parts, the Chama platform and the Brazos slope (Muehlberger, 1960); the platform is relatively flat-lying rock on either side of the Chama syncline. The slope lies between the Chama platform and the Brazos uplift of the Tusas Mountains.

Chama Platform

The Chama platform in the Cebolla area consists of a broad synclinal basin, the center of which is approximately marked by the axis of the Chama syncline. In this region, Mesozoic rocks display low dips and few dislocations.

Chama Syncline

Three and a half miles south of Tierra Amarilla, the axis of the Chama syncline is easily established in a broad synclinal mesa of the Mesaverde Group,

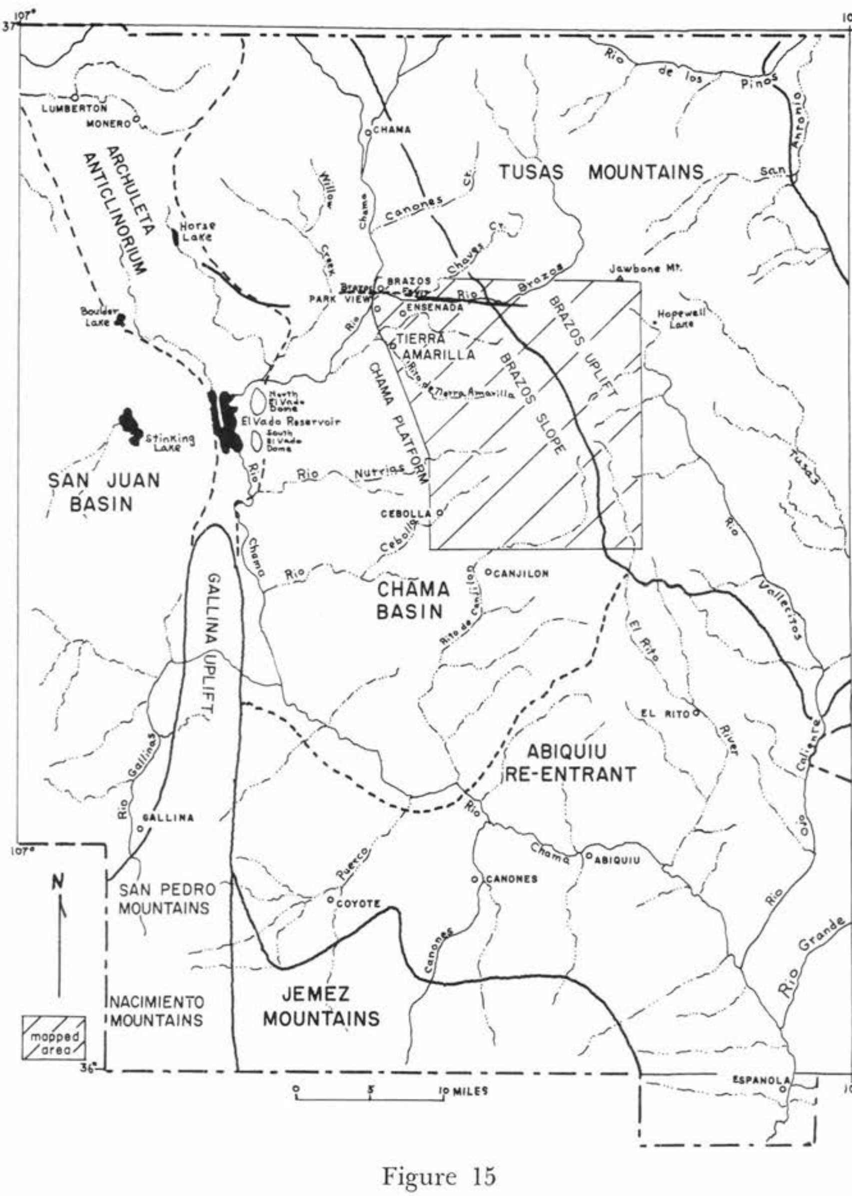


Figure 15

STRUCTURAL ELEMENTS OF THE CEBOLLA AND ADJACENT AREAS IN EASTERN RIO ARRIBA COUNTY

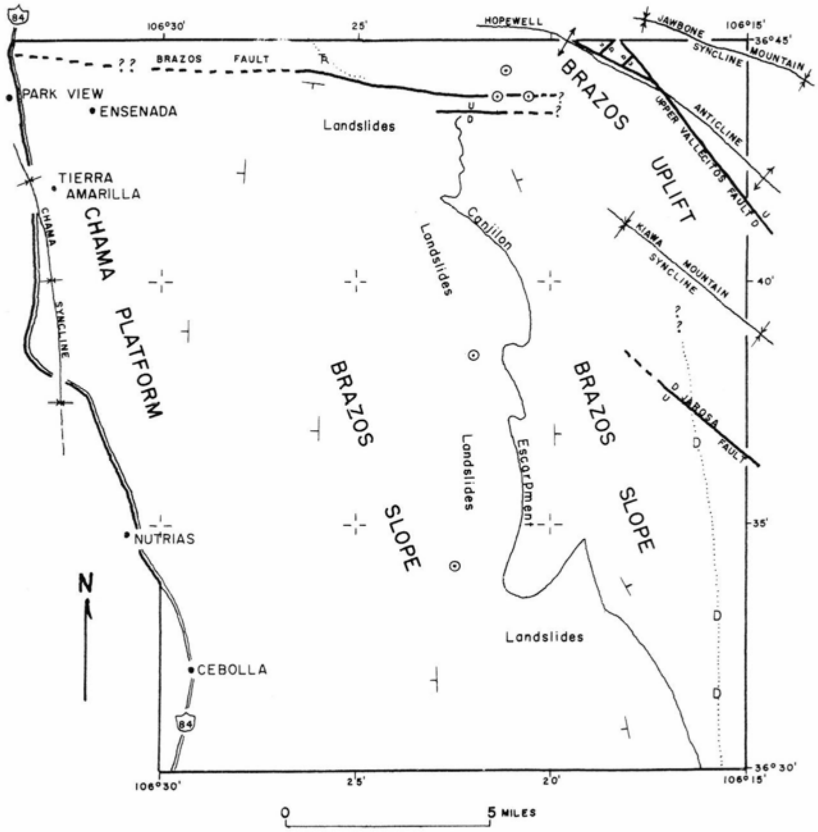


Figure 16
STRUCTURAL FEATURES IN THE CEBOLLA AREA

where it trends approximately north. The northern extension of this axis in the eastern part of the Tierra Amarilla quadrangle is concealed by the elaborate terrace system and alluvial fan of the Rito de Tierra Amarilla, but it probably passes near the village of Tierra Amarilla.

Brazos Fault

This fault extends from the south rim of the Brazos Box and the cluster of Quaternary volcanoes on the Brazos slope across the northern edge of the Cebolla quadrangle. Its westward trace is obscured by alluvium and terraces of the Rio Brazos. It probably leaves the area between the villages of Park View and Brazos. Muehlberger (1960) has traced it west to Horse Lake; the total mapped length is 30 miles.

This fault has had a profound effect on the structure of the Tusas Mountains and the Chama Basin. The folds of the Brazos uplift trend generally N. 45° W., but opposite the Brazos fault, the Jawbone Mountain syncline and the Hopewell anticline axes trend almost east. The upper Vallecitos fault has a similar effect. The folds and faults in the Chama platform also reflect the effect of the Brazos fault (Muehlberger, 1960).

Movement along the fault appears to be a combination of strike-slip and dip-slip The adjustments of the faults and folds of the Brazos uplift seem to point to a dominant strike-slip component. Movement has brought Cretaceous Mancos against Precambrian quartzite. Unfortunately, massive landslides and talus slopes mask this area, greatly hindering the study of its structure.

The fact that such Precambrian structural features as the Hopewell anticline and the Jawbone Mountain syncline are controlled by the fault indicates that it was active in Precambrian time. Muehlberger (1960) demonstrated Laramide movement on the fault, where it dislocated Cretaceous rocks in the Horse Lake and Willow Creek anticlines along the Archuleta anticlinorium. South of the Brazos Box, Mesozoic rocks tilt along the Brazos fault, also demonstrating Laramide displacment. Quaternary cinder cones Qb_3 and Qb_4 lie along this same fault and suggest recent movement along this zone.

Brazos Slope

The Brazos slope is between the Brazos uplift and the Chama platform. On this slope, outcropping Mesozoic sedimentary rock dips dominantly westward the dips increasing toward the uplift. Much of the slope is covered by a veneer of landslides. The Cenozoic formations dip gently to the east and northeast. The northern and eastern boundaries of the uplift are vague and poorly defined because much of the Brazos uplift has been covered by a mantle of Cenozoic rock. The boundary between the Brazos slope and uplift is marked by the outcropping Dakota Formation on the east and the Triassic on the north (Mu ehlb erger , 1960).

Canjilon Escarpment

The cuesta of the Canjilon escarpment is the most conspicuous topographic feature in the Cebolla quadrangle, rising high above the surrounding physiographic features in the area. The highest point in the quadrangle is Canjilon Mountain, 10,913 feet above sea level, located east of Red Hill (Qb_6) volcano at the southern end of the escarpment. This high, northward-trending ridge nearly bisects the quadrangle. The west edge slopes steeply into the Chama Basin, but the slope on the east side is gentle and coincident with the dip of the capping Cenozoic formations toward the Brazos uplift. The seemingly anomalous eastward dip of the rocks in the direction of the Brazos uplift suggests possible fault or fold control of the escarpment.

Quaternary Volcanoes

Six Quaternary cinder cones dot the Brazos slope along and in front of the edge of the Canjilon escarpment. They seem to align with Red Hill (Qb6) on the south; cone Qb_5 in the center; cone Qb_4 east of Penasco Amarillo; and the cone cluster, Qb_3 , Qb_2, and Qb_1 , in the north. The eruptions possibly resulted from recent differential movement along the Brazos slope between the uplift on one side and the Chama Basin on the other. The movement fractured and jointed the Cenozoic rocks, making them more subject to mass-wasting that has cut the escarpment back beyond the zone of weakness and extrusion. The previous westward extent of the Cenozoic rocks beyond the present position of the escarpment is undetermined. Penasco Amarillo, and erosional outlier from the escarpment, gives some idea of the former extent of the Cenozoic rocks.

Brazos Uplift

"Tusas Mountains" names the southern extension of the San Juan Mountains in northern New Mexico. They trend from northwest to southeast, separating the Rio Grande depression on the east from the San Juan Basin on the west. The

Tusas Mountains consist mainly of a highland area with peaks of Precambrian rock jutting through a veneer of eastward-dipping Cenozoic sedimentary rock. Their orogenic history is complicated by a number of episodes of uplift, faulting, folding, and tilting. Muehlberger (1960) listed nine periods of uplift, ranging from Pennsylvanian through Quaternary .

That part of the Tusas Mountains in the Cebolla quadrangle is termed the Brazos uplift. In the Cebolla quadrangle, three periods of tectonism can be recognized from the stratigraphic relationships. During Precambrian time, large-scale folding of the Precambrian metasedimentary rocks of the Brazos uplift area took place, resulting in two major synclines, the Kiawa Mountain and the Jawbone Mountain, and one major anticline, the Hopewell. These folds trend in the same northwest direction as the major faults. Many minor folds range from hand-sample to hundreds of feet across in the highly deformed Precambrian rocks.

The second period of tectonism is post-Lewis. Cretaceous formations rise from the Chama platform toward the Brazos uplift. The Mesaverde Group and the Lewis Shale near the axis of the Chama syncline south of Tierra Amarilla lie at an elevation of 7800 feet above sea level. The beds of the Cretaceous units rise to 10,300 feet at Penasco Amarillo on the Brazos slope where they are truncated and unconformably overlain by the Cenozoic El Rito and Ritito Formations.

The third period of tectonism was post-Los Pinos, the youngest Cenozoic formation in the area. On the Brazos uplift and the Brazos slope, the Cenozoic strata have a prevailing regional dip of 5 to 6 degrees east and northeast. The tilting involves all the Cenozoic formations in the Cebolla area and some younger rock in the Tusas—Las Tablas quadrangles to the east. Butler placed the tilting as post-Santa Fe.

Further tectonic activity is indicated by the northwest-trending faults that cut the Cenozoic in the Brazos uplift. Barker described two major Cenozoic fault systems in Las Tablas quadrangle, the Tusas and Vallecitos. Faults probably related to the Vallecitos system cross into the northern part of the Cebolla quadrangle .

Jawbone Mountain Syncline

The axis of the Jawbone Mountain syncline crosses the extreme northeast corner of the Cebolla quadrangle, trending N. 75^0 W. into the Brazos Peak quadrangle. The steep dips in the Jawbone Conglomerate Member, ranging from 20 to 88 degrees, outline the fold axis, but most of the dips occur within the upper part of the range. Stretched pebbles in the conglomerate indicate intense deformation. Drag-fold axes in the conglomerate and cross-bedded quartzite subparallel the main synclinal axis. This fold trends more to the west than is characteristic of folds in the Tusas Mountains, probably reflecting the effect of the Brazos fault.

