LOWER MESOZOIC ROCKS IN COLORADO[1]

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INTRODUCTION

The Triassic and Jurassic systems are represented in Colorado by sedimentary rocks whose composition and physical properties produce spectacularly scenic and colorful erosional remnants in the State's dominantly semiarid climate. By far the great bulk of uranium and associated metal reserves in the Colorado Plateau lie within these rocks (Finch, 1959, p. 125; Fischer, 1956), as well as a few small oil and gas fields. The rocks have long been a source of world-famous dinosaur remains as well as the stormy center of prolonged geologic controversy—whose resolution, largely by consensus, remains open to question. Despite intensive studies during the past two decades, many questions concerning origin and age remain unresolved.

[1] Publication authorized by the Director, U. S. Geological Survey. Not all the stratigraphic names and age assignments presented here have been accepted for use by the Geological Survey.

Lower Mesozoic rocks in Colorado form an eastwardly thinning wedge. The rocks were deposited on a moderately stable shelf, sloping westward toward a geosyncline whose eastern flank lay in western Utah. The alternation of marine and nonmarine deposits records several transgressions and regressions of the sea across areas of moderately low relief.

Stratigraphic units included in the Triassic and Jurassic systems of Colorado are shown in table 1. Both artificial and natural boundaries account for diversity of rock nomenclature. Many of the rock units extend beyond areal limits within which individual names are applied. For this reason, the discussion that follows is organized in terms of the map intervals shown in table 1; formations and members are described briefly under the appropriate map interval, and a combined isopach and lithofacies map for each interval accompanies the text. Some formations not

TABLE 1. Generalized Correlation chart of Triassic and Jurassic stratigraphic units in Colorado.

Age	European stages	MAP INTERVALS	Northwestern	Central western	Southwestern	Central northern	Central	Central southern	Northeastern	Central eastern	Southeastern
JURASSIC Late	Portlandian	Interval D	Morrison formation: Brushy Basin member; Salt Wash member; Morrison formation undivided	Morrison formation: Brushy Basin member; Salt Wash member	Morrison formation: Brushy Basin member; Westwater Canyon mbr.; Recapture member; Salt Wash member	Morrison formation	Morrison formation	Morrison formation	Morrison formation	Morrison formation	Morrison formation
	Kimeridgian										
	Oxfordian	Interval C	San Rafael group: Curtis formation; Entrada sandstone	San Rafael group: Summerville formation; Entrada sandstone	San Rafael group: Junction Creek Sandstone; Summerville formation; Wanakah formation; upper morrison member; Bill Creek Ls. mbr.; Pony Express ls. mbr.; Entrada sandstone	Ralph Creek formation; Sundance formation; upper part (Redwater shale member); lower part	Ralston Creek formation; Entrada sandstone	Wanakah formation; Ralston Creek formation; Entrada sandstone	middle unit of Jurassic age	lower unit of Morrison formation; middle unit of Jurassic age	middle unit of Jurassic age; Entrada sandstone
	Callovian	Interval B	San Rafael group: Carmel formation								
	Bathonian										
	Bajocian										
Middle											
Early	Toarcian	Interval A	Glen Canyon group (undivided); Nugget sandstone or Navajo sandstone	Glen Canyon group: Navajo sandstone; Kayenta formation; Wingate sandstone	Glen Canyon group: Navajo sandstone; Kayenta formation; Wingate sandstone						
	Pliensbachian										
	Sinemurian										
	Hettangian										
TRIASSIC Late	Rhaetian	Interval C	Chinle formation: red siltstone; Church Rock member; ocher unit; mottled unit; Gartra grit[1]	Chinle formation Church Rock member	Chinle formation; Church Rock member; Moss Back member; Dolores formation	Jelm formation		Dockum group			Dockum group: Sloan Canyon formation[5]; unnamed formation
	Norian										
	Karnian										
Middle	Ladinian	Interval B									
	Anisian			Moenkopi formation: Pariott member; Sewemup member; Ali Baba member; Tenderfoot member							
Early	Scythian	Interval A	Moenkopi formation (upper part); State Bridge[2] formation (upper part)			Lykins formation (upper part); Chugwater formation; Goose Egg formation[3]; Red Peak member (upper part)	Lykins formation (upper part) Strain shale member[4]				

1. Of Thomas and Krueger (1946). 2. Of Donner (1949). 3. Of Burk and Thomas (1956). 4. Of LeRoy (1946). 5. Of Parker (1933).

shown in table 1 but reported in publications dealing with Colorado are included in the discussion below.

Acknowledgments.—This brief stratigraphic summary is based on long-range studies undertaken by the U. S. Geological Survey. Most of the material used here is drawn freely from the Paleotectonic Map folios of the Jurassic and Triassic Systems (McKee and others, 1956; in press). Data on Colorado for these folios were compiled by James C. MacLachlan, Marjorie E. MacLachlan, Melville R. Mudge, and Steven S. Oriel. Many of the compiled data, however, were drawn from the extensive field studies made in connection with the investigation of uranium deposits on the Colorado Plateau by the Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission. Responsibility for the Colorado Plateau studies rests with Lawrence C. Craig, John H. Stewart, James C. Wright, and their associates. Data collected by Clifford N. Holmes were available to the writers. Subsurface data on the two systems were made available by James G. Mitchell of the American Stratigraphic Company.

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TRIASSIC INTERVAL A

Rocks assigned to Interval A of the Triassic system are those regarded as largely or entirely of Early Triassic or Scythian age. The interval may also include some rocks of possible Middle Triassic age.

Rocks of this interval are restricted to the northwestern and central-northern parts of Colorado and to a small area in the Salt Valley region in the central-western part of the State (fig. 1). In general, the rocks thin both southward and eastward to the margins of a wedge which has a maximum thickness of about 850 feet in northwesternmost Colorado. The rocks are still thicker locally in the Salt Valley region, attaining more than 1,200 feet in Mesa County (Shoemaker and Newman, 1959, p. 1841), but they thin markedly in short distances to the northeast, east, and south. The rocks are absent, because of nondeposition, on the ancestral Uncompahgre highland, the ancestral Rocky Mountains, and in southeastern Colorado.

Rocks of Triassic Interval A are composed predominantly of very fine-grained red detritus (fig. 1). Mudstone, including claystone and siltstone, makes up the bulk of the unit in most places but conglomerate and very fine-grained sandstone beds are also present locally, particularly in the Salt Valley region. The unit is characterized by evenness of bedding, ripple laminae, fineness of grain, traces of salt casts, and anhydrite or gypsum.

Environments of deposition inferred for these rocks are streams and tidal flats in a semiarid climate (McKee, 1954, p. 76-81; Stewart and others, 1959, p. 499; McKee and others, in press). Transgressions of the sea, as represented by the Timpoweap, Virgin, and Sinbad limestone members of the Moenkopi formation in Utah (McKee, 1954), probably did not extend as far east as Colorado during Early Triassic time. Coarse-grained arkosic and conglomeratic sandstone in the Salt Valley region in cen-

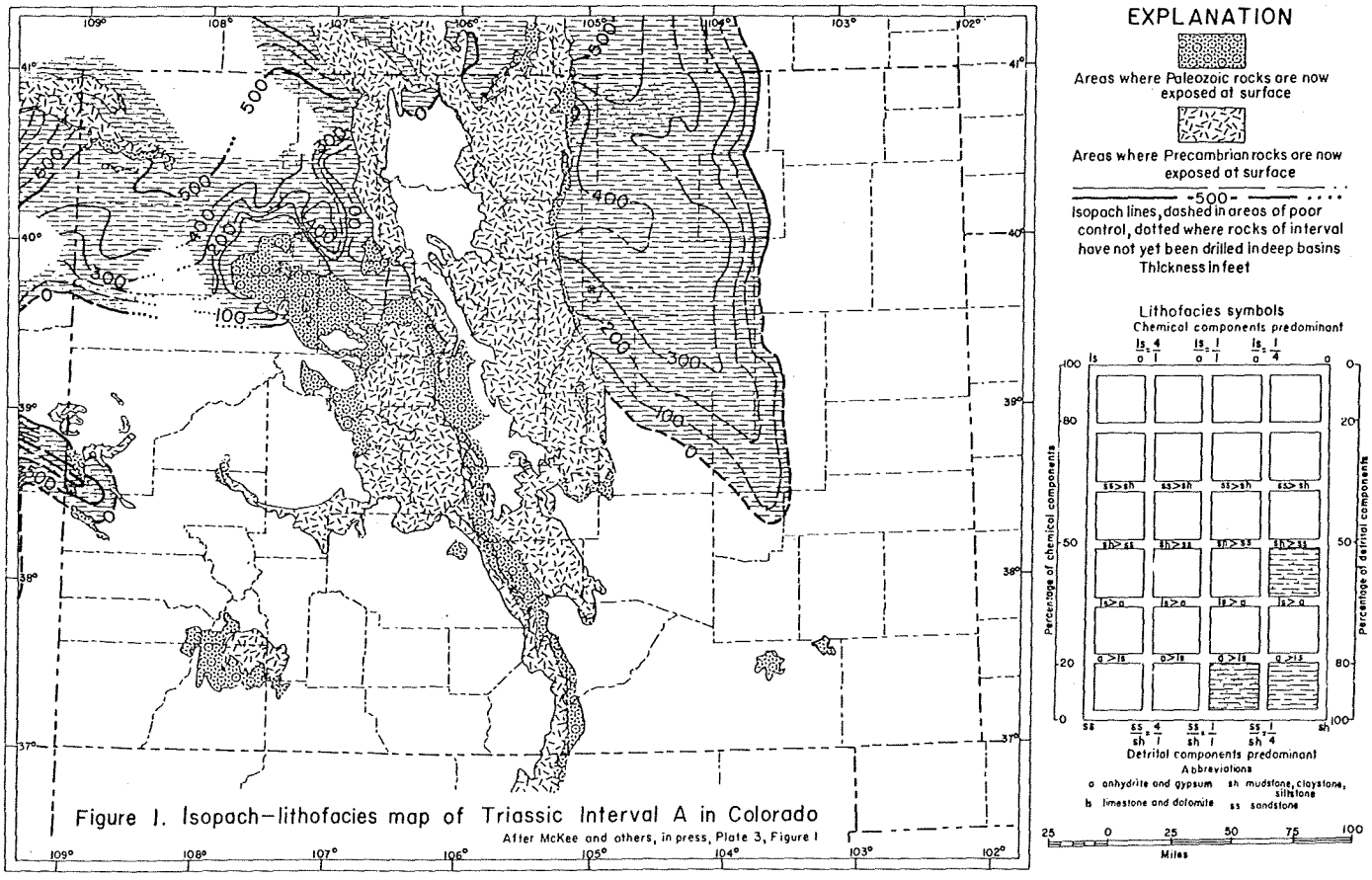

Figure 1. Isopach–lithofacies map of Triassic Interval A in Colorado
After McKee and others, in press, Plate 3, Figure 1

tral-western Colorado indicates that at least some rocks were derived from the granitic core of the ancestral Uncompahgre highland and possibly from the conglomeratic facies of the underlying Cutler formation. Some coarse debris along the eastern margin of the Moenkopi formation in northwestern Colorado may have been derived from the ancestral Rocky Mountains.

