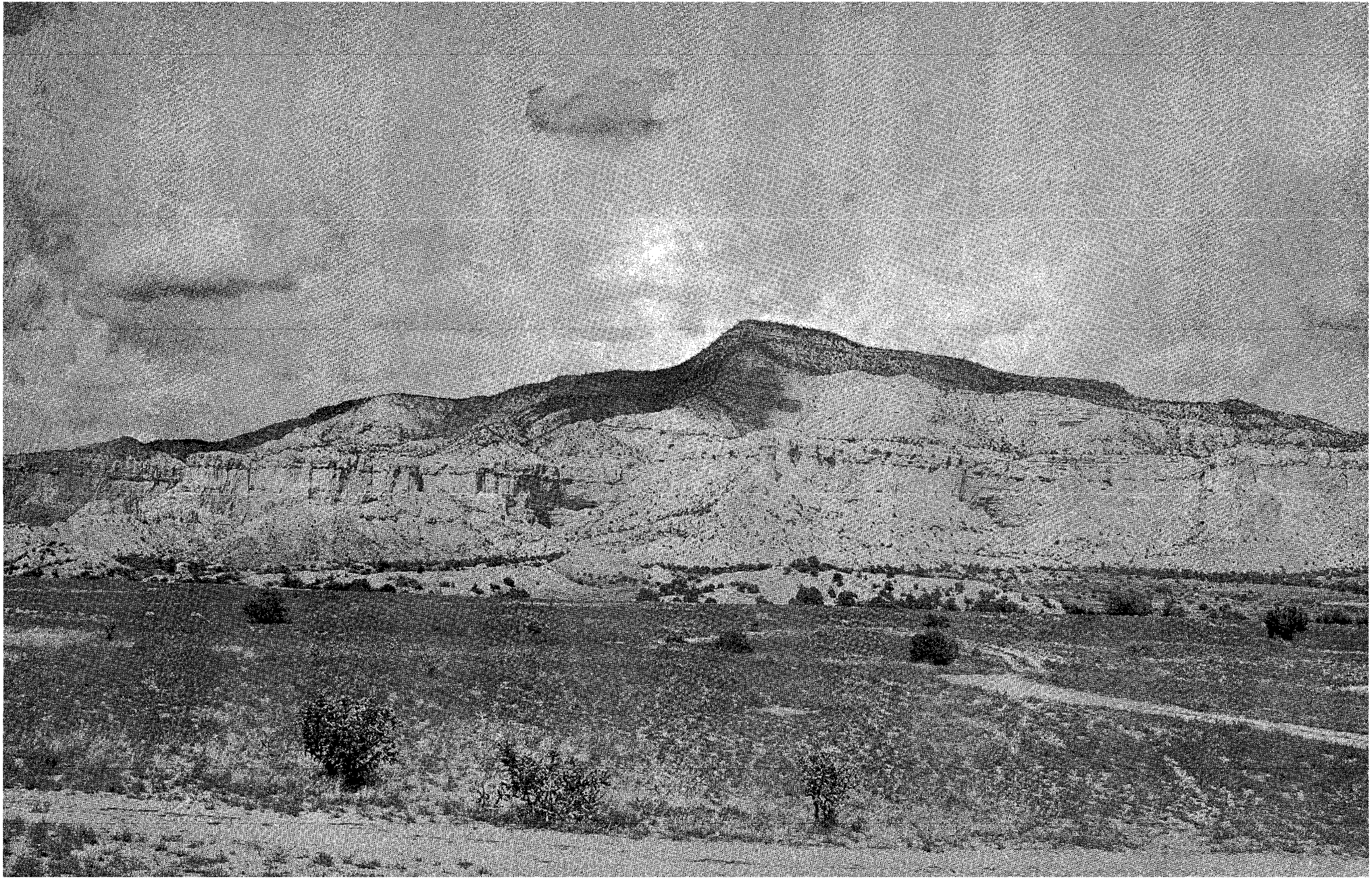

BULLETIN 75

Geology of the Southeastern Part of the Chama Basin

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Frontispiece

WEST END OF MESA MONTOSA LOOKING NORTHEAST FROM ARROYO SECO

Well-exposed Jurassic beds overlie Chinle formation at base of cliff and are capped by Dakota sandstone below top of Mesa.

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Abstract

The Chama Basin is a shallow basinal structure closely related to the San Juan Basin to the northwest and lying between the Rio Grande trough to the east and the northward extension of the Nacimiento uplift to the west. Late Paleozoic and Mesozoic sediments fill the southeastern part of the basin and Tertiary and Quaternary volcanic rocks and sediments overlap the older beds from the northeast and south. The southeastern part of the basin is characterized by broad open folds, and gentle regional dips to the north and west; steep normal faults with a north to northeast trend are prominent, and exhibit stratigraphic throws of 200 feet or more. Some of the faults in the extreme southeastern portion of the area have been filled by basalt. The basin was filled with marine Pennsylvanian rocks and nonmarine Permian rocks with scarcely any hiatus; the alternating marine and nonmarine environment continued throughout the Mesozoic, culminating in the extensive marine invasion of the upper Cretaceous Mancos sea. During Tertiary time widespread volcanism to the north, east, and south covered much of the area with tuffaceous debris, gravel fans, and lava. Glaciation was extensive during the Pleistocene in the northern part of the Chama Basin, but no glacial deposits can be identified in the southeastern part. However, solifluction and landsliding probably became pronounced under the periglacial conditions of the Pleistocene, and continued post-glacial erosion has developed the numerous terraces and alluvial fills found in the larger valleys.

Ranching and farming are the principal economic resources of the southeastern part of the Chama Basin. A paucity of water has hampered development. Sparse showings of uranium were staked, but no production has been developed. Two wells have been drilled in the southeastern part of the basin but no shows of oil or gas were encountered.

Introduction

GEOGRAPHY

The Chama Basin is a shallow basinal structure merging to the northwest with the much larger San Juan Basin. The Chama Basin is bounded on the west by Gallina Mountain and Capulin Mesa, northward extensions of the Nacimiento—San Pedro uplift, on the south by the Jemez plateau, on the southeast by the Arroyo del Cobre anticline, and on the northeast by the Brazos uplift (see fig. 1).

The area between 106° 15' and 106° 37' 30" west longitude and between 36° 15' and 36° 30' north latitude in the southeastern part of the basin was mapped during the early summer months of 1956 and 1957 by students from the New Mexico Institute of Mining and Technology and Louisiana State University. The Alire, Canjilon, Echo Amphitheater and Ghost Ranch quadrangles were studied in 1956, and the Magote Peak and Canjilon SE quadrangles were completed in 1957 (see index map).

The southern portion of the Chama Basin is an area of high mesas and low plains, intricately dissected by the Rio Chama and its ephemeral tributaries. Exposed bedrock ranges from a small outcrop of Pennsy1vanian rocks in the northeastern part of Arroyo del Cobre in the Canjilon SE quadrangle to the Tertiary Santa Fe formation. This formation conceals the older rocks along the southeast margin of the basin in the southeastern part of the Canjilon SE quadrangle. Quaternary surficial deposits mask bedrock in areas of low relief on the high mesas as well as in many of the lower canyons and gullies.

LOCATION

The area is served by a hard-surfaced highway, U.S. 84, which extends the length of the Chama Basin. New Mexico Highway 96, partly hard surfaced and partly a gravel road, marks approximately the southern and eastern boundaries of the basin, giving access to the southern parts of the Canjilon SE, Ghost Ranch, and Echo Amphitheater quadrangles. New Mexico Highway 110, a graveled road, follows El Rito Creek through the Magote Peak quadrangle and then turns westward to Canjilon, affording access to these two quadrangles.

A number of unimproved roads and jeep trails traverse the low plains and valleys in the southern tier of quadrangles. Similar roads branching from U.S. 84 as well as State Roads 96 and 110 lead into the high mesa areas in the northern quadrangles. However, although no part of the six quadrangles is more than three miles from some type of road or trail, the slopes between plain and mesa can be reached only on foot or horseback.

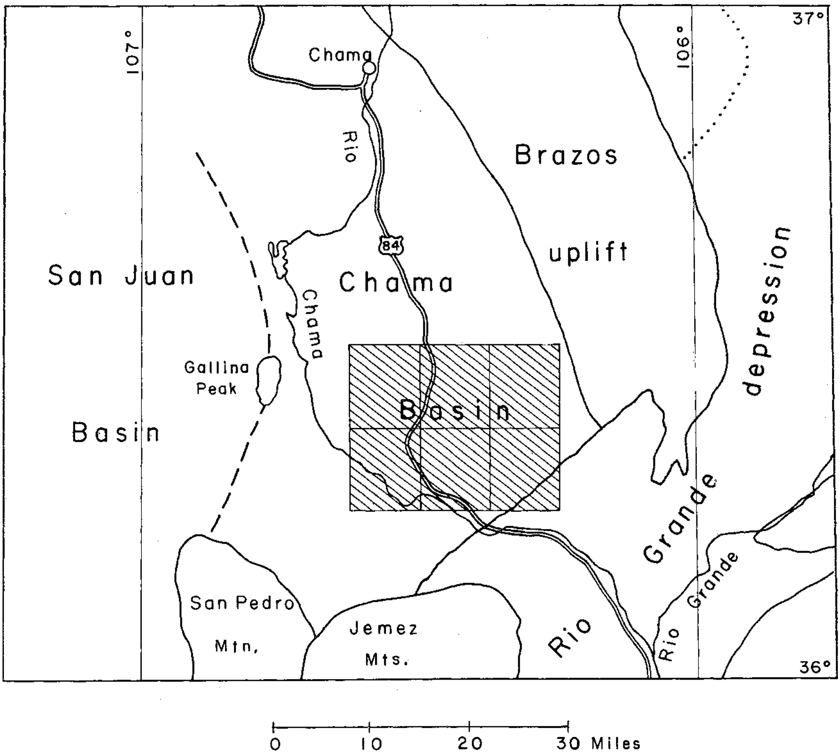

Figure 1
THE CHAMA BASIN IN RELATION TO OTHER STRUCTURAL UNITS IN NORTH CENTRAL NEW MEXICO.

From San Pedro Mountain, which forms part of the Nacimiento Uplift, a flexure or buried ridge extends northward, passing through Gallina Peak, and separating the San Juan Basin from the Chama Basin. The Brazos Uplift is part of an old structural element, that has been active since late Paleozoic time, and which attained its present elevated position during a series of movements that began during the Laramide orogeny. To the southeast the Chama Basin is bounded by the Rio Grande depression. The Jemez Mountains are of volcanic origin, with eruptions starting in the Pliocene; their extensive lava flows and ash beds cover the southern boundary of the Basin.

METHODS

Mapping was done by Brunton compass methods by students under the supervision of the writers, who assume full responsibility for the accuracy of the results. Base maps were U.S. Geological Survey 7½ minute topographic quadrangle sheets at a scale of 1/24,000 with a 20-foot contour interval; these topographic sheets were compiled by photogrammetric methods from aerial photographs originally taken for a 40-foot contour interval. The additional detail required by the 20-foot contour interval resulted in some discrepancies, although most errors could be satisfactorily resolved by utilizing the aerial photographs as adjuncts to the mapping. Contacts between stratigraphic units are indicated by solid lines where precisely located, by dashed lines where approximately located, and by dotted lines where the contact was concealed and its position inferred. Inasmuch as the map is a composite of work done by several field parties, some inconsistency in the evaluation of a contact is to be expected. A contact which one party would consider "approximately located" might well seem "concealed" or "inferred" to another. Such inconsistency is likely to be greatest along contacts with alluvium.

ACKNOWLEDGMENTS

Sincere thanks are extended to the United Presbyterian Church in the United States of America, and to the staff of Ghost Ranch for permission to camp on Ghost Ranch property and for their generally helpful attitude. The U.S. Forest Service was most cooperative, providing water for the camps from their installations at Coyote and El Rito; rangers at Canjilon, Coyote, and El Rito, furnished much information regarding access roads and property ownership. All ranchers in this region were most gracious in allowing access over their property. This project was made possible through the cooperation of the College Division of the New Mexico Institute of Mining and Technology, The Louisiana State University, and the New Mexico Bureau of Mines and Mineral Resources.

Geology

The Chama Basin lies in a reentrant between the Rio Grande trough to the east and the northward extension of the Nacimiento uplift to the west. The Jemez volcanic plateau to the south conceals the relations between the southeastern part of the basin and the junction of the bounding structures. The basin is filled with late Paleozoic and Mesozoic sediments over whose upturned edges to the east and south are spread Tertiary and Quaternary volcanic rocks and sediments (see table 1). The southeastern part of the basin exhibits a gentle northwestward plunge; the southeastern margin is marked by several northeastward and north trending faults, some filled with basaltic dikes, whose irregular displacements suggest late Tertiary adjustments to the sinking of the Rio Grande trough.

STRATIGRAPHY

PENNSYLVANIAN ROCKS

In the north central part of the Canjilon SE quadrangle in Arroyo del Cobre, thin-bedded carbonaceous, gypsiferous and micaceous siltstone is exposed along a small fault. A well preserved flora, consisting predominantly of *Alethopteris serlii,* and identified by C. B. Read of the U.S. Geological Survey (personal communication) is found in the upper part of this unit. Dr. Read states that these beds are either Desmoinesian or Missourian in age, probably Desmoinesian. About 35 feet of beds are exposed, and the upper contact is partly gradational. The outcrop exposes insufficient section to determine whether these beds are more closely related to the Hermosa—Rico beds of the Colorado Pennsylvanian section or to the Magdalena group of the Central New Mexico exposures.

A middle Desmoinesian fossil assemblage, apparently of marine origin, has been described by Muehlberger (1957) from Chavez Canyon, about 35 miles north of the Arroyo del Cobre exposures. Approximately 250 feet of grayish-red and brown siltstones and sandstones, calcareous in their upper part, here rest on Precambrian quartzite.

These limited exposures suggest a rather irregular coastline and relatively low-lying land masses during Desmoinesian time along the eastern margin of the Chama Basin. Thickening of these Pennsylvanian rocks westward has been demonstrated by drilling in the San Juan Basin (see Bradish and Mills, 1950; Wengerd and Matheny, 1958), although the irregular topography suggested by the differing environments of the two exposures extends to the northwestern part of the Chama Basin, where younger rocks rest directly on Precambrian as in wells drilled on El Vado dome. A few miles east of Chavez Canyon and Arroyo del Cobre, Precambrian rocks are exposed on which only Tertiary sediments are found.

TABLE 1. SUMMARY OF EXPOSED STRATIGRAPHIC UNITS IN SOUTHEASTERN CHAMA BASIN

ERA	PERIOD	EPOCH	ROCK UNITS	LITHOLOGY	THICKNESS
Cenozoic	Quaternary		Alluvium	stream deposits and recent terrace gravels	variable
			Landslide debris	talus breccia, in part incised by recent drainage	variable
			Terrace Gravel	coarse gravel deposits, not related to present drainage	variable
	Tertiary	Pliocene(?)	Sierra Negra basalt	dikes and flows of olivine basalt	at least 90 feet
		Miocene(?)	Northeast: Cordito member of Los Pinos formation; Southeast: Abiquiu tuff	Northeast: tuffaceous sandstone and siltstone with volcanic conglomerate; Southeast: tuffaceous sandstone and siltstone	Northeast: at least 670 feet; Southeast: at least 1350 feet
		Eocene(?)	El Rito formation	sandstone and conglomerate with Precambrian rock fragments	at least 400 feet
Mesozoic	Cretaceous		Mancos shale: Carlile and Niobrara(?) members	gray, thin-bedded shale	at least 1650 feet
			Mancos shale: Greenhorn member	thin-bedded limestone	25 feet
			Mancos shale: Graneros member	gray, calcareous shale with thin sandstone beds	100 feet
			Dakota(?) formation	massive, cross-bedded sandstone with shale and coal layers	average 380 feet
	Jurassic		Morrison formation: Brushy Basin member	variegated gray, green, and red mudstone with thin sandstone lenses	average 275 feet
			Morrison formation: Lower member	gray to chocolate-brown thin-bedded sandstone, siltstone, and mudstone	maximum 400 feet
			San Rafael group: Todilto formation	thin-bedded limestone overlain locally by massive white gypsum	average 60 feet
			San Rafael group: Entrada formation	massive, cross-bedded, fine-grained sandstone	maximum 200 feet
	Triassic		Chinle formation: Upper shale member	variegated red, green, and brown mudstone, siltstone, and sandstone	maximum 450 feet
			Chinle formation: Lower sandstone member	coarse-grained, conglomeratic sandstone	maximum 250 feet
Paleozoic	Permian		Cutler formation	alternating cross-bedded purple arkosic sandstone and mudstone	at least 1500 feet
	Pennsylvanian		Beds equivalent to Desmoinesian or Missourian Series	thin-bedded carbonaceous siltstone	at least 35 feet

PERMIAN ROCKS

South of 36° N latitude in New Mexico the Permian beds are divided into the Abo, Yeso, and San Andres formations. North of that line the Abo, Yeso, and San Andres lose their distinguishing characteristics, and the Permian beds are all assigned to the Cutler formation, a term borrowed from southwestern Colorado (Northrop and Wood, 1946).

Cutler Formation

The Cutler formation was described by Whitman Cross and Ernest Howe (Cross, Howe, and Ransome, 1905, p. 5) from exposures along Cutler Creek near Ouray, Colorado, where the formation comprised the "bright red sandstones, and lighter red or pinkish grits and conglomerates alternating with sandy shales and earthy limestones of varying shades of red" between the underlying Rico formation and the overlying Dolores formation.

Outcrops of the Cutler formation are limited to Chama Canyon and its deeper tributaries to the south, to Arroyo del Cobre, and to the canyon of El Rito Creek and some of its tributaries. In the southeastern corner of the Ghost Ranch quadrangle the formation is brought up on the SE sides of a series of SW trending faults. The outcrops in Chama Canyon are terminated on the east by faulting while elsewhere the exposures disappear westward and northward as a result of gradual rise of the stream valleys and of overlap by younger rocks.

The Cutler consists of a seemingly cyclic alternation of cross-bedded, purple, arkosic sandstones which are locally conglomeratic, and of purple to orange mudstones. The arkosic sandstones, which average 10 to 15 feet in thickness, are resistant to erosion and form small cliffs; the thicker, less competent mudstone units form slopes. All units exhibit rapid lateral changes in lithology. At least 1,500 feet of Cutler beds are present in the southeastern Chama Basin (see appendix A). The basal contact is exposed in Arroyo del Cobre where a massive channel sand-stone has scoured the underlying Pennsylvanian shales, producing a relief of more than 35 feet.

Collections of vertebrate remains, principally *Limnoscelis* skeletons, were made from Arroyo del Cobre in 1877 by David Baldwin (Romer, 1950). Such remains suggest an early Permian age for these Cutler beds; more extensive finds, located southwest of the mapped area near Arroyo del Agua in similar formational units, are thought to be somewhat younger. Romer and Price (1940) suggest that the Arroyo del Cobre beds may be late Pennsylvanian (i.e., Virgilian time), which suggestion is not in conflict with the Desmoinesian flora of the underlying shales. However, the uppermost beds in Arroyo del Cobre are certainly lower Permian, and since no lithologic break could be found throughout the section, the entire thickness is mapped as Permian Cutler formation.

