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CORRELATION OF THE JURASSIC FORMATIONS OF PARTS OF UTAH, ARIZONA, NEW MEXICO AND COLORADO

BY

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By A. A. Baker, C. H. Dane, and J. B. Reeside, Jr.

ABSTRACT

This paper summarizes certain results obtained in recent field work in eastern Utah and adjacent parts of Arizona, New Mexico, and Colorado and revises the interpretations and correlations of the Jurassic formations of the area as they are affected by these results.

The name "Glen Canyon group" is applied to the lower part of the sequence, including the Wingate sandstone, the Kayenta formation, and the Navajo sandstone. The name "Kayenta" is used for the beds heretofore correlated doubtfully with the Todilto limestone of New Mexico. The Wingate sandstone and Kayenta formation form large lenses whose boundaries can be approximated, particularly on the northeast and southwest. The Navajo sandstone forms a great wedge with the thick part to the southwest in Nevada and the thin edge in western Colorado. It is not known to enter New Mexico. It is believed that the typical Nugget sandstone is equivalent to the Navajo sandstone. Questions as to the real relationship of the formations are raised by differences between the Navajo sandstone and the Wingate and Kayenta formations in distribution and lithologic character and by the nature of the lower boundary of the Wingate, but for convenience they are kept together as a group.

The name "San Rafael group" applies to the middle part of the sequence, including the Carmel formation, the Entrada sandstone, the Curtis formation, and the Summerville formation. All these formations continue northwestward beyond the area considered but are sharply limited on the south, scarcely entering Arizona and New Mexico. The Carmel and Summerville formations do not extend far eastward into Colorado. The Curtis formation is interpreted as represented in the area considered in this paper by several fairly well defined lobes extending southeastward, one of which enters northwestern Colorado and has been misidentified as Twin Creek formation in recent literature. The Entrada sandstone is interpreted as extending widely into Colorado, where it forms the lower part of the typical †La Plata sandstone[1] of Cross and the upper part of the so-called "Nugget" sandstone of northwestern Colorado.

The Morrison formation is interpreted as including, besides the more usual variegated mudstones (†McElmo formation of many authors), in New Mexico the Todilto limestone and beds heretofore called "Navajo" sandstone (†Zuni sandstone of Dutton) and in Colorado beds formerly assigned to the middle and upper † La Plata sandstone by Cross and others.

Ten series of columnar sections are presented and discussed to show in some detail the correlations offered in the paper, and a summary diagram assembling the sections into one picture is presented. Eight tables are shown to interpret the nomenclature of previous publications in terms of the nomenclature of this paper.

The distribution and thickness of the formations are shown by eight maps, which bring out similarities between the Wingate and Kayenta formations, between the Navajo and Carmel formations, and between the Entrada sandstone and the Curtis and Summerville formations. The Jurassic seas that entered the area came from the north.

The conditions of deposition of the Wingate are interpreted to be those of an arid region where in a central area the material was largely deposited by wind and in the marginal areas was both wind borne and water borne; the Kayenta consists wholly of stream-borne material; the Navajo sediments are dominantly those of a wind-swept desert, which received material from the far southwest; the San Rafael group comprises the deposits of an arid region into which the sea made two major incursions, neither of very long duration; and the Morrison deposits were laid down by streams and lakes on a flat plain, perhaps semiarid.

The age of the Glen Canyon group is accepted as Jurassic(?), with the suggestion that the Wingate and Kayenta formations may eventually prove to be Triassic and that the Navajo sandstone may prove to be unquestioned Jurassic. The San Rafael group is assigned to the Upper Jurassic—the Carmel formation to the basal part of the European standard section (Callovian) and the Curtis to the middle part (Argovian), on the basis of their marine fossils. The Morrison is assigned to the late Upper Jurassic, to a certain extent because of its intimate relations to the San Rafael group but chiefly because of the relationship of the vertebrate fauna to those of Jurassic formations in other parts of the world.

[1] A dagger (†) preceding a geologic name indicates that the name has been abandoned or rejected for use in classification in publications of the U. S. Geological Survey. Quotation marks, formerly used to indicate abandoned or rejected names, are now used only in the ordinary sense.

INTRODUCTION

Purpose of the report.—Since the early days of exploration of the Colorado Plateaus and the adjacent parts of the Southern Rocky Mountain province geologists have been keenly interested in certain cliff-forming sandstones and associated strata, in part known to be of Jurassic age and in part more or less arbitrarily assigned to the Jurassic. Comprehensive correlations of these formations have been offered, but as few individual students have had opportunity to see the whole or even the greater part of the region, and as units of somewhat similar lithology but different age have not always been discriminated, the correlations have diverged rather widely.

The present writers have had a share in a large amount of recent field work in southern and eastern Utah, northern Arizona, northwestern New Mexico, and western Colorado—a region where the Jurassic rocks are conspicuous and important members of the stratigraphic section. Inasmuch as it seems worth while to summarize the revision and adjustment of correlation required by the increased information available, the writers offer here a new interpretation of the Jurassic stratigraphy.

A discussion of the Permian rocks of the region has already appeared,[2] and it is hoped at a later date to deal with the Triassic beds.

Character of the region.—Extensive areas in the Colorado Plateaus are underlain by flat-lying or slightly inclined beds. Locally the strata are gently folded, and at a few places they are sharply folded and faulted. Several laccolithic mountain masses and many smaller plugs of igneous rock rise above the general level. On the border of the Rocky Mountains and in the mountain area itself the strata in their greater degree of folding and faulting reflect the more complicated history of the mountain area.

In the Colorado Plateaus the climate is arid to semi-arid, vegetation is scant, and streams have deeply dissected the surface. Deep canyons abound, and sheer-walled mesas and buttes expose much bare rock. Exposures are so nearly complete and continuous over long distances as to permit direct observation of the details of lateral variations. The barrenness and ruggedness of much of the region, however, make it difficult to traverse, for the population is scant and the roads few and poor. Many critical localities are in out-of-the-way places, and much time is consumed in reaching them. Along the mountain border and in the mountains the climate is more humid, vegetation is much more abundant, and the exposures are therefore somewhat less favorable for study.

Field work.—The data used in preparing this report have in large part been gathered during six seasons of field work by United States Geological Survey parties. In 1926 and 1927 parties in charge of A. A. Baker, E. T. McKnight, and C. H. Dane mapped in detail a large area in the vicinity of Moab, Utah. C. E. Dobbin and J. B. Reeside, Jr., were associated with these parties for various periods. In 1928 a party in charge of Baker mapped in detail an area between the San Juan River and the Utah-Arizona State line. In connection with this work Reeside and Baker made stratigraphic studies in a large part of the area considered in this report. H. E. Gregory joined them for 10 days at the beginning of the season. In 1929 C. H. Dane continued detailed mapping in the Moab district and also made stratigraphic studies over a large area. He was accompanied by H. D. Miser and Reeside during part of his reconnaissance stratigraphic work. In 1930 Baker mapped the northern part of the Green River Desert, Utah, and in company with Reeside and Gregory visited southwestern Utah and adjacent parts of Arizona. Reeside and J. S. Williams also studied the Triassic and Jurassic rocks in the upper Colorado River basin in northwestern Colorado and visited localities along the Front Range. In 1931 Baker mapped the southern part of the Green River Desert. During the six seasons of field work several thousand square miles of the region has been mapped in detail, and numerous stratigraphic sections have been measured in the areas of detailed mapping and elsewhere. During these seasons or previous field seasons one or all of the writers have visited almost all the localities cited in this report, checking or reviewing previously published information and obtaining much additional information.

[2] Baker, A. A., and Reeside, J. B., Jr., Correlation of the Permian of southern Utah, northern Arizona, northwestern New Mexico, and southwestern Colorado: Am. Assoc. Petroleum Geologists Bull., vol. 13, pp. 1413-1448, 1929.

GENERAL FEATURES OF THE STRATIGRAPHY OF THE REGION AND STRATIGRAPHIC LIMITS OF THE PRESENT DISCUSSION

THE FORMATIONS

In the region treated in this paper there is an incomplete and little-known sequence of Paleozoic formations older than the Pennsylvanian. Over most of the region these formations are not exposed.

Within the Plateau province the deeper canyons, broad anticlinal folds, and a few areas of complicated structure reveal rocks of Pennsylvanian and Permian age, and in the Rocky Mountains there are extensive exposures.

Resting upon the Permian with unconformity, locally angular, is the Lower Triassic Moenkopi formation, in part, at least, of marine origin. This formation, composed chiefly of red beds, is wide-spread in the Plateau province in Utah and Arizona but extends into Colorado only a short distance near the Dolores River. It is not present farther south in Colorado nor in New Mexico. In the eastern Uinta Mountains, in northeastern Utah and the adjacent part of Colorado, it is represented by the Thaynes(?) and Woodside formations.

Upon the Moenkopi lies, with unconformity, likewise locally angular, the Shinarump conglomerate, probably of Upper Triassic age. Upon the Shinarump in turn lies conformably the Upper Triassic Chinle formation, a group of nonmarine red beds containing vertebrate remains, fresh-water invertebrates, and silicified wood. In southwestern Colorado the place of the Shinarump and Chinle formations is occupied by the greater part of the Dolores formation. It seems likely that the Dolores formation may include in its upper part a thin equivalent of the Wingate sandstone, though because of discontinuity of exposures and changes in lithology it is difficult to identify such a member. In northeastern Utah beds equivalent to the Dolores formation have been called the "Ankareh(?) formation."

Above the Chinle red beds rise, in the Plateau province, the massive cliffs of the Glen Canyon group (p. 4)—at the base the Wingate sandstone, in the middle a variable unit often called the Todilto formation but named by the present writers the Kayenta formation, and at the top the Navajo sandstone. The geographic distribution of the Wingate sandstone is much different from that of the Navajo sandstone, and its physical characteristics, when taken for its whole extent, ally it more with the underlying Chinle formation than with the Navajo sandstone. The Glen Canyon group is a convenient unit, however, particularly for eastern Utah, and the name is here retained with the reservation that it is used primarily for convenience. The whole group crops out extensively in southeastern Utah and northeastern Arizona, and it extends eastward into southwestern Colorado. The Navajo sandstone alone is recognizable in southwestern Utah and the adjacent parts of Arizona and Nevada. The Wingate sandstone alone extends into the Rocky Mountain border in Colorado and into northern New Mexico. It is believed that the typical Nugget sandstone of southwestern Wyoming and the Wasatch Mountains is the direct equivalent of the Navajo sandstone. The Glen Canyon group has yielded no diagnostic fossils, and until such fossils are discovered its assignment to the Jurassic or Triassic will depend upon a balancing of various sorts of physical evidence against one another, with a legitimate basis for difference of opinion as to the correct conclusion. The Nugget sandstone of the Wasatch Mountains has yielded a single pelecypod [3] that would tend to indicate a Jurassic age for the upper part of the Glen Canyon group. The United States Geological Survey, however, in recent reports has designated the whole group "Jurassic(?)", an assignment which is followed in this report. (See pp. 56–58.)

Above the sandstones of the Glen Canyon group in the Plateau province lies the Upper Jurassic San Rafael group (p. 6). At its type locality, in the San Rafael Swell, Utah, it contains, in ascending order, the Carmel formation, Entrada sandstone, Curtis formation, and Summerville formation. There are pronounced lateral changes in the lithology of this group, however, and marked differences in the geographic distribution of the constituent formations. The Entrada sandstone is the most widely distributed, extending well into the Rocky Mountains on the east and into Arizona on the south. In the Wasatch Mountains the group appears to be represented exactly by the so-called "Twin Creek formation" as identified by Mathews, and farther east in Wyoming in part at least by the Sundance formation. The typical Twin Creek limestone of southwestern Wyoming is considered the equivalent of the Carmel formation, and higher marine beds included in the Beckwith formation of southwestern Wyoming represent the Entrada sandstone and Curtis formation.

A group of sandstones which in southwestern Colorado rest unconformably on the Dolores formation were long ago called the †"La Plata formation." [4] In the original sense it included what are here identified as the Entrada sandstone and part of the Morrison formation, but in attempts to extend the use of the name various other formations were included. The confusion in usage makes the name of so little service that it is discarded in this paper.

In northwestern New Mexico the Todilto limestone rests on the Wingate sandstone unconformably. It has been variously interpreted but is here assigned to the base of the Morrison formation. Beds previously called "Todilto" or "Todilto(?)" formation in Arizona and Utah have recently been renamed "Kayenta formation."

Above the San Rafael group are the conglomerates, sandstones, thin limestones, and variegated shales of the widespread Morrison formation (pl. 23, *C*). For reasons given on page 63 it is here regarded as of Jurassic age, though it has for some years been designated "Cretaceous(?)" by the United States Geological Survey. Most of the beds here called "Morrison" have at one time or another been placed in the †McElmo formation, named from exposures in McElmo Canyon in southwestern Colorado, but the name "McElmo" is now abandoned.

The wide-spread, relatively thin conglomeratic sandstone and shale of the Dakota (?) formation mark the beginning of Cretaceous sedimentation in the region covered by this paper. The Dakota (?) at places is probably in part of Lower Cretaceous age, but it surely in part and locally in its entirety represents the introductory deposits of an advancing Upper Cretaceous sea in which subsequently the thick marine Mancos shale and other formations were laid down.

DIFFICULTIES OF CORRELATION

The stratigraphic sequence just described is relatively simple, and exposures are good over large areas. For the part of it between the earlier Permian and the later Morrison, however, the widespread correlation of the formations involves peculiar difficulties. The few formations that yield distinctive fossils contain them in small areas only; elsewhere fossils are exceedingly rare, and some of the formations have nowhere yielded any that are determinable. Some of the formations have distinctive lithologic characteristics that persist over wide areas, but others are, at least in places, so deceptively similar in lithology that confusion can be avoided only by continuous tracing or measurement of sections at short intervals. In some of the broad basin flexures of the region younger rocks conceal the Jurassic strata for miles. At other places the Jurassic strata have been removed by erosion. The difficulties are by no means insuperable,

[3] Mathews, A. A. L., Mesozoic stratigraphy of the central Wasatch Mountains: Oberlin Coll. Lab. Bull., new ser., no. 1, p. 42, 1931.

[4] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Telluride folio (no. 57), p. 3, 1899.

however, and with sufficient work a satisfactory interpretation may be made. It has been well said that "when the entire region has been systematically surveyed there should be few important problems of correlation left unsolved."[5]

LIMITS OF THIS PAPER

The lower limit of the rocks considered in detail in this paper is the base of the Wingate sandstone. At many places this boundary is sharp, and at a few places it affords evidence of unconformity. Previous writers have generally considered it to mark a widespread interruption of sedimentation. At many places, however, there seems on close inspection to be no sharp break between the massive resistant sandstone of the Wingate and the underlying softer interbedded sandstone and shale of the Chinle formation, though from a distance there may appear to be a sharp change. Toward the margins of the area in which the Wingate now appears, which is probably approximately the same as its original basin of deposition, shale members within the Wingate increase greatly in number, and numerous bedding planes appear, with the result that the lithologic distinction from the underlying Chinle formation is much less striking. Owing to such a change eastward nearly all the earlier geologists who worked in western Colorado included the two units in one formation in that region. In the Echo Cliffs, in Arizona, a change similar to that in Colorado makes the selection of the lower boundary of the Wingate, or even the recognition of the formation, very uncertain. Over the area of distribution of the formation as a whole, however, the base is definite enough to be a serviceable plane of division.

The upper limit of the rocks considered is actually the top of the Morrison formation, though as there has been little question concerning the identity or correlation of the upper part of the Morrison this part will not be discussed at great length and at many localities will not enter into the discussion at all. The lower part of the Morrison, however, is discussed both because of the part its deceptive lithologic variations have played in past correlations and because of the importance of a correct understanding of its stratigraphic relations with the underlying beds.

JURASSIC(?) FORMATIONS

GLEN CANYON GROUP

The name "Glen Canyon group" was applied by Gregory and Moore[6] to the Wingate, Kayenta [their "Todilto?"], and Navajo formations in Glen Canyon, Utah and Arizona. It now appears that only the Navajo sandstone is present in the lower part of Glen Canyon, but the three formations of the group are present in the upper part of Glen Canyon. The name is still appropriate, therefore, and is here accepted for its convenience in description and mapping. It is most useful in eastern Utah and the contiguous area in which the three parts are present. As very briefly outlined above, the Glen Canyon group is herein classified as Jurassic (?).

WINGATE SANDSTONE

The massive sandstone constituting the basal unit of the Glen Canyon group derives its name from exposures several miles north of Fort Wingate, in northwestern New Mexico.[7] At the type locality it is the only part of the group present.

The Wingate sandstone occurs in full development in southeastern Utah, northeastern Arizona, northwestern New Mexico, and apparently across north-central New Mexico. It passes eastward from Utah into Colorado but reaches the mountains only in an attenuated form. Westward it probably did not extend past the middle of Arizona and Utah. The northern boundary is not known but seems to be somewhere under the Uinta Basin, for the formation cannot be recognized in the Uinta Mountains. It seems probable that the Wingate is not represented in the Nugget sandstone of the Wasatch Mountains nor in the typical Nugget of southwestern Wyoming, both of which are believed to correspond to the younger Navajo sandstone.

The Wingate sandstone is in the greater part of its area of distribution perhaps the most conspicuous of the Jurassic formations, for its outcrop is almost everywhere a sheer cliff, in many places vertically jointed (pl. 5, *C*). The normal surface color is deep reddish buff, but in the more arid sections the sandstone is much streaked and coated with blue-black desert varnish, and locally wash from the overlying formation colors it a bright red. The freshly broken surface is pale red to very light buff. Cross-bedding is not conspicuous in the vertical cliff faces, but wherever there has been opportunity for deeper weathering the Wingate shows intricate cross-bedding. Although much of this is of large-scale, unsystematic, tangential type, there is also more or less of regular cross-bedding between true bedding planes, the torrential type. The rock is composed principally of quartz in subangular to rounded grains more or less coated with a film of iron oxide. In the few specimens examined from widely spaced localities, the grains varied only slightly from an average of 0.1 millimeter in diameter. The rock is very massive and poorly cemented with both lime and silica. Toward both the east and the west it includes progressively more and more beds of sandy

[5] Longwell, C. R., and others, Rock formations in the Colorado Plateau of southeastern Utah and northern Arizona: U. S. Geol. Survey Prof. Paper 132, p. 2, 1923.
[6] Gregory, H. E., and Moore, R. C., The Kaiparowits region, Utah and Arizona: U. S. Geol. Survey Prof. Paper 164, p. 61, 1931.
[7] Dutton, C. E., Mount Taylor and the Zuni Plateau: U. S. Geol. Survey 6th Ann. Rept., pp. 136–137, 1885. Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, pp. 53–55, 1917.

shale and exhibits much more division by bedding planes (pl. 6, *B*). Siltstone is rather uncommon in the central part of the area. Conglomerate was noted only on the Gunnison River in Colorado, where the Wingate rests directly on the pre-Cambrian, and at one locality near Moab, Utah, where it is, however, a very minor occurrence. In a few places thin, local lenses of dense gray sandy limestone are known (pl. 5, *A*).

The formation is as much as 470 feet thick, but in most of its extent it is about 300 feet. It thins as a recognizable unit to a vanishing edge eastward in Colorado. Westward in Arizona and Utah it is covered for a long distance but is very thin where it reappears in the Echo Cliffs. Southeastward in New Mexico it passes beyond the region known at first hand by the writers and is reported to disappear in eastern New Mexico.

The Wingate sandstone has a sharp basal boundary at some places and a more or less arbitrary boundary at others. The massive Wingate sandstone at most places grades into the overlying, irregularly bedded sandstones of the Kayenta formation.

Dinosaur tracks have been reported in the Wingate sandstone,[8] but no other fossils are known.

KAYENTA FORMATION

The name "Kayenta formation" is here used for the beds in northern Arizona and southeastern Utah that have been previously designated "Todilto" and "Todilto (?)" formation. The Todilto limestone of New Mexico is now known to be of later age (p. 17).

The type locality is in Comb Ridge, 1 mile northeast of Kayenta, Ariz., where the formation is 144 feet thick. The general section at the locality is shown in figure 7. The Kayenta formation is recognized in northern Arizona, in southeastern Utah, and in Colorado near the Utah-Colorado line.

The formation is in the main a bench-forming unit, though the lower part is commonly hard and forms a cap on the Wingate cliff (pl. 5, *C*). The upper part is softer and usually weathers back to form a broad bench between the Wingate and Navajo sandstones. The formation is composed chiefly of irregularly bedded sandstones (pls. 7, *B*; 8, *A*), which vary much in grain size, passing locally into grits and fine conglomerates. There are subordinate lenses of shale or mudstone and local thin beds of impure limestone and beds of mud-pellet conglomerate. The color is mostly reddish, certain lavender tones being characteristic, though brown and buff and more rarely green occur.

The lower boundary of the Kayenta formation has been described above as arbitrary. The upper boundary must likewise be chosen arbitrarily in an apparently continuous transition zone (pl. 8, *C*). In many places there would be general agreement as to the location of both upper and lower planes of contact; in others there would be room for considerable divergence of opinion.

The thickness is as much as 320 feet, though it is very variable and at places is very much less than the maximum, even in the heart of the area of distribution. Possibly this variation is due in part to the transitional nature of both boundaries and the arbitrary choice of them at different places.

Dinosaur tracks, unnamed species of unionid pelecypods, and indeterminable stems of some plant have been found in the Kayenta formation.

NAVAJO SANDSTONE

The Navajo sandstone was named originally [9] without more specific type locality than the "Navajo country." There can be no doubt, however, of the identity of the formation, and in the subsequent work it has been traced through a large area. It occurs across southern Utah, in north-central and northwestern Arizona, and in eastern Nevada. The western and northern limits are not definitely known, but a thin eastern edge extends a few miles into Colorado. It is not present in New Mexico, in the writers' opinion, the beds usually called "Navajo" in New Mexico being here assigned to the Morrison formation. The Nugget sandstone of the Wasatch Mountains and southwestern Wyoming and possibly of the western Uinta Mountains is believed to represent the Navajo sandstone. The Navajo is believed to be present in the eastern Uinta Mountains and may be represented in the basal part of the Sundance formation of central and eastern Wyoming, though in the writers' opinion the entire basal member of the Sundance is younger.

The topographic expression of the Navajo sandstone is generally that of huge domes and rounded masses in the areas where it is not immediately overlain by resistant rocks and of rounded to almost sheer cliffs where it is capped by hard layers. Its outcrops form picturesque features in the landscape. It is everywhere exceedingly massive; true bedding planes are few, but intricate cross-bedding on a very large scale is characteristic (pl. 15, *C*). This cross-bedding is almost all of the unsystematic tangential type though some of the regular, torrential type is also present. The Navajo is usually buff to gray-white but at places is red. It is composed of subangular to rounded grains consisting predominantly of quartz with numerous grains of feldspar and a few grains of ferromagnesian minerals, poorly cemented by lime and silica. The examination of a few specimens from widely spaced localities disclosed a maximum grain size of 0.5 millimeter and an average grain size of about 0.15 millimeter. The sand grains of the Navajo sandstone differ from those of the Wingate sandstone by coarser size, slightly greater angularity of grains,

[8] Longwell, C. R., and others, Rock formations in the Colorado Plateau of southeastern Utah and northern Arizona: U. S. Geol. Survey Prof. Paper 132, p. 18, 1923.

[9] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, p. 57, 1917.

inferior sizing, and usual lack of a coating of iron oxide. Limestone in thin lenses, usually small in extent, occurs at a number of places, particularly in the upper part of the formation (pl. 11, *A*). These lenses are commonly sandy and grade off into sandstone. They are more abundant in the Navajo than in the Wingate sandstone. Many of them show mud cracks and curled fragments that suggest desiccation. At several localities in San Rafael Swell and the northern parts of the Green River Desert numerous "dreikanter" have been found embedded in the formation, though elsewhere pebbles of any kind are extremely rare (pls. 13, 14). Silt and shaly beds are also very rare, except as thin partings in the basal transition zone. Mathews [10] reports a thick basal conglomerate in the Nugget sandstone in the Wasatch Mountains.

The thickness of the Navajo increases from east to west, from a vanishing edge in Colorado and northeastern Arizona to more than 2,000 feet in southwestern Utah and adjacent Nevada. In Nevada an unknown amount has been removed by erosion, and the original thickness is conjectural.

The lower boundary of the Navajo sandstone is arbitrary, but the upper boundary is nearly everywhere sharp. Whether the upper boundary represents a widespread unconformity has not yet been definitely determined, though it is probable that local unconformities occur. It seems most likely that the contact is not an important break. Mathews [10] has interpreted the top of the Nugget sandstone in the Wasatch Mountains as an unconformity.

Fossils are very rare in the Navajo sandstone. A small saurischian dinosaur was found near Kayenta, Ariz.,[11] and dinosaur footprints have been observed in the lower part of the formation on the east flank of the San Rafael Swell, Utah. A single specimen of *Trigonia* is reported from the lower part of the Nugget sandstone in the Wasatch Mountains, indicating marine deposits there and post-Triassic age.

JURASSIC FORMATIONS

SAN RAFAEL GROUP

The name "San Rafael group" was applied to the formations included between the Navajo sandstone and the Morrison formation in the San Rafael Swell, Utah.[12] These units are, in ascending order, the Carmel formation, Entrada sandstone, Curtis formation, and Summerville formation. The so-called "Twin Creek limestone" of the Wasatch Mountains, as identified by Mathews, and the typical Twin Creek limestone and lower part of the overlying Beckwith formation of southwestern Wyoming appear to represent essentially this group. At least part of the so-called "Nugget sandstone" and the so-called "Twin Creek formation" in the eastern Uinta Mountains together represent it, and certain sandstones in Colorado long assigned to the † La Plata sandstone are part of it.

CARMEL FORMATION

The name "Carmel" was applied by Gregory and Moore [13] specifically to the exposures near the town of Mount Carmel, in southwestern Utah. The formation was traced by them around the south end of the High Plateaus to the Waterpocket Fold, and thence it has been carried to the San Rafael Swell and other areas. It is now recognized all over southern Utah and a short distance into northern Arizona and western Colorado. It is very likely that the actual scope of the name is not everywhere the same. For example, it would seem almost certainly to include a smaller time interval in the San Rafael Swell than at the type locality. The Carmel is represented in the lower part of the so-called "Twin Creek formation" of the Wasatch Mountains and by the typical Twin Creek of southwestern Wyoming, where distinctive fossils are present. Possibly a little-studied lower marine zone of the Sundance formation of Wyoming represents it, though until more information is available the writers prefer to view the basal Sundance as equivalent to the Entrada sandstone.

The constitution of the formation varies much. In southwestern Utah it is composed, as the writers interpret it, of a fairly thick lower red shale and sandstone division and an overlying division of cream-colored, brown, and greenish-gray limestone with subordinate shale and gypsum. The next higher beds seem to the writers referable to the Entrada sandstone, though Moore and Gregory originally excluded the basal red unit and included the overlying sandstone and still higher beds. Gregory [14] more recently has limited the name "Carmel" to the limestone division and assigned the overlying beds to "undifferentiated Jurassic(?)." In the San Rafael Swell there is a variable lower division containing a thin basal reddish limy sandstone and above it a relatively thin unit of resistant gray limestones and limy shales, which seem to correspond to the basal red sandstone and overlying limestone of southwestern Utah; and an upper division of gray, orange-red, and greenish shales with much gypsum in thick layers and contorted beds, which seem to appear on the Paria River and thicken eastward, perhaps by lateral change from limy to nonlimy beds. Eastward and southeastward from the San Rafael Swell the Carmel thins much, loses its limestones, and becomes

[10] Mathews, A. A. L., op. cit., p. 42.

[11] Camp, C. L., and Vanderhoof, V. L., Small bipedal dinosaur from the Jurassic of northern Arizona [abstract]: List of papers, with abstracts, 33d annual meeting of the Geol. Soc. America (Cordilleran section), Paleont. Soc., Seismol. Soc. America, Le Conte Club, Berkeley, Calif., 1934.

[12] Gilluly, James, and Reeside, J. B., Jr., Sedimentary rocks of the San Rafael Swell and some adjacent areas in eastern Utah: U. S. Geol. Survey Prof. Paper 150, p. 73, 1928.

[13] Gregory, H. E., and Moore, R. C., The Kaiparowits region, Utah and Arizona: U. S. Geol. Survey Prof. Paper 164, p. 69, 1931.

[14] Gregory, H. E., Colorado Plateau region: 16th Internat. Geol. Cong., Guidebook 18, p. 15, 1933.

a series of red sandy shales and red sandstones with bedding remarkably contorted at many places (pl. 16, *C*). Where the limestones are present their resistant beds form a ledge and make a protecting cover for the Navajo sandstone (pl. 11, *A*), but elsewhere the formation is soft and forms a bench between the Navajo and Entrada sandstones.

The thickness of the Carmel reaches a maximum of 650 feet, but in the normal phase it is commonly between 300 and 400 feet and in the red sandy phase usually less than 100 feet.

The lower boundary is distinct, but there is little evidence of an important break in the sequence at that plane. The upper boundary is transitional and arbitrary at most places (pl. 16, *C*), but at other places it is sharp (pl. 16, *B*).

Marine fossils, chiefly pelecypods, of lower Upper Jurassic age (Callovian) are reported in relative abundance from the limestone division [15] and occur locally in gray sandstone overlying the limestone, but in no other part have any fossils been found. The species recorded are such as occur in the Ellis formation of Montana and in the lower part of the typical Twin Creek formation. The single fragmentary ammonite recorded from the Carmel in San Rafael Swell was identified by Reeside as *Cardioceras*, an Argovian form, but it is a macrocephalitid of Callovian age. A similar form is recorded by Mathews [16] from the lower part of his so-called "Twin Creek" of the Wasatch Mountains. The Carmel formation is older than the abundantly fossiliferous upper part of the Sundance of Wyoming, as noted by Crickmay,[17] and not of the same age, as indicated by Gilluly and Reeside.[18]

ENTRADA SANDSTONE

The Entrada sandstone was named from the exposures at Entrada Point, in the San Rafael Swell, Utah.[18] It extends far eastward into and, in the north, across the Rocky Mountain province in Colorado and a relatively short distance southward into New Mexico and Arizona. A sandy zone above the Carmel in southwestern Utah has the position and lithology of the Entrada and is here correlated with it. Its northern and northwestern limits are not well known, but there seems no question that the upper part of the so-called "Nugget sandstone" of the eastern Uinta Mountains is the Entrada sandstone, and that, inasmuch as Curtis fossils are listed by Mathews in the upper part, some part, perhaps much, of the middle of his so-called "Twin Creek formation" of the Wasatch Mountains is equivalent to it. It is represented in the lower part of the Beckwith formation of southwestern Wyoming. The lower member of the †La Plata sandstone of Cross at many localities in southwestern Colorado is Entrada, and so also is the entire †La Plata of north-central Colorado. A part of the Sundance formation of Wyoming must represent the Entrada, and the sandstone in the northern Front Range of Larimer County, Colo., called "Jelm (?) formation" by Lee,[19] is the Entrada.

In the vicinity of Moab, Utah, the somewhat lighter-colored Moab sandstone tongue is recognized at the top of the Entrada sandstone.

The Entrada sandstone in the San Rafael Swell is a deep-red fine-grained earthy sandstone that weathers into small bosses, "stone babies", and other rounded forms and at many localities is not much more resistant than shale (pl. 21, *B*). This facies occurs also in southwestern Utah. Eastward from the San Rafael Swell this earthy facies passes into a less earthy, irregularly bedded sandstone (pl. 17, *A*). This in turn passes eastward into a sandstone composed of clean, fine to medium-sized lime-cemented quartz grains, red, orange-red, or gray, banded at many places with conspicuous zones of color (pl. 18, *A*), in sharp distinction to the uniform coloring of the Navajo and Wingate, with intricate cross-bedding between horizontal bedding planes (pl. 18, *D*). This third facies yields outcrops in which at some places great domes and rounded masses are conspicuous but which at others show rounded ledges and distinct bedding. The weathered surface is marked by numerous pits or cavities with definite linear arrangement parallel to the true bedding (pl. 17, *C*).

The presence of larger well-rounded grains scattered through a greater proportion of smaller grains has been noted widely in western Colorado and along the eastern edge of Utah. Where it has been observed the larger grains have diameters of 0.5 to 0.8 millimeter and are well rounded to perfectly rounded, with a frosted or mat surface. The smaller grains average less than 0.15 millimeter in diameter and are subrounded. The grains are predominantly quartz, but grains of feldspar are common, and grains of chert and chalcedony are conspicuous though not numerous. Grains of schist and calcium carbonate rock have been observed. The grains are normally cemented by calcium carbonate, but there is some silica cement.

The maximum thickness is about 1,000 feet near the Circle Cliffs, Utah.[20] The formation thins out southward, but on the east, though it thins much, it is persistent across the Rocky Mountain province as far as the eastern foothills of the northern Front Range. In the eastern Uinta Mountains and the adjacent part

[15] Gilluly, James, and Reeside, J. B., Jr., op. cit., p. 75.

[16] Mathews, A. A. L., op. cit., p. 44.

[17] Crickmay, C. H., Jurassic history of North America—its bearing on the development of continental structure: Am. Philos. Soc. Proc., vol. 70, p. 48, 1931.

[18] Gilluly, James, and Reeside, J. B., Jr., op. cit., p. 76.

[19] Lee, W. T., Correlation of geologic formations between east-central Colorado, central Wyoming, and southern Montana: U. S. Geol. Survey Prof. Paper 149, p. 14, 1927. Reeside, J. B., Jr., The supposed marine Jurassic (Sundance) in the foothills of the Front Range of Colorado: Am. Assoc. Petroleum Geologists Bull., vol. 15, pp. 1095–1103, 1931.

[20] Gilbert, G. K., Geology of the Henry Mountains, pp. 5–8, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1877. Gregory, H. E., and Moore, R. C., The Kaiparowits region, Utah and Arizona: U. S. Geol. Survey Prof. Paper 164, pp. 76–80, 1931.

of northwestern Colorado the so-called "Nugget" approaches 1,000 feet in thickness, but only the upper part of this is believed to represent Entrada sandstone.

The lower boundary of the Entrada sandstone is arbitrary where the Carmel formation is present, but elsewhere it is sharp. The contact with the overlying Curtis formation in the San Rafael Swell is an erosional unconformity, but elsewhere the upper boundary is only moderately sharp and probably not an unconformity. In the eastern Uinta Mountains the boundary between the so-called "Nugget sandstone" and so-called "Twin Creek formation" is gradational.

No fossils are known from the Entrada sandstone, except dinosaur footprints in the Moab tongue at a locality 15 miles north of Moab, Utah.

CURTIS FORMATION

The Curtis formation was named from the exposures at Curtis Point, in the San Rafael Swell, Utah.[21] In its typical phase it is limited to the northern part of the Swell, but in an attenuated form it extends as far eastward as the Green River and as far southward as the north end of the Waterpocket Fold. A fossiliferous zone in the upper part of the section at Mount Carmel, in southwestern Utah, included by Gregory and Moore [22] in the type Carmel formation, seems to represent the Curtis formation. The so-called "Twin Creek formation" of the eastern Uinta region and its extension into north-central Colorado are certainly equivalent to the Curtis. A zone in the upper part of the so-called "Twin Creek" as identified by Mathews in the Wasatch Mountains and in the upper part of the Beckwith formation of southwestern Wyoming is also equivalent. The three separate areas of southwestern Utah, the San Rafael Swell, and northwestern Colorado seem to be separate southeastward extensions from a main area represented by part of the Beckwith formation of southwestern Wyoming and the Sundance formation of central and eastern Wyoming.

In its typical facies the Curtis formation is a fine-grained thin- to medium-bedded glauconitic sandstone with a coarse basal conglomerate, light brown on the weathered surface and greenish gray on a fresh surface. The cement is chiefly lime, but with some ferruginous material, irregularly distributed so that irregular forms are produced by weathering. Ripple marks and cross-bedding are common, greenish shales occur in the upper part of the formation, and some bedded gypsum is present. This facies forms a cliff or a ridge with a dip slope (pl. 21, *B*). Eastward and southward the sands become finer until the whole unit is an unresistant greenish shaly sandstone (pl. 22, *B*). In southwestern Utah the unit interpreted as Curtis consists of gypsiferous soft sandstone and gypsum, the whole pinkish or light yellow. In the eastern Uinta Mountains and in north-central Colorado oolitic sandy limestone is the most persistent constituent, accompanied by sandstone and shale.

The maximum thickness known in the San Rafael Swell is 260 feet, but the thickness decreases rapidly eastward and southward from this place. In southwestern Utah the thickness is 250 feet; in north-central Colorado it is only 10 or 15 feet, but it increases westward to 180 feet in northeastern Utah. A gradation laterally into Summerville lithology has been noted at places, and it is likely that much of the apparent thinning is really a progressive lateral lithologic change of the upper part by which it becomes like the Summerville and is inseparable from that formation.

The basal boundary is a marked erosional unconformity in the San Rafael Swell and in southwestern Utah, but the time value of the break is almost certainly small. Elsewhere the contact is transitional. The upper boundary where the Summerville is present is arbitrary, as just noted above, and there is no convincing physical evidence of unconformity where the Morrison formation directly overlies it.

The Curtis formation of the San Rafael Swell has yielded a small fauna of marine invertebrates [23] that belong to the fairly well known fauna of the upper part of the Sundance formation (middle Upper Jurassic, Divesian and Argovian). This relationship is more clearly shown by the larger fauna found in the eastern Uinta Mountains and in Colorado, where ammonites (*Cardioceras* and some of its close allies) have been found.[24] The Curtis has yielded a small indeterminate fauna in southwestern Utah.

SUMMERVILLE FORMATION

The Summerville formation was named from the exposures at Summerville Point, in the San Rafael Swell, Utah.[25] It extends eastward a short distance into western Colorado and southward a short distance into northeastern Arizona. It is not recognized in southwestern Utah, and its northern limits must lie under the Uinta Basin, for it is not known in the Uinta Mountains.

The Summerville formation in the vicinity of the San Rafael Swell is a series of evenly thin-bedded red and white very fine grained sandstones and maroon shales (pl. 22, *A*, *B*). Small chalcedony concretions are common, and bedded gypsum also occurs. Mud cracks and ripple marks abound. Eastward and southward the formation changes to brownish red, somewhat irregular sandstone, ripple-marked sandy shale, and mudstone, at places containing large masses of chert (pl. 22, *D*). The formation is usually less resist-

[21] Gilluly, James, and Reeside, J. B., Jr., op. cit., p. 78.
[22] Gregory, H. E., and Moore, R. C., op. cit., p. 73.
[23] Gilluly, James, and Reeside, J. B., Jr., op. cit., p. 79.
[24] Reeside, J. B., Jr., Notes on the geology of Green River Valley between Green River, Wyo., and Green River, Utah: U. S. Geol. Survey Prof. Paper 132, pp. 38, 43, 44, 1933.
[25] Gilluly, James, and Reeside, J. B., Jr., op. cit., p. 79.

ant than the enclosing rocks and forms a slope or bench.

The thickness is as much as 400 feet but usually is less, the formation thinning toward the eastern and southern margins of the area in which it is identified.

The boundary with the Curtis formation is arbitrary. Where the Curtis formation is not recognized and the Summerville rests on the Entrada the boundary is fairly sharp, but intertonguing has been observed in the Moab district, where the Moab tongue of the Entrada sandstone passes out into the Summerville. The upper boundary in the San Rafael Swell is at places an angular unconformity, but toward the east and south the formation cannot be discriminated with certainty from parts of the overlying Morrison formation except where detailed mapping has been done.

No fossils have been reported from the Summerville formation, and it is assigned to the San Rafael group because of its intimate relations with the underlying beds.

MORRISON FORMATION

The Morrison formation was named from the exposures near the town of Morrison, in east-central Colorado,[26] and is widespread in the Western Interior. It is present over most of the region dealt with in this paper, the extreme western part in south-western Utah and adjacent Arizona and Nevada forming an exception. In the San Rafael Swell and the Moab district the basal member has been called the "Salt Wash sandstone member."[27] In northwestern New Mexico the Todilto limestone has long been considered older than Morrison, but in this paper it is made the basal member of the Morrison.

The Morrison formation is composed of rather diverse sorts of rocks, for the most part in irregular and discontinuous beds. The most characteristic rocks are mudstones, predominantly green-gray with a conspicuous admixture of red, purple, and brown, and soft whitish or greenish-white sandstones (pl. 23, *C*). All the beds are more or less limy. In the San Rafael Swell and the Moab district much of the formation is of this type, with the Salt Wash member of conglomeratic sandstones at the base and a few conglomeratic sandstone layers in the upper part (pl. 26, *A*). There are also a few thin beds of gray limestone and some bedded gypsum. In north-central Colorado much of the formation is mudstone with many intercalated thin limestones and sandstones; locally a conspicuous algal limestone occurs at the base, and in places there is a discontinuous sandstone that has usually been placed in the †La Plata rather than Morrison (as †McElmo). In the eastern Uinta region the Morrison formation is mostly mudstone, with lenses of vertebrate-bearing conglomerate. Southeast and south of the San Rafael Swell sandstones are more conspicuous and the fine sediments are more or less restricted to the upper part. In extreme northeastern Arizona and in northwestern New Mexico the formation is composed almost entirely of buff to gray and pink sandstone (pl. 25, *A*, *B*, *D*), the Todilto limestone[28] at the base (pl. 23, *B*) forming a somewhat incongruous associate, though it seems certainly to belong with the sandstones and is here treated as a member of the Morrison. This sandstone type of Morrison constituted the †Zuni sandstone of Dutton.[29] At places in New Mexico thick beds of gypsum lie immediately above and locally replace the Todilto limestone member, and the upper part of the sandy Morrison passes eastward into mudstones (pl. 24, *A*, *B*).

An interesting feature of the mudstone facies of the Morrison formation is the widespread occurrence of scattered well-rounded and highly polished pebbles of resistant, usually siliceous material—quartz, chert, etc. These were long considered to be connected with the reptilian fauna and believed to be gastroliths or "stomach stones", because of a few occurrences of small groups of pebbles intimately associated with skeletal remains and because some living reptiles swallow pebbles and carry them internally. It seems more likely now that such pebbles used internally would have a dull surface and that there are, moreover, too many of the polished "gastroliths" to be accounted for. A more likely original cause of the polish is wind-blown dust, though bright pebbles might well have been picked up by animals and distributed by them.

The thickness of the Morrison formation varies greatly from place to place. It is as much as 850 feet and may be more locally, though at most places it is less. In most of the area in which it is present its thickness is more than 500 feet. The Salt Wash member is from 50 to 300 feet thick, the Todilto limestone is as much as 30 feet thick, and the maximum observed thickness of the basal gypsum is 80 feet.

The lower boundary shows local angular discordance in the San Rafael Swell. In northwestern New Mexico, where several formations are missing beneath it, it is sharp and marked at some places also by a zone of pebbles, though not strikingly irregular. At most places, however, it is not easy to select a satisfactory lower boundary, though an arbitrary separation of gross units can usually be made. The upper boundary has been accepted as a plane of marked erosional unconformity by nearly everyone who has discussed the matter, though there have been some differences of opinion as to this boundary where the Morrison, as interpreted in this paper, contains conglomeratic beds in the upper part.

[26] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Pikes Peak folio (no. 7), p. 2, 1894.

[27] Lupton, C. T., Oil and gas near Green River, Grand County, Utah: U. S. Geol. Survey Bull. 541, p. 127, 1914.

[28] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, pp. 55–56, 1917.

[29] Dutton, C. E., Mount Taylor and the Zuni Plateau: U. S. Geol. Survey 6th Ann. Rept., pp. 135–138, 1885.

At several places in the Colorado Plateau province and on the border of the Rocky Mountains reptilian fossils have been found which identify the Morrison formation, the locality at Dinosaur National Monument near Jensen, Utah, in the eastern Uinta region, being especially notable.[30] A few nonmarine invertebrates (*Unio*, various gastropods, cyprid ostracodes) and much silicified wood have been noted. *Chara*-like algae and other algae are widespread in the limestones of the formation.

Several writers have assigned to the beds here included in the Morrison formation an age widely different in one area from that assigned in another area, as may be noted in the discussion of nomenclature on pages 32–44. For example, the Morrison (of this paper) of southeastern Utah has been called "early Jurassic", while the Morrison (of this paper) of northeastern Utah was being called on a later page of the same paper "late Jurassic." The writers can see no basis for any such separation but consider the formation everywhere of essentially the same age.

RELATIVE CERTAINTY OF DATA

Only three of the formations considered in this paper, as noted in the descriptions given above, have so far yielded significant fossils—the Carmel, Curtis, and Morrison formations. Even in these the stratigraphic and geographic distribution of the occurrences is such that the value of the fossils lies chiefly in their use for correlation with distant regions. Correlation of lesser scope must therefore depend on such direct tracing of the formations as can be done and on the identification of individual lithologic peculiarities and stratigraphic sequences of such peculiarities.

For the parts of the region where detailed mapping has been done, particularly southeastern Utah, the correlations here offered are made with great confidence. For the parts of the region adjacent to this area, where the type of work done has consisted chiefly of reconnaissance tracing and examination of more or less isolated sections, the correlations are made with somewhat less assurance—they may, indeed, seem wholly dogmatic to the reader. It should be borne in mind, however, that much contact with the formations in the areas where their identity is sure produces a familiarity with characteristic physical features and facilitates recognition of the various units in other areas. Knowledge of the trends of lateral change in the formations, gained in the areas of relative certainty, is also of great service. The correlations here made for western Colorado, northern Arizona, and northwestern New Mexico are of this second type, and though there are gaps in the continuity of outcrops, the writers have taken every means possible to avoid confusion of units and consequent errors, and they believe that the correlations offered are well founded. For certain areas lying still farther away, as southwestern Utah and eastern Nevada on the west, the Uinta region on the north, and the Puerco River on the east, the correlations made are offered as reasonable suggestions based on the more definite knowledge of the central area. Not enough work has yet been done to permit a greater degree of certainty.

[30] See various descriptive papers by C. W. Gilmore, J. B. Hatcher, W. J. Holland, and E. S. Riggs.

REGIONAL CORRELATIONS

The correlations proposed by the writers are shown in the following pages by ten sets of columnar sections passing in various directions across the region and by a composite of these sections and other data in a perspective diagram. The columnar sections are all based on local measured sections and are arranged with the top of the Glen Canyon group as a datum. Their geographic locations, as well as that of the lines of sections, are shown on the map constituting plate 1.

TUBA, ARIZONA, TO SAN RAFAEL SWELL, UTAH

The line of sections shown in figure 1 is oriented a little east of north, passing from Tuba, Ariz., through Navajo Mountain and the Circle Cliffs to the western flank of the San Rafael Swell, Utah. It shows the Navajo to have a lenticular north-south cross section, much thinner on the ends than in the middle; and the San Rafael group thickening from a thin edge in the south to a great thickness in the north and acquiring fossiliferous marine members. The Morrison formation above and the Chinle, Wingate, and Kayenta formations below are recognized at all the localities.

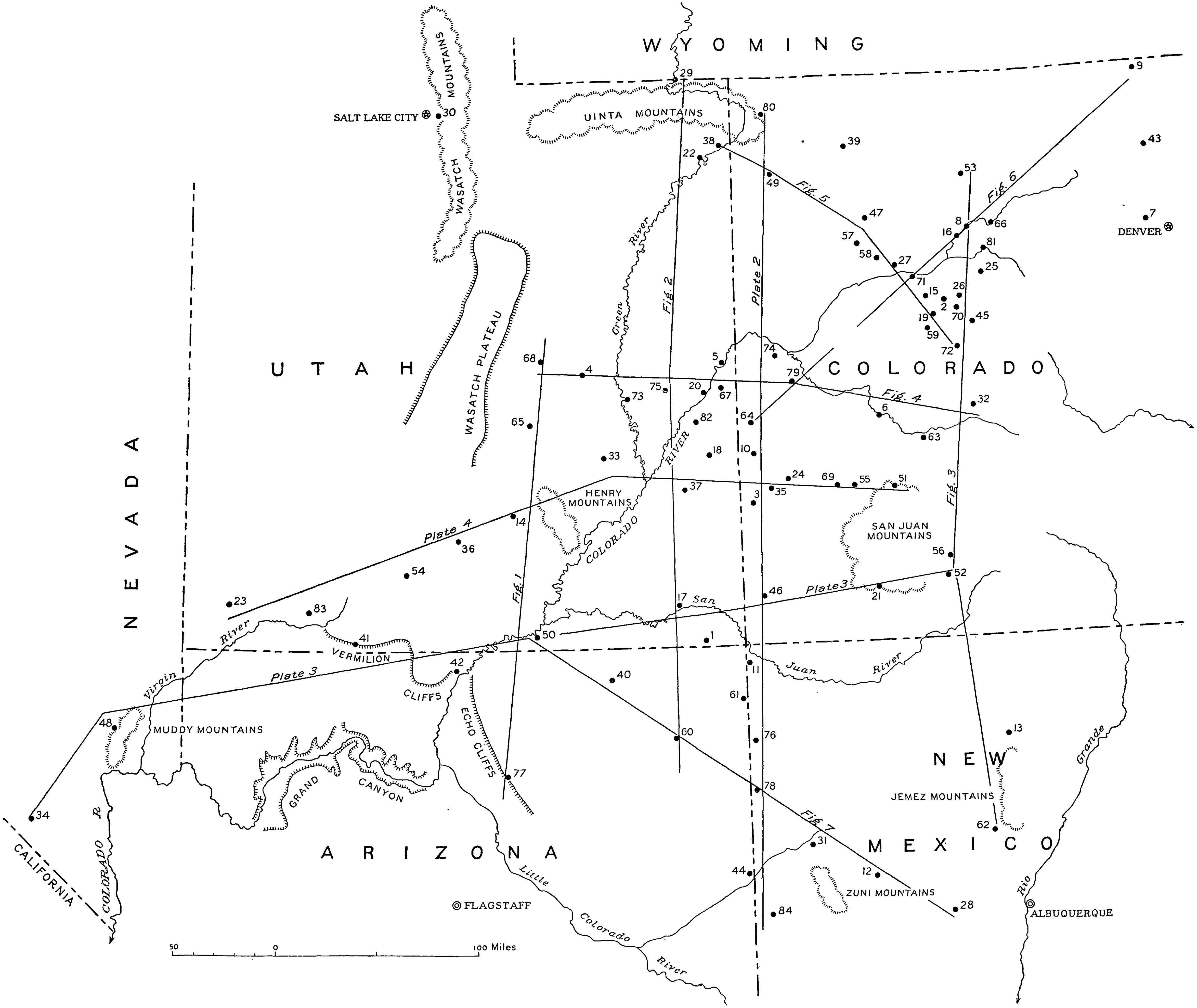
The section near Tuba was taken in part from Gregory [31] and in part from observations by the writers; that at Navajo Mountain from measurements by the writers. The section for the Circle Cliffs is in part that given by Gregory and Moore [32] and is in part from observations by the writers. The section on Starvation Creek and the composite section in Saddle Horse Canyon and Horn Silver Gulch, in the northwestern part of the San Rafael Swell, have been described by Gilluly.[33]

At Tuba and Navajo Mountain there seems to be no sharp separation between the Chinle formation and the overlying Wingate sandstone, but in the San Rafael Swell and apparently also at the Circle Cliffs the top of the Chinle formation is marked by an erosional break. At Moenkopi Village, near Tuba, a massive cross-bedded salmon-colored sandstone about 75 feet thick is like the Wingate and is here interpreted to represent it. It is overlain by 75 feet of soft red sandy shale, mudstone, and limestone that is interpreted to

[31] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, p. 57, 1917.

[32] Gregory, H. E., and Moore, R. C., The Kaiparowits region, Utah and Arizona: U. S. Geol. Survey Prof. Paper 164, pp. 61–89, 1931.

[33] Gilluly, James, Geology and oil and gas prospects of part of the San Rafael Swell, Utah: U. S. Geol. Survey Bull. 806, p. 79, pl. 35, 1929.



1. Boundary Butte, Utah.
2. Basalt, Colo.
3. Bush Canyon, Colo.
4. Black Dragon Canyon, Utah.
5. Big Hole, Utah.
6. Bostwick Park, Colo.
7. Boulder, Colo.
8. Burns, Colo.
9. Boxelder Creek, Colo.
10. Bedrock, Colo.
11. Biltabito, N. Mex.
12. Bluewater, N. Mex.
13. Chama Basin, N. Mex.
14. Circle Cliffs, Utah.
15. Carbondale, Colo.
16. Colorado River above Dotsero, Colo.
17. Bluff and Comb Ridge, Utah.
18. Cane Springs, Utah.
19. Crystal River, south of Carbondale, Colo.
20. Dewey, Utah.
21. Durango, Colo.
22. Dinosaur Quarry, Utah.
23. Diamond Valley, Utah.
24. Dry Creek, Colo.
25. Brush Creek, south of Eagle, Colo.
26. Four miles east of Basalt, Colo.
27. Elk Creek, Colo.
28. El Rito, N. Mex.
29. Flaming Gorge, Utah.
30. Fort Douglas, Utah.
31. Fort Wingate and Navajo Church, N. Mex.
32. Gunnison, Colo.
33. Green River, Desert, Utah.
34. Goodsprings quadrangle, Nev.
35. Gypsum Valley, Colo.
36. Escalante, Utah.
37. Indian Creek, Utah.
38. Island Park, Utah.
39. Juniper Hot Springs, Colo.
40. Kayenta, Ariz.
41. Kanab Canyon, Utah.
42. Lees Ferry, Ariz.
43. Loveland, Colo.
44. Lupton, Ariz.
45. Maroon Canyon, Colo.
46. McElmo Canyon, Colo.
47. Southeast of Meeker, Colo.
48. Muddy Mountains, Nev.
49. Midland Ridge, Colo.
50. Navajo Mountain, Utah.
51. Ouray, Colo.
52. Piedra River at mouth of First Fork, Colo.
53. Phippsburg, Colo.
54. Paria River, Utah.
55. Five miles northeast of Placerville, Colo.
56. Piedra River at mouth of Wiminuche Creek, Colo.
57. East of Rio Blanco, Colo.
58. Rifle Creek, Colo.
59. Redstone, Colo.
60. Rough Rock, Ariz.
61. Redrock, Ariz.
62. Rio Salado, N. Mex.
63. Sapinero, Colo.
64. Sinbad Valley, Colo.
65. Starvation Creek, Utah.
66. Statebridge, Colo.
67. Scharf ranch, Utah.
68. Saddle Horse Canyon, Horn Silver Gulch, Utah.
69. San Miguel Canyon, Colo.
70. Snowmass Canyon, Colo.
71. South Canyon, Colo.
72. Scofield Park, Colo.
73. Mouth of San Rafael River, Utah.
74. Serpents Trail, Colo.
75. Salt Valley, Utah.
76. Toadlena, N. Mex.
77. Tuba, Ariz.
78. Todilto Park, N. Mex.
79. Unaweep Canyon, Colo.
80. Vermilion Creek, Colo.
81. Wolcott, Colo.
82. Wilson Mesa, Utah.
83. Zion Canyon, Utah.
84. Zuni, N. Mex.