Stratigraphic units included in Triassic Interval A are the following:

CHUGWATER FORMATION

The name Chugwater formation, proposed by Darton in 1904 (p. 394-401) and used extensively for a sequence of red beds through most of Wyoming and southern Montana, has been extended into Colorado by geologists working in the southern part of the Laramie basin, in North Park, and in the area on the west flank of the Sierra Madre. The type locality is Chugwater Creek, near Iron Mountain in southeastern Wyoming.

In Wyoming, the formation has been subdivided by Love (1939, p. 44) and subsequent writers into the following members:

Popo Agie member.—The uppermost member consists of ocher and red mudstone, lighter colored, lenticular sandstone beds, and analcite beds between the Alcova limestone member and the overlying Nugget sandstone. Vertebrate remains found along the northeastern flank of the Wind River Mountains indicate that this unit is of Late Triassic age and equivalent to the lower part of the Chinle formation and of the Dockum group. The name Popo Agie has not been applied to rocks in Colorado, although the characteristic ocher beds are recognized in the northwesternmost part of the State.

Alcova limestone member. — The middle member, named the Alcova limestone member by Lee (1927, p. 14), consists of resistant limestone containing the nothosaur *Corosaurus* and marine invertebrates. The unit pinches out southward in southern Wyoming and is not present in Colorado.

Red Peak member.—The lowest and thickest member of the Chugwater formation consists predominantly of very evenly bedded and laminated deep-red to maroon and red-brown claystone, siltstone, mudstone, and muddy, fine-grained sandstone. The lower part of the member, as used in previous reports, includes beds and tongues (Thomas, 1934) of limestone, dolomite, and anhydrite of both Permian and Triassic age. Adoption of the name Goose Egg formation (Burk and Thomas, 1956) by many geologists in Wyoming has resulted in restriction of the names Red Peak and Chugwater to the beds above the Little Medicine tongue of the Dinwoody formation (Thomas, 1934). The Red Peak member, therefore, now includes only rocks of Early and possibly of Middle Triassic age. The age designation is based primarily on intertonguing relations westward with the well-dated marine Thaynes limestone in western Wyoming.

GOOSE EGG FORMATION

Red beds and interbedded evaporites, including anhydrite, dolomite, and limestone, formerly included in the basal part of the Chugwater formation, are now assigned to the Goose Egg formation (Burk and Thomas, 1956) in central and eastern Wyoming and in the northern part of central-northern Colorado. The strata involved are the same as the limestone and red-bed tongues described by Thomas (1934).

Only the upper part of the formation is here placed in Triassic Interval A. The uppermost evaporite bed, called the Little Medicine tongue of the Dinwoody formation in Wyoming, and the underlying red beds, above the Ervay tongue of the Phosphoria formation (Thomas, 1934) or the Ervay carbonate rock member of the Park City formation (McKelvey and others, 1956, p. 2844), are assigned an Early Triassic age. The underlying units are believed to be of Permian age.

LYKINS FORMATION

The striking deep brick red sequence of even-bedded mudstone and muddy sandstone with interbedded limestone and some anhydrite, which is exposed along the east side of the Front Range, was named the Lykins formation by Fenneman (1905, p. 24-26) for Lykins Gulch, about 9 miles north of Boulder. Since 1905 when Fenneman assigned the unit a questionable Triassic age, the age of strata included in the formation has been a source of disagreement.

The formation has been subdivided by LeRoy (1946, p. 30-47) into the following 5 members, in ascending order: Harriman shale, Falcon limestone, Bergen shale, Glennon limestone, and Strain shale. The Triassic-Permian boundary is placed by LeRoy (1955, p. 20) at the top of the Glennon limestone.

The present writers follow Mudge (*in* McKee and others, in press) in arbitrarily placing the base of the Triassic system at the top of a thin dolomite bed, 90 feet above the base of the Strain shale member; the dolomite may be correlative with the Ervay tongue of the Phosphoria (or Park City) formation of Wyoming (Thomas, 1934, p. 1664, 1666). The systemic boundary is placed by Chronic (*in* McKee, 1957, p. 18) at the position of a persistent change in color of the red beds, 100 to 300 feet above the base of the Strain shale member. The upper or Strain shale member is believed, on the basis of subsurface sample and electric log correlations, to be equivalent to the Chugwater and upper part of the Goose Egg formations in Wyoming. The precise relation of individual limestone beds in the Lykins formation, however, to those in the Goose Egg formation is not known with certainty, according to Broin.[2]

MAROON FORMATION

Red beds of Early Triassic age have been assigned to the Maroon formation (Eldridge, 1894) by some geologists (Bass and Northrop, 1950, p. 1547; Tweto,

[2] Broin, T. L., 1957, Stratigraphy of the Lykins formation in eastern Colorado: Univ. Colorado unpubl. Ph. D. thesis.

1949, p. 229). The name, however, is now restricted by many geologists (Murray, 1958, p. 55) to the beds below the State Bridge formation of Donner (1949).

MOENKOPI FORMATION

The Moenkopi formation, named by Ward (1901, p. 17), consists of red and pale reddish brown, relatively nonresistant, micaceous, ripple-laminated and horizontally laminated claystone, siltstone, and sandy siltstone, as well as minor, ledge-forming beds of pale reddish brown and yellowish-gray, very fine-grained, cross-stratified sandstone (McKee, 1954; Stewart and others, 1959, p. 497). The name has been extended from the type area at Moenkopi Wash, north-central Arizona, through most of Utah to northwestern Colorado where the names Woodside and Ankareh formations have been applied to similar dominantly red mudstone.

The Moenkopi formation has been subdivided in the Salt Valley region by Shoemaker and Newman (1959) into the following members, in descending order:

Pariott member.—The Pariott member consists of red-brown to purplish-brown sandstone and chocolate-brown, orange, and red mudstone, siltstone, and claystone. The member is characterized by a relatively high proportion of sandstone and by heterogeneity of composition and color.

Sewemup member.—The Sewemup member consists mainly of chocolate-brown, fissile siltstone, or claystone with subordinate light-brown, fine-grained sandstone and a few beds of maroon, coarse-grained sandstone. Gypsum is present throughout the member in most places, mainly as interstitial cement but also as discrete, thin, nodular beds near the top, and makes the unit lighter colored than the underlying member.

Ali Baba member.—Red-brown to purplish, ledge-forming beds of conglomeratic, arkosic sandstone separated by red-brown and chocolate-brown mudstone and fine- to coarse-grained sandstone form the Ali Baba member. The member exhibits marked facies change from ledge-forming, very arkosic and conglomeratic sandstone on the northwest, near the Uncompahgre Plateau, to much finer grained, better sorted, and less abundant sandstone on the southwest.

Tenderfoot member.—The basal member consists of brick-red or orange-brown to dark-brown poorly sorted sandy mudstone and silty mudstone mainly in poorly bedded, massive ledges, but includes discontinuous basal units of weathered, coarse, arkosic detritus, derived from the underlying Cutler formation. In many places the basal coarse units are overlain by a bed of gypsum as much as 7 feet thick.

The Tenderfoot member is considered to be equivalent at least in part to the Hoskinnini member of the Moenkopi formation in Utah (Stewart, 1959; Shoemaker and Newman, 1959, p. 1850) and both may be of Permian age, Early Triassic age, or both. Although shown in table 1, the Tenderfoot member is not included on figure 1.

In northwestern Colorado red beds of Permian age are assigned by some geologists (Poole, 1958) to the undifferentiated Moenkopi formation, although they are not included on figure 1. Other geologists, however, prefer to restrict the name Moenkopi to rocks of Triassic age.

SPEARFISH FORMATION

The name Spearfish formation has been applied by some geologists (Condra, Reed, and Scherer, 1950, p. 9) to red beds of Early Triassic or Permian and Triassic age in central-northern Colorado and southeastern Wyoming. The names Lykins and Chugwater formations have been used more commonly.

STATE BRIDGE FORMATION

The names State Bridge siltstone and State Bridge formation have been applied to red beds in the McCoy area in central-northwestern Colorado. Named by Donner in 1936 in an unpublished dissertation (Univ. Mich.), the unit was subsequently described (Donner, 1949, p. 1228-1229) as "... composed mainly of thin-bedded, micaceous, brick-red siltstone, shale, and fine, limy sandstone. ... Approximately 140 feet from the base is an impure limestone which at State Bridge is 7 feet thick ... in which fossils have been found." These fossils are believed by Brill (1944, p. 636, 640) to be of Permian age. Despite the absence of fossils in beds above the limestone, the upper part of the unit is now assigned, on the basis of regional relations (MacLachlan *in* McKee and others, in press) an Early Triassic age. The base of the Triassic system is arbitrarily placed 100 feet above the top of the limestone.

TRIASSIC INTERVAL B

Triassic Interval B is intended to include rocks considered of Middle Triassic age. Because no fossils of this age have been found in Colorado, no rocks are included in this interval, although some unfossiliferous sequences, near the top of the Moenkopi formation for example, may well be of Middle Triassic age.