Hopewell Anticline

Southwest of the Jawbone Mountain syncline lies the Hopewell anticline, named by Barker for the ghost town of Hopewell, half a mile east of the Cebolla quadrangle boundary. It enters the northeast part of the quadrangle just north of the upper Vallecitos fault and Quartzite Ridge. Opposite Quartzite Ridge, it trends N. 45° W., but upon leaving the Cebolla quadrangle, the anticlinal axis swings around to No. 30° W.; in the Brazos Peak quadrangle, it trends almost west. Again, this reflects the influence of the Brazos fault. The exact placement of the axis of the Hopewell anticline is difficult because it is covered by Los Pinos Formation. Nevertheless, the strata on Jawbone Mountain on the southwest limb of the Jawbone syncline dip steeply northeastward, and the upper quartzite member of the Kiawa Mountain Formation on Quartzite Ridge dips southwestward, thus bracketing the axis. The dips on Quartzite Ridge are steep, ranging from 72 degrees to vertical. The cross-bedded pink quartzite contains many minor folds that parallel the anticlinal axis. Some of these are hematite-banded. In the quartzite outcrops that extend northwest from Quartzite Ridge, the dips are less steep. The south dips in the quartzite of the Brazos Box and of the quartzite outcrop north of cone Qb_2 delineate the south flank of the anticline as it trends east in this vicinity.

Kiawa Mountain Syncline

Barker traced the very prominent Kiawa Mountain syncline in Las Tablas quadrangle about 14 miles to the western edge of the Cebolla quadrangle southwest of Quartzite Ridge. In the Cebolla quadrangle, Los Pinos gravel covers the axis, but the dip of the southernmost Precambrian outcrops to the northeast opposed to the southwest dips on Quartzite Ridge bracket the axis. The syncline trends N. 40° W., more or less paralleling the Hopewell anticline and the Vallecitos fault. Cenozoic cover conceals the northwest extension of this fold.

Upper Vallecitos Fault

A single fault enters the quadrangle immediately north of Quartzite Ridge. This continues the Vallecitos fault zone in Las Tablas quadrangle (Butler; Barker). It trends N. 45° W., paralleling Quartzite Ridge in its southern part. As it approaches the northern boundary of the Cebolla quadrangle, it bifurcates. Its southern branch trends N. 30° W.; the northern branch continues N. 45°W. Between these branches are two cross faults. Typical of most of the faults in the Tusas Mountains, the Vallecitos fault is normal; the downthrown side to the west has brought Los Pinos Formation opposite the basal Cenozoic El Rito Formation and the Precambrian Moppin Formation. The thickness of the Cenozoic formations involved in the faulting is difficult to estimate because of basement relief, but it appears that the displacement ranges between 800 and 900 feet. This fault can be traced 7 miles across this part of the quadrangle.

Jarosa Fault

The Jarosa fault crosses the boundary between Las Tablas and Cebolla quadrangles about midway between the north and south boundary. It trends No. 30° W., extending about 2.5 miles to where Los Pinos Formation covers it. It differs from the upper Vallecitos fault and the majority of the other faults in the Tusas Mountains by having the downthrown side to the northeast. The movement brought Los Pinos and Ritito Formations together. The displacement is probably less than that of the upper Vallecitos fault.

Cenozoic Structure

Tertiary formations in the Cebolla quadrangle all have a general dip of 5 degrees northeast to east. Higher local dips probably occur in areas of local flexure. These formations tilted with the Brazos uplift in the Tusas Mountains after Los Pinos deposition.

If, as some authors (Smith, 1938; Butler; Stearns, 1953) have postulated, the source of the sediments lay north and east of the Cebolla quadrangle, and if the Cenozoic sediment was at least in part alluvium deposited by Cenozic streams, the original dip was probably slightly to the west. Post-Los Pinos tilting has reversed the dip from slightly west to east.

Gemorphology

MASS-WASTING

Conditions in the Cebolla area are ideal for mass-wasting. All the types of slow flowage defined by Sharpe (1938), soil creep, rock creep, talus creep, solifluction, and rock glacier creep, are visible and their effects are conspicuous. The more dramatic slump-and-earthflow topography tends to overshadow the subtler slow-flowage features.

Howe (1909) and Atwood and Mather have described conditions that favor mass-wasting in the San Juan Mountains; similar conditions prevail in the Cebolla area. The Ritito and Los Pinos Formations, which cap the Canjilon escarpment, are for the most part unconsolidated or only partly consolidated. Competent beds resting on incompetent beds furnish stratigraphic conditions that favor mass-wasting. El Rito Formation, a well-cemented conglomerate, overlies incompetent Lewis Shale, and the Mesaverde Group with its massive sandstone overlies incompetent Mancos Shale.

Uplift, tilting, and folding of the beds have placed the competent and incompetent units in positions for severe weathering to promote mass-wasting. Jointing in the upper Mancos limestone and sandstone, in the Mesaverde Group, and in El Rito Formation has made large blocks of material available for mass-wasting. Faulting has uplifted such areas as that along the upper Vallecitos fault and along the Brazos fault.

The climate and topography both favor mass-wasting. In the Cebolla area, where the elevation of the higher ridges is above 10,000 feet, heavy snowfalls are common. The accumulated total precipitation, including snowfall, is more than 100 inches; some of the snow remains on the higher, protected slopes into early June.,

Slow Flowage

Rock creep is more evident and widespread than soil creep. On the flanks of the quartzite hills and ridges, rock creep is especially apparent. The poorly consolidated Cenozoic conglomeratic formations, El Rito, Ritito, and Los Pinos, occupying higher topographic positions, provide a prolific source of material for rock creep. The quadrangle, subjected to glacial and periglacial activity in the past, still is subjected to great frost action. Probably most of the physical weathering in this region comes from frost; as a result, some slopes are almost completely covered by rock debris.

In areas where hillsides are especially steep or youthful streams like the Rio Brazos have cut canyons, large talus piles have accumulated. These are most common in the northeast quarter of the quadrangle.

Rock creep, talus creep, periglacial action, and postglacial action have combined in the northeastern quarter of the quadrangle to form rock streams or glaciers (fig. 17). These masses of highly angular, mainly quartzite, blocks move down a gentle slope. The largest of these occupies a cirquelike basin in Jawbone Mountain. Three other rock streams move down Jawbone Mountain, one in the valley between Quartzite ridge and the scarp of the upper Vallecitos fault and two between cone Qb 2 and the quartzite mass northwest of the cone.

The gently sloping surface that extends from the crest of the Canjilon escarpment eastward toward the headwaters of the upper Vallecitos drainage exhibits numerous wrinkles and corrugations that appear to be solifluctionderived surfaces. Grass and forests now cover the area, which still receives a high annual snowfall. The development of surfaces probably began during the last maximum of Wisconsin glaciation and continued to a fairly recent time, if they are not still developing. In the Trout Lakes landslide area west of the Canjilon escarpment are poorly developed stone stripes.

Rapid Flowage

The most evident manifestations of mass-wasting in the Cebolla quadrangle occur in the slide areas west and south of the Canjilon escarpment and northwest of Penasco Amarillo(figs. 18 and 19). In these areas, more than 60 square miles of the surface have been disrupted, mainly by a combination of slump and earthflow movement characteristic of the San Juan Mountains. The surface is hummocky, consisting of alternating transverse ridges and depressions. The ridges and troughs more or less parallel the escarpment from which the movement originated. Most of the bouldery, asymmetric, transverse to crescent-shaped ridges have their steep sides away from the escarpment. The ridges nearest the escarpment display classic slump movement with a slight backward slip and with the axis of the ridges nearly parallel to the escarpment. The toe of the slide area consists of more chaotic, bulgy masses with less definition of the constituent parts. Bouldery material makes up most of the ridges and is scattered throughout the entire slide area; it is derived mainly from the Ritito and El Rito Formations, which cap the escarpment. Because of the difference in induration of the two formations, slides have carried, unbroken, some large blocks of El Rito, up to 20 feet high, to their present resting place, some of them several miles from the present outcrop. The bulk of the slide material consists of sand, tuff, and gravel from the poorly consolidated units.

Figure 17
ROCK STREAM ADJACENT TO VOLCANO QB_2

Figure 18
WESTWARD VIEW OF THE CANJILON LAKES LANDSLIDE AREA

Figure 19
VIEW EASTWARD OF ONE OF THE LAKES IN THE CANJILON LAKES LANDSLIDE AREA

Lakes, marshes, and meadows occupy the trough areas between the ridges. The vegetation cover of the slide area varies from place to place. In some troughs, meadows prevail with little tree cover, while in others, a dense pine cover has re-established itself. All degrees of cover between these extremes also appear.

The Mesozoic rocks that underlie the Canjilon escarpment and Penasco Amarillo consist mainly of Lewis and Mancos shales dipping westward beneath an angular unconformity at the base of the escarpment-capping Cenozoic rocks (fig. 20). The escarpment is capped by conglomeratic, tuffaceous, and sandy rock that dips gently northeastward. The porous and permeable Cenozoic beds can accommodate large amounts of water. The downward-percolating water is halted by the impermeable westward-dipping shale, which, when wet, acts as a slide plane and gives way under the water-saturated conglomeratic and tuffaceous rocks.

Water from heavy snowfall and summer rain is available in large supply. Excess water finds its way to the surface in numerous springs clustered about the headwaters of all the streams that head in this quadrangle. The most notable example is the cluster of 15 springs at the headwaters of El Rito Creek. The valley of this creek is cut mostly in shale. The porous and permeable Ritito and El Rito Formations, which dip toward the stream, carry the water along the unconformity surface in sufficient quantity to maintain the springs throughout the summer months.

Penasco Amarillo, Canjilon Mountain, Red Hill volcano, and cone Qb_5 serve as reference points in describing the major slump and earthflow areas. The largest single area, between Canjilon Mountain and Red Hill on the south and the Rio Nutrias on the north (fig. 2), is called the Trout Lakes landslide area; it covers more than 20 square miles. The largest of the lakes, about a mile north-northwest of Canjilon Mountain, is 660 feet long; the others range down to ponds. The slide area consists of three poorly defined lobes and one well-defined lobe that contains the Trout Lakes and has been active more recently than those surrounding it. Recent movement left this area lower than the surrounding slide areas. The many springs along the south scarp of this slide supply most of the water for Trout Lakes and the Rio Nutrias. The foot of the Trout Lakes lobe is a bulgy mass displaying the characteristic features of slow earthflow movement. Some of the transverse ridges stand as much as 40 feet above the lake-, marsh-, and meadow-filled depressions.

Another area of massive slump and earthflow at the headwaters of the Rito de Tierra Amarilla between basalt cone Qb_5 and Penasco Amarillo exhibits three major earthflow lobes between the Canjilon escarpment and the valley of the Rito de Tierra Amarilla. Less distinct earthflow lobes mark the southern slopes of Penasco Amarillo.

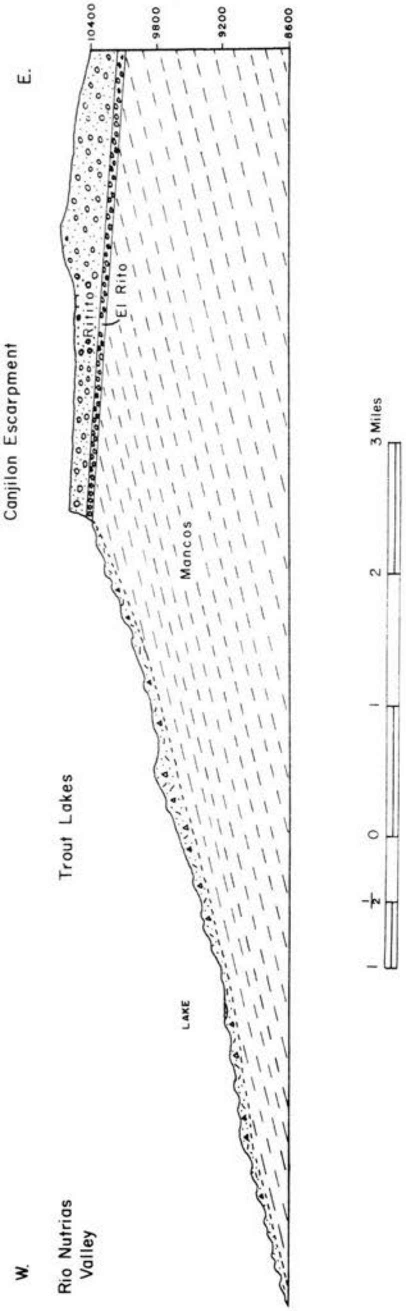


Figure 20
DIAGRAM ACROSS THE TROUT LAKES LANDSLIDE AREA

Between Penasco Amarillo and the Rio Brazos, outcrops of Precambrian quartzite and the Dakota hogback south of the Brazos Box stand like islands and abutments in an otherwise badly slumped area. Numerous lakes and high transverse ridges characterize the northeastern part of this slump area. Northwest and west of Penasco Amarillo, the slump and earthflow areas do not contain ridges so high or lakes so numerous as those in the Trout Lakes area. Three quarters of a mile east of the village of Ensenada, an alluvial fan has formed near the margin of the slumped area and the terraced, alluviated valley. A similar alluvial fan extends west from the slide area to the eastern edge of Tierra Amarilla.

South of Canjilon Mountain and Red Hill volcano (figs. 18 and 19), spectacular slumping, along with many springs, has created many beautiful lakes called collectively the Canjilon Lakes. Many springs show where slumping and mass-wasting have removed the capping Ritito and El Rito Formations in the headwaters of the Rito de Canjilon east of Canjilon Mountain, and smaller lakes occupy an area around Vega Paz south of Red Hill and on the north slope of Magote Peak in the southeastern part of the quadrangle.