INDEX MAP SHOWING LOCATION OF LINES OF SECTIONS THAT FORM PLATES 2 TO 4 AND FIGURES 1 TO 7.

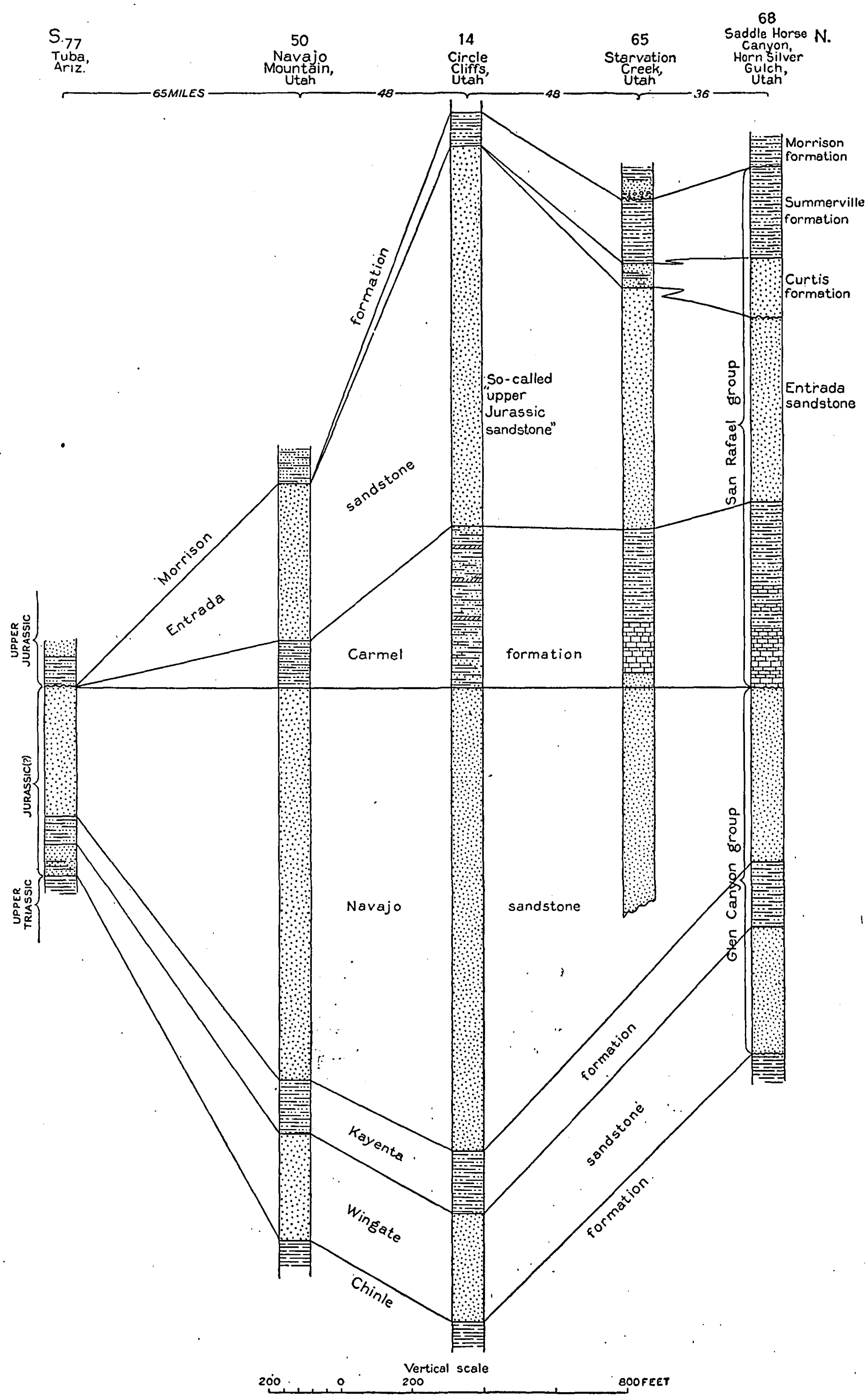


FIGURE 1.—Sections from Tuba, Ariz., to San Rafael Swell, Utah.

be the Kayenta formation. The Wingate sandstone is lenticular, and the series of beds included in the Wingate sandstone and Kayenta formation is slope-forming. The underlying beds here assigned to the Chinle contain sandstones, but they are silty and deep red. It is difficult, in short, to draw a satisfactory boundary near Tuba between Wingate and Chinle or even to be sure that any of the rocks are really Wingate or Kayenta. For the area southeastward from Tuba Gregory reports similar difficulty with the Wingate. In exposures of the lower part of the Jurassic strata along the Echo Cliffs from Tuba northwest as far as Lees Ferry it does not seem possible to recognize a definite Wingate sandstone (pl. 7, *D*). Lees Ferry lies southwest of Navajo Mountain and about 40 miles west of the line of sections. Near Navajo Mountain the Wingate sandstone is 300 feet thick. In the area between Lees Ferry and Navajo Mountain the lower part of the Jurassic rocks is not exposed. The average thickness of the Wingate in the Circle Cliffs is 300 feet, and in Saddle Horse Canyon it is 350 feet thick. At these three localities the Wingate sandstone is of the normal massive type and is practically identical in lithology. Moore stated the consensus of earlier opinion to the effect that the Wingate sandstone "continues westward into Washington County [Utah], where, although retaining characteristic features, it cannot be differentiated precisely from the superjacent sandstone."[34] The writers believe, on the basis of the later work, that the Wingate sandstone thins westward from the line of sections under discussion and cannot be recognized at Lees Ferry or westward in southern Utah, and that all of the sandstone commonly included in the Glen Canyon group in that region is the Navajo sandstone, much thickened toward the west.

The Kayenta formation ("Todilto?" of previous writers) is typically developed at the localities of this line of sections, except at Tuba, where as noted above, 75 feet of red shale and limestone may represent it. The normal Kayenta formation, composed of irregularly bedded buff, red, and lavender sandstone with subordinate red and lavender shale and conglomerate, is 150 to 225 feet thick in the vicinity of Navajo Mountain, 175 feet thick in the Circle Cliffs, and 150 feet thick at Saddle Horse Canyon, in the San Rafael Swell. The lower part of the formation commonly caps the cliff of Wingate sandstone, and the rest of it forms a bench rising gradually to the cliffs formed by the overlying sandstone. On the west side of Piute Canyon, a few miles east of Navajo Mountain, there is local evidence of an erosional unconformity between the Kayenta formation and the Wingate sandstone, but elsewhere there appears to be a gradational boundary between the Kayenta formation and the Navajo and Wingate sandstones. Dinosaur tracks have been reported from the Kayenta formation at Tuba and in Navajo Canyon west of Navajo Mountain, by Gregory[35] and also from Navajo Canyon by Bernheimer.[36]

The Navajo sandstone is present throughout the line of sections. For Willow Springs, near Tuba, Gregory[37] gives a measurement of 365 feet. North of Tuba along the Echo Cliffs the sandstone increases in thickness. Bryan[38] measured about 1,200 feet at Lees Ferry, accepting the then current opinion that Navajo and Wingate sandstones were both included in it. From Lees Ferry northeastward the upper part of the massive sandstone crops out continuously along the Colorado River to the vicinity of Navajo Mountain, where the entire formation, 1,100 feet thick, is exposed. Northwest of Navajo Mountain, between the mountain and the Colorado River, the Navajo sandstone is dissected into innumerable huge domes that block all travel in the area except by a single built trail which leads to the picturesque Rainbow Bridge, a natural bridge carved in the Navajo sandstone. The same massive cross-bedded gray to buff sandstone is about 1,300 feet thick in the Circle Cliffs but thins northward to 650 feet in the southern part of the San Rafael Swell and to 485 feet in the northwestern part.

Beds equivalent to the San Rafael group do not crop out in the vicinity of Tuba and are believed to be absent, though a sandstone facies of the Morrison formation is recognized nearby.

At Navajo Mountain the Navajo sandstone is overlain by a unit 130 feet thick consisting of bright-red sandy shale and sandstone with numerous ledges of fine-grained red and gray sandstone (pl. 25, *C*). This unit is correlated with a series of red and light-blue sandy shale, siliceous limestone, sandstone, and gypsum 450 feet in thickness in the Circle Cliffs[39] and with the fossiliferous marine Carmel formation of the San Rafael Swell. On Starvation Creek, in the San Rafael Swell, the Carmel formation is 450 feet thick, with a basal sandy zone 59 feet thick, a marine fossiliferous limestone zone 109 feet thick, and an upper zone of gypsiferous shale and siltstone. In Horn Silver Gulch it is 520 feet thick, the lower 100 feet composed of dense and oolitic fossiliferous limestone and the upper part of sandstone, sandy shale, shale, and gypsum. There is apparent conformity between the Carmel formation and the Navajo sandstone at Navajo Mountain and the Circle Cliffs, but in the San Rafael Swell the formations may be unconform-

[34] Moore, R. C., Stratigraphy of a part of southern Utah: Am. Assoc. Petroleum Geologists Bull., vol. 6, p. 217, 1922.

[35] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, p. 56, 1917.

[36] Bernheimer, C. L., Rainbow Bridge, p. 176, Doubleday, Page & Co., 1928.

[37] Gregory, H. E., op. cit., p. 57.

[38] Bryan, Kirk, in Longwell, C. R., and others, Rock formations in the Colorado Plateau of southeastern Utah and northern Arizona: U. S. Geol. Survey Prof. Paper 132, pl. 1, 1923.

[39] Gregory, H. E., and Moore, R. C., The Kaiparowits region, Utah and Arizona: U. S. Geol. Survey Prof. Paper 164, p. 81, 1931.

able. The Carmel formation appears to grade upward into the Entrada sandstone at all three localities.

An orange-red cliff-making sandstone 440 feet thick near Navajo Mountain (pls. 16, *D*; 25, *C*) is correlated with the Entrada sandstone. In the Circle Cliffs the Entrada sandstone, which consists of a massive soft cross-bedded orange-brown sandstone, is about 1,070 feet thick. The Entrada sandstone on Starvation Creek, in the San Rafael Swell, is 675 feet thick, and on Horn Silver Gulch it is 520 feet thick. At both places it is composed of massive cliff-forming red silty sandstone and subordinate shale.

Near Navajo Mountain the Entrada sandstone is overlain by sandstones of the Morrison formation. In the Circle Cliffs it is separated from the Morrison formation by the Summerville formation 90 feet thick. In the San Rafael Swell the Entrada sandstone is unconformably overlain by the marine fossiliferous Curtis formation, a greenish glauconitic sandstone. Along Starvation Creek the Curtis is 76 feet thick, and in Horn Silver Gulch it is 165 feet thick. The Curtis formation everywhere grades upward into the Summerville formation. Near Dellenbaugh Butte, on the Green River, it passes laterally into the Summerville formation.[40] Southward it thins, becomes shaly,[41] and disappears near the Circle Cliffs.

The Summerville formation is 90 feet thick in the Circle Cliffs. On Starvation Creek, in the San Rafael Swell, it is 184 feet thick, though 15 miles northeast of this locality, on Wildhorse Creek, it is 400 feet thick; in Horn Silver Gulch it is 260 feet thick. Along this line of sections the Summerville formation is composed of thin-bedded red-brown sandstones, maroon mudstones, and chocolate-brown shales with gypsum beds common in the upper part.

The Summerville formation in the San Rafael Swell is overlain at some localities with gently angular unconformity by the Morrison formation. At the other localities the local evidence of unconformity is not striking, and the apparent absence of entire units may be due to complete lateral change in lithology or nondeposition.

Mathews [42] has described the Jurassic rocks of the central Wasatch Mountains in Utah, about 130 miles N. 20° W. of Saddle Horse Canyon. The locality might well be considered an extension of the present line of sections. The rocks present he assigned to the Nugget formation, the Twin Creek formation, and the Morrison formation. The Nugget formation contains a basal conglomerate above which lie reddish to white sandstones with minor intercalations of gypsiferous shales and ripple-marked limestones. The thickness has not been determined. A single marine pelecypod was found near the base. Mathews' Twin Creek formation is principally limestone of various types, and its thickness is probably over 2,000 feet. A fauna like that of the Carmel formation occurs in the lower part, and another like that of the Curtis formation occurs in the upper part, as nearly as can be ascertained from the published faunal lists. The formation is said to be unconformable on the Nugget. The Morrison formation consists chiefly of variegated mudstones and rests unconformably on the so-called "Twin Creek." It seems to the writers that the Nugget sandstone is essentially equivalent to the Navajo sandstone. The faunas make it very likely, indeed, that the so-called "Twin Creek formation" of Mathews' report is equivalent to the San Rafael group.

[40] Sears, J. D., and McKnight, E. T., personal communications.

[41] Gilluly, James, and Reeside, J. B., Jr., op. cit., pp. 78–79.

[42] Mathews, A. A. L., Mesozoic stratigraphy of the central Wasatch Mountains: Oberlin Coll. Lab. Bull., new ser., no. 1, pp. 40–48, 1931.

ROUGH ROCK, ARIZONA, TO FLAMING GORGE, UTAH

The line of sections shown in figure 2 is oriented nearly due north, approximately parallel to and 65 to 85 miles east of that shown in figure 1. It passes from Rough Rock, Ariz., by way of Comb Ridge, Indian Creek, upper Salt Valley (pl. 26, *A*), and Dinosaur Quarry to Flaming Gorge, Utah. All the sections shown were obtained by the writers, and those at Dinosaur Quarry and in Flaming Gorge have been previously published.[43] In addition, the intervals between Rough Rock, Comb Ridge, and Indian Creek are in part bridged by sections obtained at several localities not shown in the illustration and by visits to other intervening localities. In the central part the line crosses an area which has been mapped in detail and in which the formations have been carefully traced. In the northern part a long interval under the Uinta Basin is wholly unknown. This line of sections again shows the Navajo sandstone to have a lenticular form and the overlying San Rafael group to thicken from a thin edge on the south to a considerable thickness northward and to acquire a fossiliferous member at the top. The Chinle formation below and the Morrison formation above are recognized at all the localities. The Kayenta and Wingate formations are present in the south but do not appear north of the Uinta Basin.

The upper contact of the Chinle formation is fairly sharp near Rough Rock, but elsewhere it is difficult to draw a definite boundary between the sandstones in the upper part of the Chinle formation and the overlying Wingate sandstone.

The Wingate sandstone is typically developed as a cliff-forming, vertically jointed sandstone at Comb Ridge, on Indian Creek, and in the upper part of Salt Valley, where its thickness is 345, 300, and 295 feet, respectively. Near Rough Rock it contains a lower division, 100 feet thick, of earthy dark-red sandstone that weathers into small bosses and rounded forms and

[43] Reeside, J. B., Jr., Notes on the geology of Green River Valley between Green River, Wyo., and Green River, Utah: U. S. Geol. Survey Prof. Paper 132, pp. 37, 44, 1923.

is characterized by vertical jointing, and an upper more massive division, 200 feet thick and of lighter color, that weathers into large domes.

In this line of sections the Kayenta formation has its typical lithology (pl. 7, *B*) of irregularly bedded gray to lavender and red sandstones, red-brown to lavender shale, and some limestone conglomerates. Near Rough Rock its thickness is 30 feet, but it thickens northward to about 100 feet on Comb Ridge, 270 feet on Indian Creek, and 205 feet in the upper part of Salt Valley.

The Navajo sandstone thins toward both the north and south ends of the section, making its cross section lens-shaped. Near Rough Rock it is 100 feet thick. It thickens northward to about 500 feet at Comb Ridge and 425 feet on Indian Creek and then thins to 245 feet in the upper part of Salt Valley. It is not recognized with certainty north of the Uinta Basin in the Uinta Mountains, though it is believed to be present in the so-called "Nugget sandstone" of that region. Throughout the section the Navajo sandstone is a buff to gray, intricately cross-bedded massive sandstone with a few thin lenses of nonfossiliferous limestone.

The San Rafael group in this line of sections cannot be correlated with as much confidence as the Glen Canyon group. Near Rough Rock the Morrison formation apparently rests directly upon the Navajo sandstone, and no strata that can be correlated with the formations of the San Rafael group have been recognized. However, a thin buff to red sandstone and the underlying red shales and sandstone and overlying red sandy shale, all of which crop out in the valley just south of Kayenta, Ariz., 45 miles northwest of Rough Rock, are believed to represent the Carmel, Entrada, and Summerville formations and to be nearly at the southern limit of the San Rafael group. At Bluff, Utah, in the upper part of the Comb Ridge section, an orange-red sandy shale about 50 feet thick and an orange-red sandstone 30 feet thick are correlated with the Carmel formation and the Entrada sandstone, respectively. As much as 75 feet of well-bedded sandstone and shale above the Entrada is correlated somewhat doubtfully with the Summerville.

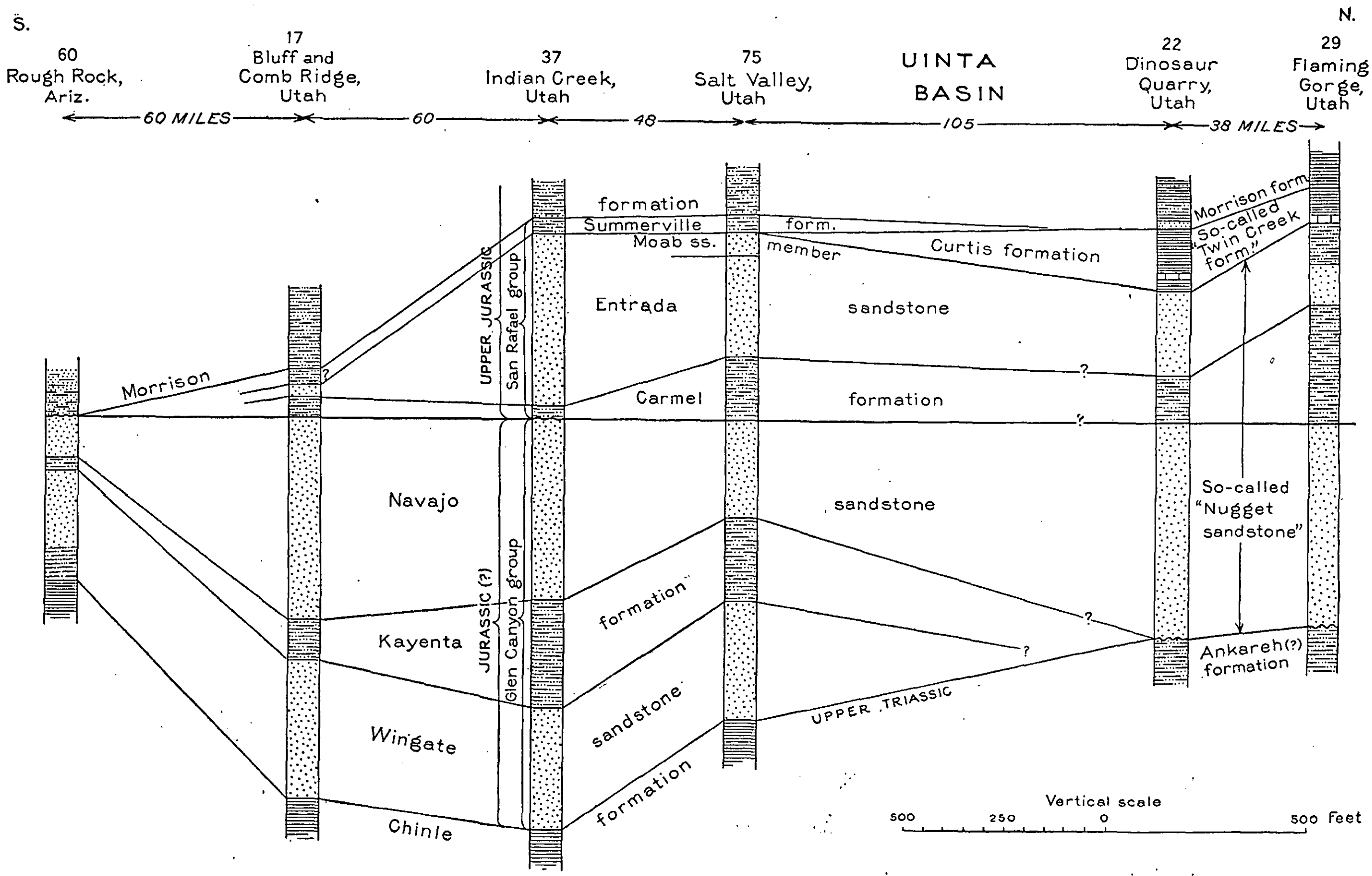


FIGURE 2.—Sections from Rough Rock, Ariz., to Flaming Gorge, Utah

In the central sections the Carmel formation is a thin unit of red sandy shale and mudstone, in which the bedding has suffered much contortion. It is 10 feet thick in Cottonwood Wash, 25 miles north of the San Juan River, 30 feet thick on Indian Creek, and 150 feet thick in the upper part of Salt Valley. It is not recognized in the Uinta Mountains but is believed to be present in the so-called "Nugget sandstone" of that region.

The Entrada sandstone is 100 feet thick and massive in Cottonwood Wash and continues to thicken northward to 425 feet on Indian Creek. In the upper part of Salt Valley it is only 300 feet thick. A single bed of light-gray sandstone, 55 feet thick, at the top of the Entrada sandstone in Salt Valley is correlated with the Moab sandstone member.[44] The Entrada sandstone is represented on the south flank of the Uinta Mountains by some part of the so-called "Nugget sandstone," which is nearly 900 feet thick at Dinosaur Quarry and contains in the upper part a red-bed member. It is even thicker (nearly 1,000 feet) on the north flank, in Flaming Gorge (pl. 21, *A*), and has also a red-bed member. Whether the lower part of this so-called "Nugget sandstone" is Navajo, the red-bed unit Carmel, and the relatively thin overlying sandstone Entrada, the writers cannot say definitely, as they have not seen the region west of the Green River and have not sufficient data on which to base a judgment. This sandstone has long been called "Nugget," but the evidence of the Curtis fossils above it would seem to place it, in part at least, as younger than the real Nugget of southwestern Wyoming and the Wasatch Mountains, which is considered to be equivalent to the Navajo sandstone.

Resting upon the Entrada with conformity is a zone of marine beds—gray oolitic limestone, gray shales, and thin buff calcareous sandstone. The fossils are like those of the Curtis of the San Rafael Swell. This unit has long been called "Twin Creek" but is better designated "Curtis", as it is younger than the typical Twin Creek of southwestern Wyoming, which is now considered to be wholly of Carmel age. It is 180 feet thick at the Dinosaur Quarry and about 75 feet thick in Flaming Gorge.

The Summerville formation at Indian Creek and in the upper part of Salt Valley, 40 and 45 feet thick, respectively, is composed of red thick-bedded shale and mudstone, with abundant chert present locally as large nodules (pl. 22, *D*). It is not recognized in the Uinta Mountains, though it may possibly pass into the Curtis of that area.

Above the San Rafael group at both Kayenta and Bluff are thin and uniformly bedded red and gray sandy shale and sandstone. This unit has suffered deformation much like that of the red-bed facies of the Carmel formation and largely on that account has been previously correlated with it.[45] The overlying gray cliff-forming sandstone, known at Bluff as the "Bluff sandstone", has been correlated lately with the Entrada, though Butler[46] in 1920 had already considered the sandstone at Bluff to be Salt Wash and therefore a part of the Morrison formation (then called †"McElmo"). The more recent data, showing the southward thinning of the San Rafael group and the presence of this group in the beds under the contorted unit, together with a wider acquaintance with the variations in the lithology of the Morrison formation, have convinced the writers that the contorted beds at Bluff and over a large adjacent area are the basal part of the Morrison formation and that the overlying sandstone is therefore also Morrison. The sandstone at Bluff, in addition, differs from the Entrada sandstone in its color and texture and is much more like sandstones elsewhere assigned to the lower Morrison, particularly in McElmo Canyon and in the San Juan Mountain area; and the contorted beds in part grade laterally into part of the so-called "Bluff sandstone" in places, indicating the close relationship between them.

In the central sections massive gray sandstones with interbedded red shales constitute the basal Salt Wash member of the Morrison formation, above which lie mudstone and sandstone, in part conglomeratic. This member overlies the Summerville formation on Indian Creek and in the upper part of Salt Valley with apparent conformity. In the Uinta Mountains most of the Morrison consists of soft mudstone with a few lenticular conglomeratic sandstones.

ZUNI, NEW MEXICO, TO VERMILION CREEK, COLORADO

The line of sections shown in plate 2 is, like those of figures 1 and 2, oriented approximately north. It crosses the region near the east boundary of Utah and Arizona, 40 to 45 miles east of the line of figure 2. There is a long interval in the northern part, across the eastern extension of the Uinta Basin, where younger rocks conceal the Jurassic formations. Sections of the Jurassic rocks were measured by the writers at Lupton, Ariz.; Toadlena, N. Mex.; Red Rock, Ariz.; Biltabito Dome (pls. 6, *C*; 23, *A*), N. Mex.; McElmo Canyon, Bush Canyon, Bedrock (in Paradox Valley) (pl. 18, *B*), Sinbad Valley, Serpents Trail, and Midland Ridge, Colo. The sections at Zuni and Todilto Park, N. Mex., and on Vermilion Creek, Colo., were measured by Winchester,[47] Gregory,[47a] and Sears,[48] respectively. The Chinle formation—in the northernmost sections long called "Ankareh"—is recognized in all the sections. The Wingate formation is recognized in all but the two northernmost sections and exhibits a lenticular cross section. The Kayenta formation is present in the central part, and the Navajo sandstone also as a thin lens. A thin representative of the San Rafael group is present in the middle sections, consisting chiefly of Entrada sandstone, which thickens

[44] Baker, A. A., and others, Notes on the stratigraphy of the Moab region, Utah: Am. Assoc. Petroleum Geologists Bull., vol. 11, p. 804, 1927.

[45] Longwell, C. R., and others, Rock formations in the Colorado Plateau of southeastern Utah: U. S. Geol. Survey Prof. Paper 132, pl. 1, 1923. Gilluly, James, and Reeside, J. B., Jr., Sedimentary rocks of the San Rafael Swell and some adjacent areas in eastern Utah: U. S. Geol. Survey Prof. Paper 150, p. 74, 1928. Lee, W. T., Boyer, W. W., and Gilluly, James, Possibility of finding oil in southeastern Utah and southwestern Colorado: U. S. Geol. Survey Press Mem. 6064, p. 3, 1926.

[46] Butler, B. S., The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, p. 84, 1920.

[47] Winchester, D. E., unpublished notes.

[47a] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, pp. 54, 55, 57, 1917.

[48] Sears, J. D., Geology and oil and gas prospects of part of Moffat County, Colo., and southern Sweetwater County, Wyo.: U. S. Geol. Survey Bull. 751, p. 278, 1925.

northward and acquires a marine upper member in the northernmost sections.

In McElmo Canyon and Bush Canyon and at Biltabito Dome the base of the Jurassic(?) sequence is not exposed. At Biltabito Dome the base of the section is believed to be near the base of the Wingate, though this cannot now be proved. At all the other localities the Chinle formation is exposed, and in the southern sections it is overlain with apparent conformity by the Wingate sandstone.

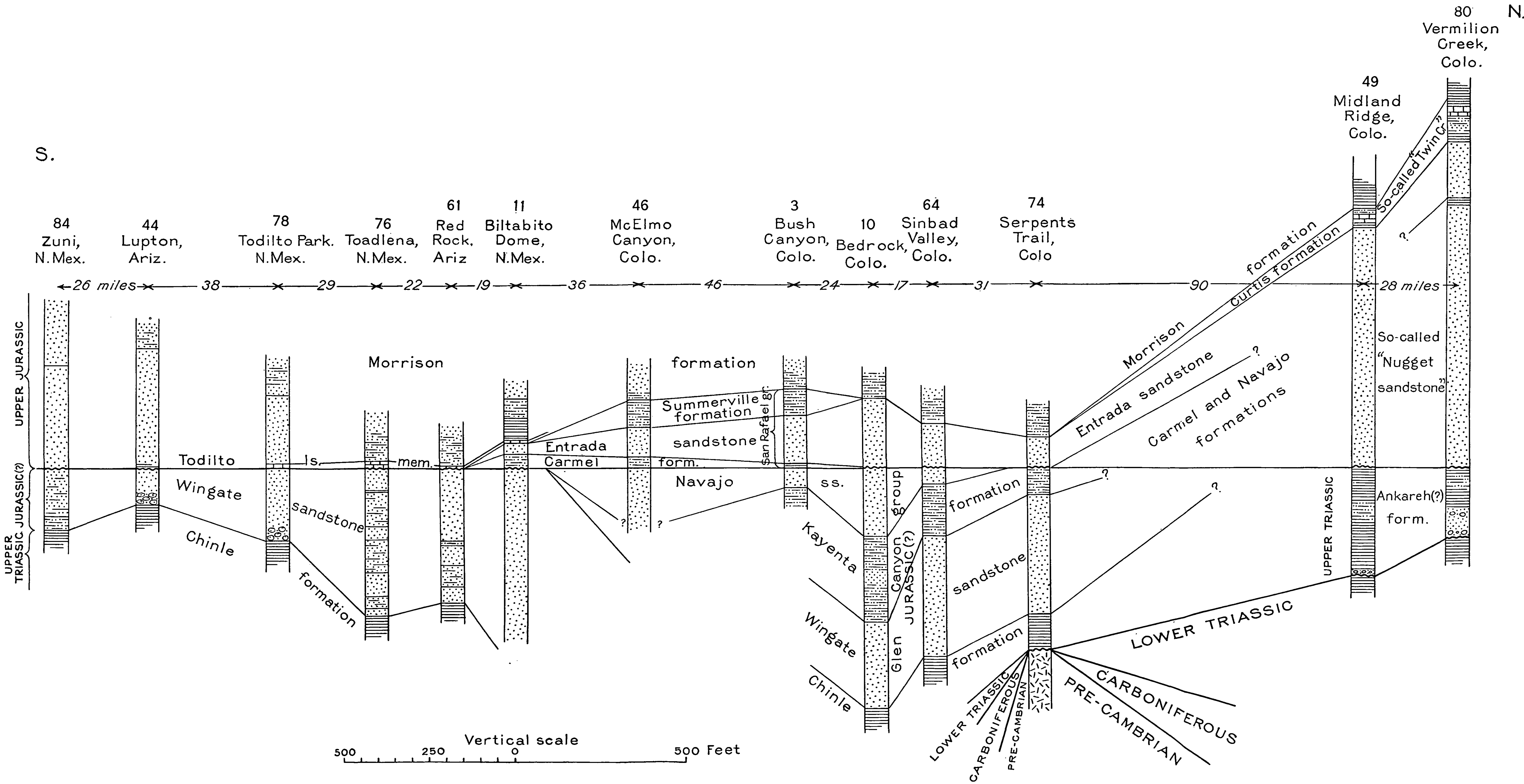
The Wingate sandstone in the central sections is relatively thick, at some places massive and cliff forming and at others in thick beds separated by shale (pl. 6, *C*). It is thin and unresistant in the south and is not present in the north. Apparently the line of sections almost completely crosses the basin of Wingate deposition. At Zuni the Wingate is 175 feet thick and composed of buff sandstone and red shale, thicker bedded toward the top. It was estimated to be 100 feet thick at Lupton, where it is a massive red cliff-forming sandstone. The Wingate sandstone at Todilto Park, much like that at the type locality, is 210 feet thick and composed of massive reddish-brown cliff-forming sandstone except in the lower 50 feet, which is earthy and rather soft. At Toadlena the Wingate sandstone is 430 feet thick and contains four ledge-forming layers of salmon-red cross-bedded sandstone separated by somewhat thicker soft zones of deeper red earthy sandstone and shale. The topmost of the ledges is the thickest. The Wingate here is distinguished from the underlying Chinle formation only by its hard ledge-forming layers, and the boundary adopted is somewhat arbitrary. A few miles south of the Red Rock trading post the Wingate is about 400 feet thick and is composed of four massive buff to red sandstones with several zones of softer sandstone and shale that form benches. The topmost sandstone is thickest here, and the base is an arbitrary boundary. A section with similar lithology at Biltabito Dome showed 470 feet of Wingate sandstone, though the base of the exposure may not be quite as low as the actual base of the Wingate. This sandstone does not crop out in either McElmo Canyon or Bush Canyon. At Bedrock, in Sinbad Valley, and at Serpents Trail the Wingate sandstone is a thin-bedded to massive red to buff cliff-forming sandstone of the facies common in southeastern Utah (pl. 18, *B*). It is 250 feet thick at Bedrock and 350 feet thick in Sinbad Valley and at Serpents Trail, but does not appear farther north.

The middle unit of the Glen Canyon group, the Kayenta formation, is present only in the middle part of this line of sections, with the possible exception of 25 to 50 feet of thin-bedded sandstone and conglomerate that rest upon the Wingate sandstone at Lupton. The upper few feet of the Kayenta formation crops out in Bush Canyon. It is about 250 feet thick at Bedrock, in Paradox Valley (pl. 18, *B*), but thins northward to 150 feet in Sinbad Valley and 80 feet at Serpents Trail. It seems probable that the Kayenta extends farther south than McElmo Canyon, as is shown in plate 2, although there are no exposures to bring it to the surface.

The southernmost occurrence of the Navajo sandstone on this line of sections is in McElmo Canyon, where an incomplete exposure shows 165 feet of massive cross-bedded yellowish-tan sandstone. The log of a well drilled in McElmo Canyon records a great thickness of sandstone beds, but the writers are not able to determine in it the base of the Navajo or identify the underlying formations. In Bush Canyon the Navajo sandstone is 50 feet thick. At Bedrock it is 200 feet thick where measured (pl. 18, *B*), but in the northeast wall of the valley it is thin or absent. In Sinbad Valley it is 40 to 50 feet thick. It is not present at Serpents Trail. The line of sections is very nearly the eastern limit of the formation. At Midland Ridge and on Vermilion Creek the so-called "Nugget sandstone" may contain an equivalent of the Navajo sandstone.

The Carmel formation is not a conspicuous unit at the localities shown in this line of sections. At Biltabito Dome red shale and mudstone 38 feet thick rest upon the Wingate sandstone and are here interpreted as the Carmel formation. In McElmo Canyon and Bush Canyon red muddy sandstone beds about 20 feet thick form a bench between the Navajo sandstone and the Entrada sandstone and are correlated with the Carmel formation principally because of their stratigraphic position. At Bedrock and in Sinbad Valley nothing strongly suggestive of the Carmel formation is present, the Entrada sandstone resting directly upon the Navajo sandstone (pl. 18, *B*). North of Sinbad Valley the Entrada rests upon the Kayenta.

The Entrada sandstone is present only in the northern part of this line of sections. At Biltabito Dome 38 feet of massive orange-red to gray cross-bedded sandstone is correlated with it (pl. 23, *A*). It is 83 feet thick in McElmo Canyon, 125 to 150 feet thick in Bush Canyon, about 200 feet thick at Bedrock, 125 feet thick in Sinbad Valley, and 85 feet thick at Serpents Trail. The Entrada sandstone rests upon the Carmel formation at Biltabito Dome, in McElmo Canyon, and in Bush Canyon; directly upon the Navajo sandstone at Bedrock and in Sinbad Valley; and upon the Kayenta formation at Serpents Trail. There is no measurable angular discordance or marked indication of erosion at the base of the Entrada sandstone, but the contact is very sharp, and its extension over successively older formations is believed to be a normal overlap over beds with smaller areas of deposition. The constitution of the section changes under the Uinta Basin, for on the northern margin a very thick, massive sandstone appears, the so-called "Nugget" of the literature. It is 700 feet thick at the Midland Ridge anticline (pl. 21, *C*) and 950 feet thick



SECTIONS FROM ZUNI, N. MEX., TO VERMILION CREEK, COLO.

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on Vermilion Creek. It seems undoubtedly to contain an equivalent of the Entrada and may also include an equivalent of the Navajo.

In the two northernmost sections the so-called "Nugget" is succeeded conformably by a marine fossiliferous unit of shale, sandstone, and limestone. It is about 50 feet thick at Midland Ridge and 125 feet on Vermilion Creek. This marine unit is the so-called "Twin Creek formation" of the literature of this area but, like its equivalent farther west shown in figure 2, would best be called "Curtis", as the typical Twin Creek limestone of southwestern Wyoming is considered to be of Carmel age.

The Summerville formation cannot be recognized with complete confidence at any of the localities in this line of sections. Because of similarity in lithology to beds of Summerville age farther west a unit of thin-bedded red sandstone, shale, and mudstone 75 feet thick in McElmo and Bush Canyons is tentatively correlated with the Summerville formation but possibly should be included in the Morrison formation.

The Morrison formation is present throughout this line of sections. In the southern part, nearly as far north as Toadlena, it is composed predominantly of massive buff to light-gray and pinkish sandstone, but farther north it contains, especially in the upper part, the variegated mudstones and other rocks more typical of the formation. A short distance north of the school at Toadlena the Todilto limestone crops out as a persistent narrow but low ridge. The following section was measured at this place.

Section north of school at Toadlena, N. Mex.

	Ft.	in.
Dakota (?) sandstone.		
Morrison formation:		
Principally greenish and variegated shale	200±	
Sandstone, fine-grained, soft, earthy, pinkish buff, poorly exposed	400±	
Sandstone, greenish white, slightly argillaceous, with one irregular red streak at the base		6
Sandstone, argillaceous, soft, greenish-gray		6
Todilto limestone member:		
Limestone, dense, light gray, hard irregularly thin-bedded, with small concretions of crystalline calcite; top beds discontinuous and equivalent to shaly and sandy beds at places	7	
Limestone, shaly, thin-bedded, gray	5	
Clay, soft, very sandy, gray, and sand, argillaceous, with a few layers of soft greenish-gray sandstone, light greenish-gray clay, and hard white sandstone	4	
Sand, earthy, red, soft	3	
Contact sharp but poor exposures of soft rock reveal no irregularities.		
Wingate sandstone: Top 6 inches weathers white; remainder is buff to red sandstone.		

At Todilto Park and northward to Biltabito Dome the thin Todilto limestone forms the basal member of the Morrison, becoming discontinuous, however, at Red Rock and Biltabito Dome. Five miles south of the Red Rock trading post the top of the Wingate sandstone is exposed. The top 15 feet is a medium- to coarse-grained buff sandstone with some irregular thin muddy streaks. A 3-foot overlying bed of red softer muddy sandstone probably also goes in the Wingate. This is succeeded by a bed, about 1 foot thick, of red muddy sandstone and thin sandy limestone which is included as the lower part of the Todilto limestone member of the Morrison. Above this lies a bedded dense gray limestone 3 feet thick. The top is not exposed, but white Morrison sandstone crops out just across the shallow valley to the east. At another locality 4 miles from Red Rock on the road to Lukachukai and Round Rock the basal Morrison is a white and gray coarse grit and sandstone with no limestone exposed at the base.

The discontinuous Todilto limestone rests, at Biltabito Dome, on a thin series of beds which the writers correlate with the San Rafael group, but at Red Rock, Toadlena, and Todilto Park it rests with very sharp contact on Wingate sandstone. At Red Rock and Toadlena it is overlain by thin white sandstones and reddish and variegated shale much like those present in the basal part of the Morrison farther north in this line of sections where the Salt Wash member of the Morrison is recognized. The Salt Wash member consists of interbedded gray to white massive sandstones and red shale or shaly sandstone.

A massive sandstone that rests upon the Wingate at Zuni and Lupton and upon the Todilto limestone member at Todilto Park has been designated "Navajo" by most earlier writers.[49] The regional data now in hand as well as the lithologic characters of the sandstone itself seem to the writers to show definitely that the unit is a part of the Morrison formation and that there is no representative of the Navajo sandstone in the area where this particular member of the Morrison occurs.

RIO SALADO, NEW MEXICO, TO PHIPPSBURG, COLORADO

The line of sections shown in figure 3 is oriented approximately north and is 100 miles east of that shown in plate 2. It passes from the Rio Salado, N. Mex., by way of the western part of the Chama Basin, the Piedra River, Gunnison, Scofield Park, Maroon Canyon, Snowmass Canyon, Basalt, Brush Creek, Wolcott, and the Colorado River above Dotsero to Phippsburg, Colo. The sections in New Mexico are taken from Darton,[50] and those on the Piedra River from Cross and Larsen.[51] The remainder were measured by the writers. The line of sections in its middle part crosses an old positive area where the Morrison formation rests directly upon rocks of pre-Cambrian age. The

[49] See, for example, Darton, N. H., "Red Beds" and associated formations in New Mexico: U. S. Geol. Survey Bull. 794, p. 145, 1928 [1929]. Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, p. 57, 1917.

[50] Darton, N. H., op. cit., p. 167.

[51] Cross, Whitman, and Larsen, E. S., Contributions to the stratigraphy of southwestern Colorado: U. S. Geol. Survey Prof. Paper 90, p. 45, 1914.

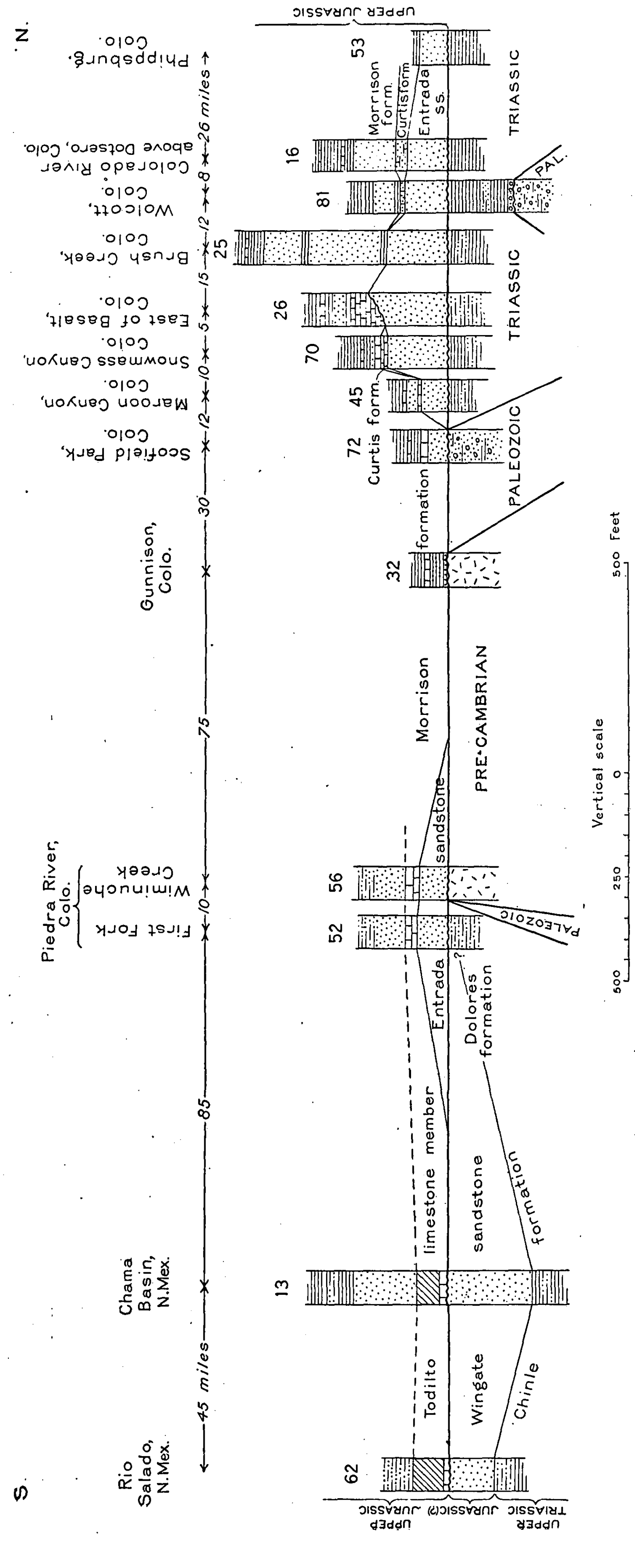


FIGURE 3.—Sections from Rio Salado, N. Mex., to Phippsburg, Colo

Entrada sandstone extends eastward on both sides of the area of pre-Cambrian rocks, and in the northern part of the line of sections an equivalent of the marine Curtis formation is present. In the southern part of the line of sections the Wingate sandstone is recognized. The Morrison formation extends the entire length of this line of sections, containing in the south the Todilto member. The Chinle formation is recognized in the southern part, and equivalent beds of Triassic age (the Dolores formation) in the north.

On the Rio Salado and in the Chama Basin the Wingate sandstone is a soft, rather muddy salmon-colored sandstone but poorly differentiated from the underlying Chinle shale at most localities. It is about 100 feet thick on the Rio Salado and 200 feet in the Chama Basin but is not recognized farther north. At both of these localities it is directly overlain by the Todilto limestone (and gypsum) member of the Morrison (pl. 24, *A*).

The next younger Jurassic formation present in the line of sections is the Entrada, which is exposed on the Piedra River. The lower †La Plata (Entrada) rests on 350 to 400 feet of Dolores formation at the mouth of the First Fork of the Piedra River,[51] but in 10 miles northeastward to the mouth of Wiminuche Creek it cuts across the Carboniferous Cutler, Hermosa, and Molas formations and the Devonian Ouray and Elbert formations—the whole Paleozoic section of the area—and rests on pre-Cambrian Uncompahgre rocks (pl. 20, *B*). It is there 75 feet thick, has pebbles of pre-Cambrian rocks in the basal part, and is overlain by limestone (25 feet) and sandstone (70 feet), the three units constituting Cross' normal †La Plata sandstone sequence. The two upper units are surely Morrison and seem to the writers probable equivalents of the Todilto member and overlying sandstone of New Mexico.

In the region adjacent to the Gunnison River the Morrison formation alone is present, resting directly on the pre-Cambrian crystalline rocks. At Bostwick Park, 40 miles to the west, a thin representative of the Wingate rests on pre-Cambrian, but at Sapinero, 20 miles to the west, and at other nearer localities only the Morrison is present. However, at Scofield Park, 30 miles north of Gunnison, a very thin debatable sandstone rests on Carboniferous beds, which have come into the section again. The writers arbitrarily consider this sandstone to be also a Morrison sandstone, but it is as likely to prove to be Entrada. In Maroon Canyon,

[51] See footnote 51 on p. 17.

near Aspen, undoubted Entrada, though relatively thin (60 feet), is present as a brown massive sandstone. It thickens to 145 feet of light-buff sandstone in Snowmass Canyon and to 190 feet 4 miles east of Basalt (pl. 19, *B*), then thins to 150 feet of light-brown sandstone on Brush Creek south of Eagle, to 103 feet of buff sandstone on the Eagle River near Wolcott, to 95 feet on the Colorado River, and to 70 feet near Phippsburg. Apparently there are in this line of sections two separate lobes of Entrada sandstone separated by the pre-Cambrian rocks along the Gunnison River.

In Snowmass Canyon the Entrada sandstone is overlain with gradational contact by 11 feet of beds—soft gray sandstone in the lower part, passing upward through sandy oolitic limestone into dark-gray shale with some layers of impure limestone. From these limestone layers a few species of marine pelecypods were obtained, as follows: *Cardinia* sp., *Modiola subimbricata* Meek, *Thracia?* sp., *Astarte* sp., *Dentalium?* sp. (U. S. G. S. locality 15405).

Resting with very sharp base on this marine zone is a single massive bed of gray oolitic limestone, 10 feet thick and containing *Chara*-like algae; then 5 feet of bedded gray limestone, followed by greenish shale, 15 feet of buff sandstone, and some hundreds of feet of shales of typical Morrison aspect (pl. 19, *C*). The writers assign the massive limestone and overlying beds to the Morrison and consider the marine zone an approximate equivalent of the Curtis formation. Near Basalt a similar, perhaps the same basal fresh-water limestone is thicker—28 feet at Wingo siding and 50 feet 4 miles east of Basalt—with marked erosional irregularity at the base. On Brush Creek, 15 miles farther north, however, nearly 200 feet of sandstone, rather fine grained and brownish, rests on the Entrada with only a few feet of softer beds between. No trace of the marine beds was found at Basalt nor on Brush Creek. On the Eagle River near Wolcott the marine zone is again present as an oolitic sandy rock which grades irregularly both vertically and laterally into oolitic limestone or into clean sandstone. It is highly variable and can be separated only arbitrarily from the Entrada: in a short distance it ranges from 7 to 25 feet in thickness by changing in lithology. Above the marine zone are 14 feet of soft variegated shales and 50 feet of massive greenish-white to gray-white sandstone and then normal Morrison shale, limestone, etc. The marine zone here yielded *Cardinia* sp., *Modiola subimbricata* Meek, *Pleuromya* cf. *P. newtoni* Whitfield, *Pleuromya* sp., *Homomya* sp., and *Trapezium subequalis* Whitfield (U. S. G. S. locality 15399). On the Colorado River 16 miles above Dotsero the marine zone is again the curious lime-oolite sandy rock, dark gray in the aggregate and 24 feet thick. Here *Pentacrinus asteriscus*, *Ostrea strigilecula*, *Camptonectes* sp., *Neritina?* sp., *Modiola* sp., and *Tancredia?* sp. were noted. Above the marine zone lies 108 feet of massive, rather soft greenish-gray sandstone which the writers place in the Morrison formation, then fine-grained rocks of the usual Morrison types. At Phippsburg only a few feet of marine beds were exposed above the Entrada sandstone, though abundant float indicated a considerably greater thickness than could be seen.

Throughout the northern part of this line of sections it is notable that as a rule a more or less arbitrary boundary must be drawn between the Morrison and the preceding rocks. A difference in gross lithology is plain enough between the Entrada and Morrison formations, but at most places there is no abrupt change of lithology nor striking evidence of unconformity.

GOODSPRINGS QUADRANGLE, NEVADA, TO PIEDRA RIVER, COLORADO

The line of sections shown in plate 3 extends from the Goodsprings quadrangle, Nev., N. 45° E. to the Muddy Mountains, Nev., thence N. 80° E. through Lees Ferry, Ariz., Navajo Mountain and Comb Ridge, Utah, and McElmo Canyon and Durango, Colo., to the Piedra River, Colo., roughly at right angles to the lines of figures 1 to 3 and plate 2.

It shows the Jurassic strata thick in the west and thinning eastward. The Navajo exhibits this thinning very strikingly; the San Rafael group in less marked fashion and with some irregularity. The Wingate and Kayenta show a complete lenticular cross section. The sections at Navajo Mountain and Comb Ridge, Utah, and McElmo Canyon and Durango, Colo., were measured by the writers. The section in the Goodsprings quadrangle was measured by Hewett,[52] in the Muddy Mountains by Longwell,[53] in Kanab Canyon by Walcott,[54] at Lees Ferry by Bryan,[55] and on the Piedra River by Cross and Larsen.[56] The writers have not examined the sections in the Goodsprings quadrangle and the Muddy Mountains and on the Piedra River.

The characteristic red sandstones and shales of the Chinle formation in the west and the Dolores formation in the east appear at the base of all the sections except that in McElmo Canyon, where the section is incompletely exposed.

The Wingate sandstone is not recognizable at Lees Ferry but may possibly be represented by thin beds

[52] Hewett, D. F., Geology and ore deposits of the Goodsprings quadrangle, Nev.: U. S. Geol. Survey Prof. Paper 162, p. 35, 1931.

[53] Longwell, C. R., Geology of the Muddy Mountains, Nev.: U. S. Geol. Survey Bull. 798, pp. 62–68, 1928.

[54] Walcott, C. D., in Cross, Whitman, and Howe, Ernest, Red beds of southwestern Colorado and their correlation: Geol. Soc. America Bull., vol. 16, pp. 484–485, 1905.

[55] Bryan, Kirk, in Longwell, C. R., and others, Rock formations in the Colorado Plateau of southeastern Utah and northern Arizona: U. S. Geol. Survey Prof. Paper 132, pl. 1, 1923.

[56] Cross, Whitman, and Larsen, E. S., Contributions to the stratigraphy of southwestern Colorado: U. S. Geol. Survey Prof. Paper 90, p. 47, 1915.

of sandstone now assigned to the topmost part of the Chinle formation. It forms a sheer wall 300 feet high near Navajo Mountain and is 345 feet thick at Comb Ridge. The Wingate sandstone is not exposed in McElmo Canyon, and the writers were unable to distinguish it from other sandstones in the log of a well drilled there. In the canyon of the Animas River above Durango an earthy red sandstone 60 feet thick at the top of the Dolores formation is taken to be the Wingate, although it may perhaps be only a local sandstone of the Dolores. Any such correlation of units across the concealed intervals from Comb Ridge to Durango would be of very doubtful value if the relationships and the trend of changes in the rocks had not been determined with some assurance over a large area. It seems quite likely on the basis of the general studies that the Wingate, as such, extends as far as Durango, and that it may be represented on the Piedra River by thin sandstones in the uppermost part of the Dolores formation but has not been discriminated as a separate formation.