TRIASSIC INTERVAL C

Rocks assigned to Interval C of the Triassic system are those regarded as of Late Triassic age and correlative with the Karnian, Norian, and Rhaetian of Europe. The boundary between the Triassic and Jurassic systems is difficult to recognize in western Colorado and adjacent States and is subject to disagreement. Therefore, some rocks not here included may belong in this interval, whereas some included in the interval may be of Jurassic age. Moreover, because a lithologic contact approaching the systemic boundary cannot be traced across western Colorado, the top of the interval as now used is not consistent; in southwestern Colorado, the top is placed within the Glen Canyon group, whereas in northwestern Colorado it is placed essentially at the base of the group (table 1). For this reason, isopach lines (fig. 2) are not drawn continuously across central-western Colorado.

Rocks of Triassic Interval C are more extensive in Colorado than those of Interval A; they are present throughout most of the State, except in central, central-eastern, and northeastern Colorado (fig. 2). The rocks

are thickest in the southwesternmost part of the State where they are almost 1,700 feet, but they thin markedly in a short distance to the northeast. They are more than 600 feet thick in southeastern Colorado and thin gradually westward and northeastward.

Rocks of Interval C are more heterogeneous in grain size and primary structures than are those of Interval A. They range from claystone to very coarse conglomerate and, in general, contain far more sandstone. Cut-and-fill structures, lentils, prominent cross bedding, and lateral discontinuities characterize the unit.

The loci of maximum thickness in Colorado reflect parts of a broader structural framework of the Western Interior. This framework consisted, in general, of roughly elliptical overlapping basins or localized downwarps into which detrital sediments were transported from various directions (McKee and others, in press). The rocks are thickest and relatively fine grained near the centers of the basins, thinning and becoming coarser grained toward the basin margins. The deposits, entirely of continental origin, were derived mainly from the ancestral Rocky Mountains and ancestral Uncompahgre highland which, however, were more extensively covered than in Early Triassic time. Some detritus also was derived from the south, in Arizona and New Mexico, and from western Kansas. The Wet Mountain uplift area, in south-central Colorado, was apparently an important source of detritus in Late Triassic time. Many conglomerates and conglomeratic sandstones at various horizons suggest recurrent uplifts in parts of the source areas. During much of Late Triassic time the climate in Colorado may have been warm and moist, probably subtropical, with alternating rainy and dry seasons; but the climate became more arid toward the end of Triassic time as indicated by eolian deposits in southwestern and northwestern Colorado.

Stratigraphic units included in Triassic Interval C are the following:

ANKAREH FORMATION

The name Ankareh, first applied to red beds in north-central Utah by Boutwell (1907), has had a long and tortuous history that has been reviewed recently by Kummel (1954, p. 179-180), Anderman (1956, p. 56-58), and McKee and others (in press). The name is now applied by many geologists to the red beds that overlie the Thaynes limestone and underlie the Nugget sandstone in northeastern Utah and southwestern Wyoming. Despite agreement on field relations of the strata involved, geologists are not in agreement on nomenclature.

The units as now recognized, as well as Kummel's terminology (1954, p. 178) for them, are shown on figure 3. For rocks east of the easternmost tongue of the Thaynes limestone, many geologists (Kinney, 1955, p. 56; Unterman and Unterman, 1955, p. 20) use the Colorado Plateau terminology, although some geologists (e. g., Scott, 1959, p. 106) use the names Shinarump and Chinle even where the Thaynes limestone is present. Moreover, the name Ankareh is restricted by some geologists (e. g., Thomas and Kreuger, 1946) to the red beds between the Thaynes limestone and the overlying conglomerate.

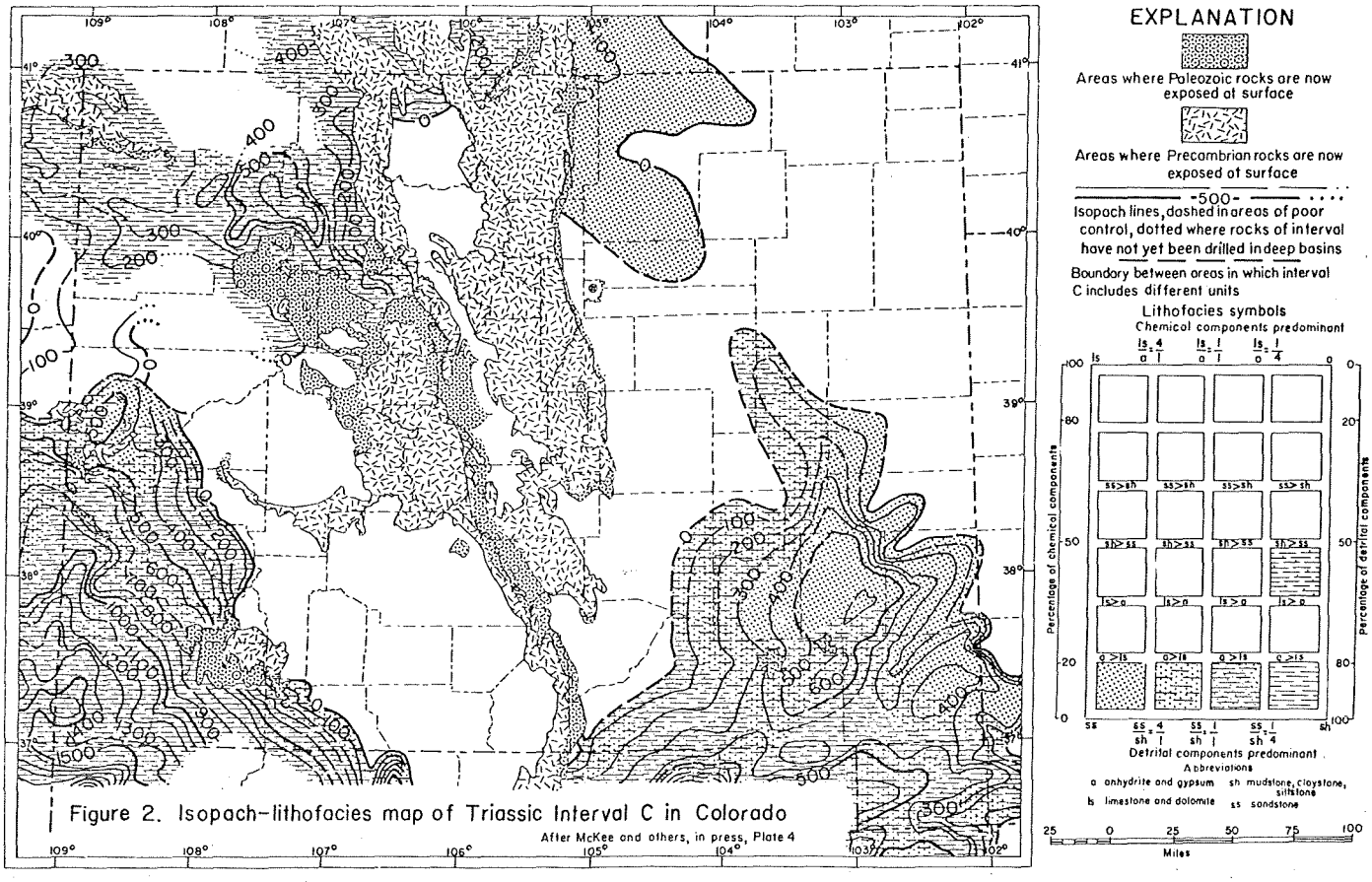

Figure 2. Isopach-lithofacies map of Triassic Interval C in Colorado
After McKee and others, in press, Plate 4

Because the Shinarump member of the Chinle formation is now known to be of far more limited extent than formerly believed (Stewart and others, 1959, p. 505-506, fig. 74), the name is not applied by the present writers to rocks in northwestern Colorado. The name Gartra grit seems more suitable. Whether the names Gartra and Stanaker should be given member or formation status may best be determined by geologists working in the region. The status of the name Ankareh in northwestern Colorado is not yet settled.

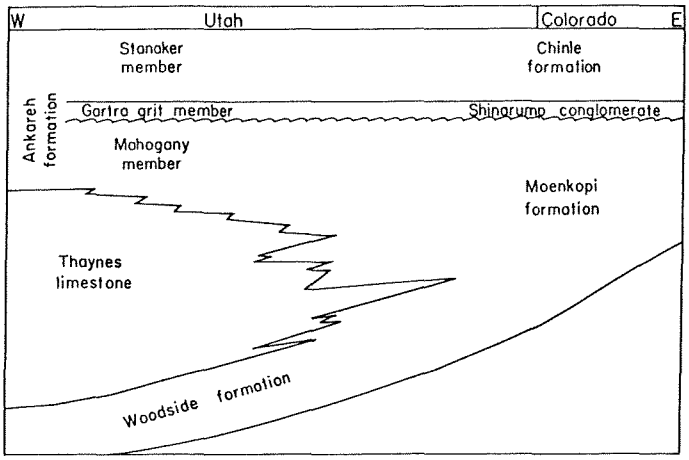

Figure 3. Triassic stratigraphic nomenclature used by Kummel in northeastern Utah and northwestern Colorado (1954, p. 178).

CHINLE FORMATION

The Chinle formation, named by Gregory (1916) for exposures in Chinle Valley, northeastern Arizona, is present in much of western Colorado and consists mainly of red siltstone and sandstone but includes variegated claystone, mudstone, conglomerate, and minor amounts of limestone and limestone-pebble conglomerate. In southwestern Colorado, the formation passes eastward into the Dolores formation; in northwestern Colorado, it grades westward into rocks which in Utah are assigned to the Ankareh formation. The Chinle formation probably was deposited in fluvial and lacustrine environments during Late Triassic time (Reeside and others, 1957) and, in Utah and Arizona, it includes large amounts of volcanic debris.

Recently named subdivisions or members of the Chinle formation in southeastern Utah are discussed by Stewart and others (1959, p. 500-523, 543-551). Some of these members have been traced into southwestern Colorado. They are, in descending order, as follows: the Church Rock member, mainly red siltstone; the Owl Rock member, alternating limestone and red siltstone; the Petrified Forest member, mainly variegated bentonitic claystone; the Moss Back member, sandstone; the Monitor Butte member, green and red bentonitic claystone; the Shinarump member, sandstone; and the Temple Mountain member, mottled purple and white siltstone.