TRIASSIC ROCKS

Chinle Formation

The Chinle beds were first described by H. E. Gregory in 1916, from Chinle valley in NE Arizona, although an earlier paper by Gregory (1915) had established the name. The formation has since been recognized in parts of Arizona, Utah, Colorado, Nevada, and New Mexico. Northrop and Wood (1946) subdivided the Chinle formation of the Nacimiento Mountains of northern New Mexico into four units (ascending): (1) the Agua Zarca sandstone member; (2) the Salitral shale tongue; (3) the Poleo sandstone lentil; and (4) the upper shale member. Although the units of Northrop and Wood appear to be locally distinct in the Ghost Ranch quadrangle, they are not everywhere distinguishable, and do not serve as logical units for mapping. For purposes of this report the Chinle formation is divided into two members, a lower sandstone member, which probably represents the Agua Zarca, Salitral, and Poleo of Northrop and Wood (1946), and an upper shale member.

Lower sandstone member. The lower sandstone member of the Chinle crops out extensively in the SE½ of the Ghost Ranch quadrangle and over the NW½ of the Canjilon SE quadrangle. Good exposures are found along the Chama Canyon and in the larger tributary arroyos to the west in the Echo Amphitheater quadrangle; however, the unit is generally covered by soil and alluvium in the flat areas bordering the Chama Canyon, and in the canyon of El Rito Creek. The contact of the lower Chinle with the underlying Cutler is unconformable. No angularity was measured at the contact in the Ghost Ranch quadrangle, but in the Echo Amphitheater and Youngsville quadrangles, to the west and southwest, and in Canjilon SE quadrangle to the east, angularity of as much as 30 degrees has been noted at several localities. The western rim of Arroyo del Cobre exposes a northeasterly truncation of approximately 400 feet of Cutler by the lower Chinle. Where angularity exists, the basal Chinle consists of pebble conglomerate. The overlying beds are white, gray, or buff, quartzose to micaceous sandstone, which weathers buff to brown. Bedding ranges from massive to slabby, and cross-bedding is exceedingly common. For the most part the massive beds are coarse grained; the slabby beds are medium to fine grained. Conglomerate lenses occur at various levels. Fossils are rare, but a few pieces of carbonized wood were noted. Thickness of the lower sandstone member does not exceed 250 feet, and the unit thins eastward and westward from the Ghost Ranch quadrangle.

Upper shale member. The upper shale member of the Chinle crops out in a belt of low, intricately dissected hills southeast of Mesa del Yeso, and extends northeastward into the canyon of El Rito Creek in the Magote Peak quadrangle; a similar belt southwest of Mesa Montosa extends westward into the Chama River canyon and southward along the base of Mesa Prieta in the Echo Amphitheater quadrangle. Other outcrops are found beneath erosional remnants of terrace gravels, rising above the general lower Chinle surface in the southern part of the Ghost Ranch and Echo Amphitheater quadrangles, and in limited exposures beneath the El Rito conglomerates in the southwestern part of the Canjilon SE quadrangle. The contact between the lower and upper Chinle members is characterized by complex intertonguing relationships; therefore, it is difficult to place precisely, especially in areas where the contact zone is poorly exposed. The upper Chinle consists of interbedded and intertonguing red, chocolate, purple and variegated mudstones, siltstones, and sandstones, with red colors and finer-grained facies predominating (see fig. 2A). Small irregular bleached areas in the red mudstones are common, particularly in the upper portions of the member. The upper Chinle is topographically incompetent for the most part; however, the upper 50 to 75 feet consist of interbedded sandstone and siltstone, which are relatively resistant to erosion and in many places form the base of the overlying Entrada cliffs (see fig. 2B). The upper Chinle has yielded an abundant fauna of terrestrial vertebrates, particularly late Triassic reptiles, in the vicinity of Ghost Ranch. Thickness of the upper Chinle shale member is 400 to 450 feet.

JURASSIC ROCKS

The Jurassic rocks of the southeastern Chama Basin are here divided into the San Rafael group and the Morrison formation. The San Rafael group comprises the Entrada and Todilto formations.

SAN RAFAEL GROUP

Entrada Formation

The Entrada formation was described and named for exposures at Entrada Point in the San Rafael Swell area of Utah by Gilluly and Reeside (1928). Baker, Dane, and Reeside (1947) concluded that the beds in the Fort Wingate, New Mexico, area, which had been named Wingate by Dutton (1885), actually correlate with the Entrada of Utah. They also stated that the Wingate formation, as the term is used in Utah, is an entirely different unit which is not present in New Mexico. Believing that the name Wingate is most securely affixed to the Utah rocks, Baker, Dane, and Reeside (1947) proposed dropping Fort Wingate as the type locality for the Wingate, and redefining the formation as the Wingate of Utah in order to agree with popular usage. In this nomenclatorial scheme, the old type-section at Fort Wingate consists of rocks assigned to the Entrada formation, despite the fact that the term *Wingate* has 41 years priority over the term *Entrada*. Harshbarger, Repenning, and Irwin (1957, p. 8) after a reexamination of the old Fort Wingate locality, concluded that Dutton's type section includes rocks customarily assigned to both the Wingate and the Entrada formations. The lower 355 feet is "composed of sedimentary rocks now considered to be the Wingate sandstone, as recognized throughout northeastern Arizona, southeastern Utah, and parts of western Colorado." The upper 303 feet at Fort Wingate correlates with the Entrada of the San Rafael Swell. Harshbarger, Repenning, and Irwin (1957), therefore, propose to restrict the term *Wingate sandstone* to the lower part of Dutton's original type locality. The cliff-forming Jurassic sandstones of the Chama Basin correlate with the upper half of the Fort Wingate section; hence, they are the Entrada formation of Baker, Dane, and Reeside (1947) and Harshbarger, Repenning, and Irwin (1957).

In the Ghost Ranch and Echo Amphitheater quadrangles the Entrada formation forms the steepest part of the slopes marking the escarpments of Mesa Montosa, Mesa del Yeso, Mesa Prieta, and Mesa de Los Viejos. The rocks weather back in such a way as to produce rounded amphitheaters with overhanging cliffs. In the Magote Peak quadrangle

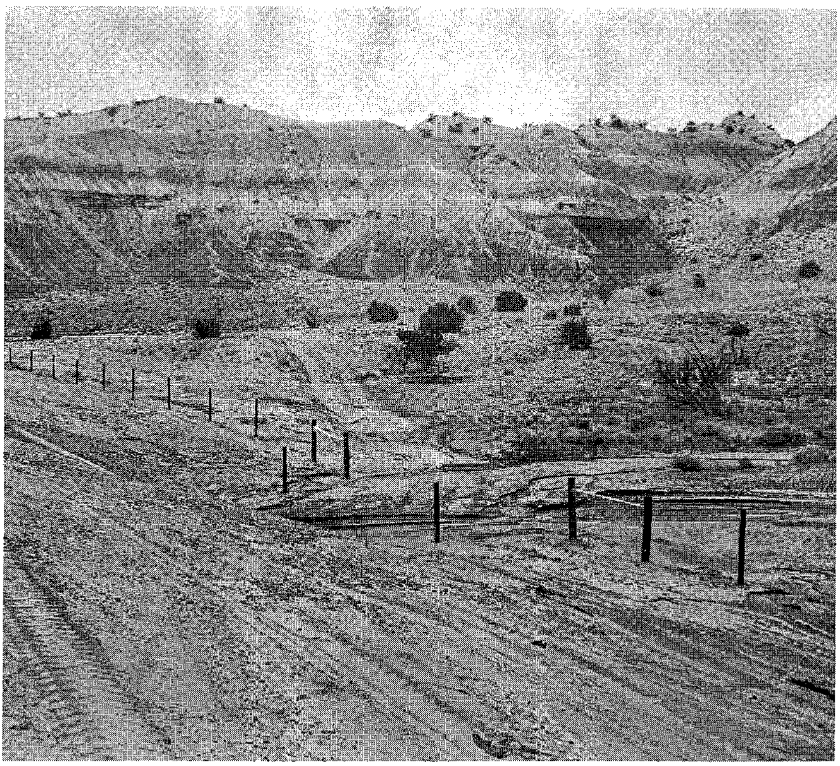

Figure 2A

CHINLE. FORMATION

Badland erosion in variegated maroon and greenish-gray beds of the upper shale member of the Chinle formation, in sec. 12, T. 24 N., R. 4 E.

the Entrada sandstone is often the only outcrop between the valley of El Rito Creek and the crest of Magote Ridge.

The Entrada rests unconformably upon the Chinle. However, in the quadrangles mapped there is little if any evidence of the unconformity; the contact is exceedingly sharp (see fig. 2B). The Entrada consists for the most part of well-rounded, well-sorted quartz sand of fine to medium grain. Cross-bedding is present throughout, but the long, sweeping fore-sets so characteristic of aeolian beds are confined to the lower part. The color of the fresh material is generally tan or white, but the weathered cliff faces show more diversity in color. In the southern tier of quadrangles, where exposures are excellent, the lower 120 to 150 feet of the Entrada weathers red, the next 25 to 50 feet is white and the upper 50 to 75 feet weathers buff; the total thickness throughout these exposures ranges between 200 and 265 feet. However, rapid thinning to the north is exhibited in the Magote Peak quadrangle where the thickness at the southwestern corner of the quadrangle is about 200 feet, while in the northeast corner it is only 120 feet.

Todilto Formation

The name Todilto was applied by Gregory (1916) to the limestones and calcareous shales overlying the Wingate sandstone and underlying

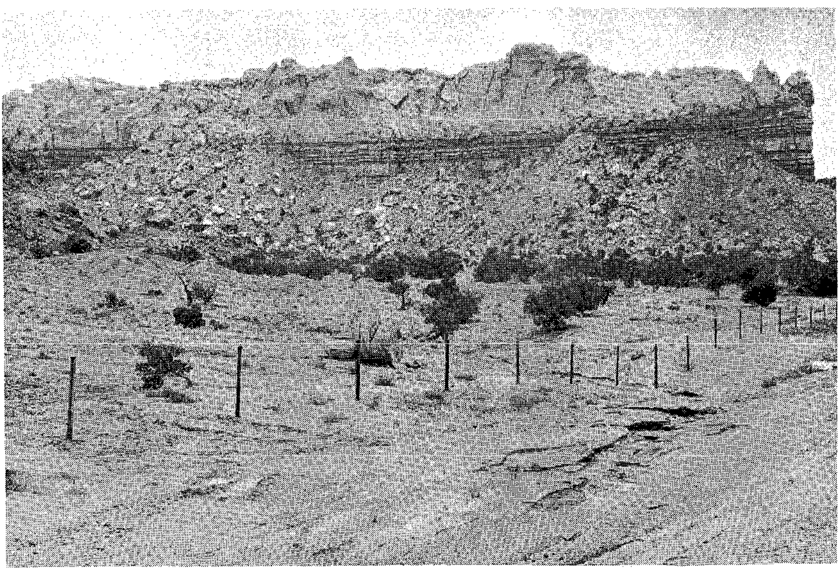

Figure 2B

ENTRADA SANDSTONE

Contact between upper shale member of the Chinle formation and Entrada sandstone, as exposed in sec. 18, T. 24 N., R. 5 E.

the Navajo sandstone in the Todilto Park area of McKinley County, New Mexico. Baker, Dane, and Reeside (1947) concluded that the beds underlying and overlying the Todilto at its type locality are, respectively, the Entrada sandstone and the Morrison formation. In an earlier paper, Baker, Dane, and Reeside (1936) had considered the Todilto to be the basal member of the Morrison formation, but in their revision (1947) they considered it a member of the Wanakah formation, which itself was elevated from the status of a member of the Morrison. Their separation of the Todilto from the Morrison was based on the transitional nature of the Todilto—Entrada contact and the fact that in some places the Todilto—Morrison contact is disconformable. Northrop (1950) and Harshbarger, Repenning, and Irwin (1957) regarded the Todilto of northwestern New Mexico as a separate formation, and their usage is followed here. The character of the Entrada—Todilto contact strongly suggests that the Todilto be considered a part of the San Rafael group.

The Todilto formation crops out in a narrow continuous belt, capping the Entrada, protecting it from erosion and contributing to the formation of the overhanging cliff exposures. Exposures of the Todilto formation are very good in the Ghost Ranch and Echo Amphitheater quadrangles, although locally, where gypsum is developed, flowage and slumping have allowed great blocks to move downslope out of their normal stratigraphic position. Throughout the area the upper part of the unit is often covered by slump blocks of the overlying formations, and along El Rito Creek the entire formation is concealed with outcrops often several thousand feet apart.

The contact between the Todilto and the underlying Entrada formation is conformable throughout the Ghost Ranch quadrangle. In some places—as for example in Arroyo del Yeso—intertonguing is evident.

Two members of the Todilto formation are recognized in the area, a lower member, consisting of limestone and calcareous shale, and an upper gypsum member. The lower member occurs in each of the quadrangles mapped; whereas, the gypsum member is limited to exposures along the Arroyo Seco and the Rio Chama. Actually the gypsum is best developed in areas to the west and south of the Ghost Ranch quadrangle, but even there it is discontinuous.

Lower member. The lower member of the Todilto consists of dark-colored, fetid, fissile calcareous shales at the base, grading upward into very thin-bedded, grey, medium crystalline limestone and finally into more massive gray limestone. Locally the limestone contains blebs of gypsiferous material. The thickness of the member ranges from less than a foot to about 18 feet.

Upper member. The contact between lower and upper members of the Todilto is gradational. Typically gypsum blebs and stringers appear in the limestones of the lower member and gradually become quantitatively more important higher in the section. Thus it is difficult to pinpoint the contact between the two members; however, the boundary can generally be picked within 2 or 3 feet. The upper member consists of white, massive gypsum with numerous and conspicuous shaly partings. It ranges from 0 to 105 feet in thickness; distribution is spotty, due, in part, to extensive channeling before deposition of the overlying Morrison formation. Rapid changes in thickness are the rule rather than the exception, a change from zero to 80 feet having been observed in a horizontal distance of only about 100 feet (see fig. 3). In general, the thickness of the gypsum is greatest where the thickness of the underlying limestones is least.

Morrison Formation

The Morrison formation was named by G. H. Eldridge (Eldridge, Cross, and Emmons, 1896), for exposures near Morrison, Colorado, where the beds in question overlie the Lykins formation (Permian–Triassic) and are in turn overlain by the Dakota sandstone. Although the formation is credited to Eldridge, the first reference to it in the literature was by Cross (1894), who noted the beds in the Pikes Peak area.

The Morrison crops out extensively throughout the quadrangles, forming the rather steep slopes between the lower Entrada–Todilto cliff and the upper Dakota cliff. Outcrops are found on the southern escarpment of Mesa del Yeso and Mesa Montosa and along the southern and eastern sides of Mesa de Los Viejos; scattered outcrops are found on the west side of El Rito Creek. Despite the wide belt of outcrop, good exposures of the Morrison are rare. Large blocks of the overlying Dakota sandstone break off and come to rest on the Morrison slope in extensive talus cones; this fact, plus the soft, friable nature of the Morrison itself, greatly limits reliable exposures. The best-exposed section lies just east of U.S. Highway 84 on the west end of Mesa Montosa (see frontispiece).

The Morrison formation is here divided into two members, although contacts between these units cannot be drawn with certainty in many places. This two-fold division is intended to express gradual changes in lithology rather than sharp breaks.

Lower member. The contact of the Morrison formation with the underlying Todilto appears sharp whether the basal Morrison beds rest on the Todilto gypsum or on the limestone. In most places where the Morrison rests on the limestone, the absence of the gypsum seems best explained by channeling. The lowest beds consist primarily of gray to cream-colored sandstones and siltstones, which are interbedded with lesser amounts of red or green mudstone. The lower beds grade upward into the main part of the member as the mudstone and siltstone units become predominant over the sandstone layers; no sharp boundary can be identified. The bulk of the lower member consists of an alternating sequence of pale brown, chocolate, or deep purple mudstones and white to pale gray siltstones. The siltstone beds average 10 feet in thickness, and where not covered by rubble from above, they form low cliffs. The

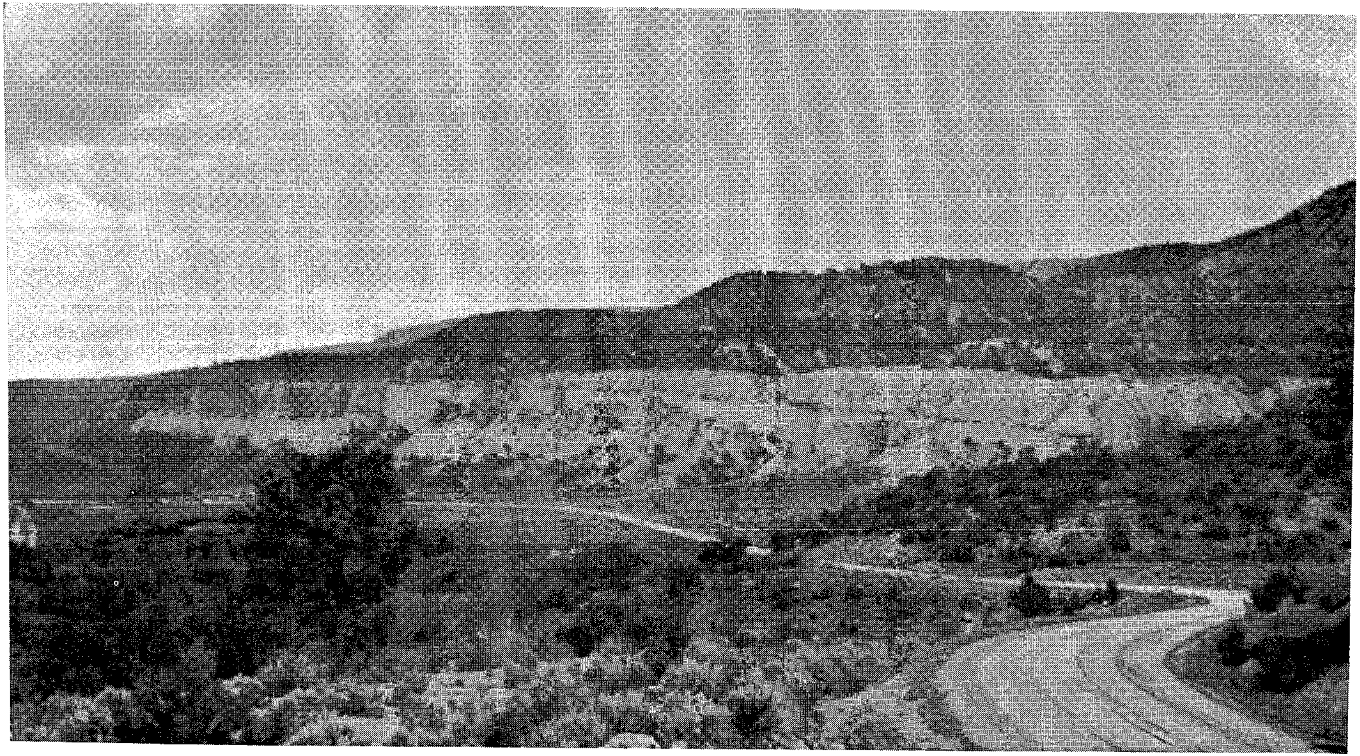

Figure 3

ENTRADA AND TODILTO FORMATIONS ON WEST SIDE OF ARROYO SECO

The variations in thickness of gypsum in the upper part of the Todilto formation from right (100') to left (0') is characteristic of the beds in the southeastern Chama Basin.

mudstones average 30 feet in thickness and generally form slopes. The lower member ranges between 300 and 400 feet in thickness.