The Kayenta formation is not recognized at Lees Ferry but is 150 to 225 feet thick in the vicinity of Navajo Mountain and about 100 feet thick where the San Juan River crosses Comb Ridge. At these localities it shows the normal lithology. It is not exposed in McElmo Canyon and is not recognized at Durango or on the Piedra River.

The Wingate sandstone was believed by most earlier writers [57] to be present in the region west of Navajo Mountain but to be generally inseparable from the overlying Navajo sandstone and with it to form a thick unit of massive sandstone, which was variously named. The present writers interpret the data now in hand as showing that the Wingate sandstone and the overlying Kayenta formation thin westward and are entirely absent at outcrops west of Navajo Mountain or are represented only by thin indefinite units that are not separable from the underlying Chinle formation.

The Navajo sandstone is not fully represented in the Goodsprings quadrangle nor in the Muddy Mountains, Nev., for the top is eroded and the next younger beds in the region are of Tertiary age. Even so the thickness still remaining in the Goodsprings quadrangle, where Hewett called it the Aztec sandstone, is at least 2,100 feet. In the Muddy Mountains it is 2,000 feet thick. In Kanab Canyon the section given by Walcott is complete and amounts to 1,985 feet (Walcott's units 13 to 18). At these localities it is red to buff and white massive sandstone, strikingly cross-bedded on a large scale. In the lower part in Kanab Canyon a soft red zone of shaly beds is present, but this appears to fade out westward and eastward. Gregory [58] in a late publication assigns this red zone to the Kayenta formation and the underlying sandstone to the Wingate formation. At Lees Ferry in a complete section a massive sandstone 1,200 feet thick has been previously correlated with the Glen Canyon group but is correlated by the writers with the Navajo sandstone alone. At Navajo Mountain the thickness is 1,100 feet in a complete section. In Comb Ridge the Navajo is about 500 feet thick, and in McElmo Canyon in an incomplete exposure it is 165 feet thick. East of McElmo Canyon on this line of sections the Navajo sandstone is absent.

The Carmel formation in Kanab Canyon is 410 feet thick and contains a fossiliferous limestone unit below and a red gypsiferous unit above. From Lees Ferry eastward it is a relatively thin unit, eventually wedging completely out. A section measured by Gregory and Moore [59] 8 miles northeast of the Crossing of the Fathers, on the Colorado River above Lees Ferry, includes in the Carmel a thickness of 129 feet. At Navajo Mountain it is 130 feet thick. At Bluff, on the San Juan River above Comb Ridge, as noted in the description of figure 2, it is about 50 feet thick, and in McElmo Canyon it is 20 feet thick. In these sections the Carmel shows the red sandy facies only. The Carmel formation is absent at Durango and on the Piedra River.

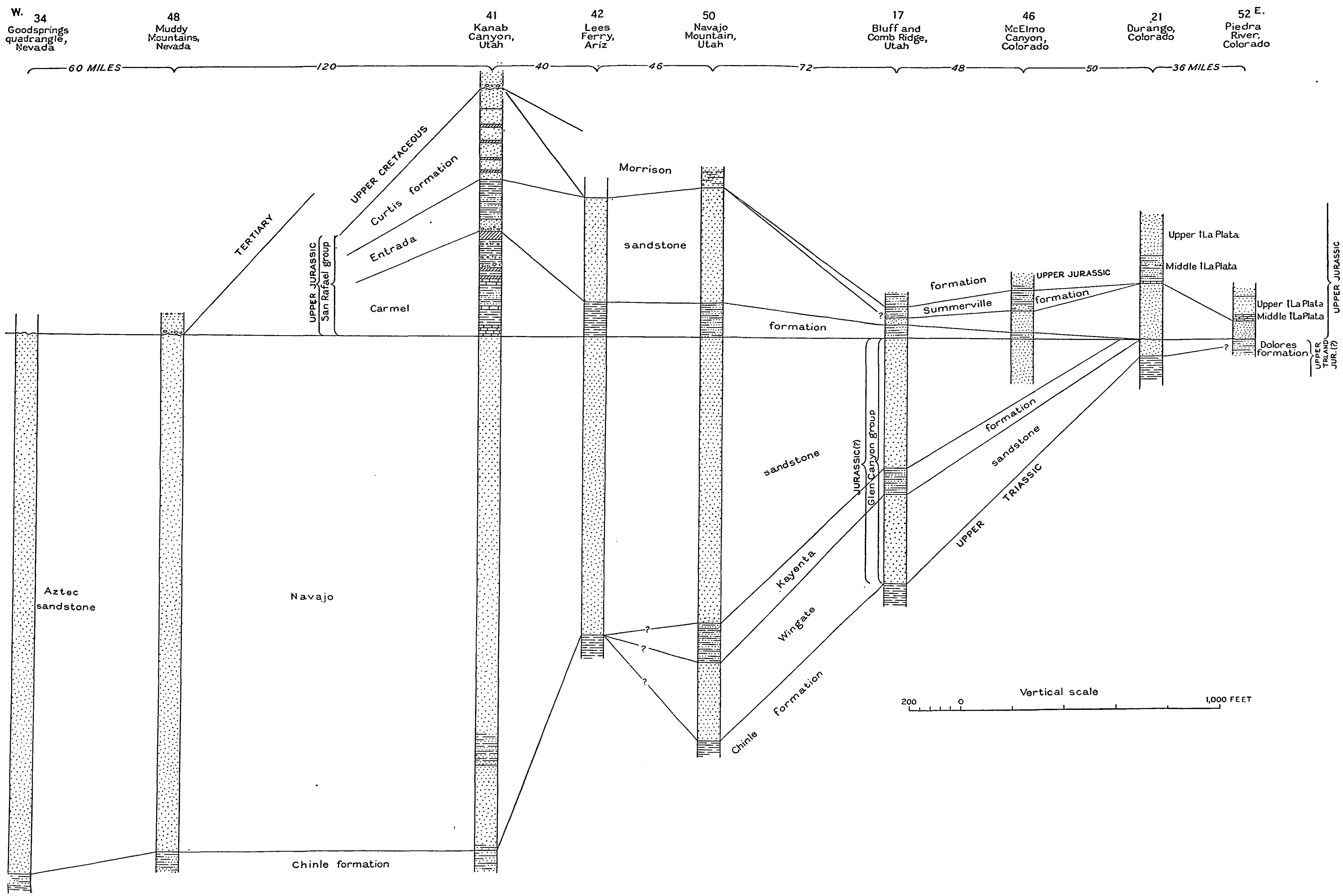
The Entrada sandstone persists from Kanab Canyon eastward to the Piedra River, though there are two areas of maximum deposition; the line of sections appears to cut across two southward-extending tongues. A conglomerate of quartz, sandstone, and limestone and an overlying unit of red sandy shale are tentatively assigned to the Entrada in Kanab Canyon, where the total thickness is 200 feet. Gregory and Moore [60] give a thickness of 400 feet for the Entrada near the mouth of Warm Creek, about 7 miles southwest of the Crossing of the Fathers, above Lees Ferry, and its measured thickness at Navajo Mountain is 440 feet. In the vicinity of Bluff its thickness is about 30 feet. In McElmo Canyon it is 83 feet thick, increasing to 215 feet at Durango and decreasing to 75 feet at the Piedra River. The writers have no data for the region east of the Piedra River, but it seems doubtful that the Entrada extends much farther. The Entrada is a massive cliff-forming orange-red sandstone at Navajo Mountain. It is a conspicuous brown-red ledge in the midst of a 150-foot red zone cropping out above the Navajo in the cliffs rising above the San Juan River at

[57] Longwell, C. R., and others, Rock formations in the Colorado Plateau of southeastern Utah and northern Arizona: U. S. Geol. Survey Prof. Paper 132, p. 13, 1923. Reeside, J. B., Jr., and Bassler, Harvey, Stratigraphic sections in southwestern Utah and northwestern Arizona: U. S. Geol. Survey Prof. Paper 129, p. 64, 1922. Dake, C. L., The horizon of the marine Jurassic of Utah: Jour. Geology, vol. 27, no. 8, pp. 634–646, 1919. Gregory, H. E., and Moore, R. C., The Kaiparowits region, Utah and Arizona: U. S. Geol. Survey Prof. Paper 164, pp. 36, 59–67, 1931. Gilluly, James, and Reeside, J. B., Jr., Sedimentary rocks of the San Rafael Swell and some adjacent areas in eastern Utah: U. S. Geol. Survey Prof. Paper 150, p. 69, 1928. Gregory, H. E., Colorado Plateau region: 16th Internat. Geol. Cong. Guidebook 18, p. 15, 1933.

[58] Gregory, H. E., Colorado Plateau region: 16th Internat. Geol. Cong. Guidebook 18, p. 15, 1933.

[59] Gregory, H. E., and Moore, R. C., The Kaiparowits region, Utah and Arizona: U. S. Geol. Survey Prof. Paper 164, p. 87, 1931.

[60] Gregory, H. E., and Moore, R. C., op. cit., p. 87.



SECTIONS FROM GOODSPRINGS QUADRANGLE, NEV., TO PIEDRA RIVER, COLO.

Bluff. It also crops out near the mouth of Butler and Cottonwood Washes (pl. 19, *A*). In McElmo Canyon it is a massive sandstone with the upper part grayish white and the lower part reddish orange. At Durango the change in color is complete, and the Entrada sandstone is a very massive cross-bedded grayish-white cliff-forming unit, the lower †La Plata of Cross (pl. 26, *C*). On the Piedra River it is white with a light yellowish-gray band at the top, again forming the lower †La Plata (pl. 20, *B*).

In Kanab Canyon the beds above those assigned to the Entrada are light-colored gypsiferous sandstones about 350 feet thick. These appear to be identical with the marine beds assigned to the Curtis at Mount Carmel and are tentatively so correlated here. They do not seem to be present at any other locality in this line of sections.

Above the Entrada sandstone at Bluff is a series of thin-bedded red sandstone and shale, 40 to 75 feet thick, which is considered with some doubt to be equivalent to the Summerville formation. In McElmo Canyon a similar series of bright-red thin-bedded sandstone, shale, and mudstone, 75 feet thick, resting upon the Entrada sandstone and underlying a soft pale-lavender sandstone is correlated with the Summerville formation. This unit of thin-bedded shale and sandstone in McElmo Canyon is not greatly different from parts of the overlying Morrison formation and might with propriety be included in it, but that is true also of beds at localities farther north where more definite data warrant an assignment of such beds to the Summerville. These beds in McElmo Canyon were once included in the †McElmo formation of Cross.

The Morrison formation is present from the vicinity of Lees Ferry eastward. It varies in details of lithology, although maintaining the same general lithologic aspect over a large area. The strata at the base of the formation are not uniform throughout this line of sections. At the Crossing of the Fathers and at Navajo Mountain gray conglomeratic sandstones, locally siliceous, rest upon the Entrada sandstone (pl. 25, *C*). At Bluff the lower part of the Morrison is composed of thin red and gray sandstones and red shales with highly contorted bedding, overlain by a massive gray sandstone that forms the cliffs along the San Juan River and is locally known as the "Bluff sandstone" (pl. 19, *A*). The contorted beds, as noted in the description of figure 2, have been previously correlated with the Carmel formation, and the overlying sandstone with the Entrada. The lower third of the Morrison formation in McElmo Canyon is composed of soft gray to yellow or lavender gritty sandstone. The middle †La Plata at Durango, which is here included in the Morrison formation, is composed of soft red sandstone and shale 60 feet thick, with a basal bed of dense gray limestone, discontinuous but at places 4 feet thick. The contact with the Entrada is sharp. Above this soft zone is interbedded massive gray to light-buff sandstone and purplish-brown sandy shale 45 feet thick, overlain by a thick, massive light-gray to buff sandstone 160 feet thick, the upper †La Plata sandstone of Cross (pl. 26, *C*). On the Piedra River this section of the lower Morrison beds is similar to that at Durango except that the middle †La Plata of Cross and Larsen (the basal Morrison of this paper) is composed of 25 feet of dark shaly limestone, brecciated in the upper part. Cross and Larsen inferred that the soft upper †La Plata sandstone was present in a 70-foot concealed interval above the limestone. They suggested that this upper †La Plata sandstone on the Piedra River should possibly be included in the †McElmo formation.[61] The basal Morrison limestone is discontinuous, perhaps because of deposition in depressions in the underlying Entrada sandstone, though no indisputable evidence of unconformity between the Morrison and underlying formations was noted at the localities of this line of sections.

DIAMOND VALLEY, UTAH, TO OURAY, COLORADO

The line of sections shown in plate 4 extends about N. 75° E. from Diamond Valley, Utah, to the Henry Mountains, Utah, and almost due east from the Henry Mountains to Ouray, Colo. It is roughly parallel to that shown in plate 3 and 50 miles farther north. It shows the progressive thinning of the Navajo sandstone from west to east, also a complete lenticular cross section of the Wingate and Kayenta formations and the changes eastward in the San Rafael group that leave only the Entrada sandstone.

The sections at Diamond Valley, Zion Canyon, the Paria River, Escalante, the Flattops in the Green River Desert, and Indian Creek, Utah, and at Bush Canyon, Gypsum Valley, the San Miguel River, and Placerville, Colo., were measured by the writers. The section at the Circle Cliffs, Utah, was measured in part by Gregory and Moore[62] and is in part from observations by the writers; and that at Ouray, Colo., by Burbank.[63] The present writers have not examined the complete section in the Circle Cliffs.

Red sandstone and shale of the Chinle formation or, in the Rocky Mountains, the Dolores formation are present beneath the lowest Jurassic formations in each section except in Bush Canyon, where the base of the Wingate sandstone is not exposed.

The Wingate sandstone is recognized in the sections from the Circle Cliffs eastward, except perhaps at Ouray, and rests with apparent conformity upon the underlying red sandstone and shale. Its thickness at the Circle Cliffs averages 300 feet. In the Henry Mountains it forms the major part of the 500-foot sandstone called †"Vermilion Cliff sandstone" in early

[61] Cross, Whitman, and Larsen, E. S., Contributions to the stratigraphy of southwestern Colorado: U. S. Geol. Survey Prof. Paper 90, p. 47, 1915.

[62] Gregory, H. E., and Moore, R. C., The Kaiparowits region, Utah and Arizona: U. S. Geol. Survey Prof. Paper 164, p. 61-89, 1931.

[63] Burbank, W. S., unpublished data.

reports, but its exact thickness is not known. In the Green River Desert and along the valley of Indian Creek its average thickness is about 300 feet. In Gypsum Valley no complete exposure was found, although as much as 200 feet was measured. It seems likely that the total thickness here is less than 300 feet rather than more. Eastward from Gypsum Valley the Wingate sandstone decreases rapidly in thickness and includes a progressively greater number of soft zones. It is 100 feet thick along the San Miguel River 7 miles below Placerville and only 50 feet thick 5 miles northeast of Placerville. At Ouray the Wingate sandstone cannot be definitely identified but may perhaps be represented by thin sandstone beds separated by softer red sandy shales in the upper part of the Dolores formation. Cross [64] long ago considered the Wingate sandstone (then called †"Vermilion Cliff") to be equivalent to part of his Dolores formation. This is surely true of the Dolores as the name was applied in extension of its use westward from the typical area and perhaps even in the typical area.

The Kayenta formation in this line of sections is nearly coextensive with the underlying Wingate sandstone but thins out eastward before the Wingate disappears. It is 175 feet thick in the Circle Cliffs. Gilbert [65] recognized a purple sandstone at the top of his †Vermilion Cliff group in the Henry Mountains but did not differentiate it as a separate formation. It is at least partly equivalent to the Kayenta formation. Near the mouth of Trachyte Creek, southeast of the Henry Mountains, Longwell [66] measured a thickness of 249 feet. In the Green River Desert the Kayenta formation is 260 feet thick. The formation is 270 feet thick at Indian Creek (pl. 7, *B*). It is incompletely exposed in Bush Canyon, is 150 feet thick in Gypsum Valley, and is absent near Placerville and Ouray. Local unconformities have been recognized between the Kayenta formation and the Wingate sandstone, but at most outcrops there appears to be a gradation between the formations and no evidence of an unconformity of marked importance. At its upper contact also the Kayenta formation grades into the overlying Navajo sandstone, so that a sharp boundary between them can seldom be drawn.

As noted in the discussion of plate 3, the writers interpret the Wingate and Kayenta formations to be either absent in the region westward from the Circle Cliffs by thinning out or else inseparable from the Chinle formation by a change in lithology from massive sandstone into softer bedded sandstone and shale. In the past it has been assumed that the Wingate and Kayenta formations were represented by inseparable parts of what is here called "Navajo sandstone."

[64] Cross, Whitman, Stratigraphic results of a reconnaissance in western Colorado and eastern Utah: Jour. Geology, vol. 15, pp. 641–649, 1907.

[65] Gilbert, G. K., Geology of the Henry Mountains, pp. 5–7, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1877.

[66] Longwell, C. R., and others, Rock formations in the Colorado Plateau of southeastern Utah and northern Arizona: U. S. Geol. Survey Prof. Paper 132, pl. 2, 1923.

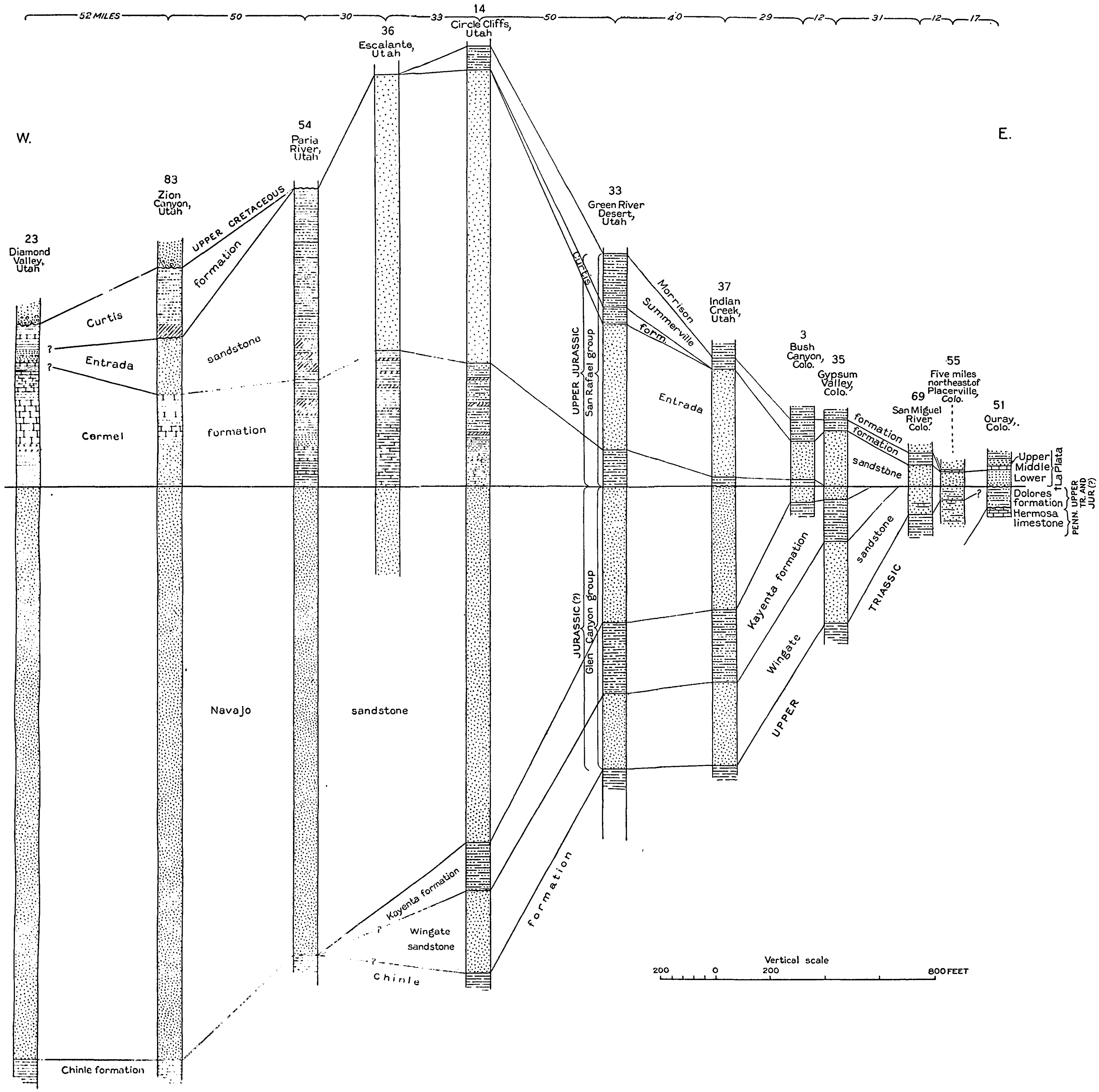
The Navajo sandstone has its maximum development in the western part of the region and thins greatly toward the east. It is not present east of Gypsum Valley but is 50 feet thick on the east wall of the valley and in Bush Canyon. It thickens westward to 425 feet in Indian Creek Valley and is 500 feet thick in the Green River Desert. Gilbert's †Gray Cliff group of the Henry Mountains [67] is described as buff to red cross-bedded sandstone 500 feet thick. It is approximately equivalent to the Navajo sandstone but may include at the base the upper part of the Kayenta formation. The Navajo sandstone thickens rapidly between the Henry Mountains and the Circle Cliffs, where it is reported by Gregory and Moore [68] to be about 1,400 feet thick. West of the Circle Cliffs on this line of sections the Navajo continues to thicken. It is 2,100 feet thick in Coalpits Wash, just west of Zion Canyon, Utah (pl. 9), and about the same at Diamond Valley.

The Carmel formation is present above the Navajo sandstone throughout the part of this line of sections that lies in Utah. The type locality, at Mount Carmel, is not far east of Zion Canyon and practically on the line of sections. The formation thins eastward and is not recognized east of Bush Canyon, Colo. It varies considerably in lithology. At Diamond Valley [69] about 170 feet of red shale and sandstone, with a gypsum bed at the top, rests on the Navajo and is overlain by 55 feet of shale, limestone, and gypsum with marine fossils, followed by 110 feet of cream-colored limestone and 147 feet of light greenish-gray shale and thin limestone containing marine fossils. These beds seem to the writers all part of the Carmel formation. At Mount Carmel the Carmel formation, as interpreted in this paper, contains a variable basal member, 150 to 200 feet thick, of red shale and yellow sandstone, overlain by 150 feet of cream-colored, brown, gray, and greenish-white limestone and limy shale. The limestone member contains marine Upper Jurassic (Callovian) fossils. As noted on page 6 of this paper, Gregory and Moore originally excluded the basal member and included beds above the limestone member. Later Gregory restricted the name "Carmel" to the limestone member. On the Paria River the beds assigned to the Carmel formation include about 150 feet of gray limy shale, sandy limestone, and red and greenish shale, together forming a light-colored unit (pl. 15, *D*), resting upon which are 50 to 75 feet of yellow and white banded massive sandstone (pl. 16, *A*) and 200 feet of red and greenish soft gypseous sandstone and shale with a light-greenish gypsum shale zone at the middle. This upper unit resembles the upper beds of the Carmel of the San Rafael Swell. At Escalante, about 30 miles

[67] Gilbert, G. K., op. cit., p. 6.

[68] Gregory, H. E., and Moore, R. C., The Kaiparowits region, Utah and Arizona: U. S. Geol. Survey Prof. Paper 164, p. 65, 1931.

[69] Reeside, J. B., Jr., and Bassler, Harvey, Stratigraphic sections in southwestern Utah and northwestern Arizona: U. S. Geol. Survey Prof. Paper 129, p. 77, 1922.



SECTIONS FROM DIAMOND VALLEY, UTAH, TO OURAY, COLO.

northeast of the Paria River, the Carmel formation is 500 feet thick; approximately the lower half consists of interbedded limestone and sandstone and the upper half consists of gypsum interbedded with red shale.

The Carmel formation of the Circle Cliffs is 450 feet thick and composed of red and light-blue sandy shale, siliceous limestone, sandstone, and gypsum. In the Henry Mountains it was included by Gilbert in the basal part of his †Flaming Gorge group, but no measurement of its thickness at that locality is available. In the Green River Desert it is 130 feet thick and composed of red sandy shale and gypsum. It contains in the lower part a few feet of fossiliferous marine Jurassic limestone, an extreme southern extension from the San Rafael Swell of the marine limestone facies (pl. 15, *B*). The Carmel is 30 feet thick on Indian Creek and about 20 feet thick in Bush Canyon, at both places consisting of red shale and sandstone with contorted bedding. In Gypsum Valley the Entrada sandstone rests directly upon the Navajo sandstone, and the Carmel formation is absent.

In Diamond Valley the Carmel is succeeded by 45 feet of greenish-gray sandy shale and platy sandstone of uncertain equivalence, which is here tentatively correlated with the Entrada sandstone, though the correlation is weak. The Entrada sandstone is believed by the writers to be represented at Mount Carmel by 200 feet of light-red earthy sandstone which rests upon Carmel limestone and is overlain by a gypsum bed with erosional unconformity. On the Paria River the Carmel is overlain by 250 feet of alternating thin beds of purplish-red shale and gypsum. The bedding is more or less contorted, as are some facies of the Carmel. Above these beds is 200 feet of red muddy "stone baby" sandstone exactly like the Entrada of the western part of the San Rafael Swell, followed by 50 feet of thin-bedded red rocks. These three units together are interpreted by the writers to be the Entrada. Near Escalante, the Entrada consists of about 1,000 feet of soft red silty sandstone with a few layers of buff massive cross-bedded sandstone that are more resistant to erosion. Gregory and Moore [70] described the Entrada sandstone at the Bitter Creek divide, a short distance east of the Circle Cliffs, as composed of massive soft cross-bedded tan to reddish-brown sandstone 1,070 feet thick. The Entrada, according to Gilluly and Reeside,[71] forms the major part of the †Flaming Gorge group of the Henry Mountains described by Gilbert. The thicknesses of the Entrada sandstone at the rest of the localities shown in this line of sections are as follows: Green River Desert, 460 feet; Indian Creek, 425 feet; Bush Canyon, 125 to 150 feet; Gypsum Valley, 350 feet; San Miguel River, 76 feet; 5 miles northeast of Placerville, 50 feet; Ouray, 60 feet. The writers have no data from the region directly east of Ouray, but it is inferred from regional relations that the Entrada sandstone did not extend much farther east.

In and west of the Circle Cliffs the Entrada is a soft red or reddish-brown sandstone, and in the Green River Desert it is a less earthy sandstone with irregular bedding (pl. 17, *A*), but elsewhere along this line of sections it has a typical lithology—cliff-forming; intricately cross-bedded between horizontal bedding planes; orange-brown, pink, or gray frequently banded in shades of orange-brown and tan; and marked by conspicuous rows of solution pits parallel to the bedding (pl. 17, *C*). The Entrada sandstone rests on the Carmel formation as far east as Bush Canyon, in Colorado. Farther east the Entrada rests successively upon the Navajo sandstone, Kayenta formation, and Wingate sandstone and finally upon the Dolores formation where the Wingate sandstone is not recognized, if present at all. The extension of the Entrada sandstone over successively older strata is believed by the writers to be a normal overlap and not to indicate a structural disturbance prior to its deposition.

Cross[72] considered the Navajo sandstone of eastern Utah to be equivalent to his lower †La Plata sandstone, but, as has been stated above, the Navajo does not extend eastward to the typical area of the †La Plata, and the lower †La Plata is Entrada sandstone.

Above the possible Entrada sandstone in Diamond Valley lie 55 feet of brick-red shale containing some thin white limestones and then 40 feet of steel-gray mudstone, above which lie brown Cretaceous sandstones. The equivalence of the shale and mudstone is uncertain, but they may be equivalent to the highest marine fossiliferous zone at Mount Carmel. This zone at Mount Carmel begins with a gypsum bed about 50 feet thick, which rests on an irregular base whose irregularities are as much as 30 feet. The gypsum bed is succeeded by sandy soft beds, reddish in the lower part and gray-white in the upper. About 20 feet above the gypsum the writers found rather poorly preserved shells which include *Ostrea* sp., *Dosinia jurassica* (Whitfield)?, *Neritina* sp., and Ostracoda (U. S. G. S. locality 15498). This marine zone seems to the writers comparable to the Curtis formation of the San Rafael Swell indicated in the section in the Green River Desert. The Circle Cliffs are at the southern edge of the Curtis formation, and it is not present at any other localities in this line of sections east of the Green River Desert. At Mount Carmel it is followed by Cretaceous sandstones.

The Summerville formation may possibly be represented by a 50-foot zone of thin-bedded red rocks at the top of the Jurassic section on the Paria River, though the writers believe it to be better included in the Entrada sandstone. The Summerville in the

[70] Gregory, H. E., and Moore, R. C., op. cit., p. 80.

[71] Gilluly, James, and Reeside, J. B., Jr., op. cit., p. 76.

[72] Cross, Whitman, Stratigraphic results of a reconnaissance in western Colorado and eastern Utah: Jour. Geology, vol. 15, pp. 642, 645, 1907.

Circle Cliffs is described by Gregory and Moore [73] as about 90 feet thick. It is 140 feet thick on the northeast flank of the Henry Mountains, where it forms a thin upper part of Gilbert's †Flaming Gorge group. In the Green River Desert the Summerville formation, which is 200 feet thick, is separated from the Entrada sandstone by the Curtis formation, consisting of gypsiferous greenish-gray sandstone and shale 60 feet thick (pl. 22, *A*). Elsewhere along this line of sections the Summerville formation is not a conspicuous unit. On Indian Creek it is made up of red sandstone and mudstone 40 feet thick, with a few thin layers of blue limestone and abundant large nodules of chert. This correlation is based upon detailed mapping between Indian Creek and the mouth of the San Rafael River, where strata of the Summerville formation with more typical lithology crop out. In Bush Canyon, in Gypsum Valley, and on the San Miguel River red thin-bedded sandstone and shale are present above the Entrada sandstone and are probably equivalent at each place to the Summerville formation. The thickness at these localities is 75 feet, 40 feet, and 44 feet, respectively. The correlation is based upon the stratigraphic position above the Entrada sandstone and lithologic similarity to the Summerville formation at such localities as Indian Creek. It is possible, however, that these beds should be included in the overlying Morrison formation, as they resemble in many respects the red shale and sandstone interbedded with the massive white sandstones in the lower part of the Morrison. The writers did not identify the Summerville formation northeast of Placerville or at Ouray and believe it to be absent.

The Morrison formation overlies the older Jurassic formations at all the localities shown in this line of sections east of the Circle Cliffs, Utah. It varies much in details of lithology but at most of the localities consists of a lower zone of massive buff to gray conglomeratic sandstone with interbedded shale and an upper zone of variegated shale, red shale, thin-bedded sandstone, and minor gray limestone. A prominent sandstone near the base of the Morrison in the vicinity of Placerville and Ouray, Colo., is the upper †La Plata sandstone of Cross. The discontinuous middle †La Plata limestone shown in the sections near Placerville and Ouray is interpreted by the writers to be basal Morrison because of its relations to the underlying Entrada and the overlying Morrison beds and because of the local occurrence of thin limestone beds of similar lithologic character at the base of the Morrison in eastern Utah and at many localities in central Colorado. Because of its stratigraphic position and lithologic character the writers consider it equivalent to the Todilto limestone of New Mexico although not continuous with the Todilto. The Morrison is separated from the underlying formations by an erosional irregularity at some localities within the area discussed in this report, but no conspicuous irregularity or unconformity has been observed at any of the localities shown in this line of sections.

SAN RAFAEL SWELL, UTAH, TO GUNNISON, COLORADO

The line of sections shown in figure 4 extends from the northern part of the San Rafael Swell, Utah, nearly due east through Salt Valley (pl. 26, *A*) and Dewey to Unaweep Canyon, Colo., and thence somewhat south of east to Gunnison, Colo. It is thus parallel to the eastern part of the lines of sections shown in plates 3 and 4 and about 50 miles north of the line of plate 4. Like the preceding lines of sections it shows in very marked fashion the progressive eastward thinning and final disappearance of the Glen Canyon and San Rafael groups. The composite section in Saddle Horse Canyon and Horn Silver Gulch has been obtained from Gilluly,[74] and the section in Black Dragon Canyon from Gilluly and Reeside.[75] The other sections were obtained by the writers.

The Wingate sandstone is underlain in each section from the San Rafael Swell to Unaweep Canyon by red sandstone and shale of the Chinle formation. Its thickness is 350 feet in Saddle Horse Canyon, 320 feet in Black Dragon Canyon, 295 feet at the north end of Salt Valley, 320 feet near Dewey, 294 feet near Scharf's ranch, and 250 to 300 feet in Unaweep Canyon. The Wingate sandstone in these sections is a massive cross-bedded cliff-forming buff to red-brown sandstone with horizontal bedding planes becoming more conspicuous toward the east (pl. 6, *A*). In Unaweep Canyon the Chinle is thin and rests directly on pre-Cambrian. In Bostwick Park, near the Black Canyon of the Gunnison River, the Chinle is absent, and the Wingate sandstone rests directly on granite. There it is a salmon-colored to yellow massive fine-grained sandstone with a basal conglomerate of granitic debris and is 60 feet thick. At Sapinero and Gunnison the Morrison rests directly on the crystalline rocks. Gilluly recognized an unconformity at the base of the Wingate sandstone in the San Rafael Swell (pl. 5, *B*), but no unconformity was observed at the other localities shown in this line of sections where the Chinle is present, and, in fact, at most of the outcrops visited by the writers it is difficult to draw a sharp boundary between the Wingate sandstone and the Chinle formation. The impression gained from following the contact for many miles is that it is gradational rather than unconformable.

The Kayenta formation is present in the western half of the line of sections, where it is composed of irregularly bedded gray to red-brown and lavender

[73] Gregory, H. E., and Moore, R. C., op. cit., pl. 5.

[74] Gilluly, James, Geology and oil and gas prospects of part of the San Rafael Swell, Utah: U. S. Geol. Survey Bull. 806, p. 76, 1929.

[75] Gilluly, James, and Reeside, J. B., Jr., Sedimentary rocks of the San Rafael and some adjacent areas in eastern Utah: U. S. Geol. Survey Prof. Paper 150, p. 105, 1928.

sandstone, with subordinate shale and limestone. Its thickness is 180 feet in Saddle Horse Canyon, 239 feet in Black Dragon Canyon, 205 feet at the north end of Salt Valley, 320 feet at Dewey, and 293 feet near Scharf's ranch, on the Dolores River. It is absent at Unaweep Canyon.

Black Dragon Canyon, 245 feet thick at the north end of Salt Valley, 215 feet thick at Dewey, and 184 feet thick near Scharf's ranch.

The Carmel formation also thins eastward and changes in lithology as it thins. In Horn Silver Gulch, in the northwestern part of the San Rafael Swell, it is

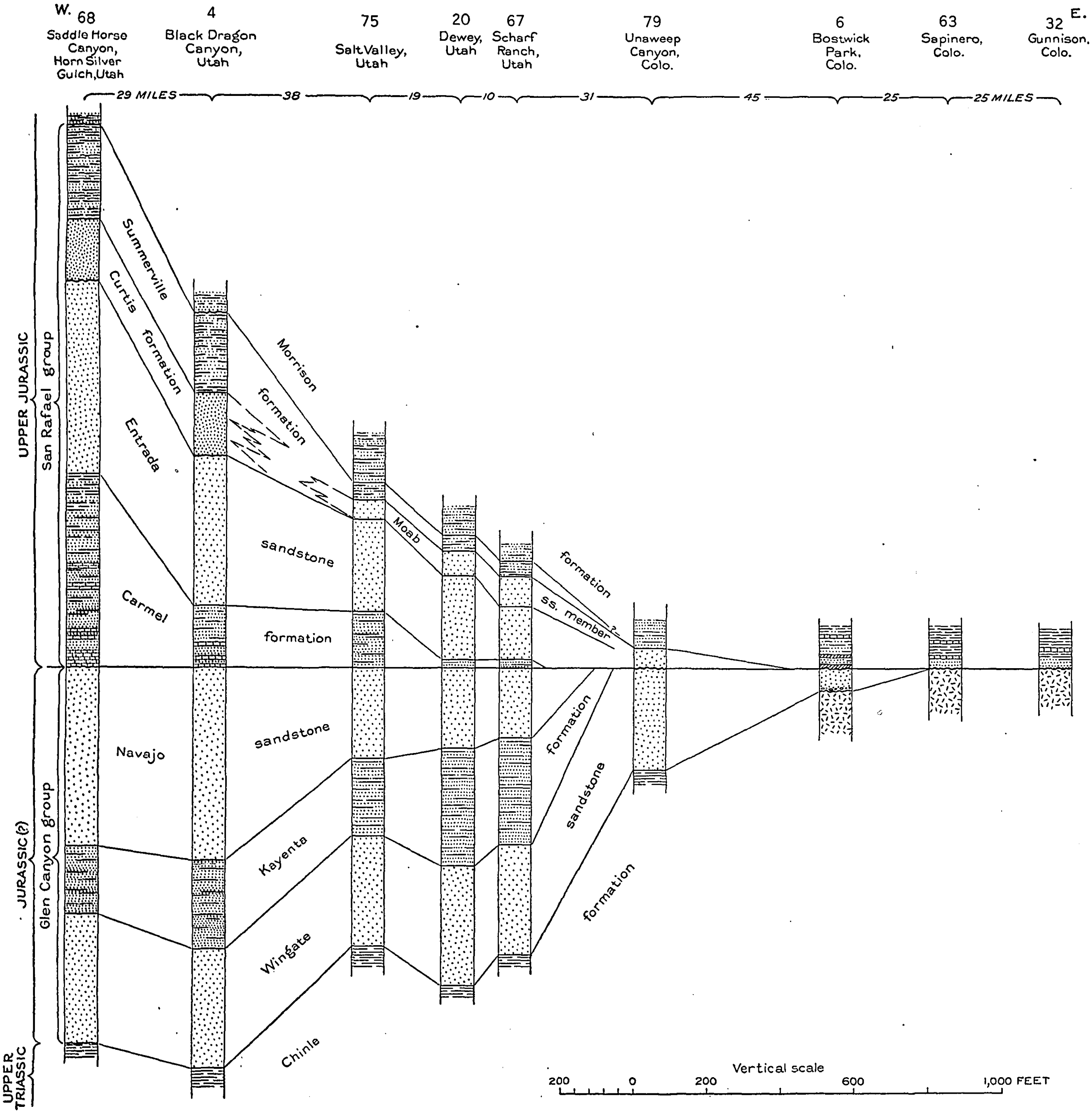


FIGURE 4.—Sections from San Rafael Swell, Utah, to Gunnison, Colo.

The Navajo sandstone is a cross-bedded tan to light-gray sandstone, thinning eastward from its maximum thickness in the San Rafael Swell and disappearing a few miles east of Scharf's ranch. It is 485 feet thick in Saddle Horse Canyon, 520 feet thick in

520 feet thick, the lowest quarter composed of resistant gray sandstone at the base and marine fossiliferous limestone, and the softer upper part composed of irregularly bedded gray, orange-red, red, and greenish-gray sandstone, shale, and gypsum. In Black Dragon

Canyon the thickness is only 170 feet, but the twofold division is still present. Between Black Dragon Canyon and the north end of Salt Valley the thickness decreases to 150 feet, but the formation changes in lithology to pink, red, or reddish-brown muddy sandstone with contorted bedding and the marine limestone member does not extend as far east as the Green River. At Dewey and near Scharf's ranch the Carmel formation is about 20 feet thick and is composed of soft muddy red sandstone, and shale which weather back at the top of the Navajo sandstone to form a bench between the Navajo and the overlying Entrada sandstone. The Carmel disappears as a recognizable unit a short distance east of Scharf's ranch, where the Entrada sandstone rests directly upon the Navajo sandstone. The writers have observed the Carmel formation resting upon an irregular surface of the Navajo sandstone at a few localities, and nearly everywhere there is a sharp boundary between these two formations, but at its upper contact the Carmel formation grades into the overlying Entrada sandstone.

The Entrada sandstone thins notably from west to east but persists to some point beyond Unaweep Canyon. It does not, however, extend to Bostwick Park, nor is it known farther east on this line of sections. In Horn Silver Gulch it is a muddy red "stone baby" sandstone (pl. 21, *B*); in Black Dragon Canyon there is an alternation of this muddy rock with massive beds of gray to orange-brown cross-bedded sandstone. From the Green River eastward only this second facies is present. The progressive eastward thinning is shown by the measurements of its thickness—518 feet in Horn Silver Gulch, 405 feet in Black Dragon Canyon, 305 feet at the north end of Salt Valley, 295 feet at Dewey, 227 feet near Scharf's ranch (pl. 18, *A*), and 50 feet in Unaweep Canyon. In the vicinity of Moab, Utah, the light-gray massive cliff-forming Moab sandstone member, 100 feet thick, forms the upper part of the Entrada sandstone and is separated by its lighter color and a basal shale parting from the rest of the formation. This member has been traced northwestward from Moab and found to pass by intertonguing into the lower part of the Summerville formation (pl. 17, *B*).[76] It can be recognized eastward to the State boundary, though with an uncertain lower limit.

The Curtis formation succeeds the Entrada sandstone in the San Rafael Swell with erosional unconformity but does not extend much farther south or east. It is composed typically of fossiliferous greenish-gray glauconitic conglomerate and sandstone and minor shales (pl. 21, *B*). It is about 170 feet thick in Horn Silver Gulch and Black Dragon Canyon but disappears eastward near Dellenbaugh Butte, on the Green River, largely by lateral change to a lithology like that of the Summerville, so that the two are inseparable.[77] It grades upward into the overlying Summerville formation.

The Summerville formation, like the Carmel and Entrada, has its maximum thickness on this line of sections in the San Rafael Swell, thins very much eastward, and finally disappears or becomes unrecognizable in western Colorado. In Horn Silver Gulch and Black Dragon Canyon it is 258 feet and 211 feet thick, respectively, and is composed of thin and regularly bedded red and white sandstones and maroon shales with much silica in small nodules or crusts. At the north end of Salt Valley, where the Curtis formation is absent and the Moab sandstone member of the Entrada sandstone is present, the Summerville formation is only 45 feet thick and consists of thin-bedded red sandy shale and sandstone with a few thin gray limestone beds. At Dewey and near Scharf's ranch the thickness and lithology are approximately the same as in Salt Valley (pl. 22, *C*). In Unaweep Canyon no sediments surely equivalent to the Summerville formation were seen.

The contact between the Summerville and Morrison is in many places difficult to locate otherwise than arbitrarily, because of the general similarity of the Summerville rocks to those interbedded with the massive sandstones in the lower part of the Morrison. At many places where it has been possible to recognize a definite base the Morrison sediments, whether limestone, white sandstone, variegated shale, or gypsum, rest on an erosional irregularity, but such irregularities are not known to be persistent and may be matched by similar irregularities within the Morrison itself. They therefore seem to have little significance. Concordance of bedding between the two formations is the rule, but an angular discordance separating the Summerville from the Morrison formation has been observed at places in the San Rafael Swell and the Green River Desert.

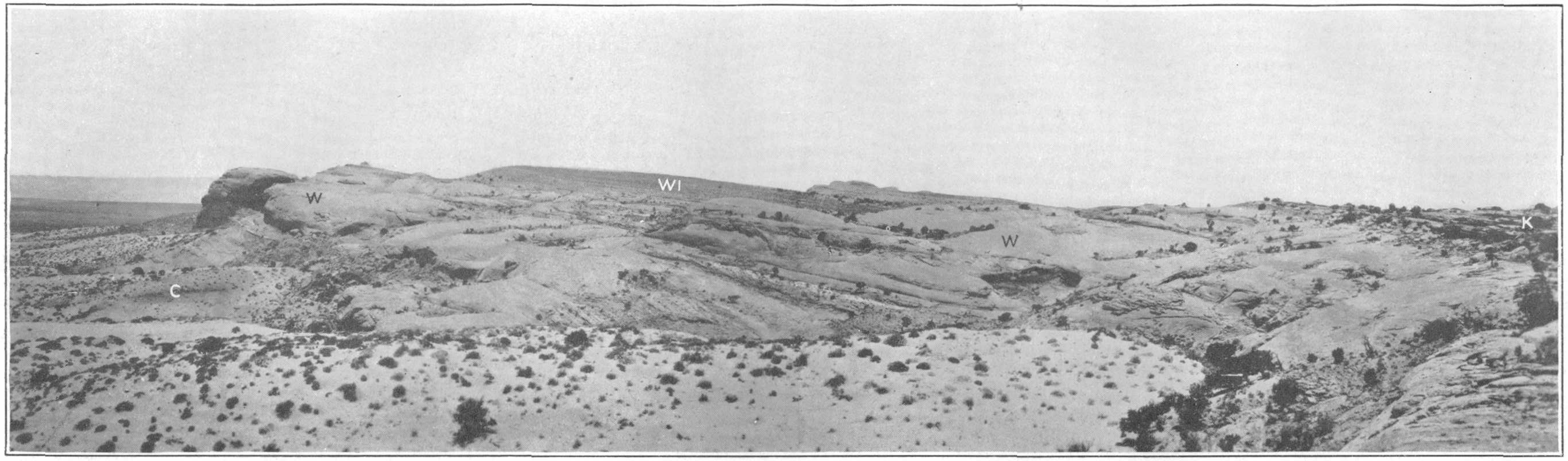
The Morrison through most of this line of sections contains a basal unit, the Salt Wash sandstone member, discontinuous and relatively thin in the western part but much thicker in the central part. The remainder of the formation is the more typical variegated shale facies. In the eastern sections it thins much and is not divided, though it is persistent as the only member of the Jurassic sequence.

ISLAND PARK, UTAH, TO SCOFIELD PARK, COLORADO

The line of sections shown in figure 5 extends southeastward from Island Park, Utah, across northwestern Colorado to Scofield Park and is oblique to those previously described. All these sections were measured by the writers. They show the marked thinning and eventual disappearance of the Entrada southeastward and also the disappearance of the marine zone above it.

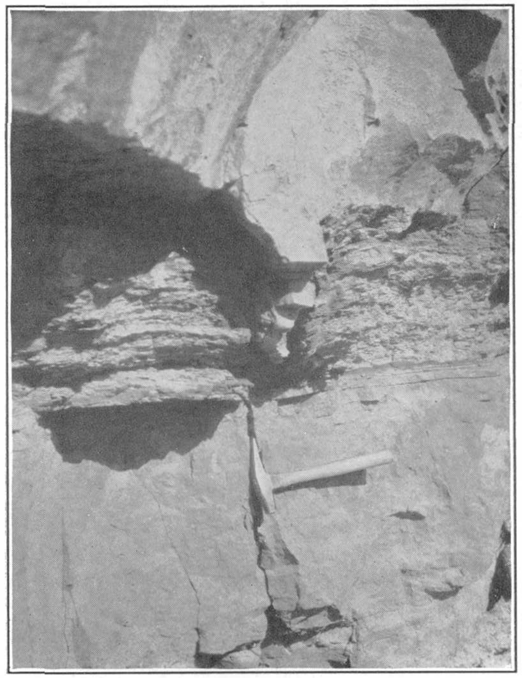
[76] Baker, A. A., and others, Notes on the stratigraphy of the Moab region, Utah: Am. Assoc. Petroleum Geologists Bull., vol. 11, no. 8, p. 804, 1927.

[77] McKnight, E. T., unpublished data.



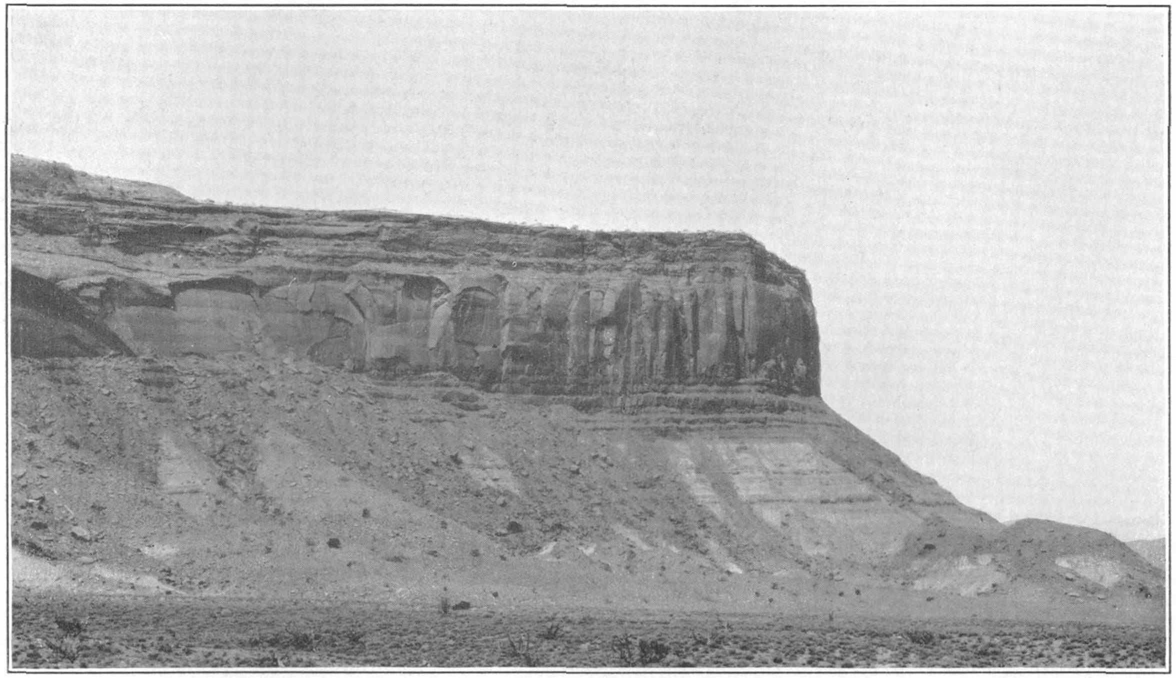
A. LIMESTONE LENS (*Wl*) IN THE WINGATE SANDSTONE (*W*) IN COMB RIDGE SOUTH OF THE SAN JUAN RIVER, UTAH.

The Chinle formation (*C*) forms slope at left, and the Kayenta formation (*K*) caps the ridge at right. Photograph by J. B. Reeside, Jr.



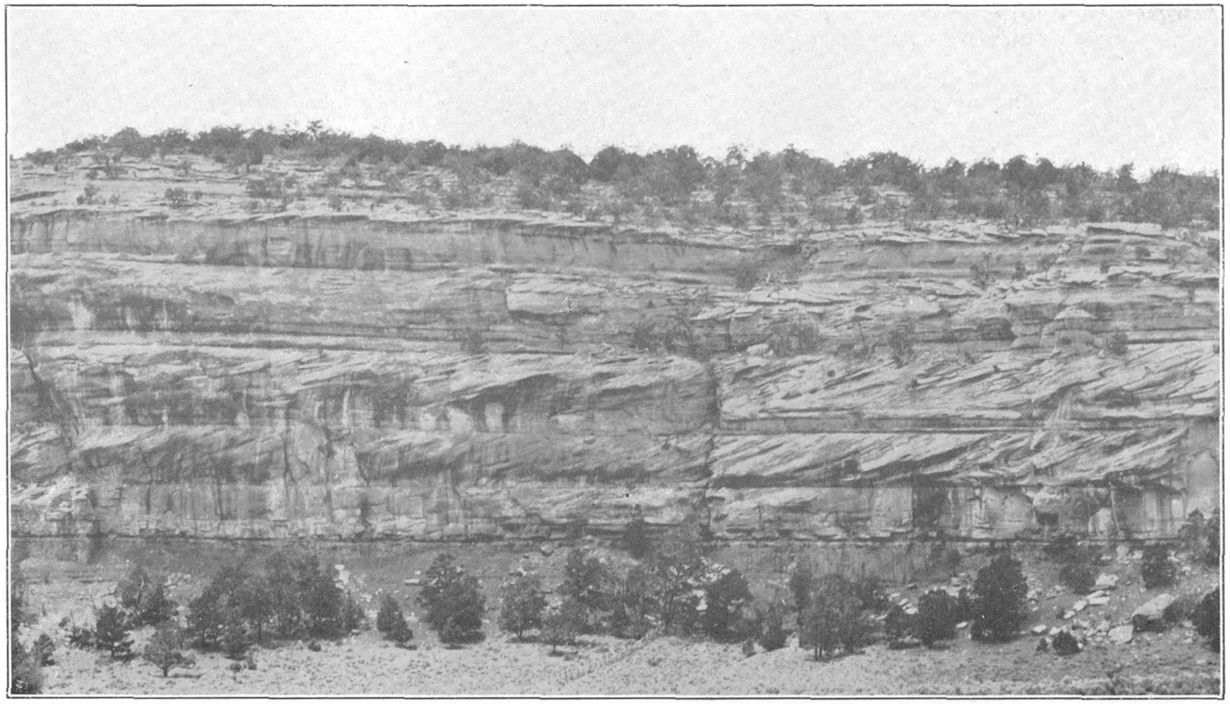
B. SAND-FILLED CHANNEL IN RED SHALE.

At the top of the transition zone between the Chinle formation and the overlying Wingate sandstone. Photograph by James Gilluly.