In Colorado, only the Church Rock and Moss Back members are present. The intervening members, the Owl Rock and Petrified Forest, pass laterally into beds included in the Church Rock member near the Colorado-Utah boundary; the lower members are absent.

Members of the Chinle formation reported in Colorado are as follows, from top down:

Church Rock member.—The uppermost or Church Rock member is composed of pale reddish brown and light-brown, very fine-grained, sandy siltstone in massive, structureless and thin- to thick-bedded, locally ripple-laminated strata, with some pale-red to greenish-gray, very fine-grained sandstone. The unit makes up the bulk of the Chinle formation in western Colorado (R. F. Wilson, oral communication, 1959).

Moss Back member.—The Moss Back member (Stewart, 1957, p. 453) forms the base of the Chinle formation in part of southwestern Colorado and is composed of yellowish-gray and very pale orange, fine- to medium-grained sandstone with many lenses of pebble conglomerate and conglomeratic sandstone. Pebbles may include either light-brown or gray siltstone and limestone or vitreous quartz, quartzite, and chert. Although the Moss Back member has been assigned to the Shinarump conglomerate in many reports, the two are distinguishable (Stewart and others, 1959, p. 512).

Shinarump member.—The name Shinarump, previously applied in much of western Colorado to conglomerate beds at many stratigraphic horizons, is now restricted (Stewart, 1957, p. 449-452) to strata correlative with the type Shinarump in southwestern Utah. These strata are absent in Colorado. The member consists of yellowish-gray and pale yellowish orange medium- to coarse-grained sandstone composed of clear subangular quartz. Lenses of conglomeratic sandstone and conglomerate with granules and pebbles predominantly of quartz, quartzite, and chert are common.

Subdivisions of the Chinle formation recognized in northeastern Utah and northwestern Colorado (Poole, 1958) are as follows:

(6) upper orange, brown, and gray sandstone; red and green mudstone.

(5) red siltstone with subordinate sandstone and siltstone-limestone pebble conglomerate.

(4) red, brown, and gray sandstone, mudstone, and mudstone-limestone pebble conglomerate.

(3) ocher and lavender mudstone, correlative with beds of the Popo Agie member of the Chugwater formation in Wyoming.

(2) purple and red mudstone, mottled siltstone, and sandstone.

(1) basal sandstone and conglomerate, assigned by many geologists to the Shinarump conglomerate but more properly called the Gartra grit of Thomas and Kreuger (1946).

Units 6 and 4 are absent in northwestern Colorado.

DOCKUM GROUP

The Dockum group, named by Cummins (1890, p. 189) for exposures near Dockum, Dickens County, Texas, consists in southeastern and central-southern Colorado of red mudstone, red to white sandstone, conglomerate, and limestone (Oriel and Mudge, 1956, p. 20).

The group was subdivided in Union County, New Mexico, by Parker (1933) into three formations, in descending order:

Sheep Pen sandstone.—The Sheep Pen sandstone does not extend into Colorado.

Sloan Canyon formation.—The Sloan Canyon formation consists mainly of red, purple, and orange mudstone with some green and gray mudstone, but includes pink to white, fine- to very fine-grained sandstone, subaphanitic to sandy limestone, finely crystalline dolomite, and a few limestone-pebble conglomerate lenses.

Unnamed formation.—The basal unit of the Dockum group, unnamed by Parker, consists almost entirely of orange, pink, gray, and red sandstone but includes conglomerate, limestone and interbedded red and maroon claystone and siltstone.

DOLORES FORMATION

Some red detrital rocks exposed near the San Juan Mountains in southwestern Colorado were named the Dolores formation by Cross (1899) from exposures along the Dolores River. The arkosic part of the underlying Cutler formation, though originally included in the Dolores, was subsequently removed with the definition of the Cutler formation (Cross and Howe, 1905).

The Dolores formation consists dominantly of various shades of red siltstone but locally includes quartzose sandstone and conglomerate with granite, schist, gneiss, and quartzite pebbles derived from the nearby ancestral Uncompahgre highland, and with limestone and claystone pellets. Late Triassic fossils in the formation, lateral tracing of beds, and the presence of rock units comparable to those in the Chinle formation of southeastern Utah indicate (Stewart, 1956, p. 91) the Dolores is equivalent to the upper part of the Chinle formation.

JELM FORMATION

Triassic Interval C is represented in central-northern Colorado by sandstone assigned (Lee, 1927, p. 14-15; Heaton, 1939) to the Jelm formation. The Jelm sandstone, named by Knight (1916, p. 120) for exposures at Jelm Mountain in the Laramie quadrangle, Wyo., consists, at the type locality, of irregularly interbedded red to brown mudstone, claystone, and siltstone, with some green and gray units. It also includes gray to red sandstone and gray conglomeratic sandstone. The unit grades eastward into highly cross-bedded sandstone with a basal conglomeratic unit. Cross-bedded sandstone, part of which was questionably assigned to the Nugget sandstone, has been named the Troublesome Creek member of the Jelm formation by Hubbell (1956, p. 2744-2745). Rocks assigned to the formation in Colorado consist of orange, fine- to medium-grained, locally cross-bedded sandstone that contains some thin beds of conglomerate and red siltstone.

WINGATE SANDSTONE

The Wingate sandstone is the uppermost unit assigned to Triassic Interval C in southwestern and central-western Colorado. The formation was named by Dutton (1885, p. 136) for exposures near Fort Wingate in New Mexico. Although subsequent work (Baker, Dane, and Reeside, 1947) has shown that the type exposures are mainly correlative with the Entrada sandstone, the name Wingate has been retained for only the thin basal unit at the type locality (Harshbarger, Repenning, and Irwin, 1957, p. 8). In southeastern Utah it is applied to the sandstone unit that forms the base of the Glen Canyon group.

The Wingate sandstone consists of very pale orange and light-brown, cross-bedded, fine-to very fine-grained sandstone with dominantly rounded to well-rounded quartz grains. The Wingate sandstone intertongues with and grades into the overlying Kayenta formation. The unit is inferred to be of eolian origin.

JURASSIC INTERVAL A

Interval A is the lowest of four subdivisions of the Jurassic system. Stratigraphic units assigned to Interval A of the Jurassic system are in large part of Early Jurassic age, correlative with the Lias of Europe. Difficulty in recognizing the Triassic-Jurassic systemic boundary, however, makes it probable that at least some rocks of Triassic age (table 1) are included in this interval.

Rocks of Jurassic Interval A are present in westernmost Colorado and adjoining States. They attain a thickness of slightly more than 800 feet along the Uinta Mountains in northwestern Colorado (fig. 4). The rocks are part of a westward-thickening wedge that is more than 3,000 feet thick in western Utah. The rocks were deposited predominantly as wind-blown sand but also in part as alluvial mud and sand.

Stratigraphic units included in Jurassic Interval A are as follows:

GLEN CANYON GROUP

The Glen Canyon group (Wilmarth, 1938, p. 826; Gilluly and Reeside, 1928, p. 68) in Colorado includes, in descending order, the Navajo sandstone, the Kayenta formation, and the Wingate sandstone. The Wingate sandstone is discussed above. The three formations are widespread and easily recognized in southeastern Utah and southwestern Colorado. They have not been recognized, however, along the east side of the Uinta basin (central-western Colorado). Some geologists (Stokes and Holmes, 1954, p. 36; Holmes, 1956, p. 36) interpret the Wingate sandstone and Kayenta formation as pinching out northward and the type Navajo and type Nugget as direct equivalents (Baker, Dane and Reeside, 1936, p. 3). However, the rocks of the Glen Canyon group have also been interpreted (MacLachlan, 1957, p. 84, 89; McKee and others, in press) as grading northward in the Uinta basin into interbedded sandstone and mudstone not now divided into formations; moreover, these rocks grade still farther northward into sandstone in the Uinta Mountains assigned to the Navajo or Nugget sandstone. The latter interpretation is adopted here.

In parts of northwestern Colorado, where the Glen Canyon group cannot be divided into its three formations, all the rocks are assigned to Jurassic Interval A, although at least some are of Triassic age.

KAYENTA FORMATION

The Kayenta formation, named for a community in northern Arizona (Baker, Dane, and McKnight, 1931), is recognized in parts of southwestern and central-western Colorado, and its equivalents are believed to extend northward into northwestern Colorado (see above). The formation consists of purplish-weathering, pale-red and pale-orange sandstone and siltstone with subordinate mudstone and limestone of continental, subaqueous origin.

Although the age of the formation is in dispute (Harshbarger, Repenning, and Irwin, 1957, p. 19; McKee and others, 1956, in press) it is here assigned to Jurassic Interval A.

NAVAJO SANDSTONE

The uppermost formation of the Glen Canyon group in southwestern and central-western Colorado is the Navajo sandstone, named by Gregory (1917, p. 57-59) for exposures in the Navajo country of northeastern Arizona. The Navajo forms prominent cliffs of sweepingly cross-bedded, pale-orange to pale reddish brown, fine- to medium-grained sandstone, considered largely of eolian origin (Harshbarger, Repenning, and Irwin, 1957, p. 19-22).

The name Navajo has also been applied to cross-bedded rocks composed of dominantly eolian fine- to medium-grained sandstone (Kinney, 1955, p. 73-76) prominently exposed along the flanks of the Uinta Mountains in northeastern Utah and northwestern Colorado. These rocks are also assigned to, and believed to be correlative with, the Nugget sandstone (Baker, Dane, and Reeside, 1936, p. 5; Anderman, 1956, p. 58-59). If the rocks are indeed equivalent to all the Glen Canyon group, rather than just the upper part (McKee and others, in press), then perhaps Nugget is the more suitable name. Anderman (1956, p. 58), however, suggests that the two names have different lithologic and perhaps genetic connotations.

Despite the absence of diagnostic fossils, the formation is assigned an Early Jurassic age (Imlay, 1952).

NUGGET SANDSTONE

The name Nugget sandstone, proposed by Veatch (1907, p. 56) for rocks exposed close to Nugget station in southwestern Wyoming, has been applied to sandstone which ranges from red to gray, white, and buff, from highly cross bedded to very even bedded, from dominantly fine- to medium-grained, and which contains local beds, lenses, and tongues of red mudstone. The name has been applied correctly to rocks in central to southwestern Wyoming, northeastern Utah, and northwestern Colorado, and incorrectly, according to Hubbell (1956), to sandstone beds in southeastern Wyoming and central-northern Colorado.