TERRACES

Gravel-covered terraces are conspicuous geomorphic features in the region west of the Canjilon escarpment. They range in elevation from a few feet above present stream level to the tops of some of the highest ridges, 300 to 400 feet above present stream level. Each of the tributary streams of the Rio Chama, the Rio Brazos, Rito de Tierra Amarilla, Rio Nutrias, Rio Cebolla, and Rito de Canjilon, possesses its own set of terraces. For ease of identification, the terraces have been labeled Qt_1 through Qt_5; the numbers refer to each stream valley separately. Terrace Qt_1 is the lowest and most recent, terrace Qty the highest and oldest. I have not attempted to correlate the terraces of the different stream systems.

Besides these numbered terraces, others (designated merely Qt) are referred to as the "higher terraces." In composition, degree of rounding of their gravel, and elevation they are distinct. Terrace Qt_4 of the Rio Nutrias should be included with this group. Still other gravel benches on many of the higher ridges are not plotted on the geologic map but are discussed with the higher terraces.

Figure 21, a diagram of the terraces along the Rio Brazos east of the village of Ensenada, represents a noncyclic, nonpaired system of four distinct levels. Their pattern suggests continued downcutting with lateral erosion, as opposed to discontinuous downcutting. Other higher, more vague levels in the Rio Brazos system belong with the higher terraces. East of Ensenada in the Rio Brazos

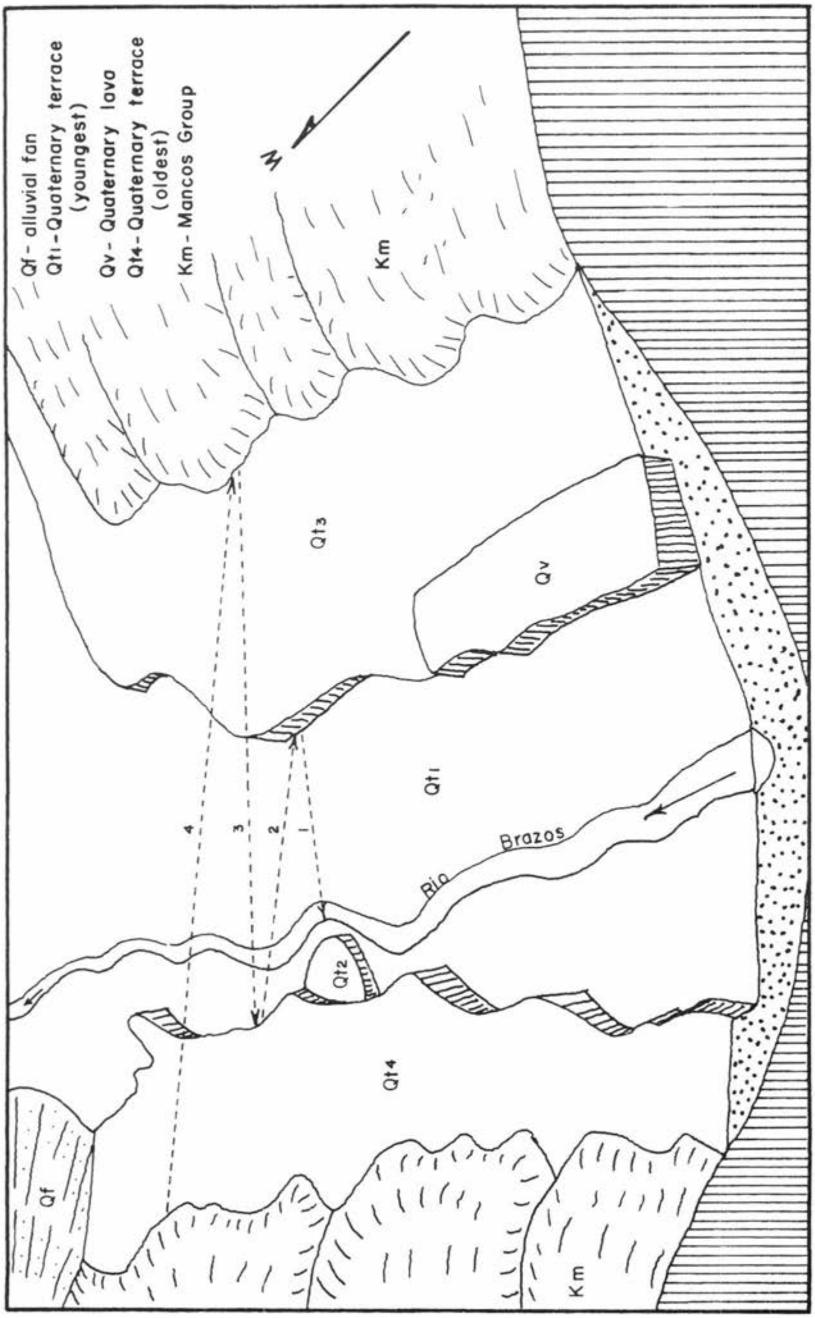


Figure 21

SKETCH SHOWING THE RELATIONSHIP OF THE TERRACES OF THE RIO BRAZOS system and immediately east of Tierra Amarilla in the Rito de Tierra Amarilla system at the change of slope below Penasco Amarillo, alluvial fans mask the terrace systems in their immediate area.

A decrease in the grain size of the gravel fraction from terraces Qt_4 to Qt_1, accompanied by an increase in rounding, may reflect a decrease in the volume of water or a long-continued stream action or perhaps different transportation media or combinations of these conditions. After rejuvenation, streams would accelerate and form the older terraces more rapidly than younger terraces because of greater initial gradient and accompanying greater discharge. This accelerated activity would produce larger grain size and less rounding. As the stream approached local base level and its activity diminished, smaller grain size and better sorting in the younger terraces would result.

The composition of the gravel fraction of all the terraces reflects the outcropping rocks of the Cebolla and adjacent quadrangles. Terrace Qt_1 in the Brazos system contains 95 per cent pinkish-gray quartzite gravel ; the remaining 5 per cent consists of tuff, vesicular basalt, schist, and greenschist. Terrace Qt_2 in this system has 10 per cent vesicular basalt, cross-bedded quartzite making up most of the remaining 90 per cent. Terrace Qt3 contains larger pebbles, few have a diameter less than 1 inch; 96 per cent consist of subrounded quartzite gravel. The remaining 4 per cent is shared by vesicular basalt, greenschist, El Rito conglomerate, and hornblende schist. Terrace Qt_4 contains subrounded quartzite cobbles and pebbles with a tiny fraction of vesicular basalt, schist, gneiss, and Dakota Sandstone.

Two higher terraces (Qt) southeast of Ensenada and immediately west of the alluvial fan reveal poorer sorting and higher angularity of fragments; they lack any fragments of vesicular basalt. This pattern remains consistent for each of the stream systems. The lack of vesicular basalt fragments in the higher terraces perhaps indicates some regional tectonic activity, at least indirectly. This lack, coupled with the relationship between the presumed periglacial-derived rock stream and the as flow from Terrace Qb_2, establishes a firm case for postglacial volcanic activity. The fresheners of the relatively undisturbed lava and cinder cones further corroborates the conclusion that volcanic activity commenced after the last glaciation. Perhaps the volcanism resulted from regional tilting that also rejuvenated the streams and augmented the terrace development to its present rate. If so, the lower terraces are postglacial.

There is a possibility that the higher terraces (Qt) may be outwash from Cerro glaciation, the Florida gravel of Atwood and Mather, who described this as a widespread gravel capping surfaces between the highest summits and the valley floors, generally between 100 and 300 feet above the present valley floors. The gravel is widespread in Colorado and the Tusas Mountains in New Mexico. All the properties of the Florida gravel described by Atwood and

Mather are incorporated in the higher terraces (Qt) and in the numerous gravel caps on the higher ridges in the western part of the Cebolla quadrangle. The gravel is also angular compared with gravel of the lower terraces.

Larsen and Cross stated that uplift of the San Juan region was continuous at least to the end of Durango glaciation. In other words, tectonic activity occurred in the San Juan Mountains after Cerro glaciation. The "higher terraces" in the Cebolla area were probably cut by streams rejuvenated by this uplift. The development of the lower terraces may reflect a reduction of load in the headwaters of the Rio Chama at the termination of Wisconsin glaciation.

The terrace system along the Rito de Tierra Amarilla covers more surface area than any other; many higher terraces are preserved, perhaps because the resistant Mesaverde Group rests on either side of the alluviated valley. The higher terraces might qualify as rock-defended terraces; certainly resistant rock has helped preserve them. This Rito de Tierra Amarilla system appears to be a combination of cyclic and noncyclic terraces. Colluvium has considerably masked the Qt_3 and Qt_4 terrace levels, resulting in poor definition. Because of this, they have been grouped together. As elsewhere, the higher terraces of this system contain highly angular fragments in which quartzite dominates. None of the higher terraces contains vesicular basalt, even though terrace Qb_5 occupies the headwater region.

In the lower three terraces of the Rio Nutrias system, fragments of rounded Precambrian quartzite and vesicular basalt predominate. Terrace Qt4 of this system contains angular fragments of quartzite averaging 2.5 inches in their longest dimension. There are also boulders up to 2 feet in diameter. No vesicular basalt was found.

The glacial and periglacial features in the Cebolla quadrangle are not so conspicuous as in areas to the north. The Brazos Peak quadrangle immediately north contains glacial moraines and associated features. If the higher terraces are indeed Cerro outwash, then they are the most conspicuous glacial features in the Cebolla quadrangle. Patches in the ridges of conglomerate in Jawbone Mountain exhibit polished surfaces that seem to point to active glaciation at some time in the past. The U-shaped, cirquelike valley in Jawbone Mountain, now occupied by a rock stream, could have contained a small glacier. Other indications of periglacial action are stone stripes, solifluction lobes, and rock streams. Thus, the Cebolla quadrangle probably rested near the edge of the Quaternary glacial erosion and desposition.

Economic Geology

COAL

Subbituminous to bituminous coal containing a high percentage of sulfur is being mined from the Menefee Formation of the Mesaverde Group in the western part of the quadrangle. In the past, coal has been mined from the Mesaverde, which crops out both north and south of the Rito de Tierra Amarilla.

Two main coal seams appear in the Menfee; only the bottom seam, with a thickness in places of 5 feet, is of commercial grade, although it has shale partings that greatly detract from its value. The upper seam, generally less than 1 foot thick, does not lend itself to profitable mining. An intervening sandstone bed 20 feet thick prevents mining both seams together. Several adits, now abandoned, were dug into the Menefee on the synclinal mesa south of Tierra Amarilla. The only currently active mine is the Dandee, north of the Rito de Tierra Amarilla on the slope of Penasco Amarillo. This small-scale operation provides coal for local use.

GOLD

The Hopewell district, which centers at Hopewell, lies mainly within Las Tablas quadrangle, but a fringe of its western part extends into Cebolla quadrangle.

Along the upthrown side of the upper Vallecitos fault opposite Quartzite Ridge, the mineralized Moppin metavolcanic rocks and the Burned Mountain Metarhyolite are exposed. This ridge is covered with prospect pits and adits. The pits are mainly on narrow and irregular quartz veins that cut the Moppin phyllite and schist. Mineral-bearing sulfides were probably brought into the area with the instruction of the Burned Mountain Metarhyolite and the quartz veins into the Moppin Formation.

In the phyllite, euhedral crystals of pyrite are common. Lindgren, Graton, and Gordon stated that the better ore was not usually associated with the euhedral pyrite crystals but occupied the quartz veins where the pyrite was poorly crystallized. Tailings from these mines and pits show a mineral assemblage of pyrite, chalcopyrite, and garnet and stains of malchite and azurite.

Most of the gold produced from the Hopewell district came principally from two placer deposits on Eureka Creek: the Fairview at Hopewell and the Lower

Flat at the junction of Placer Creek (Eureka) and the branch of the Vallecitos Creek that flows between Quartzite Ridge and the upper Vallecitos fault. The edge of the Lower Flat placer overlaps the Cebolla quadrangle, as shown on the geologic map recently prepared by Bingler.

PETROLEUM

Three wells have been drilled in the Tierra Amarilla quadrangle just west of the Cebolla quadrangle boundary in the Chama Basin. Continental and Hughes drilled their Esquibel No. 1 well 3 miles north of Nutrias in 1938 (sec. 27, T. 28 N., R. 4 E.). It started in the upper Mancos and pierced 1920 feet of the Dakota, with a show of water. The other wells also started in the upper Mancos. Penn Building Company abandoned its Southwest No. 1B in the Morrison as a dry hole in 1948 after drilling 1889 feet (sec. 33,T. 28 N., R. 4 E.). Its Hamilton No. 1 (sec. 33, T. 28 N., R. 4 E.), drilled in 1957, started and ended in the Mancos after 1332 feet with no show (Bieberman). In 1959, Spill Brothers extended this well to a depth of 1659 feet; the well showed water in the Dakota and Entrada and oil in the Todilto.

Resume of Geology History

PRECAMBRIAN ERA

The earliest documented event in the Cebolla quadrangle was volcanic extrusion and the deposition of small amounts of quartz sand. Later deformations and intrusions converted these to greenschist, muscovite-biotite schist, phyllite, and quartzite. Collectively, these constitute the Moppin Formation. The base upon which these rocks accumulated was probably the Ortega Quartzite. Although the Ortega does not crop out in the Cebolla quadrangle, it is exposed to the east, where Barker estimated it between 14,000 and 20,000 feet thick.