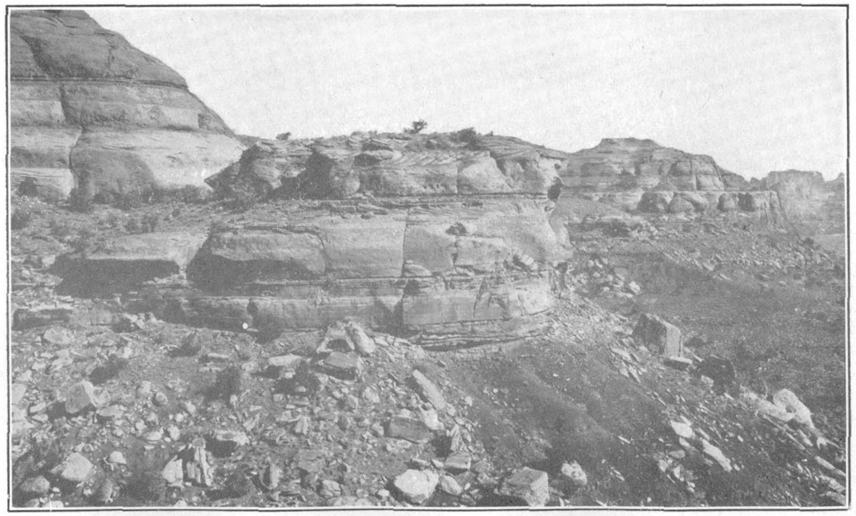
C. TYPICAL EXPOSURE OF THE WINGATE SANDSTONE IN A CLIFF NEAR KAYENTA, ARIZ.

Note the indefinite contact between the Wingate sandstone and the underlying Chinle formation, the sheer wall of sandstone characterized by vertical jointing and alcoves, and the Kayenta formation in the upper part of the cliff. Photograph by W. T. Lee.



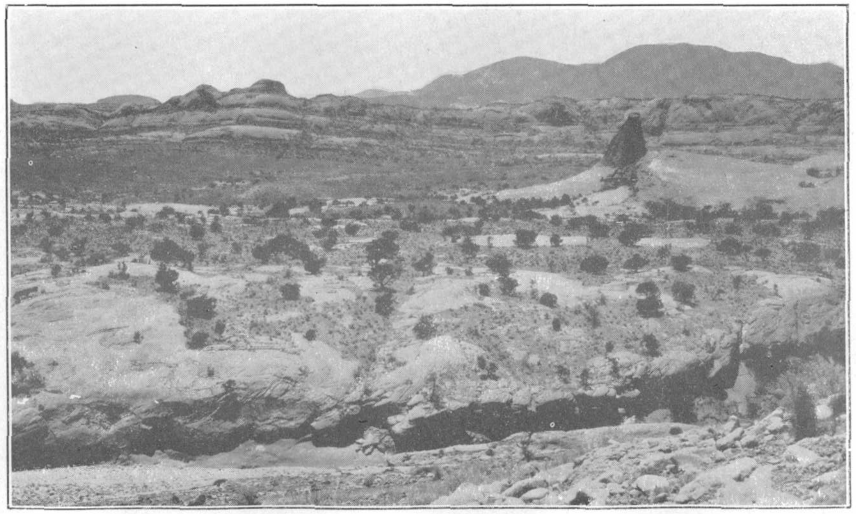
A. CROSS-BEDDED WINGATE SANDSTONE AT THE EAST END OF UNAWEEP CANYON, ABOUT 10 MILES WEST OF WHITEWATER, COLO.

Wingate rests conformably on shale of the Chinle formation exposed at base of cliff. Photograph by W. T. Lee.



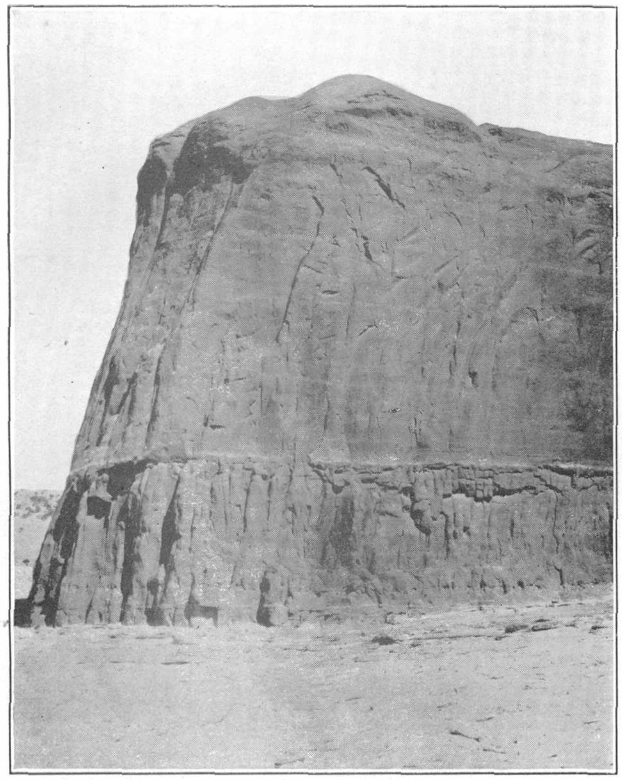
B. WINGATE SANDSTONE AND UNDERLYING SOFTER CHINLE SHALE EXPOSED AT BIG HOLE, ON THE COLORADO RIVER 8 MILES EAST OF CISCO, UTAH.

Note the extensive horizontal softer beds in the Wingate sandstone and the cross-bedding within the thicker sandstone beds. Photograph by C. E. Erdmann.



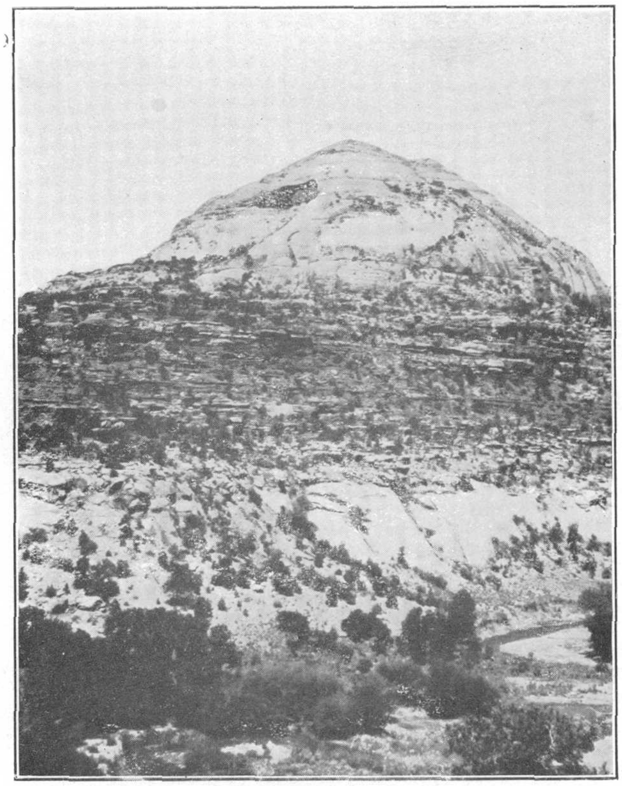
C. WINGATE SANDSTONE IN MASSIVE BEDS AT BILTABITO, NEAR THE NORTHWEST CORNER OF NEW MEXICO.

Photograph by J. B. Reeside, Jr.



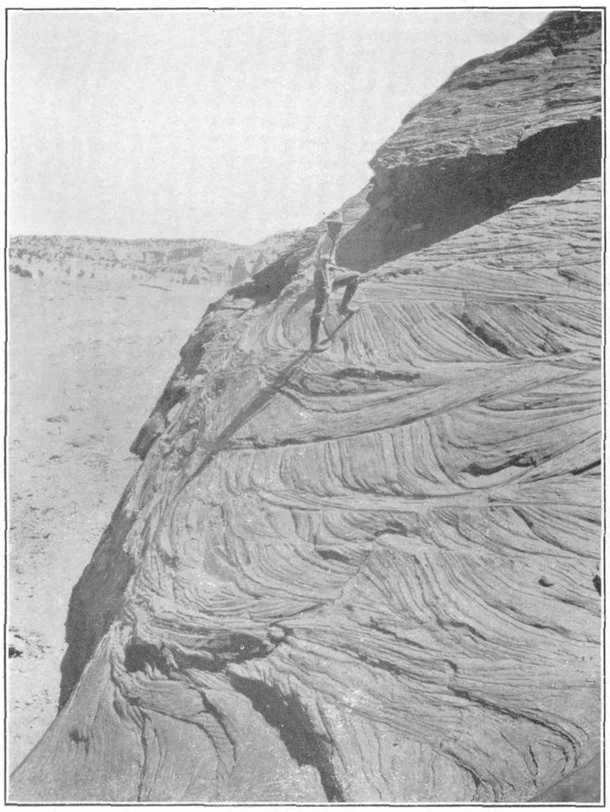
A. MASSIVE WINGATE SANDSTONE NEAR NAVAJO CHURCH, IN NORTHWESTERN NEW MEXICO.

Showing the basal unit of softer muddy sandstone that is characteristic of the formation in this part of New Mexico. Photograph by J. D. Sears.



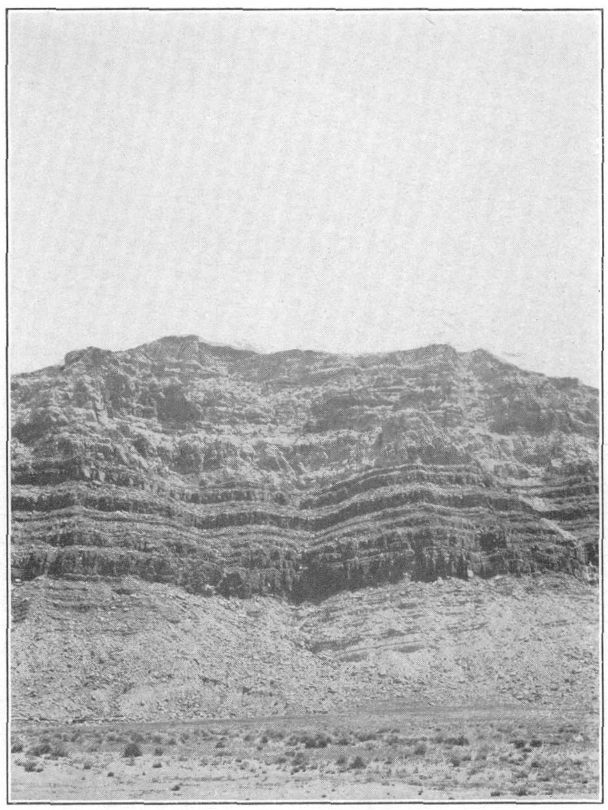
B. OUTCROP OF THE WINGATE AND NAVAJO SANDSTONES AND THE KAYENTA FORMATION NEAR THE HEAD OF INDIAN CREEK, IN SEC. 29, T. 32 S., R. 22 E., UTAH.

Showing the massive Wingate sandstone at the base of the cliff, the typical bedding of the Kayenta formation, and the massive Navajo sandstone forming the high dome. Photograph by A. A. Baker.



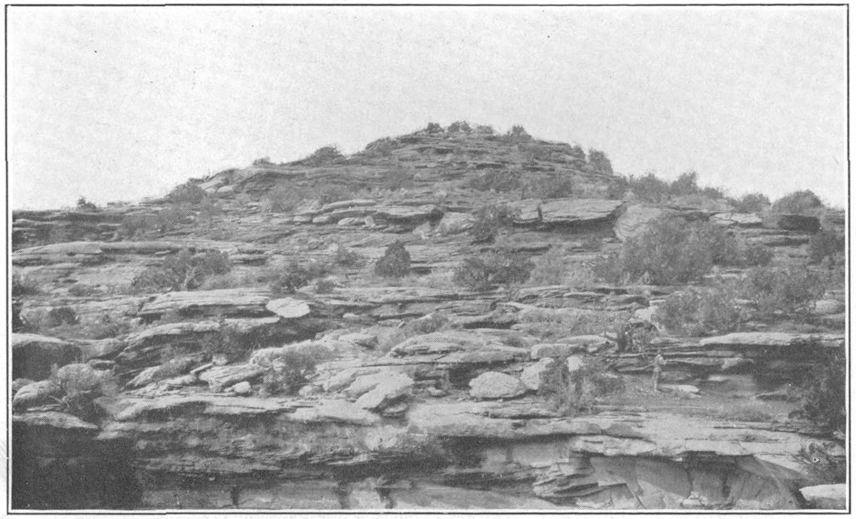
C. CROSS-BEDDING IN THE WINGATE SANDSTONE NEAR NAVAJO CHURCH, N. MEX.

Photograph by J. D. Sears.



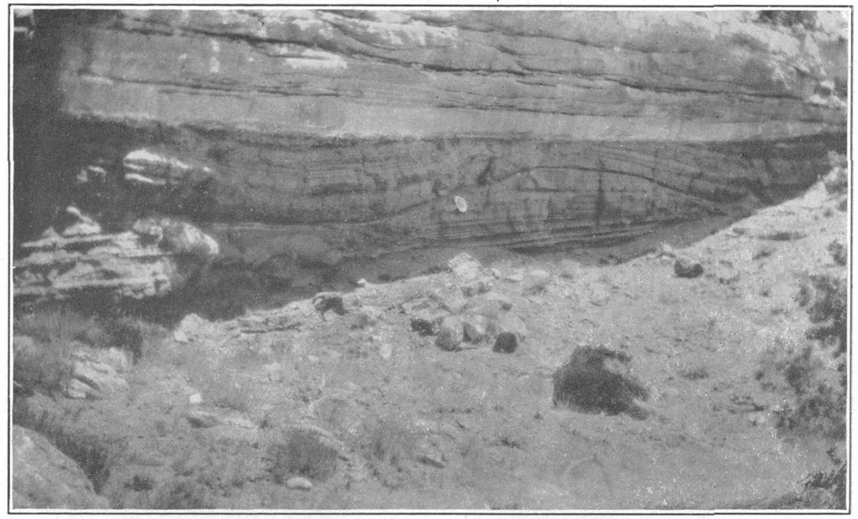
D. ECHO CLIFFS, 16 MILES SOUTH OF THE BRIDGE ACROSS THE COLORADO RIVER NEAR LEES FERRY, ARIZ.

Showing the massive Navajo sandstone underlain by dark ledges of thinner-bedded sandstone that probably include thin representatives of the Kayenta formation and Wingate sandstone but may be a sandy phase of the Chinle formation, which is typically exposed in the slope at the base of the cliff. Photograph by A. A. Baker.



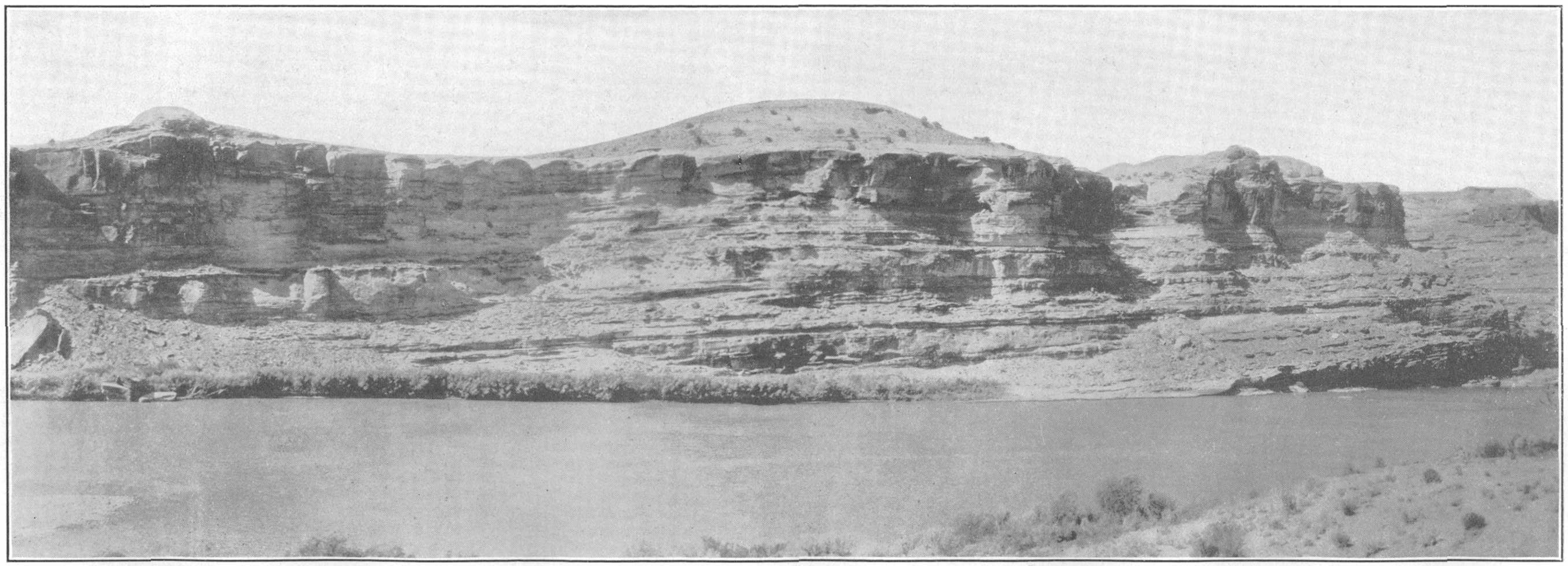
A. SANDSTONE LEDGES AND SLOPES OF THE LOWER PART OF THE KAYENTA FORMATION AT BIG HOLE, ON THE COLORADO RIVER 8 MILES EAST OF CISCO, UTAH.

The top of the cliff formed by the Wingate sandstone is shown toward the left at the bottom of the picture. Photograph by C. E. Erdmann.



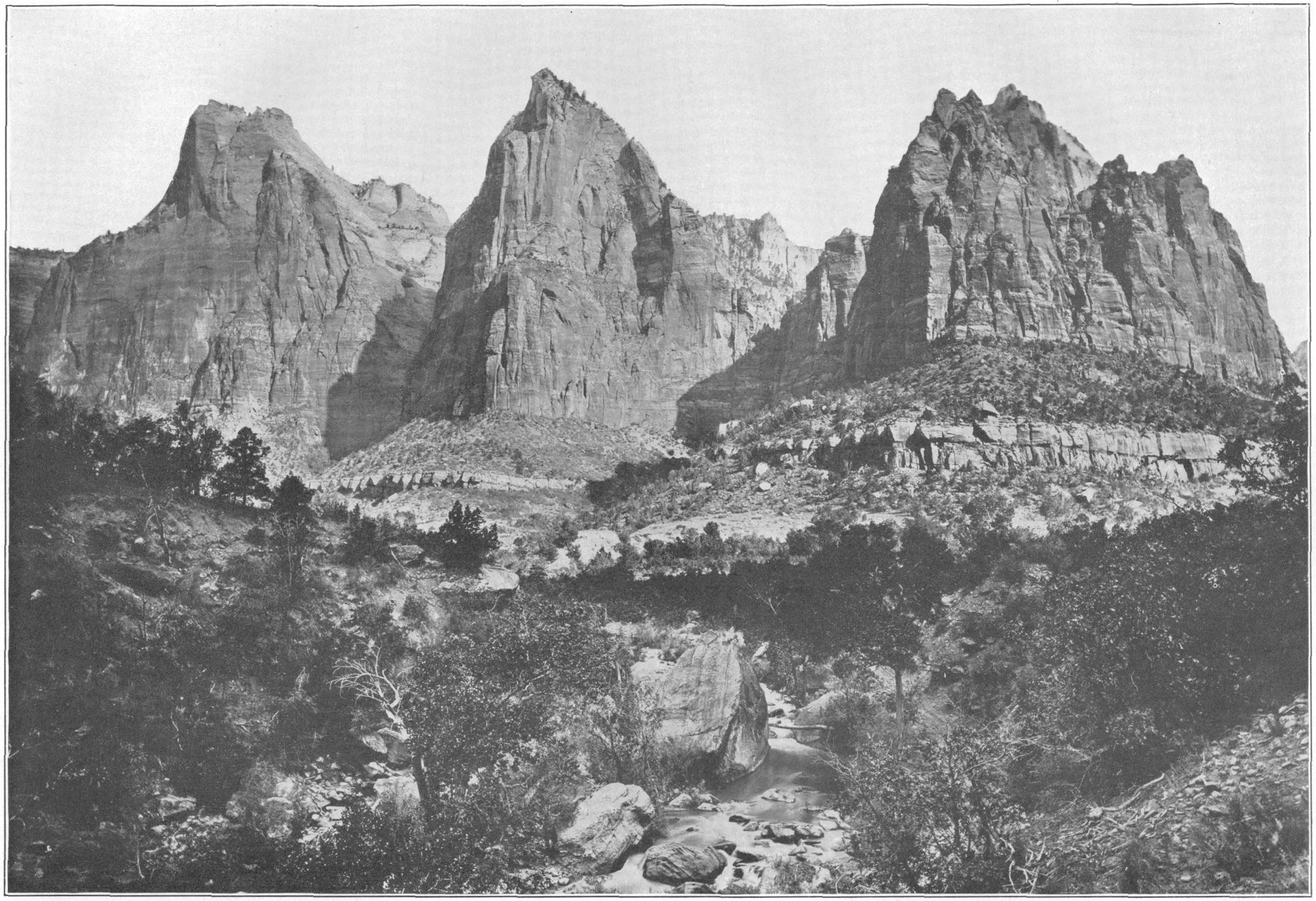
B. INTRAFORMATIONAL UNCONFORMITY ABOUT 50 FEET BELOW THE TOP OF THE KAYENTA FORMATION ON THE EAST SIDE OF COTTONWOOD CANYON.

Sec. 2, T. 32 S., R. 21 E., Utah. Photograph by L. W. Clark.



C. INDEFINITE CONTACT BETWEEN THE KAYENTA FORMATION AND THE OVERLYING NAVAJO SANDSTONE.

On the west bank of the Colorado River at the mouth of Nigger Bill Creek, in sec. 19, T. 25 S., R. 22 E., Utah. Photograph by A. A. Baker.



THE THREE PATRIARCHS, CARVED FROM THE NAVAJO SANDSTONE AT ZION CANYON, UTAH.

The underlying Chiule formation crops out in the slope at the base of the cliff. Photograph by J. K. Hillers.

All but the last three (southeastern) sections are underlain by Upper Triassic rocks. These maintain a thickness of 300 to 400 feet but between South Canyon and Carbondale thin rather abruptly to 68 feet and within a short distance farther on die out completely, the Jurassic rocks resting directly on the Carboniferous.

The lowest unit of the Jurassic sequence present is the so-called "Nugget sandstone." At Island Park, on the slope of the eastern Uinta Mountains, it is 878 feet thick and consists of a massive light-buff basal sandstone 560 feet thick, an overlying red sandy shale 200 feet thick, and a top sandstone 118 feet thick. At Midland Ridge there is a seemingly single massive sandstone 700 feet thick. Near Meeker, where the formation has been called †"La Plata", it is 320 feet thick; on Rifle Creek about 125 feet, on Elk Creek 100 feet, in South Canyon 77 feet, at Carbondale 98 feet, and south of Carbondale 100 feet. At Redstone it is absent, though a 50-foot sandstone is present that from a distance resembles it. This sandstone seems to the writers to be a Morrison unit. At Scofield Park a debatable sandstone has been placed by the writers arbitrarily in the Morrison. In these sections the sandstone is a buff to light-gray massive, much cross-bedded rock with very sharp basal boundary. The Entrada sandstone seems to the writers to be represented by the entire thickness in the southern sections and by at least the upper part in the thicker northern sections. The lower part is believed to contain a representative of the Navajo sandstone.

In the two northwestern sections the Entrada sandstone is overlain by a zone of marine fossiliferous beds that have in the past been called "Twin Creek formation" but are here considered to be younger than the typical Twin Creek of southwestern Wyoming and to represent the Curtis formation. These beds comprise sandstone, shale, and limestone, mostly light-colored—greenish gray, light gray, cream-colored, etc. The fossils present are listed for Island Park by Reeside,[78] and at Midland Ridge the following were observed: *Eumicrotis curta* (Hall), *Ostrea strigilecula* White, *Camptonectes?* sp., *Astarte packardi* White, *Thracia* cf.

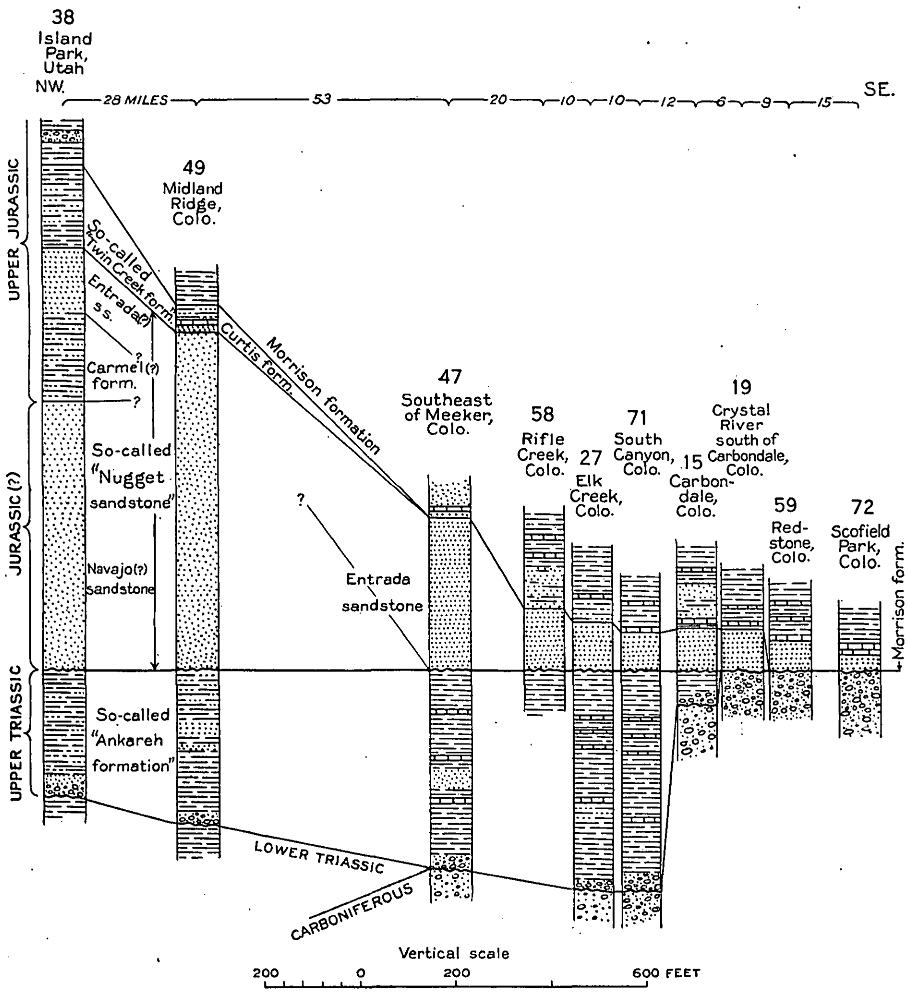


FIGURE 5.—Sections from Island Park, Utah, to Scofield Park, Colo.

[78] Reeside, J. B., Jr., Notes on the geology of the Green River Valley between Green River, Wyo., and Green River, Utah: U. S. Geol. Survey Prof. Paper 132, p. 43, 1923.

T. weedi Stanton, *Trigonia?* sp., and a fish bone (U. S. G. S. locality 15401). The thickness of the marine zone at Island Park is 178 feet, and at Midland Ridge about 50 feet. It is not recognizable near Meeker and is probably absent, and there is no trace of it farther southeast. It is conformable with the Entrada and apparently with the Morrison also.

The Morrison is present throughout this line of sections, showing its usual varied character. At places between Meeker and Scofield Park a basal sandstone forms a conspicuous unit; at some places 8 or 10 feet of massive algal limestone is also present in the lower part. In general the upper part is the softer variegated shale, thin limestone, and sandstone facies, and at some localities the whole formation is of this type. The thickness is usually from 400 to 500 feet. Toward the southeast the Morrison formation rests successively on Curtis, Entrada, and Carboniferous rocks, and it is likely that if the line of sections were continued toward Gunnison the Morrison would be shown to pass across the older Paleozoic rocks. Near Gunnison it rests on the pre-Cambrian.

SINBAD VALLEY TO BOXELDER CANYON, COLORADO

The line of sections shown in figure 6 extends northeastward from Sinbad Valley by way of Unaweep Canyon and the upper Colorado River Valley, then across the mountains by a long interval to the northern foothills of the Front Range at Boxelder Canyon. All the sections shown were measured by the writers except that in Boxelder Canyon, which was measured by Lee.[79] This line of sections crosses nearly at right angles the line of figure 5 and shows the northeastward thinning of the Glen Canyon group, the persistence on the line of sections of the Entrada sandstone, and the lenticular cross section of the marine Curtis formation.

The sections at Sinbad Valley and in Unaweep Canyon have been described in connection with other illustrations. They show the thinning out of the Glen Canyon group—the Navajo sandstone going first, then the Kayenta formation, and finally the Wingate sandstone. The point of disappearance of the Wingate is not known, for the interval between Unaweep Canyon and South Canyon is a syncline whose surface rocks are Cretaceous and younger. No part of the Glen Canyon group reappears northeast of Unaweep Canyon.

The Entrada sandstone persists as far as State Bridge, at first thinning a little, then maintaining a thickness of about 100 feet. It changes in color northeastward from a light-gray or buff to a salmon-pink, but other characters remain the same (pl. 20, *A*). Little is known of the Entrada in the long interval across the mountains from State Bridge to Boxelder Canyon, but at these two localities it shows very great similarity in constitution and in relations to the enclosing beds. Reports of areas north of the line of sections, such as the Rabbit Ears region[80] and North Park,[81] suggest strongly that Entrada is not now and may never have been present, nor is there suggestion of any marine beds, though still farther north in Wyoming both Entrada and overlying marine beds seem to be present and to constitute the Sundance formation. The Entrada in Boxelder Canyon, Larimer County, Colo.,

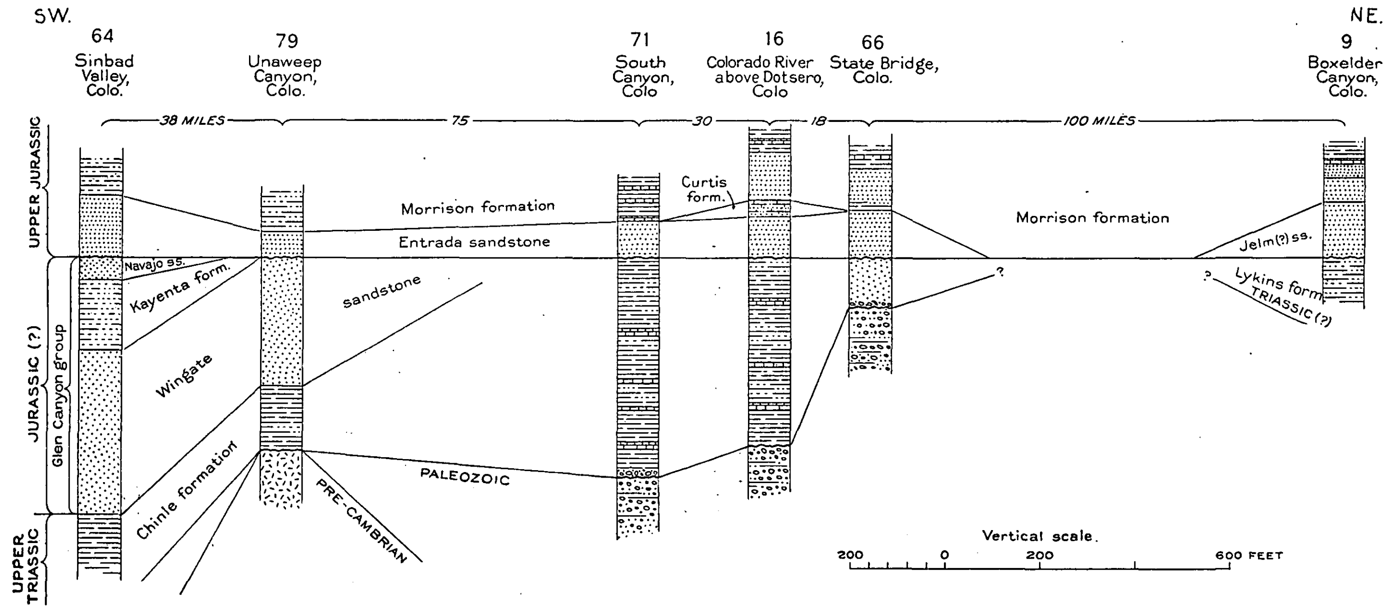


FIGURE 6.—Sections from Sinbad Valley to Boxelder Canyon, Colo.

[79] Lee, W. T., Correlation of geologic formations between east-central Colorado, central Wyoming, and southern Montana: U. S. Geol. Survey Prof. Paper 149, pp. 25–40, 1927.

[80] Grout, F. F., Worcester, P. G., and Henderson, Junius, Reconnaissance of the geology of the Rabbit Ears region, Routt, Grand, and Jackson Counties, Colo.: Colorado Geol. Survey Bull. 5, pt. 1, pp. 21, 26, 1913.

[81] Beekly, A. L., Geology and coal resources of North Park, Colo.: U. S. Geol. Survey Bull. 596, pp. 28–29, 1915.

was called "Jelm (?)" by Lee, and the overlying lower Morrison was called "Sundance."

On the Colorado River a fossiliferous marine zone 27 feet thick composed of oolitic sandy gray limestone and sandstone peppered with lime-oolite grains represents the Curtis formation (pl. 20, *A*). It definitely thins out and is absent from the sections on each side.

NAVAJO MOUNTAIN, UTAH, TO EL RITO, NEW MEXICO

The line of sections shown in figure 7 extends from Navajo Mountain, Utah, S. 50° E. to El Rito, N. Mex., through Kayenta and Rough Rock, Ariz., and Todilto Park, Navajo Church, and Bluewater, N. Mex. The writers have visited all the localities, and all the sections were measured by them except those at Todilto

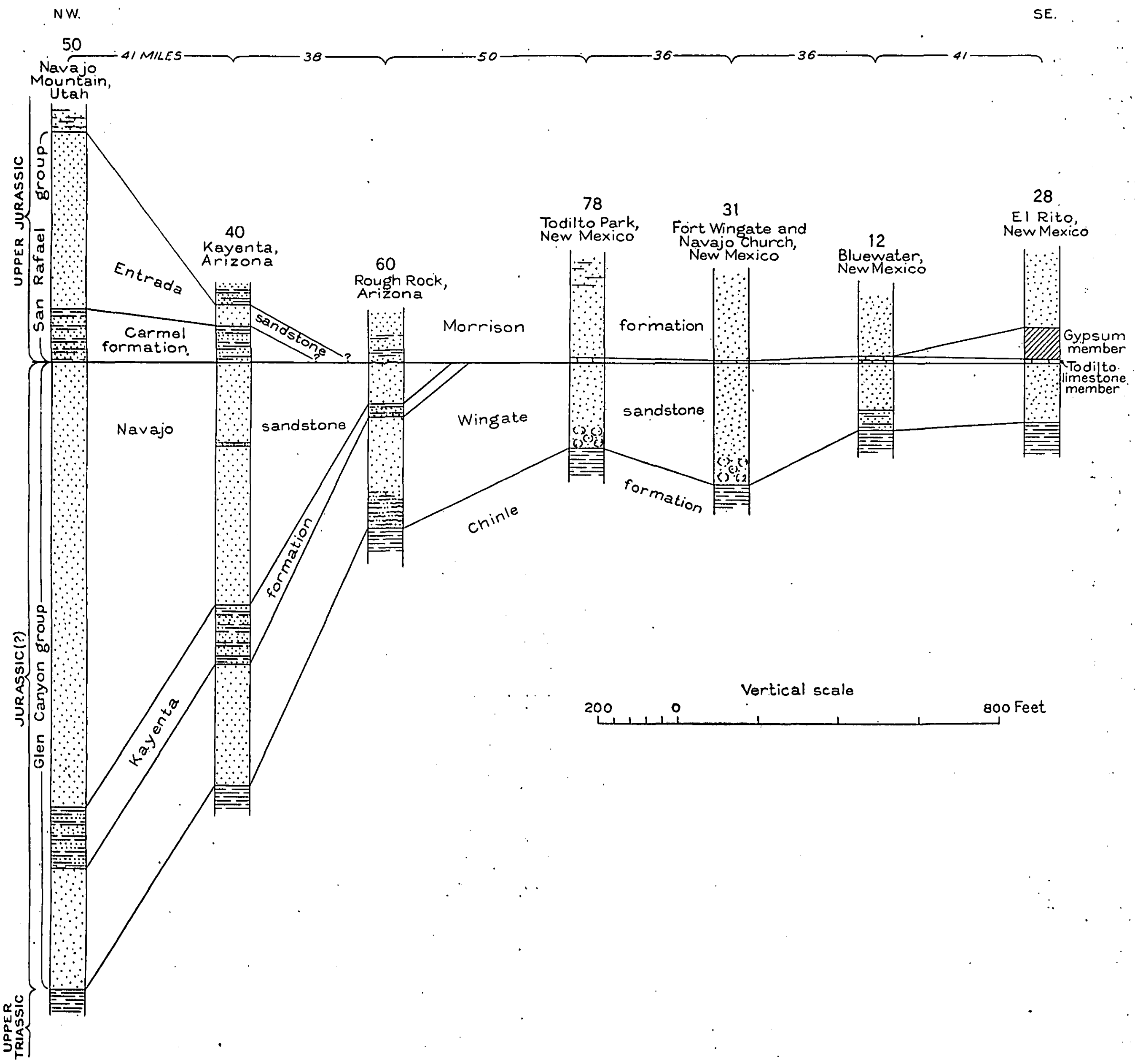


FIGURE 7.—Sections from Navajo Mountain, Utah, to El Rito, N. Mex.

The Morrison formation is present throughout the line of sections, varying in composition from locality to locality. At some places a definite basal sandstone zone is present; at others the somewhat more typical variegated shales, thin sandstones, and algal limestones make up the whole of the formation.

Park, Navajo Church, and El Rito, which were measured by Gregory,[82] Sears,[83] and Darton,[84] respectively.

[82] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, pp. 54, 55, 57, 1917.

[83] Sears, J. D., unpublished field notes.

[84] Darton, N. H., "Red Beds" and associated formations in New Mexico: U. S. Geol. Survey Bull. 794, p. 120, 1928 [1929].

This line of sections is oblique to those previously described. It shows the persistence southeastward of the Wingate sandstone and the rapid thinning and disappearance of the formations between the Wingate and the Morrison.

The Wingate sandstone is present throughout the line of sections, thinning gently and somewhat irregularly toward the southeast. From Todilto Park southeastward it is all that is left of both the Glen Canyon and San Rafael groups. It is 300 feet thick at Navajo Mountain and Kayenta, 275 feet thick near Rough Rock, 210 feet thick at Todilto Park, 300 feet thick at Navajo Church, 165 feet thick at Bluewater, and 140 feet thick at El Rito. At Navajo Mountain and Kayenta it consists of the massive cliff-forming vertical-jointed buff to red sandstone so typical of its outcrops in southeastern Utah (pl. 5, *C*). Near Rough Rock it is changed to a reddish-brown sandstone, still cross-bedded and cliff forming but weathering to rounded surfaces and having at the base about 75 feet of earthy red nodular-weathering sandstone. This basal earthy phase of the Wingate is also present at Todilto Park, Navajo Church (pl. 7, *A*), Bluewater, and the type locality north of Fort Wingate. The cross-bedding in the upper massive part of the formation is shown in plate 7, *C*.

The Kayenta formation, composed of irregularly bedded sandstone and subordinate shale, is 150 to 225 feet thick in the vicinity of Navajo Mountain, and 144 feet thick at Kayenta, its type locality. Near Rough Rock the strata correlated with the Kayenta formation are only 30 feet thick and are variable along the strike, but they consist of coarse white sandstone, purplish-gray sandstone, and conglomerates of red shale pellets and limestone pebbles—an assemblage of beds typical of the Kayenta formation. At Todilto Park and the other localities farther southeast there are no strata resembling the Kayenta formation.

The Navajo sandstone thins rapidly southeastward from Navajo Mountain. It is 1,100 feet thick there, about 600 feet thick at Kayenta, and about 100 feet thick near Rough Rock. The writers recognize no Navajo sandstone at Todilto Park or farther southeast.

The Carmel and Entrada formations both thin southeastward from a maximum thickness at Navajo Mountain. The red sandstone and shale of the Carmel formation is 130 feet thick at Navajo Mountain (pl. 16, *D*) and about 70 feet thick near Kayenta. The massive orange-red Entrada sandstone is 440 feet thick at Navajo Mountain (pl. 25, *C*) and about 50 feet thick near Kayenta. Both the Carmel and Entrada are absent to the southeast. Near Kayenta exposures are inadequate to permit satisfactory determination of the lithologic character and thickness of the Entrada and Carmel formations, but thin representatives of the formations are certainly present there and may be observed in part at outcrops both east and west of Kayenta. It is likely also that the Summerville formation is represented here.

The basal part of the Morrison formation consists of conglomeratic gray sandstone at Navajo Mountain (pl. 25, *C*), but east of Kayenta the lowermost beds of the Morrison consist of thin-bedded muddy red-brown sandstone with contorted bedding, overlain by massively bedded gray sandstone—a type of lower Morrison already noted in several sections in southern Utah. Sediments of this type continue southeastward to Rough Rock.

At Todilto Park an outcrop of somewhat different aspect is found. Resting directly upon the Wingate sandstone with sharp contact but apparent conformity is the Todilto limestone member of the Morrison formation, 12 feet thick. Above the Todilto member the Morrison strata are composed almost entirely of buff to white sandstone, with a few thin partings of red muddy sandstone and some coarse-grained conglomeratic sandstone in the upper part. Near Navajo Church and Bluewater (pls. 25, *A*, *B*, 26, *B*) it is similar in appearance to the outcrop at Todilto Park. No conglomerate occurs in the sandstone, however, and it contains a somewhat greater amount of red shaly, regularly bedded material a short distance above the Todilto limestone and a little variegated shale of more typical Morrison aspect in the upper part.

Locally the Todilto limestone has a slightly irregular base with stringers of chert pebbles apparently resting in depressions in the surface upon which it was deposited. In the Navajo Church section the base of the Morrison is taken to be a layer 1 inch thick containing subrounded polished chert and jasper pebbles which are scattered through a matrix of sandstone. Above this pebble layer lies bedded sandstone which ranges from 6 inches to 1 foot in thickness and grades upward into the bedded gray limestone of the Todilto. It is suggestive to note here the local sandy character of the Todilto limestone and the possibility that at a locality 20 miles south of Grant it may be represented by white conglomerate.[85]

At El Rito siding a bed of gypsum 80 feet thick occurs between the Todilto limestone and overlying beds, which include at the base a softer bedded zone resembling the contorted beds at Bluff and above it a more massive red-brown sandstone (pl. 24, *B*). This gypsum zone is known over a wide area in northern New Mexico (pl. 24, *A*) and is represented by discontinuous beds in parts of Colorado.

The Todilto limestone was long correlated with the Kayenta formation and the overlying Morrison strata with the Navajo sandstone. As stated elsewhere in this paper, the writers believe that the sum of the evidence in hand shows that both Kayenta and Navajo formations and indeed the whole San Rafael group

[85] Darton, N. H., "Red Beds" and associated formations in New Mexico: U. S. Geol. Survey Bull. 794, p. 34, 1928 [1929].

also thin out southeastward, in all probability by nondeposition, and scarcely enter New Mexico. The so-called "Navajo" is 200 feet thick at Todilto Park,[86] 550 to 650 feet at Navajo Church,[87] and 190 feet at El Rito siding.[88] The massive sandstone facies decreases in thickness southeastward from Gallup in proportion as the variegated shale facies increases. The two are more or less contemporaneous and interfinger. The Todilto limestone has been correlated by Gregory [89] with the middle member of the †La Plata of Cross in the San Juan Mountains and the overlying so-called "Navajo" with the upper member—correlations which seem to the writers wholly reasonable, even though it would be difficult to prove precise equivalence. Darton[90] has correlated—erroneously, in the writers' opinion—the so-called "Navajo" with the lower †La Plata.

The only fossils from the Todilto limestone known to the writers are cyprid ostracodes of types that have little value in correlation.

The writers wish to emphasize the fact that in correlating the post-San Rafael beds, in this line of sections and elsewhere, they have included in the Morrison at places rocks that differ much from the more typical variegated shale facies—that is, fairly thick, massive limestones and thick, massive sandstones. Yet each of these divergent lithologic facies can be found in lesser development in areas where there can be little doubt of its Morrison age. Some of the units have already received individual names. It seems not only possible but probable that in various regions other lithologic units in this mass of sediments will eventually be discriminated and traced with sufficient accuracy to justify the application of local member names. Such discrimination and naming is eminently desirable, but in the present state of knowledge and in view of the characteristic variability and irregularity manifested where the formation has been studied in great detail, it seems legitimate to include under the name Morrison all the Jurassic continental sediments deposited subsequent to the deposition of the San Rafael group.

COMPOSITE CORRELATION DIAGRAM

The composite diagram given in plate 10 brings together in one picture many of the data set forth in figures 1 to 7 and plates 2 to 4 and other data not included in those sections. It shows in perspective, as if from a viewpoint above central New Mexico and looking diagonally across Utah, the extent and gross form of the masses of sediment included in the formations recognized in this paper and permits a visualization of the main features of the correlation more readily than the unconnected lines of sections or the verbal descriptions.

Because of the large size of the area concerned, the complexity of the stratigraphy, and the small thickness of some of the units involved, it has been necessary to generalize certain features. The "fences" are to be viewed as uniformly 3,000 feet high, and thus the exaggeration of the vertical scale is large, of the order of 200 times the horizontal. Lithologic symbols have been reduced to a minimum: softer sandstones and shales are shown by the standard shale symbol, massive sandstones by the standard sandstone symbol, and predominantly limestone units by the standard limestone symbol. Some geographic locations have been shifted slightly from their true positions in order to make them fall along straight lines, on the assumption that for such short distances there would be no appreciable difference between the sequence at the points shown and the measured sequence at the true positions. No attempt is made to distinguish in the diagram between observed and inferred data, and geologic structure is ignored.

The datum of the diagram is the base of the Morrison formation, shown as a plane forming the top of the stereogram. Morrison beds are not shown, though present over the whole region except in the far southwestern part. Here an irregular top indicates the absence of the datum horizon. The lower part of each "fence" represents the pre-Wingate rocks undifferentiated.

The greatest thickness of Jurassic sediments is found in the western and northwestern part of the region discussed in this paper. In the southwest the large thickness is due entirely to the thickening of the Navajo sandstone; in the northwest the large thickness is due to the elaboration of the San Rafael group as well, resulting in the presence of a greater number of named units, most of which, however, are not comparable in thickness to the Navajo sandstone of Zion Canyon, Utah, or the Goodsprings quadrangle and the Muddy Mountains, Nev.

The changes in each of the formations from Saddle Horse and Black Dragon Canyons, in the San Rafael Swell, Utah, where the full section is present, can be readily traced on the diagram.

The Wingate sandstone thins toward the southwest and is not recognized beyond Tuba, Ariz., and west of Navajo Mountain, Utah. Its western and northwestern limits are unknown, but no comparable unit has been reported where Jurassic rocks appear west of the Wasatch Plateau, and it is likely that it is not present many miles west of San Rafael Swell. It likewise thins out eastward toward Sapinero, Ouray, and Piedra River, Colo., and is not recognized at these localities. Northward it fades out somewhere under the Uinta Basin. Toward the south and southeast it persists to the limits of the region discussed, although

86 Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, p. 57, 1917.
87 Darton, N. H., op. cit., p. 145.
88 Idem, p. 120.
89 Gregory, H. E., op. cit., p. 53.
90 Darton, N. H., op. cit., p. 35.

somewhat reduced in thickness. It is recorded, in fact, as extending much farther southeastward across northern New Mexico.[91] The limits of the basin of deposition of the Wingate sandstone are therefore defined in part toward the southwest, west, north, and east and suggest the form of a trough with axis trending southeast. It is possible that an equivalent of the Wingate may exist outside this area in a form indistinguishable from the Chinle in the west or from the Dolores in the east, but it is not now possible to prove or disprove this thesis.

The Kayenta formation thins to the southwest, south, southeast, and east from the San Rafael Swell. It is doubtfully present at Tuba, Ariz., and is absent at Red Rock, Ariz.; in Zion Canyon, Utah; at Todilto Park and Biltabito, N. Mex.; and in San Miguel Canyon, and Unaweep Canyon, Colo. The limits of the Kayenta formation are therefore fairly well defined in these directions. Its northern margin is somewhere under the Uinta Basin, and it is likely that the western margin is under the Wasatch Plateau.

The Navajo sandstone thickens greatly toward the southwest and may originally have been much thicker at and beyond the limits of the region shown in the diagram. In the Muddy Mountains, Nev., where perhaps nearly the maximum thickness of the Navajo sandstone is exposed, and farther to the southwest in the Goodsprings quadrangle, Nev., the upper part of the sandstone has been removed by erosion. In the northwest at Fort Douglas, Utah, the seemingly equivalent Nugget is likewise fairly thick. Between these southwestern and northwestern localities in the region west of the San Rafael Swell no unit comparable to the Navajo sandstone has been reported, though it is possible that one may be present for some distance and not exposed. Southeast and east of the San Rafael Swell the Navajo sandstone thins rapidly and disappears. It is not known to extend into New Mexico, though it may do so under cover for a short distance south of McElmo Canyon. It is absent in Unaweep Canyon and San Miguel Canyon and at Durango, Colo. Its northern limit is not shown by the writers' data, though it is believed to be present along the Uinta Mountains and beyond them in southwestern Wyoming. The Navajo, therefore, forms a great wedge, with its line of maximum thickness apparently trending northeast from southern Nevada. The limit of the thinning wedge can be drawn approximately through Rough Rock, Ariz., the common corner of the four States, and Durango, San Miguel Canyon, and Unaweep Canyon, Colo.

The Carmel formation is thick in the west and northwest, where it contains marine limestone, but thins rapidly toward the southeast and east. Its northeastern limit is undetermined. After the marine limestone wedges out the Carmel formation persists for a long distance as a thin series of red sandstones and shales. It is absent, however, at Tuba, Rough Rock, and Red Rock, Ariz.; and at Durango, a short distance east of Gypsum Valley, in Unaweep Canyon, Colo.

The Entrada sandstone apparently attains its maximum thickness in the vicinity of the Circle Cliffs, Utah. It thins away from this locality in all directions in which it has been observed. Toward the south it eventually thins out upon the Navajo and disappears. Toward the southeast it thins out upon the Wingate sandstone, as at Biltabito. To the east it persists across the older sediments and rests on the crystalline rocks, as on the Piedra River, Colo. To the northeast it is lacking on the Gunnison River but reappears farther north and persists to the edge of the region considered. Seemingly a lobe of Entrada sandstone extends eastward into southern Colorado, and another extends southward into northern Colorado. The Entrada sandstone is thin or absent at Diamond Valley, Utah; at Tuba, Rough Rock, and Red Rock, Ariz.; and in the Chama Basin, N. Mex. It persists eastward to the Piedra River, Ouray, and Unaweep Canyon, Colo., but probably goes only a little farther. It is lacking at Bostwick Park, Redstone, Scofield Park, and Boulder, Colo.

The Curtis formation is present in the San Rafael Swell, Utah; in southwestern Utah; and in the eastern Uinta region and northwestern Colorado. It is also represented in the so-called "Twin Creek limestone" of Mathews in north-central Utah and in the Beckwith formation of southwestern Wyoming. Probably the three areas noted first are lobes of a larger body of marine sediments lying to the northwest and north.

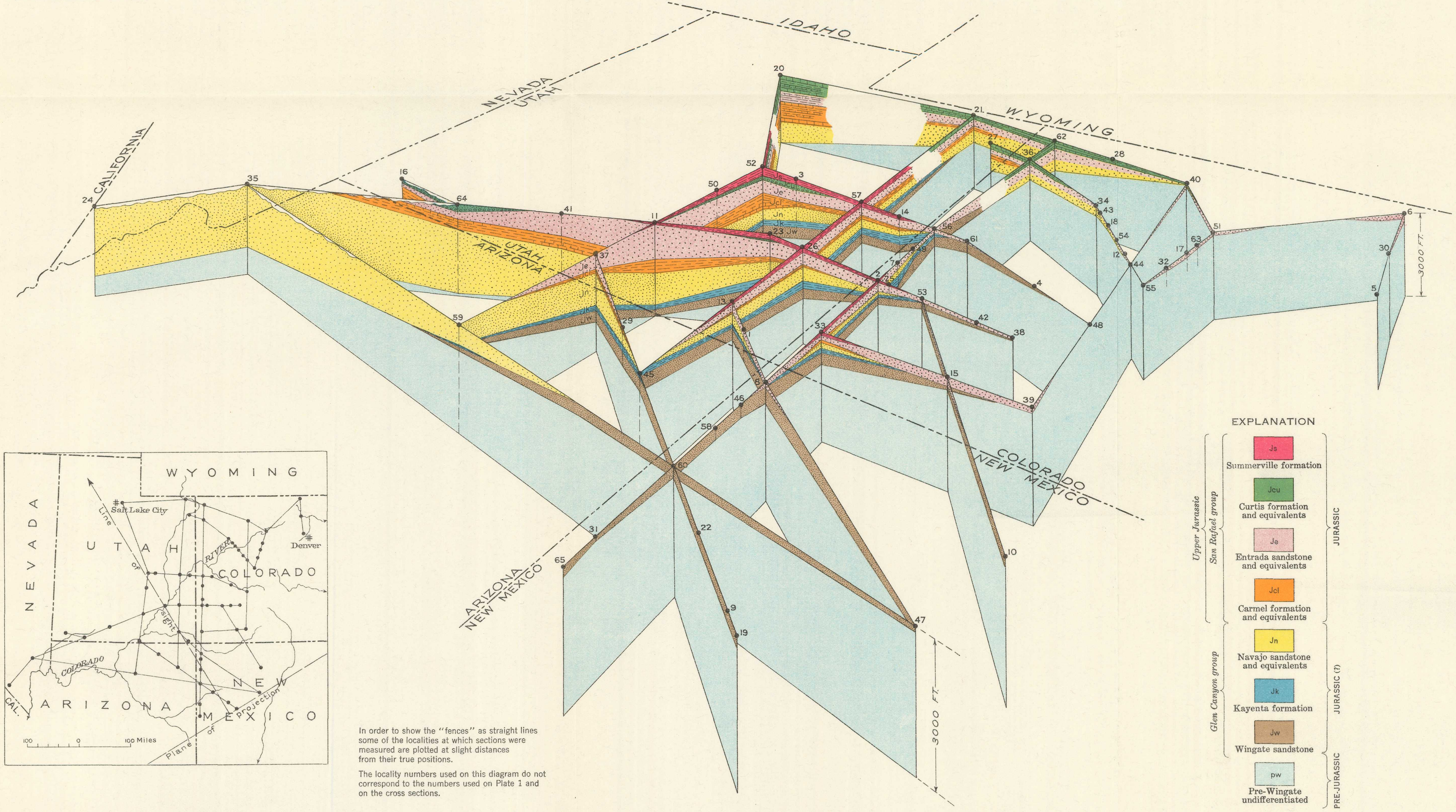
The Summerville formation is prominent in the San Rafael Swell but where thin cannot be traced with confidence very far to the south or east. It is known in southeastern Utah and extreme western Colorado.