Although the formation has not yielded reliable, diagnostic fossils, it has long been considered of Early Jurassic age (Imlay, 1952). Evidence presented by Hubbell [3] that

[3] Hubbell, R. G., 1954, Stratigraphy of the Jelm, Nugget, and Sundance formations of northern Carbon County, Wyo.: Univ. Wyoming unpubl. M.A. Thesis.

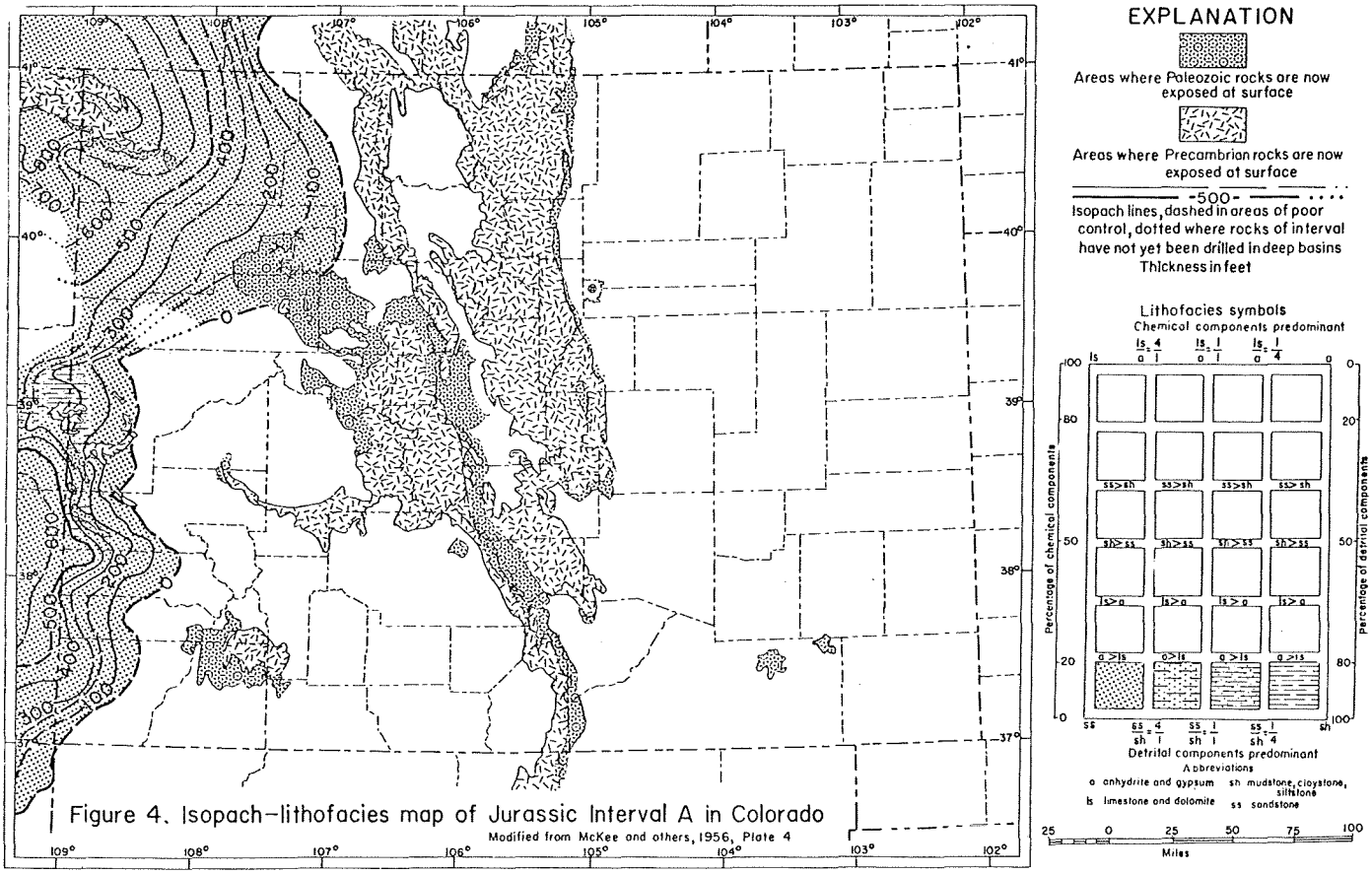

Figure 4. Isopach–lithofacies map of Jurassic Interval A in Colorado
Modified from McKee and others, 1956, Plate 4

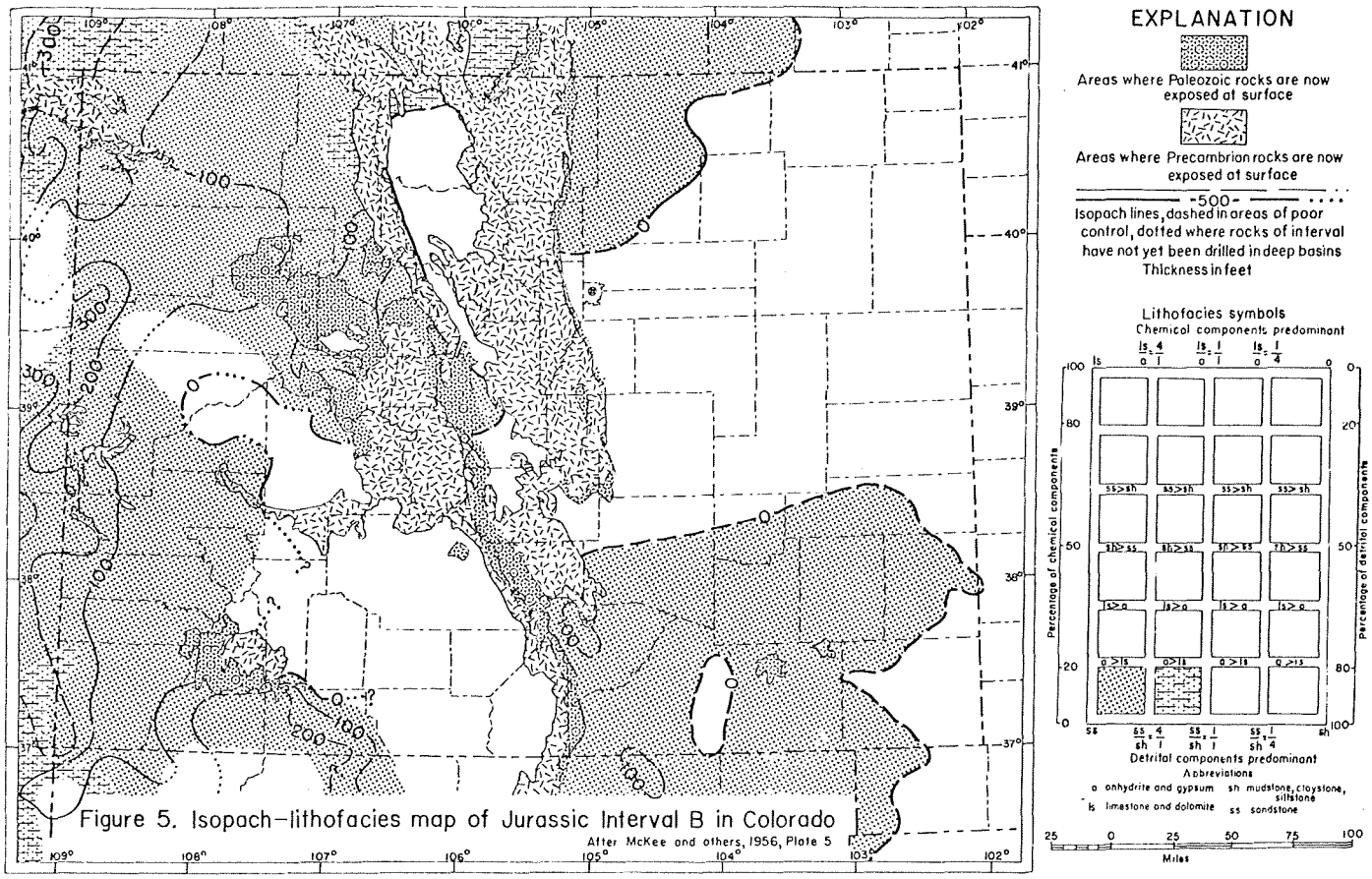

Figure 5. Isopach–lithofacies map of Jurassic Interval B in Colorado
After McKee and others, 1956, Plate 5

at least the lower part of the unit grades eastward into the Popo Agie member of the Chugwater formation has led to its assignment by some geologists to the Triassic system (Gudim, 1956, p. 72; Love, 1957, p. 43-44). The lateral equivalence of the Nugget sandstone with most of the Glen Canyon group, on the other hand, is cited as evidence that the Triassic-Jurassic systemic boundary lies within the formation (McKee and others, in press). Although it probably contains some rocks of Triassic age, it is here included in Jurassic Interval A.

JURASSIC INTERVAL B

Jurassic Interval B contains rocks of Middle and early Late Jurassic age correlative with the Bajocian, Bathonian, and Callovian stages of Europe.

Rocks assigned to Interval B of the Jurassic system are more extensive than those of Interval A. The area of distribution is similar to that of Triassic Interval C. Rocks of Jurassic Interval B are absent in most of central, central-eastern, and northeastern Colorado (fig. 5).

The rocks are less than 200 feet thick over most of Colorado, but they thicken in the western part of the State to more than 300 feet and form part of a westward-thickening wedge which is as much as 5,000 feet thick in north-central Utah. In Colorado the rocks consist almost entirely of sandstone, although some mudstone is present at the base of the sequence along the western edge of the State.

Rocks of Interval B in Colorado probably were deposited as dunes and in alluvial plains which sloped northward and westward toward marine embayments in Wyoming and Utah. Whether marine incursions entered Colorado much beyond the northwesternmost corner is not established. The ancestral Rocky Mountains and ancestral Uncompahgre highland were both exposed to erosion during deposition, but they contributed only a small volume of detritus, very little of which was coarse grained (Holmes, 1956, p. 34, 37).

