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Mesozoic strata flanking the southwestern San Juan Mountains, Colorado and New Mexico

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are coarse-grained, "dumped" continental arkosic clastics.

The transition to Permian nonmarine strata is almost everywhere one of a complex and horizontally shifting vertical gradation from thin marine beds to predominantly red-bed facies. This transition facies, called the Rico formation, ranges from latest Des Moines to Hueco (Wolfcamp) age depending upon its geographic relation to the withdrawing seas and the clastic-shedding uplifts.

Permian Time

This last period of the Paleozoic era was one of continental deposition in the Four Corners region, mainly because of tectonism in the Ancestral (Colorado) Rockies which supplied abundant fine to coarse arkosic clastics. These tectonic elements were the rejuvenated San Luis uplift, the Peñasco (Nacimiento) uplift, the Uncompahgre uplift, and the lower-lying Zuni-Defiance uplift which was virtually completely covered by clastic continental Permian rocks.

Marine waters encroached the southeastern part of the Four Corners region during San Andres (post-Yeso) time, and the contemporaneous Kaibab seas encroached from the southwest and west over the westernmost part of the Four Corners region. However, the rapidity of clastic deposition from the Uncompahgre-San Luis-Peñasco uplifts kept the Permian depositional surface well above sea level over most of the site of previous marine deposition in the earlier Paradox geosyncline.

MESOZOIC STRATA FLANKING THE SOUTHWESTERN SAN JUAN MOUNTAINS COLORADO AND NEW MEXICO

By

Frank E. Kottlowski

New Mexico Bureau of Mines and Mineral Resources

Mesozoic sedimentary rocks underlie most of the mesa and canyon country south, west, and northwest of the main mass of the San Juan Mountains. They extend into the mountains along the canyons of the Uncompahgre and San Miguel Rivers. Two well exposed sections of these Mesozoic rocks will be seen along the field trip route near Durango and north of Ouray, in the canyons of the Animas River and Uncompahgre River respectively. About 3½ miles north of the Durango Fiesta Grounds, a gray coarse-grained crossbedded sandstone (Shinarump or basal Chinle-Dolores) relatively conformably overlies the Permian Cutler redbeds, a typical lower contact relationship for the southwestern part of the area. The upper contact, between the Cretaceous and Tertiary rocks, is within the Animas formation in the Durango region. Near Silverton, and in much of the main mass of the San Juan Mountains, the Mesozoic beds are absent, and the early Tertiary Telluride conglomerate or younger volcanic units rest erosionally unconformably on various of the Paleozoic formations or the Precambrian rocks. North of Ouray the Triassic Dolores formation unconformably overlies the Cutler redbeds or the Hermosa formation, and the Telluride conglomerate or San Juan tuff rests unconformably on the Mancos shale and older beds. The upper and lower contacts of the Mesozoic strata on the west side of the San Juan Mountains and in the outlying Rico and San Miguel Mountains are similar to those near Ouray.

Although the Mesozoic rocks occur only on the flanks of the southwestern San Juan Mountains, having been removed by early Tertiary erosion, not deposited, or concealed beneath thousands of feet of volcanic rocks within the higher parts of the mountains, these strata are important in the adjacent areas to the south and west where they contain large amounts of gas, oil, uranium, and coal. The entrance route from Albuquerque to Durango crosses many outcrops of the Mesozoic beds as do the exit routes to Cortez and Pagosa Springs. To quote Larsen and Cross (1956, p. 48), "An excellent place to study the complete Mesozoic section is near Durango . . . and also farther east in the Ignacio quadrangle." To paraphrase our Morman friend Brigham Young – This is the place. This article, as planned, was to be written by an eminent authority on the Mesozoic strata of the area, one who has walked out the beds in the field. Unfortunate last-minute circumstances prevented this promised contribution from crystallizing; therefore the present material is a hectic compilation of previously published papers plus very little field checking.

HISTORICAL REVIEW

Some of the earliest descriptions of the Mesozoic rocks in this region were those by Cross and Purington (1899) in the Telluride folio, Cross and Spencer (1900) of the Rico Mountains, Cross et al. (1907) in the Ouray folio, and Cross and Hole (1910) in the Engineer Mountain folio. Near Ouray the Triassic beds were referred to the Dolores formation, and a sharp angular unconformity was noted at the base whereby fossiliferous Dolores conglomerates rest on inclined and beveled Cutler redbeds and marine Hermosa rocks. The Dolores consists of marl,

sandy shale, fine-grained sandstone, and near the base, several fossiliferous limestone pebble conglomerates. Thickness ranges from 40 to 100 feet, and most of the beds are bright red in color. Jurassic beds were named the La Plata sandstone and overlying McElmo formation. The La Plata sandstone included rocks now assigned (Eckel, 1949, p. 27) to the Entrada sandstone and to the Pony Express limestone member and Bilk Creek sandstone member of the Wanakah formation. The McElmo formation included the upper marl member of the Wanakah formation (lower Summerville), the Junction Creek sandstone (Bluff, Cow Springs, or upper Summerville), and the Morrison formation (Brushy Basin member, and a lower part equivalent to the Salt Wash member). The base of the Entrada sandstone, as mapped near Ouray and to the north, overlaps all older sedimentary formations down to the Precambrian metamorphic rocks. The Dakota sandstone rests conformably on the Brushy Basin member of the Morrison (McElmo formation) and was described as a quartzose sandstone with interbeds of carbonaceous shale and thin coal seams. Remnants of the Mancos shale were mapped along Uncompahgre River Canyon, and to the northwest the shale unit is as much as 1,200 feet thick, capped by sandstones and minable coal beds of the Mesaverde group.

Gregory's (1917) description of the Navajo country geology was chiefly of the area southwest of the San Juan Mountains but was tied into the earlier reports of the mountain area. Collier (1919) described the coal beds in the Mesaverde group south of type locality of the Mancos shale, and subdivided the Mesaverde group into a basal Point Lookout sandstone, medial Menefee formation, and upper Cliff House sandstone. The Point Lookout sandstone is described as a cliff-forming massive sandstone 250-300 feet thick. The Menefee formation, about 400 feet thick, was estimated to consist of 55 percent shale, 42 percent sandstone, and 3 percent coal. The Cliff House sandstone, more than 400 feet thick, varies (near Mancos) from hard and massive to thin-bedded and friable with shaly partings.

Reeside (1924) described the Upper Cretaceous and Tertiary formations of the western San Juan Basin, split the McDermott formation from the lower part of the Animas formation, and listed many sections measured on the north edge of the basin.

Burbank (1930) described the formations near Ouray, referred the lower sandstone of the La Plata sandstone to the Entrada, and the upper La Plata and McElmo formations to the Morrison formation. Baker, Dane, and Reeside (1936), in their study of the Jurassic formations in the Four Corners and adjoining areas, noted lithologic characteristics, thicknesses, faunas, and floras of the formations from the Wingate to the Morrison; columnar sections, isopach maps, and conditions of deposition were also presented. Their Jurassic units north of Durango are: Wingate 60 feet, Entrada 215 feet, and Morrison 600 feet. North of Ouray they measured 60 feet of Entrada sandstone and only the lower part of the Morrison formation which they considered to include the beds from the Pony Express limestone up to the base of the Dakota sandstone. Gregory's (1938) geologic reconnaissance of the San Juan Country was of the area in Utah west of the San Juan Mountains and serves as an orientation to that area where most of the Triassic and Jurassic formations are thickest.

Intensive geologic work in the Colorado Plateau region began during and after the Second World War. The boom in the use (?) of uranium, and of oil and gas, brought more prospectors, geologists, mining engineers, oilmen, and promoters to this area in a single month than had tracked the arid lands since the coming of the white man. Geologic work by the A.E.C., mining companies, petroleum companies, U. S. Geological Survey, State agencies, and by members of the various geological societies increased proportionally.