Brushy Basin member. Gregory (1938, p. 59) named the Brushy Basin member for exposures in Brushy Basin, San Juan County, Utah. At the type locality it consists of 350 to 470 feet of "brightly banded shales, thin limestones, conglomerates, and sandstones" forming the top of the Morrison in the San Juan area. The member name is carried into the Chama Basin area on the basis of lithologic similarity and similar stratigraphic position. The contact between the lower member of the Morrison and the Brushy Basin is gradational. In the field, it is picked in the interval below the red claystone of the Brushy Basin and above the chocolate-colored mudstones of the lower member. The Brushy Basin consists for the most part of banded green and orange mudstones. There seems to be a change from a predominance of orange near the base to green near the top. Lenses of poorly sorted white to gray massive sandstone occur at intervals throughout the section. Of particular interest are a number of beds of brick-red, thoroughly indurated claystone which occur in the lower half of the member. The thickness of the Brushy Basin member is about 275 feet.

CRETACEOUS ROCKS

The stratigraphic position of the lowermost Cretaceous rocks in the southeastern part of the Chama Basin is in considerable doubt. In many outcrops, a three-fold lithologic subdivision can be made; elsewhere, a single sandstone unit occupies all of the interval between the under-lying Morrison formation and the fossiliferous overlying Mancos shale. Farther west in the San Juan Basin a sand-shale sequence of lower Cretaceous (?) age has been called the Burro Canyon formation (Stokes and Phoenix, 1948). In northeastern New Mexico alternating beds of black carbonaceous shale and coarse sandstone containing lower Cretaceous (Comanchean) fossils are referred to the Purgatoire formation (Stose, 1912). Stokes (1944) discusses the problem of the Jurassic–Cretaceous boundary and concludes that a thin layer of lower Cretaceous rocks is probably present over much of the Rocky Mountain region, although not necessarily everywhere directly correlative.

In the southeastern Chama Basin the Cretaceous rocks are readily divisible into two major groups: a lower sandstone facies rarely more than 400 feet in thickness and an upper marine shale facies several thousand feet thick. Locally, in the Magote Peak quadrangle and in most of the exposures along the south and west sides of Mesa de Los Viejos in the Alire quadrangle, the lower sandstone facies is further divisible into a lower conglomeratic sandstone, a medial carbonaceous siltstone and shale unit with sparse coal lenses, and an upper massive coarse-grained sandstone. Exposures are poor in many areas, and as a result, these units are not everywhere mappable. Accordingly, the lower sandstone facies is mapped as Dakota (?) formation, although correlatives of the Burro Canyon or Purgatoire formations may be present in the lower beds.

Dakota (?) Formation

The Dakota sandstone was named by F. B. Meek and F. V. Hayden (1862) for exposures in Dakota County, Nebraska. The name has been applied rather loosely throughout the Rocky Mountain area to the basal sandstone of the Upper Cretaceous series. Present usage of the U.S. Geological Survey restricts "Dakota sandstone" to areas east of the front ranges, and Dakota (?) formation is applied in areas to the west. "Dakota (?) formation" does not imply time equivalence with the type Dakota sandstone; rather it indicates similar lithology and similar stratigraphic position.

The Dakota (?) formation occurs only in the northern part of the mapped area. There it forms the caprock of the several mesas as well as the eastern edge of the Magote Ridge. The Dakota (?) is perhaps the most competent bed in the section; hence, it is almost invariably a cliff-former. Often two sandstone cliffs are found separated by a narrow bench.

The contact between the Dakota (?) and the subjacent Morrison is generally covered by detritus from the Dakota (?). Where exposed, the contact is unconformable, although no angularity could be detected in the limited exposures which were available.

The rocks mapped as Dakota (?) formation consist of a lower sand-stone unit, a middle claystone unit not everywhere present, and an upper sandstone unit.

The lower standstone unit consists of tan to white, medium- to coarse-grained, well-sorted sand, which is thoroughly cemented with silica; it forms a prominent cliff. Some conglomerate beds are present, particularly near the base, but they do not appear to persist laterally for any appreciable distance. Conglomerate is more prominent in the Magote Peak quadrangle and is less abundant to the west. Cross-bedding is common in the coarser zones. The lower standstone unit ranges from 180 to 200 feet in thickness.

The middle unit consists of dark gray, silty claystone and sandy silt-stone. Numerous thin beds of carbonaceous materials and even a few very thin restricted coal beds are present. The middle unit is usually poorly exposed. It intergrades with subjacent and superjacent beds; hence, its thickness is difficult to ascertain exactly but is approximately 80 to 100 feet.

The upper unit, which forms the upper Dakota(?) cliff, is essentially similar in lithology to the lower sands, and is about 100 feet thick. Conglomerate is less abundant and the uppermost beds grade into the overlying shales.

Mancos Shale

The Mancos shale was named by Cross (1899) from exposures in the Mancos valley in and around the town of Mancos, Colorado. The formation now includes all the dark gray marine shale tongues lying between the Dakota (?) sandstones and the overlying Mesaverde formation. In the San Juan Basin to the west and south, considerable intertonguing between the lower part of the Mesaverde and Mancos units indicates extensive transgressive and regressive relationships.

Faunal assemblages in beds in the southeastern part of the Chama Basin indicate that units correlative with the Graneros, Greenhorn, and Carlile members of the Mancos shale are probably present, although lithologic boundaries are lacking in most areas. A thin platy-bedded, well-jointed limestone sequence was mapped as the Greenhorn throughout the Magote Peak, Canjilon, and Alire quadrangles.

The lower 75 to 100 feet of Mancos shale is light gray to dark gray calcareous shale, sandy at the base where the contact with the Dakota (?) formation is gradational. Locally, concretions are abundant, and this unit probably represents the Graneros member as mapped farther north and west in the basin. Because of the gradational nature of the contact with the underlying Dakota (?) formation, the thickness is variable, and in some places sandstone layers may occur several feet above the base (see fig. 4). The lighter-colored shale is commonly more calcareous, and the darker colored areas, sometimes with shades of brown, are arenaceous.

Overlying the Graneros member is a white-weathering, well-jointed, slabby limestone unit up to 35 feet in thickness; the jointing and bedding surfaces are so closely spaced that weathering yields a zone of white chips in the shaly soil. This zone serves as a persistent marker throughout the mapped area. This member has been correlated with the Greenhorn limestone member of the Mancos shale on the basis of its fossil content and lithology. The limestone beds of the Greenhorn are interbedded with gray calcareous shale and grade both upward and downward into darker calcareous shales; accordingly, the thickness is variable depending upon where the contact is chosen. The unit, however, is rarely less than 20 feet thick. The fracturing is remarkably uniform and very closely spaced and characterizes most of the outcrops of the member.

The shale above the Greenhorn member is uniformly drab, gray, thin-bedded, and poorly exposed. It is correlated with the Carlile member of the Mancos formation on the basis of stratigraphic position and fossil evidence (see fig. 4). In the central and northern parts of the Chama Basin persistent sandy zones presumed to represent the Juana Lopez sandstone of Rankin (1944) are characterized by a brownish to yellowish weathered soil and slightly greater resistance to erosion than that of the underlying shales. These sandy zones cannot be identified in the Magote Peak, Canjilon, and Alire quadrangles because of a lack of exposures,

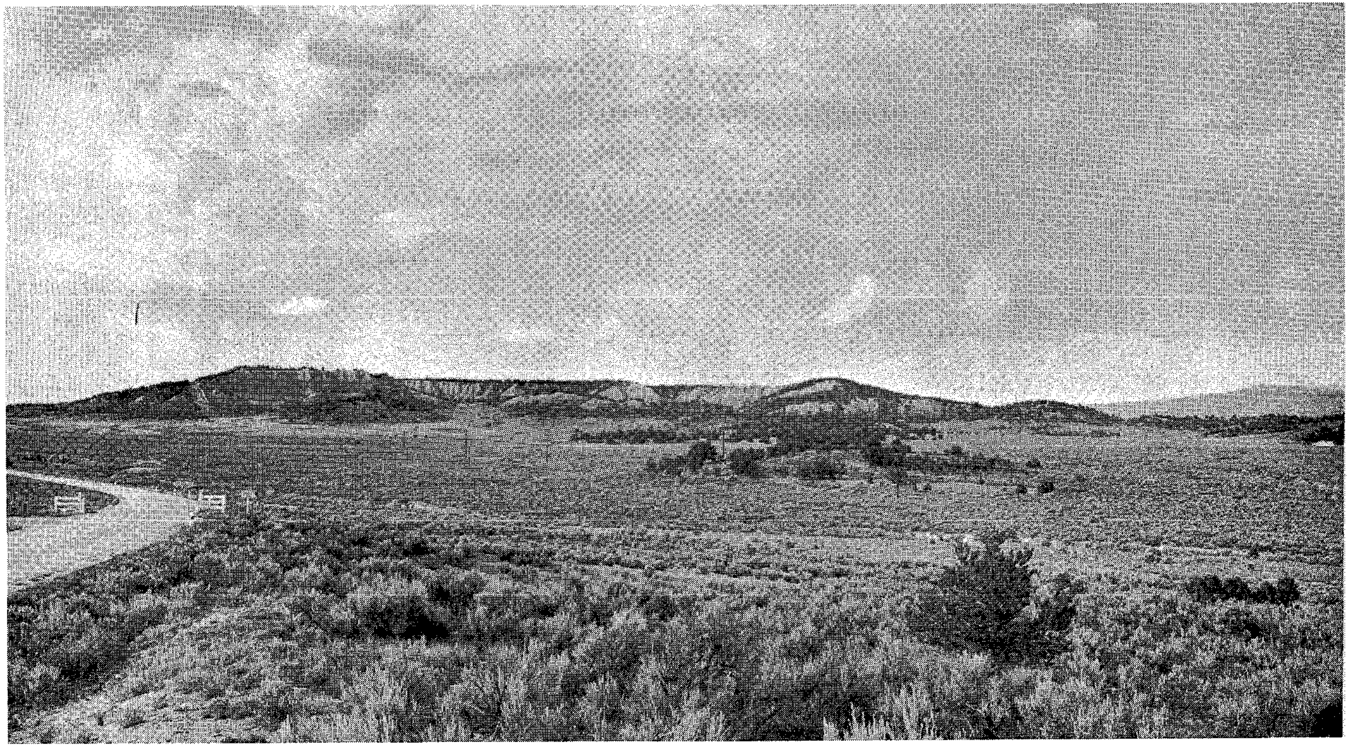

Figure 4

LOOKING NORTH OVER LAS JOLLAS; TYPICAL SURFACE CUT ON MANGOS SHALE
Low knob in foreground exposes lower Mancos (Graneros) sandstone with badlands on skyline cut in upper Mancos (Carlile?) shale. White outcrop at extreme right is Greenhorn limestone.

although some of the higher portions of Magote Ridge might be underlain by such units.

Fossils are abundant throughout much of the Mancos shale, and detailed studies might allow further subdivision of the section. Exposures are very poor; north of the Canjilon quadrangle in sec. 12, T. 26 N., R. 4 E., 650 feet of shale were measured in an incomplete section. The measurement was well above the Greenhorn exposures in the Canjilon quadrangle and a thickness of nearly 1,800 feet can be projected from cross sectional data in the Magote Peak quadrangle. It is quite likely that the uppermost beds in the northern parts of the Canjilon and Magote Peak quadrangles are correlatives of the Niobrara member of the Mancos, although this unit was not identified during the mapping in the southeastern part of the basin. All the Mancos units are so similar in lithology and grain size that excellent exposures are necessary to delineate the members; the Greenhorn member is the only series of beds which may be identified in soil or weathered areas without fossil evidence, and even it is not always mappable in zones of thick soil or gravel cover.

Younger Cretaceous rocks are known in the northern part of the Chama Basin, but in the southeastern part, the Mancos is the uppermost Cretaceous unit exposed. The Mancos shale is overlain unconformably by Tertiary and Quaternary gravels and igneous materials, which are related to the volcanic and glacial activity of the San Juan Mountains to the northwest in Colorado.

TERTIARY ROCKS

Tertiary rocks are represented by the El Rito formation, the Abiquiu tuff member of the Santa Fe formation, the Los Pinos formation, and the Sierra Negra basalt. Outcrops of these rocks are restricted to the eastern margins of the Magote Peak and Canjilon SE quadrangles.

In part these formations can be correlated with adjacent Tertiary successions. In Table 2 a set of possible relationships between the well-known Tertiary sequence in the San Juan Mountains of southwestern Colorado, the Tertiary succession in the Rio Grande valley near Santa Fe, New Mexico, and the Tertiary section of the Las Tablas quadrangle (Barker, 1958) is illustrated.

El Rito Formation

The El Rito formation was named by H. T. U. Smith from exposures in the Abiquiu 30' quadrangle of New Mexico (Smith, 1938). It is the oldest of the Tertiary beds in the southwestern part of the Chama Basin and unconformably overlies older formations. Within the Abiquiu 30' quadrangle, important localities are to be found in the Ortega Mountains, along El Rito Creek, and east of Arroyo del Cobre. Smith (1938, p. 940) describes the formation as follows:

TABLE 2. CORRELATION OF TERTIARY SEQUENCES IN ADJACENT REGIONS IN COLORADO AND NEW MEXICO

Epoch	SE San Juan region, Larsen and Cross, 1956	Las Tablas region Barker, 1958	El Rito Creek area, present report	Rio Grande valley
Pliocene	Hinsdale formation	Dorado basalt unconformity Cisneros basalt	Sierra Negra basalt unconformity(?)	Santa Fe formation
	peneplanation	unconformity		
Miocene	Fisher quartz latite and Los Pinos gravel	Los Pinos formation: Cordito member Jarita basalt Biscara-Esquibel member Biscara member	North: Cordito member / South: Abiquiu tuff	
	unconformity	unconformity	Not present	
	Other Miocene rocks present	Present		
Oligocene	Possibly present	Not present		
			unconformity	
Eocene	Present	Ritito conglomerate	El Rito formation	Galisteo formation
		great unconformity	great unconformity	
Pre-Tertiary	Present	Precambrian	Permian to Upper Cretaceous	Pennsylvanian (?) or older to Upper Cretaceous

> It comprises sandstone, conglomerate, and breccia—all of which have a characteristic brick-red color. The rock is well consolidated and commonly stands in steep cliffs. The pebbles are dominantly of quartzite, and volcanic material is absent. The maximum thickness of the formation is about 200 feet.

The El Rito formation, as exposed in the area under consideration, is very similar to this description. However, its areal extent is somewhat larger than that indicated on Smith's map. The lithology of the formation is well displayed in steep slopes along El Rito Creek (see fig. 5A) and in valleys east of Arroyo del Cobre. Boulder-conglomerate beds are numerous and are separated by micaceous, arkosic sandstones. The matrix material varies from coarse sand- to silt-sized particles, and has a reddish-orange to reddish-brown color. The fragments in the conglomerate beds are for the most part well-rounded, ranging in size from boulder to pebble; and are nearly all made up of a bluish-gray quartzite, very similar to the Precambrian Ortega quartzite (Just, 1937) exposed extensively in the Ortega Mountains. The degree of rounding of the quartzite boulders suggests that the lower part of the El Rito is derived from reworked sediments and is a second or third generation conglomerate (see fig. 5B). In the upper part, beds appear which contain pebbles and cobbles of schist, gneiss, and feldspar, in addition to quartzite; the conglomerate in this part of the section exhibits a rude shingling.

Outcrops of the El Rito formation are confined to the southeast corner of the Magote Peak quadrangle and the east half of the Canjilon SE quadrangle. It is estimated that at least a 400-foot thickness of the formation is present east of Madera Canyon. A number of outcrops of the El Rito formation are also present near the crest of Magote Ridge.[1] Similar outcrops are named "Canjilon till of the Cerro (?) glacial stage" on H. T. U. Smith's map of 1938. The present authors assign at least part of the boulders and gravels on Magote Ridge to the El Rito formation, particularly the exposures on the east side of Magote Peak (see fig. 6A). Extensive exposures are not present in this area, but boulders and pebbles of the bluish-gray quartzite are found on the surface in large quantities. These boulders are very similar, both in shape and composition, to the boulders found in the El Rito conglomerate. Evidence that these boulders have reached their present location by way of large scale glacial transport—at least eight miles according to Smith (1936)—was not found. Smith also points out the presence of hummocky land forms veneered with quartzite boulders near Magote Ridge, and their similarity to morainal structures. However, he notes that this kind of topography is also present along lower elevations of the ridge. The necessary condition for the development of hummocky terrane at this elevation seems to be the presence of Mancos shale, an incompetent bed,

1. This ridge is referred to as Canjilon Divide by Smith (1936), but is named Magote Ridge on the Magote Peak quadrangle map, published in 1953.

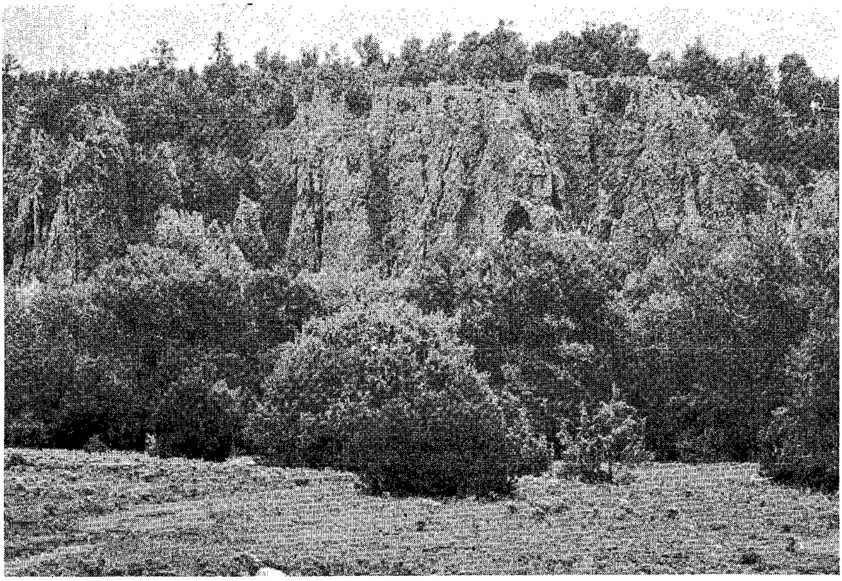

Figure 5A
EL RITO FORMATION
Steep cliffs in the El Rito formation, exposed along the east bank of El Rito Creek.