This volcanic event was followed by deposition of the Kiawa Mountain Formation, an extremely thick sequence of quartz sand and pebbles with minor basalt. This unit, now largely quartzite, Barker estimated between 5000 and 10,000 feet thick. The source of the quartz sand is unknown; it probably accumulated under epineritic conditions in a slowly subsiding geosyncline.

Next came intense folding and metamorphism, probably accompanied or followed by intrusion of the sill-like masses of Burned Mountain Metarhyolite and Maquinita Granodiorite. The Kiawa Mountain and the Moppin folded into a series of northwest-trending anticlines and synclines. Mineralized quartz veins probably related to the metarhyolite and granodiorite were emplaced in the older formations, especially the Moppin. Mountains probably occupied the area in late Precambrian time.

PALEOZOIC ERA

The Cebolla area must have been positive during much of the Paleozoic Era. The absence of Paleozoic outcrops in the quadrangle renders interpretation of the position of the sea and the relative elevation of the land difficult. No deposits from the beginning of the Cambrian until well into the Pennsylvanian have been found along the flank of the Brazos uplift in northern New Mexico. If sediment were deposited in this vicinity during this part of the Paleozoic Era, it was subsequently removed, at least in the areas available for study.

The following information on the Paleozoic in the San Juan region comes principally from the works of Beaumont and Read (1950), Eardley (1951), Lookingbill, Larsen and Cross, and Muehlberger (1957). The evidence from adjacent areas demonstrates scant Paleozoic deposition. In late Precambrian time, the San Juan Mountain region was high, and it remained as a fairly stable, positive area until late in the Cambrian Period. Then, a sea transgressed northward and eastward over a partly peneplaned Precambrian surface, depositing sediments in central New Mexico and around what is now Durango, Colorado. Above the Cambrian System in southwestern Colorado, there is an unconformity. The hiatus represents part of the Cambrian, all the Ordovician and Silurian, and the lower and middle Devonian. Ordovician sedimentary rock, however, rests on the Precambrian along the northeastern flank of the San Juan near Saguache, Colorado.

In late Devonian time, more extensive submergence in the San Juan region began resulting in the deposition of Devonian and Mississippian sediments in southwestern and south-central Colorado. The deposition was followed by slight uplift and erosion, perhaps referable to the emergence of the Paleozoic ancestral Rocky Mountains. That the Brazos uplift and Sierra Nacimiento were positive features at this time is recorded by the wedgelike accumulation of Pennsylvanian marine arkosic sandstone, siltstone and limestone 6 miles north of Tierra Amarilla along Chavez Canyon (Muehlberger, 1967). This section thins rapidly eastward into the Brazos uplift. Arkosic and other clastic sedimentary rocks make up the Upper Pennsylvanian Madera Formation in the Gallina region, about 15 miles west-southwest of Cebolla; Lookingbill suggested that the source lay in the vicinity of Sierra Nacimiento. The Pennsylvanian sea also transgressed over southern Colorado, depositing the mud and sand that became the Molas Formation. This was followed by sand, shale, and limestone of the Hermosa Formation.

Uplift and erosion in the San Juan area of southwestern Colorado and north-central New Mexico during the Permian Period resulted next in deposition of the continental Cutler Formation. The interfingering of the Cutler with the marine Yeso and San Andres Formations in the Gallina area locates the strand line during this phase of Permian sedimentation.

Afterward, the area was probably slightly uplifted, and a long episode of erosion and no tilting ensued.

MESOZOIC ERA

Slight uplift and erosion probably continued well into the Triassic Period, because the Permian, Pennyslvanian, and Precambrian formations are disconformably or nonconformably overlain by the Upper Triassic Chinle Formation. This red and white shale, siltstone, and sandstone contains bones of land vertebrates of the types that indicate an alluvial flood plain deposit. This again suggests a postive land area in the Tusas Mountains.

Succeeding period of erosion with no profound uplift in the Tusas Mountain area saw development of a broad east-west structural arch south of the present San Juan Basin (Hoover, 1950). Sedimentation in the area commenced with deposition of the Upper Jurassic Entrada Sandstone, which thins in a northeast direction and seems to indicate that a persistent high still existed in the Cebolla area. In the Brazos Peak quadrangle, the Entrada has a basal brecciated zone containing fragments of Precambrian rocks like those in the Cebolla. Muehlberger (1960) suggested that this zone formed when the Entrada strata overstepped earlier beds onto the Precambrian. The disconformity between the Triassic Chinle and the concordant Jurassic Entrada indicates little upward movement between late Triassic and late Jurassic time.

The withdrawal of the Entrada sea preceded deposition of the multicolored heterogeneous Morrison Formation. This stream-and-flood-plain deposit rests with seeming conformity on the Entrada.

Activity along the east-west arch that separated northern and southern New Mexico kept the early Cretaceous sea out of northern New Mexico.

A period of erosion succeeded deposition of the Morrison until transgression of the late Cretaceous Dakota sea reached the Cebolla area. The Dakota represents flood plain, swamp, lagoon, and, toward the top, marine deposition, which reflects gradual encroachment of the marine environment. That the Precambrian high was still a positive feature is demonstrated in the Brazos Peak quadrangle, where the Dakota rests on Precambrian (Muehlberger, 1960). Dane (1960) thought that a barrier separated the Dakota in the San Juan Basin from that in northeastern New Mexico.

The Late Cretaceous sea continued to transgress southwestward and the marine Graneros Shale of the Mancos Group deposited conformably on the Dakota Formation. A series of major and minor transgressions and regressions followed. Many smaller movements did not appreciably affect the Cebolla area, because the strand line of the Mancos sea lay far to the south and west. During this interval, the Greenhorn Limestone, Carlile Shale, and the upper shale of the Mancos Group were deposited.

A major regression of the Mancos sea, R_2 of Weimer, brought the accompanying advance of the Mesaverde sandstone, coal, and shale. The change from the normal marine Mancos to the continental Mesaverde is well manifested in the Cebolla area by a transtitional zone with shells of nearshore molluscs separating a zone with shells of typical marine invertebrates from the lagoonal flora of the Mesaverde. The Mesaverde Group thins from the west into the Cebolla quadrangle sufficiently to place this area near the eastern edge of Mesaverde deposition.

Another major transgression of the sea brought a return of marine water to the Cebolla quadrangle and deposition of the Lewis Shale. This is the youngest

Cretaceous formation exposed in the area. Cretaceous deposition continued with the Pictured Cliffs Sandstone and Fruitland and Kirtland Formations; perhaps these younger formations were deposited in the area, but if so, any trace of them has been removed by subsequent erosion.

Late in the Cretaceous Period, one of the greatest periods of deformation, the Laramide orogeny, began. The main movements continued into the Eocene, for Eocene beds are also affected by the folding (Larsen and Cross). During the Laramide orogeny, the San Juan and Tusas mountains were uplifted along a line approximately coincident with their present positions. To the west and south, the result of this positive deformation was the creations of the San Juan Basin (Kelly).

CENOZOIC ERA

Erosion accompanied and followed the Laramide orogeny, stripping off some of the earlier deposits to expose great masses of the underlying Precambrian. The area continued as one of moderately high relief. El Rito Conglomerate was deposited across this area in the Oligocene Epoch or early in the Miocene, probably by south- and west-flowing streams from a source near or within the Cebolla quadrangle. The conglomerate is composed of pebbles and cobbles of the same Precambrian rock as that now exposed. In the Abiquiu quadrangle, Smith (1938) observed a northward coarsening of this conglomerate.

The tuffaceous sand and conglomerate of the Ritito were deposited on El Rito Formation. Source areas lay in southern Colorado and the Tusas region of northern New Mexico (Smith, 1938; Stearns). Local sources again probably supplied the gravel of the Precambrian part of the formation. The Ritito Formation appears to be a marginal facies of the Conejos Quartz Latite found in New Mexico north of the Cebolla quadrangle and in Colorado. In the Brazos Peak quadrangle to the north, this poorly consolidated, tuffaceous, conglomeratic formation with Precambrian gravel interfingers with the more typical Conejos with an abundance of quartz latite and volcanic fragments. The Ritito of the Cebolla quadrangle correlates with the Conejos (?) of Las Tablas quadrangle and with the basal part of the Abiquiu Formation in the Abiquiu quadrangle to the south.

The extrusion of rhyolite and welded tuff of the Treasure Mountain Formation, whose source lay to the north, probably in southern Colorado, followed Ritito deposition. The Treasure Mountain thins southward; only an isolated remnant is present in the Cebolla quadrangle.

The youngest Cenozoic formation in the Cebolla area is Los Pinos gravelly tuff and associated lava. This tuff fan probably radiated from volcanic centers east of the quadrangle (Stearns). It correlates with the upper part of the Abiquiu Formation and the basal part of the Santa Fe Formation. To the north and east of the Cebolla quadrangle, basaltic flows of the Hinsdale Formation spread over adjacent areas.

After Los Pinos deposition, the Tusas Mountains were again uplifted and tilted. Tilting of Cenozoic formations to the east was accompanied by faulting that produced a zone of northwest-trending, down-to-the-east, normal faults. These probably resulted from movement accompanying the development of the Rio Grande depression to the east.

The final touches to the sculpturing of the Cebolla area were applied during the Quaternary when three glacial epochs brought widespread action in the form of small mountain glaciers and abundant outwash material, mainly during the Cerro epoch. Through the increased supply of water and the periglacial activity, erosion speeded up. After recession of the ice, movement along the west flank of the Brazos uplift and the Brazos fault was accompanied by volcanic outbursts that left six cinder cones and associated lavas. The rejuvenated downcutting of west-flowing streams developed a system of terraces. Continual landslides of the slump and earthflow variety along the Brazos slope carried the Cenozoic rocks on the leading edge of the Canjilon escarpment into the Chama Basin and disrupted the drainage in the upper reaches of the streams, creating a beautiful group of landslide lakes.

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Appendix A

MEASURED SECTIONS

Pattern of Description of Units

1. Rock name.
2. Compositional adjective and mineral composition; that is, cements (such as calcareous, siliceous, ferruginous, clayey), and detrital minerals (such as quartz, micas, calcite, feldspar, pyrite, rock fragments, and chert).
3. Color on fresh surface, as well as banding and mottling, using Rock Color Chart names and symbols.
4. Grain size, shape, roundness, and crystal structure.
5. Bedding, as to thickness and mode.
6. Special characteristics, such as chert nodules, mud cracks, concretions, cross-lamination, and fossils.
7. Topographic expression, hardness, and degree of consolidations.

MEASURED SECTION ONE

E = El Rito
Cretaceous
Dakota Formation, incomplete section

LOCATION:

3 miles north of intersection of N. Mex. 110 with El Rito Creek in the Cebolla quadrangle. The section is exposed on the steep east side of the quadrangle. The section is exposed on the steep east side of the creek valley. The outcrop extends several tenths of a mile up a tributary valley, Hachita Canyon. The base of the formation is not exposed, and measurement of the Section was started with unit El at the edge of El Rito Creek and stopped with unit E19 on the hillside above E 1.

MEASURED BY:

T. E. Longgood and H. H. Doney, 28 July 1956; C. J. Mankin and H. H. Doney, 7 September 1957.

UNIT NO.	DESCRIPTION	THICKNESS (feet)
	Gravel	
E19-18	Sandstone; argillaceous, porous, very pale yellowish-orange (10YR 8/4) on fresh surface, grayish-orange-pink (5YR 7/2) on weathered surface, massive, fine-grained, limonite-stained, ledge-former	28
CI	Covered interval; may be part of the middle Dakota shale, forms rubble-covered slopes	62
E17	Sandstone; porous, moderate reddish-orange (10YR 6/6) to very pale orange (YR 8/2) on fresh surface, pale yellowish-brown (10YR 6/2) to pale brown (YR 5/2) on weathered surface, thickbedded, fine-grained, spotty limonite and hematite stains, worm burrows (?), plant impressions, forms small ledge	4
CI	Covered interval; gentle, grass-covered slope	22
E16	Sandstone; siliceous cement, porous, pinkish-gray (5YR 8/1) to moderate orange-pink (5YR 8/4) on fresh surface, light brown (5YR 6/4) on weathered surface, medium-bedded, gray fraction very fine-grained, orange fraction medium-grained, well rounded, almost no limonite stain, forms small ledge	2
CI	Covered interval; steep rubble-covered slope, may be in part same as below	34
E15	Sandstone; siliceous cement, porous, basic color very pale orange (10YR 8/2) but speckled with white and black on fresh surface, grayish-orange-pink (5YR 7/2) on weathered surface, medium-bedded, friable, fine- to medium-grained, well rounded, poorly sorted, top disappears into cover, forms weak slope	3
E14	Sandstone; cherty, porous, white (N9) with black specks in irregular bands on fresh surface, grayish-orange (10YR 7/4) on weathered surface, medium-bedded, very fine-grained with zones of fine-grained, limonite stain on weathered surface, sharp break between overlying and underlying units, good ledge-former	2
	Sandstone; siliceous cement, basic color very pale orange (10YR 8/2) but speckled with white and black on fresh surface, grayish-orange-pink (5YR 7/2) on weathered surface, massive, friable, fine-grained, well rounded, forms weak ledges	15
E13	Sandstone; siliceous cement, porous, white (N9) with occasional	