Wood, Kelley, and MacAlpin (1948) mapped and described the Mesozoic rocks in southern Archuleta County, Colorado, south of Pagosa Springs, and northwest of Chama. The area is traversed by U. S. Highway 84 from Chama to Pagosa Springs, part of the route for the First Field Conference of the New Mexico Geological Society. Outcrops and well cuttings indicate that the Dolores redbeds unconformably overlie various Paleozoic formations and the Precambrian metamorphic rocks on a pre-Dolores surface related to the Uncompahgre-San Luis Highland. The formation ranges from 10 to 335 feet in thickness, thinning to the southeast onto an early Triassic (?) highland. The Entrada sandstone unconformably overlies the Dolores or older rocks and is 117-230 feet thick. Above are the Pony Express limestone member (Todilto) and possible Bilk Creek sandstone member of the Wanakah formation. The Pony Express limestone appears to thicken to the southeast from 26 to 170 feet and as it thickens includes considerable amounts of gypsum. The Bilk Creek (?) member is about 70 feet thick and is mostly light-red fine-grained sandstone, siltstone, and shale. The beds above the Wanakah were mapped as the Morrison formation; the lower part is a massive white to light-gray sandstone, 110-218 feet thick, that resembles the Junction Creek sandstone. The upper part of the Morrison, called the variegated

sandstone and shale member, is 334-420 feet thick, and is disconformable beneath the Dakota sandstone.

The Dakota sandstone is 177-270 feet thick and consists of three members: (1) lower buff crossbedded massive medium- to coarse-grained conglomeratic sandstone, (2) medial dark-gray to buff, carbonaceous silty shale, and (3) upper buff crossbedded massive medium- to fine-grained sandstone. Conformably above the Dakota sandstone is the Mancos shale which was divided into 5 members: (1) lower shale member, Graneros shale equivalent, (2) lower limestone, Greenhorn equivalent, (3) middle shale member, Carlile shale equivalent, (4) upper limestone or limy shale member, Ft. Hays limestone, lower Niobrara equivalent, and (5) upper shale member, equivalent to the upper Niobrara and lower Pierre shale. The Mancos shale is 2,100-2,370 feet thick in southern Archuleta County and intertongues with the overlying Mesaverde formation. This formation (note it was not called a group) is 365 feet thick along the Piedra River where it consists of buff to gray sandstone ledges separated by variable thicknesses of gray shale; northeastward toward Pagosa Springs the Mesaverde formation grades laterally into the overlying and underlying shale units.

The Lewis shale overlies and intertongues with the Mesaverde formation, is about 2,400 feet thick, and in turn is conformable with and intertongues with the overlying Pictured Cliffs sandstone. This sandstone is light gray to brown, medium to fine grained, and thins from 160 feet in thickness northeastward to a knife edge near Pagosa Springs. The overlying Fruitland formation and Kirtland shale were not differentiated in mapping, total about 830 feet in thickness a few miles southwest of Pagosa Springs but thin eastward and are absent in Blanco Basin about 15 miles east of Pagosa Springs. The overlying Animas formation is as much as 2,665 feet thick and consists of gray, brown, olive, and purple, fine- to coarse-grained sandstone, conglomerate, shale, and siltstone. The coarser debris includes many fragments of volcanic rocks, latitic and andesitic, pebbles and cobbles of Paleozoic and Precambrian rocks, and abundant feldspar and olivine grains. As shown by Dane (1946) to the south in Rio Arriba County, New Mexico, along the east side of the San Juan Basin, the Animas formation intertongues and grades southward and eastward into the Lewis shale, Pictured Cliffs sandstone, Kirtland shale, and Fruitland formation. Near Blanco Basin the beds mapped as the Animas formation by Wood, Kelly, and MacAlpin (1948) are shown by Larsen and Cross (1956, pl. 1) as part of the early Tertiary Blanco Basin formation.

Dane (1948) and others mapped the area to the south in Rio Arriba County and described the beds outcropping on the northeastern edge of the San Juan Basin. The formations are similar in lithology and thickness to those mapped in southern Archuleta County. The Triassic beds, however, are referred to the Chinle formation, and were encountered chiefly in oil tests where they are 400-1,000 feet thick. Along the east flank of the basin they appear to unconformably overlie Precambrian rocks rather than late Paleozoic strata. Although mainly red shales and clays, the Chinle includes lenses of quartzite angular-pebble conglomerate in middle and lower beds. The basal limestones and gypsum of the Wanakah formation were referred to the Todilto limestone member. The Mesaverde formation was divided into three members; (1) lower Hosta sandstone, (2) medial Gibson coal member, and (3) upper La Ventana sandstone.

Read et al. (1949) mapped and described the outcrops along the Piedra River Canyon in northwestern Archuleta County, Colorado. The Dolores formation is more than 200 feet thick where not removed by pre-Entrada erosion. The Entrada sandstone, a massive ledge of crossbedded quartzose sandstone, 80-240 feet thick, rests with slight to marked angularity on underlying rocks that range in age from Triassic to Precambrian, the basal beds of the sandstone overlapping older rocks in a northeastward direction on the Piedra uplift. Note the similarity to pre-Entrada erosion near Ouray. The Wanakah formation, Junction Creek sandstone, Morrison formation, Dakota sandstone, and younger Cretaceous formations are similar to the units described to the south.

Zapp (1949) mapped and described the Cretaceous coal-bearing formations near Durango and listed a relatively detailed columnar section of the strata from the Dakota sandstone into the Animas formation. The lower cliff-forming conglomeratic sandstone unit referred to the lower part of the Dakota sandstone is suggested as a possible equivalent of Stokes and Phoenix's (1948) Burro Canyon formation of probable lower Cretaceous age. Although the Mancos shale was not subdivided in mapping, limy shales and argillaceous limestones in the lower part were considered correlative with the Greenhorn limestone, and near the middle of the shale sequence a series of hard calcareous shales were believed equivalent to the Ft. Hays limestone. The Mesaverde is considered a group in the area, and the Point Lookout, Menefee, and Cliff House are termed formations. The Point Lookout sandstone is divided into

two members, a lower member of thin sandstones interbedded with shales, and an upper member of massive-bedded cliff-forming medium-grained sandstone. The sandstones become progressively finer grained eastward, and shaly beds appear higher and higher, with the result that the lower shaly member thickens eastward at the expense of the upper massive sandstone. East of the area, east of the Florida River, the Point Lookout sandstone is reported by Zapp (1949) to grade into the Mancos shale and to be indistinguishable from the Mancos.

The Menefee formation consists of lenticular cross-bedded sandstones, brown to black shales, and coal beds. The coal beds occur as tabular lenses several miles in lateral extent and with a maximum thickness of 9 feet. The coal is low ash, high volatile, bituminous, coking coal. Thickness of the Menefee formation varies greatly depending in large part on the thickening and thinning of sandstone wedges between the coal and shale beds. The Cliff House sandstone shows the same intertonguing with shale units as the Point Lookout sandstone, eastward being indistinguishable from the overlying Lewis shale. The marine Cliff House sandstone consists of lenticular ledges of hard medium-grained calcareous sandstone within softer argillaceous fine-grained sandstones and silty shales; the sandstones weather to a characteristic yellow brown to reddish brown.

The marine Lewis shale thickens eastward from the Durango area (Zapp, 1949) by intergonguing with the underlying and overlying sandstones. Although most of the shale is dark-gray to black clay-shale, there are a few beds of bentonite in the upper part, and scattered concretions of aphanitic ferruginous argillaceous limestone. The overlying Pictured Cliffs sandstone consists of massive-bedded medium-grained sandstone with lower shaly beds, and in lithology and outcrop characteristics resembles the Point Lookout sandstone. The sandstone is transitional with the underlying Lewis shale and overlying Fruitland formation. The Fruitland formation consists of a lower series of beds resembling the coal-bearing Menefee formation, and upper beds of greenish shale and fine-grained greenish chloritic feldspathic sandstone. The coal beds are higher in ash than those of the Menefee formation but are thicker. The Carbonero coal bed, near the base of the Fruitland formation, is about 80 feet thick although including numerous thin bone coal and carbonaceous shale partings. This coal bed outcrops along U. S. Highway 550-160 several miles south of Durango (see entrance road log, Albuquerque to Durango).

Gradationally above the Fruitland formation is the Kirkland shale, which was divided by Zapp (1949) in the Durango area into upper and lower shale members and a medial Farmington sandstone member. The lower member consists chiefly of greenish shale and sandy shale with some thin lenses of greenish chloritic sandstone, carbonaceous shales, and local thin coal seams. The Farmington sandstone member is light-gray to greenish, massive-bedded medium-grained hard sandstone interbedded with greenish shales; the sandstone contrasts with the older quartzose sandstones of the Cretaceous in containing numerous feldspar grains and flakes of biotite. The upper member is of interbedded sandstone and shale in about equal amounts, and is not reported to grade up into the overlying McDermott formation.