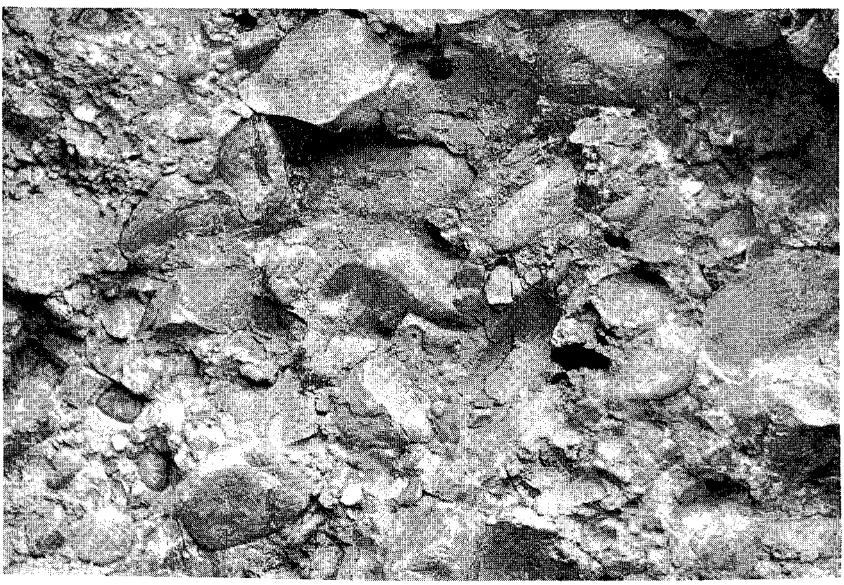

Figure 5B
EL RITO FORMATION
Rounded boulders of bluish-gray quartzite in the El Rito formation. Close-up of outcrop shown in Figure 5A. Approximate scale 1 inch = 1 foot.

where solifluction and landsliding can readily take place, particularly under perigiacial conditions. (See fig. 6B).

The major difference in interpretation of the geologic features on Magote Ridge is to be found in the mode of transport of the metamorphic-rock boulders. Whereas Smith (1936) advocated glacial transport during the Pleistocene, the present authors look upon the boulders as having attained their present location by fluvial action during El Rito time, with subsequent rearrangement during later periods, particularly during the Pleistocene.

The El Rito formation overlies older formations (Cutler, Agua Zarca, Chinle, Entrada, and Mancos) with an angular unconformity. The average dip of the El Rito is six degrees to the southeast. The El Rito formation is unconformably overlain by the Abiquiu tuff member of the Santa Fe formation.

The deposition of the El Rito was the result of strong vertical movements, which uplifted the Brazos Mountains to the north and east. Active erosion stripped the uplift of its veneer of sediments and exposed the Ortega quartzite, a process which apparently had been repeated several times during Paleozoic and Mesozoic time. The El Rito formation accumulated with little or no sorting as a fanglomerate type of deposit from intermittent torrential streams. The red matrix of sand and silt was probably derived from the "red beds" of the Cutler–Agua Zarca–Chinle sequence rather than as a result of weathering and sedimentation under tropical climatic conditions, as suggested by Smith (1938). The torrential conditions of sedimentation were, of course, not amenable to the preservation of fossils in these beds. As fossil evidence is entirely lacking, the age of the El Rito formation is uncertain; probably it is early Tertiary, possibly Eocene, in age.

Abiquiu Tuff Member of the Santa Fe Formation

The Abiquiu tuff was named and described by Smith (1938) from exposures near Abiquiu, New Mexico. He described the main body as a stream-laid deposit of tuff and volcanic conglomerate. It consists of well-bedded, fine-grained material. In the lower elevations, it weathers to steep, almost vertical slopes.

The Abiquiu tuff is exposed in the southeast corner of the Canjilon SE quadrangle. The formation consists essentially of very light gray to very pale orange silty tuff and micaceous, tuffaceous sandstone. A thin-bedded to laminated appearance is most common. The tuff overlies the El Rito formation unconformably and has an average dip of 4 degrees to the SSE. Good exposures are found on the west slope of Sierra Negra, where at least 1,350 feet of Abiquiu tuff is present. In areas to the east and north where beds continuous, or at least correlative, with the type Abiquiu tuff are present, several variations are found. Conglomeratic layers and coarse-grained sandstones predominate over the finer-grained

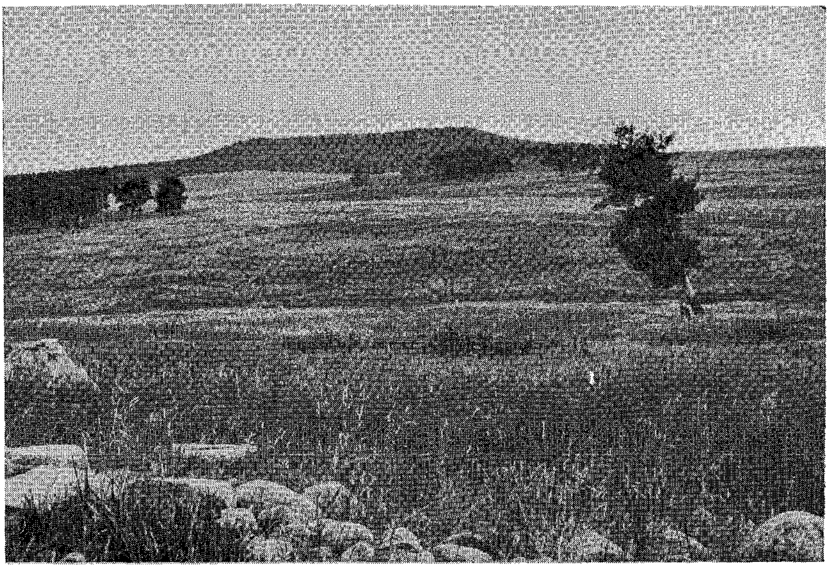

Figure 6A

LANDSLIDE AND SOLIFLUCTION PHENOMENA ALONG CREST OF MAGOTE RIDGE

View looking southwest at Magote Peak showing numerous landslide scars on gentle slope in Mancos Shale. Exposure on Magote Peak on skyline is El Rito formation (Canjilon Till of Smith), source of quartzite boulders in foreground.

Figure 6B

LANDSLIDE AND SOLIFLUCTION PHENOMENA ALONG CREST OF MAGOTE RIDGE

Solifluction lobes of quartzite boulders on Mancos Shale slope. Quartzite boulders are derived from El Rito formation which caps timbered ridge in background.

tuffaceous layers, and torrential-type crossbedding replaces the more evenly-bedded zones. East of El Rito Creek such beds are interlayered with one another, and it is apparent that the upper part of the Abiquiu tuff member, as well as the lower part of the Santa Fe formation, is equivalent to the upper part of the Los Pinos formation of Butler (1946) and Barker (1958). The upper contact with the overlying Santa Fe formation is gradational and the selection of the contact is arbitrary.

Los Pinos Formation

A sequence of waterlaid sands, gravels and conglomerates, exposed east of El Rito Creek in the Magote Peak quadrangle, is believed to represent part of the Los Pinos formation. This formation was first recognized in the Summitville quadrangle of southwestern Colorado and was named the Los Pinos gravel by Atwood and Mather (1932). It was found to thicken considerably where it extends southward into New Mexico. Larsen and Cross (1956, p. 185, 186) in an extensive discussion of the Los Pinos gravel, point out that its thickness does not exceed 500 feet in Colorado.

A careful study by Butler (1946) showed that in the Tusas–Tres Piedras area of New Mexico, the Los Pinos gravel can be subdivided into four members; he was the first to use the term *Los Pinos formation.* Butler's terminology was adopted by Barker (1958) in his work on the Las Tablas quadrangle, which adjoins the Magote Peak sheet to the northeast. Extensive areas in the southwest part of the Las Tablas quadrangle are underlain by the uppermost, or Cordito member, of the Los Pinos formation, and it seems likely that the outcrops along El Rito Creek are a continuation of these exposures. The Los Pinos formation thickens southeastward in the Las Tablas quadrangle and reaches a thickness in excess of 2,000 feet.

In the Magote Peak quadrangle an incomplete section of the Los Pinos formation is exposed along the steep east bank of El Rito Creek (see appendix B). The formation presumably overlies beds of the El Rito formation, a relationship similar to the one present in the south-west portion of the Las Tablas quadrangle. Here, the Cordito member rests on the Ritito conglomerate, which is considered the equivalent of the El Rito formation (see table 1).

Although the Los Pinos formation east of El Rito Creek can be sub-divided into two units, the units have not been separated on the geologic map. The lower unit, the base of which is not exposed, consists of about 600 feet of friable, tuffaceous sandstones and siltstones, and intercalated, discontinuous gravel beds. Cross-bedding and channel features attest to deposition in a stream environment. Larger, conglomeratic fragments in these beds consist of volcanic boulders, often considerably decomposed, and a minor quantity of quartzite and other metamorphic rocks. The upper unit, at least 70 feet thick, is conglomeratic and contains very large boulders, up to four feet in diameter, of andesitic and quartz latitic volcanic rocks. This unit is well cemented and is a conspicuous cliff former.

The Los Pinos formation, exposed in the Magote Peak quadrangle, is apparently an extension of the Cordito member of the same formation, found in the Las Tablas quadrangle. Whereas the Los Pinos formation was probably formed in a series of stream channels and associated gravel fans, the Abiquiu tuff, to which it is closely related, accumulated in a lacustrine or flood-plain environment. Such conditions would explain the existence of even bedding and good sorting in the. Abiquiu tuff, in contrast to the channel features and poor sorting characteristic for the Los Pinos gravel.

The Los Pinos formation undoubtedly represents an extensive sand and gravel apron, developed south and east of the San Juan Mountains. Erosional debris was transported far to the southeast, where Precambrian rocks were exposed and fragments of quartzite mingled with transported tuffaceous and other volcanic material. As pointed out by Larsen and Cross (1956, p. 192), the sources of the volcanic material may be widespread.

IGNEOUS ROCKS

Sierra Negra Basalt

Dikes and flows of basaltic composition are present in the southern part of the Canjilon SE quadrangle. The dikes have a maximum width of 25 feet and consist of dull black basalt, with greenish-brown altered olivine phenocrysts. Vesicular and amygdaloidal textures are found in some parts of the basalt; jointing is perpendicular to the walls of the dikes and secondary calcite occurs as vein filling.

The dikes are intruded along zones of weakness, as many wedge out and have their continuation in faults. The Cerrito de la Ventana dike, for example, separates El Rito formation on the west from Abiquiu tuff on the east. In the southwest corner of the Canjilon SE quadrangle a basalt dike transects the red silts of the Cutler formation. Up to a few inches away from the contact, the host rock is bleached to a pale yellow color; however, no evidence of recrystallization is found. In the southeastern part of the same quadrangle, several dikes intrude the El Rito and Abiquiu formations. As a result of their greater resistance to erosion, the basalt dikes stand out as conspicuous ridges above the surrounding sediments.

Rocks of basaltic composition cap Sierra Negra. The basalt is of the same appearance as the dike rocks and occurs in the form of a flow, at least 90 feet thick, which overlies the Abiquiu tuff.

Microscopic examination of two thin sections, one from a dike and one from the Sierra Negra flow, shows that the rocks have the composition of olivine basalt. Olivine occurs as large euhedral to subhedral grains (up to 4 mm) which have been partly or completely altered to a greenish brown mass of iddingsite and other alteration products (see fig.

7A). Augite forms a few phenocrysts, which exhibit a zonal structure; the outer zone of the crystals is deeper brown in color, shows strong dispersion, and has a larger extinction angle than the core. These features would indicate that the outer zone is made up of titaniferous augite (see fig. 7B). The major portion of the pyroxene occurs as fine-grained (less than 0.3 mm), short, prismatic, or rounded grains in the groundmass of the rock.

Plagioclase feldspar is present in subordinate amounts and occurs as thin laths scattered throughout the groundmass; its average grain size is 0.5 mm. From composite twinning according to the Carlsbad and Albite laws, its average composition was determined as sodium-rich labradorite.

Biotite and basaltic hornblende are minor constituents. Most prominent among the accessory minerals are apatite, in the form of thin elongate crystals, and various iron oxides, the latter scattered through the groundmass in small euhedral crystals. In the dike rock, carbonate minerals occur as amygdules, together with a pale green, low-birefringent alteration product of olivine (smectite-chlorite), which lines the walls of the cavities.

A determination of the forsterite content of the olivine was made by J. H. Carman, using the method of Yoder and Sahama (1957). Assuming less than five percent orthosilicates other than forsterite and fayalite, an apparent forsterite content of 77.6 percent is indicated for the dike rock, and 80.1 percent for the flow. The difference is less than the errors inherent in the measurements and is not statistically significant; the dikes and flows are thus probably derived from the same magmatic source.

On the basis of its petrographic composition and stratigraphic position, the Sierra Negra basalt and accompanying dikes can be correlated with the Pliocene Hinsdale volcanic sequence of the San Juan Mountains.

QUATERNARY ROCKS

Broad areas along the Chama River, many of the larger tributary valleys, and some of the higher mesas in the southeastern part of the Chama Basin are covered by terrace gravels and alluvium which are here assigned to the Quaternary period, but which may be Tertiary in part.

Terrace Gravels

Terraces composed of very well rounded cobbles and pebbles of granite, gneiss, schist, quartzite and metarhyolite are widespread in the southern half of the Ghost Ranch and Echo Amphitheater quadrangles. In places in the eastern part of the Ghost Ranch quadrangle the terraces reach elevations in excess of 7,400 feet; however, toward the southwest there is a general decline in terrace height until, near the Rio

Figure 7A
SIERRA NEGRA BASALT
Photomicrograph of olivine crystals (white) partly or wholly altered into iddingsite (gray). Groundmass consists of plagioclase, augite and iron oxides. Plane polarized light; x 20.

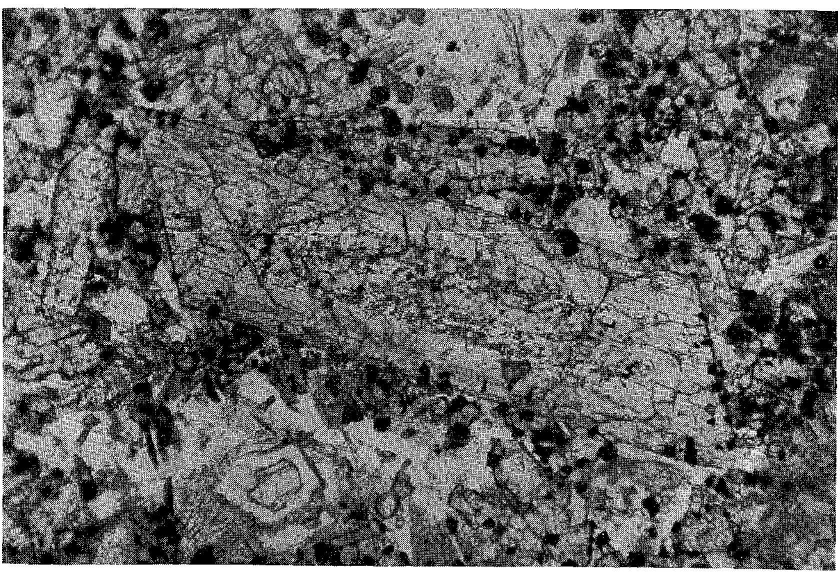

Figure 7B
SIERRA NEGRA BASALT
Photomicrograph of zonal structure in augite phenocryst. Plane polarized light; x 65.

Chama, most deposits occur between elevations of 6,200 and 6,400 feet. Terrace relationships are rather complex. It is certain that several separate episodes of terrace building are represented in the southwestern part of the area near the Rio Chama. However, the relationship of the higher terraces in the east-central part of the area to the lower ones near the Rio Chama is not clear. The higher level of the terraces in the east seems to suggest that they are older. However, it is interesting to note that the southwesterly decline in terrace level parallels the dip of the Mesozoic rocks and is of approximately the same magnitude. Also, the tops of the high level eastern terrace remnants invariably slope gently toward the southwest. The degree of slope is such that if these eastern terraces were projected to the southwest, their level would approximately coincide with that of the terraces near the Rio Chama. It seems most logical, therefore, to assume that the two levels of terraces are of approximately the same age. The southwesterly decrease in terrace level was probably caused by crustal warping after the deposition of the gravels.

Large areas along the crest of Magote Ridge and some of the tops of the high mesas, such as Mesa Juan Domingo and La Mesita, are also mapped as terrace gravel. These higher level deposits (in excess of 8,000 ft elevation) appear to be remnants of a large sheet of debris, perhaps best described as a lag gravel resulting from the erosion of the El Rito and Los Pinos formations. Cross section FGH illustrates the relationships around Magote Peak. Since the composition of the gravel is essentially the same regardless of its level of preservation, the mapping did not attempt to distinguish between true stream terraces, as found locally in the valley of the Rio Chama, and the higher level debris accumulations, whose origin may be quite different.

The composition of the gravels leaves no doubt that the main source area was an igneous and metamorphic terrane. If one assumes that the drainage at the time of terrace formation was similar to the modern drainage, at least in gross aspect, then the Brazos Mountains to the north and the San Pedro Mountains to the west emerge as the most logical source areas, with an undetermined contribution from earlier sedimentary formations.

Alluvium

The low plains in the south-central part of the southern tier of quadrangles are covered by a thin mantle of silt. The mantle is largely of local derivation and probably wind laid for the most part. The canyons of the Rio Chama and some of its tributaries contain much unconsolidated material, ranging from fine sand to cobbles. Some of this material is of local origin, but much of it was derived from igneous and metamorphic sources. In the northern part of the Canjilon and Alire quadrangles broad alluviated valleys are filled with Mancos shale fragments to depths of 15 to 20 feet or more.

STRUCTURAL GEOLOGY

The Chama Basin is separated from the San Juan Basin to the west by a low sill which marks the position of the Archuleta arch. According to Kelley (1955), this arch forms a connection between the Nacimiento uplift in New Mexico, and the San Juan dome in southwestern Colorado. To the southeast a definite boundary for the basin cannot be established. On the northeast side, the basin is bounded by the Brazos uplift. Both the Brazos and Nacimiento uplifts are old structural elements that can be traced back to Pennsylvanian time (Read and wood, 1947). However, they attained their present elevated position during the Laramide orogeny, and during late Tertiary fault adjustments.

The most conspicuous structural features in the southeastern Chama Basin are the gentle regional dips of the Mesozoic and older sediments to the north and west, broad open folds, and steep, normal faults, many of which have a north to northeast trend.