CARMEL FORMATION

The Carmel formation was named for Mount Carmel in central-southern Utah (Gregory and Moore, 1931, p. 69). In Colorado this formation consists dominantly of red sandy mudstone, claystone, and siltstone, and fine-grained sandstone. The formation is present in northwesternmost Colorado, but thins to a wedge-edge eastward and southeastward (Wright and Dickey, 1958, p. 175, fig. 3). Strata in southwestern Colorado formerly assigned to the Carmel formation (Cater, 1955; Craig and Dickey, 1956, p. 96) are now placed in the red, earthy siltstone member of the Entrada formation (Wright and Dickey, 1958, p. 177).

ENTRADA SANDSTONE

The Entrada sandstone was named for exposures of evenly bedded, red, earthy siltstone and interstratified crossbedded buff sandstone in the northern part of the San Rafael Swell, Utah (Gilluly and Reeside, 1928, p. 76). It makes up the preponderant part of Interval B in Colorado where it has been traced almost continuously (Baker, Dane, and Reeside, 1947; Heaton, 1939) and is composed almost entirely of buff to pink and gray, massive

to cross-bedded, well-sorted, fine- to medium-grained, quartzose sandstone that contains some frosted, coarse grains.

In southwestern Colorado, the formation is divided (Wright and Dickey, 1958, p. 174) into a lower, red, earthy siltstone member and an upper sandstone member. These members are also recognized in northeastern Arizona (Harshbarger, Repenning, and Irwin, 1957, p. 35).

EXETER SANDSTONE

The Exeter sandstone was named by Lee (1902, p. 45-46) for exposures in Union County, New Mexico, consisting of red to white, well to poorly indurated, massive, cross-bedded and well-laminated, partly shaly sandstone. The name has been used in northeastern New Mexico, southeastern Colorado, and westernmost Oklahoma (Wilmarth, 1938, p. 712), although many geologists (McLaughlin, 1954, p. 88; Oriel and Mudge, 1956, p. 21) apply the name Entrada to the unit in these areas. Although Exeter has priority, Entrada is more widely used and is accepted for use in southeastern Colorado by the U. S. Geological Survey (Johnson, in press). The name Exeter sandstone has been abandoned for use in southeastern Colorado by the U. S. Geological Survey.

OCATE SANDSTONE

The name Ocate sandstone was proposed by Bachman (1953) for gray, medium-bedded to massive, partly cross-laminated sandstone in Mora County, New Mexico. The rocks are regarded as correlative with the Entrada sandstone of western New Mexico. The name was extended into central-southern Colorado (Johnson and Stephens, 1954), but later Johnson (in press) proposed that the name Ocate sandstone be abandoned in southeastern Colorado and northeastern New Mexico, and the name Entrada sandstone be used throughout this area. The name Ocate sandstone has been abandoned for use by the U. S. Geological Survey.

SUNDANCE FORMATION

The Sundance formation, named by Darton (1899) for green mudstone and buff to pink sandstone in the Black Hills region, is recognized throughout southeastern Wyoming (Pipiringos, 1953; Peterson, 1954; Berg, 1956) and in central-northern Colorado.

The formation has been subdivided in the type area by Imlay (1947) into five widely traced members. They are, from top to bottom, the Redwater shale member, the Lak member, the Hulett sandstone member, the Stockade Beaver shale member, and the Canyon Springs sandstone member.

Pipiringos (1953; 1957) recognized two additional members, one above and one below the Redwater shale member, in the Laramie basin in Wyoming. The Redwater shale member is assigned to the upper part of the Sundance formation which is of Oxfordian age, whereas all the underlying members are assigned to the lower part of the formation which is of Callovian age. The equivalents of the Redwater shale and Lak members only have been recognized in Colorado.

JURASSIC INTERVAL C

Rocks assigned to Interval C of the Jurassic system are those of middle Late Jurassic or Oxfordian age. As shown on figure 6, they are present in most of Colorado but are absent locally in the west-central, north-central, and southeasternmost parts of the State.

Strata of Jurassic Interval C are thickest in southwestern Colorado where they exceed 400 feet. However, they are about 100 feet thick throughout most parts of the State. The lithofacies are more diverse than those of any other lower Mesozoic interval; the rocks range from dominantly sandstone to dominantly mudstone, from beds composed almost entirely of detrital components to those with abundant limestone, gypsum, or anhydrite.

During the deposition of Interval C, Colorado was covered by marine embayments extending from the north and from the northwest, as indicated by marine beds of the Curtis and Sundance formations. South and southeast of the embayments were extensive, relatively stable, shallow lagoons in which evaporites were deposited. The ancestral Rocky Mountains and the ancestral Uncompahgre highland were still positive and furnished some detritus; the Wet Mountain uplift area was especially active and furnished arkosic sand and gravel to the Canon City area. But coarse detritus was dominant only close to source areas; it graded within short distances into muds and evaporites in the lagoonal areas. Toward the southwest, eolian-type sands like those in the Navajo sandstone were again deposited.

Stratigraphic units included in Jurassic Interval C are as follows:

CURTIS FORMATION

The Curtis formation was named (Gilluly and Reeside, 1928, p. 78) for green-gray mudstone and conglomerate and gray sandstone on the northeastern side of the San Rafael Swell in Utah. In both northwestern Colorado and northeastern Utah the formation grades southeastward into rocks assigned to the Summerville formation (Baker, Dane, and Reeside, 1936, p. 8).

The Curtis formation has been divided into two members along the eastern end of the Uinta Mountains (Kinney, 1955, p. 85). The lower member consists of thin-bedded, partly cross-bedded, glauconitic, greenish-gray, medium- to coarse-grained sandstone. The upper member is mainly glauconitic, greenish-gray mudstone with thin intercalations of fine-grained, calcareous sandstone and sandy, partly oolitic limestone.

The basal sandstone is distinguished from the underlying Entrada sandstone by an abundance of glauconite, the evenness of parallel bedding, and by the presence of marine invertebrate fossils (Bradley, 1955, p. 23).

JUNCTION CREEK SANDSTONE

The Junction Creek sandstone in Colorado (Goldman and Spencer, 1941, p. 1750-51) is considered to be the same unit as that termed the Bluff sandstone in Utah, Arizona, and New Mexico (Craig and Cadigan, 1958, p. 182). The formation consists mainly of well-sorted, cal-

careous, fine- to very fine-grained sandstone containing disseminated, well-rounded, medium to coarse grains of quartz.

The Junction Creek sandstone is present in southwestern Colorado where it attains a maximum thickness of more than 400 feet. Where best exposed, the formation has been divided by Cadigan [4] into four informal members.

The Junction Creek sandstone is here included in Interval C because in many places the basal beds grade laterally into the Summerville formation. However, the upper part of the unit may be as young as Kimeridgian because it intertongues locally with basal beds of the Morrison formation (Eckel, 1949, p. 30).

MIDDLE UNIT OF JURASSIC AGE

Between the Entrada sandstone and the Morrison formation in eastern Colorado lies a sequence of very evenly bedded, detrital and evaporitic rocks informally designated as the middle unit of Jurassic age (Oriel and Mudge, 1956, p. 22). These rocks are included in the lower part of the Morrison formation of most previous reports and correspond in western Kansas to the lower unit of the Morrison formation of Merriam (1955, p. 32).

The middle unit of Jurassic age includes several distinctive facies. Evaporites, including gypsum, anhydrite, and limestone, compose much of the unit within the Denver basin and southward to New Mexico, but mudstones of various pastel colors are also present. Arkosic conglomerate is dominant at Canon City but the unit contains relatively greater amounts of gypsum eastward (DeFord, 1929, p. 77-79). Mudstone and marlstone are the dominant lithology northward along the Front Range where the names Ralston and Ralston Creek formation have been applied. Dominantly red mudstone, sandstone, and some conglomerate compose the unit (McLaughlin, 1954, p. 214) in southeasternmost Colorado and western Oklahoma.

Recognition of these facies relations is aided by the presence, within a thin stratigraphic interval, of several nodular, red to orange chalcedonic beds (Oriel and Mudge, 1956, p. 22), the upper limit of which is considered the top of the unit. The chalcedonic beds, first described by Lee (1902, p. 44), are widely distributed (McKee and others, 1956) and have been found from Mora County, New Mexico (Bachman, 1953), to southern Wyoming (Pipiringos, 1953, p. 38), and from western Kansas (Merriam, 1955, p. 32) to northwestern Colorado (Ogden, 1954, p. 915) and central Utah (Stokes and Holmes, 1954, p. 38).

The chalcedonic beds and underlying strata are assigned an Oxfordian age because the chalcedonic beds are present near the top of the Sundance formation in Wyoming, near the top of the Curtis formation in northwestern Colorado, and near the top of the Summerville formation in central Utah (Stokes and Holmes, 1954, p. 38), and because strata below the chalcedony are similar

[4] Cadigan, R. A., 1952, The correlation of the Jurassic Bluff and Junction Creek sandstones in southeastern Utah and southwestern Colorado: Pennsylvania State College, unpubl. M.S. Thesis, 163 p.