The McDermott and Animas formations are chiefly of lithic tuffs, largely of andesitic debris, and range in fragments size from coarse boulder-conglomerate to clay-shale. The lower 300 feet of these volcanic sediments along the Animas River are various shades of purple, consist chiefly of unweathered andesitic detritus, and constitute the McDermott formation. The overlying Animas formation consists of greenish andesitic tuffs in which the fragments of volcanic rocks are weathered, and are mixed with "normal sedimentary material." Although Reeside (1924) had considered the McDermott and Animas formations to be separated by an unconformity, Zapp (1949) found only gradational contacts between the two units, and based his mapping chiefly on the color change from purple to green. The base of the McDermott is marked by a conglomeratic sandstone, argillaceous, feldspathic, and greenish, about 5 feet thick but locally filling 60-foot channels cut into the underlying Kirtland shale. Well-rounded pebbles and cobbles of weathered silica rocks, chiefly quartzite and chert, occur in the basal sandstone and are thought to represent debris from a residual mantle swept from an upland mass to the north near the present San Juan Mountains.

The andesitic debris of the McDermott and Animas formations, as well as the chlorite and feldspars in units as old as the upper part of the Fruitland formation, are believed (Zapp, 1949; Dane, 1946) derived from volcanic piles that were extruded contemporaneously in an area to the north and northeast. Presumably this was a phase of the late Cretaceous-early Tertiary Laramide orogeny. The landmass source of the older Cretaceous units is assumed to have been to the southwest, and sedimentation in the Durango area, as in much of the

San Juan Basin area, was related to the continual shifting of northwest-trending shorelines.

Eckel (1949) mapped and described the rocks of the La Plata Mountains northwest of Durango. The Mesozoic formations in the area are the Dolores formation, Entrada sandstone, Wanakah formation, Junction Creek sandstone, Morrison formation, Dakota sandstone, and Mancos shale. There was the usual difficulty of a contact between the Permian Cutler redbeds and the Triassic Dolores redbeds; Eckel (1949, p. 16) drew the contact below limestone conglomerate and associated gray flaggy sandstones characteristic of the lower Dolores. In the San Miguel River Valley the base of the Dolores is marked by a quartz-chert pebble-conglomerate or by a coarse-grained quartzose friable "grit" that is as much as 30 feet thick. Near Ouray this coarse clastic bed is angularly unconformable on Cutler redbeds but resembles some of the Cutler beds especially where friable or iron-stained. The Dolores formation is 500-750 feet thick in the La Plata Mountains area, where it appears conformable on the Cutler redbeds, and is distinguished from the Permian strata by presence of limestone conglomerates, which contain vertebrate fossils, and by the absence of coarse grits except at the base. The fresh color of the beds is in most places distinctly brighter red than the dull reds of the Cutler. At some places, the top of the Dolores is a thick bed of fine-grained salmon-pink sandstone which passes abruptly to the typical white sandstone of the overlying Entrada sandstone. This sandstone is considered to be the Wingate near Durango by Hoover (1950) and Kilgore (1955). It is not present along Junction Creek a few miles to the west and is considered by Eckel (1949, p. 26) as part of the Dolores formation.

The Entrada sandstone, 100-265 feet thick near the La Plata Mountains, characteristically weathers to sheer cliffs, and is mostly massive, somewhat friable, and strikingly crossbedded. The sandstone is white to light gray although locally it is pale cream to buff. Most beds contain numerous well-rounded relatively coarse grains of glassy quartz in a matrix of much finer grained quartz sand, cemented by silica and some calcite. Locally the lowest 40-50 feet of the formation is of slabby, grayish or pinkish, fine-grained sandstone.

The Wanakah formation was separated by Eckel (1949) as well as by Goldman and Spencer (1941) into 3 members: (1) a lower Pony Express limestone member, Todilto equivalent, (2) Bilk Creek sandstone member, and (3) upper marl member. The Pony Express limestone is a thin bed of dense dark-blue to nearly black relatively pure limestone that averages 3 feet in thickness in the La Plata Mountains area but is as much as 30 feet thick. No gypsum is associated with the Pony Express limestone member in the area mapped by Eckel (1949). The medial Bilk Creek sandstone, about 20 feet thick, is friable even-bedded fine-grained grayish to reddish sandstone, marly in part, with a top layer of hard limy sandstone, ½-2 feet thick, containing grains of red chert, and called the "carnelian sandstone" by Goldman and Spencer (1941). The marl member, 25-100 feet thick, consists of light pinkish-red to greenish-gray marl, siltstone, and sandstone in lenticular beds. Argillaceous limestone occurs as concretions and thin lenses. From 10 to 15 feet above the base is a persistent "green chert" bed of concretionary authigenetic red chert coated with a green glauconitic shell.

The Junction Creek sandstone, in the La Plata area of its type locality, is 200-500 feet thick, and is made up of massive white crossbedded sandstone resembling the Entrada sandstone. The unit is strikingly crossbedded but less distinctly so than the Entrada. Thin lenticular arkosic sandstones are especially numerous in the uppermost slabby beds, as are greenish or pinkish shale locally. Compared with the Entrada sandstone, the Junction Creek sandstone is more friable, its quartz grains are more angular and better sorted, and it contains specks of dull-white clayey material and red orange chert which are not found in the Entrada (Eckel, 1949, p. 30).

The Morrison formation as mapped by Eckel (1949) is 400-625 feet thick and is composed of thin alternating beds of varicolored shales and sandstones. Flakes and lenses of brilliant-green shale are distinctive, although they also occur in the marl member of the Wanakah. The sandstones are similar to the Junction Creek sandstones, except that they are thinner, somewhat shaly, and pebbles tend to be coated with a dark-green film. The contact with overlying Dakota sandstone is sharp, with the basal beds of the Dakota being conglomeratic and containing numerous chert pebbles. The Dakota and younger Cretaceous beds are similar to the units described by Zapp (1949) to the southeast.

The First Guidebook of the New Mexico Geological Society included 4 articles on the Mesozoic rocks near the southwestern San Juan Mountains. Wengerd (1950) described the Triassic rocks, Hoover (1950) the Jurassic formations, Umbach (1950) the Cretaceous rocks,

and Silver (1950) the occurrence of gas in Cretaceous strata. Wengerd (1950) noted that Moenkopi formation probably pinches out west of the Durango-Telluride area, but that the Shinarump conglomerate equivalent may be present in the Animas River Valley in the lower part of the Dolores formation. He presented an isopach map of the Triassic rocks in the northwestern New Mexico-southwestern Colorado area and a correlation chart. Hoover (1950) discussed the Jurassic formations in the Four Corners area, presented several cross-sections, and listed the section near Durango, in ascending order: Wingate sandstone, Entrada-Exter sandstone, Todilto limestone, Wanakah formation, and Morrison formation. Umbach (1950) briefly summarized the Cretaceous formations in the San Juan Basin, and Silver (1950) related the occurrence of gas to the lithologies.

The Second Guidebook of the New Mexico Geological Society, although concerned chiefly with the south and west sides of the San Juan Basin, contained three articles on the Mesozoic rocks in that area and in part the comments reached to the northwestern New Mexico-southwestern Colorado area. McKee (1951) described the Triassic deposits of the Arizona-New Mexico border area. He noted that the Moenkopi formation thins to a vanishing point near the Utah-Colorado and Arizona-New Mexico border, and that the Shinarump conglomerate-Chinle redbeds form a blanket of relatively uniform thickness across northern New Mexico and southwestern Colorado as well as adjoining areas of Utah and Arizona. Smith et al. (1951) discussed the problems of lithology and formation names of the Jurassic strata in the Colorado Plateau region. Silver (1951) gave a detailed description of the Cretaceous lithic units and their relationships in the San Juan Basin, noting that they can be divided into an older lower group which includes all sediments deposited while marine conditions dominated, and an upper younger group which bridged the transition from marine to wholly continental conditions of deposition. The Pictured Cliffs sandstone was suggested as the uppermost unit of marine deposition. Younger Cretaceous deposits were concentrated in the "Kirtland Basin", the western half of the present San Juan Basin. Silver (1951) noted evidence of unconformity between the McDermott and Animas formations in parts of the basin.

Stokes (1952) described Lower Cretaceous beds in the Colorado Plateau and noted that the Burro Canyon formation, with its type locality in the valley of the Dolores River west of the San Juan Mountains, contains Lower Cretaceous index plant remains. Guides for these beds include a lavender or purple and green color, numerous calcareous to siliceous nodules, and abundance of gastroliths. The basal beds of the Burro Canyon formation are in many places siliceous-pebble conglomerates, erosionally unconformable on Morrison beds, whereas the upper contact is drawn below cliff-forming "typical" Dakota sandstones. Stokes suggested that the basal conglomerates or pebbly sandstones of the Dakota (?) sandstone, as much as 50 feet thick, should be considered as of possible Lower Cretaceous age in northwestern New Mexico and southwestern Colorado. A section of the Burro Canyon formation near the type locality, sec. 33, T. 44 N., R. 18 W., San Miguel County, Colorado, is, in stratigraphic (descending) order (Stokes, 1952, p. 1773):

Dakota formation:

Light-gray to tan cliff-forming sandstone with shale, impure coal, and conglomerate.