FOLDING AND REGIONAL DIP

The rocks in the Alire, Echo Amphitheater, and the northern part of the Canjilon quadrangles are so nearly horizontal that very minor local flexures can cause profound changes in the direction of strike. Thus, local measurements of strike and dip often tend toward confusion rather than clarification of the overall structural pattern, particularly as these measurements may have been taken on cross-bedded strata. However, when changes in elevation of key horizons are noted over larger areas, the true regional dip and strike become clear. With these facts in mind, a structure contour map on the base of the Cretaceous has been prepared for the six quadrangles (pl. 8). Many of the structural features of the region can be recognized on this map.

In the Alire, Canjilon, and Echo Amphitheater quadrangles, the regional dip of the sediments is north and northwest and usually does not exceed a few degrees. In the central portion of the latter quadrangle the position of the beds is almost horizontal; here an east-trending structural terrace is developed south of the Chama River. In the Ghost Ranch and Magote Peak quadrangles, the homoclinal dip of the Mesozoic sediments remains to the west and northwest, but increases to values of 10° to 12° in the Magote Peak quadrangle. Structurally, this quadrangle represents the highest part of the area.

Some very shallow fold structures are superimposed on this regional, basinal pattern. One of the most striking is the Arroyo del Cobre anticline, named after the arroyo. This structure is a southwest-plunging anticline. The resistant lower sandstone member of the Chinle formation has been breached by erosion along the axis of the fold, exposing a thick section of Permian Cutler beds in the walls of Arroyo del Cobre. The lower sandstone member makes up the rim of the canyon and forms a long dip slope to the northwest. Farther north this limb grades into the west-dipping homocline of Magote Ridge. The northeast flank of the Arroyo del Cobre structure is less distinct, mainly because of the presence of numerous faults and the unconformable overlap of the Tertiary El Rito formation and the Abiquiu tuff.

FAULTING

Many short faults with relatively small displacements are found in all six quadrangles; in addition, there are faults with lengths up to six miles and with stratigraphic throws of 200 feet or more. Although in most cases the dip angle of the fault plane cannot be determined with certainty, most faults seem to be steeply inclined or vertical. Their prevalent strike varies between N. 20° W. and N. 70° E. (see pl. 8). The west and northwest sides are downthrown in most cases, although exceptions to this rule can be observed on the Banco Aragon fault and the Martinez Canyon fault.

In the Alire quadrangle, two faults can be traced for a distance of four miles. Both strike north-south and have the downthrown side to the west. The most westerly fault, which passes through the center of the quadrangle, has a maximum stratigraphic throw of 100 feet, where the top of the Dakota (?) formation is in contact with the lower boundary of the Greenhorn limestone. To the north this fault disappears under the alluvial cover of Arroyo Blanco. The southern extension is lost in the lower Mancos shales which form the northern portion of Mesa de Los Viejos. The eastern fault of the Alire quadrangle has a measurable stratigraphic throw of not more than 20 feet. Its southern end disappears under the landslide debris in the southeastern corner of the map; its northern extension is covered by alluvium.

No major faults exist in the Echo Amphitheater quadrangle; a few short faults, generally less than a mile in length, occur in the southeast quarter and are confined to the Permian and Triassic rocks. In the center of the quadrangle a north-south fault with less than 50 feet of throw appears to control the channel of the Chama River for about one mile.

In the Canjilon quadrangle a major northeast-southwest trending fault follows the course of Martinez Canyon and extends into the quadrangle to the south; it is here named the Martinez Canyon fault. It has been traced for seven miles across the two quadrangles. Along its northern half the Dakota (?) formation is present on either side of the fault, but the drag indicated by strike and dip observations shows the southeast block to be downthrown. The southwest extension of the Martinez Canyon fault follows a Dakota (?) escarpment, and its trace is obscured by landslide debris west of Mesa Montosa. Near the southwestern end, the Martinez Canyon fault is intersected by another fault, trending N. 33' W. in the northern part and changing in direction to N. 10° W. further south. Near Arroyo Seco this cross fault has a stratigraphic throw of about 120 feet, with the downthrown side to the west, the displacement being calculated from the Todilto beds. The cross fault transacts the Morrison and Dakota (?) formations of the western end of Mesa Montosa and loses its identity in the shales of the Brushy Basin member, although it may well be a southern extension of a fault extending several miles to the north in the eastern part of the Alire quadrangle.

In the Ghost Ranch quadrangle, two faults deserve special mention. One of them, here called the Ojitos de los Gatos fault, strikes N. 45° E. through the central part of the quadrangle. About one half mile northeast of Ojitos de los Gatos this fault apparently bifurcates, with the west branch heading in a general northerly direction. The east branch disappears beneath talus slightly northeast of the bifurcation, but the Entrada–Todilto scarp on the southeast flank of Mesa del Yeso may represent a northeasterly continuation. Near the place of bifurcation the fault brings the Entrada formation of the northwest block into contact with Chinle beds of the southeast block. At this point the fault's maximum stratigraphic throw is about 200 feet.

The other major fault is found in the southeastern part of the quadrangle and is here called the Arroyo de Comales fault. It exhibits some bifurcation and slight changes in trend, but in general strikes about N. 30° E. The maximum observed stratigraphic throw is 220 feet; brecciated zones, up to 10 feet in width, accompany the faulting. The dip of the fault, where determinable, is 70° NW.

In the northeast corner of the Magote Peak quadrangle, several faults have a north-south trend. A prominent fault, here called the Banco Aragon fault, extends from the SE¼, S. 33, T. 26 N., R. 6 E., in a northern and northeastern direction across Banco Aragon and Banco Iona. This fault has a stratigraphic throw of 200 feet, with the downthrown side to the east. Two shorter faults, almost parallel and to the west of the Banco Aragon fault, also have the eastern block downthrown. About one mile east, and almost parallel to the Banco Aragon fault, runs the El Rito Creek fault; this fault, which follows the course of El Rito Creek for a distance of at least five miles, has a stratigraphic throw of approximately 60 feet and has the downthrown side to the west. The Jose Maria fault runs east-west in sec. 22, T. 26 N., R. 6 E., with the down-thrown side to the south. Its stratigraphic throw is small, probably less than 40 feet, but the fault has a rather prominent topographic expression.

Near the southern border of the Magote Peak quadrangle two faults occur, both striking N. 20° W. Both faults show bifurcation near their northern ends, where short subsidiary faults branch off to the north or northeast. The main faults and their branches have the downthrown block on the east side. The western fault is a high-angle normal fault, dipping about 75 degrees to the west; it has a stratigraphic throw of approximately 150 feet. In the Canjilon SE quadrangle the two above-mentioned faults extend south for some distance beyond the northern boundary of the quadrangle.

Faulting in the southern half of the Canjilon SE quadrangle is complex. The involvement of later Tertiary rocks in the faulting in this part of the area allows many of the faults to be dated as pre-El Rito or post-El Rito in age. Fault gouge and breccia, and occasionally calcite veins, are found in the major fault zones.

Local names have been given to faults and fault systems in order to facilitate the description and interpretation of these faults. In general a genetic significance should not be attached to the grouping of more than one fault in a system.

In Arroyo del Cobre a fault strikes in a northeast direction and dips 85 degrees northwest, passing between MP 5 and MP 6 of the National Forest–Plaza Colorado Grant boundary. This fault is a northeastern extension of faulting of similar trend occurring in the extreme southeast corner of the Ghost Ranch quadrangle. The upthrown side is to the southeast.

The Las Minas Jimmie fault system has a predominant north to northeast trend. It consists of a number of faults which more or less parallel the east rim of Arroyo del Cobre. A northern branch of the system crosses the canyon near its head and offsets the Cutler–Chinle con-tact of the northwest rim. Some of the faults of this system show evidence of post-El Rito movement.

The El Puertecito fault is exposed in the southwest corner of the Canjilon SE quadrangle and trends northeast through El Puertecito. In its southern part lenticular fault slices, containing beds of lower Chinle sandstone, are present in the fault zone. The fault has its down-thrown side to the southeast. The northeast extension of the El Puertecito fault meets one of the major north-trending faults of the Las Minas Jimmie system about 1,000 feet north of Ojito Carrizo, and a possible extension continues northeast from this point into the lower Chinle beds east of Las Minas Jimmie. Various north-trending branches of the El Puertecito fault are found here.

The fault south of the El Puertecito fault extends from the south-west corner of the quadrangle northeastward for approximately 2½ miles, where it disappears under the beds of the El Rito formation. Movement along this fault has been down to the southeast, with a stratigraphic throw of from 200 to 300 feet. This fault is pre-El Rito in age.

Complex faulting near the upper part of Arroyo Hondo exposes the Cutler and lower Chinle formations as a lens-shaped horst on the El Rito dipslope. Projecting the Cutler–Chinle contact to this horst from the exposures farther west suggests a stratigraphic displacement of at least 600 feet on the bordering faults.

The Cerrito de la Ventana fault system in the southeast corner of the Canjilon SE quadrangle consists of six sub-parallel faults, three of which are extensions of basalt dikes. Tertiary formations are displaced along these faults.

The major characteristics of the above-mentioned faults can be summarized as follows:

1. Wherever the angle of dip can be established, the faults are of the high-angle, normal type.
2. The stratigraphic throw of the faults averages 200 feet or more.
3. With the exception of the Martinez Canyon and Banco Aragon faults, most faults have their downthrown side to the west or north. However, the complexly faulted southern half of the Canjilon SE quadrangle exhibits no such general pattern.
4. Many faults bifurcate near their ends and terminate in incompetent beds.

Much of the faulting seems to have been the result of differential movements of the basin elements, notably the floor of the basin to the west and the Brazos uplift to the east. These movements caused a tensional stress field between the basin proper and the adjacent uplift, which in turn gave rise to the formation of normal faults in the sedimentary cover. Many faults exhibit branching near their ends and terminate in incompetent beds, such as the Cutler formation, the upper Chinle formation, the upper Jurassic beds, or the Mancos shale. Because of the bifurcation, the stratigraphic throw becomes distributed over a number of smaller faults, which in turn die out in the incompetent beds.

GEOLOGIC HISTORY

The Precambrian history of the southeastern part of the Chama Basin is obscure, since the only Precambrian rocks exposed lie east of the basin proper. The principal deposits are quartz sandstones, conglomerates, and some fine-grained sediments, with minor amounts of basaltic volcanics and rhyolitic hypabyssal intrusive rocks. Intense folding and deformation in Precambrian time was accompanied by metamorphism of the rocks to low and moderate rank. These beds comprise the Ortega quartzite and Hopewell series of just (1937), which have been studied recently in much more detail by Barker (1958). Following the folding and metamorphism, there was intrusion of several plutonic bodies of granite and granodiorite, and finally emplacement of pegmatites, accompanied by hydrothermal metamorphism. Erosion beveled the beds to a surface of gentle relief.

In the northwestern part of the San Juan Basin, early Paleozoic rocks are present in a fairly complete sequence. However, if any early Paleozoic rocks were deposited in the southeastern part of the Chama Basin, they must have been eroded before the advent of Pennsylvanian time, because Pennsylvanian sediments rest directly upon Precambrian rocks locally along the eastern margin of the basin. By Pennsylvanian time erosion had reduced the area to an irregular topography, with islands of Precambrian rocks projecting above the sea. Lagoonal or swamp areas developed along highly irregular coast lines. The presence of arkose and clastic material interbedded with limestone in the Pennsylvanian rocks to the south and west suggests that intermittent uplift and orogeny occurred concurrently with deposition. The irregular shelf and island topography must have extended over a large area of northern New Mexico well beyond the confines of the Chama Basin.

The Permian Cutler formation, containing only minor amounts of fine sediment, indicates that the source areas of the quartzite and metamorphic boulders in the conglomerates were not far removed from the depositional sites. Late Pennsylvanian marine conditions were gradually supplanted during the Permian by flood plain conditions with innumerable braided channels; torrential floods must have been common since complexly cross-bedded, coarse-grained sediments are characteristic of the formation. Vertebrate fossils found in the Cutler in Arroyo del Cobre, and to the southwest around Arroyo del Agua, suggest that only a brief hiatus, if any, occurred between Pennsylvanian and Permian time in this area; some of the forms could be Virgilian while others higher in the section are definitely Permian.

During late Permian or early Triassic time slight uplift took place to the east or, conversely, the basin sank slightly; evidence for this statement is the fact that Triassic beds bevel the underlying Cutler units to the east. The angularity is slight, and the conditions under which the Triassic beds accumulated were not very different from those which existed in Permian time. However, by late Triassic time the area had been reduced to a low, featureless surface, over which accumulated several hundred feet of non-marine silt and mud. (See fig. 2A). It has been likened to a savannah-like environment with sluggish rivers flowing across broad grasslands and with scattered forested areas in the uplands. Colbert (1950, p. 63) has described the environment as deduced from the fossil evidence:

> The association of Chinle fossils in northern New Mexico would seem to point to a stream and lowland ecology. Here in association are found fresh-water clam shells and fish, aquatic stereospondyl amphibians and the aquatic phytosaurs. It is probable that *Typothorax* was more of an upland animal than was its relative, *Machaeroprosopus,* while the little dinosaur, *Coelophysis,* certainly must have been an inhabitant of fairly dry land, across which it could move about with great agility. But these upland forms probably came down to the streams frequently, with the result that they are found in association with the more typically aquatic vertebrates. . . .

Following a hiatus during which only slight erosion and little or no crustal disturbance took place, the Entrada formation was deposited as a widespread sand sheet under partly fluviatile, partly aeolian, and, perhaps, partly marine conditions. The bedding structures in the Entrada sandstone are complex and suggest an alternate wetting and drying of the sand with continuous rearrangements of the bedding during accumulation. By late middle Jurassic time the area had become part of a restricted marine environment and the fetid, thin-bedded limestone layers of the Todilto formation had been precipitated. As salinity increased in the restricted environment, gypsum was also precipitated. The marked irregularity of the gypsum deposits as observed today is not readily explained; small steep-sided gypsum reefs or basins are illogical, and there is no evidence for gypsum dunes similar to those in the White Sands, New Mexico, area. Local solution and channeling of the gypsum layer may have occurred, but if so, it must have taken place before the deposition of the overlying Morrison sandstones and mudstones. The contact between the gypsum and the overlying Morrison is sharp and shows some erosional unconformity, but no gypsum fragments are contained in the overlying elastics. Apparently, recent erosion or solution has had little effect upon the distribution of gypsum.

During late Jurassic time the mudstones and siltstones of the Morrison formation were deposited across a vast area of low relief. Numerous bentonitic layers and glass shards attest to volcanic activity which occurred some distance away from the depositional basin. Far to the west and northwest of the Chama Basin the lower part of the Morrison formation was deposited by meandering streams, giving rise to lenticular sand layers which persist for many miles. In the southeastern part of the Chama Basin there is little sandstone, representing only occasional channeling by streams. Conditions seem to have been a repetition of the environment of the upper part of the Chinle formation. Fossils have not been reported from this area, although dinosaur remains from the upper part of the Morrison formation are well known elsewhere. By Morrison time the local highs on the Precambrian surface, which probably contributed some sediment to the early sandstones of the Chinle formation, had been completely reduced and covered by several layers of younger rocks.

Only slight erosion occurred before lower Cretaceous seas began to invade the Rocky Mountain region, yet some of the structurally higher Precambrian surfaces were stripped of any earlier sedimentary cover. The evidence is inconclusive in the Chama Basin as to whether lower Cretaceous rocks were deposited in the basin, although such rocks are known both to the east and west of the area. However, the Dakota (?) sandstone was deposited across the entire area as beach and lagoonal sand of the advancing upper Cretaceous sea. The complex intertonguing of marine and non-marine deposits which accompanied the transgressions and regressions of the upper Cretaceous sea has been discussed at great length by numerous authors. (See Dane, 1960; Rankin, 1944; Sears, Hunt, and Hendricks, 1941; Silver, 1951). Although evidence of such relationships has been removed by post-Cretaceous erosion in the southeastern part of the Chama Basin, the beds to the north suggest that, despite the fact that this area was very close to the shoreline during Mesaverde time, it was almost continuously submerged.

The close of Cretaceous sedimentation was marked by the Laramide revolution which raised the entire Rocky Mountain region above sea level and effectively outlined the San Juan Basin; the earlier positive areas of the Brazos uplift and the Nacimiento uplift were markedly rejuvenated and began contributing sediment to the adjacent basins. The southeastern part of the Chama Basin was only slightly affected by the folding, faulting, and intense deformation which accompanied the Laramide orogeny in other areas.

Paleocene and Eocene rocks are known to the west in the adjacent San Juan Basin, but the El Rito formation is the oldest preserved Tertiary unit in the southeastern part of the Chama Basin. The El Rito is a fanglomerate derived from newly formed highlands to the north and east and contains practically no volcanic material. In the upper part of the formation metamorphic materials other than quartzite are present, but the well-rounded cobbles of quartzite which make up much of the lower part of the unit strongly suggest that most of the El Rito beds are second or third generation sediments derived from the Pennsylvanian, Permian, and Triassic rocks which were stripped off the rejuvenated Brazos highland.

North and west of the Chama Basin, volcanism may have begun nearly contemporaneously with the Laramide orogeny; and by Oligocene time most of the uplift areas were buried by an extensive series of flows, tuffs, and other volcanic debris. Intermittent volcanism continued throughout most of Tertiary time, accompanied by deposition of volcanic conglomerate, sandstone, and ash along the flanks of the old uplifts and off the slopes of the newly built volcanic peaks. Local alluvial fans and fanglomerates, interbedded with thin flows, accumulated and coalesced to form broad debris sheets which filled and smoothed older topographic irregularities. The Abiquiu tuff member of the Santa Fe formation and the Los Pinos formation belong to this group of deposits; these units were deposited from perhaps early Miocene until late Pliocene time, although not continuously, nor everywhere contemporaneously, during this interval.

In late Tertiary time faulting was renewed, and many of the earlier faults were rejuvenated, although the movements were not necessarily of the same magnitude nor in the same direction as the previous displacements. Some new faults were initiated, and many served as feeder channels for the Pliocene, Pleistocene, and Recent basalt flows which seem to represent the dying stages of the extensive volcanism.

The northern part of the Chama Basin was extensively glaciated during the Pleistocene, particularly in the higher elevations; and three stages, Cerro, Durango, and Wisconsin, are recognized. Smith (1938) described boulder-sized conglomerates on the crest of Magote Ridge as the Canjilon till and ascribed these beds to the Cerro glacial stage; however, the present authors favor the following explanation for the outcrops found on Magote Ridge. The El Rito formation once covered Magote Ridge and may well have been continuous with the El Rito exposed east of El Rito Creek and in the vicinity of Pine Canyon. On the ridge itself, the formation was resting on Mancos shale. After El Rito time, erosion removed large parts of the formation and left only small patches as an intermittent veneer on Magote Ridge. (See fig. 6A.) Subaerial weathering may have removed a considerable amount of the sandy and silty matrix, which matrix is largely responsible for the red color of the conglomerate. At the same time, the exposed boulders were subject to weathering, resulting in some cases in a rotted appearance of the fragments (Smith, 1936). With further dissection of the ridge, landsliding began and hummocky relief developed. It is quite possible, as Smith (1938) has pointed out, that solifluction and landsliding became pronounced under the periglacial conditions of the Pleistocene, and that many topographic features were formed at that time. (See fig. 6B.)