NOMENCLATURE

The region treated in this paper is large, the local sequences of formations differ much, and the many geologists who have shared in the study of the stratigraphy have had rather diverse points of view and aims in their work. The classifications and correlations of the strata offered in the literature therefore differ considerably. Some of them, indeed, conflict so much that it is difficult to write a clear record of the successive views expressed. Some sort of compact record is needed, however, as an aid toward understanding the nomenclatorial history, and the writers have ventured to compile the appended tables and brief discussions, dividing the matter into eight arbitrary geographic units.

A convenient regional standard is offered by the sequence recognized in the San Rafael Swell, where all the units are present except the Todilto limestone

[91] Darton, N. H., "Red Beds" and associated formations in New Mexico: U. S. Geol. Survey Bull. 794, p. 33, 1928 [1929].



In order to show the "fences" as straight lines some of the localities at which sections were measured are plotted at slight distances from their true positions.

The locality numbers used on this diagram do not correspond to the numbers used on Plate 1 and on the cross sections.

LOCALITIES

1. Boundary Butte, Utah.
2. Bush Canyon, Colo.
3. Black Dragon Canyon, Utah.
4. Bostwick Park, Colo.
5. Boulder, Colo.
6. Boxelder Creek, Colo.
7. Bedrock, Colo.
8. Biltabito, N. Mex.
9. Bluewater, N. Mex.
10. Chama Basin, N. Mex.
11. Circle Cliffs, Utah.
12. Carbondale, Colo.
13. Comb Ridge, Utah.
14. Dewey Bridge, Utah.
15. Durango, Colo.
16. Diamond Valley, Utah.
17. Brush Creek south of Eagle, Colo.
18. Elk Creek, Colo.
19. El Rito, N. Mex.
20. Fort Douglas, Utah.
21. Flaming Gorge, Utah.
22. Fort Wingate and Navajo Church, N. Mex.
23. Green River Desert, Utah.
24. Goodsprings, Nev.
25. Gypsum Valley, Colo.
26. Indian Creek, Utah.
27. Island Park, Utah.
28. Juniper Hot Springs, Colo.
29. Kayenta, Ariz.
30. Loveland, Colo.
31. Lupton, Ariz.
32. Maroon Canyon, Colo.
33. McElmo Canyon, Colo.
34. Southeast of Meeker, Colo.
35. Muddy Mountains, Nev.
36. Midland Ridge, Colo.
37. Navajo Mountain, Utah.
38. Ouray, Colo.
39. Piedra River, Colo.
40. Phippsburg, Colo.
41. Paria River, Utah.
42. Placerville, Colo.
43. Rifle Creek, Colo.
44. Redstone, Colo.
45. Roughrock, Ariz.
46. Redrock, Ariz.
47. Rio Salado, N. Mex.
48. Sapinero, Colo.
49. Sinbad Valley, Colo.
50. Starvation Creek, Utah.
51. Statebridge, Colo.
52. Saddlehorse Canyon, Utah.
53. San Miguel Canyon, Colo.
54. South Canyon, Colo.
55. Scofield Park, Colo.
56. Serpents Trail, Colo.
57. Salt Valley, Utah.
58. Toadlena, N. Mex.
59. Tuba, Ariz.
60. Todilto Park, N. Mex.
61. Unaweep Canyon, Colo.
62. Vermilion Creek, Colo.
63. Wolcott, Colo.
64. Zion Canyon, Utah.
65. Zuni, N. Mex.

COMPOSITE CORRELATION DIAGRAM

ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

TABLE 1.—*Nomenclature used in southwestern Utah and southeastern Nevada*

Standard divisions adopted for comparison	Powell, J. W. Country north of the Grand Canyon 1873	Powell, J. W. Eastern part of Uinta Mountains 1876	Dutton, C. E. High Plateaus 1880	Huntington, Ellsworth, and Goldthwait, J. W. Toquerville district 1904	Cross, Whitman, and Howe, Ernest Red Beds 1905	Lee, W. T. Iron County coal field 1907	Lee, W. T. Mesozoic physiography 1918	Reeside, J. B., Jr., and Bassler, Harvey Southwestern Utah and northwestern Arizona 1922	Longwell, C. R. Muddy Mountains 1928	Hewett, D. F. Goodsprings quadrangle 1931	Gregory, H. E., and Moore, R. C. Kaiparowits region (west of the plateau) 1931	Gregory, H. E. Colorado Plateau region 1933	This paper
Cretaceous	Cretaceous	Cretaceous	Cretaceous	[Not described]	Cretaceous	Cretaceous	Upper Cretaceous	Cretaceous(?) sandstone	[Absent]	[Absent]	Upper Cretaceous	Cretaceous	Cretaceous
(Jurassic) Morrison formation	[Apparently not noted]	(Jurassic) Flaming Gorge group	(Jurassic) [Not described]		[Absent]	[Absent]	[Absent]	[Absent]			[Absent]	[Absent]	[Absent]
(Jurassic; San Rafael group) Summerville formation													
Curtis formation					(Jurassic) Flaming Gorge group	(No age assignment made) Gypsum, earthy limestone, red sandstone, etc., not clearly assigned but below base of Cretaceous	(Lower Cretaceous) McElmo or Morrison	Cretaceous(?) variegated shale			(Lower Cret.?) Morrison formation (Jurassic; Upper Jurassic; San Rafael group) Summerville formation (Carmel formation) Gypsiferous zone	(Jurassic(?)) Undifferentiated beds	(Jurassic; San Rafael group) Curtis formation
Entrada sandstone											Sandstone zone		Entrada sandstone
Carmel formation	(Jurassic) Gray limestones		Fossiliferous Jurassic shales and limestones				(Jurassic) Marine Jurassic	Jurassic limestone and shale			Limestone zone ?	(Jurassic) Carmel formation	Carmel formation
(Jurassic(?); Glen Canyon group) Navajo sandstone	(Triassic) Sandstone of Gray Cliffs	(Triassic(?)) White Cliff group	Jurassic white sandstone (White Cliffs)	(No age assignment made) Colob sandstone Kanab sandstone (part)	White Cliff sandstone Triassic beds (part)	Kanab sandstone (part)	White Cliff and Vermilion Cliff, nonmarine	Jurassic sandstone	Jurassic(?) sandstone	(Jurassic(?)) Aztec sandstone	(Jurassic(?); Lower Jurassic(?); Glen Canyon group) Navajo sandstone Todilto(?) formation Wingate sandstone	(Jurassic(?); Glen Canyon group) Navajo sandstone *Kayenta formation* Wingate sandstone ?	(Jurassic(?); Glen Canyon group) Navajo sandstone
Kayenta formation	[Absent]	[Absent]	[Absent]	[Absent]	[Absent]	[Absent]	[Absent]	[Absent]	[Absent]	[Absent]	[Absent]	[Absent]	[Absent]
Wingate sandstone													
Triassic (Chinle formation)	*Sandstone of Vermilion Cliffs*	*Vermilion Cliff group*	*Triassic sandstones and shales (Vermilion Cliffs)*	*Kanab sandstone (part) Painted Desert formation*	*Triassic beds (part)*	*Kanab sandstone (part) Painted Desert formation*	Upper Triassic	(Triassic) Chinle formation	(Triassic) Chinle formation	(Triassic) Chinle formation	(Triassic) Chinle formation	(Triassic) Chinle formation	(Triassic) Chinle formation

member of the Morrison formation and the Moab tongue of the Entrada sandstone. This sequence is shown at the left of each table. The vertical spacing there and throughout the table implies only relative position; it does not in any way imply thickness or length of time represented by the sediments to which the individual names are attached. A wavy line indicates an unconformity postulated by the author cited. Incomplete blocks in the column representing the nomenclature accepted in this paper indicate that certain formations do not persist throughout the region covered by the table.

SOUTHWESTERN UTAH AND SOUTHEASTERN NEVADA

Powell [92] in 1873 applied the names Shinarump Cliffs, Vermilion Cliffs, and Gray Cliffs to topographic features of southwestern Utah and described the rocks included in them. In 1876,[93] in connection with a discussion of the eastern part of the Uinta Mountains, he described again the section in southern Utah, applying the name †"Vermilion Cliff group" to rocks included in the Chinle formation of the present paper; the name †"White Cliff group" to most of the rocks of the Gray Cliffs, the Navajo sandstone of the present paper; and the name †"Flaming Gorge group" to the marine limestones in the uppermost part of the Gray Cliffs and the overlying beds, now constituting the San Rafael group and probably the Morrison formation. Powell assigned the †Vermilion Cliff and †White Cliff to the Triassic and the †Flaming Gorge to the Jurassic.

Dutton [94] in 1880 described the geology of southern and southwestern Utah and made wide correlations of the Triassic and Jurassic units. He used Powell's names in large part, but his work covered a great area and the names are not applied consistently. In general he used †"Vermilion Cliffs" and †"White Cliffs" as Powell used them. The †"Jurassic shales and limestones" of Dutton are the basal part of Powell's †Flaming Gorge, the present-day Carmel formation. The higher Jurassic beds are not clearly identified. Dutton differed from Powell by assigning the †White Cliffs to the Jurassic.

Huntington and Goldthwait [95] in 1904 described the rocks near Toquerville, Utah, using the name †"Kanab sandstone" for part of the Chinle and the overlying red part of the Navajo sandstone of the present paper; and the name †"Colob sandstone" for the white upper part of the Navajo (pl. 11, *B*). They did not discuss the higher beds but suggested that the Cretaceous deposits succeed the †Colob sandstone.

Cross and Howe [96] in 1905 interpreted a section which C. D. Walcott had measured in Kanab Canyon, Utah. They recognized in it the †Flaming Gorge group of Powell, lying between the Cretaceous and the †White Cliff sandstone and with the †White Cliff constituting the Jurassic. The underlying red rocks they put largely into the Triassic but did not attempt to identify the †Vermilion Cliff sandstone. In the present paper the upper part of the so-called "Triassic" of the section and the †White Cliffs are considered to be Navajo sandstone. The †Flaming Gorge is considered to include Carmel at the base, representatives of the overlying San Rafael group, and any part of the Morrison formation that may be present, though it seems doubtful that any part of it is there.

Cross [97] in 1908 repeated the interpretation made in 1905 with the addition of a tentative identification of the †Vermilion Cliffs group at the top of his Triassic.

Lee [98] in 1907 noted in Iron County, Utah, units which he thought equivalent to Huntington and Goldthwait's †Kanab sandstone but no †Colob sandstone. Lee's †Kanab contains the upper part of the Chinle formation and all of the Navajo sandstone of the present paper and is overlain by the Carmel formation and beds believed to be the upper part of the San Rafael group. He made no age assignments.

In 1918 Lee [99] recognized †Vermilion Cliff and †White Cliff sandstones, marine Jurassic, and †McElmo or Morrison formations in southwestern Utah. The sandstones are the Navajo sandstone of this paper, the "marine Jurassic" is the Carmel formation, and the †McElmo is probably the upper part of the San Rafael group and any Morrison that may be present. Lee assigned these units to the Jurassic, except the †McElmo, which he called Lower Cretaceous.

Reeside and Bassler [1] in 1922 applied the term "Jurassic sandstone" to the Navajo sandstone of the present paper, supposing it to contain the †Vermilion Cliff and †White Cliff sandstone. They applied "Jurassic limestone and shale" to the present Carmel formation and "Cretaceous(?) variegated shale" to beds above it that probably represent the upper part of the San Rafael group.

[92] Powell, J. W., Some remarks on the geological structure of a district of country lying to the north of the Grand Canyon of the Colorado: Am. Jour. Sci., 3d ser., vol. 5, pp. 456–465, 1873.

[93] Powell, J. W., Geology of the eastern portion of the Uinta Mountains and a region of country adjacent thereto, pp. 51–54, 68, text fig. 9, U. S. Geol. and Geog. Survey Terr., 1876.

[94] Dutton, C. E., Geology of the High Plateaus of Utah, pp. 143–154, 207–208, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 208, 1880.

[95] Huntington, Ellsworth, and Goldthwait, J. W., The Hurricane fault in the Toquerville district, Utah: Harvard Coll. Mus. Comp. Zoology Bull., vol. 42, pp. 203, 207, 1904.

[96] Cross, Whitman, and Howe, Ernest, Red beds of southwestern Colorado and their correlation: Geol. Soc. America Bull., vol. 16, pp. 482–487, 1905.

[97] Cross, Whitman, The Triassic portion of the Shinarump group, Powell: Jour. Geology, vol. 16, pp. 104–108, 1908.

[98] Lee, W. T., The Iron County coal field, Utah: U. S. Geol. Survey Bull. 316, pp. 362–365, 1907.

[99] Lee, W. T., Early Mesozoic physiography of the southern Rocky Mountains: Smithsonian Misc. Coll., vol. 69, no. 4, p. 22, 1918.

[1] Reeside, J. B., Jr., and Bassler, Harvey, Stratigraphic sections in southwestern Utah and northwestern Arizona: U. S. Geol. Survey Prof. Paper 129, pp. 63–64, 1922.

Longwell [2] and Hewett [3] in recent papers record for eastern Nevada a massive sandstone, 2,000 feet or more in thickness and resting on the Chinle formation. Longwell did not name the unit in the Muddy Mountains, but Hewett called it the "Aztec sandstone" in the Goodsprings quadrangle. Both assign it to the Jurassic with doubt. The next higher beds are middle Tertiary deposits.

Gregory and Moore [4] in connection with a description of the Kaiparowits region described the Jurassic rocks of the adjacent region to the west. They recognized an equivalent of the Glen Canyon group in Paria, Kanab, and Zion Canyon, though they considered it impossible to separate the constituent formations in Zion Canyon. At Mount Carmel they recognized doubtful Morrison and Summerville formations overlying the typical Carmel formation. The Carmel formation included an unconformity and was interpreted as possibly unconformable on the Navajo sandstone. The upper part of the Carmel formation of Gregory and Moore is assigned in the present paper to the Entrada and Curtis formations, and their Summerville and Morrison to the Curtis formation. Their Glen Canyon group is interpreted as Navajo sandstone and the basal part of the Carmel formation.

Gregory,[5] in a brief description of the rocks of the Colorado Plateau, recognized the Glen Canyon group as containing in Kanab Canyon, Utah, the Wingate sandstone, the Kayenta formation, and the Navajo sandstone. To the Carmel formation he assigned 100 to 250 feet of limestone and shale, placing the next higher 250 feet of rocks in "undifferentiated Jurassic(?)" and suggesting that they may represent the remainder of the San Rafael group and the Morrison formation.

In the present paper the Navajo sandstone is considered to be the only recognizable representative of the Glen Canyon group in southwestern Utah and adjacent Nevada. The Carmel formation is represented by its typical development. The Entrada sandstone is represented by a soft red facies in the east and may be absent in the west. The Curtis formation is represented by gypsum and gypsiferous marine sandstone and shows an erosional unconformity at its basal boundary. It is absent toward the east. The Summerville and Morrison formations are believed to be absent. In Nevada all these higher beds are missing, and only the Navajo is present.

[2] Longwell, C. R., Geology of the Muddy Mountains, Nev.: U. S. Geol. Survey Bull. 798, pp. 62–68, 1928.

[3] Hewett, D. F., Geology and ore deposits of the Goodsprings quadrangle, Nev.: U. S. Geol. Survey Prof. Paper 162, p. 35, 1931.

[4] Gregory, H. E., and Moore, R. C., The Kaiparowits region, Utah and Arizona: U. S. Geol. Survey Prof. Paper 164, pp. 36, 67–73, 1931.

[5] Gregory, H. E., Colorado Plateau region: 16th Internat. Geol. Cong. Guidebook 18, pp. 13–16, 1933.

MIDDLE EASTERN UTAH

Newberry [6] in 1876 described exposures along the Colorado River near Moab. Units 5 and 6 of his section, assigned to the Jurassic, seem surely to be the Morrison and Summerville formations of the present paper; unit 7, assigned with the underlying units to the Triassic, contains the Entrada, Carmel, and Navajo formations; unit 8 is the Kayenta formation; unit 9 is the Wingate sandstone. The underlying Chinle and Shinarump formations are also identifiable in Newberry's section.

Cross and Howe [7] in 1905 interpreted Newberry's section in Canyon Colorado (which is now known as Indian Creek), near the La Sal Mountains, as containing in the upper part of Newberry's Trias the three divisions of the †La Plata sandstone, with undoubted †McElmo formation above and an equivalent of the Dolores formation below.

Cross [8] in 1907 differentiated the †McElmo formation in the Colorado Valley near Moab, including in it the Summerville and Morrison formations, as defined in the present paper. He also differentiated the Jurassic †La Plata sandstone, in which he included the beds here assigned to the Entrada, Carmel, and Navajo sandstones. His Triassic Dolores formation included the Kayenta, Wingate, and Chinle formations of this paper. Cross considered the sandstone now called Wingate to be equivalent to the †Vermilion Cliff sandstone.

Lupton [9] in 1914 described the beds near Green River, Utah, assigning to the †McElmo formation the beds here included in the Morrison, Summerville, and Curtis formations, and including in the †McElmo the Salt Wash member as it is now identified. His †La Plata sandstone is the Entrada sandstone of the present paper. The older beds are not described.

In 1916 Lupton [10] described the geology of Castle Valley, Utah, accepting ostensibly the same terminology as in his earlier paper but really applying it differently. His †Vermilion Cliff sandstone seems to include the Chinle, Wingate, and Kayenta formations of the present paper; his †La Plata sandstone is the Navajo sandstone; and his †McElmo formation includes the whole San Rafael group and the Morrison formation. The name "Salt Wash member", how-

[6] Newberry, J. S., Report of the exploring expedition from Santa Fe, N. Mex., to the junction of the Grand and Green Rivers of the Great Colorado of the West in 1859, pp. 95, 99, Washington, U. S. Army Eng. Dept., 1876.

[7] Cross, Whitman, and Howe, Ernest, Red beds of southwestern Colorado and their correlation: Geol. Soc. America Bull., vol. 16, p. 475, 1905.

[8] Cross, Whitman, Stratigraphic results of a reconnaissance in western Colorado and eastern Utah: Jour. Geology, vol. 15, pp. 641–649, 1907.

[9] Lupton, C. T., Oil and gas near Green River, Grand County, Utah: U. S. Geol. Survey Bull. 541, pp. 124–127, 1914.

[10] Lupton, C. T., Geology and coal resources of Castle Valley in Carbon, Emery, and Sevier Counties, Utah: U. S. Geol. Survey Bull. 628, pp. 22–26, 1916.

TABLE 2.—*Nomenclature used in middle eastern Utah*

Standard divisions adopted for comparison	Newberry, J. S. Expedition to junction of the Grand and Green Rivers 1876	Cross, Whitman, and Howe, Ernest Red Beds 1905	Cross, Whitman Reconnaissance in western Colorado and Utah 1907	Lupton, C. T. Green River 1914	Lupton, C. T. Castle Valley 1916	Lee, W. T. Mesozoic physiography 1918	Forrester, J. B. Jurassic of southeastern Utah 1918	Butler, B. S., and others Ore deposits of Utah 1920	Campbell, M. R. Denver & Rio Grande Western guidebook 1922
Cretaceous		[Not described]	Cretaceous	Cretaceous	Cretaceous	Upper Cretaceous	[Not described]	Cretaceous	Cretaceous
Morrison formation	Jurassic beds	McElmo formation	McElmo formation	Jurassic (?) McElmo formation: Salt Wash sandstone member		Lower Cretaceous: McElmo or Morrison	Upper: Conglomerate and variegated beds	McElmo formation	
Summerville formation									
Curtis formation		Jurassic	Jurassic		Jurassic McElmo formation: Salt Wash sandstone member		Limestone and other rocks	Jurassic	Cretaceous (?) and Jurassic: McElmo formation and La Plata sandstone
Entrada sandstone				Jurassic: La Plata sandstone		Upper	Jurassic		
Carmel formation		La Plata sandstone	La Plata sandstone			Middle (marine Jurassic)	Middle	La Plata sandstone	
Navajo sandstone	Triassic beds				La Plata sandstone	Jurassic La Plata sandstone			
Kayenta formation				[Not described]		Lower	Coarse-grained sandstone		
Wingate sandstone		Triassic beds	Triassic: Dolores formation		Triassic: Vermilion Cliff sandstone			Triassic sandstone and shale	[Not described]
Triassic						Triassic	Lower: Red shale and sandstone		

Standard divisions: Morrison formation through Carmel formation are Jurassic (Summerville formation through Carmel formation: San Rafael group); Navajo sandstone through Wingate sandstone are Jurassic (?) (Glen Canyon group).

Standard divisions adopted for comparison	Prommel, H. W. C. Grand and San Juan Counties 1923	Keyes, C. R. Grand staircase of Utah 1924	Harrison, T. S. Colorado-Utah salt domes 1927	Baker, A. A., and others Moab region 1927	Gould, L. M. La Sal Mountains 1927	Branson, E. B. Triassic-Jurassic "red beds" 1927	Gilluly, James, and Reeside, J. B., Jr. San Rafael Swell 1928	Reeside, J. B., Jr. Triassic-Jurassic "red beds" 1929	Mathews, A. A. L. Central Wasatch Mountains 1931	This paper
Cretaceous	Cretaceous	Middle Cretacic	Cretaceous	Upper Cretaceous	Cretaceous		Upper Cretaceous	[Not described]	[Not described]	Cretaceous
Morrison formation	McElmo formation		Cretaceous: McElmo (Morrison?) formation	Cretaceous(?) Morrison formation: Salt Wash sandstone member	Jurassic(?): McElmo formation		Lower Cretaceous(?) Morrison formation: Salt Wash sandstone member	Cretaceous(?): Morrison formation	Upper Cretaceous: Morrison formation	Morrison formation: Salt Wash sandstone member
Summerville formation				Summerville formation		[Not described]	Summerville formation	Summerville formation	Summerville formation	Summerville formation
Curtis formation	White sandstone	McElmo shale		Moab sandstone member			Curtis formation	Curtis formation	Curtis formation	Curtis formation; Moab sandstone member
Entrada sandstone	Jurassic; Upper: Pink sandstone	Early Jurassic Zunian series		Upper Jurassic San Rafael group: Entrada sandstone			Upper Jurassic San Rafael group: Entrada sandstone	Upper San Rafael group: Entrada sandstone	Upper San Rafael group: Entrada sandstone	Jurassic San Rafael group: Entrada sandstone
Carmel formation	Middle		Jurassic La Plata sandstone: Navajo sandstone	Carmel formation	Jurassic La Plata group: Navajo sandstone		Carmel formation	Jurassic: Carmel formation	Jurassic: Carmel formation	Carmel formation
Navajo sandstone	La Plata sandstone; Navajo sandstone: Lower	Whitecliff sandstone		? Navajo sandstone		Navajo sandstone	? Navajo sandstone	? Navajo sandstone	Middle: Navajo sandstone	Navajo sandstone
Kayenta formation	Todilto formation	Todilto formation	Todilto formation	Jurassic(?) Glen Canyon group: Todilto(?) formation	Todilto formation	Upper Triassic or Jurassic Vermilion Cliffs La Plata: Todilto formation	Jurassic(?) Glen Canyon group: Todilto(?) formation	Lower and Middle Glen Canyon group: Todilto(?) formation	Glen Canyon group: Todilto formation	Jurassic(?) Glen Canyon group: Kayenta formation
Wingate sandstone	Wingate sandstone	Wingate sandstone	Wingate sandstone	Wingate sandstone	Trias.(?): Wingate sandstone	Wingate sandstone	Wingate sandstone	Wingate sandstone	Lower: Wingate sandstone	Wingate sandstone
Triassic	Triassic: Chinle formation	Triassic: Doloresian series	Triassic: Chinle formation	Triassic: Chinle formation	Triassic: Chinle formation	Triassic: Chinle formation	Triassic: Chinle formation	Triassic: Chinle formation	Triassic: Chinle formation	Triassic: Chinle formation

ever, is misapplied to the Curtis formation of the present paper.

Lee [11] in 1918 interpreted Lupton's section in Castle Valley as containing equivalents of lower, middle, and upper †La Plata. As he made the Salt Wash sandstone the base of the Morrison, and his middle †La Plata is the marine Carmel, the upper †La Plata is the Entrada and the lower †La Plata is the whole Glen Canyon group. Lee assigned the overlying beds to the †McElmo or Morrison and called them "Lower Cretaceous."

Forrester [12] in 1918 published an account of the Jurassic of southeastern Utah, describing particularly the western part of the San Rafael Swell. He gives a section in which all the divisions of the present paper are clearly distinguished. His Lower Jurassic is the Shinarump conglomerate and Chinle formation, of Triassic age. His Middle Jurassic is the Glen Canyon and San Rafael groups. He suggests that his "coarse-grained sandstones" are the †White Cliffs and †Vermilion Cliffs groups and the overlying fossiliferous beds are the †Flaming Gorge group. His Upper Jurassic "conglomerate and variegated beds" he compares correctly to Morrison.

Butler [13] in 1920 used for the La Sal Mountains the terms "Triassic shale and sandstone," †"La Plata sandstone," and †"McElmo sandstone." The first includes the Chinle, Wingate, and Kayenta formations; the second the Navajo, Carmel, and Entrada formations; the third the Summerville and Morrison of the present paper.

Campbell [14] in 1922 applied to exposures near the Denver & Rio Grande Western Railroad the designation †"McElmo formation and †La Plata sandstone." These beds are assigned in the present paper to the Navajo sandstone, the San Rafael group, and the Morrison formation. Campbell placed them in the Cretaceous(?) and Jurassic.

Prommel [15] in 1923 recognized for the Moab district Wingate as here applied and used †"Todilto" for the Kayenta formation of this paper; "Navajo" for the Navajo, Carmel, and Entrada formations of this paper; and †"McElmo" for the overlying beds. In 1927 Harrison [16] and Prommel and Crum [17] used much the same units for the same area.

Keyes [18] in 1924 assigned to a Triassic †Doloresian series the Chinle of Gregory, naming Gregory's four divisions. He assigned to the early Jurassic a †Zunian series, containing Wingate sandstone at the base unconformable on the †Doloresian series, so-called "Todilto" formation above it, then unconformable †Whitecliff sandstone (apparently Navajo of Gregory), and at top the †McElmo shales (apparently all the San Rafael group and the Morrison of the present paper). The "mid" and "late" Jurassic in middle eastern Utah are interpreted as not represented here by sediments, but elsewhere the †Flaming Gorge group represents late Jurassic and is followed by the Dakota [?] formation, which he referred to the †Middle Cretacic.

Baker and others [19] in 1927 used the nomenclature of the present paper for the Moab district except for the Kayenta formation, for which "Todilto (?)" was used. An unconformity was noted beneath the Morrison, a doubtful one beneath the Carmel formation, and an unconformity beneath the Wingate. The Morrison was assigned to the Lower Cretaceous with doubt, the San Rafael group to the Upper Jurassic, and the Glen Canyon group to the Jurassic with doubt.

Gould [20] in 1927 used in the La Sal Mountains much the same units as those of Prommel. He included the so-called "Todilto" in the †La Plata group but excluded the Wingate, assigning it to the Triassic (?). He assigned the †McElmo to the Jurassic (?). In his descriptions all the units of the present paper are easily recognized.

Branson [21] in 1927 correlated the Wingate, so-called "Todilto", and Navajo with the †Vermilion Cliffs sandstone and with the †La Plata sandstone, assigning them to the Upper Triassic or Jurassic. He did not discuss other Jurassic formations of eastern Utah.

Gilluly and Reeside [22] in 1928 used for the San Rafael Swell the nomenclature applied in the present paper except for the Kayenta formation, which they called "Todilto (?)." The age assignments were the same as in the paper by Baker and others, and unconformities were noted beneath the Morrison, Curtis, Carmel, and Wingate formations, that beneath the Carmel being doubtful. Gilluly [23] repeated this nomenclature in a somewhat later paper.

[11] Lee, W. T., Early Mesozoic physiography of the southern Rocky Mountains: Smithsonian Misc. Coll., vol. 69, no. 4, fig. 4, 1918.

[12] Forrester, J. B., A general survey of the Jurassic in southeastern Utah: Utah Acad. Sci. Trans., vol. 1, p. 33, 1918.

[13] Butler, B. S., and others, Ore deposits in Utah: U. S. Geol. Survey Prof. Paper 111, pp. 608–610, 1920.

[14] Campbell, M. R., Guidebook of the western United States, Part E, The Denver & Rio Grande Western Route: U. S. Geol. Survey Bull. 707, pp. 207, 210, sheet 8, 1922.

[15] Prommel, H. W. C., Geology and structure of portions of Grand and San Juan Counties, Utah: Am. Assoc. Petroleum Geologists Bull., vol. 7, pp. 384–399, 1923.

[16] Harrison, T. S., Colorado-Utah salt domes: Am. Assoc. Petroleum Geologists Bull., vol. 11, pp. 111–133, 1927.

[17] Prommel, H. W. C., and Crum, H. E., Salt domes of Permian and Pennsylvanian age in southeastern Utah and their influence on oil accumulation: Am. Assoc. Petroleum Geologists Bull., vol. 11, pp. 373–374, 1927.

[18] Keyes, C. R., Grand staircase of Utah: Pan-Am. Geologist, vol. 41, pp. 36, 60, 1924.

[19] Baker, A. A., Dobbin, C. E., McKnight, E. T., and Reeside, J. B., Jr., Notes on the stratigraphy of the Moab region, Utah: Am. Assoc. Petroleum Geologists Bull., vol. 11, pp. 785–808, 1927.

[20] Gould, L. M., The geology of La Sal Mountains of Utah: Michigan Acad. Sci. Papers, vol. 7, pp. 64–77, 1927.

[21] Branson, E. B., Triassic-Jurassic "red beds" of the Rocky Mountain region: Jour. Geology, vol. 35, pp. 610, 614, 1927.

[22] Gilluly, James, and Reeside, J. B., Jr., Sedimentary rocks of the San Rafael Swell and some adjacent areas in eastern Utah: U. S. Geol. Survey Prof. Paper 150, pp. 61–110, 1928.

[23] Gilluly, James, Geology and oil and gas prospects of part of the San Rafael Swell, Utah: U.S. Geol. Survey Bull. 806, pp. 69–130, 1929.

Reeside [24] in 1929 used the same units as those of the paper by Gilluly and Reeside, assigning the Glen Canyon group, however, to the Middle and Lower Jurassic without query and recognizing unconformities beneath the Morrison, Carmel, and Wingate formations.

Mathews [25] in 1931 followed Reeside essentially for eastern Utah but assigned the Morrison of the region to the Cretaceous without query and placed it as equivalent to beds elsewhere that are interpreted as part of the Upper Cretaceous (his Kelvin formation of the Wasatch Mountains). He indicated a wholly older Morrison (Jurassic) in other regions.

In the present paper middle-eastern Utah has supplied the standard section, represented by the left-hand part of the column. The Curtis is interpreted to pass entirely into beds showing a Summerville lithology and inseparable from that formation. Farther east the Moab sandstone member of the Entrada appears within the Summerville and replaces its basal part. It is, however, at most places so similar to the Entrada that it has been mapped with it and considered part of it.

SOUTHEASTERN UTAH

Gilbert [26] in 1877 used in the Henry Mountains the names devised by Powell. He applied "Henrys Fork group" to the lower part of his Cretaceous, including in it part of the Morrison formation and the Dakota(?) sandstone of the present paper; †"Flaming Gorge group" to the remainder of the Morrison formation and the San Rafael group; †"Gray Cliff group" to the Navajo sandstone; and †"Vermilion Cliff group" to the Kayenta and Wingate formations. The underlying Chinle he called †"Shinarump group, division a." Gilbert assigned the beds below his Cretaceous to the †Jura-Trias.

Dutton [27] in 1880 discussed the section in the Waterpocket Fold and Circle Cliffs. The †Vermilion Cliff sandstones seem to include Chinle, Wingate, and Kayenta formations; the †Jurassic white sandstones seem to include Navajo and Entrada sandstones; but the overlying Jurassic rocks are not clearly described.

Cross and Howe [28] in 1905 interpreted the section on the lower San Juan River as reported by H. S. Gane. They considered all the massive sandstones to be parts of the †La Plata sandstone, which therefore includes the Wingate, Kayenta, Navajo, Carmel, and Entrada. Vertebrate-bearing red beds (Chinle) immediately beneath the sandstones were assigned to the Dolores.

Woodruff [29] in 1912 assigned to the Dolores formation the rocks now called "Chinle", "Wingate", and "Kayenta" along the San Juan River near Bluff and to the †La Plata sandstone the beds from the Navajo up to and including the massive Morrison sandstone at Bluff. Higher beds were not described.

Gregory [30] in 1917, in his discussion of the northern part of the Navajo country, carried in from New Mexico the names "Wingate" and "Todilto" and proposed the name "Navajo." "Wingate" and "Navajo" are used in the present paper in the same sense, but "Todilto" is restricted to New Mexico, and "Kayenta" is substituted for it in Utah. For the three units he proposed to bring in Cross' name "†La Plata" as a group term. The overlying rocks now recognized as San Rafael and Morrison he put into the †McElmo formation, locally, however, leaving certain San Rafael beds in an indefinite status as †undifferentiated La Plata and McElmo.

Lee [31] in 1918 correlated with the Wingate or lower †La Plata the sandstones named the †"Vermilion Cliff" and †"Gray Cliff" in the Henry Mountain area. He correlated the marine Jurassic zone [Carmel] with the Todilto and the overlying beds up to an undetermined horizon with the Navajo sandstone. The beds above these were called †"McElmo" [Morrison].

Emery [32] in 1918 described the rocks of the Green River Desert. He applied the name "Wingate sandstone" to rocks here designated the "Glen Canyon group", the name "Todilto (?)" to the Carmel formation, the name "Navajo sandstone" to the remainder of the San Rafael group, and the name †"McElmo" to the Morrison. Emery inferred unconformities beneath each of his major units, though expressing doubt about those beneath his Navajo and Todilto.

Thorpe [33] described the Abajo Mountains in 1919. He used †Vermilion Cliff sandstone, †White Wall sandstone, and †McElmo formation, assigning the first two to the †La Plata group. The first appears to be Wingate and Kayenta, the second is Navajo, the third the San Rafael group and Morrison formation of the present paper.

Dake [34] in 1919 interpreted the section in the Fremont Valley much as it is here interpreted. For the rocks here designated the Glen Canyon group he used the name †"La Plata group" and applied "Wingate", "Todilto", and "Navajo" to the three parts. He interpreted the San Rafael group as of Sundance age

[24] Reeside, J. B., Jr., Triassic-Jurassic "red beds" of the Rocky Mountain region—a discussion: Jour. Geology, vol. 37, pp. 49, 50, 1929.

[25] Mathews, A. A. L., Mesozoic stratigraphy of the central Wasatch Mountains: Oberlin Coll. Lab. Bull., new ser., no. 1, pl. 2, 1931.

[26] Gilbert, G. K., Geology of the Henry Mountains, pp. 5–8, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1877.

[27] Dutton, C. E., Geology of the High Plateaus of Utah, pp. 281–283, 287–291, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1880.

[28] Cross, Whitman, and Howe, Ernest, Red beds of southwestern Colorado and their correlation: Geol. Soc. America Bull., vol. 16, pp. 475–477, 1905.

[29] Woodruff, E. G., Geology of the San Juan oil field, Utah: U. S. Geol. Survey Bull. 471, pp. 80, 88–89, 1912.

[30] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, pp. 50–68, 1917.

[31] Lee, W. T., Early Mesozoic physiography of the southern Rocky Mountains: Smithsonian Misc. Coll., vol. 69, no. 4, pp. 13–14, 1918.

[32] Emery, W. B., The Green River Desert section, Utah: Am. Jour. Sci., 4th ser., vol. 46, pp. 551–577, 1918.

[33] Thorpe, M. R., Structural features of the Abajo Mountains, Utah: Am. Jour Sci., 4th ser., vol. 48, p. 379, 1919; also in Butler, B. S., and others, Ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, pp. 618–619, 1920.

[34] Dake, C. L., The horizon of the marine Jurassic of Utah: Jour. Geology, vol. 27, pp. 634–646, 1919.

Table 3.—*Nomenclature used in southeastern Utah*

			(top to bottom; age and group names printed vertically at left are given before the colon)
Standard divisions adopted for comparison			Cretaceous Upper Jurassic: Morrison formation Upper Jurassic, San Rafael group: Summerville formation; Curtis formation; Entrada sandstone; Carmel formation Jurassic(?), Glen Canyon group: Navajo sandstone; Kayenta formation; Wingate sandstone Triassic
Gilbert, G. K.	Henry Mountains	1877	Cretaceous Jura-Triassic: Flaming Gorge group; Gray Cliff group; Vermilion Cliff group; Shinarump group (division a)
Dutton, C. E.	High Plateaus	1880	Cretaceous [Not described] Jurassic: Jurassic white sandstone Triassic: Vermilion Cliff sandstone
Cross, Whitman, and Howe, Ernest	Red Beds	1905	[Not described] Jurassic: La Plata sandstone Triassic: Dolores formation
Woodruff, E. G.	San Juan oil field	1912	[Not described] Jurassic: La Plata sandstone Triassic: Dolores formation
Gregory, H. E.	Navajo country	1917	Cretaceous Jurassic(?): McElmo formation Jurassic, La Plata group: Navajo sandstone; Todilto formation; Wingate sandstone Triassic: Chinle formation
Lee, W. T.	Mesozoic physiography	1918	Upper Cretaceous Lower Cretaceous(?): McElmo (Morrison) ? Jurassic, La Plata group: Navajo sandstone; Todilto formation; Wingate sandstone Triassic: Chinle formation
Emery, W. B.	Green River Desert	1918	Upper Cretaceous Cretaceous(?), McElmo formation: Salt Wash sandstone member Jurassic, La Plata group: Navajo sandstone; Todilto(?) formation; Wingate sandstone Triassic: Chinle formation
Thorpe, M. R.	Abajo Mountains	1919	Cretaceous Jurassic: McElmo formation Jurassic, La Plata: White Wall sandstone; Vermilion Cliff sandstone Triassic: Chinle formation
Dake, C. L.	Marine Jurassic of Utah	1919	Cretaceous Lower Cretaceous or Jurassic, McElmo formation: Upper member; Salt Wash sandstone member; Lower member (Sundance) Jurassic, La Plata group: Navajo sandstone; Todilto shaly sandstone; Wingate sandstone Triassic: Dolores formation
Butler, B. S., and others	Ore deposits of Utah	1920	Cretaceous Jurassic: Flaming Gorge formation; White Cliff sandstone Triassic: Vermilion Cliff sandstone; Older Triassic
Moore, R. C.	Circle Cliffs	1922	Cretaceous Cretaceous: McElmo formation Jurassic: Upper Jurassic sandstone; Gypsiferous zone Jurassic, La Plata group: Navajo sandstone; Todilto formation; Wingate sandstone Triassic: Chinle formation
Longwell, C. R., and others	Southeastern Utah	1923	Cretaceous Lower Cretaceous(?): McElmo formation Jurassic: Varicolored shales and sandstones; Gypsiferous shales and sandstones; Navajo sandstone; Todilto(?) formation; Wingate sandstone Triassic: Chinle formation
Keyes, C. R.	Grand staircase of Utah	1924	Middle Cretacic Early Jurassic, Zunian series: McElmo shales; Whitecliff sandstone; Todilto formation; Wingate sandstone Triassic: Doloresian series
Branson, E. B.	Triassic-Jurassic "red beds"	1927	[Not described] Jurassic or upper Triassic, Vermilion Cliffs, La Plata: Navajo; Todilto; Wingate Triassic: Chinle
Reeside, J. B., Jr.	"Triassic-Jurassic 'red beds'"	1929	[Not described] Cretaceous(?): Morrison formation Jurassic, Upper, San Rafael group: Summerville formation; Entrada sandstone; Carmel formation ? Jurassic, Lower and Middle, Glen Canyon group: Navajo sandstone; Todilto(?) formation; Wingate sandstone Triassic: Chinle formation
Gregory, H. E., and Moore, R. C.	Kaiparowits Plateau	1931	Upper Cretaceous Lower Cretaceous(?): Morrison formation Upper Jurassic, San Rafael group: Summerville formation; Entrada sandstone; Carmel formation Lower Jurassic(?), Glen Canyon group: Navajo sandstone; Todilto(?) formation; Wingate sandstone Triassic: Chinle formation
Mathews, A. A. L.	Central Wasatch Mountains	1931	[Not described] Upper Cretaceous: Morrison formation Jurassic, Upper, San Rafael group: Summerville formation; Entrada sandstone; Carmel formation Jurassic, Lower | Middle, Glen Canyon group: Navajo sandstone; Todilto formation; Wingate sandstone Triassic: Chinle formation
This paper			Cretaceous Upper Jurassic: Morrison formation Upper Jurassic, San Rafael group: Summerville formation; Curtis formation; Entrada sandstone; Carmel formation Jurassic(?), Glen Canyon group: Navajo sandstone; Kayenta formation; Wingate sandstone Triassic: Chinle formation

TABLE 4.—*Nomenclature used in northern Arizona*

Standard divisions adopted for comparison	Dutton, C. E. Grand Canyon district 1882	Darton, N. H. Reconnaissance, northwestern New Mexico and northern Arizona 1910	Gregory, H. E. Navajo country 1917	Lee, W. T. Mesozoic physiography 1918	Keyes, C. R. Framework of Arizona geology 1922	Reagan, A. B. Hopi Buttes 1924
Cretaceous	Cretaceous	Upper Cretaceous	Cretaceous	Upper Cretaceous	Cretacic	Cretacic
Jurassic Morrison formation	[Not described]	Triassic(?) "Painted Desert formation"	Jurassic(?) McElmo formation	Lower Cretaceous McElmo formation	Early Jurassic Zunian series McElmo formation	Jurassic Zunian series McElmo formation
San Rafael group Summerville formation						[Absent]
Curtis formation						
Entrada sandstone						
Carmel formation			?			
Jurassic(?) Glen Canyon group Navajo sandstone	Jurassic sandstone of White Cliffs		Jurassic La Plata group Navajo sandstone	Jurassic La Plata group Navajo sandstone	La Plata sandstone	La Plata (Navajo) sandstone
Kayenta formation	Triassic sandstone of Vermilion Cliffs		Todilto formation	Todilto formation	Todilto formation	Todilto limestone
Wingate sandstone			Wingate formation	Wingate sandstone	Wingate sandstone	Wingate sandstone
Triassic		Triassic "Leroux formation"	? Triassic Chinle formation	Triassic Chinle formation	Triassic Doloresian series	Triassic Doloresian series

Standard divisions adopted for comparison	Reagan, A. B. Black Mesa 1925	Darton, N. H. Arizona geology 1925	Reagan, A. B. Navajo country 1927	Branson, E. B. Triassic-Jurassic "red beds" 1927	Reeside, J. B., Jr. Triassic-Jurassic "red beds" 1929	Mathews, A. A. L. Central Wasatch Mountains 1931	This paper
Cretaceous	Cretacic	Cretaceous	Cretaceous	[Not described]	[Not described]	[Not described]	Cretaceous
Jurassic Morrison formation	Jurassic McElmo formation	Cretaceous(?) McElmo formation	Jurassic McElmo formation		Cretaceous(?) Morrison formation	Upper Cretaceous Morrison formation	Morrison formation
San Rafael group Summerville formation					Jurassic Upper San Rafael group Summerville formation	Jurassic Upper San Rafael group Summerville formation	Jurassic San Rafael group Summerville formation
Curtis formation							
Entrada sandstone					Entrada sandstone	Entrada sandstone	Entrada sandstone
Carmel formation					Carmel formation	Carmel formation	Carmel formation
Jurassic(?) Glen Canyon group Navajo sandstone	Zunian series La Plata group Navajo (La Plata) sandstone	Jurassic La Plata group Navajo sandstone	La Plata group Navajo sandstone	Upper Triassic or Jurassic Vermilion Cliffs La Plata group Navajo sandstone	? Lower and Middle Glen Canyon group Navajo sandstone	Middle Glen Canyon group Navajo sandstone	Jurassic(?) Glen Canyon group Navajo sandstone
Kayenta formation	Todilto limestone	Todilto formation	Todilto formation	Todilto formation	Todilto(?) formation	Todilto formation	Kayenta formation
Wingate sandstone	Wingate sandstone	Wingate sandstone	Wingate sandstone	Wingate sandstone	Wingate sandstone	Lower Wingate sandstone	Wingate sandstone
Triassic	Triassic Doloresian series	Triassic Chinle formation	Triassic Chinle formation	Triassic Chinle formation	Triassic Chinle formation	Triassic Chinle formation	Triassic Chinle formation

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and applied to it the name †"lower McElmo." The Salt Wash member and overlying part of the †McElmo he regarded as approximately of Morrison age.

Butler [35] in 1920 accepted †Vermilion Cliff, †White Cliff, and †Flaming Gorge for southern Utah. His †Vermilion Cliff sandstone appears to be Wingate and Kayenta, his †White Cliff sandstone appears to be Navajo, and his †Flaming Gorge formation appears to be the San Rafael group and Morrison formation together.

Moore [36] in 1922 described the region near the Circle Cliffs. He used the same nomenclature as Dake for the Glen Canyon group of the present paper but used "gypsiferous zone" for the Carmel and †Upper Jurassic sandstone for the remainder of the San Rafael group. The name †"McElmo" he restricted to the Morrison formation.

Longwell, Miser, Moore, Bryan, and Paige [37] used in 1923 for southeastern Utah much the same classification as Dake and Moore. They did not, however, use †"La Plata group" for the rocks later named "Glen Canyon group", and they questioned the Todilto. They used "gypsiferous shales and sandstones" for the present Carmel, "varicolored sandstones and shales" for the remainder of the San Rafael group, and †"McElmo" for the Morrison.

Miser [38] in 1924 used for San Juan Canyon the same classification as that of the paper last cited.

Keyes [39] in 1924 recognized as a †Doloresian series the Chinle of Gregory; as a †Zunian series the Wingate, so-called "Todilto", †Whitecliff, and †McElmo formations, assigning unconformities beneath the Wingate and †Whitecliff formations. He assigned the †Doloresian series to the Triassic and †Zunian series to the "early" Jurassic, postulating for southeastern Utah a hiatus representing the "mid" and "late" Jurassic. Next above is unconformable †Cretacic. The †Whitecliff is the Navajo of the present paper, and the †McElmo is the San Rafael group and Morrison. Keyes considers the †Flaming Gorge series of northern Utah to be late Jurassic and wholly distinct from the †McElmo.

Branson [40] in 1927 for southeastern Utah correlated the Wingate, Todilto, and Navajo with the †Vermilion Cliffs and †La Plata.

Reeside [41] in 1929 used for southern Utah the classification of the present paper, except that "Todilto (?)" was used for Kayenta and the Glen Canyon group was assigned without query to the Jurassic. Mathews [42] in 1931 used the same names that Reeside used but assigned the local Morrison to the Upper Cretaceous and omitted the query from "Todilto." Both Reeside and Mathews recognized unconformities beneath the Morrison, Carmel, and Wingate formations. Gregory and Moore [43] used in 1931 for the Kaiparowits region the same units as the two preceding, assigning the Morrison to the Lower Cretaceous with doubt and the Glen Canyon group to the Lower Jurassic with doubt. They recognized unconformities beneath the Dakota(?), Morrison, Carmel, Navajo, and Wingate formations.

The present paper recognizes in southeastern Utah all the units of the standard section.

NORTHERN ARIZONA

Dutton [44] in 1882 used for the Echo Cliffs the terminology of his earlier reports—†"Vermilion Cliffs sandstone", white "Jurassic sandstones", and red "Jurassic shales." In places he used †"White Cliffs" for the white "Jurassic sandstone." The terminology applied to the upper beds is not clear.

Darton [45] in 1910 seems to apply in northern Arizona the name †"Painted Desert formation", originated by Ward, to all the rocks between what are here called Chinle formation and the Cretaceous.

Gregory [46] in 1917 in his discussion of the Navajo country used †"La Plata group" for what is here called "Glen Canyon group" and applied "Wingate", "Todilto", and "Navajo" to the constituent members. The overlying beds he called †"McElmo", including the San Rafael group and the Morrison.

Lee [47] in 1918 correlated Gregory's units widely, assigning the †La Plata group to the Jurassic and the †McElmo to the Lower Cretaceous. In his correlations, however, Lee brought the formations of the Jurassic into equivalence with what are now known to be a diverse assortment of units. For example, he considered the Todilto [=Kayenta] to be equivalent to the Carmel formation of some localities, the Curtis formation of others, and the lower Morrison of still others.

Keyes [48] in 1922 for northeastern Arizona assigned to the Triassic a †Doloresian series—the Chinle of Gregory. He assigned to the "early" Jurassic an unconformable †Zunian series containing the Wingate,

[35] Butler, B. S., and others, Ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, pp. 76, 81–84, 1920.

[36] Moore, R. C., Stratigraphy of a part of southern Utah: Am. Assoc. Petroleum Geologists Bull., vol. 6, pp. 199–227, 1922.

[37] Longwell, C. R., and others, Rock formations in the Colorado Plateau of southeastern Utah and northern Arizona: U. S. Geol. Survey Prof. Paper 132, pp. 5, 11–14, 1923.

[38] Miser, H. D., The San Juan Canyon, southeastern Utah: U. S. Geol. Survey Water-Supply Paper 538, pp. 34, 38–39, 1924.

[39] Keyes, C. R., Grand staircase of Utah: Pan-Am. Geologist, vol. 41, pp. 36, 60, 1924.

[40] Branson, E. B., Triassic-Jurassic "red beds" of the Rocky Mountain region: Jour. Geology, vol. 35, pp. 610, 614, 1927.

[41] Reeside, J. B., Jr., "Triassic-Jurassic 'red beds' of the Rocky Mountain region"—a discussion: Jour. Geology, vol. 37, p. 50, 1929.

[42] Mathews, A. A. L., Mesozoic stratigraphy of the central Wasatch Mountains: Oberlin Coll. Lab. Bull., new ser., no. 1, pl. 2, 1931.

[43] Gregory, H. E., and Moore, R. C., Geology of the Kaiparowits region, Utah and Arizona: U. S. Geol. Survey Prof. Paper 164, pp. 36, 59–95, 1931.

[44] Dutton, C. E., Tertiary history of the Grand Canyon district: U. S. Geol. Survey Mon. 2, pp. 17, 34–43, 1882.

[45] Darton, N. H., A reconnaissance of parts of northwestern New Mexico and northern Arizona: U. S. Geol. Survey Bull. 435, pp. 11, 42, 1910.

[46] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, pp. 50–68, 1917.

[47] Lee, W. T., Early Mesozoic physiography of the southern Rocky Mountains: Smithsonian Misc. Coll., vol. 69, no. 4, pp. 12–14, 18–24, 1918.

[48] Keyes, C. R., Framework of Arizona geology: Pan-Am. Geologist, vol. 38, pp. 246, 250, 1922.

so-called "Todilto", †La Plata [=Navajo], and †McElmo formations. The "mid" and "late" Jurassic are absent, and the next higher beds are unconformable †Cretacic.

Reagan [49] in 1924 for the area south of Black Mesa, Ariz., accepted the units proposed by Keyes, though noting that the so-called "Todilto limestone" and †"La Plata sandstone" (Navajo of Gregory) are very thin and the Wingate sandstone a very soft formation. His map at places shows †McElmo in contact with †Doloresian, but the text does not account for this.

Reagan [50] in 1925 used Keyes' units for the northern rim of Black Mesa, with several modifications, however. He removed the †McElmo formation from the †Zunian series, making the series essentially the †La Plata group of Gregory, and used "Navajo" as interchangeable with †"La Plata, restricted."

Darton [51] in 1925, in a description of northern Arizona, followed essentially Gregory's classification but assigned the †McElmo to the Cretaceous (?).

Reagan [52] in 1927 used essentially Gregory's classification of Triassic Chinle formation; Jurassic †La Plata group and †McElmo formation, followed by Cretaceous Dakota [?] sandstone.

Branson [53] in 1927 correlated the Wingate, Todilto, and Navajo with the Vermilion Cliff and La Plata. He did not discuss the younger beds.