Unconformity

Burro Canyon formation:		**Feet**
12.	Mudstone, greenish-gray, slope-forming	5
11.	Chert, olive-green, impure, hard; forms ledge	1
10.	Mudstone, gray to greenish; many calcareous nodules; slope forming	40
9.	Chert congomerate and quartzites, gray to white, resistant; weathers chocolate brown to black	15
8.	Shale, pale-green; many sandy limestone nodules, 1-12 inches in diameter	5
7.	Limestone, gray, nodular, poorly bedded, siliceous	4
6.	Shale with chert lenses; chert in layers up to 3 inches thick; light apple-green to gray in color	15½
5.	Conglomerate (35 percent) and sandstone (65 percent) dirty-brown to gray; most pebbles are limestone, some chert; crossbedded	11½
4.	Mudstone, drab gray to purplish-gray, forms low bench	11
3.	Sandstone, medium-grained, white to light-green; weathers brown and massive; some crossbedding; numerous small angular chert pebbles	54
2.	Shale and siltstone, variegated colors; purplish-gray, red, light-green	38
1.	Conglomerate and sandstone, dull-white to light-gray, crossbedded; pebbles mainly chert, some quartzites; in local pockets pebbles make up 75 percent of rock; prom-	

inent cliff. Contact with underlying Brushy Basin member of Morrison formation is sharp and marked by channeling and by leach zone	66
Total thickness of Burro Canyon formation	266

Barnes (1953) mapped and described the rock units in the Ignacio area southeast of Durango and west of the southern part of Archuleta County, the area mapped by Wood, Kelley, and MacAlpin (1948). The Cretaceous section is somewhat similar to that near Durango. The Mesaverde formation, however, is a 325-foot sandstone unit believed correlative with the Menefee formation of the Durango area, with the underlying Point Lookout sandstone having graded eastward into the Mancos shale, here 2,000 feet thick, and the upper Cliff House sandstone grading eastward into the Lewis shale, which is 2,350 feet thick along Los Pinos River and thicker to the east. The Pictured Cliffs sandstone, Fruitland formation, and Kirtland shale thin eastward from the Durango area, the Kirtland, for example, being 1,200 feet thick along the Animas River and only 735 feet thick along the Los Pinos River. The McDermott formation is not mentioned, the andesitic clastic strata above the Kirtland shale being mapped as the Animas formation which is greenish to tan in color.

The Red Mesa area, southwest of Durango and west of the Ignacio area, was mapped and the strata described by Barnes, Baltz, and Hayes (1954). The oldest Mesozoic beds exposed are upper Mancos shales, and the Cretaceous strata are similar in lithology and thickness, with relatively minor variations, to the formations of the Durango area. The local variations in lithology and thickness, and the intertonguing relationships of the Cretaceous lithic units, are described in some detail. The McDermott was reduced to a member of the Animas formation, and was observed to be conformable with the underlying Kirtland shale and overlying greenish member of the Animas formation.

McKee (1954), in his detailed description of the Moenkopi formation, noted that the Moenkopi is only 30 feet thick at Fort Wingate, New Mexico, and is missing at Canyon de Chelly and Lukachukai in northeastern Arizona, in the Rico Mountains area of southwestern Colorado, as well as in northwestern New Mexico (except near Gallup), and in the Durango-Ouray region of Colorado.

Wanek (1954) mapped the Mesa Verde area, south of Cortez and west of Red Mesa, and illustrated the inter tonguing of the lithic units of the type Mesaverde by numerous columnar sections. Strobell (1956) mapped and described the rock units in the Carrizo Mountains area of northeastern Arizona and northwestern New Mexico, just southwest of the "Four Corners" Mesozoic strata indentified in the northeast part of the area are, in ascending order: (1) Shinarump conglomerate, 20-95 feet thick, thins eastward; (2) Chinle formation, 900-1,500 feet thick, thickens eastward; (3) Wingate sandstone, 450-1,100 feet, thins eastward; (4) Entrada sandstone, 90-120 feet thick, (5) Todilto limestone, 2-11 feet thick ;(6) Summerville formation, 49-144 feet thick; (7) Bluff sandstone, 24-70 feet thick; (8) Morrison formation, 700-900 feet thick, subdivided into the lower Salt Wash member, Recapture member, Westwater Canyon member, and upper Brushy Basin member; the upper part of the Brushy Basin member contains beds similar to the Lower Cretaceous Burro Canyon formation; (9) Dakota sandstone, about 200 feet thick, with basal beds at one locality bearing a Lower Cretaceous flora; (10) Mancos shale and lower tongues of the Mesaverde group, the youngest Cretaceous strata preserved in the Carrizo Mountains area.

Bozanic (1955) discussed the subsurface Cretaceous stratigraphy of the San Juan Basin, emphasizing correlation by electric logs, illustrating the various facies changes with several electric log and outcrop correlation cross-sections, and presenting isopach maps of the Mesaverde group and Fruitland-Kirtland-McDermott sequence. Kilgore (1955) described the geology of the Durango area, gave a cross-section along the Animas River Valley from Bondad, Colorado (near the junction of the Florida and Animas Rivers, 15 miles south of Durango), northward to Bakers Bridge, and discussed in some detail the section exposed along the Animas River. He suggested that the lower 25 feet of the unit termed the Dolores formation may possibly be an equivalent of the Moenkopi formation. This basal dark-red shale unconformably overlies upper lenticular sandstones of the Permian Cutler redbeds and is unconformably beneath pinkish-red and gray, coarse-grained sandstone and conglomerate, less than 50 feet thick, that Kilgore (1955, p. 119) and Wengerd (1950, p. 70) believed correlative with the Shinarump conglomerate. The overlying 500-600 feet of Triassic dark-red shales and sandstones are referred to the Chinle formation, which is considered gradational into superadjacent Jurassic strata. A thin-bedded, pink to red, fine-grained sandstone, about 25 feet thick and cropping out along the road about a mile north of Durango, is considered the Wingate sandstone; a thin overlying red shale is suggested as a possible wedge-edge of the

Kayenta formation; and the 10 feet of tan crossbedded sandstone above is identified as correlative with the Navajo sandstone.

Kilgore (1955) measured 265 feet of white crossbedded Entrada sandstone; 1-5 feet of gray to black, oolitic and sandy Todilto limestone; about 80 feet of pink marly concretionary shale containing thin lenses of sandstone, referred to the Summerville formation; 200 feet of the whitish somewhat friable Junction Creek sandstone; and about 620 feet of the Morrison formation, divided into a lower Salt Wash member and an upper Brushy Basin member. The Salt Wash member is more than 50 percent sandstone, white, tan, and gray, in thin platy lenticular beds, interbedded with red and gray shale and claystone. The upper Brushy Basin member consists of greenish-gray and maroon mudstone and shale, bentonite beds, and thin white and green sandstones. A 67-foot unit of lower white to light-tan massive conglomeratic sandstone and upper irregularly-bedded green and purple shale was noted above typical Brushy Basin beds and below the Dakota sandstone in the Junction Creek Valley just west of the Animas River Valley and was referred to the Lower Cretaceous Burro Canyon formation. The unit is not well exposed along the field trip route. The description of the overlying Upper Cretaceous sequence agreed with that of Zapp (1949).

Larsen and Cross (1956) reviewed the work of the U. S. Geological Survey in the San Juan Mountains up to 1949, emphasizing the petrology of the igneous rocks, but summarizing the occurrence of the sedimentary rocks. Beaumont, Dane, and Sears (1956) revised the official U. S. Geological Survey nomenclature of the Mesaverde group in the San Juan Basin, substituting group for formation, and raising the Point Lookout, Menefee, and Cliff House to formations throughout the basin, as well as redefining some of the terms for parts of the Mesaverde group in the southern part of the basin. Also presented are a diagrammatic cross-section from La Ventana on the northeast to Gallup on the southwest, and a sketch map showing the outcrop distribution of the Mesaverde group beds in the San Juan Basin from the Colorado-New Mexico state line south to the Zuni Mountains.