Continued post-glacial erosion has developed the numerous terraces and the alluvial fill found in the larger valleys. In areas where Cretaceous shales form the surface rocks and along the over-steepened slopes of the mesas, extensive landsliding is continuing; blocks of sandstone, conglomerate, or volcanic material may be found several thousand feet from their original position.

ECONOMIC GEOLOGY

The southeastern part of the Chama Basin has been primarily an agricultural and grazing area and lacks the metamorphic and intrusive rock types with which mineral deposits are generally associated. In the early 1950's, during the intensive search for uranium deposits, a great many claims were staked on sparse showings in both the Dakota (?) and Chinle formations, but no production has been developed. Inadequate water supplies have hampered development throughout the region.

GROUND-WATER RESOURCES

Ground-water supplies in the quadrangles mapped are stored in sediments underlying the Chama River valley, locally in the Entrada sandstone and in the Dakota (?) formation, or are scattered in limited amounts in perched water tables in the Mancos shale on the high mesas in the northern parts of the quadrangles. The Rio Chama is essentially a permanent stream although its flow is controlled by El Vado Dam about 35 miles upstream; water use from the surface flow of the Rio Chama is subject to claims of downstream users as well as claims made by the state of Texas on the entire Rio Grande watershed, of which the Rio Chama is a part.

The valley of the Rio Chama is underlain by sediments of the Chinle and Cutler formations, which in turn are capped with several levels of terrace gravels and recent alluvium. The Cutler outcrops are limited to Arroyo del Cobre, part of the valley of El Rito Creek and the extreme southern portions of the Ghost Ranch and Echo Amphitheater quadrangles. Lithology and stratification in parts of the Cutler beds are favorable for storage, but the lenticularity of the units results in extremely variable permeabilities. Recharge of the formation is rather favorable along El Rito Creek and in Arroyo del Cobre, but the variations in permeability limit development possibilities. A test well, Watson Pack No. 1, drilled in sec. 2, T. 23 N., R. 4 E., north of Las Lomas de los Marios in the southwest corner of the Ghost Ranch quadrangle, flows water, charged with H_2S and containing several thousand parts per million hardness, from a depth of less than 2,500 feet. This flow might be from either Pennsylvanian rocks or the Cutler formation, but detailed information is lacking. A second well, Lowry et al. Morton No. 1, drilled in sec. 24, T. 24 N., R. 5 E., in Arroyo del Cobre, collared in the lower part of the Cutler formation, flows water (fit only for cattle) from an unknown depth; again the source of the water could be either Cutler or Pennsylvanian beds. These flowing wells are collared at elevations well above the level of the Rio Chama and thus indicate a strong artesian circulation in the late Paleozoic rocks, but the quality seems to preclude the development of potable water from these sources.

The lower sandstone member of the Chinle formation locally contains as much as 200 feet of coarse-grained, permeable sandstone, but the lenticular nature of beds and the impermeable mudstone partings result in little recharge or storage over much of the outcrop area. In the northwest part of the Canjilon SE quadrangle a recharge area of 4 or 5 square miles is exposed, but since the sands are not confined, conditions are not particularly favorable for ground-water accumulation. In the southeastern part of the Ghost Ranch quadrangle, in the northern part of the Canjilon SE quadrangle, and in the southern part of the Magote Peak quadrangle small faults have controlled the drainage pat-tern and to some extent the ground-water distribution (i.e., Ojito del Comanche and Ojito de los Cienaguitas). Locally, the faults serve as channelways for groundwater as at Ojitos de las Gatos, although this spring was dry when examined in June, 1956.

The most favorable area for ground-water accumulation in this section of the Rio Chama valley lies along the valley of Arroyo Seco in the western part of the Ghost Ranch quadrangle and in the northeastern corner of the Echo Amphitheater quadrangle. Here the lower sandstone member of the Chinle is buried by 100 to 300 feet of upper Chinle shale. Arroyo Seco drains nearly all of the Canjilon quadrangle to the north and part of the Alire quadrangle to the northwest. Although the flow disappears shortly after entering the quadrangle, it is a flowing permanent stream in the extreme northeast corner of the Echo Amphitheater quadrangle, continuously recharging the rocks immediately beneath its bed. Reasonable amounts (averaging perhaps 40—50 gpm) of ground-water could be drawn from depths of less than 300 feet at almost any drill site along the Arroyo Seco in the Ghost Ranch quadrangle and in the northeast part of the Echo Amphitheater quadrangle.

Above Ghost Ranch several springs flow from the base of the Entrada sandstone in Arroyo del Yeso. A few seeps occur about 2½ miles south along the same horizon above Ojitos de los Gatos, although they are not related to the faulting exposed there. The Entrada sandstone is well sorted and has good permeability, but it crops out as a steep cliff over the entire mapped area and thus has very limited recharge. The flow of the springs above Ghost Ranch fluctuates from a few hundred gallons a minute to a minimum of 20 to 30 gallons per minute, but there is no record of their ever having gone dry. The only possible recharge area for these springs lies northwest of Ghost Ranch in Arroyo Seco, where the arroyo is crossed by the small northwest striking fault which displaces the west end of Mesa Montosa. Since records of variations in flow of the springs, which might be correlated with changes in flow of Arroyo Seco, are not available, the recharge area for these springs must remain conjectural. A well drilled at Ghost Ranch headquarters in the alluvial fill of Arroyo del Yeso pumped more than 80 gpm on a 24-hour test with only a few feet of drawdown; the source of this water is obviously the same Arroyo del Yeso springs.

The Morrison formation lacks sufficient sand layers to be considered a potential aquifer; the many bentonitic layers in the Brushy Basin shale member reduce the permeability practically to zero. Most of the exposures are on relatively steep slopes, and recharge is greatly reduced. Jose Maria Spring, in the northern part of the Magote Peak quadrangle, lies within the zone of the lower member of the Morrison formation, but since landsliding and local faulting may account for its presence, ground-water reserves are limited.

Extensive gentle dip slopes are cut on the Dakota (?) formation in the northern parts of the Echo Amphitheater and Ghost Ranch quadrangles, and over much of the Alire, Canjilon, and Magote Peak quadrangles. The coarse-grained sandstone beds are excellent aquifers with good permeability, and several springs are developed in the Alire, Canjilon, and Magote Peak quadrangles from these beds. Farther north, artesian circulation in the Dakota (?) formation is common because of the impermeable Morrison formation below and the impervious Mancos shale above. Over much of the northern tier of quadrangles, potable water is available from the Dakota (?) formation at depths of less than 500 feet except on those mesas where dissection by erosion has prevented appreciable storage.

Scattered springs in the Mancos shales along Magote Ridge, from the Tertiary formations east of El Rito Creek, and in the southeastern part of the Canjilon SE quadrangle appear to be related to fault or landslide blocks, and thus are dependent on local surface precipitation and recharge, rather than on the general ground-water circulation. A number of small, perched water tables are present as lakes in landslide depressions throughout the Mancos outcrop area. The El Rito, Los Pinos, and Abiquiu formations are coarse grained with many boulder and pebble layers which give rise to excellent permeability; however, the lack of impermeable layers to confine and store groundwater, combined with their limited outcrop area in the quadrangles mapped, makes these units unsatisfactory for ground-water development.

The two dry holes mentioned above penetrate more than 2,000 feet of Pennsylvanian limestones, but had no shows of oil or gas. Each well flows a considerable quantity of very poor quality water, scarcely fit for livestock, but source beds for the water are unknown.

MINERAL RESOURCES

Discoveries of uranium mineralization in the Dakota (?) formation and at two or three widely scattered spots in the Chinle formation have resulted in considerable exploration; drilling on Mesa del Peso and Mesa Montosa failed to find additional mineralization away from the outcrop. No ore bodies have been found and the formations do not contain sufficient carbonaceous or asphaltic material to warrant further search.

Copper mineralization in sandstone about 150 to 200 feet below the top of the Cutler formation has been prospected in Arroyo del Cobre in the Canjilon SE quadrangle, but no other showings have been found in the Cutler outcrops to the west. The several occurrences are typical "red bed" copper deposits with carbonaceous plant fragments replaced by chalcocite, malachite, azurite, and various copper oxides; surrounding the fragments in the clean sandstone is usually an oxidation halo of malachite and azurite. Individual specimens may contain as much as 15% to 20% Cu, but the prospects usually expose only a few tons of material, which averages less than I% Cu.

The terrace gravels which cover much of the Rio Chama valley in the Ghost Ranch and Echo Amphitheater quadrangles contain large quantities of Precambrian granite and quartzite boulders, and are an excellent source of road metal and concrete aggregate. Large acreages of these gravels are being mined at the present time to provide fill and aggregate for the Abiquiu dam, a large earth-fill structure, which is under construction in the Chama Canyon about 3 miles south of the southern boundary of the Ghost Ranch quadrangle.

MISCELLANEOUS RESOURCES

The eastern half of the Canjilon quadrangle and the Madera Canyon area in the Magote Peak quadrangle contain several stands of Ponderosa pine. These stands are principally under the control of the Forest Service and are harvested as development and growth warrant. Small commercial timber operations on scattered private tracts also harvest second- or third-growth stands, since much of the timber was completely removed during the first cutting boom 50 to 75 years ago. Mesa Alta and Mesa Meta in the southwest corner of the Echo Amphitheater quadrangle have fine stands of Ponderosa, but these are too small and inaccessible for commercial exploitation.

Since the Cutler, Chinle, Entrada, Todilto, and Morrison formations support little vegetation except where water is abundant, much of the southern tier of quadrangles is poor grazing land; only along the banks of the Rio Chama, in the Arroyo Seco, and below the Arroyo del Yeso springs is good forage available. The high mesas in the northern tier of quadrangles receive considerably more precipitation, and both grazing and farming are possible on Dakota (?) and Mancos formation soils. However, successful ranching or farming is dependent upon control of large acreages and grazing privileges on National Forest land. Even so, the limited water supplies make it difficult to keep cattle or sheep properly dispersed for optimum land use.

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Appendix A

Composite section of the Cutler formation from measurements on the west wall of Arroyo Del Cobre in Sec. 26, T. 24 N., R. 5 E., and from a driller's log of Lowry et al., Morton No. 1, in sec. 24, T. 24 N., R. 5 E.

UNIT No.	DESCRIPTION	THICKNESS IN FEET
	TRIASSIC—LOWER CHINLE (Agua Zarca member)	
	Pale-yellowish orange (10 YR 8/6) medium to coarse subrounded sandstone interbedded with dark yellowish orange (10 YR 6/6) limestone and quartz pebble conglomerate	18
	.... slight angular unconformity	
	PERMIAN—CUTLER FORMATION	
	A Member. Thickness—343 feet	
1.	Coarse to very coarse, friable, arkosic sandstone with limonite stain. Light gray (N 8)	70
2.	Very coarse, angular, copper-bearing shaly sandstone. Light-gray (N 8)	20
3.	Medium- to coarse, subangular, micaceous, arkosic, shaly sandstone, with limestone concretions and interbedded bluish-gray shale and siltstone. Grayish-orange (10 YR 7/4)	70
4.	Coarse to very coarse chloritic, arkosic, micaceous, shaly sandstone in small lenses. Yellow-green (5 GY 7/2)	7
5.	Variegated mudstone and siltstone with yellowish-gray limestone lenses. (10 R 4/2) reddish-gray	4
6.	Variegated mudstone and siltstone. Grayish-red-purple (5 RP 4/2)	34
7.	Very coarse, very friable, angular, arkosic, micaceous sandstone. Pale-greenish-yellow (10 Y 8/2)	25
8.	Dark-reddish-brown and grayish-red variegated mudstone and silt-stone. No color taken	75
9.	Variegated mudstone and siltstone (reddish-brown, 10 R 4/2) with yellowish-gray limestone lenses interbedded with a coarse to very coarse subangular, arkosic, micaceous, shaly sandstone. Grayish-redpurple and yellowish-gray (5 RP 4/2 and 5 GY 7/2)	38
	An erosional unconformity of considerable regional extent occurs at the bottom of this member.	
	B Member. Thickness—179 feet	
1.	Very coarse, friable, arksosic, angular, micaceous, shaly sandstone (grayish-red-purple, 5 RP 4/2) interbedded with variegated reddish-gray (10 R 4/2) mudstone and siltstone	38
2.	Coarse to very coarse, subangular, arkosic, micaceous, shaly sand-stone. Green-yellow (5 GY 7/2)	34
3.	Variegated mudstone and siltstone, showing a cobble-appearing type of weathering. Grayish-red (10 R 4/2)	54
4.	Variegated mudstone and siltstone. Grayish-red (10 R 4/2)	12
5.	Coarse to very coarse, angular, arkosic, micaceous, friable sandstone mottled from yellow-gray (5 Y 7/2) to grayish-purple-red (10 R 4/2)	31
6.	Variegated mudstone and siltstone (reddish-gray, 10 R 4/2) and interbedded medium to coarse, subangular, micaceous, crossbedded sandstone (pale reddish-purple, 5 RP 6/2), and a yellowish-gray limestone-pebble conglomerate	10

UNIT No.	DESCRIPTION	THICKNESS IN FEET
	C Member. Thickness—4 feet	
1.	Mottled to banded limestone pebble conglomerate. Very light gray (N 8), brownish gray (5 YR 4/1) and a medium gray (N 5)	4
	D Member. Thickness—101 feet	
1.	Very coarse, subangular, arkosic, slightly micaceous sandstone. Medium light-gray (N 6)	7
2.	Pale reddish-purple (5 RP 6/2) micaceous, sandy mudstone and silt-stone to reddish-gray (10 R 4/2) mudstone and siltstone interbedded with yellowish-gray mottled, crystalline limestone. Pale reddish-purple (5 RP 6/2) medium to very coarse, arkosic, subangular, shaly sandstone	27
3.	Fine to medium, subangular, micaceous, arkosic, shaly sandstone (grayish yellow-green, 5 GY 7/2) interbedded with a variegated mud-stone and siltstone (reddish-gray, 10 R 4/2) which weathers to a conglomerate texture	67
	Erosional unconformity at the base.	
	E Member. Thickness—132 feet	
1.	Mottled reddish-gray (10 R 4/2) very fine to fine, subangular, arkosic, micaceous, shaly sandstone	17
2.	Reddish-gray (10 R 4/2) to light-gray variegated, micaceous mud-stone and siltstone with interbedded grayish yellow-green (5 GY 7/2) fine to medium, subangular, micaceous, arkosic, shaly sandstone	17
3.	Variegated mudstone and siltstone (reddish-gray, 10 R 4/2) containing striated calcite rhombs	22
4.	Fine to medium, subangular, very micaceous, arkosic, shaly sand-stone. Light-gray (N 7)	32
5.	Reddish-gray (10 R 4/2) variegated, fissle, micaceous mudstone	9
6.	Pale reddish-purple (5 RP 6/2) very fine, subangular, arkosic, mica-ceous, shaly sandstone	4
7.	Dark reddish-brown (10 R 3/4) micaceous mudstone	11
8.	Fine, subangular, micaceous, arkosic sandstone. Grayish yellow-gray (5 GY 7/2)	8
9.	Reddish-gray (10 R 4/2) variegated mudstone and siltstone	12
	F Member. Thickness—5 feet	
	Yellowish-gray (5 Y 8/1) mottled, crystalline limestone	5
	G Member. Thickness—202 feet	
1.	Variegated, micaceous, sandy mudstone (dark reddish-brown, 10 R 3/4) interbedded with pale reddish-purple (5 RP 6/2) fine to medium, subangular, micaceous, arkosic, shaly sandstone and some dark reddish-brown (10 R 3/4) siliceous shale	38
2.	A series of interbedded grayish yellow-green (5 GY 7/2) fine to medium, subangular, arkosic, very micaceous shaly sandstone; and dark reddish-brown (10 R 3/4) variegated, micaceous, sandy mudstones, and some light-gray (N 7) fine to medium, angular arkosic, very micaceous shaly sandstone	35
3.	Moderate reddish-orange (10 R 6/6) coarse to very coarse arkosic, micaceous, subangular, porous sandstone with a well-rounded quartzite boulder conglomerate interbedded	40

UNIT No.	DESCRIPTION	THICKNESS IN FEET
4.	Micaceous, angular, pyritic, very fine to fine sandy shale greenish-gray (5 GY 6/1)	5
5.	Grayish-red (10 R 4/2) very fine to fine, angular, micaceous, shaly sandstone showing iron stain	12
6.	Very fine to fine, angular, micaceous, shaly sandstone (green-gray, 5 GY 6/1)	35
7.	Grayish orange-pink (5 YR 7/2) medium to coarse, angular, micaceous, shaly sandstone	15
8.	Grayish-red (10 R 4/2) medium to coarse, angular, micaceous, shaly sandstone	5
9.	Variegated, micaceous mudstone and siltstone. Dark reddish-brown (10 R 3/4)	10
10.	Blackish-white micaceous, arkosic, carbonaceous, subangular, shaly sandstone (5 B 9/1)	7
	H Member. Thickness—365 feet	
1.	Red, gray, brown, and purple variegated siltstone and mudstone with thin interbedded sandstone beds and conglomerate lenses capped by massive, poorly sorted, micaceous sandstone of variable thickness	210
2.	Interbedded mudstone, siltstone, and sandstone. Siltstone and mud-stone are well-indurated, red-reddish brown layers from 3 feet to 30 feet in thickness; sandstones are micaceous, arkosic, locally conglomeratic, fine-coarse grained and fairly well sorted. Conglomeratic layers locally scour the underlying mudstones and siltstones	155
	I Member. Thickness—145 feet	
1.	Massive purplish-red to light gray siltstone and mudstone. Some interbedded micaceous, well-sorted, sandstone layers with subrounded grains 145	
	J Member. Thickness—57 feet	
1.	Medium-grained, subrounded, arkosic, quartzose sandstone, strongly cross bedded, reddish to grayish in color	22
2.	Buff to white, massive, crossbedded, sandstone. Subrounded, coarse grains; arkosic, with limonite and clay cement. Lenticular, scouring the underlying Pennsylvanian shales with a relief of 20 to 30 feet	35
	.... Erosional Unconformity	
PENNSYLVANIAN—HERMOSA(?) FORMATION (DESMOINESIAN)	Micaceous, carboniferous, gypsiferous, gray-green shale containing well-preserved remains of *Alethopteris serlii*	35

Appendix B

LOS PINOS FORMATION

Partial section of tuffaceous member measured along Vallecitos road in NE¼ sec. 12, T. 26 N., R. 6 E.