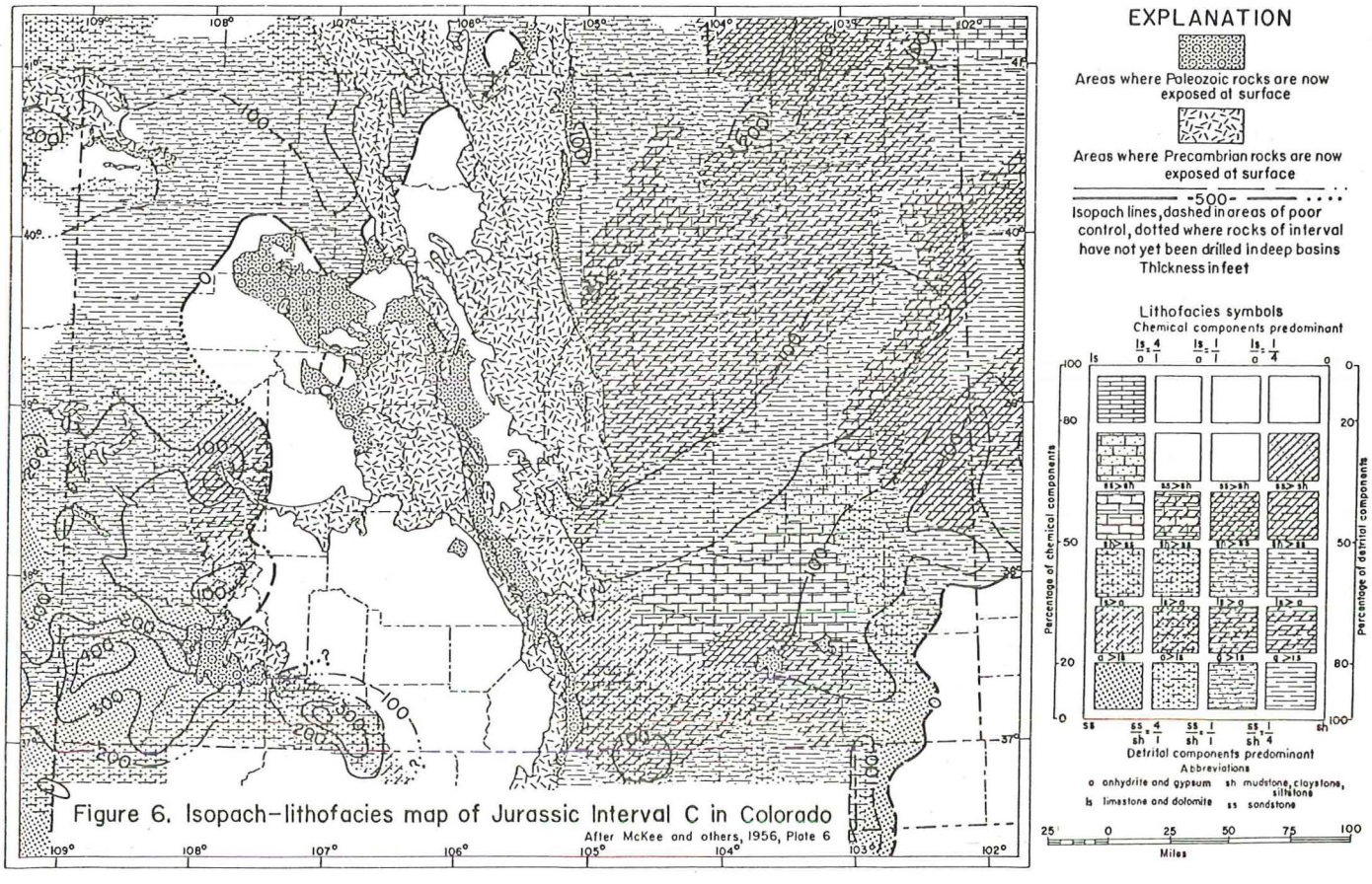

Figure 6. Isopach–lithofacies map of Jurassic Interval C in Colorado
After McKee and others, 1956, Plate 6

in lithology and stratigraphic position to the Wanakah and Sundance formations.

MORRISON FORMATION, LOWER UNIT

Strata formerly assigned to the lower part of the Morrison formation in eastern Colorado and western Kansas are described in the discussion of the middle unit of Jurassic age (see above).

RALSTON CREEK FORMATION

The name Ralston Creek formation (Van Horn, 1957) is used instead of the Ralston formation, which was named and defined by LeRoy (1946, p. 47). The formation is recognized in central-northern, central, and south-central Colorado. At its type section, a few miles northwest of Denver, the formation consists of pale-red, orange, green, light-gray, and dusky-red mudstone, light-gray, pale-red, and orange limestone, gray to pink, calcareous siltstone, and fine- to medium-grained sandstone. The formation also contains layers and nodules of light-gray, red, and orange chalcedony.

Two distinct facies of the Ralston Creek formation were recognized by LeRoy (1946, p. 47): a shale-marlstone facies and a gypsum facies. Two other facies, a dominantly arkosic conglomerate facies and a sandstone facies, were recognized in the Canon City area by DeFord (1929, p. 77-79) and described in greater detail by Fredrickson, De Lay, and Saylor (1956, p. 2133).

The top of the formation has been placed at various stratigraphic horizons (Fredrickson, De Lay, and Saylor, 1956, p. 2132). It is placed by the present writers at the top of the uppermost chalcedony bed for reasons cited above.

SUMMERVILLE FORMATION

The Summerville formation, named for exposures in the northeastern part of the San Rafael Swell, Utah, is composed of thin-bedded, chocolate-brown siltstone, earthy red-brown sandstone and mudstone, and a little gypsum (Gilluly and Reeside, 1928, p. 79-80). The formation is widespread in southeastern Utah, southwestern and central-western Colorado, and adjacent parts of Arizona and New Mexico. In Colorado it consists mainly of reddish-brown, thin, evenly bedded mudstone and claystone, with light-colored platy to slabby, fine-grained sandstone. The Summerville formation grades northward into the Curtis formation and southeastward into rocks assigned to the Wanakah formation. Additional facies relations outside of Colorado are discussed by Craig and Dickey (1956, p. 99).

SUNDANCE FORMATION, UPPER PART

Only the upper part of the Sundance formation (discussed above) in central-northern Colorado is assigned to Jurassic Interval C. These rocks are equivalent to those included in the Redwater shale member by Imlay (1947, p. 259-263) and in the Redwater shale and overlying unnamed *A* member of Pipiringos (1953, p. 34) in Wyoming.

The Wanakah formation was named by Burbank (1930, p. 172) for exposures in the Ouray district in southwestern Colorado. The three lithologic units recognized by Burbank have subsequently been assigned member status. The three members now recognized in parts of southwestern Colorado (Eckel, 1949, p. 28-29) are in descending order.

Upper marlstone member. — The upper, unnamed member is lithologically similar to strata in the Summerville formation. In consists of evenly bedded, pinkish-red to greenish-gray mudstone, marlstone, and lenticular sandstone beds.

Bilk Creek sandstone member.—The middle member consists of poorly indurated, mainly even- but locally nodular-bedded, fine- to very fine-grained but locally coarse-grained sandstone with grains of red chert.

Pony Express limestone member.—The basal member, which is thin, consists of massive to thinly laminated, gray, dark-blue, or black, subaphanitic, sandy, oolitic limestone.

The name Wanakah has been used extensively for strata that have also been assigned to the Summerville formation in northwestern and northeastern New Mexico and in southeastern Colorado. The limestone member in New Mexico was called the Todilto limestone member (Baker, Dane, and Reeside, 1947, p. 1668). The name is assigned formational status by many geologists (Harshbarger, Repenning, and Irwin, 1957, p. 38), and is called the Todilto limestone by the U. S. Geological Survey.

JURASSIC INTERVAL D

Rocks assigned to Interval D of the Jurassic system are those of late Late Jurassic or Kimeridgian and Portlandian age. Because of difficulties in the recognition of the top of the Jurassic system, they may also include locally rocks of Cretaceous age. In Colorado the interval is represented only by the Morrison formation.

Jurassic Interval D is the most widespread of the lower Mesozoic intervals and covers virtually all of Colorado except the southeasternmost corner (fig. 7) where it is believed to have been removed by erosion. The interval is thickest in western Colorado where it exceeds 800 feet, but it has a relatively uniform thickness through most of the State, ranging from 200 to 400 feet. The rocks are mainly varicolored mudstone, but in some places they include a large proportion of sandstone as well as beds of limestone and conglomerate.

Sediments deposited in Colorado during latest Jurassic time were entirely of continental origin. They apparently were deposited in aggrading streams and lakes on a relatively featureless surface. Major source areas lay to the south in west-central New Mexico, to the southwest in Arizona and California, and to the west in western Utah or eastern Nevada. Coarseness of detritus suggests uplifts in these source areas, although some detritus was also derived locally from the east and southeast. Positive areas that had been active earlier in central Colorado were now largely buried. The abundance of tuff and ash indicates regional volcanism, particularly toward the end of Jurassic deposition. A moderately warm and wet climate is inferred for most of the State.

MORRISON FORMATION

The Morrison formation was named by Eldridge (1896, p. 60-61) for the town of Morrison west of Denver, though it was described earlier by Cross (1894, p. 2). The name was applied to about 200 feet of strata, the lower two-thirds of which is green, drab, or gray marlstone with numerous lenses of limestone and beds of mudstone and sandstone, and the upper third is variegated mudstone and sandstone.

The formation is widespread in the Western Interior of the United States (Mook, 1916; Stokes, 1944; Imlay, 1952). Its age has long been a subject of controversy (Simpson, 1926). Recognition of a consistent top for the formation and its relation to the top of the Jurassic system continue to be major problems (Waagé, 1955, p. 23-25; McKee and others, 1956). Much of the difficulty in understanding the formation is attributable to its heterogeneity.

The Morrison formation has not been differentiated into members through most of Colorado (table 1). However, in part of northwestern and all of central-western and southwestern Colorado, the formation can be divided into the Brushy Basin and Salt Wash members (Craig and others, 1955). In the southwesternmost part of the State, known as the Four Corners region, the formation is divided into 4 members (Harshbarger, Repenning, and Irwin, 1957, p. 51-57; Craig and others, 1955), in descending order:

Brushy Basin member.—The Brushy Basin member is composed mainly of red, purple, gray, greenish-gray, and pink bentonitic claystone and siltstone containing varying amounts of sand grains. Lenses of conglomeratic sandstone are common; thin beds of limestone are sparse.

Westwater Canyon member.—The Westwater Canyon member consists of interstratified, yellowish-gray and orange or light-brown, fine- to coarse-grained sandstone with stringers and lenses of pebbles, light greenish-gray to pale-red or grayish-red siltstone and claystone. The general coarseness of texture and dominance of yellowish gray and greenish gray distinguish the unit from adjacent members.

Recapture member.—The Recapture member consists of interstratified sandstone, siltstone, and claystone. The sandstone is mainly friable, lenticular and cross laminated, pinkish gray to light brown, moderately to well sorted, fine- to medium-grained, and locally contains granules and pebbles. The siltstone and claystone are lenticularly bedded, pale red, grayish red, and dusky red, and contain variable amounts of silt and sand.