UNIT NO.	DESCRIPTION	THICKNESS (feet)
	black bands on fresh surface, grayish-orange (10YR 7/4) on weathered surface, medium-bedded, very fine-grained, limonite stain on weathered surface, forms ledge; sample 13	3
E12	Sandstone; siliceous cement, porous, white, light orange and black mixed, giving over-all appearance of white (N9) to very pale orange (10YR 8/2) on fresh surface, grayish-orange (10YR 7/4) on weathered surface, massive, fine-grained, well-rounded, slight to moderate limonite stain, grades into unit below, sharp contact with overlying unit, forms weak ledge	8
E11	Sandstone; siliceous cement, porous, grayish-orange-pink (10R 8/2) on fresh surface, grayish-orange (10YR 7/4) on weathered surface, massive, friable, fine-grained, well rounded, grades into E12 and E10, forms weak ledges	6
E10	Sandstone; siliceous cement, nonporous, white (N9) on fresh surface, grayish-orange-pink (5YR 7/2) on weathered surface, massive, very fine-grained, well rounded, well cemented, grades into E11 and E9, forms resistant ledges	6
E9	Sandstone; conglomeratic, siliceous cement, bluish-white (5B 9/1) on fresh surface (over-all), very pale orange (10YR 8/2) on weathered surface, irregularly bedded, friable, sand fraction coarse-grained, angular chert pebbles from coarse-grained to 1.5 inches, pebbles white to light bluish-gray (5B 7/1), poorly cemented, grades into E10 and E8, forms prominent ledge	6
E8-5	Sandstone; siliceous cement, porous, color white (N9), pinkish-gray (5YR 8/1), and grayish-orange (10YR 7/4) on fresh surface, grayish-orange and other colors in distinct beds as thin as several millimeters, pale yellowish-brown (10YR 6/2) and grayish-orange (10YR 7/4) on weathered surface, massive, cross-bedded, zones of silicification, limonite specks, very fine- to fine-grained, well rounded, some frosted, grades into E9, sharp break with E4, ledge-former	10
E4	Sandstone; siliceous cement, porous, grayish-orange-pink (5YR 7/2) and irregular grayish-orange and white (10YR 7/4) and (N9) bands on fresh surface, pale brown (5YR 5/2) and grayish-orange (10YR 7/4) on weathered surface, massive, erratic cross-beds but well developed, fine- to Medium grained, well rounded, frosted, black specks, separated by sharp break from E5 and E3, minor cliff-former	11
E3	Sandstone; conglomeratic, siliceous cement, porous, white (N9) to bluish-white (5B 9/1) on fresh surface, grayish-orange (10YR 7/4) on	

UNIT NO.	DESCRIPTION	THICKNESS (feet)
	weathered surface, chert pebbles coarse to several inches, light bluish-gray (5B 7/1), crumbly, banded with orange limonite zones, medium-grained, well rounded, sharp upper and lower contacts, forms weak ledge	1
E2	Sandstone; siliceous cement, porous, grayish-orange (10YR 7/4) on fresh surface, light brownish-gray (5YR 6/1) on weathered surface, thin-bedded, friable, medium-grained, well rounded, well sorted, limonite bands, sharp upper and lower contacts, forms poor ledges	1
E1	Sandstone; conglomeratic, siliceous cement, porous, grayish-orange (10YR 7/4) on fresh surface, pale yellowish-brown (10YR 6/2) on weathered surface, thin-bedded, friable, medium-grained, well rounded, small 2- to 4-mm chert pebbles, gray, sharp contact with E2, base concealed by river, forms weak ledges	1
	Total measured Dakota thickness	215

MEASURED SECTION TWO

P = Penasco
Upper Cretaceous
Mancos and Mesaverde groups, incomplete section

LOCATION:

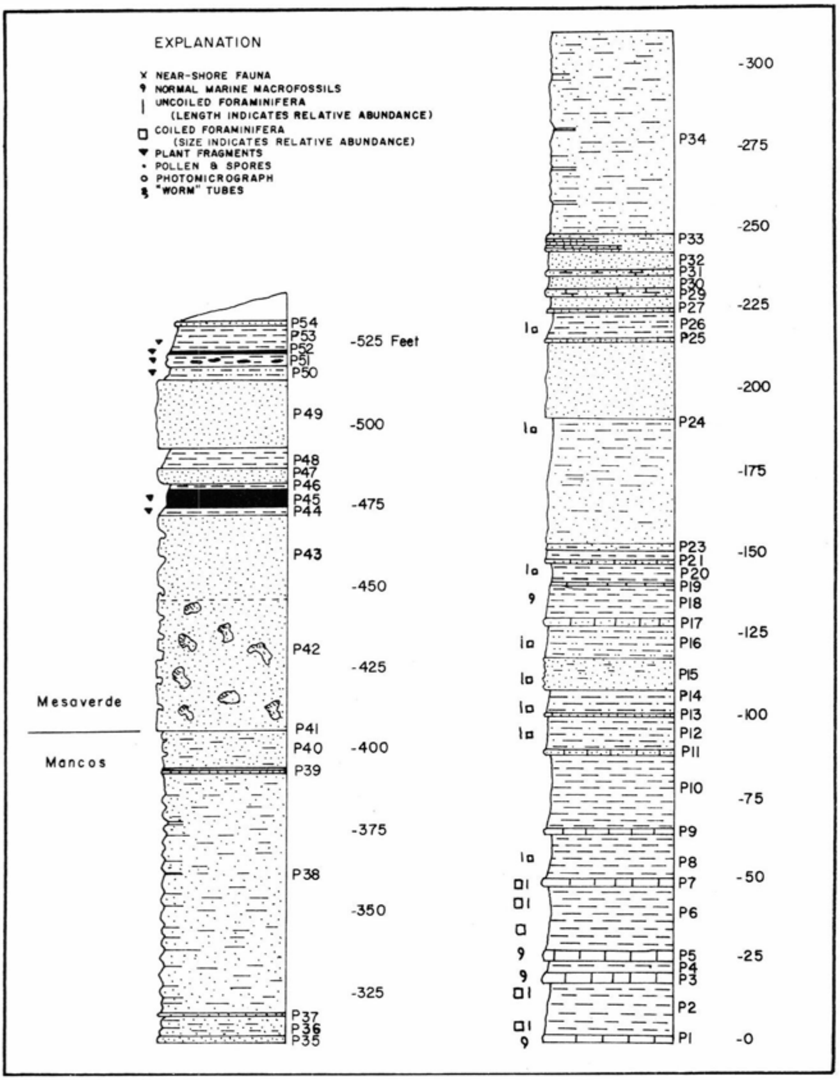
3.5 miles south of Tierra Amarilla, along U.S. 84. The section was measured from the base of a cliff that is part of the west limb of the Chama syncline. At the top of this section is Penasco B.M. 8148. Only the Mancos was measured here to the base of the Mesaverde. The Mesaverde part of the section was measured on the same synclinal limb along U.S. 84, 0.45 mile north of the Penasco B.M., where a more nearly complete upper part of the section is exposed.

MEASURED BY:

H. H. Doney (Mancos) 9 July 1955;
C. J. Mankin and H. H. Doney (Mesaverde) 6 Sept. 1957

UNIT NO.	DESCRIPTION	THICKNESS (feet)
	Mesaverde Group	
	Gravel Cover	
P54	Sandstone; pale brown (5YR 5/2) on fresh surface, grayish-orange-pink (5YR 7/2) on weathered surface; massive, fine-grained, well sorted, limonite stain; a 1-inch layer of limonite at top; ledge-former; sample 19	1
P53	Claystone; olive-gray (5Y 4/1) on fresh surface, light brownish-gray (5YR 6/1) on weathered surface; blocky, subconchoidal fracture, plant fragments; forms moderate slope; upper 4 feet covered; lower contact gradational; sample 18	8
P52	Coal; lignitic to subbituminous, black (N1), much poorly coalified plant material; limonite-stained plant fragments, sulfur; blocky fracture, forms weak slope; irregular thickness; upper and lower contacts gradational; sample 17	1
P51	Shale; brownish-black (5YR 2/1) on fresh surface, brownish-gray (5YR 4/1) on weathered surface; finely laminated to blocky; contains abundant plant material, stems and leaves; muscovite and biotite flakes; some included stringers of lignite; forms ledge; gradational upper and lower contacts; sample 16	4
P50	Siltstone; argillaceous, light olive-gray (5Y 5/2) on fresh surface, grayish-red-purple (5RP 4/2) on weathered surface; crumbly, limonite and forms moderate slope; sample 15	4
P49	Sandstone; very pale orange (10YR 8/2) on weathered surface grading upward into a pale yellowish-orange (10YR 8/4 to 8/6), slightly darker shades on fresh surface; massive, not so many black flecks as in sandstone units below, fine-grained, well sorted; forms steep cliff; gradational contact with overlying unit; samples 13 and 14	23
P48	Claystone; medium dark-gray (N4) on fresh surface, medium gray (N5) to grayish-red-purple (5 RP 4/2) on weathered surface, crumbly, limonite and hematite stains; some limonite layers; forms gentle slope; sample 12	6
P47	Sandstone; dusky yellow (5Y 6/4) on fresh surface, moderate yellow (5Y 7/6) on weathered surface; massive, fine-grained, salt-and-pepper-appearing, black lichen growth on surface, friable; forms prominent ledge; sample 11	5
P46	Claystone; brownish-black (5YR 2/1) on fresh surface, brownish-	

UNIT NO.	DESCRIPTION	THICKNESS (feet)
	gray (5YR 4/1) on weathered surface, subconchoidal fracture, carbonaceous flecks, micaceous specks, sulfur stain; forms gentle slope, basal contact gradational with coal, upper contact fairly sharp; sample 10	2
P45	Coal; lignite to subbituminous, black (N1) on fresh surface, brownish-gray (5YR 4/1) on weathered surface; blocky fracture, much visible plant material, sulfur and limonite stains; forms gentle slope, some shale interbeds; several adits, no present mining; pollen and spores present; sample 9	5
P44	Shale; clayey, brownish-gray (5YR 4/1) on fresh surface, light brownish-gray (5YR 6/1) on weathered surface; finely laminated to blocky, contains abundant plant remains and carbonaceous material, limonite stain; forms gentle slopes; lower boundary with coal gradational; sample 8	3
P43	Sandstone; grayish-orange (10YR 7/4) on fresh surface, very pale orange (10YR 8/2) on weathered surface; fine-grained, friable, massive, not vuggy, orange-speckled, salt-and-pepper appearance; minor carbonaceous material; forms cliff but not so steep as P42; contact between this unit and next lower is gradational; samples 6 and 7	25
P42	Sandstone; moderate olive-brown (5Y 4/4) on fresh surface, dusky yellow (5Y 6/4) on weathered surface, grading upward to yellowish-gray (5Y 8/1), at top this lighter unit is speckled by gray and brown spots; very fine-grained, well sorted, friable, minor carbonaceous matter giving speckled appearance; forms sheer cliffs; sharp contact with siltstone below; samples 2, 3, 4, and 5	40
	Total measured Mesaverde thickness	127
	Mancos Group	
P41	Siltstone; medium dark-gray (N4) to dark-gray (N3) on fresh surface, medium light-gray (N6) to medium-gray (N5) on weathered surface; thin-bedded to blocky; numerous carbonaceous fragments; minor amount of mica; sample 1	1/4
P40	Sandstone; color as P39; massive, with small amount of platy bedding, very fine-grained; forms moderately steep cliff	11
P39	Sandstone; moderate olive-brown (5Y 4/4) on fresh surface, dusky yellow (5Y 6/4) on weathered surface; massive in basal foot, platy in upper foot, much carbonaceous material; basal foot forms ridge, upper foot forms steep slope	2



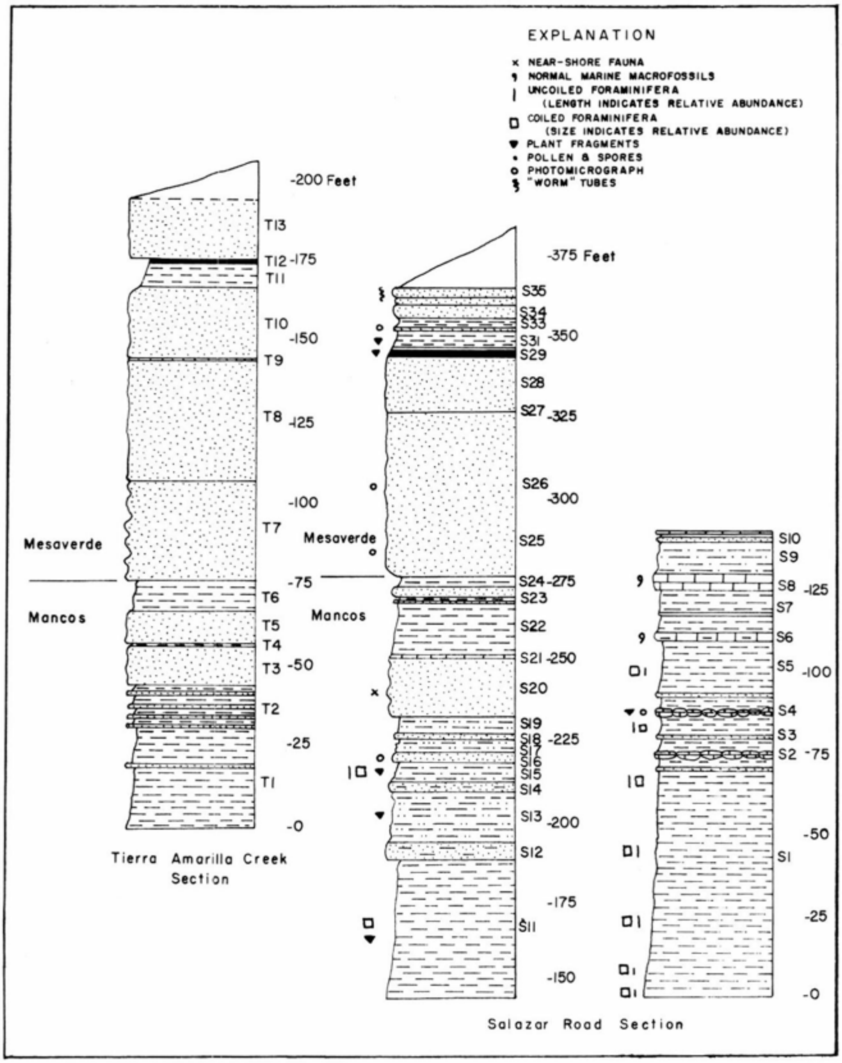
Columnar section of the Mancos and Mesaverde groups at Peñasco (B.M. 8148) 3.5 miles south of Tierra Amarilla, 800 feet east of U.S. 84