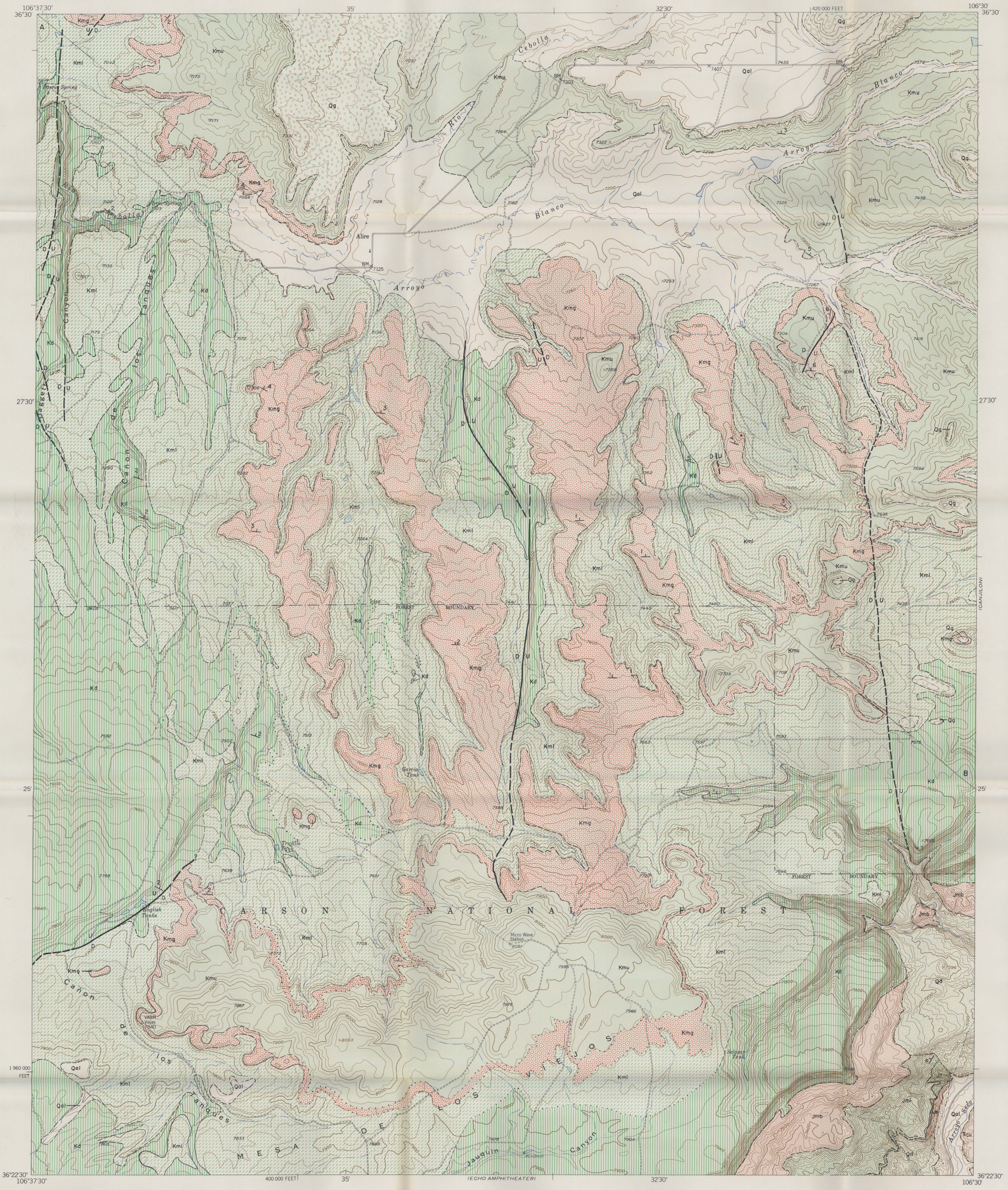
UNIT No.	DESCRIPTION	THICKNESS IN FEET
	Quartz latite boulder conglomerate, contact with underlying member concealed in 10-foot covered interval	
1.	Crossbedded, fine-grained, tuffaceous sandstone with irregular stringers of siltstone and mudstone. Grayish orange pink (5 YR 7/2) and moderate yellowish brown (10 YR 5/4)	15
2.	Crossbedded conglomerate with fragments up to $1/_8$ inch in diameter	4
3.	Micaceous, sandy mudstone. Pale greenish yellow (10 Y 8/2)	9
4.	Micaceous mudstone with black volcanic glass and feldspar fragments. Pale greenish yellow (10 Y 8/2)	24
5.	Well-bedded siltstone. Pinkish gray (5 YR 8/1)	10
6.	Covered with conglomerate float and reddish soil	204
7.	Crossbedded conglomerate with fragments up to five inches in diameter of gneiss, schist, and quartzite	15
8.	Fine-grained, tuffaceous sandstone with crossbedding and containing fragments of rhyolitic volcanic bombs. Grayish orange pink (5 YR 7/2)	10
9.	Coarse-grained, crossbedded sandstone with fragments of decomposed volcanic glass, which contain phenocrysts of hornblende, feldspar, and quartz. Grayish orange pink (5 YR 7/2)	12
10.	Coarse-grained, poorly sorted sandstone with quartzite pebbles. Grayish orange pink (5 YR 7/2)	17
11.	Interbedded sandstone and siltstone. Crossbedded sandstone is micaceous and contains fragments of decomposed volcanic bombs (very pale orange, 10 YR 8/2). Siltstone forms lenses within sandstone up to two inches thick (pinkish gray, 5 YR 8/1)	42
12.	Poorly sorted sandstone with angular grains and many accessory constituents (mainly hornblende and volcanic glass). Very pale orange (10 YR 8/2)	15
13.	Mudstone with clay balls up to 1/8 inch in diameter. Moderate yellowish brown (10 YR 5/4)	10
14.	Crossbedded, fine- to medium-grained sandstone with subangular to angular grains; contains black accessory constituents, mudballs, thin conglomerate lenses, and tuffaceous seams. Grayish pink (5 R 8/2)	8
15.	Crossbedded, fine-grained, tuffaceous sandstone, with lenses of pebble conglomerate, siltstone, and mudstone. Grayish orange pink (5 YR 7/2)	6
16.	Mudstone with clayballs up to 1/8 inch in diameter. Moderate yellowish brown (10 YR 5/4)	39
17.	Crossbedded, fine-grained, tuffaceous sandstone; contains irregular stringers of siltstone and mudstone. Grayish orange pink (5 YR 7/2)	77
18.	Micaceous siltstone with white tuffaceous material. Pale yellowish brown (10 YR 6/2)	24

UNIT No.	DESCRIPTION	THICKNESS IN FEET
19.	Fine-grained, tuffaceous sandstone with crossbedding; contains irregular stringers of siltstone and mudstone. Grayish orange pink (5 YR 7/2) and moderate yellowish brown (10 YR 5/4)	17
20.	Argillaceous and micaceous siltstone with white tuffaceous material. (Pale yellowish brown (10 YR 6/2)	
	Lower contact not exposed.	
	Total measured thickness	608

Index

Numbers in boldface indicate main references.

ALIRE QUAD



Base map from U.S. Geological Survey Alire Quadrangle

Geology by Clay T. Smith, A.J. Budding, Charles W. Pitrat, and others.

GEOLOGY OF ALIRE QUADRANGLE

Scale 1/24000

0.5 0 1 Mile

EXPLANATION

QUATERNARY

Qal — Alluvium
Stream deposits and recent terrace gravels

Qd — Landslide debris
In part incised by recent drainage

Qg — Terrace gravel
Local terraces and extensive sheets of coarse gravel deposits, not related to present drainage pattern

TERTIARY

Not exposed in this quadrangle — Sierra Negra Basalt Member of the Hinsdale Formation
Dikes and flows of olivine basalt

Not exposed in this quadrangle — Abiquiu Tuff Los Pinos Formation
Ta; *Tuffaceous sandstone and siltstone*
Tp; *Tuffaceous sandstone and siltstone with interbedded volcanic boulder conglomerate*

Not exposed in this quadrangle — El Rito Formation
Coarse sandstone and conglomerate with Precambrian rock fragments

CRETACEOUS

Kmu — Carlile and Niobrara(?) Members of the Mancos Formation
Gray, thin-bedded shale with local concretionary zones

Kmg — Greenhorn Member of the Mancos Formation
White-weathering, slabby limestone interbedded with gray calcareous shale

Kml — Graneros Member of the Mancos Formation
Light-gray to dark-gray calcareous shale, somewhat concretionary, with thin sandstone beds and brownish arenaceous zones

Kd — Dakota(?) Formation
Massive, coarse-grained crossbedded sandstone with local interbedded shale and coal layers; may contain equivalents of Purgatoire and Burro Canyon Formations in lower part

JURASSIC

Jmb — Brushy Basin Shale Member of Morrison Formation
Variegated gray, green, and red mudstone with thin sandstone and conglomerate lenses

Jml — Lower member of Morrison Formation
Alternating thin-bedded sandstone, siltstone and mudstone, weathering gray to chocolate brown

Jt — Todilto Formation
Thin-bedded, fetid, gray limestone with thin shale partings, overlain locally by massive white gypsum

Je — Entrada Formation
Massive, crossbedded, fine-grained sandstone

TRIASSIC

ꝶcu — Upper shale member of Chinle Formation
Interbedded variegated red, chocolate brown, and purple mudstone, siltstone, and lenticular sandstone

Not exposed in this quadrangle — Lower sandstone member of Chinle Formation
Coarse-grained, conglomeratic, lenticular sandstone interbedded with siltstone and mudstone; probably contains correlatives of the Agua Zarca, Salitral, and Poleo Members of the Chinle Formation

PERMIAN

Not exposed in this quadrangle — Cutler Formation
Alternating red-purple crossbedded arkosic sandstone and purple-orange mudstone

PENNSYLVANIAN

Not exposed in this quadrangle — Pennsylvanian undifferentiated
Thin-bedded, carbonaceous siltstone of probable Desmoinesian Age

Contact — *Dashed where approximately located; dotted where concealed*

Fault, showing dip (40) — *Dashed where approximately located*

Strike and dip of beds (7)

Mine (abandoned)

Well

CANJILON QUAD

Base map from U.S. Geological Survey Canjilon Quadrangle

Geology by Clay T. Smith, A.J. Budding, Charles W. Pitrat, and others.

GEOLOGY OF CANJILON QUADRANGLE

Scale 1/24000

0.5 0 1 Mile

EXPLANATION

QUATERNARY

Qal — Alluvium
Stream deposits and recent terrace gravels

Qd — Landslide debris
In part incised by recent drainage

Qg — Terrace gravel
Local terraces and extensive sheets of coarse gravel deposits, not related to present drainage pattern

TERTIARY

Not exposed in this quadrangle
Sierra Negra Basalt Member of the Hinsdale Formation
Dikes and flows of olivine basalt

Not exposed in this quadrangle
Abiquiu Tuff   Los Pinos Formation
Ta; *Tuffaceous sandstone and siltstone*
Tp; *Tuffaceous sandstone and siltstone with interbedded volcanic boulder conglomerate*

Not exposed in this quadrangle
El Rito Formation
Coarse sandstone and conglomerate with Precambrian rock fragments

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Kml — Graneros Member of the Mancos Formation
Light-gray to dark-gray calcareous shale, somewhat concretionary, with thin sandstone beds and brownish arenaceous zones

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Massive, coarse-grained crossbedded sandstone with local interbedded shale and coal layers; may contain equivalents of Purgatoire and Burro Canyon Formations in lower part

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Contact
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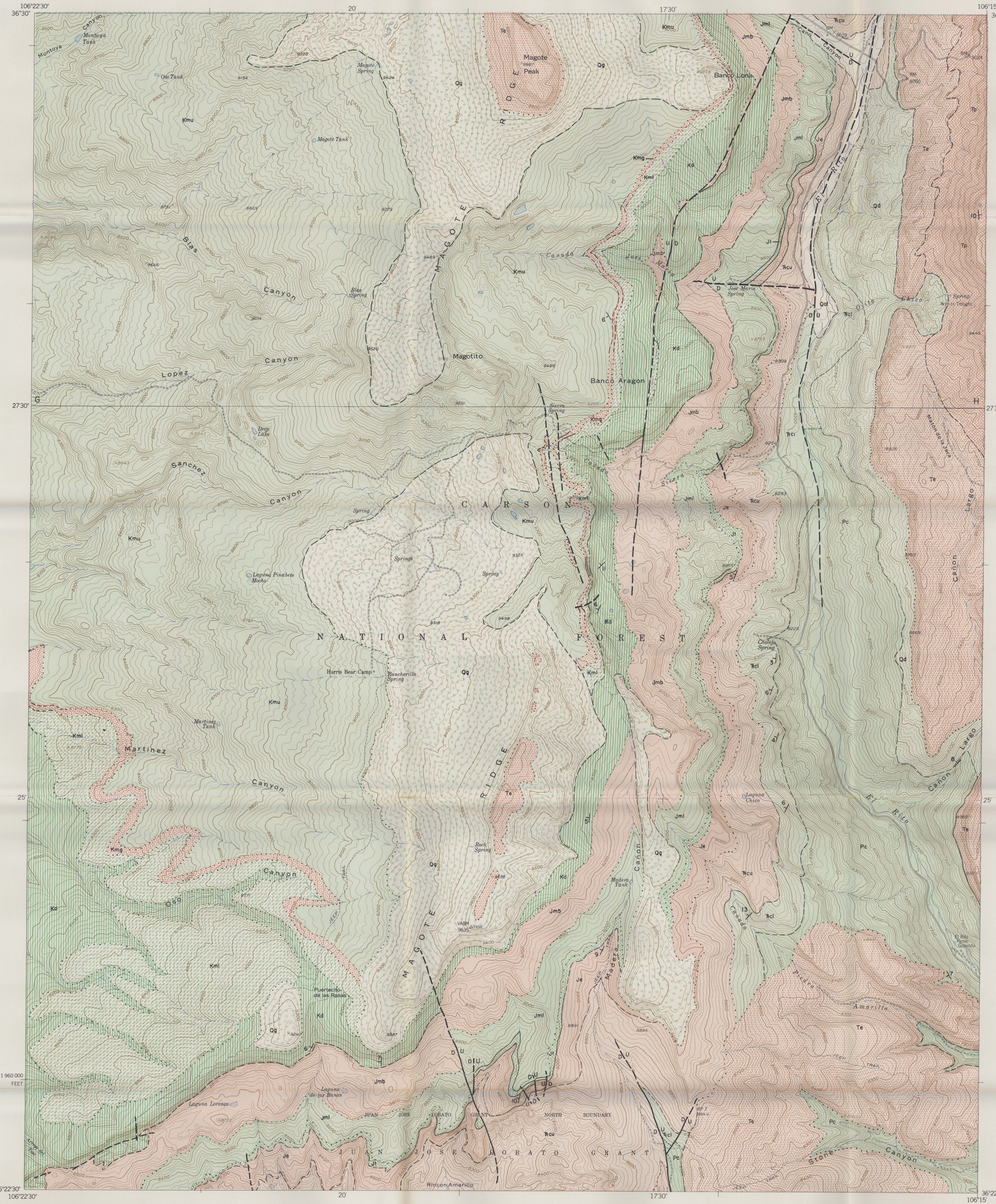
Fault, showing dip (40)
Dashed where approximately located

Strike and dip of beds

Mine (abandoned)

Well

MAGOTE PEAK QUAD



Base map from U.S. Geological Survey Magote Peak Quadrangle

Geology by Clay T. Smith, A.J. Budding, Charles W. Pitrof, and others.

GEOLOGY OF MAGOTE PEAK QUADRANGLE

Scale 1/24000

1 0.5 0 1 Mile

EXPLANATION

QUATERNARY

Qal Alluvium

Stream deposits and recent terrace gravels

Qd Landslide debris

In part incised by recent drainage

Qg Terrace gravel

Local terraces and extensive sheets of coarse gravel deposits, not related to present drainage pattern

TERTIARY

Not exposed in this quadrangle

Sierra Negra Basalt Member of the Hinsdale Formation

Dikes and flows of olvine basalt

Not exposed in this quadrangle

Abiquiu Tuff

Tp Los Pinos Formation

Ta; *Tuffaceous sandstone and siltstone*
Tp; *Tuffaceous sandstone and siltstone with interbedded volcanic boulder conglomerate*

Te El Rito Formation

Coarse sandstone and conglomerate with Precambrian rock fragments

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Kmg Greenhorn Member of the Mancos Formation

White-weathering, slabby limestone interbedded with gray calcareous shale

Kml Graneros Member of the Mancos Formation

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JURASSIC

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Thin-bedded, carbonaceous siltstone of probable Desmoinesian Age

Contact

Dashed where approximately located; dotted where concealed

40

Fault, showing dip

Dashed where approximately located

7

Strike and dip of beds

Mine (abandoned)

Well

ECHO AMPITHEATER QUAD

Base map from U.S. Geological Survey Echo Amphitheatre Quadrangle

Geology by Clay T. Smith, A.J. Budding, Charles W. Pitrat, and others.