Salt Wash member.—The Salt Wash, or basal member, consists mainly of sandstone and siltstone. The sandstone is cross laminated, lenticular, irregularly bedded, grayish yellow or pale orange, fine- to medium-grained, with stringers of granules, pebbles, and green clay fragments. The siltstone is gently to sharply lenticular, pale reddish brown, grayish red, and greenish gray, with thin beds of pale-red to light-gray, fine-grained, clayey sandstone, beds of claystone, and nodular zones or platy beds of gray limestone.

The Brushy Basin and Salt Wash members are recognized in most of western Colorado, whereas the Westwater Canyon and Recapture members are present in only the southwesternmost part of the State. The top of the

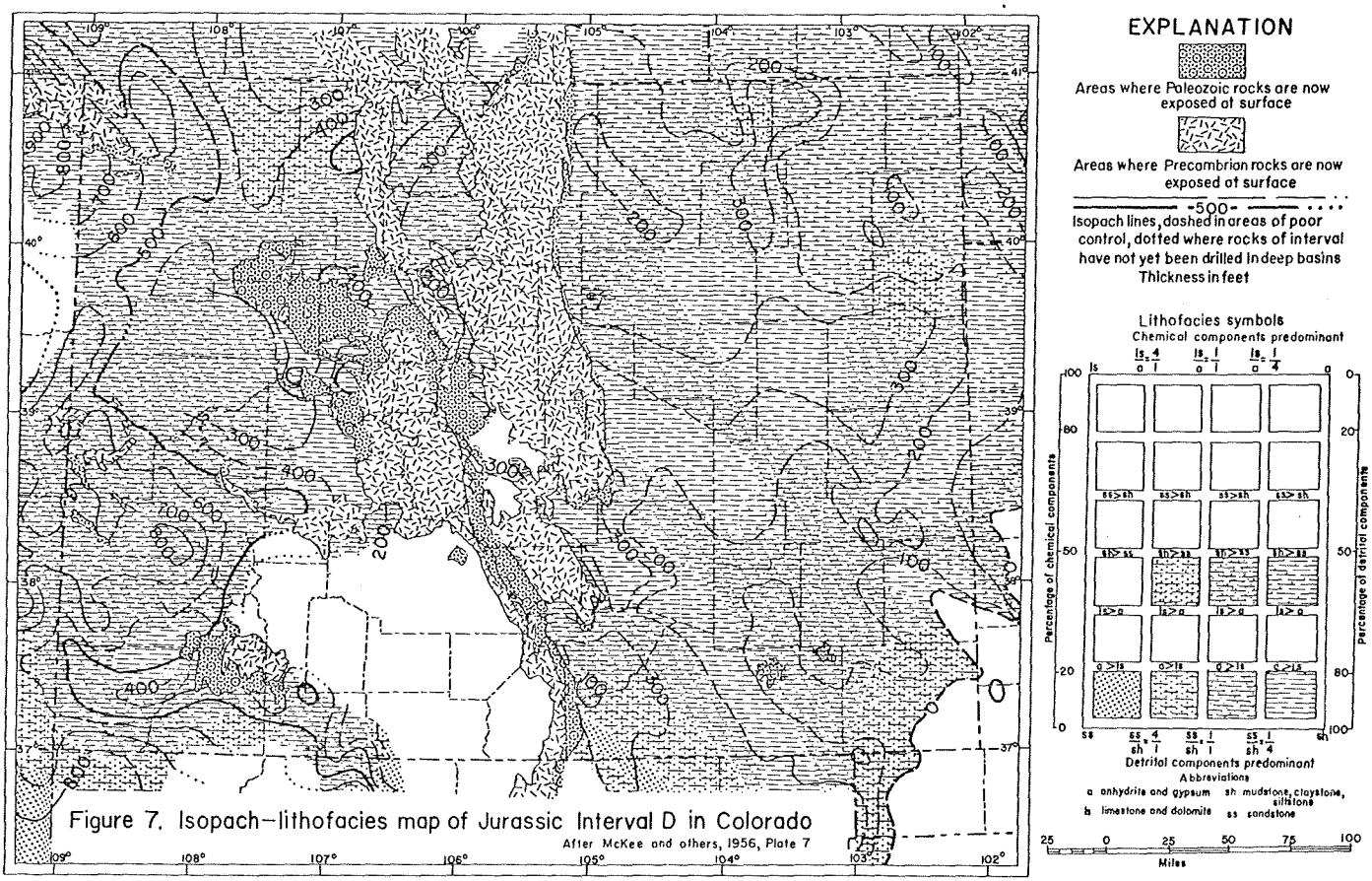

Figure 7. Isopach–lithofacies map of Jurassic Interval D in Colorado
After McKee and others, 1956, Plate 7

formation in most of western Colorado is placed at the base of conglomerate beds of the Burro Canyon formation (Peck, 1959, p. 119), but whether this represents the Jurassic-Cretaceous systemic boundary is not known (Craig and Dickey, 1956, p. 103).

The undivided Morrison formation of central and eastern Colorado is similar in composition to the Brushy Basin member, but probably all of the formation in western Colorado is represented in the generally thinner sections to the east.

SUMMARY

Tectonic elements dominant in Colorado during late Paleozoic time continued to influence sedimentation during the early Mesozoic. The ancestral Uncompahgre highland and the ancestral Rocky Mountains, though somewhat subdued in relief and modified in shape, continued to be the dominant positive elements.

During Early Triassic time the region was relatively quiescent tectonically and the highlands were reduced to low or moderate relief. Regularity of bedding, fineness of grain, and related features suggest tectonic stability and the prevalence of shallow, gently subsiding basins. Coarse detritus was shed locally by the ancestral Uncompahgre highland in the Salt Valley region. Late Triassic time, on the other hand, was characterized by tectonic instability and widely distributed, irregular orogenic pulses, as shown by irregularity of sedimentation and the many conglomerate beds and lenses. Rocks of Late Triassic age overlap those of Early Triassic age in many places. At the close of the period, a large basin was formed in the Four Corners region in which dune sands accumulated.

This basin in which the Glen Canyon group was deposited continued to be filled during Early Jurassic time. During Middle and early Late Jurassic time, sediments encroached upon the highlands from the west until the widespread Entrada sandstone was deposited over most of the State. Marine transgression from the northwest and north during middle Late Jurassic time resulted in the deposition of normal marine sediments as well as in the widespread precipitation of gypsum in lagoons and shallow basins of restricted circulation. The persistent tectonic barriers, as well as marine shoals, restricted the circulation of sea water. Local tectonic instability in Late Jurassic time is indicated by the coarse detritus supplied by the Wet Mountain uplift and the local deposition of gravel beds elsewhere in the State. The persistent positive elements, however, were almost entirely buried near the close of the Jurassic period when alluvial and lacustrine aggradation proceeded across a large, nearly featureless surface. Many conglomerate beds and the abundance of volcanic detritus are evidence of tectonism and volcanism in surrounding regions, principally to the west and south.

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CRETACEOUS STRATIGRAPHY OF COLORADO

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INTRODUCTION

Clastic sediments dominate the Cretaceous strata of Colorado, and in the northwestern part of the state they are more than 12,000 feet thick. Marine sedimentation was initiated in a seaway that transgressed across Colorado from north to south. The downward growth of the basin was accompanied by the deposition of clastics that were derived primarily from a westward source. An eastward source, however, supplied a large amount of coarse clastics during the Early Cretaceous. During a short period in Early Cretaceous and during most of Late Cretaceous the northern seaway joined the Gulf of Mexico. In slower pulses of basin subsidence, clastics completely filled portions of the seaway and nonmarine coal-bearing sediments were deposited. At these times the sea withdrew in an easterly or northerly direction, but embayments remained that extended far to the west and thereby created shoreline trends that are at wide variance with the regional north-south orientation of the seaway. During periods of maximum transgression of the sea to the south and west, limestones were deposited in the quiet waters of the eastern shelf. Cretaceous sedimentation ended with the initial pulses of the Laramide revolution.

The search for coal and petroleum in Cretaceous sediments has resulted in a mass of data that greatly facilitate our present understanding of Cretaceous stratigraphy. Much information on Cretaceous stratigraphy has been included in the *Symposium on Cretaceous Rocks of Colorado and Adjacent Areas* published in 1959 by the Rocky Mountain Association of Geologists. Cretaceous sediments have been preserved in structural basins (fig. 1) and have been eroded from the intervening positive elements. The problem of correlating between basins has required faunal study as well as regional isopachous and lithofacies work. Table 1 (primarily from the work of Cobban) presents Cretaceous zones used in the Western Interior and shows their relationship to European stages.

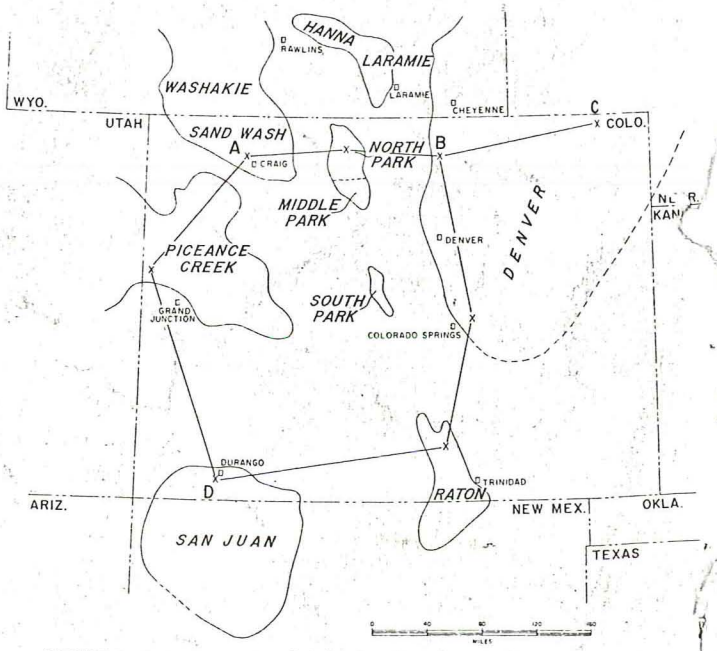

FIGURE 1. Index map showing basins that contain Cretaceous rocks. Lines of restored sections (figs. 5, 6 and 7) are shown.