UNIT NO.	DESCRIPTION	THICKNESS (feet)
P38	Sandstone; argillaceous, at base light olive-gray (5Y 5/2) on fresh surface becoming moderate olive-brown (5Y 4/4) toward top, weathered surface at base yellowish-gray (5Y 7/2) becoming dusky yellow (5Y 6/4) toward top; fine-grained, even-bedded, platy, carbonaceous material abundant increasing upward; forms steep slope with weak ridges and hollows; samples 25 (base) and 26 (top)	74
P37	Sandstone; dusky yellow (5Y 6/4) on fresh surface, dark grayish-yellow (5Y 7/4) on weathered surface; very fine-grained, platy, much carbonaceous material; forms prominent ridge	1-1/4
P36	Sandstone; argillaceous, dusky yellow (5Y 6/4) on fresh surface, dark grayish-yellow (5Y 7/4) on weathered surface; very fine-grained, platy, weakly bedded, carbonaceous; forms weak ridges	6
P35	Sandstone; dusky yellow (5Y 6/4) on fresh surface, dark grayish-yellow (5Y 7/4) on weathered surface; very fine-grained, massive, salt-and-pepper appearance; forms ridge; sample 24	2
P34	Sandstone; argillaceous, light olive-gray (5Y 5/2) on fresh surface, yellowish-gray (5Y 7/2) on weathered surface; very fine-grained, platy, carbonaceous specks abundant; forms weak ridges; gradational with lower unit; sample 23	62-1/4
P33	Sandstone; medium olive-gray (5Y 4/2) on fresh surface, dark yellowish-gray (5Y 6/2) on weathered surface; very fine-grained, platy, shaly; prominent ridge-former, much carbonaceous material; sample 22	5
P32	Sandstone; argillaceous, light olive-gray (5Y 5/2); very fine-grained, thin-bedded, salt-and-pepper appearance; abundant carbonaceous material; forms moderate slope	6-1/2
P31	Sandstone; calcareous, pale olive (10Y 6/2); very fine-grained, finely bedded, salt-and-pepper appearance; more limy on top and bottom; ridge-former; much carbonaceous material	2
P30	Sandstone; light olive-gray (5Y 5/2) on fresh surface, yellowish-gray (5Y 7/2) on weathered surface; chunky, very fine-grained; much carbonaceous material; forms steep slope. sample 21	3-3/4
P29	Sandstone; calcareous, medium yellow (5Y 7/4); fine-grained, concretionary; ridge-former	2
P28	Sandstone; light gray (N7); fine-grained, chunky fracture; abundant carbonaceous material; forms steep slope	4-1/4

UNIT NO.	DESCRIPTION	THICKNESS (feet)
P27	Sandstone, argillaceous, grayish-yellow (5Y 8/4), salt-and-pepper appearance; fine-grained, platy; ridge-former; unfossiliferous	1/2
P26	Shale; arenaceous, olive-gray (5Y 4/1) on fresh surface, light olive-gray (5Y 6/1) on weathered surface; finely laminated, fractures into chunks; forms moderate slope. microfossils fairly abundant, elongate forms more numerous than coiled forms, much carbonaceous material; sample 20	7-3/4
P25	Sandstone; calcareous, olive-gray (5Y 4/1) on fresh surface, light olive-gray (5Y 6/1) on weathered surface; forms prominent ridge; blocky fracture; abundant carbonaceous material; sample 19	1-1/2
P24	Sandstone; upper third of unit, argillaceous, light olive-gray (5Y 5/2) on fresh surface, yellowish-gray (5Y 7/2) on weathered surface, blocky and platy, fine-grained, micaceous, carbonaceous, much limonite stain; forms moderate slope; lower contact gradational, no microfossils	
	Shale; middle third of unit, arenaceous, medium olive-gray (5Y 4/2) on fresh surface, yellowish-gray (5Y 7/2) on weathered surface, fissile to platy; limonite stain, carbonaceous remains abundant; gypsum included; forms moderate slope; gradational above and below; microfossils rare, elongate forms more numerous than coiled forms	
	Sandstone; basal third of unit, moderate olive-brown (5Y 4/1) on fresh surface, dusky yellow (5Y 6/4) on weathered surface; platy, chunky, fine-grained, carbonaceous, finely laminated, micaceous; forms moderate slope; upper and lower contact gradation; microfossils absent	62-1/4
P23	Sandstone; argillaceous, light olive-gray (5Y 5/2) on fresh surface, yellowish-gray (5Y 7/2) on weathered surface; platy; fine-grained; abundant carbonaceous material; forms moderate slope; gradational upper and lower contacts	2
P22	Sandstone; argillaceous, olive-gray (5Y 4/1) on fresh surface, light olive-gray (5Y 6/1) on weathered surface; platy, fine-grained, carbonaceous fragments abundant; forms moderate slope; gradational upper boundary; microfossils rare, elongate forms more numberous than coiled forms; sample 15	3
P21	Sandstone; argillaceous, olive-gray (5Y 4/1) on fresh surface, light olive-gray (5Y 6/1) on weathered surface; platy, fine-grained; forms small ledge; abundant megafossils	3/4
P20	Shale; arenaceous, olive-gray (5Y 4/1) on fresh surface, light olive–	

UNIT NO.	DESCRIPTION	THICKNESS (feet)
	gray (5Y 6/1) on weathered surface; blocky fracture; forms moderate slope; unfossiliferous	5-3/4
P19	Sandstone; calcareous, olive-gray (5Y 4/1) on fresh surface; platy, carbonaceous, micaceous; forms small ledge	1/2
P18	Shale; slightly arenaceous, olive-gray (5Y 4/1) on fresh surface, light olive-gray (5Y 6/1) on weathered surface; blocky; moderate slope-former; abundant megafossils, Baculites; sample 14	11-1/4
P17	Sandstone; calcareous, light olive-gray (5Y 6/10 on fresh surface, yellowish-gray (5Y 8/1) on weathered surface; block; ledge-former; megafossils rare	2
P16	Shale; arenaceous, olive-gray (5Y 4/1) on fresh surface, light olive-gray (5Y 6/1) on weathered surface; very fine-grained, blocky; calcite veins perpendicular to bedding; micaceous; forms moderate slope; basal contact gradational; microfossils scarce, elongate forms dominant over coiled forms; sample 13	9-3/4
P15	Sandstone; argillaceous, olive-gray (5Y 4/1) on fresh surface, light olive-gray (5Y 6/1) on weathered surface; very fine-grained; blocky and slabby; micaceous; forms ridges; upper and lower contacts gradational	10
P14	Shale; arenaceous, olive-gray (5Y 4/1) on fresh surface, light olive-gray (5Y 6/1) on weathered surface; very fine-grained sandstone toward top; forms moderate slope; grades upward into P15; muscovite and biotite increasing microfossils rare, both coiled and elongate forms present and equal; plant fragments scarce; sample 12	7
P13	Sandstone; argillaceous, olive-gray (5Y 4/1) on fresh surface, light olive-gray (5Y 6/1) on weathered surface; fractures to blocky pieces, fine-grained, carbonaceous and micaceous, fractures filled with calcite; forms small ledge; grades at base and top into shale; Inoceramus prisms present, microfossils rare, all arenaceous, coiled forms predominant over elongate forms, plant fragments abundant; sample 11	1
P12	Shale; arenaceous, olive-gray (5Y 4/1) on fresh surface, medium olive-gray (5Y 5/1) on weathered surface; fractures into chunky pieces; scattered mica flakes; forms moderate slope; grades into overlying unit; microfossils scarce, elongate forms predominant; minor plant fragments; sample 10	10-1/4
P11	Limestone; arenaceous, greenish-gray (5GY 6/1); lenses of concretionlike blocks; forms moderate ledge; sparsely fossiliferous	1-3/4

UNIT NO.	DESCRIPTION	THICKNESS (feet)
P10	Shale; arenaceous, olive-gray (5Y 4/1) on fresh surface, light olive-gray (5Y 6/1) on weathered surface; blocky fracture; limonite stain and mica flakes common; forms a moderate slope; microfossils rare, elongate and arenaceous only; plant fragments abundant; sample 9	22
P9	I imestone; arenaceous, greenish-gray (5G 6/1); lenticular to concretionary; forms small ledge; appears unfossiliferous	1-1/2
P8	Shale; slightly arenaceous, dark gray (N3) on fresh surface, medium gray (N5) on weathered surface; blocky; forms moderate slope; microfossils fairly abundant, elongate forms dominant over coiled forms; sample 8	13-3/4
P7	Limestone; argillaceous, greenish-gray (5GY 6/1); concretionlike lenses; much vein calcite filling fractures; ledge-former; few megafossils, abundant microfossils, coiled and elongate forms about equal, mostly arenaceous; sample 7	2-3/4
P6	Shale; slightly arenaceous, dark gray (N3) on fresh surface, medium gray (N5) on weathered surface, limonite stain common in basal half of unit; blocky in basal half, fissile in upper half; forms moderate slope; coiled and elongate microfossils about equally abundant, all arenaceous; samples 5 and 6	20-1/2
P5	Limestone; argillaceous, pale yellowish-brown (10YR 6/2); concretionlike lenses; form ledge; megafossils present but scarce, microfossils rare, coiled forms dominant over elongate forms	3
P4	Shale; slightly arenaceous, dark gray (N3) on fresh surface, medium gray (N5) on weathered surface; blocky; forms moderate slope	4
P3	Limestone; argillaceous, pale yellowish-brown (10YR 6/2); concretionlike lenses; forms small ledge; abundant megafossils, Inoceramus common, scarce, microfossils, coiled forms dominant over elongate forms, pollen and spores present but rare; sample 3	3
P2	Shale; arenaceous, dark gray (N3) on fresh surface, light gray (N7) on weathered surface; blocky, weathering into small pieces; many light-gray stringers running through the shale; forms a moderate slope; gradational contacts at top and bottom; microfossils scarce, all arenaceous, coiled forms predominant, pollen and spores present but scarce; sample 1 and 2	16
P1	Limestone; arenaceous, pale brown (5YR 5/2) on fresh surface, yellowish-orange (10YR 7/6) on weathered surface; concretionlike	



COLUMNAR SECTIONS OF THE MANCOS AND MESAVERDE GROUPS

The Tierra Amarilla Creek section is 4 miles southeast of Tierra Amarilla, 750 feet north of Rito de Tierra Amarilla, on the southwest flank of Peñasco Amarillo. The Salazar Road section is 1.5 miles west of the Tierra Amarilla Creek section on the south side of a residual Mancos ridge separating Rio Nutrias and Rito de Tierra Amarilla valleys. The section is west of the road connecting these valleys.

UNIT NO.	DESCRIPTION	THICKNESS (feet)
	lenses, many irregualr fractures; ledge-former; shale and cover below; abundant megafossils, Inoceramus and Baculites	2
	Total measured Mancos thickness	407

MEASURED SECTION THREE

S = Salazar
Upper Cretaceous
Mancos and Mesaverde groups, incomplete section

LOCATION:

On the west side of graded dirt road that branches northeast from U.S. 84, 3.6 miles north of intersection of U.S. highway and the Rio Nutrias. The dirt road crosses the divide that separates the valleys of the Rio Nutrias and Rito de Tierra Amarilla. This section is at the base of the divide in the Rio Nutrias valley. The outcrop is part of the east limb of the Chama syncline; dip is about 7 degrees east.