Craig and Dickey (1956) discussed the uranium-bearing beds and stratigraphy of the Jurassic sedimentary rocks of southwestern Colorado and southeastern Utah. They noted that new paleontologic evidence had resulted in the assignment of a Triassic age to the Wingate sandstone, a Jurassic (?) age to the Kayenta formation, and a Jurassic (?) age to the Navajo sandstone. Fence diagrams of the San Rafael group (Carmel formation at the base, Entrada sandstone, Curtis formation, and Summerville formation) and of the Morrison formation were presented including sections near Durango and Ouray. The Entrada sandstone is shown thinning to the east from Durango to sections along the Piedra River, thinning northward to Ouray and westward toward Cortez, but thickening greatly in Utah west northwest of Cortez. The Pony Express member (Todilto) of the Wanakah formation thickens eastward from Durango, and occurs as a relatively thick wedge near Ouray, but is not present to the west. The upper marl member and medial Bilk Creek sandstone member of the Wanakah formation are shown to grade westward into the Summerville formation, and the Junction Creek sandstone is considered correlative to the west to the Bluff sandstone which in places in southeastern Utah grades into and intertongues with the upper part of Summerville formation and with the lower part of the Salt Wash member of the Morrison formation. The Junction Creek sandstone is believed not present near Ouray, as the Salt Wash member is shown above the Summerville formation; the sandstones and interbedded finer grained clastics above the Wanakah formation being considered as basal Morrison beds rather than as the Junction Creek sandstone. Southward from the Durango area into New Mexico, the Salt Wash member is shown grading into the Recapture member of the Morrison, and the upper beds of the Salt Wash with the lower beds of the Brushy Basin member grade into the Westwater Canyon member.

Craig and Dickey (1956) noted that the position of the Jurassic-Lower Cretaceous contact is uncertain within a sequence several hundred feet thick. Late Jurassic fossils were found in the Morrison well below the top of the formation, and the diagnostic Early Cretaceous fossils from the Burro Canyon formation were from upper beds. As the upper Morrison and the Burro Canyon strata are somewhat similar, even placing an arbitrary systemic boundary at the formational contact does not result in uniform mapping of the time line. As an example, they stated (ibid., 1956, p. 103) that beds of Lower Cretaceous age are absent in northwestern New Mexico in which area "the Dakota sandstone (Early (?) and Late Cretaceous age) lies unconformably upon Morrison or older formations." The age assignment of the Dakota is theirs and apparently means that the Burro Canyon formation is not present in north-

western New Mexico but that beds of Lower Cretaceous age may be – as suggested by Stokes (1952) and others.

Stewart (1956) discussed the Triassic strata of southwestern Colorado and southeastern Utah and illustrated the stratigraphic relationships with a fence diagram showing the sections near and west of the southwestern San Juan Mountains. The Triassic beds near Curay, Durango, and the headwaters of the Dolores River are referred to the Dolores formation, which is considered as equivalent to the upper part of the Chinle formation and part of the Wingate sandstone. The Shinarump conglomerate was redefined as a member of the Chinle formation, and it was noted that over large areas of southeastern Utah the unit formerly called the Shinarump is actually a higher member of the Chinle, the Moss Back member; neither are shown as occurring in the Durango area. The Dolores formation and the upper part of the Chinle are believed a homogenous lithologic unit in southwestern Colorado; eastward beyond the limits of the lower Chinle beds it is unconformable on the Moenkopi or Cutler formations and laps onto Precambrian rocks in the Uncompahgre Plateau area. The Dolores in the San Juan Mountains region is believed overlain by the Entrada sandstone, and pinches out eastward against the ancestral Uncompahgre Highland in the central San Juan Mountains area. The upper part of the Chinle formation and the correlative Dolores formation are thickest near the headwaters of the Dolores River even though they pinch out only 50 miles to the east.

Carter (1956) described the contact between the Burro Canyon and Dakota formations in the Mt. Peale area about 70 miles west of Ridgway and Ouray. The uppermost bed of the Burro Canyon formation, in localities where the bed has not been removed by pre-Dakota erosion, is a 1-8-foot thick light-gray silicified sandstone, although in many outcrops the basal gravels of the Dakota filled channels that were cut into the medial and upper light-green mudstone, thin siliceous limestone, limestone conglomerate, limy sandstone, and chert of the Burro Canyon. This erosional unconformity at the base of the Dakota contrasts with the conformable contact of the lower conglomeratic sandstones of the Burro Canyon formation on the variegated shales and mudstones of the Brushy Basin member of the Morrison formation. The lower unit of the Burro Canyon, 110 feet thick, consists of light-gray to light-brown medium- to coarse-grained crossbedded sandstone containing pebble congomerate lenses and sparse silicified logs. Relatively fresh brightly colored limestone and chert pebbles are characteristic of this basal unit (Mitchell, 1956, p. 111) in contrast to the numerous gray to white, spongy, highly leached chert pebbles in lower beds of the Dakota. Carter (1956, p. 113-115) noted that the basal Dakota sandstone is 1-60 feet thick, forms ledges capping mesas, is yellow brown to light orange brown in color, fine grained, and contains thin crosslaminated lenses as well as pebbly lenses. The conglomeratic lenses are composed of rounded to subrouned pebbles, 5-50 mm in diameter, of gray to black chert, milky quartz, and gray quartzite. Local channel-fills of angular cobbles and boulders are chiefly of the reworked underlying rocks; sandstones, quartzite, and chert. Medial Dakota beds are of gray carbonaceous shales with discontinuous coal seams, and along with carbonaceous and limonite-replaced plant debris in the lower and upper sandstones, are diagnostic of the Dakota as distinguishing features not present in the Burro Canyon formation.

Harshbarger, Repenning, and Irwin (1957) described in detail the uppermost Triassic and Jurassic strata of the Navajo Country in northeastern Arizona and northwestern New Mexico, introducing some new formation and member names, and presenting paleographic maps of the various stages of deposition. The southwestern San Juan Mountains are outside of the area they considered.

STRATIGRAPHIC SECTIONS

Composite Section in and near Animas River Valley

Animas formation	Feet
134. Shale, sandstone, and conglomeratic sandstone, greenish-gray to tan; contains much weathered andesitic debris	850
133. Conglomerate, massive; pebbles and cobbles as much as 6 inches in diameter, chiefly of greenish andesite but with quartz, quartzite, and chert; greenish-gray to brown	25
132. Shale, yellow, sandy; contains weathered andesitic debris	30
131. Conglomerate, massive-bedded; pebbles and cobbles; andesite dominates	10
130. Shale, yellow, sandy, soft; contains much andesitic volcanic debris	35
129. Conglomerate; fragments chiefly andesite but some siliceous rocks	25
128. Shale, greenish-gray to tan, silty, tuffaceous; much andesitic material	55
127. Conglomerate, massive; pebbles and cob-	

bles almost all of weathered greenish andesite, 6-8 inches in diameter; contains fossil logs 25

126. Tuff, andesitic; sandy to conglomeratic lenses with fragments of weathered andesite; green to buff, with some maroon bands near top, and some black carbonaceous shale 40

125. Conglomerate, massive; mostly cobbles 6-8 inches in diameter but with boulders as much as 3 feet across; poorly sorted; mostly of weathered greenish andesite but some quartzite and sandstone fragments 15

Thickness of Animas formation 1,110

McDermott formation (or lower member of the Animas formation):

124. Shale, tuffaceous; and laminated tuff; purple; to maroon, with some gray streaks; a few lenses of pebbly conglomerate 40

123. Tuff, finely conglomeratic, massive, purple; weathers to angular fragments 28

122. Conglomerate, gray to purple; subangular pebbles and cobbles of andesite, 1-8 inches in diameter with a few as much as 18 inches; matrix andesitic 15

121. Shale, tuffaceous, purple, laminated; alternates with beds of massive nonlaminated volcanic debris 45

120. Sandstone, dense, bluish-gray, laminated; weathers light-gray; breaks with a conchoidal fracture and resembles a porcellanite 8

119. Tuff, purple; contains blocks and masses of andesite as much as 4 feet in diameter 100

118. Sandstone, tuffaceous, coarse-grained, yellow; thin shale near base 15

117. Sandstone, pebbly, argillaceous, feldspathic, greenish; studded with well-rounded pebbles and cobbles of weathered siliceous rocks, chiefly chert and quartzite 5

Thickness of McDermott formation 256

Local erosional unconformity
Kirtland shale; upper shale member:

116. Sandstone, shaly to conglomeratic, light yellowish-white, fine- to coarse-grained; forms discontinuous ledges; upper lenses of well-rounded quartzite and chalcedony pebbles 40

115. Interbedded sandstone and shale, olive to gray, feldspathic, micaceous 47

114. Sandstone, olive to yellow, medium-grained; shale lenses 52

113. Sandstone, yellowish-olive, medium-grained, micaceous, feldspathic 23

112. Shale, sandy and silty, olive to gray, partly covered 38

111. Sandstone, silty, olive to yellow, micaceous, feldspathic 25

110. Shale and siltstone, gray to olive; sandy lenses; micaceous 30

109. Sandstone, argillaceous, thin-bedded, olive-gray, feldspathic 61

108. Sandstone, greenish-gray, medium-grained; forms outcropping ledge 19

107. Shale, sandy and silty, grayish-olive; thin interbeds of olive sandstone 42

106. Sandstone, olive to yellowish-brown, medium-grained, feldspathic 8

105. Shale, gray to olive; silty with sandy lenses, micaceous 20

104. Siltstone, sandy to argillaceous, olive-gray 15

103. Sandstone, greenish-gray, medium- to coarse-grained, feldspathic 10

102. Shale, sandy, olive-gray to grayish-green.. 24

Thickness of upper shale member 454

Farmington sandstone member:

101. Sandstone, light-gray to greenish-gray; ledges; medial greenish shaly beds 30

100. Sandstone, greenish, medium-grained, irregularly bedded; shale lenses 55

99. Sandstone, light-gray to greenish-gray; hard ledges; arkosic, micaceous 30

98. Shale, sandy to silty, greenish-gray, slope-forming 12

97. Sandstone; thin-bedded with shale partings and lenses; greenish-gray 10

96. Sandstone, light greenish-gray, feldspathic, massive, ledge-forming 32

95. Shale, sandy, greenish-gray; forms slope.... 20

94. Sandstone, light-olive, medium-grained; calcareous lenses; ledge-forming 22

93. Shale, sandy to silty, greenish-gray; lenses of argillaceous sandstone 44

92. Sandstone, pale-green, feldspathic, biotitic; forms hard thin to thick ledges 42

91. Shale, green to gray, silty, slope-forming .. 14

90. Sandstone, light-gray to greenish-gray;

calcareous lenses weather brown; some beds rich in feldspar and biotite; medium-grained, hard, massive to irregularly bedded; forms ledges 38

Thickness of Farmington sandstone member 349

Kirtland shale; lower shale member:

89. Shale, partly covered, silty to sandy, grayish-green to olive-green 145
88. Shale, calcareous, silty; interbeds of calcareous siltstone 35
87. Interbedded sandstone and shale; thin dense grayish-green chloritic sandstones 10
86. Shale, grayish-green to olive-gray; lenses of calcareous siltstone 44
85. Interbedded shale and siltstone; sandy, greenish gray; limestone nodules 81
84. Shale, light olive-gray to grayish-green and silty 18
83. Sandstone, calcareous, silty, dense, grayish-green, chloritic, thin-bedded 8
82. Shale and siltstone, calcareous and sandy, green; thin beds of carbonaceous shale and thin discontinuous coal seams 52
81. Shale, grayish-green to greenish-black, silty to carbonaceous; thin coal lenses. 22

Thickness of lower shale member 415

Thickness of Kirtland shale 1,218

Fruitland formation:

80. Sandstone, grayish-green, dense, fine-grained, chloritic, feldspathic; lower carbonaceous shale lenses; scattered limestone nodules 25
79. Shale, greenish-gray to olive-gray, chloritic; carbonaceous lenses 30
78. Interbedded shale and siltstone; grayish-green to olive-gray, carbonaceous to sandy; calcareous lenses; lense of dense greenish chloritic feldspathic sandstone; some thin coal beds 83
77. Sandstone, gray to brown, medium-grained, crossbedded; forms cliff or ledges 26
76. Mostly covered; basal gray, brown, and black calcareous to carbonaceous shale 66
75. Carbonero coal bed; lenses of carbonceous shale and siltstone; basal clay 85

Thickness of Fruitland formation 315

Pictured Cliffs sandstone:

74. Sandstone, calcareous to ferruginous, light-gray to dark yellowish-orange, medium-grained, well-sorted, medium- to thick-bedded, cliff-forming 53
73. Interbedded sandstone and sandy shale, calcareous, gray; ledges and slopes 30
72. Sandstone like top unit; forms cliff 18
71. Interbedded sandstones and shales; sandstones calcareous, grayish-orange, fine-grained; shales silty, dark-gray ferruginous 62
70. Alternating thick units of sandstone and silty shale; lithologies as above but scattered limestone nodules in the shale beds 52

Thickness of Pictured Cliffs sandstone 215

Lewis shale:

69. Shale, sandy; numerous lenses of light olive-gray very fine-grained shaly sandstone; some bentonite beds 210
68. Shale, dark-gray to black, clayey; scattered concretions of dense yellowish-brown-weathering limestone 1,615

Thickness of Lewis shale 1,825

Mesaverde group; Cliff House sandstone:

67. Siltstone, silty sandstone, and sandy shale with ledges of calcareous sandstone; beds erregular and lenticular; gray, weathers yellowish-brown 105
66. Sandstone, calcareous, gray, fine- to medium grained, hard; forms thin to thick ledges, weathering yellowish- to reddish-brown; beds lenticular; interbeds of argillaceous fine-grained sandstone and siltstone 130
65. Siltstone, sandy to argillaceous, calcareous, gray to brown 25
64. Sandstone like unit 66, thin to thick ledges 30
63. Siltstone and sandy shale, gray to orange-brown, slope-forming 35

Thickness of Cliff House sandstone 325

Mesaverde group; Menefee formation:

62. Sandstone, light-gray to dark yellowish-orange, lenticular, crossbedded 16

61. Shale and siltstone; gray, brown, and black; calcareous to carbonaceous; lenses of minable coal 28
60. Sandstone, yellowish-orange, crossbedded; lenticular beds; ledges 28
59. Interbedded shale, siltstone, fine-grained sandstone, and coal 36
58. Sandstone; irregular ledges; sandy shale lenses; carbonaceous 53
57. Sandstone, shaly, dark-gray to yellowish-brown, carbonaceous 27
56. Sandstone, gray to yellow, crossbedded; outcrops are ledges or cliff 27
55. Shale, sandy and silty, brown to black, carbonaceous 5

Thickness of Menefee formation 220

Mesaverde group; Point Lookout sandstone:

54. Sandstone (upper member), buff to white, medium-grained, well-sorted, crosslaminated; thick to massive even beds; cliffs and ledges 78
53. Sandstone (top of lower member); like above but thinner bedded with lenses of sandy shale; crops out as broken ledges 92
52. Sandstone, yellowish-gray to buff, fine-grained, thin-bedded; crops out as thin ledges; interbeds of gray sandy shale and siltstone 80
51. Interbedded sandstone, siltstone, and shale; gray to yellow-brown 77
50. Siltstone and shale, gray to olive-gray; lenses of yellowish-brown; upper inter- 68
49. Interbedded silty sandstone and sandy shale, dark- to yellowish-gray 20

Thickness of Point Lookout sandstone 415

Mancos shale:

48. Clay-shale, dark-gray to black; lenses and concretions of dark-gray argillaceous limestone which weather yellowish-brown; upper interbeds of silty to sandy shale 1,045
47. Shale, calcareous, gray, hard, platy (Ft. Hays limestone equivalent ?) 70
46. Clay-shale, dark-gray to black; limestone concretions 275
45. Shale, sandy; interbeds of thin-bedded argillaceous fine-grained sandstone, and thin beds of fossiliferous fetid limestone 85
44. Shale, somewhat sandy; a few ledges of dark-gray argillaceous limestone 260
43. Interbedded limy shale and thin argillaceous limestone (Greenhorn) 25
42. Shale, grayish-black, clayey; calcareous lenses 140

Thickness of Mancos shale 1,900

Dakota sandstone:

41. Sandstone, brown, hard; carbonaceous lenses; interbeds of dark-gray shale 110
40. Sandstone, brown to buff, hard, massive-bedded; cliff; plant fragments 28
39. Shale (3-15 feet thick), carbonaceous; discontinuous coal lenses 8
38. Sandstone, light-gray, medium- to coarse-grained, conglomeratic, crossbedded, cliff-forming; lower conglomeratic lenses chiefly of white chert pebbles; near top is thin light-green argillaceous sandstone, locally carbonaceous 67