Reeside [54] in 1929 used for northern Arizona the classification of the present paper except that "Todilto(?)" was used for "Kayenta" and the Glen Canyon group was assigned without doubt to the Jurassic. Mathews [55] in 1931 used the same names but assigned the local Morrison to the Upper Cretaceous and omitted the query from "Todilto." Both Reeside and Mathews recognized unconformities beneath the Morrison, Carmel, and Wingate formations. Mathews also recognized in other areas a wholly older (Jurassic) Morrison formation.

For the present paper the only divergence in classification for northern Arizona from the standard section is the absence of Curtis as a unit.

SOUTHWESTERN COLORADO

Peale [56] in 1876 recorded for the lower part of the Black Canyon of the Gunnison River, northwest of the present-day community of Montrose, a thin series of beds between the Cretaceous and the granite basement. The greenish shale and sandstone of the upper part he assigned doubtfully to the Jurassic, and the red sandstone of the lower part doubtfully to the Triassic. He also stated that the Triassic(?) part is missing farther up the Gunnison River. The units are the Morrison and Wingate of the present paper.

Peale [57] in 1877 described for the Uncompahgre uplift and the region westward units that seem to represent the softer upper part of the Morrison of the present paper, the lighter-colored sandstones from the Salt Wash member of the Morrison to the Navajo and the red rocks from the Kayenta down into the Triassic and underlying Carboniferous.

Holmes,[58] also in 1877 described the rocks of the San Juan River drainage basin, using the names "Lower Dakota" and "bone bed" for Morrison, "white and pink sandstone" for Entrada, and "red massive sandstone" for Wingate and Chinle. He referred all below the Lower Dakota with doubt to the Triassic.

Hills [59] described as †"Jura-Trias" beds that seem to be clearly the Permian Cutler formation and Triassic Dolores formation in various localities of southwestern Colorado, and as unconformable †Lower Dakota beds that seem to represent the Entrada and Morrison formations. His conformable †Upper Dakota is apparently the Dakota(?) formation of the region. In an earlier paper [60] he had called the †Upper Dakota "Cretaceous" and considered it to be unconformable on the lower beds.

Eldridge [61] in 1894 proposed the name †"Gunnison" for beds in the Anthracite and Crested Butte quadrangles which contain only the Morrison formation, though supposed by several later authors to contain also the lower †La Plata of Cross—that is, the Entrada sandstone of the present writers. The †Gunnison formation rests on Paleozoic and pre-Cambrian rocks in these quadrangles.

Cross and his associates [62] in various papers dated from 1899 to about 1914 established a terminology for western Colorado formations and have proposed

[49] Reagan, A. B., Stratigraphy of the Hopi Buttes volcanic field, Arizona: Pan-Am. Geologist, vol. 41, pp. 356–363, 1924.

[50] Reagan, A. B., Late Cretacic formations of Black Mesa, Arizona: Pan-Am. Geologist, vol. 44, pp. 285–290, 1925.

[51] Darton, N. H., A résumé of Arizona geology: Arizona Univ. Bull. 119, pp. 128, 189, 210, fig. 32, pls. 29 b, 30 a, b, 55 a, b, 1925.

[52] Reagan, A. B., Contributions to the geology of the Navajo country, Arizona, with notes on the archeology [abstract]: Stanford Univ. Abstracts of Dissertations, 1924–26, vol. 1, pp. 138–141, 1927.

[53] Branson, E. B., Triassic-Jurassic "red beds" of the Rocky Mountain region: Jour. Geology, vol. 35, pp. 610, 614, 1927.

[54] Reeside, J. B., Jr., "Triassic-Jurassic 'red beds' of the Rocky Mountain region"—a discussion: Jour. Geology, vol. 37, pp. 49–51, 1929.

[55] Mathews, A. A. L., Mesozoic stratigraphy of the central Wasatch Mountains: Oberlin Coll. Lab. Bull., new ser., no. 1, pl. 2, 1931.

[56] Peale, A. C., Middle division [of Colorado]: U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1874, p. 102, 1876.

[57] Peale, A. C., Grand River district: U. S. Geol. and Geog. Survey Terr. Ninth Ann. Rept., pp. 80–87, 1877.

[58] Holmes, W. H., San Juan district: U. S. Geol. and Geog. Survey Terr. Ninth Ann. Rept., pp. 242–244, pl. 35, 1877.

[59] Hills, R. C., Jura-Trias of southwestern Colorado: Am. Jour. Sci., 3d ser., vol. 23, pp. 242–244, 1882.

[60] Hills, R. C., Note on the occurrence of fossils in the Triassic and Jurassic beds near San Miguel in Colorado: Am. Jour. Sci., 3d ser., vol. 19, p. 480, 1880.

[61] Emmons, S. F., Cross, Whitman, and Eldridge, G. H., U. S. Geol. Survey Geol. Atlas, Anthracite-Crested Butte folio (no. 9), p. 6, 1894.

[62] Cross, Whitman, and Purington, C. W., U. S. Geol. Survey Geol. Atlas, Telluride folio (no. 57), 1899. Cross, Whitman, Spencer, A. C., and Purington, C. W., idem, La Plata folio (no. 60), 1899. Cross, Whitman, Howe, Ernest, and Ransome, F. L., idem, Silverton folio (no. 120), 1905. Cross, Whitman, and Ransome, F. L., idem, Rico folio (no. 130), 1905. Cross, Whitman, Howe, Ernest, and Irving, J. D., idem, Ouray folio (no. 153), 1907. Cross, Whitman, and Spencer, A. C., Geology of the Rico Mountains, Colo.: U. S. Geol. Survey 21st Ann. Rept., pt. 2, pp. 7–165, 1900. Cross, Whitman, and Howe, Ernest, Red beds of southwestern Colorado and their correlation: Geol. Soc. America Bull., vol. 16, pp. 447–498, 1905. Cross, Whitman, Stratigraphic results of a reconnaissance in western Colorado and eastern Utah: Jour. Geology, vol. 15, pp. 634–679, 1907. Cross, Whitman, The Triassic portion of the Shinarump group, Powell: Jour. Geology, vol. 16, pp. 97–123, 1908. Cross, Whitman, and Larsen, E. S., Contributions to the stratigraphy of southwestern Colorado: U. S. Geol. Survey Prof. Paper 90, pp. 39–50, 1914.

Table 5.—*Nomenclature used in southwestern Colorado*

Standard divisions adopted for comparison			Cretaceous (Jurassic) Morrison formation (Jurassic; San Rafael group) Summerville formation; Curtis formation; Entrada sandstone; Carmel formation (Jurassic(?); Glen Canyon group) Navajo sandstone; Kayenta formation; Wingate sandstone Triassic
Peale, A. C.	Middle division	1876	Cretaceous Jurassic(?) greenish shale and sandstone [Absent] Triassic(?) red sandstone [Absent]
Peale, A. C.	Grand River district	1877	Cretaceous (Jurassic) Shales and marls (Triassic) Cross-bedded light-colored sandstones; Blood-red massive sandstone and shales
Holmes, W. H.	San Juan district	1877	(Cretaceous) Upper Dakota; Lower Dakota (Triassic(?)) Bone bed; [Absent]; White and pink sandstones; [Absent]; Red massive sandstone
Hills, R. C.	Southwestern Colorado	1882	Upper Dakota (Cretaceous) Lower Dakota [Absent] Jura-Trias
Eldridge, G. H.	Anthracite-Crested Butte folio	1894	Cretaceous (Jura-Trias; Gunnison formation) Shale member; Quartzite member [Absent]
Cross, Whitman, and others	Various papers	1899-1914	Cretaceous (Jurassic) McElmo formation (Jurassic; La Plata sandstone) Upper; Middle; [Absent]; Lower [Absent] (Triassic) Dolores formation
Riggs, E. S.	Grand River Valley	1901	Cretaceous (Jurassic) Variegated clay; Cross-bedded sandstone; Greenish clay; Marine Jura [Absent] (Triassic) Red shale and sandstone
Lee, W. T.	Grand Mesa and West Elk Mountains	1912	Cretaceous (Jurassic(?); Gunnison formation) Shale member; Sandstone member [Absent] (Carboniferous) Maroon conglomerate
Lee, W. T.	Mesozoic physiography	1918	Upper Cretaceous (Lower Cretaceous; Gunnison formation) McElmo formation (Morrison) (Jurassic; Gunnison formation) La Plata sandstone [Absent] Carboniferous
Coffin, R. C., and others	Anticlines of western Colorado	1920	Cretaceous (Jurassic or Cretaceous) McElmo formation (Jurassic) La Plata sandstone (Triassic) Dolores formation [Not exposed]
Coffin, R. C.	Radium deposits of southwestern Colorado	1921	Cretaceous (Cretaceous) Post-McElmo (Jurassic or Cretaceous) McElmo formation (Jurassic) La Plata sandstone (Permo-Triassic) Dolores and Cutler formations
Campbell, M. R.	Denver & Rio Grande Western guidebook	1922	Cretaceous (Jurassic and Cretaceous(?); Gunnison formation) McElmo formation; La Plata sandstone Gunnison formation [Absent] (Triassic) Massive brick-red sandstone
Weeks, H. J.	Delta and Mesa Counties	1925	Cretaceous (Jurassic; Gunnison group) McElmo member; La Plata member [Absent] (Triassic) Dolores formation
Baker, A. A., and others	*Moab region*	1927	Cretaceous (Cretaceous(?)) "McElmo formation" (Jurassic) La Plata sandstone (Jurassic(?)) Dolores formation (Triassic)
Branson, E. B.	Triassic-Jurassic "red beds"	1927	[Not described] (Upper Triassic or Jurassic) La Plata sandstone [Absent] (Jurassic) Dolores formation
Reeside, J. B., Jr.	Triassic-Jurassic "red beds"	1929	[Not described] (Cretaceous(?); "McElmo formation") Morrison formation (Jurassic; Upper; "McElmo formation") Summerville formation (Jurassic; Upper) La Plata sandstone ? (Jurassic; Lower and Middle) Dolores formation; [Absent] ? (Triassic)
Mathews, A. A. L.	Central Wasatch Mountains	1931	[Not described] (Upper Cretaceous; McElmo formation) Morrison formation (Jurassic; Upper; McElmo formation) Summerville formation (Jurassic; Upper) La Plata sandstone (Jurassic; Middle; Lower) Dolores formation; [Absent] ? (Triassic)
This paper			Cretaceous (Jurassic; †McElmo formation in wide sense; Morrison formation) †McElmo formation; †Upper La Plata; †Middle La Plata (Jurassic; †La Plata sandstone in widest sense; San Rafael group) Summerville formation; Entrada sandstone (†Lower La Plata); [Absent] [Absent] [Absent] (Jurassic(?); Glen Canyon group) Navajo sandstone; Kayenta formation; Wingate sandstone; [Absent] (Triassic; Dolores formation) Chinle formation

extended correlations, most of which are considered in this paper under the appropriate regions. The names proposed were "Dolores" for beds here named "Chinle", "Wingate", and "Kayenta"; †"La Plata" for beds here called "Entrada" and "lower Morrison"; and †"McElmo" for beds here called "middle and upper Morrison." There is some doubt whether the Dolores at the type locality contains any equivalent of the Wingate, though at other places in Colorado the name was applied by Cross to beds which do contain it. The †McElmo at its type locality appears to contain the Summerville as well as the whole Morrison, though elsewhere the name was applied by Cross to only a part of the Morrison. The variations in the usage of both Cross and later writers with respect to the scope of these names make them difficult to use, and the present tendency is to displace them with more significant though later names. The Dolores was assigned to the Triassic, the †La Plata and †McElmo to the Jurassic.

Riggs [63] in 1901 described the rocks near Grand Junction, assigning to the Triassic the massive reddish sandstone and underlying red sandy shales that rest on the granite, and to the Jurassic the overlying beds up to the Dakota(?) sandstone. In these Jurassic beds he recognizes four units, citing Morrison vertebrates from the upper three and calling the lowest marine, though wholly without warrant. His Jurassic is wholly Morrison.

Lee [64] in 1912 used Eldridge's name †"Gunnison" for the beds between the Dakota(?) and the red beds on the Gunnison River near Grand Mesa, supposing the underlying beds to be part of the Carboniferous Maroon formation. The †Gunnison of Lee contains a sandy lower member and is apparently the Morrison only, but the underlying red beds are the Chinle and Wingate of the present paper.

Lee [65] in 1918 reinterpreted his section on the Gunnison River and placed his †Gunnison formation as equivalent to the combined Morrison (†McElmo) and †La Plata, still, however, assigning the underlying red beds to the Carboniferous. He assigned the †McElmo part to the Lower Cretaceous and the †La Plata part to the Jurassic.

Coffin, Perini, and Collins [66] described in 1920 and 1924 the section in McElmo Canyon, recognizing as Triassic Dolores formation beds referred in this paper to the Navajo sandstone; as Jurassic †La Plata sandstone beds here referred to the Carmel and Entrada; and as Jurassic or Cretaceous †McElmo beds here referred to the Summerville and Morrison formations.

[63] Riggs, E. S., The dinosaur beds of the Grand River Valley of Colorado: Field Columbian Mus. Pub. 60 (geol. ser., vol. 1, no. 9), pp. 267–272, pl. 39, 1901.

[64] Lee, W. T., Coal fields of Grand Mesa and the West Elk Mountains, Colo.: U. S. Geol. Survey Bull. 510, pp. 20–23, 50, 1912.

[65] Lee, W. T., Early Mesozoic physiography of the southern Rocky Mountains: Smithsonian Misc. Coll., vol. 69, no. 4, pp. 16–21, 1918.

[66] Coffin, R. C., Perini, V. C., Jr., and Collins, M. J., Some anticlines of western Colorado: Colorado Geol. Survey Bull. 24, pp. 39–46, 1920. Reprint, 1924.

Coffin [67] in 1921 described the rocks of the extreme western part of Colorado. He used the names †"post-McElmo" and †"McElmo" together for the beds here called "Morrison" and "Summerville", though the individual names are not equivalent; †"La Plata" for the beds here called "Navajo", "Carmel", and "Entrada"; and "Dolores and Cutler" together for the Kayenta, Wingate, Chinle, and older red beds. The †post-McElmo he called "Cretaceous"; the †McElmo, "Cretaceous or Jurassic"; the †La Plata, "Jurassic"; and the Dolores and Cutler, †"Permo-Trias."

Campbell [68] in 1922 used for the area near Grand Junction along the Denver & Rio Grande Western Railroad the terms "Triassic massive red sandstone" and †"Gunnison formation", designating the latter "Cretaceous(?) and Jurassic" and suggesting that its upper member is the Morrison. The †Gunnison includes the Morrison of this paper, and the Triassic sandstone, the Wingate, and Chinle. Along the Colorado-Utah State boundary he applied "massive red Triassic sandstone" to the Wingate and Chinle, †"La Plata" to the eastern edge of the Entrada of this paper, and †"McElmo (=Morrison?)" to the Morrison of this paper.

Weeks [69] in 1925 described the section on the Gunnison River. He recognized the sandstone at the base of the section as upper Dolores and the beds above as the †Gunnison group or formation, containing two members to which he gave the names †"La Plata" and †"McElmo." His La Plata member is clearly the sandy lower half of the Morrison; his McElmo member the softer upper half. He did not accept Coffin's post-McElmo formation as valid. The next overlying beds he called "Dakota."

Baker and others [70] in 1927 used for western Colorado the names †"McElmo formation", †"La Plata sandstone", and "Dolores formation." The †McElmo formation was considered to include equivalents of the Morrison and Summerville; the †La Plata, of the Entrada, Carmel, and Navajo; and the Dolores, of the Kayenta, Wingate, and Chinle.

Branson [71] in 1927 correlated the †La Plata of southwestern Colorado with the Navajo, Todilto, and Wingate and assigned it to the Jurassic or Upper Triassic. He correlated the Dolores with Triassic, Chinle, and older beds. He considered the †La Plata to grade into the Dolores.

[67] Coffin, R. C., Radium, uranium, and vanadium deposits of southwestern Colorado: Colorado Geol. Survey Bull. 16, pp. 28, 46–113, 1921.

[68] Campbell, M. R., Guidebook of the western United States, Part E, The Denver & Rio Grande Western Route: U. S. Geol. Survey Bull. 707, pp. 182, 191–193, 197, sheet 7, text fig. 47, 1922.

[69] Weeks, H. J., Oil and water possibilities of parts of Delta and Mesa Counties, Colo.: Colorado Geol. Survey Bull. 28, pp. 11–17, 32, 1925.

[70] Baker, A. A., Dobbin, C. E., McKnight, E. T., and Reeside, J. B., Jr., Notes on the stratigraphy of the Moab region, Utah: Am. Assoc. Petroleum Geologists Bull., vol. 11, p. 799, 1927.

[71] Branson, E. B., Triassic-Jurassic "red beds" of the Rocky Mountain region: Jour. Geology, vol. 35, pp. 610, 613, 1927.

Reeside[72] in 1929 used for southwestern Colorado the terms †"McElmo formation" as including the Morrison and Summerville; †"La Plata" as containing the Navajo, Carmel, and Entrada in the west and probably only the Entrada in the east; "Dolores" as containing the Chinle, Wingate, and Todilto (?) (Kayenta) in the west and probably only the Chinle in the east.

Mathews [73] in 1931 used the same divisions, differing in assigning the local Morrison to the Upper Cretaceous and recognizing an older Morrison in other areas.

Burbank [74] in 1933 used for southwestern Colorado the divisions accepted in this paper—Dolores formation, Entrada sandstone, and Morrison formation—applying them particularly in the San Juan region.

In the present paper all the formations below the Morrison are shown as missing in part of the area considered. The Kayenta, Navajo, and Summerville formations do not come into it very far from the west. The Wingate sandstone persists in the north and the Entrada sandstone in the south practically across the region, though the Wingate definitely goes out toward the east. The Dolores formation may contain locally an inseparable equivalent of Wingate and Kayenta formations. The overlying †La Plata sandstone of Cross and others included various beds at different places, the remaining strata below the Cretaceous having constituted the †McElmo formation of the several authors.

EASTERN UINTA REGION, UTAH AND COLORADO

Powell [75] in 1876 assigned certain rocks of the eastern Uinta Mountains to the †Jura-Trias, dividing them into the †Vermilion Cliff group, the †White Cliff group, and the †Flaming Gorge group. In the Flaming Gorge group he noted four units: the †White Cliff limestone at the base, containing marine fossils; "badland indurated sandstones" above, then "mid group limestones", and at the top more "badland sandstones." Apparently the †Vermilion Cliff group includes all the Triassic rocks. The †White Cliff group is the so-called "Nugget sandstone", containing certainly the Entrada sandstone and possibly the Carmel and Navajo formations; and the †Flaming Gorge group is the Curtis formation (so-called "Twin Creek" of reports on this region) and the Morrison formation.

White [76] in 1877 gave a section for the Yampa district, particularly in Midland Ridge, near the Utah-Colorado boundary, in which his unit 11 is Weber quartzite, his unit 10 (Triassic?) is the Triassic and the so-called "Nugget sandstone", and his unit 9 (Jurassic) is the Curtis and Morrison formations. Above unit 9 lies the Cretaceous.

Hague and Emmons [77] in 1877 gave for the eastern Uinta region in general merely a division into a Triassic and Jurassic formation, though some of the present-day units may be recognized in their descriptions. The Triassic †Red Bed group contained the Triassic and the so-called "Nugget sandstone"; the "Jurassic formation" contained much limestone and included the Curtis and Morrison formations.

King [78] in 1878 described for Vermilion Creek, Colo., and Flaming Gorge, Utah, a section which, though not entirely clear, can be fairly well interpreted in modern terminology. Into the Triassic he put a basal red conglomeratic sandstone, an overlying red sandstone, a massive buff sandstone, and a topmost white and red sandstone. The first two are clearly the Ankareh(?) [=Dolores] formation; the last two are the so-called "Nugget sandstone." Into the Jurassic King put four units—limestone at the base, sandstone and shale, a second limestone, and a topmost unit of variegated clay and marl. These beds are clearly the Curtis and Morrison formations, though later writers have not recognized a thick limestone unit in the Morrison. The Cretaceous is next above.

Weeks [79] in 1907 described for the eastern Uinta region red shales as †Permo-Carboniferous that are clearly the Triassic beds of present usage. Massive cross-bedded sandstones above these he assigned to the Triassic, and the †Flaming Gorge group of Powell, above the sandstone, to the Jurassic. The massive cross-bedded sandstone is the so-called "Nugget" of the present paper, and the beds above it are the Curtis and Morrison.

Gale [80] in 1908 described for the Rangely district in Colorado the †White Cliff sandstone and the †Flaming Gorge formation, assigning both to the Jurassic. He did not then deal with the underlying beds. In 1910 Gale [81] used the same names for the Jurassic and assigned the underlying beds to the Triassic †Vermilion Cliffs sandstone. The Jurassic of these two papers is that of the present paper.

Lee [82] in 1918 adopted for Flaming Gorge and Vermilion Creek a classification derived partly from eastern

[72] Reeside, J. B., Jr., "Triassic-Jurassic 'red beds' of the Rocky Mountain region"—a discussion: Jour. Geology, vol. 37, pp. 50-51, 1929.

[73] Mathews, A. A. L., Mesozoic stratigraphy of the central Wasatch Mountains: Oberlin Coll. Lab. Bull., new ser., no. 1, pl. 2, 1931.

[74] Burbank, W. S., The western San Juan Mountains: 16th Internat. Geol. Cong. Guidebook 19, p. 36, 1933.

[75] Powell, J. W., Report on the geology of the eastern portion of the Uinta Mountains and a region of country adjacent thereto, pp. 41, 51, 151, U. S. Geol. and Geog. Survey Terr., 1876.

[76] White, C. A., Report on the geology of a portion of northwestern Colorado: U. S. Geol. and Geog. Survey Terr. 10th Ann. Rept., pp. 19, 26, pl. 1, 1877.

[77] Hague, Arnold, and Emmons, S. F., Descriptive geology: U. S. Geol. Expl. 40th Par. Rept., vol. 2, pp. 200, 264, 291-293, 1877.

[78] King, Clarence, Systematic geology: U. S. Geol. Expl. 40th Par. Rept., vol. 1, pp. 259, 263, 290, 1878.

[79] Weeks, F. B., Stratigraphy and structure of the Uinta Range: Geol. Soc. America Bull., vol. 18, p. 439, 1907.

[80] Gale, H. S., Geology of the Rangely oil district, Rio Blanco County, Colo.: U. S. Geol. Survey Bull. 350, p. 10, 1908.

[81] Gale, H. S., Coal fields of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 415, pp. 42, 50, 1910.

[82] Lee, W. T., Early Mesozoic physiography of the southern Rocky Mountains: Smithsonian Misc. Coll., vol. 69, no. 4, pp. 12-16, 1918.

TABLE 6.—*Nomenclature used in eastern Uinta region, Utah and Colorado*

Standard divisions adopted for comparison	Powell, J. W. Eastern Uinta Mountains 1876	White, C. A. Yampa district 1877	Hague, Arnold, and Emmons, S. F. Descriptive geology 1877	King, Clarence Systematic geology 1878	Weeks, F. B. Uinta Range 1907	Gale, H. S. Rangely oil district 1908	Gale, H. S. Northwestern Colorado and northeastern Utah 1910	Lee, W. T. Mesozoic physiography 1918
Cretaceous	*Cretaceous*	*Cretaceous*	*Cretaceous*	*Cretaceous*	*Cretaceous*	Cretaceous	Cretaceous	Upper Cretaceous
Jurassic: San Rafael group: Morrison formation	Jura-Trias: Flaming Gorge group: Badland sandstones Midgroup limestones	Jurassic		Jurassic: Variegated clay and marl Upper limestone	Jurassic	Jurassic	Jurassic	Lower Cretaceous(?): Morrison formation
Summerville formation	Badland sandstones	Unit 9	Jurassic formation	Sandstone and shale	Flaming Gorge group of Powell	"Flaming Gorge" formation	Flaming Gorge formation	Jurassic: La Plata group: [Unnamed upper LaPlata]
Curtis formation	White Cliff limestone			Lower limestone				Twin Creek limestone
Entrada sandstone	White Cliff group	Triassic: Unit 10 [part]	Triassic formation: Red-bed group: White sandstone	Triassic: White and red sandstone	Triassic: Massive sandstones	"White Cliffs" sandstone	White Cliff sandstone	Nugget sandstone
Carmel formation				Buff sandstone				
Jurassic(?): Glen Canyon group: Navajo sandstone	?	?	?	?	?	?	?	?
Kayenta formation	[Absent]	[Absent]	[Absent]	[Absent]	[Absent]		[Absent]	[Absent]
Wingate sandstone						[Not described]		
Triassic	Vermilion Cliff group	Unit 10 [part]	Red sandstone	Red sandstone	Permo-Carboniferous		Triassic: Vermilion Cliff sandstone	Triassic

Standard divisions adopted for comparison	Schultz, A. R. Reconnaissance in Uinta Mountains 1918	Schultz, A. R. Baxter Basin 1920	Sears, J. D. Moffat County 1924	Keyes, C. R. Grand staircase of Utah 1924	Branson, E. B. Triassic-Jurassic "red beds" 1927	Reeside, J. B., Jr. "Triassic-Jurassic 'red beds' " 1929	Bartram, J. G. "Triassic-Jurassic 'red beds' " 1930	Mathews, A. A. L. Central Wasatch Mountains 1931	This paper
Cretaceous		Upper Cretaceous	Cretaceous	Middle Cretacic		[Not described]	Cretaceous	Cretaceous	Cretaceous
Jurassic: San Rafael group: Morrison formation	[Not described]	Lower Cretaceous: Beckwith formation	Lower Cretaceous(?): Morrison formation	Late Jurassic: Flaming Gorge series: Brush shale	[Not described]	Cretaceous(?): Morrison formation	Unassigned: Beckwith (Morrison) formation	Upper Jurassic: Morrison formation	Jurassic: Morrison formation
Summerville formation									
Curtis formation		Twin Creek formation	Twin Creek limestone	Junction limestone		Twin Creek limestone	Twin Creek formation	Twin Creek formation	Curtis formation
Entrada sandstone	Jurassic(?): Nugget sandstone	Jurassic: Nugget sandstone	Jurassic: Nugget sandstone	Bishop sandstone	Jurassic or Upper Triassic: Nugget sandstone	Jurassic: Nugget sandstone	Jurassic: Nugget sandstone	Middle-Lower Jurassic: Nugget sandstone	Entrada sandstone, Carmel and Navajo formations
Carmel formation				Duchesne sandstone					
Jurassic(?): Glen Canyon group: Navajo sandstone	?	?	?	?	?	?	?	?	?
Kayenta formation	Absent]	[Absent]	[Absent]	[Absent]	[Absent]	[Absent]	[Absent]		
Wingate sandstone									
Triassic	Triassic	Triassic(?): Ankareh formation	Triassic(?): Ankareh(?) shale	Triassic: Doloresian series	Triassic: Ankareh formation	Ankareh(?) formation	Triassic: Ankareh formation	Triassic: Ankareh formation	Triassic

TABLE 7.—*Nomenclature used in northwestern Colorado*

Standard divisions adopted for comparison		Holmes, W. H. Elk Range 1876	Peale, A. C. Middle division 1876	Endlich, F. M. White River district 1877	Eldridge, G. H. Anthracite-Crested Butte region 1894	Spurr, J. E. Aspen district 1898	Fenneman, N. M., and Gale, H. S. Yampa coal field 1906	Gale, H. S. Danforth Hills and Grand Hogback 1907	George, R. D., and Crawford, R. D. Hahns Peak 1909	Gale, H. S. Northwestern Colorado and northeastern Utah 1910	Grout, F. F., and others Rabbit Ears district 1913	Lee, W. T. Mesozoic physiography 1918	Crawford, R. D., and others Routt County 1920	Coffin, R. C., and others Western Colorado 1920	Campbell, M. R. Denver & Rio Grande Western guidebook 1922	This paper
Cretaceous		Cretaceous	Cretaceous No. 1	Cretaceous	Cretaceous	Cretaceous	Cretaceous	Cretaceous	Cretaceous	Cretaceous	Cretaceous	Upper Cretaceous	Cretaceous	Cretaceous	Cretaceous	Cretaceous
Jurassic	Morrison formation	Jurassic [part]	Variegated Jurassic shales	Jura (unit b)	Juratrias Gunnison formation	Triassic Gunnison formation Variegated shales	Jura-Trias(?) red beds [part]	Jurassic(?) red clay shale	Jurassic Sundance formation	Jurassic Flaming Gorge formation	Jurassic Morrison formation	Lower Cretaceous Morrison formation La Plata? sandstone	Red clay, sandstone, etc., of undetermined age [part]	Jurassic(?) shale and massive sandstone	Jurassic and Cretaceous(?) Gunnison formation	Jurassic Morrison formation
San Rafael group	Summerville formation											Jurassic White Cliff or Nugget sandstone				
	Curtis formation		Yellow sandstones			Yellow sandstones										Curtis formation
	Entrada sandstone									White Cliff sandstone						Entrada sandstone
	Carmel formation															
Jurassic(?) Glen Canyon group	Navajo sandstone	[Absent]	[Absent]	[Absent]	[Absent]	[Absent]	[Absent]	[Not described]	[Absent]	[Absent]	[Absent]	[Absent]	[Absent]	[Absent	[Absent]	[Absent]
	Kayenta formation															
	Wingate sandstone															
Triassic		Jurassic [part]	Triassic(?) red beds	Trias (unit a)		Red beds	Jura-Trias(?) red beds [part]		Carboniferous-Jurassic red beds	Triassic Red beds		Pre-Triassic beds	Red clay, etc. [part]	Triassic(?)	Triassic	Triassic

Colorado and partly from Wyoming. For the Triassic he used no names but correlated the beds with Shinarump and Chinle. Above the Triassic he recognized unconformable †White Cliff or Nugget sandstone, correlated with the Wingate sandstone (lower †La Plata); then Twin Creek limestone, correlated with the middle †La Plata; then an indefinite upper †La Plata, correlated with the Navajo (upper †La Plata) sandstone in one diagram (his fig. 2) but apparently part of the Morrison in another (his fig. 3). The remainder of the section up to the so-called "Dakota" is placed as equivalent to the Morrison and †McElmo and also as part of the Morrison. So-called "Nugget" and so-called "Twin Creek" are designated "Jurassic", and Morrison "Lower Cretaceous."

Schultz [83] in 1918 wrote rather vaguely of Triassic and Jurassic(?) as including all around the Uinta Mountains the Woodside, Thaynes, Ankareh, and Nugget formations. In 1920 [84] he used essentially a southern Wyoming classification for Flaming Gorge and Vermilion Creek. He assigned to the Ankareh shale (Triassic?) the red beds and conglomerate considered in the present paper to be Upper Triassic. The massive sandstone above he placed in the Jurassic as Nugget. Above it unconformably he recognized the Twin Creek formation; and above that in turn unconformably the Beckwith formation, extending from Jurassic to Upper Cretaceous. The so-called "Nugget" is the Entrada, Carmel, and Navajo formations of the present paper; the so-called "Twin Creek" is Curtis; and the so-called "Beckwith" contains Morrison and Dakota(?) formations.

Sears [85] in 1924 and again in 1926 used for Vermilion Creek the terms "Triassic(?) Ankareh(?) shale", "Jurassic Nugget sandstone and Twin Creek limestone", and "Cretaceous(?) Morrison formation."

Keyes [86] in 1924 proposed for northeastern Utah several new names without definition. For the Triassic he used †"Doloresian series." For the Jurassic he used †"Flaming Gorge series" with four formations that seemingly include the so-called "Nugget sandstone", the Curtis formation, and the Morrison formation. He considered these units to be only the late Jurassic, assigning here a hiatus to the Middle and early Jurassic and placing in the early Jurassic his †Zunian series of southern Utah, which the present writers consider to include the †Flaming Gorge series.

Branson [87] in 1927 recognized for northern Utah the Nugget sandstone as Jurassic or Upper Triassic, resting conformably on the Triassic Ankareh. He correlated the Nugget with the †La Plata sandstone, †Vermilion Cliffs sandstone, and Wingate, so-called "Todilto", and Navajo formations. He did not discuss younger beds.

Reeside [88] in 1929 for northern Utah placed the Ankareh(?) formation in the Jurassic as conformable with the overlying Nugget sandstone. He also placed in the Upper Jurassic the Twin Creek limestone and in the Cretaceous(?) the Morrison formation.

Bartram [89] in 1930 used for Vermilion Creek essentially the terminology of Schultz—Triassic Ankareh shale below, Jurassic Nugget sandstone and Twin Creek formation in the middle, and unassigned Beckwith (Morrison) formation above. Bartram considered the Nugget equivalent to the Glen Canyon group.

Mathews [90] in 1931 used for the eastern Uinta region Triassic Ankareh formation, unconformable Middle and Lower Jurassic Nugget sandstone, unconformable Upper Jurassic Twin Creek limestone, and Upper Jurassic Morrison formation. The so-called "Nugget" he correlated with the Wingate and so-called "Todilto" of southern Utah, the so-called "Twin Creek" with the Navajo and most of the San Rafael group, and the local Morrison with the Summerville. The Morrison of southern Utah is given a place in the Upper Cretaceous.

In the present paper the sandstone of the eastern Uinta Mountains commonly designated "Nugget" in the literature is considered equivalent to the Entrada sandstone and probably Carmel and Navajo formations; the beds commonly called "Twin Creek limestone" are here called "Curtis formation"; and the next overlying beds are called "Morrison formation."

NORTHWESTERN COLORADO

Holmes [91] in 1876 described an area adjacent to Red Creek (Crystal River), south of Glenwood Springs. His divisions are not entirely clear, but apparently his Cretaceous is the Dakota(?) sandstone; his Jurassic includes the Morrison, Entrada, and probably the Triassic; his Triassic(?) seems to be Carboniferous.

Peale [92] in 1876 for the Eagle River and Grand [Colorado] River near the mouth of Roaring Fork

[83] Schultz, A. R., A geologic reconnaissance of the Uinta Mountains, northern Utah, with special reference to phosphate: U. S. Geol. Survey Bull. 690, p. 54, 1918.

[84] Schultz, A. R., Oil possibilities in and around Baxter Basin, in the Rock Springs uplift, Sweetwater County, Wyo.: U. S. Geol. Survey Bull. 702, pp. 36-37, 75-78, 1920.

[85] Sears, J. D., Geology and oil and gas prospects of part of Moffat County, Colo., and southern Sweetwater County, Wyo.: U. S. Geol. Survey Bull. 751, pp. 277-280, 284-285, 1924; Geology of the Baxter Basin gas field, Sweetwater County, Wyo.: U. S. Geol. Survey Bull. 781, pp. 15-18, pl. 6, 1926.

[86] Keyes, C. R., Grand staircase of Utah: Pan-Am. Geologist, vol. 41, pp. 36, 60, 1924.

[87] Branson, E. B., Triassic-Jurassic "red beds" of the Rocky Mountain region: Jour. Geology, vol. 35, pp. 610, 613, 1927.

[88] Reeside, J. B., Jr., "Triassic-Jurassic 'red beds' of the Rocky Mountain region"—a discussion: Jour. Geology, vol. 37, pp. 50, 56, 1929.

[89] Bartram, J. G., Triassic-Jurassic red beds of the Rocky Mountain region—another discussion: Jour. Geology, vol. 38, pp. 336-339, 1930.

[90] Mathews, A. A. L., Mesozoic stratigraphy of the central Wasatch Mountains: Oberlin Coll. Lab. Bull., new ser., no. 1, pp. 45-48, pl. 2, 1931.

[91] Holmes, W. H., Report on the geology of the northwestern portion of the Elk Range: U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1874, p. 61, 1876.

[92] Peale, A. C., Middle division of Colorado: U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1874, pp. 81, 121-125, pl. 2, 1876.

[at Glenwood Springs] used "Cretaceous no. 1" for Dakota(?) sandstone; "variegated Jurassic shales" for much of the Morrison; "yellow sandstones" for the lower Morrison sandstone where present and also for the Curtis formation and Entrada sandstone; and †"Red Beds (Triassic?)" for the Triassic and Carboniferous red beds.

Endlich [93] in 1877 for the Grand Hogback region south of Meeker assigned to the †Trias a "unit (a)" of red beds, which include rocks of Triassic and Carboniferous age; and to the †Jura a "unit (b)" of light-gray marls, sandstones, etc., which include the Entrada and Morrison of the present paper. Above these he found Cretaceous beds.

Eldridge [94] in 1894 for the Anthracite and Crested Butte quadrangles called the beds between the Cretaceous so-called "Dakota sandstone" and the Carboniferous Maroon formation the †"Gunnison formation." It contains in this area only the Morrison formation, in which there is at many places a basal sandstone or quartzite.

Spurr [95] in 1898 in the Aspen mining district used Eldridge's name †"Gunnison" to cover softer beds now included in the Morrison formation and an underlying sandstone which is the Entrada sandstone. Under these a thick undivided red-bed series extended down to include beds now placed in the Triassic and in the Maroon formation. Spurr called the †Gunnison formation and the red beds "Triassic."

Fenneman and Gale [96] in 1906 assigned all the beds between the Cretaceous and Archean to the †Jura-Trias(?) red beds. These apparently contain the Morrison, Curtis, Entrada, and Triassic formations, with possibly some Carboniferous.

Gale [97] indicated beneath the Cretaceous of the Danforth Hills and Grand Hogback a "Jurassic? red clay shale", which is apparently the Morrison. No older beds were noted.

George and Crawford [98] in 1909 described the Hahns Peak region. It is difficult to place the units described, but apparently there is Morrison and Curtis in what they called "Jurassic Sundance formation" and Triassic and possibly a little Carboniferous in what they called "Carboniferous to Jurassic red beds." Nothing like the Entrada is described, though one would expect to find it there in view of its presence northeast and southeast of the Hahns Peak region.

Gale [99] in 1910 for the White River Plateau designated as "Jurassic" a †Flaming Gorge formation and a †White Cliff sandstone. These are Morrison and Entrada. Beneath are Triassic red beds, and above is Cretaceous so-called "Dakota sandstone."

Grout, Worcester, and Henderson [1] found in the Rabbit Ears region only the Jurassic Morrison formation between the so-called "Dakota sandstone" and Permian(?) red beds, which rest on granite.

Lee [2] in 1918 used for the section near Meeker the names †"White Cliff or Nugget" for the beds here called "Entrada" and for sandstones in the lower part of the Morrison, and he used "Morrison" for the remainder of the beds here called "Morrison." For the Crested Butte quadrangle he recognized the Morrison formation and †La Plata sandstone for beds here called "Morrison." Lee assigned his Morrison to the Lower Cretaceous.

Crawford, Willson, and Perini [3] in 1920, for the Tow Creek anticline, west of Steamboat Springs, assigned all the rocks between the Dakota [?] sandstone and the pre-Cambrian crystalline rocks to an unnamed series of red sandy clay and shale with a thick massive red sandstone bed near the middle. This sequence contains the Morrison, Entrada, and apparently Triassic rocks.

Coffin, Perini, and Collins [4] in 1920, for exposures near McCoy, described Jurassic (?) shale which they thought equivalent to the †McElmo and massive sandstone which they thought equivalent to the †White Cliff and Nugget. The Triassic (?) contains red beds, of which the upper part is the Triassic of this paper.

Campbell [5] in 1922, for the neighborhood of Gunnison, recognized Cretaceous (?) and Jurassic †Gunnison formation resting on crystalline pre-Cambrian rocks. For the neighborhood of Wolcott, on the Eagle River, he recognized the same unit resting on Triassic red beds. At the first locality the †Gunnison formation is Morrison only; at the second it includes the Entrada, Curtis, and Morrison formations.

In the present paper the Entrada sandstone is interpreted as overlapping the Triassic southward and as resting there on older beds. Farther south it is itself overlapped by the Morrison formation. The Curtis formation is thin where it is known and is probably represented at some places where it has not yet been

[93] Endlich, F. M., Report on the geology of the White River district: U. S. Geol. and Geog. Survey Terr. 10th Ann. Rept., pp. 72, 107, pl. 3, 1878.

[94] Eldridge, G. H., U. S. Geol. Survey Geol. Atlas, Anthracite-Crested Butte folio (no. 9), p. 6, 1894.

[95] Spurr, J. E., Geology of the Aspen mining district, Colo.: U. S. Geol. Survey Mon. 31, pp. 37-41, 1898.

[96] Fenneman, N. M., and Gale, H. S., The Yampa coal field, Routt County, Colo.: U. S. Geol. Survey Bull. 297, p. 20, pl. 2, 1906.

[97] Gale, H. S., Coal fields of the Danforth Hills and Grand Hogback in northwestern Colorado: U. S. Geol. Survey Bull. 316, pl. 15, 1907.

[98] George, R. D., and Crawford, R. D., The Hahns Peak region, Routt County, Colo.: Colorado Geol. Survey 1st Rept., for 1908, pp. 202-205, 1909.

[99] Gale, H. S., Coal fields of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 415, pp. 42, 56, pl. 6, 1910.

[1] Grout, F. F., Worcester, P. G., and Henderson, Junius, Reconnaissance of the geology of the Rabbit Ears region, Routt, Grand, and Jackson Counties, Colo.: Colorado Geol. Survey Bull. 5, pt. 1, pp. 21, 26, 1913.

[2] Lee, W. T., Early Mesozoic physiography of the southern Rocky Mountains: Smithsonian Misc. Coll., vol. 69, no. 4, pp. 15-18, 1918.

[3] Crawford, R. D., Willson, K. M., and Perini, V. C., Some anticlines of Routt County, Colo.: Colorado Geol. Survey Bull. 23, pp. 31, 35, 1920; reprint, 1924.

[4] Coffin, R. C., Perini, V. C., Jr., and Collins, M. J., Some anticlines of western Colorado: Colorado Geol. Survey Bull. 24, pp. 39-46, 1920; reprint, 1924.

[5] Campbell, M. R., Guidebook of the western United States, Part E, The Denver & Rio Grande Western Route: U. S. Geol. Survey Bull. 707, pp. 124, 140, sheets 3, 4, 5, 1922.

Table 8.—*Nomenclature used in northwestern New Mexico*

Standard divisions adopted for comparison	Gilbert, G. K. New Mexico and Arizona 1875	Dutton, C. E. Mount Taylor and Zuni Plateau 1885	Cross, Whitman, and Howe, Ernest Red Beds 1905	Darton, N. H. Reconnaissance of northwestern New Mexico and northern Arizona 1910	Darton, N. H. Santa Fe Railroad guidebook 1915	Gregory, H. E. Navajo country 1917	Lee, W. T. Mesozoic physiography 1918	Keyes, C. R. Geological setting of New Mexico 1920
Cretaceous	Cretaceous	Cretaceous	[Not described]	Cretaceous	Cretaceous	Cretaceous	Upper Cretaceous	Cretaceous
Jurassic Morrison formation	Trias Purple, pink, and white cross-bedded sandstone (11a–d of section)	Jurassic(?) Zuni sandstones	Jurassic Gunnison Zuni sandstones	Triassic(?) Zuni sandstone	Jurassic or Cretaceous Zuni sandstone Green and purple shale	Jurassic(?) McElmo formation	Lower Cretaceous McElmo formation	Early Jurassic Zunian series McElmo shale
					Jurassic(?) Gray sandstone	Jurassic La Plata group Navajo sandstone	Jurassic La Plata group Navajo sandstone	La Plata sandstone
	Limestone (11e)				Limestone and gypsum	Todilto limestone	Todilto limestone	
San Rafael group Summerville formation								
Curtis formation								
Entrada sandstone	[Absent]	[Absent]	[Absent]	[Absent]	[Absent]	[Absent]	[Absent]	[Absent]
Carmel formation								
Jurassic(?) Glen Canyon group Navajo sandstone								
Kayenta formation								
Wingate sandstone	Red and compact sandstone with white band near base (11f)	Trias Wingate sandstone	Triassic Dolores "Wingate sandstone"	Wingate sandstone	Wingate sandstone	Wingate sandstone	White and Vermilion Cliff sandstone Wingate sandstone	Triassic Doloresian series Wingate sandstone
Triassic	Variegated clays, shales (12, 13, 14)	Lower Trias	"Lower Trias"	Triassic Leroux formation	Triassic Red and gray shale	Triassic Chinle formation	Triassic Chinle formation	Leroux shale

Standard divisions adopted for comparison	Darton, N. H. Geologic structure of New Mexico 1922	Darton, N. H. Arizona geology 1925	Branson, E. B. Triassic-Jurassic "red beds" 1927	Darton, N. H. "Red beds" of New Mexico 1929	Reeside, J. B., Jr. "Triassic-Jurassic 'red beds'" 1929	Mathews, A. A. L. Central Wasatch Mountains 1931	Renick, B. C. Western Sandoval County 1931	This paper
Cretaceous	Cretaceous	Cretaceous		Cretaceous	[Not described]	[Not described]	Cretaceous	Cretaceous
Jurassic Morrison formation	Cretaceous(?) McElmo or Morrison formation	Cretaceous(?) McElmo formation	[Not described]	Cretaceous(?) Morrison formation	Cretaceous(?) "McElmo formation"	Upper Cretaceous McElmo formation	Cretaceous(?) Morrison formation	Jurassic Morrison formation Shale member
	Jurassic La Plata group Navajo sandstone	Jurassic La Plata group Navajo sandstone	Jurassic or Upper Triassic Vermilion Cliffs La Plata sandstone Navajo sandstone	Jurassic(?) Lower La Plata Navajo sandstone	Jurassic Upper San Rafael group Navajo sandstone	Jurassic Upper San Rafael group Navajo sandstone	?	Sandstone member
	Todilto limestone	Todilto limestone	Todilto limestone	Todilto limestone	Todilto limestone	Todilto limestone	Jurassic(?) Todilto formation	Todilto limestone member
San Rafael group Summerville formation								
Curtis formation								
Entrada sandstone	[Absent]	[Absent]	[Absent]	[Absent]	middle and Glen Canyon group [Absent]	Middle Glen Canyon group [Absent]	[Absent]	[Absent]
Carmel formation								
Jurassic(?) Glen Canyon group Navajo sandstone								
Kayenta formation								
Wingate sandstone	Wingate sandstone	Wingate sandstone	Wingate sandstone	Wingate sandstone	Lower Glen Canyon group Wingate sandstone	Lower Glen Canyon group Wingate sandstone	Wingate sandstone	Jurassic(?) Glen Canyon group Wingate sandstone
Triassic	Triassic Chinle formation	Triassic Chinle formation	Triassic Chinle formation	Triassic Chinle formation	Triassic Chinle formation	Triassic Chinle formation	Triassic Chinle formation	Triassic Chinle formation

identified by part of the beds that have been assigned to the Entrada sandstone, for there is no evidence of hiatus between the Entrada, Curtis, and Morrison.

NORTHWESTERN NEW MEXICO

Gilbert [6] in 1875 reported observations made in 1873 on the route of the Wheeler Survey parties. His section near Fort Wingate shows the †Trias beneath the Cretaceous and includes clearly equivalents of the Morrison (Todilto limestone at base), Wingate, and underlying Chinle.

Dutton [7] in 1885 described the strata of the Zuni Mountains and the region northward to Mount Taylor. He recognized the Cretaceous and called the light-colored beds beneath it †"Zuni sandstones" and assigned them to the Jurassic (?). They are exactly the Morrison of this paper. The red sandstone next below he called "Wingate", and he assigned it to the †Trias together with the underlying red beds.

Cross and Howe [8] in 1905 interpreted Dutton's †Zuni sandstones as equivalent to the †Gunnison group of Colorado (which included the La Plata and McElmo formations) and the Wingate sandstone as the upper part of the Dolores.

Darton [9] in 1910 adopted in northwestern New Mexico Dutton's names †"Zuni" and "Wingate", assigning them to the Triassic with doubt. Darton's sections show that the Todilto limestone of the present paper is the basal member of his †Zuni sandstone.

Darton [10] in 1915 used again the Dutton nomenclature, recognizing the upper part of the †Zuni sandstone as of Jurassic or Cretaceous age and the lower part, together with the Wingate, as doubtfully Jurassic.

Gregory [11] in 1917 adopted Dutton's Wingate sandstone but used the names "Todilto limestone", "Navajo sandstone", and †"McElmo formation" for the beds comprised in Dutton's †Zuni sandstone (the Morrison of the present paper). He assigned the Wingate, Todilto, and Navajo to the †La Plata group, which he classified as of Jurassic age, and assigned the †McElmo to the Jurassic with doubt.

Lee [12] in 1918 applied the names "Wingate", "Todilto", "Navajo", and †"McElmo" formations in northwestern New Mexico. He correlated the Wingate with the †White Cliff and †Vermilion Cliff sandstones of southwestern Utah (Navajo of the present paper), the Todilto somewhat doubtfully with the present Carmel, and his †McElmo with the Morrison. He also accepted his Wingate, Todilto, and Navajo as equivalent to †La Plata sandstone.

Keyes [13] in 1920 assigned to a Triassic †Doloresian series the Shinarump conglomerate, †Leroux shale, and Wingate sandstone. He assigned to the lower part of the Jurassic a conformable †Zunian series containing the †La Plata sandstone below and the †McElmo shale above. The †Zunian series is the Morrison formation of this paper. In northeastern New Mexico Keyes assigned to the upper part of the Jurassic a †Morrisonian series containing three units, which is here interpreted as being essentially equivalent to Keyes' †Zunian series.

Darton [14] in 1922 for northwestern New Mexico used Gregory's terminology. He did not find the †McElmo present everywhere and considered it essentially equivalent to the Morrison.

Darton [15] in 1925 again used for the Defiance uplift the same terminology as that applied by Gregory—Wingate, Todilto, Navajo, and †McElmo, the last three being the Morrison formation of this paper. He assigned the †McElmo to the Cretaceous with doubt.

Branson [16] in 1927 applied his general section of Wingate, Todilto, and Navajo to northwestern New Mexico, considering them to be †Vermilion Cliffs sandstone and †La Plata.

Darton [17] in 1929 interpreted the Wingate and Todilto and, to a lesser extent, the Navajo as widespread in northern New Mexico, assigning the formations to the Jurassic with doubt. He also identified a widespread Morrison, placing it in the Cretaceous with doubt. The Wingate of Darton in northwestern New Mexico is the Wingate of this paper, but the writers have few data bearing on its identity farther east. Some of the sandstones called "Wingate" farther east seem surely to be Wingate, though some may well be Morrison. The Todilto, Navajo, and Morrison of Darton are here all called "Morrison."

Reeside [18] in 1929 used Wingate, Todilto, Navajo, and †McElmo for northwestern New Mexico, placing the first three in the Jurassic and the fourth in the Cretaceous with doubt. He suggested two possible correlations—(1) the Wingate with the whole Glen Canyon group, the Todilto with the Carmel, the local Navajo with the Entrada, and the †McElmo with the Summerville and Morrison; (2) the Wingate, Todilto, and local

[6] Gilbert, G. K., The geology of portions of New Mexico and Arizona examined in 1873: U. S. Geog. and Geol. Surveys W. 100th Mer. Rept., vol. 3, pp. 543–552, 1875.

[7] Dutton, C. E., Mount Taylor and the Zuni Plateau: U. S. Geol. Survey 6th Ann. Rept., pp. 135–138, figs. 1–3, 11–12, 1885.

[8] Cross, Whitman, and Howe, Ernest, Red beds of southwestern Colorado and their correlation: Geol. Soc. America Bull., vol. 16, pp. 477–480, 1905.

[9] Darton, N. H., A reconnaissance of parts of northwestern New Mexico and northern Arizona: U. S. Geol. Survey Bull. 435, pp. 12, 43–48, 1910.

[10] Darton, N. H., Guidebook of the western United States, Part C, The Santa Fe Route: U. S. Geol. Survey Bull. 613, pp. 93, 99, 106, sheets 14–16, text figs. 18, 21, 22, 1915.

[11] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, pp. 52–60, 1917.

[12] Lee, W. T., Early Mesozoic physiography of the southern Rocky Mountains: Smithsonian Misc. Coll., vol. 69, no. 4, pp. 21–24, 1918.

[13] Keyes, C. R., Geological setting of New Mexico: Jour. Geology, vol. 28, pp. 246, 252, 1920.

[14] Darton, N. H., Geologic structure of parts of New Mexico: U. S. Geol. Survey Bull. 726, pp. 177, 184, 244, 254, 259, 263, 1922.

[15] Darton, N. H., A résumé of Arizona geology: Arizona Univ. Bull. 119, pp. 126, 207–211, pl. 28 b, text figs. 30–32, 1925.

[16] Branson, E. B., Triassic-Jurassic "red beds" of the Rocky Mountain region: Jour. Geology, vol. 35, pp. 610, 614, 1927.

[17] Darton, N. H., "Red Beds" and associated formations in New Mexico: U. S. Geol. Survey Bull. 794, pp. 7, 8, 33–37, 139, 144–145, 157, 163, 167–169, 1928 [1929].

[18] Reeside, J. B., Jr., "Triassic-Jurassic 'red beds' of the Rocky Mountain region"—a discussion: Jour. Geology, vol. 37, pp. 50, 52, 1929.

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Navajo with the Glen Canyon group and the †McElmo with the San Rafael group and Morrison. Mathews[19] used in 1931 the same units but considered the † McElmo to extend into the Upper Cretaceous.

Renick[20] for western Sandoval County recognized Wingate sandstone, Todilto formation, and Morrison formation, assigning the first two to the Jurassic with doubt and the last to the Cretaceous with doubt. He also recognized an unconformity at the base of the Morrison, though with some doubt.

In the present paper the Glen Canyon group is interpreted as represented by the Wingate sandstone only, the Kayenta and Navajo formations being absent. The San Rafael group also is absent, and the remainder of the section up to the Dakota(?) sandstone is interpreted as representing the Morrison formation.

DISTRIBUTION OF THE FORMATIONS AND SOURCES OF THE MATERIALS

It has seemed useful in this study of the Jurassic formations to bring out the distribution of the units, as here interpreted, in a series of maps that show the thickness by isopachs and the known or inferred margins of the formations. Not all the available data are shown, but representative figures are selected, and in a sense the maps show an average of conditions rather than details. The maps are not strictly an attempt to portray the paleogeography, but they do supply data that will be useful in the construction of paleogeographic maps. The most recent and by far the best effort to portray the Jurassic geography of North America is that of Crickmay,[21] whose paper will be cited at several places in the succeeding paragraphs.