MEASURED BY:

H. H. Doney, 26 August 1955

UNIT NO.	DESCRIPTION	THICKNESS (feet)
	Mesaverde Group	
	Gravel cover	
S35	Sandstone; dark yellowish-orange (10YR 6/6) on fresh surface, weathers to grayish-orange (10YR 7/4); friable, thin-bedded, fine-grained, angular, poorly sorted, limonite stain, displays many worm tubes; ledge-former; sample 35	3
S34	Sandstone; argillaceous, pale greenish-yellow (10Y 8/2), weathers to yellowish-gray (5Y 7/2); friable, thin-bedded, very fine-grained, sub-angular, poorly sorted, forms weak ledges; sample 34	6

UNIT NO.	DESCRIPTION	THICKNESS (feet)
S33	Shale; arenaceous, gray and pale brown (5YR 5/2), weathers to light yellowish-gray (5Y 7/2); crumbly, some limonite stain	2-1/2
S32	Sandstone; grayish-orange (10YR 7/4), weathers to grayish-orange-pink (5YR 7/2); thin-bedded, friable, fine-grained, small ledge-former; sample 33	1/2
S31	Shale; silty, pale brown (5YR 5/2), weathers to pale yellowish-brown (10YR 6/2); blocky contains coalified plant material; forms gentle slope; sample 32	5
S30	Shale; grayish-brown (5YR 3/2), weathers to pale brown (5YR 5/2); fissile, platy, contains abundant plant impressions and carbonaceous material; grades into coal below; sample 31	1/2
S29	Coal; subbituminous, dull to pitch black (N1), contains light brownish-gray (5YR 6/1) fragments of plant material, parts nearly parallel to bedding; some tendency to cubic fracture, minor sulfur; sample 30	2
S28	Sandstone; coaly, grayish-red (5R 4/2), weathers to blackish-red (5R 2/2); friable, fine-grained, subangular, poorly sorted, coaly partings and random veinlets of coal grading into coal above; weak ledge-former; sample 29	2
S27	Sandstone; limonite-stained ledge	1/2
S26	Sandstone; pale greenish-yellow (10Y 8/2), weathers to pale yellowish-brown (10YR 6/2); massive, fine-grained, angular, poorly sorted, low porosity; fresh surface has a salt-and-pepper appearance resulting from a mixture of dark and light grains, contains limonite ledge S27 and grades into S28 above; massive, cliff-former; sample 28	43
S25	Sandstone; grayish-yellow (5Y 8/4), weathers to yellowish-gray (5Y 7/2); massive, friable, fine-grained, subrounded, poorly sorted, grades into S26 above; cliff-former; sample 27	23
	Thickness of exposed Mesaverde Group	88
	Mancos Group	
S24	Shale; chunky, medium gray (N5), weathers to light gray (N7), contains grayish-orange (10YR 7/4) limonite zones, some gypsum; sample 26	3

UNIT NO.	DESCRIPTION	THICKNESS (feet)
S23	Sandstone; grayish-yellow (5Y 8/4), weathers to yellowish-gray (5Y 7/2); friable, blocky, fine-grained, subangular; contains a 9-inch dark-gray (N3) shale parting; forms small ledge	5
S22	Shale; medium gray (N5), weathers to medium light-gray (N6); slabby, gentle slope-former; sample 25	16
S21	Sandstone; calcareous, grayish-red (10R 4/2), weathers to medium light-gray (N6); slabby, fine-grained, poorly sorted; forms small ledge; sample 24	1
S20	Sandstone; grayish-yellow (5Y 8/4), weathers to yellowish-gray (5Y 7/2); friable, blocky, fine-grained, subangular, poorly sorted; cliff-former	18
S19	Shale; arenaceous, medium gray (N5), weathers to light gray (N7); chunky, abundant carbonaceous material; slope-former; sample 23	5
S18	Sandstone; light dusky yellow (5Y 6/2), weathers to yellowish-gray (5Y 7/2); friable, thin-bedded, fine-grained, poorly rounded, poorly sorted; ledge-former	2
S17	Shale; arenaceous, medium gray (N5), weathers to light gray (N7); chippy, carbonaceous material; forms small break in slope	4
S16	Sandstone; light dusky yellow (5Y 6/2), weathers to yellowish-gray (5Y 7/2); friable, medium-bedded, very fine-grained, angular, poorly sorted, carbonaceous material present; ledge-former; sample 22	3
S15	Shale; arenaceous, olive-gray (5Y 3/2), weathers to yellowish-gray (5Y 7/2)? chunky, crumbly, limonite stain, contains abundant plant fragments; forms gentle slope; sample 21	6
S14	Sandstone; argillaceous, moderate yellow (5Y 7/6), weathers to dusky yellow (5Y 6/4); thin-bedded, friable, fine-grained, subangular, poorly sorted, limonite stain; small ledge-former	3
S13	Shale; arenaceous, light olive-gray (5Y 5/2), weathers to yellowish-gray (5Y 7/2); breaks into small irregularly shaped pieces, plant fragments, limonite stain; sample 20	16
S12	Sandstone; argillaceous, grayish-orange (10YR 7/4), weathers to pale yellowish-brown (10YR 6/2); friable, thin-bedded, fine-grained, subrounded, poorly sorted; prominent ledge-former; sample 19	7
S11	Shale; silty, light olive-gray (5Y 5/2), weathers to yellowish-gray (5Y	

UNIT NO.	DESCRIPTION	THICKNESS (feet)
	7/2); chunky, plant fragments; gentle slope-former; sample 18, 17, and 16	43
S10	Limestone; arenaceous, argillaceous, light gray (N7), weathers to yellowish-gray (5Y 7/2); unfossiliferous; irregular ledge; sample 15	1
S9	Shale; silty, calcareous, dark gray (N3), weathers to light gray (N7); stringers of olive sandstone near top; breaks into small pieces; moderate slope-former	10
S8	Limestone; silty, carbonaceous, light gray (N7), weathers to very light gray (N8); thin-bedded, crystalline; forms prominent ledge; very fossiliferous; sample 14	5
S7	Shale; silty, grayish-black (N2), weathers to medium light-gray (N6); fissile slope-former; thin 1-foot bed of calcareous, arenaceous shale in middle	13
S6	Limestone; argillaceous, light gray (N7); thin-bedded, ledge-former; fossiliferous, Inoceramus and Baculites; sample 13	1-1/2
S5	Shale; silty, light olive-gray (5Y 6/1), weathers to yellowish-gray (5Y 7/2); thin 1-foot basal bed of calcareous, shaly sandstone; slope-formed samples 12 and 11	21
S4	Limestone; arenaceous, biointramicrite, light gray (N7); contains much carbonaceous material, nodular, small crystals; prominent ledge; sample 10	1
S3	Shale; silty, calcareous, medium dark-gray (N4), weathers to light gray (N7); chunky; slope-former; medial 1-foot bed of calcareous, shaly, yellowish-gray sandstone	11
S2	Limestone; silty, arenaceous, light gray (N7), weathers to medium gray (N6); crystalline, massive, nodular; sample 7	2
S1	Shale; calcareous, silty, medium dark-gray (N4), weathers to medium gray (N5); blocky, gypsiferous; near top is 1-foot bed of light olive-gray calcareous, shaly sandstone; slope-former; samples 6, 5, 4, 3, 2, and 1	74
	Total thickness of exposed Mancos Group	271-1/2

MEASURED SECTION FOUR

T = Tierra Amarilla

Upper Cretaceous
Mancos and Mesaverde groups, incomplete section

LOCATION:

Unit T1 is at the base of a hill 8200 feet above sea level and north of Rito de Tierra Amarilla 2.5 miles southeast of the town of Tierra Amarilla. The hill on which the section was measured is an outlier from the main mass of the mesaverde Group that underlies Penasco Amarillo.

MEASURED BY:

C.J.Mankin and H.H. Doney, 5 September 1957

UNIT NO.	DESCRIPTION	THICKNESS (feet)
	Mesaverde Group	
	Gravel cover	
T13	Sandstone; silty, porous, yellowish-gray (5Y 7/2), weathers to moderate yellow (5Y 7/6); very fine-grained, massive, subangular, poorly sorted, heavy minerals impart a speckled appearance, cross-bedded; ledge-former; at base of the unit are tubercular structures, **Halymenites** cf. **striatus**; sample 18, 17, and 16	19
T12	Coal; lignite-subbituminous, brownish-black (5YR 2/2), shaly to blocky, sulfurous, plant fragments; sample 14	1
T11	Claystone; silty, argillaceous, grayish-red (5R 4/2), weathers to pale red (10R 6/2); blocky, plant fragments very abundant, mixed with small stringers of very fine-grained sandstone; samples 15 and 13	7
T10	Sandstone; porpous, silty, grayish-orange (10YR 7/4); friable, very fine-grained, subrounded, poorly sorted; cliff-former; sample 12	22
T9	Sandstone; porous, micaceous, moderate yellowish-brown (10YR 5/4); thin-bedded, friable; thin ledge-former; sample 11	1
T8	Sandstone; porous, silty, micaceous, pale olive (10Y 6/2); massive, friable, very fine-grained, poor sorting, poor rounding; cliff-former; sample 10	37
T7	Sandstone; porous, silty, dusky yellow (5Y 6/4), weathers to light	

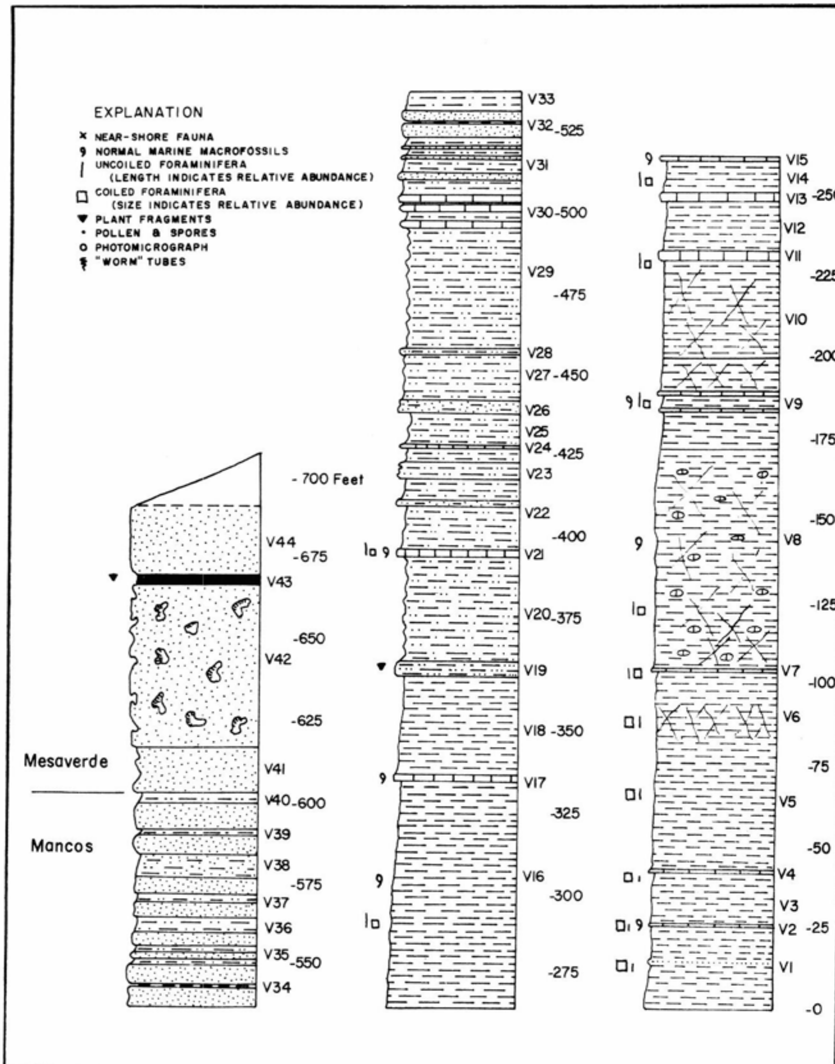
UNIT NO.	DESCRIPTION	THICKNESS (feet)
	olive-gray (5Y 5/2); massive friable, very fine-grained, poorly sorted, subangular; many black minerals give a pepper appearance over the surface; forms rounded cliff face; sample 9	31
	Total exposed Mesaverde	118
	Mancos Group	
T6	Shale; clayey, calcareous, medium light-gray (N6), weathers lighter; carbonaceous material, blocky; slope-former	9
T5	Sandstone; calcareous, silty, yellowish-gray (5Y 7/2); friable, very fine-grained, massive, ledge-former; sample 8	10
T4	Shale; clayey, silty, calcareous, medium light-gray (N6), weathers lighter; carbonaceous material, blocky; slope-former; sample 7	1
T3	Sandstone; calcareous, silty, carbonaceous, yellowish-gray (5Y 7/2), weathers darker; very fine-grained and silty, angular, poorly sorted; ledge-former; sample 6	12
T2	Interbeds; shale, silty, fissile, carbonaceous, medium light-gray (N6), slope-former; sandstone, silty, calcareous, carbonaceous, micaceous, dusky yellow (5Y 6/4); ledge-former; samples 5 and 4	13
T1	Shale; clayey, chunky, silty, medium light-gray (N6); slope-former; 1-foot bed of thin-bedded, silty, carbonaceous, calcareous, greenish-gray (5GY 6/1); very fine-grained sandstone, medial; ledge-former; samples 3, 2, and 1	31
	Total measured Mancos	76

MEASURED SECTION FIVE

V = El Vado
Upper Cretaceous
Mancos and Mesaverde groups, incomplete section

LOCATION:

This section was measured from the base to the top of a mesa 3 miles southwest of the village of El Vado on the northwest side of N. Mex. 112. The base of the section is 7550 feet above sea level (determined by Paulin



COLUMNAR SECTION OF THE MANCOS AND MESAVERDE GROUPS 3.5 MILES SOUTHWEST OF EL VADO DAM WEST OF N.M. 112

barometer). This section is not in the map area but is included because of its position on the west side of the Chama Basin.