Thickness of Dakota sandstone 213

Unconformity

Morrison formation; Brushy Basin member:

37. Mudstone, upper greenish-gray, lower maroon 55
36. Mudstone, greenish-gray, bentonitic; poorly-exposed 41
35. Sandstone, light-gray to greenish, massive-bedded to thin-bedded 6
34. Mudstone, greenish-gray; maroon lenses 13
33. Sandstone, greenish-gray, fine- to coarse-grained; scattered angular pebbles; silicified wood fragments near base; laminae and lenses of sandy shale 76
32. Conglomerate, arkosic; pebbles up to 1 inch diameter, well-rounded, chiefly of quartzite 6
31. Sandstone, light-gray to greenish-gray, fine-grained 4
30. Poorly exposed interbedded green shaly sandstone and sandy shale; limestone nodules 120

Thickness of Brushy Basin member 321

Morrison formation; Salt Wash member:

29. Sandstone, light-gray to light-brown, coarse-

	grained; beds lenticular; lenses of red, green, and gray shale	28
28.	Poorly exposed interbedded brown sandstone and reddish-brown shale	28
27.	Sandstone, light-gray, crossbedded, thick- to massive-bedded	43
26.	Sandstone, greenish gray to brown; lower beds massive	30
25.	Poorly exposed interbedded lenticular sandstone, sandy shale, and mudstone; red, gray, and purple	171
	Thickness of Salt Wash member	300

Junction Creek sandstone:

24.	Sandstone, white to light-buff, friable, cross-bedded, cliff-forming; arkosic lenses; partings of greenish-gray and light-red shale	200

Wanakah formation:

23.	Marl (top of marl member), sandy, red to green concretionary beds, and thin sandstone lenses	15
22.	Sandstone, pale yellowish-brown, massive, hard, ledge-forming	7
21.	Shale, limy, sandy, concretionary, pinkish-red	13
20.	Shale and siltstone, limy, pinkish-red and greenish; lenticular beds; interbeds of yellowish to greenish limy sandstones; basal lenses of red chert coated green	33
19.	Shale, mudstone, and silty sandstone, limy; concretionary	11
18.	Sandstone (top of Bilk Creek sandstone member), calcareous, hard, coarse-grained; grains and concretions of red chert	½-2
17.	Shale, limy, sandy, concretionary, red	5
16.	Sandstone, grayish-white to dull-red, soft; basal hard limy bed	8
115.	Limestone (Pony Express member), varies from oolitic and sandy to dense dark-gray and relatively pure with lower laminated beds	4
	Thickness of Wanakah formation	98

Entrada sandstone:

14.	Sandstone, light-gray to white, massive-bedded, strikingly crossbedded, cliff-forming; fine- to coarse-grained; grains chiefly quartz and well rounded; some calcareous cement; locally lower beds are medium-bedded slabby sandstone	265

Unconformity
Dolores formation:

13.	Sandstone (Wingate ?), massive-bedded, fine-grained, salmon-pink	22
12.	Mudstone and siltsone, red and purplish-red; 1-foot limestone conglomerate bed near middle, and another at base	70
11.	Mudstone; alternating purplish-maroon and red; upper and lower red siltstones	76
10.	Sandstone, fine-grained, salmon-pink to pale-cream	6
9.	Siltstone, massive, blocky; mottled gray-green	72
8.	Poorly exposed mudstone and shale; 1½-foot limestone conglomerate in lower part	118
7.	Mudstone and siltsone, red; thin lower conglomerate containing clay pellets	27
6.	Sandstone, gray; lenses of limestone conglomerate	28
5.	Poorly exposed red and purple shale	54
4.	Siltstone; red mottled green; two thin beds of limestone conglomerate	30
3.	Poorly exposed purplish-red shale; 22-foot beds of limestone conglomerate in lower 20 feet	76
2.	Sandstone, greenish-gray, slabby; lenses of limestone conglomerate; basal 3-foot bed of limestone edgewise conglomerate	39
1.	Sandstone, greenish-gray, fine-grained, micaceous; plant remains	20
	Thickness of Dolores formation	638

Cutler formation.

The description of the Animas Valley section was modified from published descriptions, columnar sections, and unpublished field notes. Units 117-134 are chiefly from Reeside (1924, p. 56), units 38-116 mainly from Zapp (1949) and Barnes, Baltz, and Hayes (1954), and units 1-37 chiefly from Eckel (1949, pp. 24-31).

Composite Section in and near Uncompahgre River Valley

Telluride conglomerate
Erosional unconformity
Mancos shale:

36.	Shale, dark-gray to black thin beds and concretions of limy shale and limestone; scattered marine fossils	200+

	Shale, sandy, pebbly; pebbles of quartzite numerous sharks' teeth	2

Local unconformity
Dakota sandstone:

35.	Interbedded; quartzite, light-gray, fine-grained; shale, sandy, gray	14
34.	Quartzite, dark-gray to black, carbonaceous; black shale partings	10
33.	Shale, black and dark-gray; carbonaceous leaf imprints	15
32.	Quartzite; upper dark-gray, lower greenish-gray; black shale lenses	18
31.	Shale, dark-gray; numerous brown sandstone and sandy shale laminae	23
30.	Quartzite, light-gray to brown, massive-bedded; shale partings	55
29.	Interbedded lenticular shale and sandstone; greenish-gray	14
28.	Shale, sandy, carbonaceous, purplish-gray; greenish at top; scattered chert pebbles	10
27.	Sandstone, conglomeratic, gray to brownish-gray; upper beds fine-grained; pebbles rounded, of white, red, and gray chert, gray shale, and quartz	17
	Thickness of Dakota sandstone	176

Morrison formation; Brushy Basin member:

26.	Shale; green with reddish interbeds; some limy and cherty beds; basal mudstones	60
25.	Shale, calcareous, dark-red to greenish-gray	48
24.	Upper green quartzite; middle red shaly limestone; lower red shale	17
23.	Upper shaly sandstone, lower sandy shale; reddish-brown	15
22.	Quartzite, massive-bedded, greenish-gray	15
21.	Interbedded lenticular reddish limy shale, thin greenish sandstone, and reddish argillaceous limestone	68
20.	Sandstone, gray, massive-bedded	26
19.	Interbedded reddish limy shale and gray sandstone	70
18.	Sandstone, gray, fine-grained	12
17.	Interbedded greenish-gray sandstone and reddish-brown limy shale	36
	Thickness of Brushy Basin member	367

Morrison formation; Salt Wash member:

16.	Sandstone, white, massive-bedded, fine-grained; red shale partings near top	61
15.	Mudstones, red; break into small flakes	24
14.	Sandstone, gray to white, thin-bedded; red shaly laminae	42
13.	Mudstone, red; some limy beds and some sandy beds	33
12.	Sandstone, light-gray, crossbedded	31
11.	Limestone, dense, blue-gray; nodular in places	5
10.	Interbedded lenses of gray sandstone and red shale	26
9.	Quartzite, light-gray, medium-grained, massive-bedded	29
	Thickness of Salt Wash member	251

Wanakah formation:

8.	Shale and mudstone (top of marl member), limy, brown to yellowish; many brown to light-gray limestone nodules, lenses, and thin beds	31
7.	Shale, brown to green, clayey to sandy; lower greenish sandstones	15
6.	Sandstone (Bilk Creek sandstone member), greenish-gray to yellowish-gray, hard to friable; bright-red chert grains in upper beds	20
5.	Gypsum (top of Pony Express member), banded to nodular; white with black shaly partings	51
4.	Interbedded shale and limestone, black; upper part is breccia	7
	Thickness of Wanakah formation	124

Entrada sandstone:

3.	Sandstone, light-buff to light-gray, prominently cross-bedded, cliff-forming, friable, fine-grained	75

Unconformity
Dolores formation

2.	Shale, limy, sandy, bright-red to reddish-gray; lenses of argillaceous limestones and shaly sandstones	70
1.	Interbedded fine-grained sandstone, sandy calcareous shale, impure limestone, and lenticular limestone conglomerate; reddish, with some greenish-gray beds	30
	Thickness of Dolores formation	100

Unconformity
Cutler or Hermosa formation.

The description of the Uncompahgre Valley Section was modified from descriptions by Burbank (1930, pp. 169-184), Craig and Dickey (1956), Stewart (1956), and Kelley (1946). The light-colored sandstones above the Wanakah formation were referred to the Salt Wash member of the Morrison formation rather than the Junction Creek sandstone, because they are interbedded and intertongued with red sandy to limy mudstones not present in the type Junction Creek sandstone (Eckel, 1949, pp. 29-30) except as partings.