Wingate sandstone.—The data for figure 8 are derived mainly from the writers' own work, but the southern and eastern boundaries are based on data taken from Darton.[22] The Wingate is seen to lie in a basin whose main axis trends southeast. There is no pronounced direction of change in thickness, for the formation is much the same over the center of its basin and thins to definite margins, at least as a recognizable unit, in the northeast, southwest, and south. The northern margin is somewhere under the Uinta Basin. The extent of the formation northwestward is not definitely known. It has been reported by Darton to extend southeastward to the eastern boundary of New Mexico. It appears to the writers that the general outline of the Wingate sandstone area represents substantially the original distribution, though possibly some of the Wingate was removed from New Mexico and Arizona by erosion at some time preceding the Morrison epoch.

It is not easy to determine the source of the materials of the Wingate sandstone from the data now in hand. Very likely the granitic area along the present-day Gunnison River in west-central Colorado supplied some material, particularly along the eastern margin of the basin. The positive area constituting Crickmay's Jurosonora, lying to the southwest in Arizona, Nevada, California, and Mexico, possibly also contributed. Older red beds and other sediments exposed to erosion around the margin of the Wingate basin may have supplied some material.

Kayenta formation.—The Kayenta formation (fig. 9) seems to occupy a basin lying chiefly in southeastern Utah but extending into Arizona on the south and into Colorado on the east. The northern margin is under the Uinta Basin, and the northwestern margin is not definitely known. There are irregularities in thickness, but in general the formation is less irregular than might be supposed from local field studies. It is thick in the central part of its area and thins outward to the margins on at least three sides. Data for the fourth side are lacking. It is notable that the eastern and southern edge of the Kayenta closely corresponds to the edge of the Navajo, and the southwestern edge to the edge of the Wingate.

At localities on the northeast side of the basin of deposition a relatively abrupt thinning toward the crystalline rocks of the Gunnison River area from maximum thickness to a vanishing edge accompanied by somewhat coarser grain and abundant mica, suggests a more important local source. There is no other suggestion of a major source.

Navajo sandstone.—The Navajo sandstone, as figure 10 clearly shows, introduces a feature not present with the Wingate and Kayenta formations—a strong single direction of change of thickness. A great northeastward-thinning wedge of sandstone extends from southern Nevada to the western edge of Colorado. It is thickest in the southwest, and there is a definite margin on the southeast in northeastern Arizona, and on the east at the western edge of Colorado, probably the original margins essentially. The northeastern edge is undetermined, and there is probably direct connection northwestward with the typical Nugget sandstone of southwestern Wyoming. The western margin of the Navajo sandstone is unknown, though eastern Nevada would seem to be a reasonable estimate of its position.

The dominating source of material included in the Navajo is in the southwest, almost surely the Jurosonora of Crickmay. There is no evidence known to the writers to show that any important part of the material of the Navajo sandstone came from the east or south. If the writers' conclusion is correct that the typical Nugget sandstone is equivalent to the Navajo, a local

[19] Mathews, A. A. L., Mesozoic stratigraphy of the central Wasatch Mountains: Oberlin Coll. Lab. Bull., new ser., no. 1, pl. 2, 1931.

[20] Renick, B. C., Geology and ground-water resources of western Sandoval County, N. Mex.: U. S. Geol. Survey Water-Supply Paper 620, pp. 12, 29–35, 1931.

[21] Crickmay, C. H., Jurassic history of North America—its bearing on the development of continental structure: Am. Philos. Soc. Proc., vol. 70, no. 1, pp. 1–102, 1931.

[22] Darton, N. H., "Red Beds" and associated formations in New Mexico: U. S. Geol. Survey Bull. 794, 1929.

source of material for that part of the formation must be postulated, for the Nugget is reported to have a very coarse basal conglomerate. Possibly Crickmay's Jurozephyria, a positive area north of and somewhat later in time than Jurosonora, yielded the material.

Crickmay [23] indicates on his maps and in his text that the Glen Canyon group is Lower Jurassic and long antecedent to the Carmel formation. It seems to the writers, as noted elsewhere in this paper, that the Navajo is more likely to prove Middle Jurassic, though certainly there is now only the weakest direct evidence to support this assignment.

Carmel formation.—The margin of the Carmel formation (fig. 11) follows approximtely the margin of the Navajo, but the trends of change in thickness are rather different from those shown by the Navajo, as the increase in thickness is in general toward the northwest. The marginal red nonfossiliferous facies is clearly indicated by the map. There are some marked irregularities in thickness, one in the San Rafael Swell being a thickness of 650 feet. In the northwest the Carmel is represented by the typical Twin Creek limestone. The extent westward of the Carmel formation is not known, but there is a definite margin on the south and east. The northern margin is undetermined, as sure correlations are lacking.

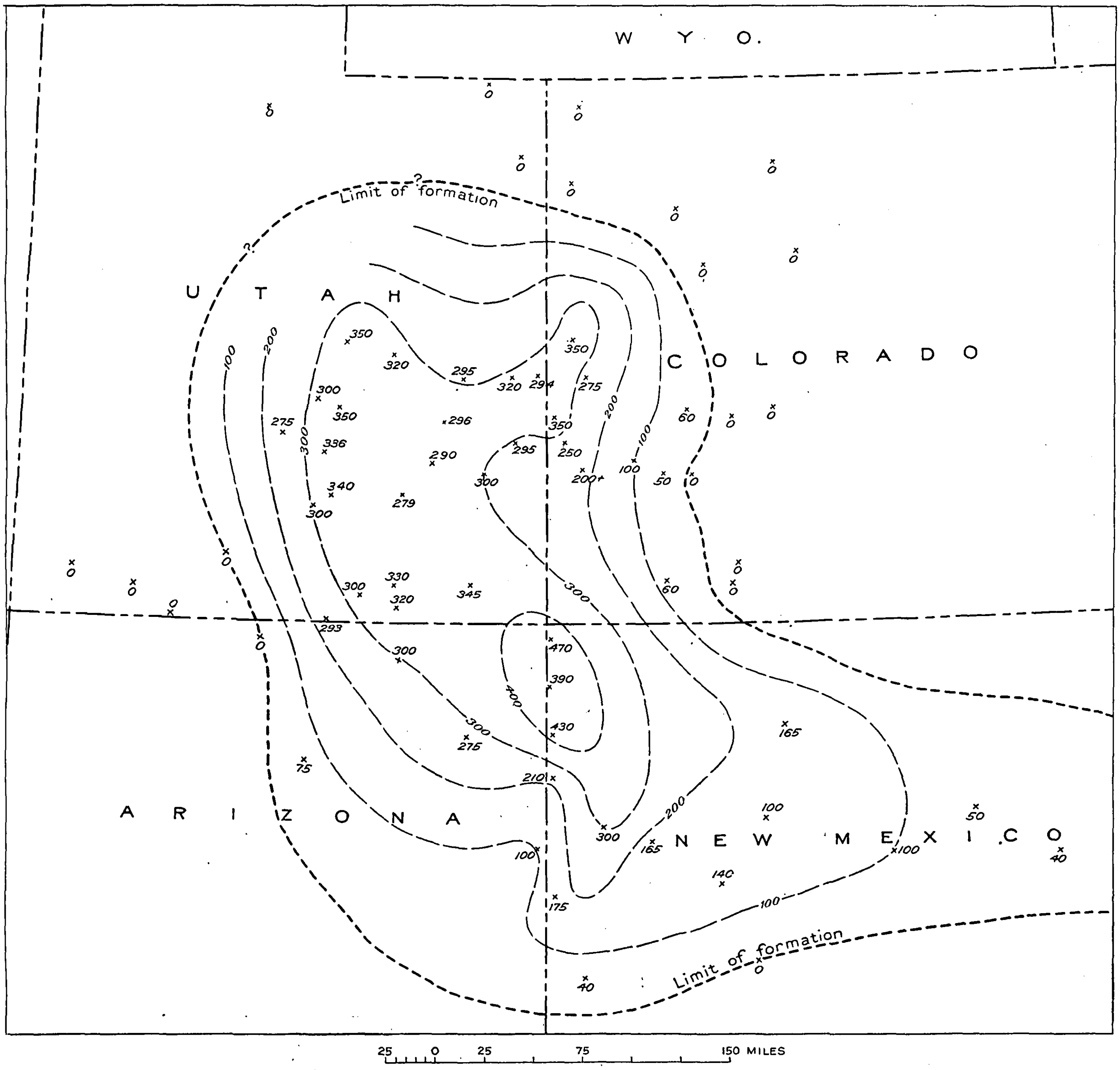


FIGURE 8.—Distribution and thickness (in feet) of the Wingate sandstone.

[23] Crickmay, C. H., op. cit., p. 38, map 1.

The source of the materials of the Carmel formation is not entirely clear. Crickmay's Jurozephyria, a northward extension of Jurosonora through Idaho and western Montana into Canada, probably supplied much of it, though parts of the material on the south and east must have come from the adjoining land areas.

Entrada sandstone.—The Entrada sandstone (fig. 12) introduces a new feature of distribution, as compared with those of the formations shown in the previous maps. The margin of the formation shows four extensions southeastward, separated by deep indentations. Each of the extensions contains an axis of maximum thickness. There are some marked irregularities of thickness also. The formation is definitely bounded on the southwest, south, and east and in the area here discussed unquestionably thickens northwestward. The distribution suggests that the margin is essentially the original margin. The formation changes in lithology northwestward from the clean, light-colored sandstone facies characteristic of eastern Utah into the red muddy sandstone facies well shown in the San Rafael Swell. A part of the so-called Twin Creek limestone of northwestern Colorado and of the Beckwith formation of southwestern Wyoming and southeastern Idaho represents the time of the Entrada and is therefore a continuation of the change northwestward. The western limit of the formation is not known, nor is the northern limit known, as the writers interpret the basal part of the Sundance formation of Wyoming as a northern representative of the Entrada sandstone.

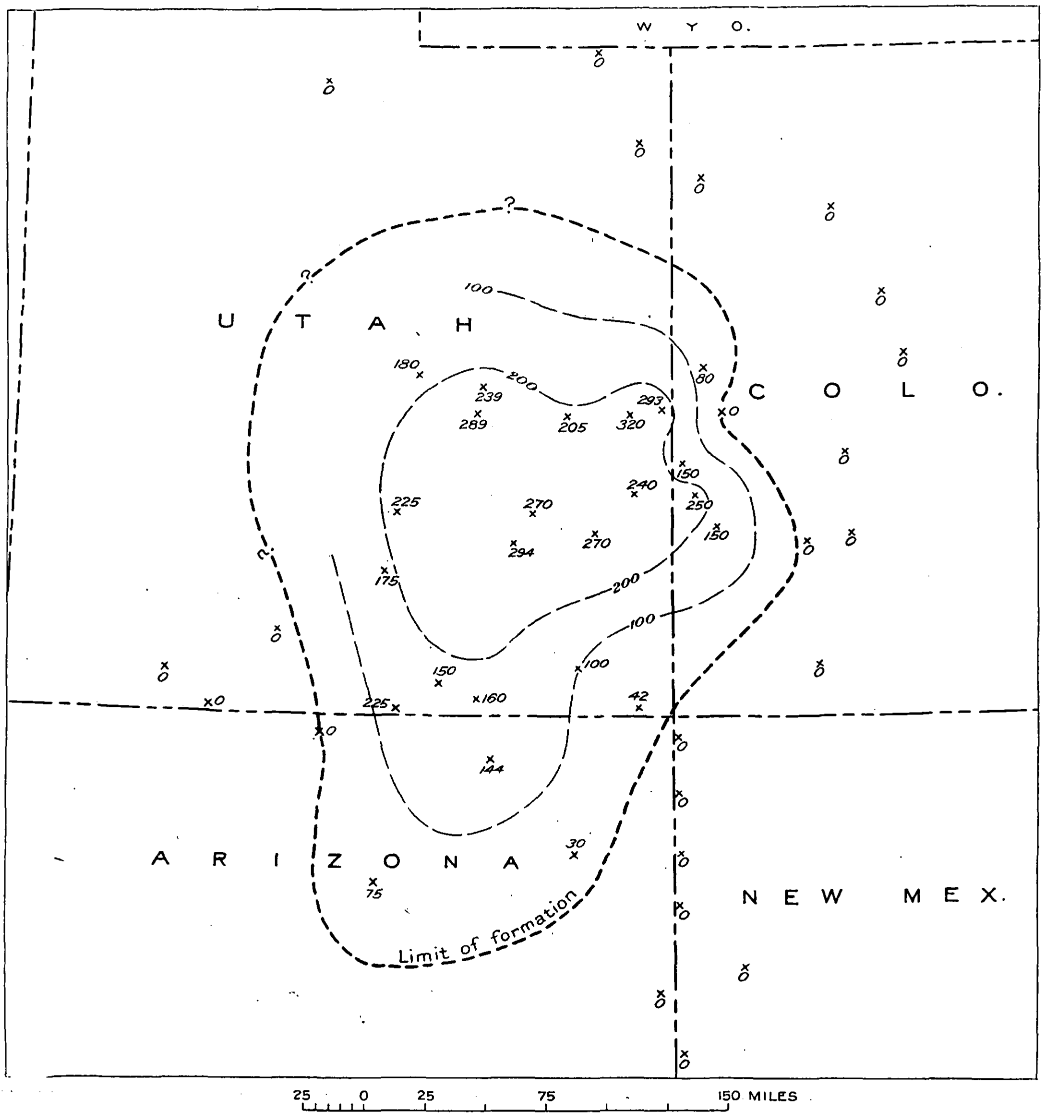


FIGURE 9.—Distribution and thickness (in feet) of the Kayenta formation.

The source of the material suggested by the distribution and thickness is again Jurozephyria, in Idaho and western Montana, with possibly Jurosonora, to the southwest in Nevada, serving as a supplemental source.

Curtis and Summerville formations.—The Curtis and Summerville formations are here represented on one map (fig. 13). The margin of the Curtis formation is similar to that of the Entrada in that there are several lobelike extensions toward the southeast. These correspond only in part to the extensions of the Entrada sandstone. The Curtis formation is recognized in southwestern Utah, in east-central Utah, and in the eastern Uinta region and northwestern Colorado. It passes laterally into the lower portion of the Summerville formation in east-central and southeastern Utah but seemingly thins out in other areas. Its western and northern margins are not known, but it is represented by part of the so-called "Twin Creek limestone" of northwestern Colorado and northeastern Utah, by part of the Beckwith formation of southwestern Wyoming, and by part of the Sundance formation of central and eastern Wyoming. The Summerville formation is in part a red marginal facies of the Curtis formation but in part persists northwestward into the San Rafael Swell as a unit above the Curtis formation. The lower part of the Summerville formation also intergrades with the top of the Entrada sandstone in eastern Utah, but this feature is not indicated on the map. The thicknesses of the two formations show no systematic arrangement, and there is little suggestion as to source of materials.

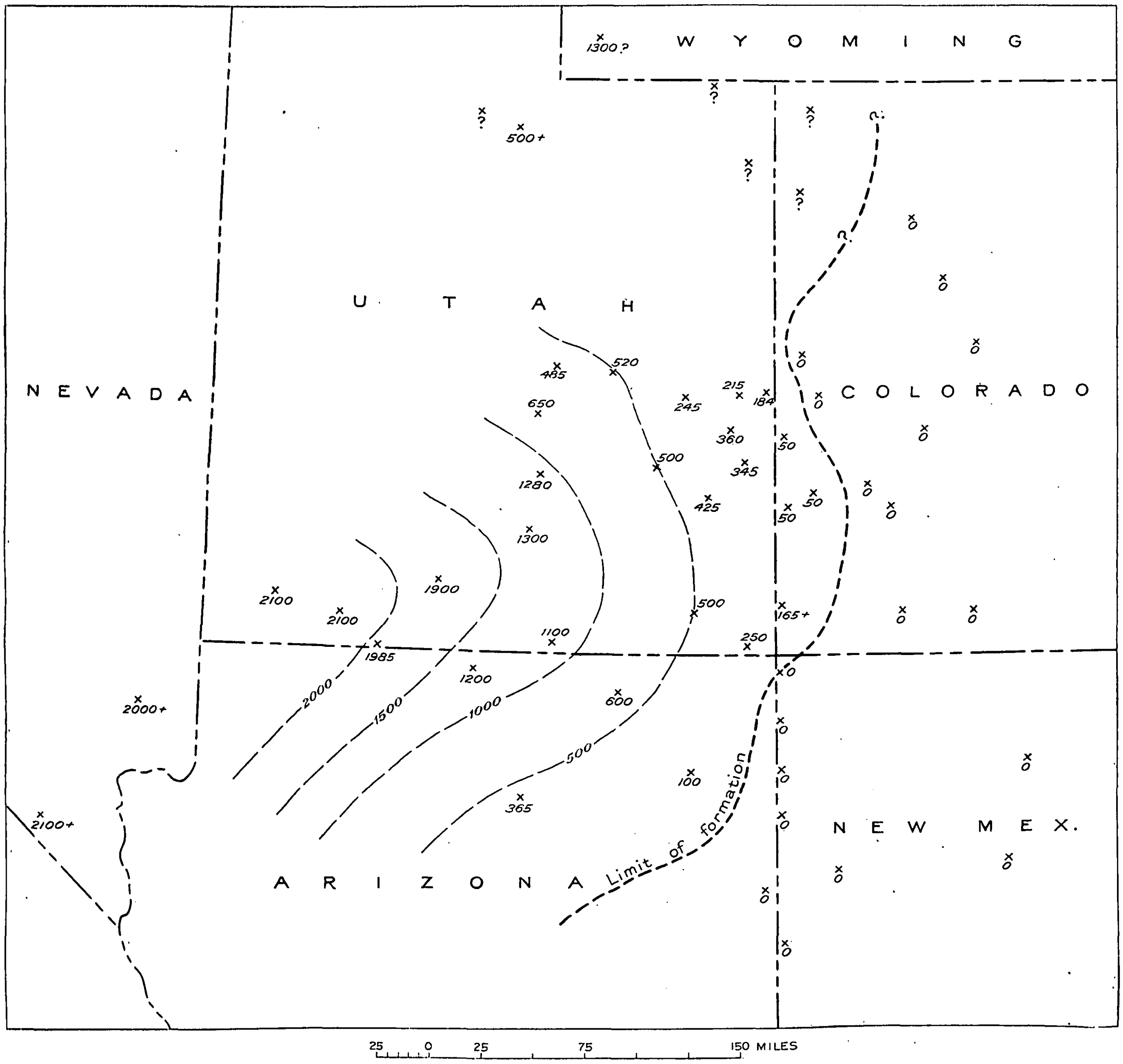


FIGURE 10.—Distribution and thickness (in feet) of the Navajo sandstone.

Morrison formation.—The extent of the Morrison formation is shown in figure 14 by indicating localities where a valid record, according to the writers' ideas, has been made of its occurrence. For many of these localities the thickness is known, but it is unsystematic in its variation, as might be expected, and there seems little value in compiling more than a few representative figures. The general area in which the Morrison consists predominantly of thick-bedded sandstone is indicated, and likewise the occurrence of the Todilto limestone member and similar limestone and gypsum from one another. The individuality of the Wingate and Kayenta areas is well displayed, also the rough correlation between the extent of the Kayenta and the area of overlap of the Navajo over the Wingate. The general similarity of the margins of the Navajo and Carmel formations and of the margins of the Curtis, Summerville, and Entrada formations are well brought out.

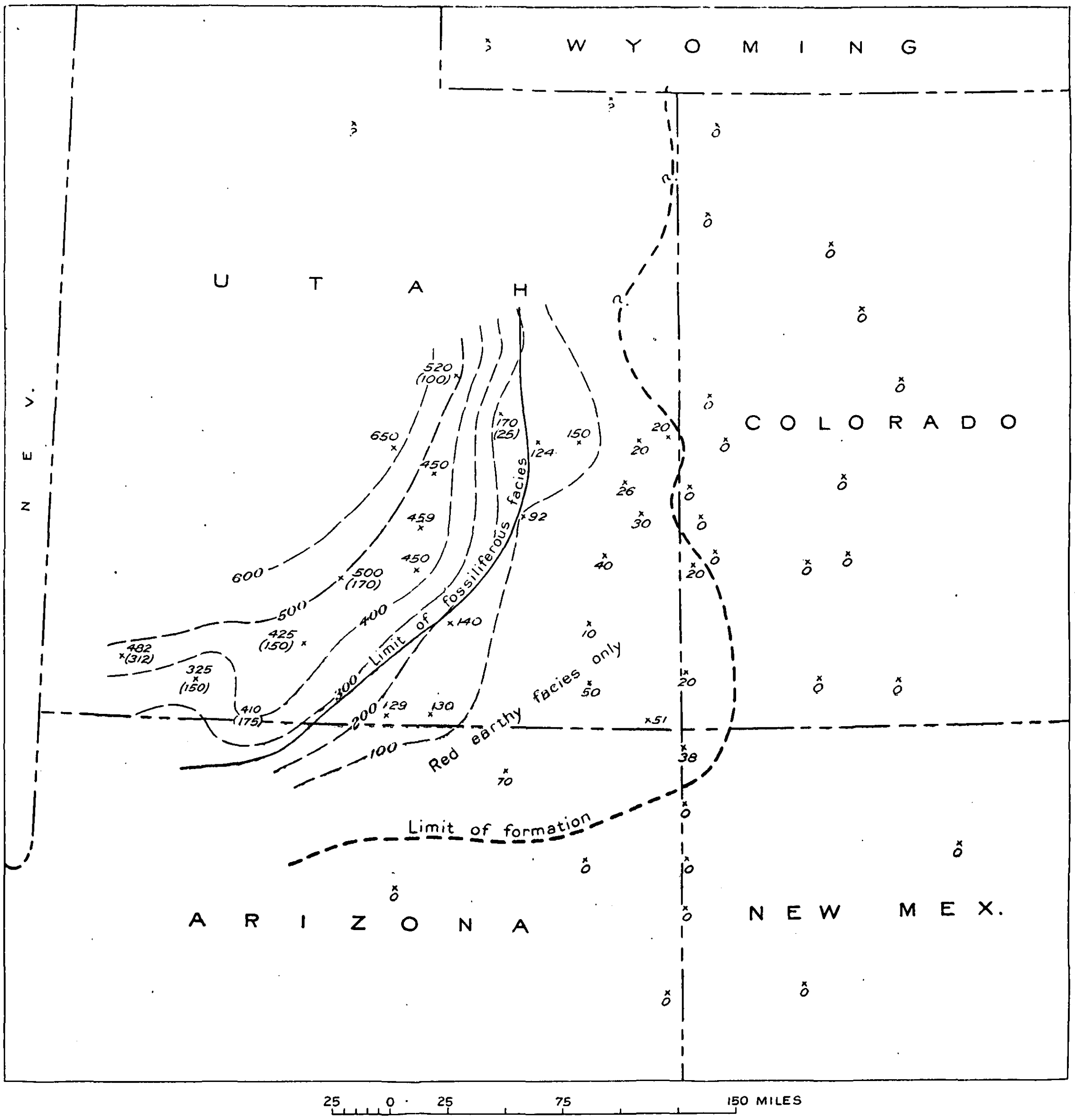


FIGURE 11.—Distribution and thickness (in feet) of the Carmel formation.

as a basal unit. The writers interpret the Morrison as not extending very far to the south and west, but the limits in other directions are far beyond the area dealt with in this paper.

Comparison of the gross distribution of the Jurassic formations.—In figure 15 the writers have shown by superimposition of the margins of the Jurassic formations except the Morrison how they resemble and differ

CONDITIONS OF DEPOSITION

The conditions of deposition of the Jurassic formations have been discussed in several papers. One of the notable efforts of fairly recent date is that by Lee,[24] who attempted regional correlations of the Jurassic

[24] Lee, W. T., Early Mesozoic physiography of the southern Rocky Mountains: Smithsonian Misc. Coll., vol. 69, no. 4, 1918.

strata from data contained in the literature and from somewhat scattered reconnaissance observations. On the basis of these correlations, he strove to describe the geomorphic conditions prevailing during the deposition of the formations. Many of Lee's correlations have been invalidated by later work and with them a considerable part of his picture of the geomorphic conditions. Some of the fundamental elements remain unchanged, however. Other writers have discussed local areas or single parts of the Jurassic. The latest general treatment is that by Crickmay,[25] in which all of North America is included and in which more details are given than in any other paper.

It will be profitable to consider the conditions of the late Triassic and then succeeding units in order.

[25] Crickmay, C. H., Jurassic history of North America—its bearing on the development of continental structure: Am. Philos. Soc. Proc., vol. 70, no. 1, 1931.

CHINLE AND EQUIVALENT FORMATIONS

Most writers have pictured the conditions under which the Chinle formation and its very similar approximate equivalents (Dolores and Ankareh) were deposited as wholly continental—probably those of a well-graded but rather arid plain across which streams meandered and on which there were perhaps scattered lakes. Gradients were low, for conglomerates of resistant materials transported from afar are scarce in most of the area here considered. Fine-grained muddy sandstones, mudstones, and beds of small pellets of impure limestone are the commoner rocks. All of these are in variable, discontinuous beds. The presence of fresh-water pelecypods at many localities, of considerable silicified wood (but virtually no remains of foliage), and of land vertebrates agrees with the

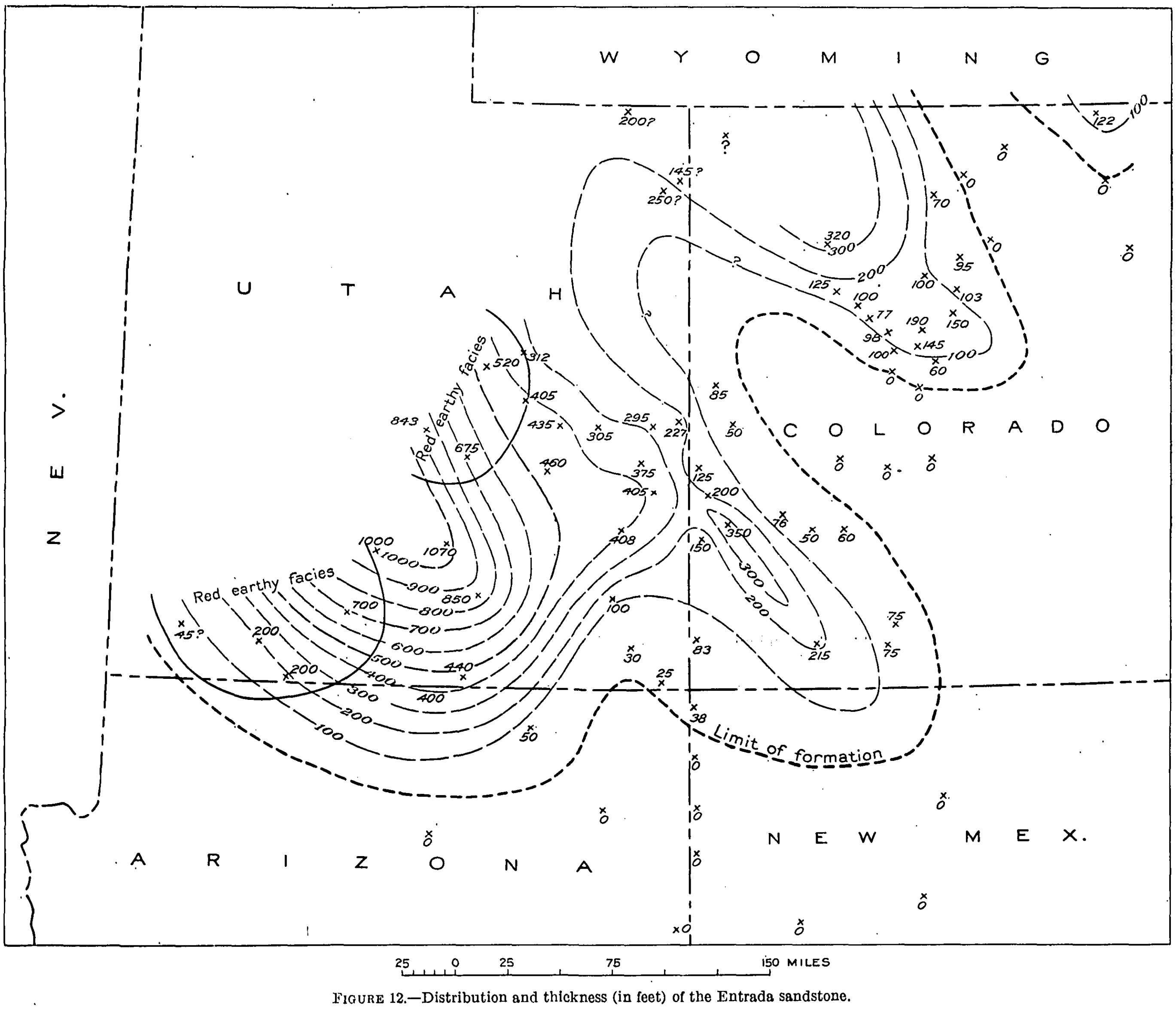


FIGURE 12.—Distribution and thickness (in feet) of the Entrada sandstone.

lithology in suggesting a continental origin. Beds of bentonite at several localities imply contemporary volcanic activity at some now unknown source, perhaps to the west. Longwell [26] reports lithology and thicknesses in southern Nevada that suggest a southern source for the materials of at least that part of the Chinle and deposition there as "broad fans and deltas." Branson [27] has interpreted the Chinle as constituted in part of marine deposits and in part of subaerial assic deposits of the Pacific coastal region and the area of Chinle deposition.[28] The Rocky Mountain area on the east seems to have had only very small high areas, for the equivalents of the Chinle are widely distributed and are made up of fine-grained rocks. It seems most likely that much of the material of the Chinle and its equivalents came from the southwest or west rather than from the east, though some of it obviously came from that direction.

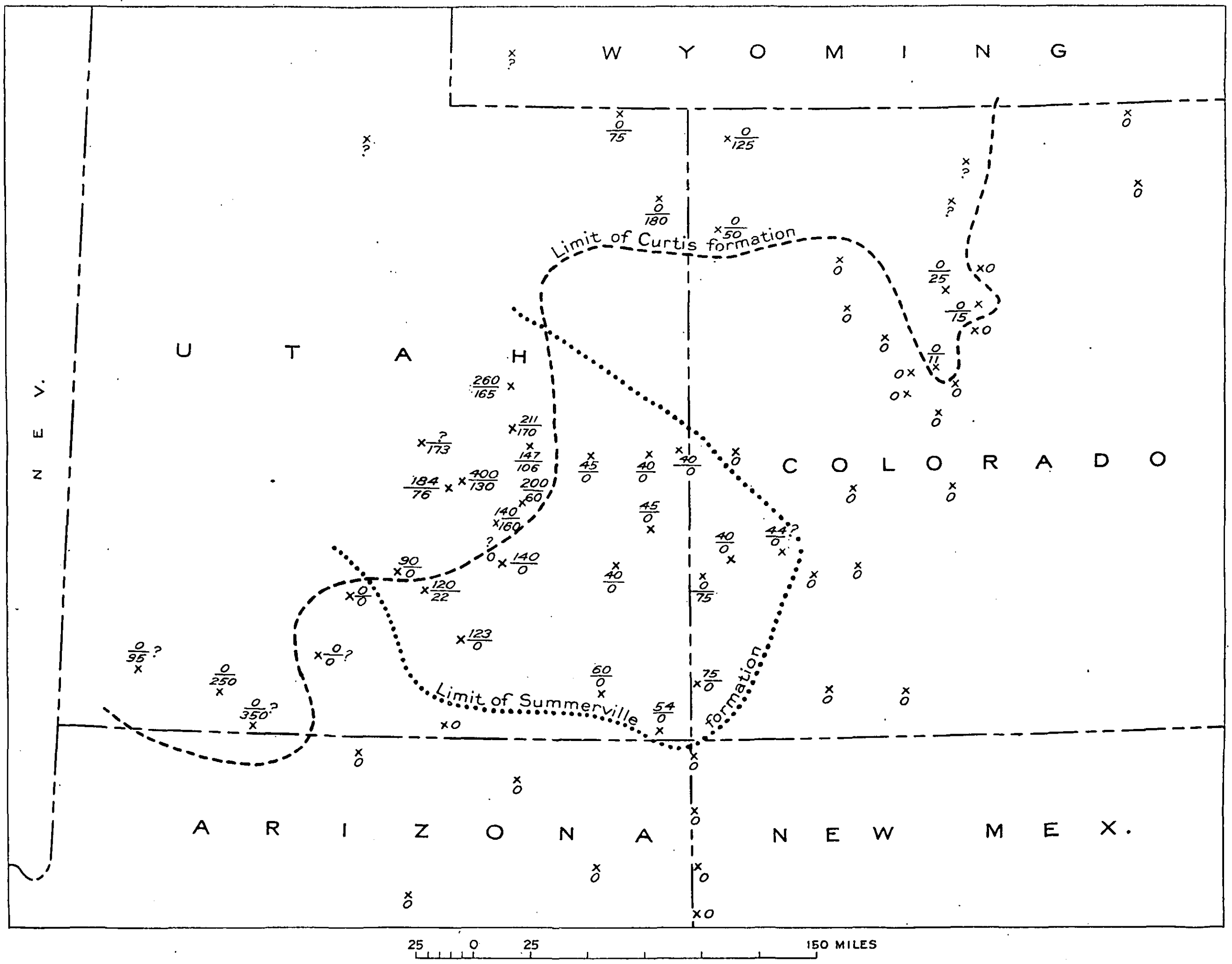


FIGURE 13.—Distribution and thickness (in feet) of the Curtis (lower figures) and Summerville (upper figures) formations.

materials extending as a great delta westward into the marine deposits. The nearest known Upper Triassic seas were a considerable distance to the west, and the writers can see no evidence of any marine deposits in the Chinle or associated with it in any way nor any evidence that the Chinle in most of its large area of distribution constitutes a great delta. There seems to have been high land to the southwest and perhaps to the west between the site of the marine Upper Tri-

GLEN CANYON GROUP

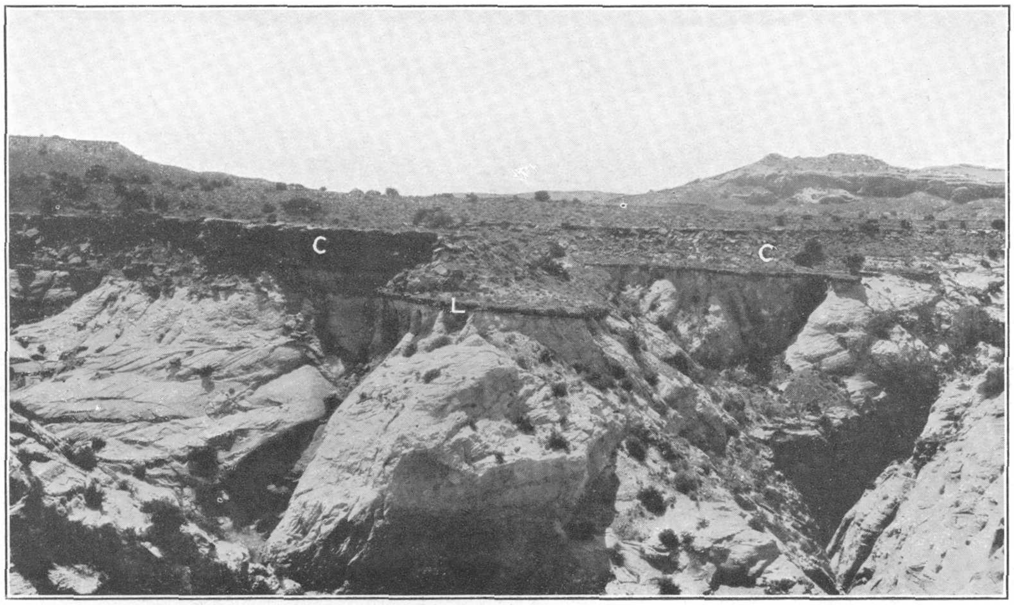
That continental conditions continued during the time of the whole Glen Canyon group seems to the writers assured. Nevertheless marked differences between the formations make it advisable to consider them separately. The origin of the Kayenta formation is more clearly evident than the origin of the Navajo and Wingate sandstones, and it will be convenient to take them up in this order.

The Kayenta formation is obviously a water-laid deposit and quite surely laid down largely by streams.

[26] Longwell, C. R., Geology of the Muddy Mountains, Nev.: U. S. Geol. Survey Bull. 798, pp. 54–56, 1928.

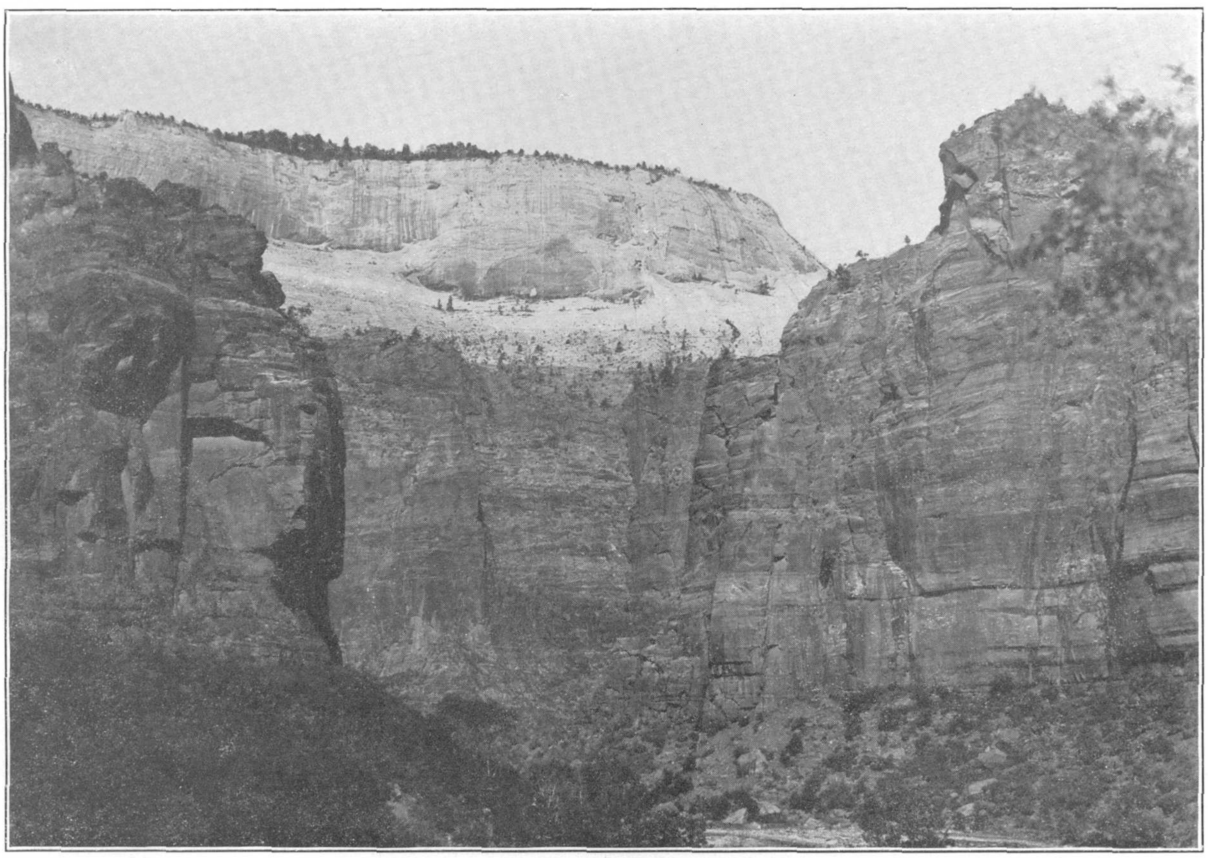
[27] Branson, E. B., Triassic-Jurassic "red beds" of the Rocky Mountain region: Jour. Geology, vol. 35, pp. 610, 627–630, 1927.

[28] Crickmay, C. H., op. cit., p. 20.



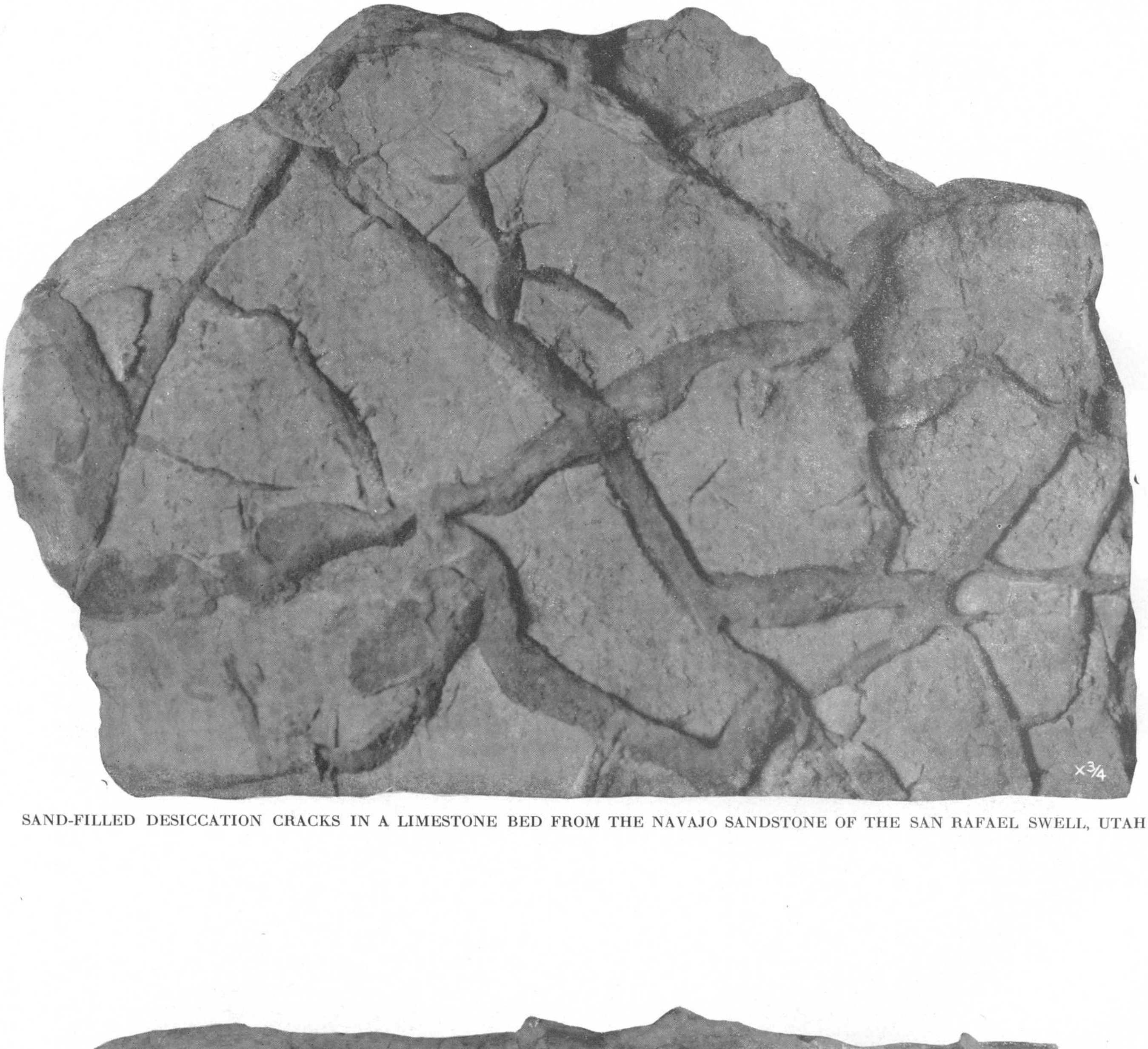
A. A THIN LENS OF LIMESTONE (*L*) NEAR THE TOP OF THE NAVAJO SANDSTONE IN THE GREEN RIVER DESERT, UTAH.

Locality 3 miles northeast of the junction of the Spur and Trail Spring Forks of the Horseshoe Canyon. The Carmel formation (*C*) crops out on the broad bench, and the Entrada sandstone forms the cliffs in the background. Photograph by A. A. Baker.

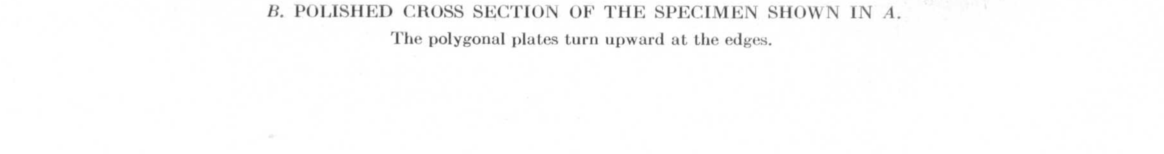


B. NAVAJO SANDSTONE IN ZION CANYON, UTAH.

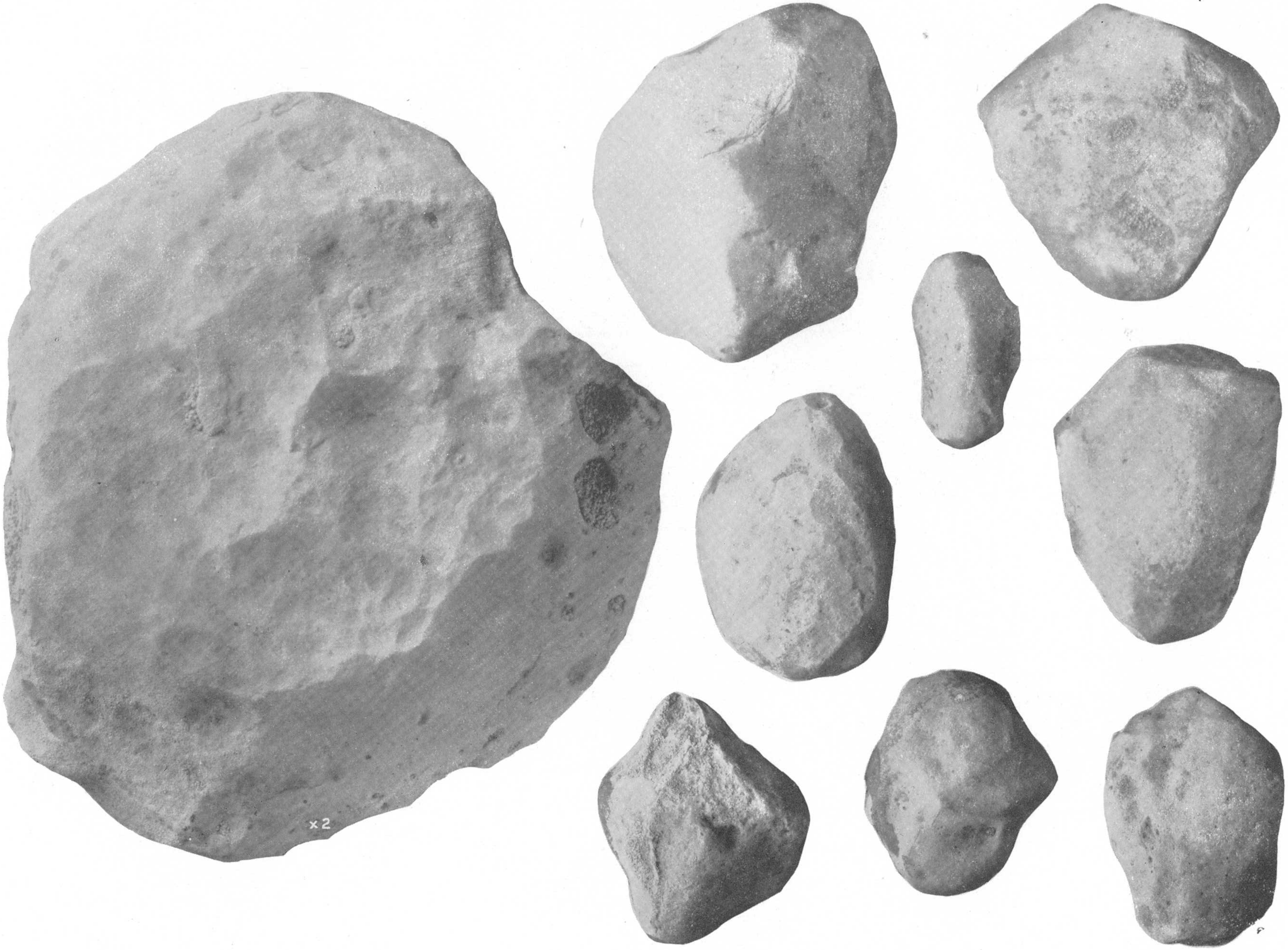
The lighter-colored sandstone forming the upper one-third of the cliff was formerly designated the "Colob sandstone", and the darker sandstone forming the lower two-thirds of the cliff was formerly designated the "Kanab sandstone." The Carmel formation caps the cliff, and the Chinle formation crops out near stream level. Photograph by W. T. Lee.



SAND-FILLED DESICCATION CRACKS IN A LIMESTONE BED FROM THE NAVAJO SANDSTONE OF THE SAN RAFAEL SWELL, UTAH.

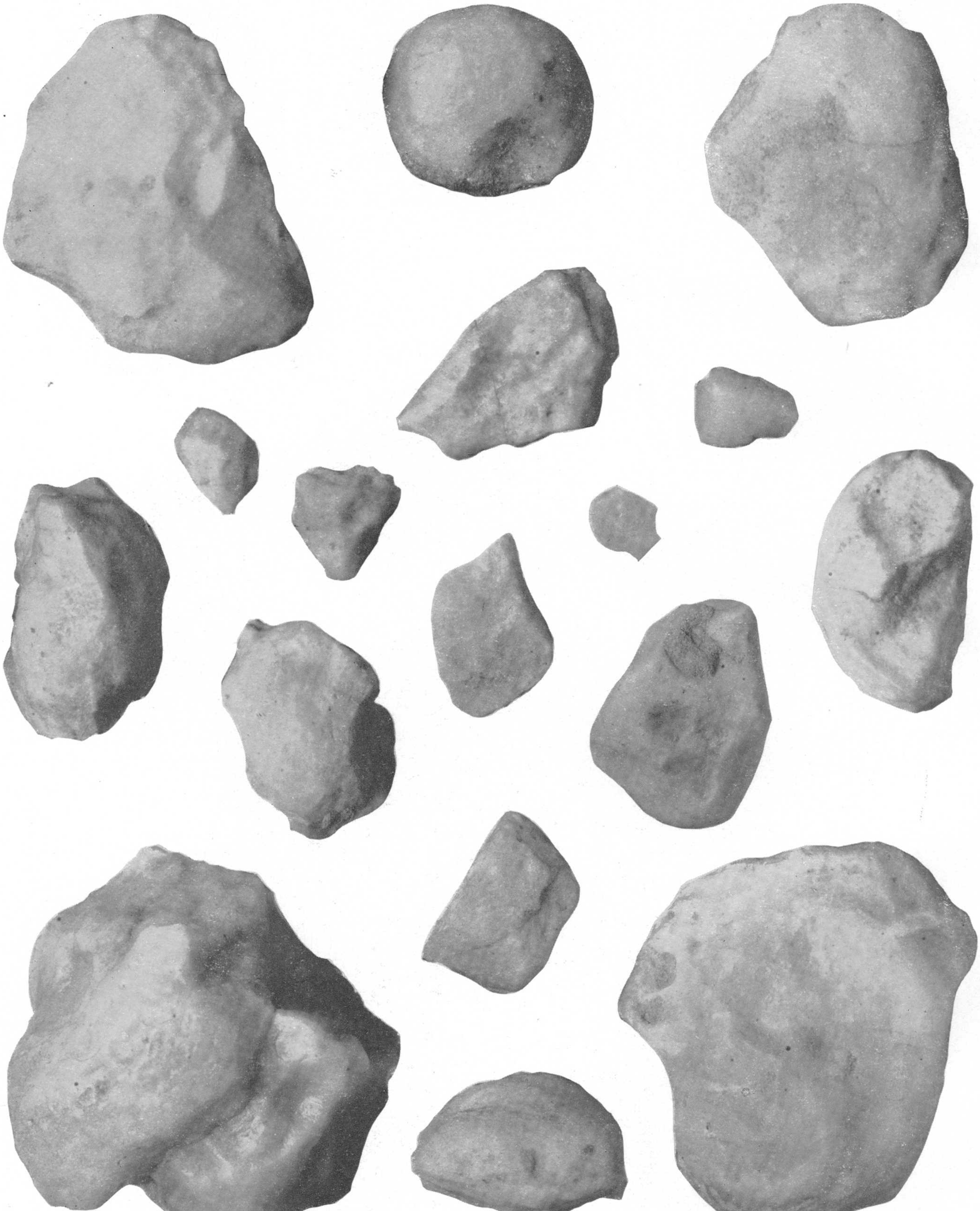


B. POLISHED CROSS SECTION OF THE SPECIMEN SHOWN IN *A.*
The polygonal plates turn upward at the edges.



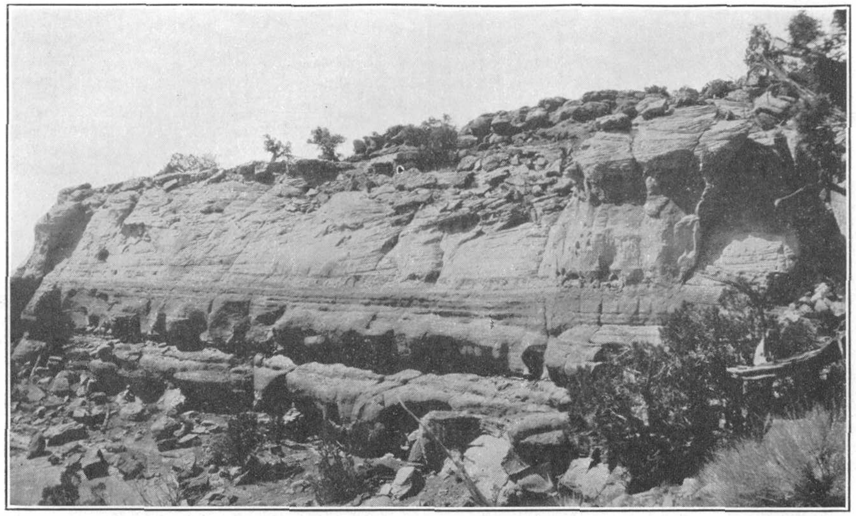
WIND-FACETED PEBBLES COMPOSED OF QUARTZ FROM THE NAVAJO SANDSTONE.