GEOLOGY OF ECHO AMPHITHEATER QUADRANGLE

Scale $\frac{1}{24000}$

1 0.5 0 1 Mile

EXPLANATION

QUATERNARY

Qal — Alluvium

Stream deposits and recent terrace gravels

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Qg — Terrace gravel

Local terraces and extensive sheets of coarse gravel deposits, not related to present drainage pattern

TERTIARY

~~Not exposed in this quadrangle~~

Sierra Negra Basalt Member of the Hinsdale Formation

Dikes and flows of olvine basalt

~~Not exposed in this quadrangle~~

Abiquiu Tuff Los Pinos Formation

Ta; *Tuffaceous sandstone and siltstone*
Tp; *Tuffaceous sandstone and siltstone with interbedded volcanic boulder conglomerate*

~~Not exposed in this quadrangle~~

El Rito Formation

Coarse sandstone and conglomerate with Precambrian rock fragments

CRETACEOUS

~~Not exposed in this quadrangle~~

Carlile and Niobrara(?) Members of the Mancos Formation

Gray, thin-bedded shale with local concretionary zones

~~Not exposed in this quadrangle~~

Greenhorn Member of the Mancos Formation

White-weathering, slabby limestone interbedded with gray calcareous shale

Kml — Graneros Member of the Mancos Formation

Light-gray to dark-gray calcareous shale, somewhat concretionary, with thin sandstone beds and brownish arenaceous zones

Kd — Dakota(?) Formation

Massive, coarse-grained crossbedded sandstone with local interbedded shale and coal layers; may contain equivalents of Purgatoire and Burro Canyon Formations in lower part

JURASSIC

Jmb — Brushy Basin Shale Member of Morrison Formation

Variegated gray, green, and red mudstone with thin sandstone and conglomerate lenses

Jml — Lower member of Morrison Formation

Alternating thin-bedded sandstone, siltstone and mudstone, weathering gray to chocolate brown

Jt — Todilto Formation

Thin-bedded, fetid, gray limestone with thin shale partings, overlain locally by massive white gypsum

Je — Entrada Formation

Massive, crossbedded, fine-grained sandstone

TRIASSIC

T̶Rcu — Upper shale member of Chinle Formation

Interbedded variegated red, chocolate brown, and purple mudstone, siltstone, and lenticular sandstone

T̶Rcl — Lower sandstone member of Chinle Formation

Coarse-grained, conglomeratic, lenticular sandstone interbedded with siltstone and mudstone; probably contains correlatives of the Agua Zarca, Salitral, and Poleo Members of the Chinle Formation

PERMIAN

Pc — Cutler Formation

Alternating red-purple crossbedded arkosic sandstone and purple-orange mudstone

PENNSYLVANIAN

~~Not exposed in this quadrangle~~

Pennsylvanian undifferentiated

Thin-bedded, carbonaceous siltstone of probable Desmoinesian Age

Contact — *Dashed where approximately located; dotted where concealed*

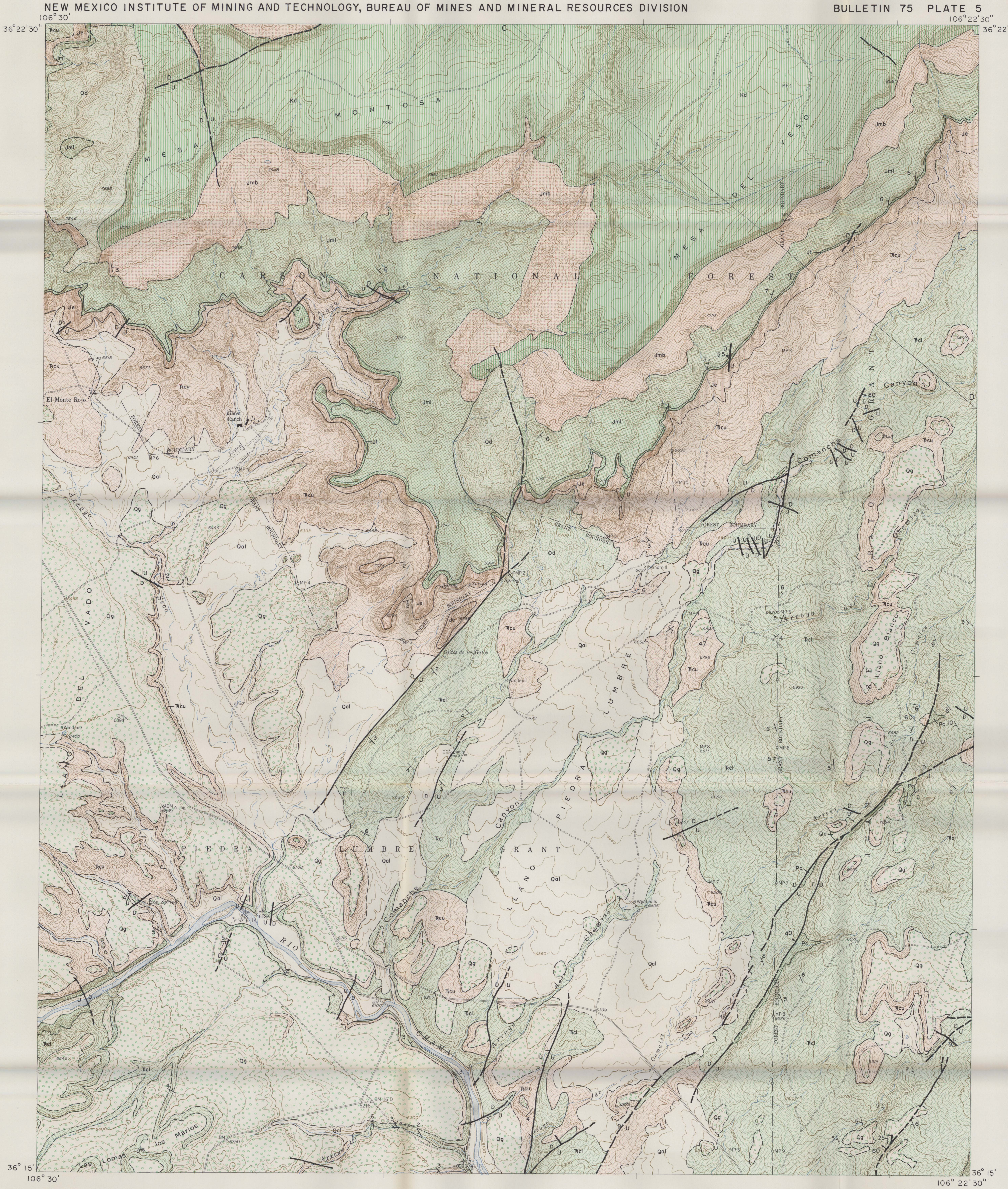
40 Fault, showing dip — *Dashed where approximately located*

7 Strike and dip of beds

Mine (abandoned)

Well

GHOST RANCH QUAD



Base map from U.S. Geological Survey Ghost Ranch Quadrangle

Geology by Clay T. Smith, A.J. Budding, Charles W. Pitrat, and others.

GEOLOGY OF GHOST RANCH QUADRANGLE

Scale $\frac{1}{24000}$

0.5 0 Mile

EXPLANATION

QUATERNARY

Qal
Alluvium
Stream deposits and recent terrace gravels

Qd
Landslide debris
In part incised by recent drainage

Qg
Terrace gravel
Local terraces and extensive sheets of coarse gravel deposits, not related to present drainage pattern

TERTIARY

Not exposed in this quadrangle
Sierra Negra Basalt Member of the Hinsdale Formation
Dikes and flows of olvine basalt

Not exposed in this quadrangle
Abiquiu Tuff   Los Pinos Formation
Ta; *Tuffaceous sandstone and siltstone*
Tp; *Tuffaceous sandstone and siltstone with interbedded volcanic boulder conglomerate*

Not exposed in this quadrangle
El Rito Formation
Coarse sandstone and conglomerate with Precambrian rock fragments

CRETACEOUS

Not exposed in this quadrangle
Carlile and Niobrara(?) Members of the Mancos Formation
Gray, thin-bedded shale with local concretionary zones

Not exposed in this quadrangle
Greenhorn Member of the Mancos Formation
White-weathering, slabby limestone interbedded with gray calcareous shale

Not exposed in this quadrangle
Graneros Member of the Mancos Formation
Light-gray to dark-gray calcareous shale, somewhat concretionary, with thin sandstone beds and brownish arenaceous zones

Kd
Dakota(?) Formation
Massive, coarse-grained crossbedded sandstone with local interbedded shale and coal layers; may contain equivalents of Purgatoire and Burro Canyon Formations in lower part

JURASSIC

Jmb
Brushy Basin Shale Member of Morrison Formation
Variegated gray, green, and red mudstone with thin sandstone and conglomerate lenses

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Lower member of Morrison Formation
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Todilto Formation
Thin-bedded, fetid, gray limestone with thin shale partings, overlain locally by massive white gypsum

Je
Entrada Formation
Massive, crossbedded, fine-grained sandstone

TRIASSIC

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Interbedded variegated red, chocolate brown, and purple mudstone, siltstone, and lenticular sandstone

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Coarse-grained, conglomeratic, lenticular sandstone interbedded with siltstone and mudstone; probably contains correlatives of the Agua Zarca, Salitral, and Poleo Members of the Chinle Formation

PERMIAN

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Cutler Formation
Alternating red-purple crossbedded arkosic sandstone and purple-orange mudstone

PENNSYLVANIAN

Not exposed in this quadrangle
Pennsylvanian undifferentiated
Thin-bedded, carbonaceous siltstone of probable Desmoinesian Age

Contact
Dashed where approximately located; dotted where concealed

40
Fault, showing dip
Dashed where approximately located

7
Strike and dip of beds

Mine (abandoned)

Well

CANJILON SE QUAD

Base map from U.S. Geological Survey Canjilon S.E. Quadrangle

Geology by Clay T. Smith, A.J. Budding, Charles W. Pitrat, and others.

GEOLOGY OF CANJILON SE. QUADRANGLE

Scale 1/24000

0 0.5 1 Mile

EXPLANATION

QUATERNARY

Qal — Alluvium

Stream deposits and recent terrace gravels

Not exposed in this quadrangle — Landslide debris

In part incised by recent drainage

Qg — Terrace gravel

Local terraces and extensive sheets of coarse gravel deposits, not related to present drainage pattern

TERTIARY

Ths — Sierra Negra Basalt Member of the Hinsdale Formation

Dikes and flows of olvine basalt

Ta — Abiquiu Tuff; Not exposed in this quadrangle — Los Pinos Formation

Ta; *Tuffaceous sandstone and siltstone*
Tp; *Tuffaceous sandstone and siltstone with interbedded volcanic boulder conglomerate*

Te — El Rito Formation

Coarse sandstone and conglomerate with Precambrian rock fragments

CRETACEOUS

Not exposed in this quadrangle — Carlile and Niobrara(?) Members of the Mancos Formation

Gray, thin-bedded shale with local concretionary zones

Not exposed in this quadrangle — Greenhorn Member of the Mancos Formation

White-weathering, slabby limestone interbedded with gray calcareous shale

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Not exposed in this quadrangle — Todilto Formation

Thin-bedded, fetid, gray limestone with thin shale partings, overlain locally by massive white gypsum

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Massive, crossbedded, fine-grained sandstone

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₽ — Pennsylvanian undifferentiated

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Contact — *Dashed where approximately located; dotted where concealed*

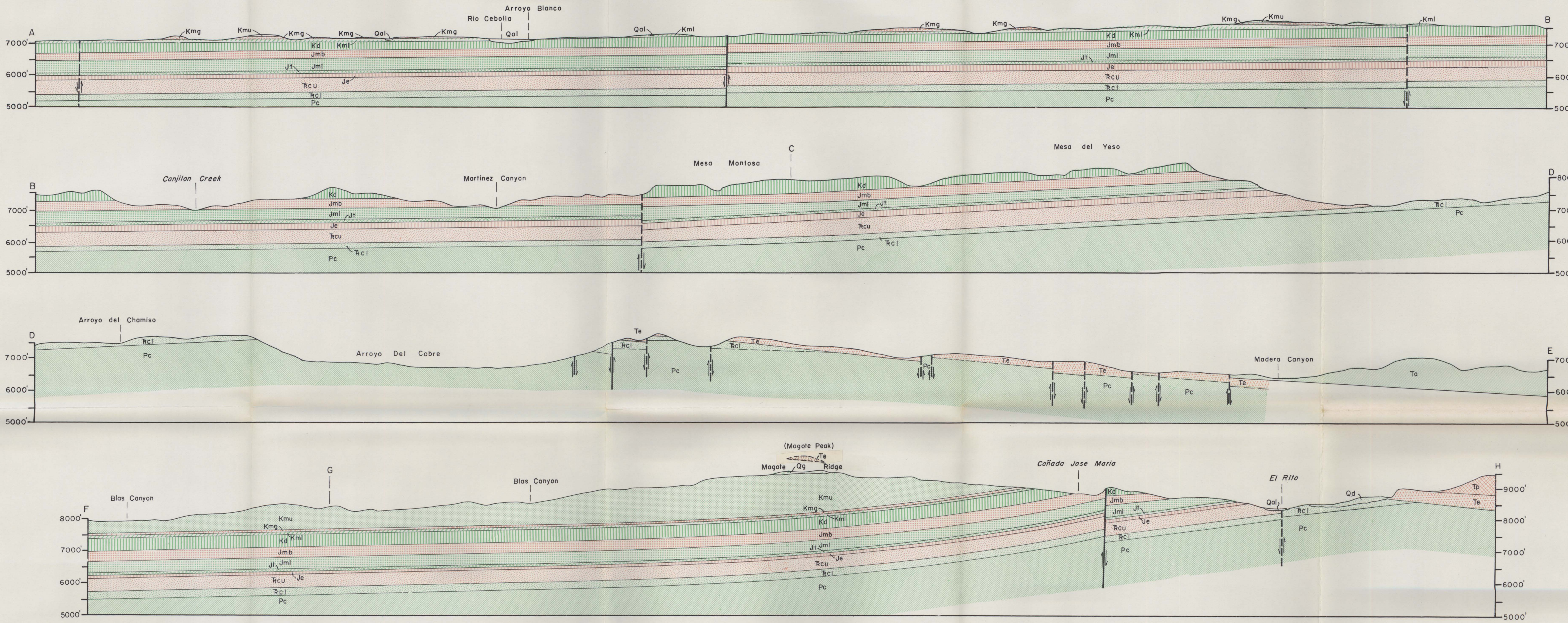
Fault, showing dip (40) — *Dashed where approximately located*

Strike and dip of beds (7)

Mine (abandoned)

Well

CROSS-SECTIONS SE PART OF CHAMA BASIN



EXPLANATION

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Alluvium

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Local terraces and extensive sheets of coarse gravel deposits, not related to present drainage pattern

QUATERNARY

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Sierra Negra Basalt Member of the Hinsdale Formation

Dikes and flows of olvine basalt

Ta Abiquiu Tuff **Tp** Los Pinos Formation

Ta; *Tuffaceous sandstone and siltstone*
Tp; *Tuffaceous sandstone and siltstone with interbedded volcanic boulder conglomerate*

Te

El Rito Formation

Coarse sandstone and conglomerate with Precambrian rock fragments

TERTIARY

Kmu

Carlile and Niobrara(?) Members of the Mancos Formation

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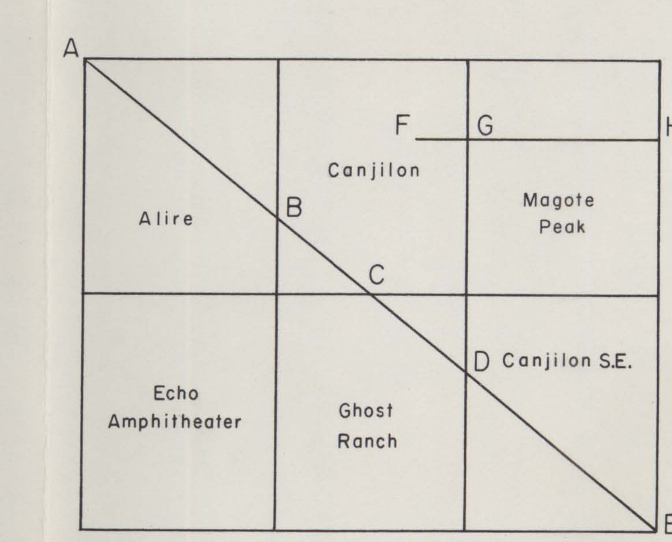
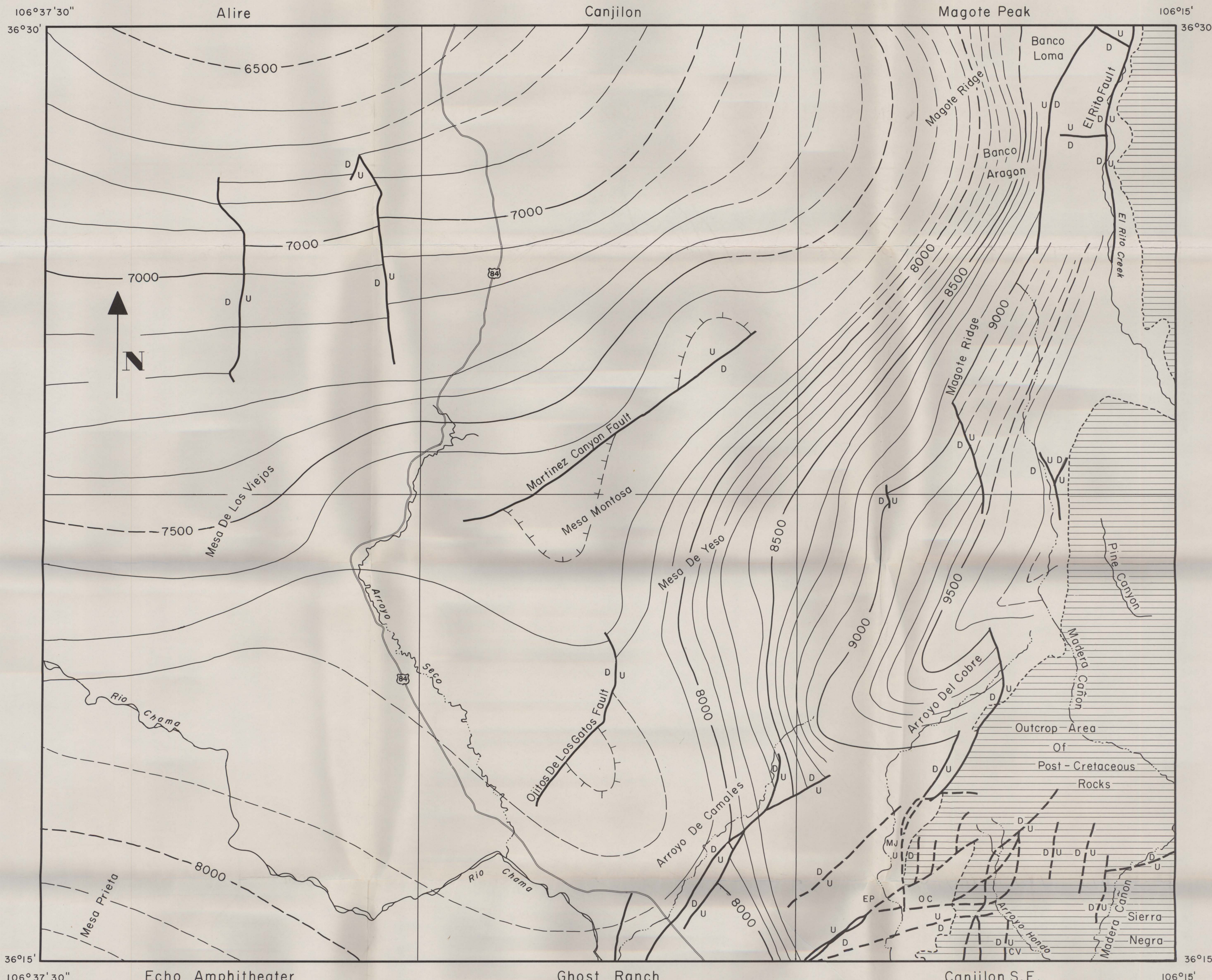


Index map showing location of quadrangles, and lines of cross sections

CROSS SECTIONS OF THE SOUTHEASTERN PART OF THE CHAMA BASIN

Scale $\frac{1}{24000}$

1 0.5 0 1



Contour interval 100 feet; contours drawn on base of Cretaceous sediments; faults simplified for clarity.

STRUCTURE CONTOUR MAP OF THE SOUTHEAST CHAMA BASIN, NEW MEXICO

1 0 1 2 3 4 Miles

CV - Cerrito de la Ventana
EP - El Puertecito
MJ - Las Minas Jimmie
OC - Ojito Carrizo