MESOZOIC HISTORY

Near the close of the Permian, the San Juan region was probably an area of low monadnocks amid extensive semiarid plains that may have drained toward the Ochoan "dead sea" of southeast New Mexico and west Texas. The youngest Permian deposits remaining are those of the Cutler redbeds, which are relatively conformable beneath Triassic strata but are absent to the east, where Upper Triassic sediments overlap older rocks down to the Precambrian. The Cutler redbeds intertongue southward with the Abo-Yeso-Glorieta-San Andres units, and appear to be no younger than Leonard in age; they thin and become coarser to the east toward the ancestral Rockies or Colorado Mountains, whose westernmost range, the Uncompahgre highland, was somewhere east of Silverton.

The Uncompahgre region of southwestern Colorado, and much of western New Mexico, was an upland source of the Moenkopi sediments during Early Triassic time; from these relatively low "uplands" a broad plain sloped gently westward toward the Moenkopi sea. Near the shifting shorelines the alluvial-plain and delta deposits interfingered with extensive tidal-flat deposits that graded westward into shallow-marine sediments. Durango is near or not far east of the feather-edge of the early Triassic alluvial sandy beds.

Upper Triassic sedimentary rocks are erosionally unconformable on the Moenkopi formation in the region west and southwest of the San Juan Mountains, and the lower beds of the Chinle formation overlie chiefly Permian redbeds in northwestern New Mexico. The lower part of the Chinle formation is thickest to the west (in south-central Utah, east of the junction of the San Juan and Colorado Rivers) and to the south (in northwestern New Mexico in central McKinley County). The upper part of the Chinle formation, which is correlated with most of the Dolores formation (for example, Stewart, 1956) is thick along the Dolores River near the Rico Mountains and in the central McKinley County area of northwestern New Mexico. The Shinarump conglomerate, or Shinarump member of the Chinle formation, ranges from a wedge-edge to 225 feet in thickness in northern Arizona and southern Colorado, but Stewart (1956), McKee (1951), and others believe the unit does not extend into southwestern Colorado and northwestern New Mexico except near the Arizona-New Mexico border and in the Gallup area.

The type Shinarump is yellowish-gray medium- to coarse-grained crossbedded sandstone, with lenses of silica-pebble conglomerate, and with abundant silicified and carbonized wood. The coarser fractions are pebbles and cobbles of chert, quartz, and quartzite. Similar conglomeratic sandstones at or near the base of the Chinle or Dolores formation in northwestern New Mexico could be pockets of coarse clastic material correlative with the type Shinarump, as suggested by Kilgore (1955) and Wengerd (1950).

The Wingate sandstone, just recently considered to be of Upper Triassic age, thins eastward from thick sections in northeastern Arizona and southeastern Utah, and in the Durango area it either intertongues into the upper part of the Dolores formation, is represented by a discontinuous (Eckel, 1949, p. 26) salmon-pink sandstone, or has pinched out. The absence of the Wingate in the San Juan Mountains area is due either to pre-Entrada erosion or to eastward depositional thinning.

The lower part of the Chinle formation was deposited on an alluvial plain with the chief source postulated (Stewart, 1956, p. 90-91) to be a large area of southern Arizona southwest of the Four Corners. However, the area east of the Durango and Ouray area apparently supplied some coarse clastics to the conglomeratic Moss Back member. The upper Chinle and Dolores formations were deposited on widespread alluvial plains of low relief containing numerous lakes, as attested to by the limestone and limestone-pebble beds. Dip of crossbeds and onlap of the sediments onto the Uncompahgre highland indicate (Craig and Dickey, 1956) that this upland was the source of most of the Dolores beds; streams flowed westward to south-central Utah and northeastern Arizona, where the Owl Rock member was deposited in a large lake. The Wingate sandstone is, in large part, an eolian deposit, whipped across the desolate and barren plains of late Triassic time, southwest of the low but persistent Uncompahgre highland. The amount of wind-blown sand in the Triassic and Jurassic deposits is in large part due to the lack of grasses; the alluvial plains bordering upland areas had no cover of

grass, sagebrush, and low shrubs but were essentially barren. Along streams and lakes the conifers and cycads flourished, along with an undergrowth of ferns and scouring rushes, and supplied food for the herbivorous dinosaurs. Deciduous trees and plants were not conspicuous until early Cretaceous time when they became the source of most of the thick Cretaceous coal deposits.

In early Jurassic time the San Juan region supplied supplied much of the continental sediments deposited to the west as the Kayenta formation and eolian Navajo sandstone. The region was part of the highlands east of the shoreline of the Carmel Sea. These periods of erosion are reflected by the unconformity at the base of the Entrada sandstone in parts of the area, as near Ouray and in the upper Piedra River Canyon. The Entrada near Durango and Ouray appears to be chiefly an eolian dune sand, but to the west in south-central Utah, where the formation is thicker, silty even-bedded sandstones were probably deposited in a marine environment. The Wanakah formation records an early period of lagoonal marine deposition of the basal Pony Express member and the correlative Todilto limestone and gypsum; and a later alternation of marine and continental deposition of the upper members, correlative with the Summerville formation; the Junction Creek sandstone and related Bluff and Cow Springs sandstones are eolian lenses intertonguing with the Summerville and with the overlying Morrison formation.

The Morrison formation is relatively uniform in thickness near the San Juan Mountains and was probably deposited over the entire area of Colorado, northern New Mexico, northeastern Arizona, and most of Utah, as well as to the north and east. Source of these extensive fluvial and lacustrine continental deposits appears to have been to the west and south.

Lower Cretaceous strata are thin or not present near the southwestern San Juan Mountains, although to the west the Burro Canyon formation (Stokes, 1952) is as much as 266 feet thick; it apparently is conformable to erosionally unconformable on Morrison beds, and has a similar contact with the overlying Dakota sandstone. The Burro Canyon beds resemble not only some of the Morrison strata but also sandstones and conglomerates of the Dakota. The contact between Lower Cretaceous and Upper Cretaceous strata is a difficult boundary to determine, and, although the Lower Cretaceous beds are not types that are deposited slowly, they may represent latest Jurassic to latest Lower Cretaceous age, depending on locality. The Dakota sandstone as mapped by most geologists has been suggested as possibly containing beds of Lower Cretaceous age (Stokes, 1952). The relationships and lithologies of the Burro Canyon-Dakota are similar to those of the Purgatoire-Dakota of northeastern New Mexico and south-central Colorado (Baldwin and Bushman, 1957; Waage, 1955), and to the Sarten-Dakota (?) of south-central New Mexico (Kottlowski et al., 1956, pp. 62-67). The Burro Canyon-Dakota sediments appear to have been deposited chiefly by aggrading streams on a vast plain between the marine deeps of the southwestern New Mexico-southeastern Arizona trough and a local gulf of the Arctic sea in southwestern Wyoming, eastern Idaho, and western Montana.

The Upper Cretaceous marks one of the most widespread marine inundations of North America. Transgression of the sea from both the south and north was ushered in by the aggraded stream deposits of the Dakota sandstone. The Cordilleran geosyncline, or Rocky Mountains trough, was in places more than 1,000 miles wide and extended from an expanded Gulf of Mexico to the Arctic Ocean. The chief source of the sediments was the Mesocordilleran geanticline to the west, and the deposits are a complex of fine-grained marine deposits from the east side of the geosyncline interfingering with periodic floods of deltaic and continental sediments flushed out of the mountains to the west. Thus in the area south of Durango, the Mesaverde group clastic beds intertongue eastward into the marine Lewis and Mancos shales, and the Point Lookout sandstone grades into the Lewis shale. The Fruitland formation marks the beginning of dominance of continental sedimentation, and in its upper beds, as in the overlying Kirtland shale, notable amounts of chlorite and feldspars appear, in contrast to the prominence of quartz in lower clastic beds. The arkosic micaceous sediments appear to be in part derived from the San Juan Mountains area and may record the intrusions of stocks and laccoliths, such as near Ouray and in the La Plata and Rico Mountains. Uplift of the San Juan Mountains area was accompanied in Late Cretaceous and early Tertiary time by the extrusion of andesitic lavas and pyroclastics whose debris formed a large part of the McDermott and Animas formations. The last moment of Cretaceous time, if we could be so precise, was ushered out unnoticed with mountains rising to the north and andesitic and quartzose detritus being deposited to the south in the upper beds of the Animas formation.