MEASURED BY:

H. H. Doney, 14 August 1955

UNIT NO.	DESCRIPTION	THICKNESS (feet)
	Mesaverde Group	
	Gravel cover	
V44	Sandstone; porous, yellowish-gray (5Y 7/2); many carbonaceous fragments give it a speckled salt-and-pepper appearance; fine-grained, subrounded, friable, massive, cliff-former	21
V43	Coal; shaly, subbituminous, grayish-black (N2), breaks into slabs, sulfurous	3
V42	Sandstone; silty, calcareous, pale olive (10Y 6/2); very fine-grained, vuggy, massive, carbonaceous flakes; cliff-former; samples 35, 34, and 33	50
V41	Sandstone; silty, calcareous, pale olive (10Y 6/2); very fine-grained, friable, subangular, speckled with carbonaceous material; cliff-former; samples 32a and 32b	14
	Total measured Mesaverde	88
	Mancos Group	
V40	Shale; clayey, medium gray (N5), with brownish-gray (5Y 4/1) laminae; chunky; slope-former; sample 31	3
V39	Sandstone; silty, calcareous, light olive-gray (5Y 5/2); carbonaceous specks, very fine-grained, massive; ledge-former; thin, 1-foot, clayey, medium-gray (N5) shale interbed; sample 29	16
V38	Sandstone; porous, silty, carbonaceous, yellowish-gray (5Y 7/2); very fine-grained, friable, thin-bedded; ledge-former	7
V37	Interbedded sandstone and shale; sandstone, silty, calcareous, carbonaceous, micaceous, light olive-gray (5Y 5/2); very fine-grained, angular, poorly sorted, friable; ledge-former; shale, middle 3 feet, arenaceous, medium light-gray (N7); blocky; samples 27 and 26	12

UNIT NO.	DESCRIPTION	THICKNESS (feet)
V36	Shale; silty, calcareous, carbonaceous, medium gray (N5); blocky; slope-former	5
V35	Interbedded sandstone and shale; sandstone, silty, calcareous, carbonaceous, micaceous, light olive-gray (5Y 5/2); very fine-grained, friable; ledge former; shale, silty, carbonaceous, calcareous, medium light-gray (N7); blocky; slope-former; sample 25 and 24	10
V34	Sandstone; silty, calcareous, light olive-gray (5Y 6/1), speckled with carbonaceous material; very fine-grained, friable; ledge-former; shale parting, 1 foot, light gray (N7), clayey, blocky, carbonaceous	13
V33	Shale; silty, carbonaceous, medium light-gray (N6); blocky, pale reddish-brown laminae; slope former.	6
V32	Sandstone; silty, porous, carbonaceous, pale olive (10Y 6/2); massive, friable, very fine-grained; ledge-former; 1-foot shale parting, light gray (N7); carbonaceous, calcareous, blocky; slope-former	8
V31	Interbedded sandstone and shale; sandstone, silty, porous, carbonaceous, yellowish-gray (5Y 8/1); friable, thin-bedded, fine-grained, poorly rounded; ledge-former; shale dark gray (N3), carbonaceous, chunky; slope-former; sample 22	18
V30	Limestone; arenaceous, dark gray (N3), weathers light gray (N7); aphanitic, nodular, fractured, fossiliferous, nearshore; ledge-former; interbeds of shale, arenaceous, medium light-gray (N7); blocky, carbonaceous, slightly calcareous, gypsum crystals; slope-former; samples 21 and 20	10
V29	Interbedded shale and sandstone; shale, silty, calcareous, dark gray (N3); blocky; slope former; sandstone, argillaceous, yellowish-gray (5Y 7/2); very fine-grained; minor ridge-former	37
V28	Shale; arenaceous, calcareous, carbonaceous, yellowish-gray (5Y 7/2); blocky; ledge-former; sample 19	2
V27	Shale; silty, calcareous, carbonaceous, greenish-gray (5GY 6/1); blocky; slope-former	14
V26	Sandstone; argillaceous, carbonaceous, calcareous, dark gray (N3); friable, very fine-grained; ledge-former; sample 18	4
V25	Shale; silty, calcareous, medium light-gray (N6); plant remains, blocky; slope-former	10
V24	Limestone; nodular, concretionary, septaria, yellowish-gray (5Y 8/1)	

UNIT NO.	DESCRIPTION	THICKNESS (feet)
	to medium light-gray (N6), aphanitic, coarse-grained veins, limonite stain; ledge-former; sample 17	1
V23	Shale; silty, light gray (N7), calcareous, carbonaceous, fissile, slope-former grades into arenaceous light gray (N7) calcareous, carbonaceous, blocky, minor ledge-former	9
V22	Shale; arenaceous, carbonaceous, calcareous, greenish-gray (5GY 6/1); blocky; slope-former; sandstone parting, shaly, yellowish-green (5Y 8/1); very fine-grained, carbonaceous, friable; ledge-former; sample 16	22
V21	Limestone; aphanitic, yellowish-gray (5Y 8/1); fossiliferous, slabby, ledge-former; sample 15	2
V20	Shale; silty, medium light-gray (N6); carbonaceous, blocky; slope-former	32
V19	Sandstone; calcareous, silty, carbonaceous, light olive-gray (5Y 5/2); thin-bedded, blocky, very fine-grained, poorly sorted, abundant plant fragments; ledge-former; sample 14	5
V18	Shale; silty, carbonaceous, dark gray (N3), weathers to light gray (N7); fissile; slope-former	30
V17	Limestone; yellowish-gray (5Y 8/1); lenticular, fossiliferous, aphanitic; ledge-former	2
V16	Shale; silty, dark gray (N3); fissile to blocky, flakey, fossiliferous; slope-former; sample 12	70
V15	Limestone; lenticular, pale brown (5YR 5/2); aphanitic; fossiliferous, **Baculites**; ledge-former	1/2
V14	Shale; clayey, dark gray (N3); fissile; slope-former	9-1/2
V13	Limestone; concretionary, septaria, pale yellowish-brown (10YR 6/2); aphanitic; unfossiliferous; 3-foot concretions; ledge-former; sample 11	3
V12	Shale; clayey, greenish-gray (5GY 6/1); thin-bedded, fissile, gypsiferous; slope-former	15
V11	Limestone; nodular, concretionary, 2.5-foot diameter average, pale brown (5YR 5/2); aphanitic; ledge-former	2-1/2
V10	Shale; clayey, dark gray (N3); chunky to blocky, veins and stringers of gypsum, scattered limestone nodules; slope-former	40

UNIT NO.	DESCRIPTION	THICKNESS (feet)
V9	Limestone; lenticular, concretionary, carbonaceous, pale brown (5YR 5/2), weathers to dusky yellow (5Y 6/4); aphanitic; fossiliferous, **Baculities;** ledge-former; 4-foot shale parting, greenish-gray (5GY 6/1); silty, blocky; slope-former; sample 9	6
V8	Shale; clayey, dark gray (N3), weathers to medium light-gray (N6) and greenish-gray (5GY 6/1); fissile in part, blocky in part; calcareous, carbonaceous, gypsiferous, thin 1-inch dark yellowish-orange (10YR 6/6) and pale reddish-brown (10R 5/4) layer near top; limestone concretions 2 inches in diameter irregularly spaced; fossiliferous; gypsum veins and stringer throughout; slope-former; samples 8 and 7	79
V7	Limestone; silty, pale brown (5YR 5/2), weathers to grayish-orange (10YR 7/4); limonite stain, concretionary; unfossiliferous; ledge-former; sample 6	1
V6	Shale; silty, light olive-gray (5Y 5/2); yellowish-gray and dark-gray laminae; slabby, limonite stain, gypsum veins and coatings; slope-former; sample 5	20
V5	Shale; silty, slightly calcareous, dark gray (N3), weathers medium gray (N5); chunky; slope-former; sample 4	41
V4	Limestone; silty, carbonaceous, moderate yellowish-brown (10YR 5/4); concretionary; ledge-former; sample 3	1
V3	Shale; clayey, dark gray (N3); fissile, paper thin; slope-former; sample 2	17
V2	Limestone; pale brown (5YR 5/2); concretionary; sparingly fossiliferous; carbonaceous; ledge-former; sample 2	1
V1	Shale; silty, carbonaceous, calcareous, dark gray (N3), weathers to light gray; chunky; slope-former; medial 2-foot sandstone, fine-grained grayish-orange (10YR 7/4); ledge-former; sample 1	26
	Total measured Mancos	610

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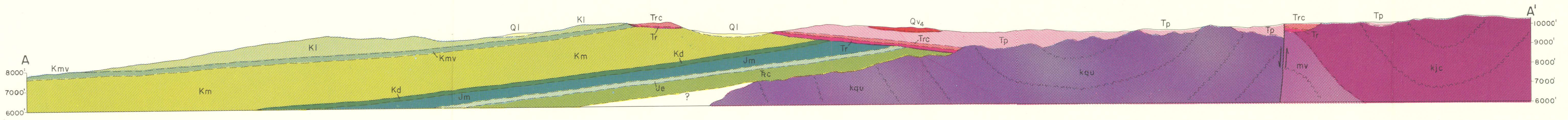
Numbers in **boldface** indicate main sections

Base from U.S. Geological Survey

Geology by Hugh Doney, Northeast Louisiana State College
Surveyed 1955-1958



EXPLANATION

QUATERNARY

Qal — Alluvium
Stream deposits, silt, silty sand, sand and gravel

Qs — Scree
Unstratified slope veneer of angular rock fragments

Qr — Rock streams
Unconsolidated stream-like masses of mainly Precambrian rock fragments

Ql — Landslides
Unstratified heterogeneous mixture of soil and bedrock. Dashed lines separate individual landslide lobes

Qt1–4 — Terraces
Poorly sorted gravel-capped remnants of earlier stream action

Qv1–6 — Volcanic cones and flows
Recent volcanic cinder cones and associated flows. Numbers do not relate to relative age

TERTIARY

Tp, Tpj — Los Pinos Formation
White and tan tuff with conglomeratic layers of volcanic fragments
Tpj–Jarita Basalt Member. *Flows of mainly olivine basalt*

Trc — Ritito Formation
Poorly lithified conglomerate consisting of Precambrian gravel with minor gray tuff

Tr — El Rito Formation
Red to pinkish well-cemented conglomerate consisting mainly of well-rounded Precambrian quartzite clasts

CRETACEOUS

Kl — Lewis Formation
Chiefly gray to brown calcareous marine shale with a few lenses of limestone and septarian concretions

Kmv — Mesaverde Group
Yellow, buff, and gray ripple-marked, cross-bedded thick sandstone. Middle part is brown silty shale with coal beds

Km, Kmo — Mancos Group
Chiefly gray, calcareous, marine shale containing many beds of fine-grained sandstone near the top of the unit and concretionary limestone lenses throughout
Kmo–*Basal thin zone of Ostrea congesta on Inoceramus prisms*

Kd — Dakota Formation
Yellow to buff locally conglomeratic sandstone with some beds of brown to black shale and coal in the middle part

JURASSIC (Upper Jurassic)

Jm — Morrison Formation
Chiefly green clay shale with beds of poorly sorted sandstone

Je — Entrada Formation
Cream-colored, fine-grained sandstone and siltstone

TRIASSIC (Upper Triassic)

Trc — Chinle Formation
Chiefly red shale with fine-grained sandstone and siltstone beds. Locally some coarse-grained sandstone

PRECAMBRIAN

mg — Maquinita Granodiorite
Gray granodiorite

br — Burned Mountain Metarhyolite
Reddish-orange metamorphosed rhyolite displaying flow structure

Kiawa Mountain Formation:

kqu — Upper quartzite member
Gray- to light-purple, massive, vitreous. crossbedded quartzite

kjc — Jawbone Conglomerate Member
Light-gray quartzite with darker gray pebbles, some elongated

mv — Moppin Formation
Schist, conglomerate, and phyllite containing veins of milky quartz with local mineralization

Contact
Dashed where approximately located; dotted where concealed

Fault (U / D)
Dashed where approximately located; dotted where concealed
U– upthrown side; D–downthrown side

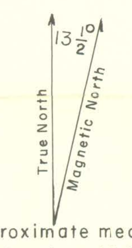
Anticline

Syncline

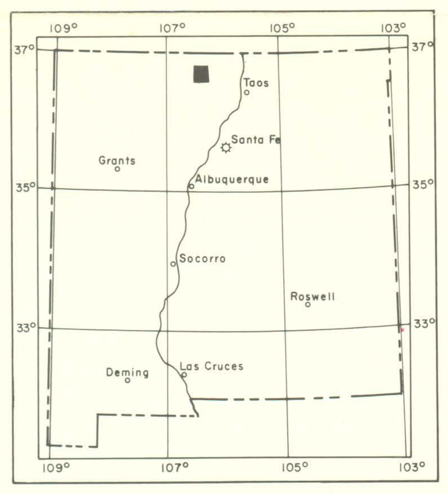
25 — **Strike and dip of beds**

Mines and prospect pits

Generalized direction of movement of landslides



Approximate mean declination 1965



GEOLOGIC MAP AND SECTION OF THE CEBOLLA QUADRANGLE NEW MEXICO

Scale 1:48,000

1 0 1 2 3 Miles

Contour interval 40 Feet
Datum is mean sea level