The small pebbles on the right (natural size) are from the wedge between Buckhorn, Wash., and the San Rafael River, San Rafael Swell, Utah. The large pebble on the left (enlarged 2 diameters to show the characteristic-pitted surface) is from the Green River Desert, Utah. It is shown natural size at the lower right-hand corner of plate 14.



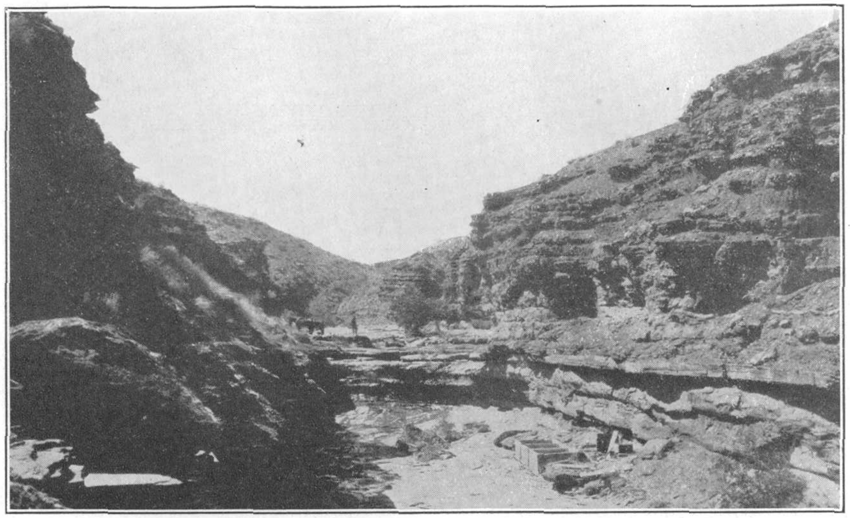
WIND-FACETED PEBBLES COMPOSED OF QUARTZ FROM THE NAVAJO SANDSTONE.

From sec. 34, T. 23 S., R. 13 E., Green River Desert, Utah. Natural size.



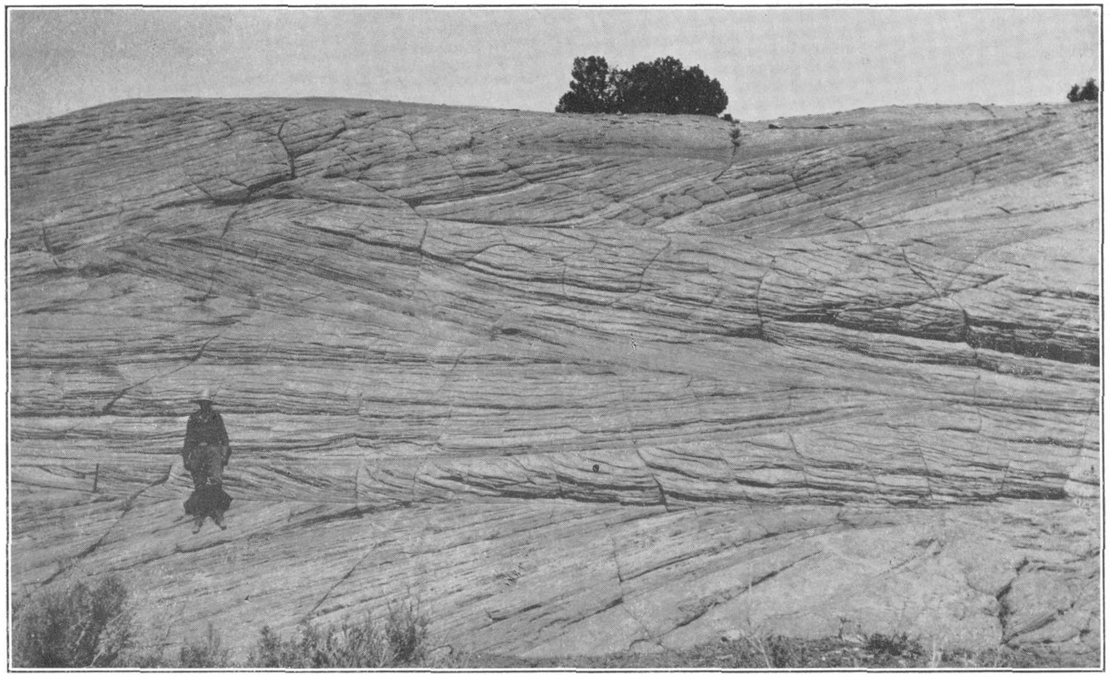
A. WATER-LAID BED OF NODULAR-WEATHERING SILTY RED SANDSTONE NEAR THE TOP OF THE NAVAJO SANDSTONE.

Locality 15 miles southeast of Moab, at the southeast corner of sec. 11, T. 28 S., R. 22 E., Utah. Photograph by A. A. Baker.



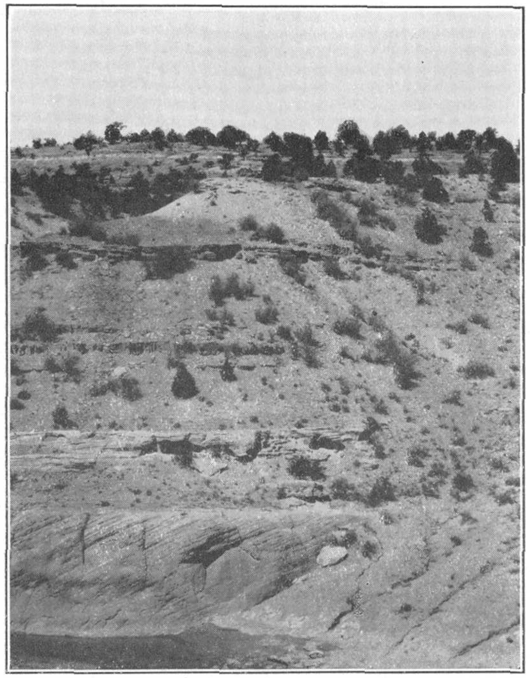
B. OUTCROP OF THE CARMEL FORMATION IN A FORK OF MOONSHINE CANYON IN SEC. 20, T. 24 S., R. 16 E., GREEN RIVER DESERT, UTAH.

The tanks in foreground rest on the Navajo sandstone, which is overlain by the limy sandstone beds at the base of the Carmel formation. Gypsiferous shale and sandstone beds of the Carmel formation form the upper part of the canyon wall. Photograph by A. A. Baker.



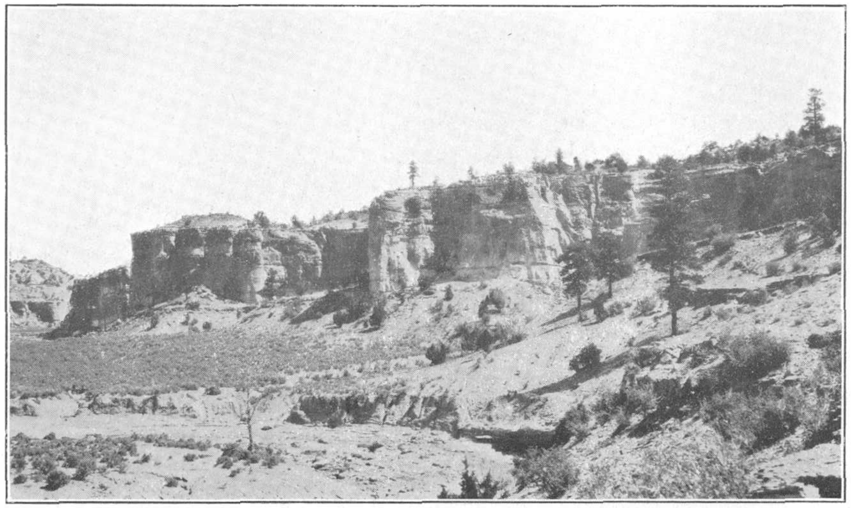
C. TANGENTIAL CROSS-BEDDING IN THE UPPER PART OF THE NAVAJO SANDSTONE IN DRY VALLEY, UTAH.

Sec. 9, T. 30 S., R. 23 E. Photograph by W. T. Lee.



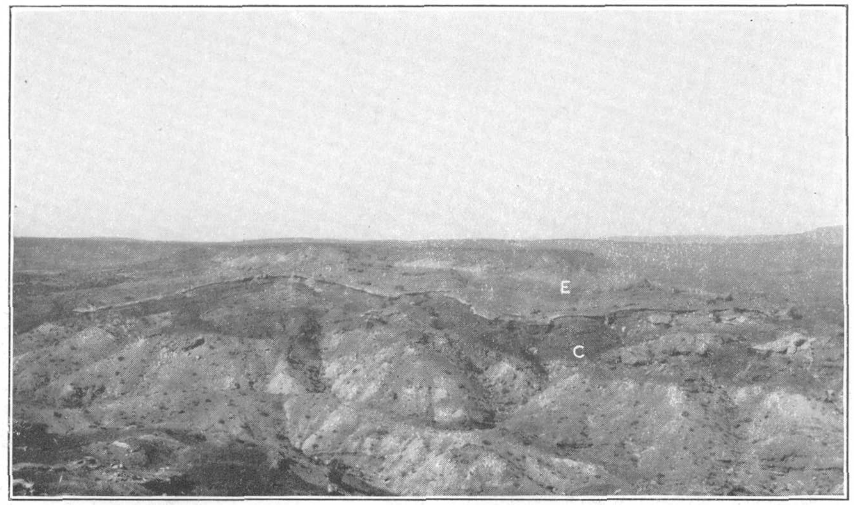
D. INTERBEDDED SANDSTONE AND SHALE OF THE CARMEL FORMATION RESTING ON CROSS-BEDDED NAVAJO SANDSTONE.

On the Paria River 6 miles below Cannonville, Utah. Photograph by A. A. Baker.



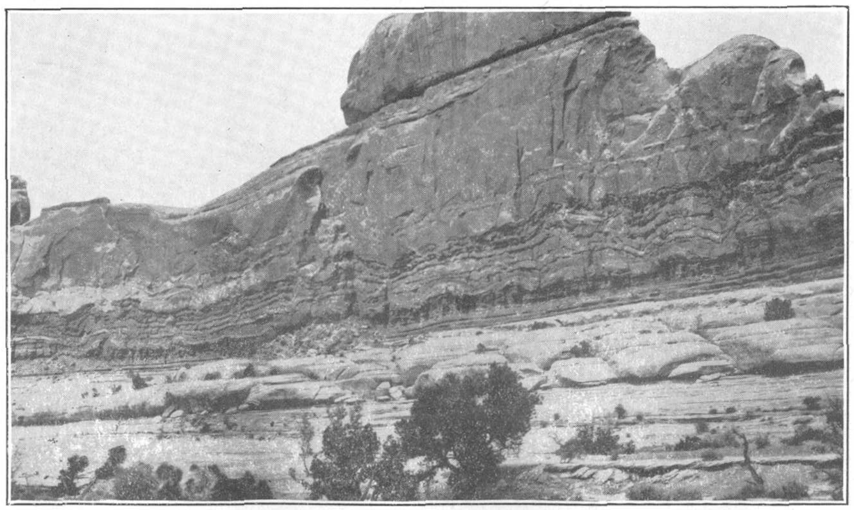
A. LEDGE OF MASSIVE SANDSTONE IN THE CARMEL FORMATION ABOUT 150 FEET ABOVE THE BASE.

On the Paria River about 6 miles below Cannonville, Utah. Photograph by A. A. Baker.



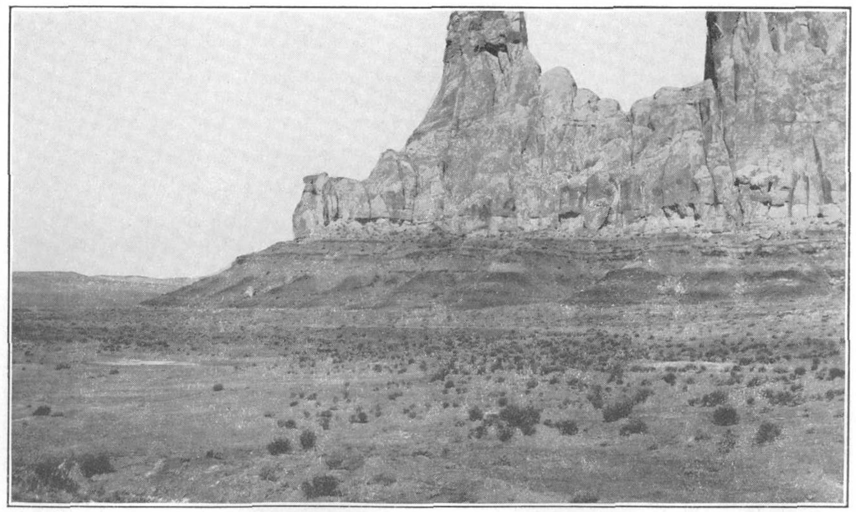
B. IRREGULAR CONTACT BETWEEN THE CARMEL FORMATION (*C*) AND THE OVERLYING ENTRADA SANDSTONE (*E*).

On the San Rafael River in sec. 14, T. 24 S., R. 15 E., Utah. Photograph by A. A. Baker.



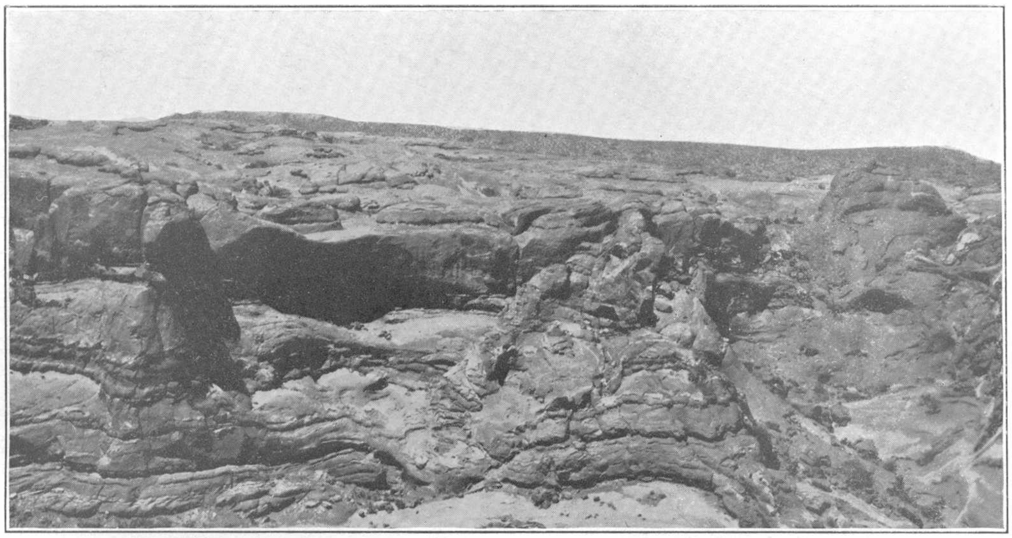
C. CRINKLY BEDDING IN THE CARMEL FORMATION NEAR COURTHOUSE MAIL STATION, 17 MILES NORTHWEST OF MOAB, UTAH.

The light-colored rocks in the foreground are the Navajo sandstone, and the Entrada sandstone overlies the crinkly bedded Carmel formation. Photograph by James Gilluly



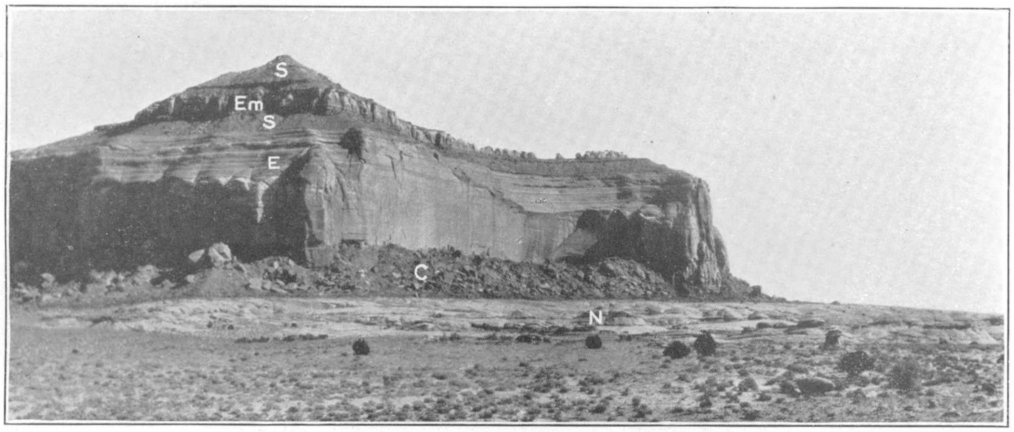
D. CLIFF OF ENTRADA SANDSTONE RISING ABOVE SLOPES FORMED BY THE CARMEL FORMATION NEAR WARM CREEK, UTAH.

About 15 miles northeast of Lees Ferry. Photograph by H. E. Gregory.



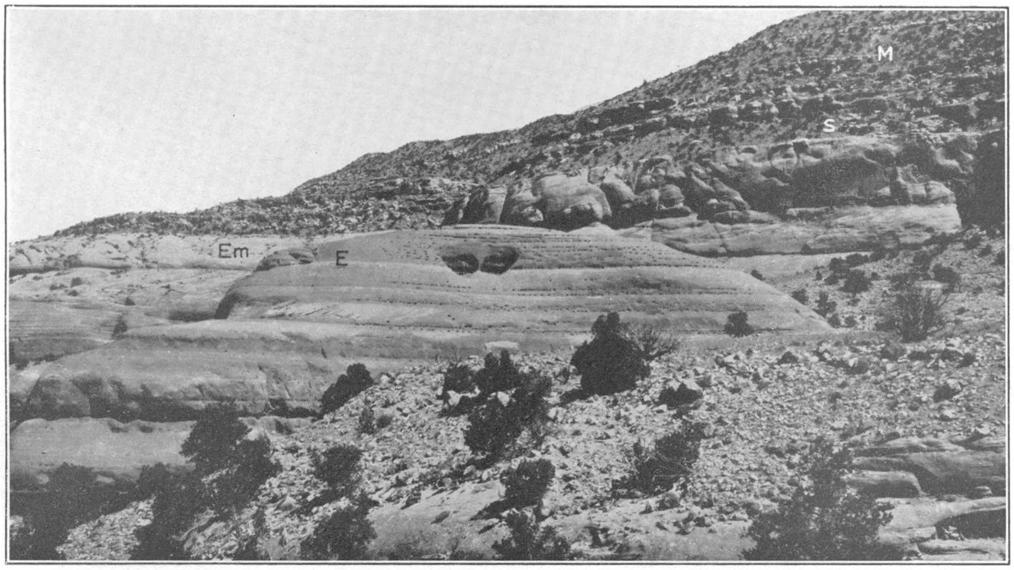
A. IRREGULAR BEDDING IN THE MASSIVE ENTRADA SANDSTONE.

About 8 miles east of the Flattop Buttes, in the Green River Desert, Utah. Photograph by A. A. Baker.



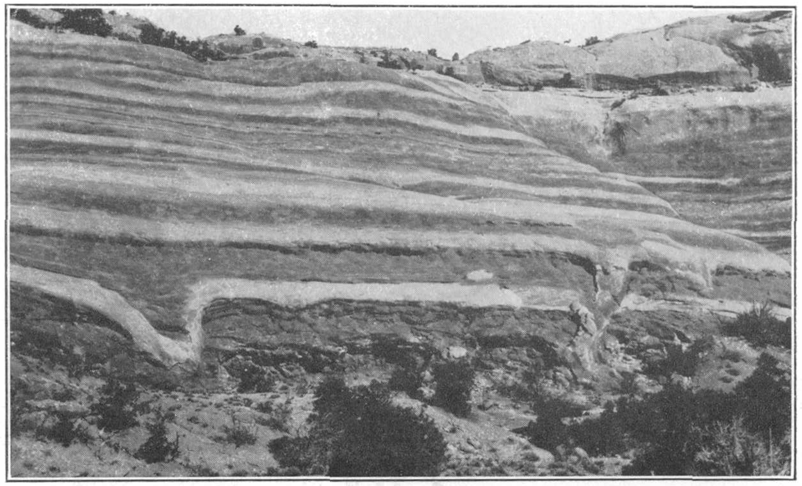
B. ENTRADA SANDSTONE IN TENMILE BUTTE, ABOUT 23 MILES SOUTHEAST OF GREEN RIVER, UTAH.

Shows a tongue of the Summerville formation (*S*) separating the Moab sandstone tongue (*Em*) from the rest of the Entrada sandstone (*E*). The Carmel formation (*C*) crops out in the slope beneath the cliff of Entrada sandstone, and the light-colored Navajo sandstone (*N*) crops out in the foreground. Photograph by Otho Murphy.



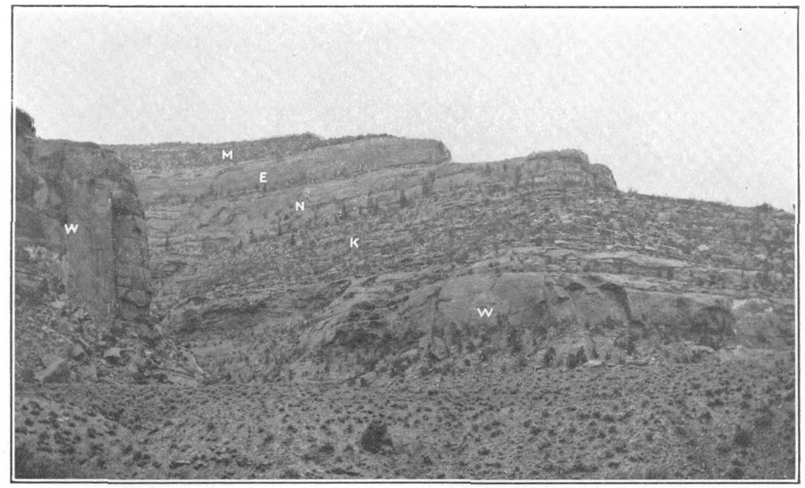
C. SOLUTION PITS IN THE ENTRADA SANDSTONE ABOUT 1 MILE SOUTHEAST OF CANE SPRINGS, UTAH.

The Moab sandstone member (*Em*) at the top of the Entrada sandstone (*E*) is overlain by the Summerville formation (*S*) and the Morrison formation (*M*). Photograph by A. A. Baker.



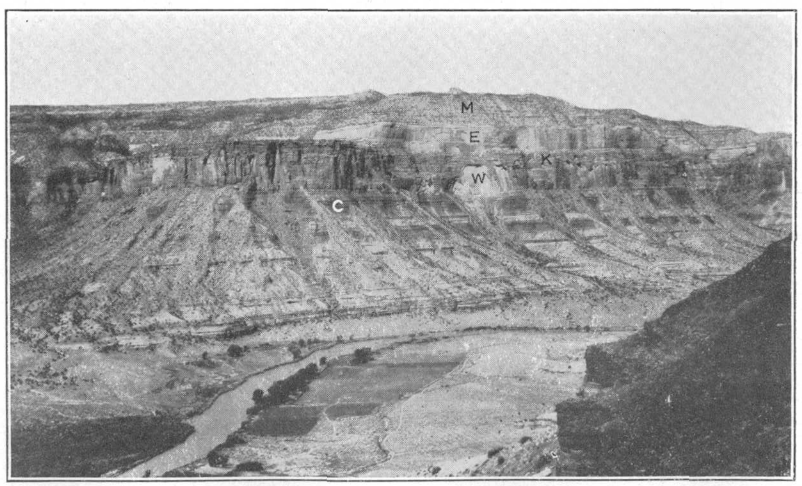
A. ENTRADA SANDSTONE WITH CHARACTERISTIC LIGHT AND DARK BANDING, ABOUT 4 MILES SOUTHEAST OF DEWEY, UTAH.

Shows the Moab sandstone member at the top of the cliff. The irregularities of bedding at the base of the cliff are apparently due to movements in the unconsolidated sediments. The dark beds at the base of the cliff are the silty beds of the Carmel formation. Photograph by John Vanderwilt.



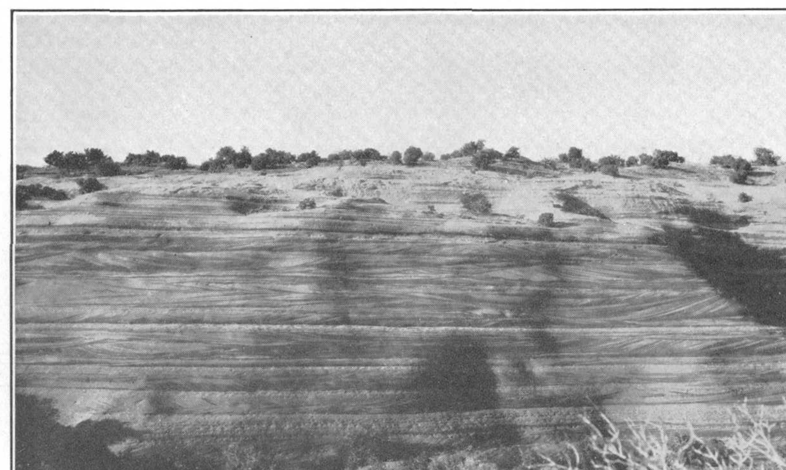
B. CANYON OF THE DOLORES RIVER WEST OF BEDROCK, COLO.

W, Wingate sandstone; *K*, Kayenta formation; *N*, Navajo sandstone; *E*, Entrada sandstone; *M*, Morrison formation. Photograph by W. T. Lee.



C. WEST WALL OF THE CANYON OF DOLORES RIVER AT GATEWAY, COLO.

C, Chinle formation; *W*, Wingate sandstone; *K*, Kayenta formation; *E*, Entrada sandstone; *M*, Morrison formation. Rocks of Carboniferous age underlie the Chinle formation and crop out in the lower part of the canyon wall. Photograph by C. H. Dane.



D. INTRICATE CROSS-BEDDING IN THE ENTRADA SANDSTONE.

In the northern part of sec. 5, T. 21 S., R. 23 E., about 8 miles northeast of Cisco, Utah. The white sandstone at the top is the lower part of the Moab sandstone member. Photograph by C. E. Erdmann.

The occurrence of fresh-water mollusks (*Unio*), reptilian tracks, and indeterminate plant remains accords with this view. The material is conspicuously coarser than that of the underlying Wingate and overlying Navajo; and this comparative coarseness of grain, together with regular cross-bedding, lenticularity of the beds, truncation of beds by local unconformity (pl. 8, *B*), and channeling between beds, points to rapid deposition by streams. Some even-bedded sandy shales and sandstones point to deposition in quiet water. The abundance of mud-pellet and limestone-pellet conglomerates in some places indicates an alternation of quiet waters and rapid movements. The local irregularities at the base of the Kayenta formation appear to represent sudden changes in type of deposition, but in many places a completely transitional relation is evident and the lower part of the Kayenta is lithologically much like the Wingate. Toward the top of the Kayenta a transition toward the lithology of the Navajo begins, and thick beds of white even-grained and fine-grained cross-bedded sandstone become increasingly abundant (pl. 8, *C*). As noted on page 44, the material seems to have had no preponderant source and probably came from various directions. There is much suggestion of conditions in Kayenta time like those of Chinle time.

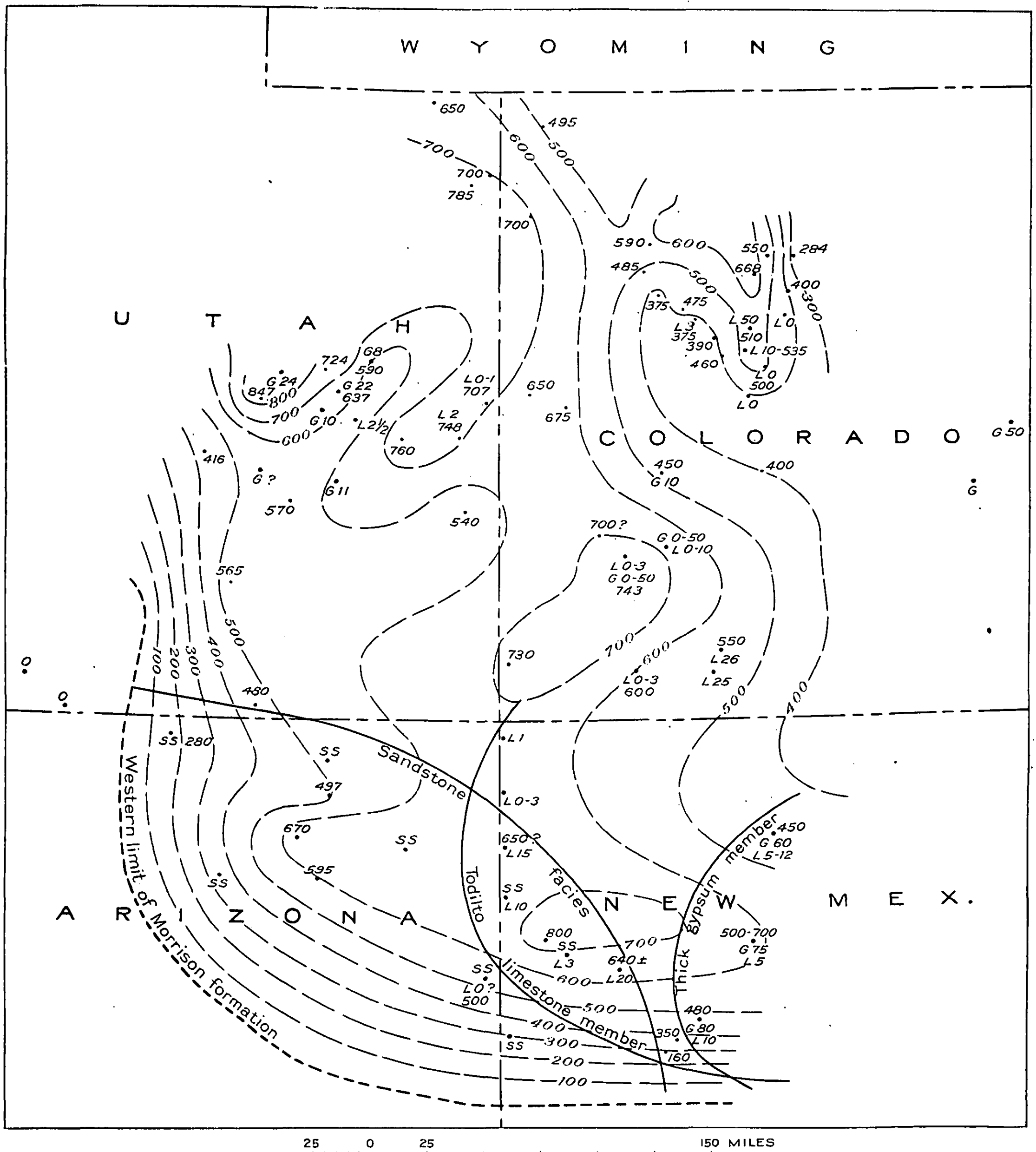


FIGURE 14.—Distribution and thickness (in feet) of the Morrison formation. •, Locality where Morrison is known; *L*, locality where a basal limestone occurs; *G*, locality where a basal gypsum occurs; *SS*, locality where sandstone is the dominant rock.

The Navajo has been considered a typical eolian desert deposit by many writers since the suggestion of this origin by Huntington and Goldthwait [29] and later by Gregory.[30] Many features are in accord with this interpretation. One may cite for much the greater part of its area the lack of either numerous or regular true bedding planes; the abundance of cross-bedding on a gigantic scale, characterized by the tuncation of the sets of false beds by other sets at all angles apparently without system, the so-called "tangential" type; the well-rounded grains, usually well sorted but in places with a scattering of coarser grains along cross-bedding planes; and the great scarcity of silt, ripple marks, mud cracks, mud-pellet conglomerates, or other evidence of water action. The absence of wind-rippled surfaces is perhaps curious but certainly less surprising than the absence of features typical of deposition in water if the sandstone had been so deposited. The occurrence in the Navajo of local thin lenses of dense unfossiliferous gray limestone from a few feet to several miles in diameter accords well with the eolian theory of origin, for ephemeral water-filled basins might be expected in a desert dune country, and in them such limestones might be formed through algal or purely chemical action. These limestones show mud cracks (pl. 12, *A*, *B*) and other features indicating desiccation. The occurrence of excellent dreikanter in the Navajo sandstone at several localities in the

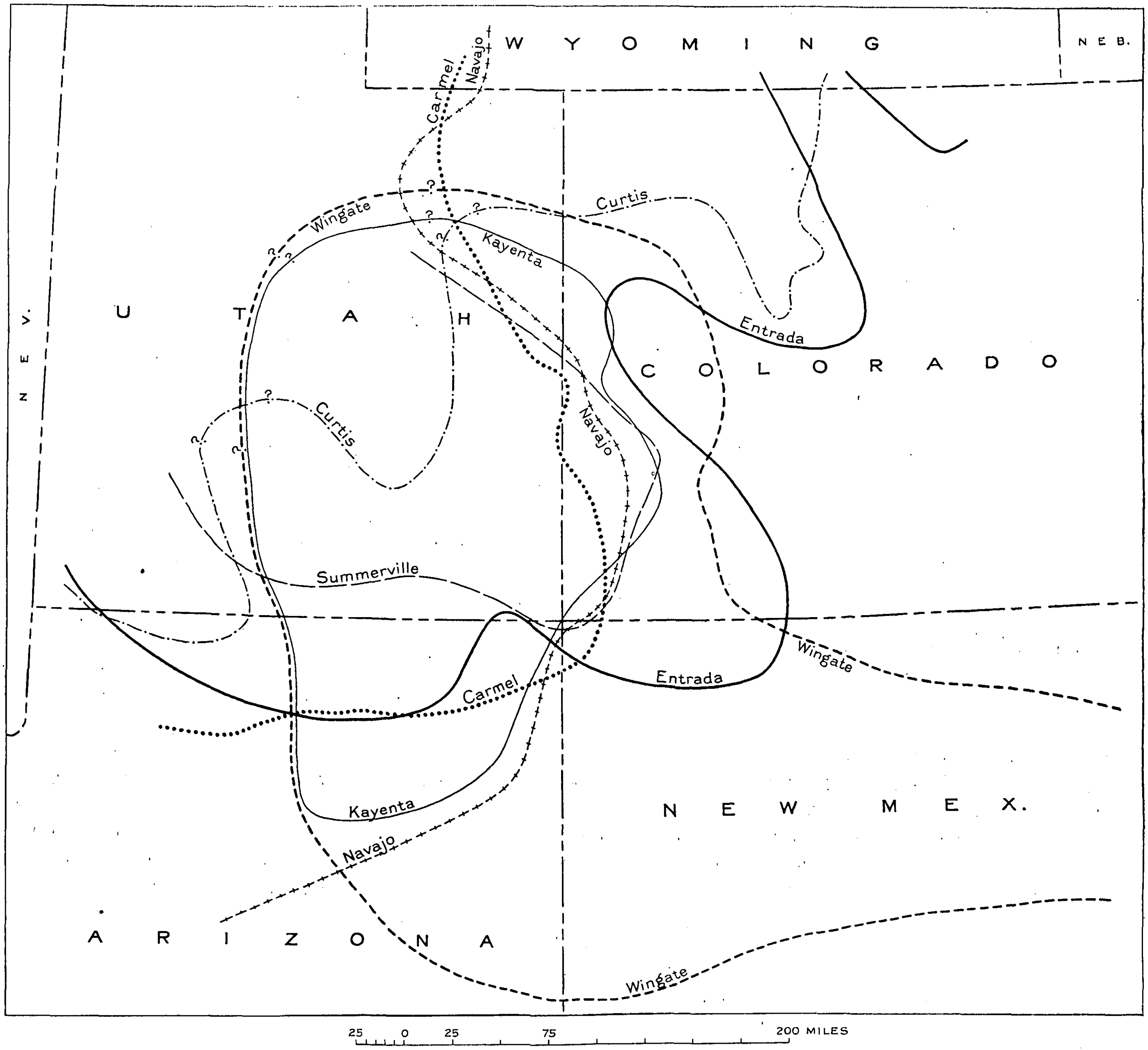


FIGURE 15.—Comparison of the gross distribution of the Jurassic formations except the Morrison.

[29] Huntington, Ellsworth, and Goldthwait, J. W., The Hurricane fault in the Toquerville district, Utah: Harvard Coll. Mus. Comp. Zoology Bull., vol. 42, pp. 203, 207, 1904.

[30] Gregory, H. E., Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, p. 59, 1917.

San Rafael Swell and the Green River Desert definitely proves the eolian deposition of the part of the Navajo in which they occur and tends to support the thesis that much of it is wind-deposited (pls. 13, 14). The existence at a few places of some thin layers with regular horizontal bedding in the Navajo, particularly in the lower part, and very rare shaly beds shows that a small part of it was deposited in water (pl. 15, *A*). Toward the southwest, in Nevada, Longwell has noted a considerably greater amount of water-laid sandstone than is found farther east, though the type with tangential cross-bedding is conspicuous.[31] The source of the materials of the Navajo seems to have been to the southwest.

The formation of the Wingate sandstone has also been attributed by several writers chiefly to eolian deposition. Some features of the Wingate, however, are incompatible with this hypothesis. Although in the central part of its basin, in southeastern Utah, it is tangentially cross-bedded on a large scale and composed of well-sorted, rounded grains, largely of quartz, there are some horizontal bedding planes. Toward the margins of the basin, in Colorado and in southern Utah and northern Arizona, regular horizontal bedding planes are much more conspicuous, and thin shale beds are not uncommon. It seems probable that some horizontal planes might well be developed in an eolian deposit by dune migration, but the occurrence of repeated and regular horizontal planes in the marginal portions is much more in accord with deposition in water. Muddy or earthy phases are also prominent in the marginal phases of the Wingate, and the writers believe that it merges at its borders into red shales and sandstones indistinguishable from the mass of the Dolores and Chinle formations. No fossils, except a few dinosaur tracks in the lower part, have been found in it. Mud cracks and ripple marks are not uncommon in the lower part, and the repeated occurrence of narrow but deep sand-filled erosional channels in shale beds in the lower Wingate and in the top of the Chinle clearly signifies subaerial action (pl. 5, *B*). To a lesser degree the repeated occurrence of angular chunks of shale or clay in the base of the Wingate sand is significant. Such sharp-edged clay chunks could scarcely be transported unless previously dried to hardness. Unfossiliferous dense gray limestone beds similar to those found in the Navajo also occur in the Wingate but are smaller, thinner, and much less common. These limestone beds appear to the writers to be less numerous in those phases of the Wingate where regularity of bedding and other evidences of water deposition are most conspicuous. In brief, a subaerial origin for the Wingate seems assured, and although eolian deposition appears probable for a large part of the formation at places, evidence of deposition in water is equally strong for a large part of the formation at other places. It appears probable that the Wingate in the central area is an eolian deposit slightly modified by water action but in the marginal facies represents a commingling of water-worked and wind-worked material. No preponderant source of materials is evident from the data now available, and it is probable that some materials came into the Wingate basin from all sides.

The lithologic features of the sediments of the Glen Canyon group summarized above seem to the writers to make wholly untenable the view expressed by Branson [32] that the group represents the foreset beds of a delta of Chinle time.

A possible sequence of events in the area covered by this paper during the time of the Glen Canyon group is as follows: The deposition of the Chinle formation by streams with low gradients, flowing perhaps from moderate highlands on the west, south, and east, passed without important interruption into the deposition of the Wingate sandstone in a basin lying chiefly in southeastern Utah, northeastern Arizona, and northern New Mexico. Arid or semiarid conditions had prevailed over most of the region and seemingly continued. Winds transported much of the material, but around the margins water-borne material mingled with the wind-borne material. Subsequently, streams extended virtually across the basin and rapidly deposited the material of the Kayenta formation. Then followed an extensive development of desert conditions over an enormous area. Ephemeral streams brought out sands from southwestern highlands and spread them over the area, though a much more active process was the transportation and deposition of the material by winds. Occasionally small, short-lived depressions held bodies of water and served as pans for the accumulation of limestone. Locally pebbles of a siliceous rock, perhaps an indigenous limestone thoroughly silicified, were exposed to wind action and became dreikanter. The deposits accumulated during this period of desert conditions form the Navajo sandstone. As the next overlying deposits were marine beds laid down in waters that came in from the north and spread widely over a large area in Utah, the surface of the Glen Canyon sediments seems not to have had very much slope nor considerable irregularity. Possibly the region had been depressed about as fast as the sediments of the Glen Canyon group were deposited.

Mathews' record of a marine Jurassic fossil (*Trigonia*) at the base of the Nugget sandstone in northern Utah is the only suggestion of the existence during the Glen Canyon epoch of marine waters anywhere in the vicinity of the area treated in this paper. The nearest occurrence of Lower Jurassic deposits that might have a bearing on the matter is that in the

[31] Longwell, C. R., Geology of the Muddy Mountains, Nev.: U. S. Geol. Survey Bull. 798, pp. 67–68, 1928.

[32] Branson, E. B., op. cit., pp. 627–630.

Fernie shale of British Columbia.[33] The geographically nearer deposits in southwestern Nevada[34] appear on almost every count to be related to Pacific coast deposits rather than to those of the interior region. The much more abundant occurrences of Middle Jurassic deposits in eastern British Columbia and western Alberta[35] would seem to offer a greater likelihood of relationship to the Nugget than the single Lower Jurassic locality, and it seems therefore more probable that the Middle Jurassic sea sent from the north a brief extension as far as Utah than that such an extension came from the Lower Jurassic sea. If the Navajo can be thus placed in the Middle Jurassic, the early Jurassic would be a reasonable time for the deposition of the Wingate and Kayenta formations.

Lee first suggested and Crickmay later amplified the picture of a long and broad Cordilleran intermontane geosyncline extending in width from Nevada into Colorado. To the west lay the Sonoran geanticline, which formed Jurosonora and later its northern prolongation Jurozephyria. In the geosyncline most of the Jurassic sedimentation took place.

SAN RAFAEL GROUP

The origin of the San Rafael group, unlike that of the Glen Canyon group, is intimately bound up with an invasion of marine waters. The deposits of the group in central eastern Utah are largely marginal facies. Toward the northwest they grade into an open-sea facies, for in north-central Utah and western Wyoming there seems to have been in the time of the San Rafael group extensive deposition of limestones, now included chiefly in the Twin Creek limestone, which is correlated with the Carmel, the basal formation of the group. Toward the south and east the marginal facies passes by lateral gradation and intertonguing into sands which appear to be, at least in part, an eolian deposit. The margins of the marine invasions fluctuated widely, and there were two periods of maximum invasion toward the southeast, which had quite different geographic limits.

During the earlier of these invasions the sediments of the Carmel formation were deposited. The marine waters came down from the north through central Montana, western Wyoming, and eastern Idaho and diagonally across Utah into the southwest quarter. In central and south-central Utah there was at many places an initial deposit of reworked Navajo sand, followed chiefly by limestone, though gypsum and shale were also formed, indicating a shallow sea with perhaps small lagoon areas where the sea waters could evaporate. The conditions that favored the formation of limestone were succeeded somewhat irregularly by those that favored the deposition of gypsum and red shale. In southeastern Utah the Carmel deposits are thin-bedded red muddy sandstone and sandy shale, in many places contorted in a fashion hard to explain except as due to flowage of unconsolidated water-saturated materials (pls. 16, *C*; 18, *A*). These deposits apparently represent the farthest extension of the Carmel invasion. The gypsum and red shale facies of the Carmel farther west may represent lagoon deposits formed during the withdrawal of the open waters into north-central Utah.

With the withdrawal of the Carmel sea from large parts of southern and southeastern Utah clean light-colored sands of the Entrada accumulated, which apparently in large part represent wind-laid deposits (pl. 18, *D*). These sands were also extensively deposited in western and northern Colorado beyond the limits of the Carmel invasion. Toward the northwest these clean sands grade laterally into a muddy red well-bedded facies, the Entrada of the San Rafael Swell (pl. 21, *B*), which in turn seems to be a marginal facies of wholly marine rocks that form part of the Beckwith formation of southwestern Wyoming.

The sea margin again advanced from this central area, but the waters of this later incursion spread more widely east and west and not as far south as those of the earlier one. They covered the partly eolian sands of the preceding phase over large areas. As might be expected in an area of advancing and retreating sea waters, the deposits formed during this phase show considerable irregularities in their internal arrangement, and deposits of differing lithology, formed at different positions with respect to the sea margin, grade into one another and intertongue. The deposits of this later and more extensive incursion, including marine fossiliferous coarse sands, sandy oolitic limestone, and other near-shore facies, have been included in the Curtis formation. There was, however, a marginal facies in southeastern Utah, beyond this region of fossiliferous marine deposits, where barren but well-bedded red rocks accumulated, forming the lower part of the Summerville formation. These in turn intertongue with a clean white sandstone, the Moab sandstone tongue, which merges with the main mass of the Entrada sandstone toward the east (pl. 17, *B*).

The sedimentation associated with the Upper Jurassic marine invasion in central Utah ended with the extensive accumulation of the well-bedded red rocks that form the Summerville of eastern Utah (pl. 22, *A*, *B*). These were deposited prior to or during the final withdrawal of the sea, for they rest upon the more assuredly marine rocks of the Curtis in the San Rafael Swell. The deposition of the red rocks did not extend into northern Utah or northern Colorado, for there is no Summerville in the north. The fauna of the Curtis occurs also in the upper part of the so-called

[33] Warren, P. S., A Lower Jurassic fauna from Fernie, British Columbia: Roy. Soc. Canada Trans., 3d ser., vol. 25, sec. 4, pp. 105-111, 1931.

[34] Muller, S. W., several papers published in abstract in Geol. Soc. America Bull., vol. 40, p. 259, 1929; vol. 41, pp. 198, 214, 1930.

[35] See McLearn, F. H., Some Canadian Jurassic faunas: Roy. Soc. Canada Trans., 3d ser., vol. 21, sec. 4, pp. 61-73, 1927; and other papers. See also Crickmay, C. H., op. cit.

"Twin Creek limestone" of Mathews in north-central Utah and in the lower part of the Beckwith formation of southwestern Wyoming. Seemingly these rocks are deposits in the more open sea waters of Curtis time.

The widespread excursions of the Upper Jurassic sea seem to have passed over low-lying lands. The sands of the Entrada particularly testify to the extent of relatively smooth surface on the bordering lands, for they cut across all the older deposits onto the old areas of crystalline rocks and nowhere rest on any notable irregularities nor contain any coarse detritus. The recurrence of red rocks and the repetition of gypsum deposits throughout the San Rafael group testify to colored cross-bedded sandstone, probably a marginal facies of the Morrison and possibly in part of eolian origin.[36] In places the Todilto limestone is intimately associated with or is replaced by a thick bed of gypsum, which would suggest aridity. The highly polished pebbles ("gastroliths") so widely distributed in the Morrison mudstones may owe their lapidary's finish to wind-borne dust,[37] which also might suggest some degree of aridity.

The thesis that the Morrison deposits represent river and lake sediments laid down upon a little dissected and poorly drained surface, perhaps under semiarid climatic conditions, has been supported in the main by virtually

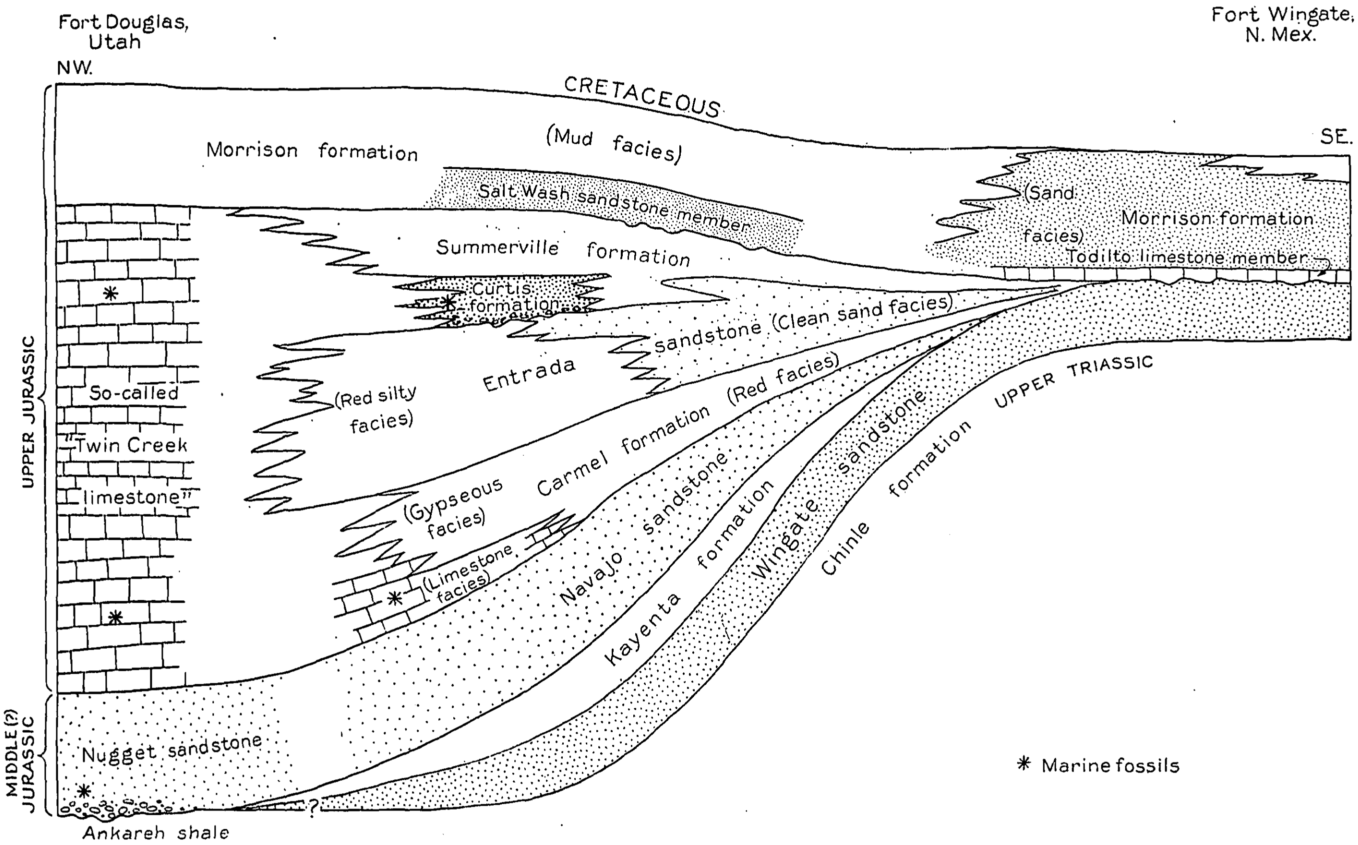


FIGURE 16.—Diagram of stratigraphic relations from north-central Utah to northwestern New Mexico.

the aridity of the land surrounding the seas and in these characteristics support the evidence offered by the Entrada sandstone.

MORRISON FORMATION

Upon the withdrawal of the marine waters there followed, with apparently no large lapse of time, an interval of deposition in rivers and lakes upon an extensive, undissected plain. The materials laid down upon this plain were dominantly fine muds, though some sandstone, limestone, gypsum, and conglomerate are present. The conglomerates indicate at least occasional currents of sufficient rapidity to carry coarse materials. In the south a relatively large body of water is indicated by the Todilto limestone member. This was succeeded by a large thickness of light-everyone who has dealt with the Morrison.[38] It seems to the writers to need no further discussion.

A partial summary of the relations discussed in this section on conditions of deposition is given in figure 16.

AGE OF THE FORMATIONS

GLEN CANYON GROUP

As noted in the discussion of nomenclature the formations of the Glen Canyon group have in the

[36] Mook, C. C., McElmo formation in northeastern Arizona [abstract]: Geol. Soc. America Bull., vol. 41, no. 1, p. 107, 1930.

[37] Compare Berkey C. P., and Morris, F. K., Geology of Mongolia: Natural history of Central Asia, vol. 2, pp. 208, 379, 1927. The Eocene Irdin Manha formation, with a mammalian fauna, contains many highly polished pebbles. The residual accumulation of these on the surface is the source of the name "Irdin Manha" (the Valley of Gems).

[38] See, for example, Simpson, G. G., Paleobiology of Jurassic mammals: Palaeobiologica, Band 5, Lief. 2, pp. 150-155, 1932.

older literature most commonly been divided between the Triassic and the Jurassic, with a few references to †Permo-Carboniferous and a few wholly to either Triassic or Jurassic. In the later literature the assignment has been almost entirely Jurassic or Jurassic (?).

The Glen Canyon group has yielded no significant fossils, unless the recently reported dinosaur (see p. 6), whose significance is not now known, eventually proves to be useful for age determination. The dinosaur tracks in the Wingate, Kayenta, and Navajo formations and the unionid pelecypods and obscure plant remains in the Kayenta formation have little present value in making an age assignment. It is therefore necessary, for the present at least, to rely wholly on evidence of other sorts, both from the group itself and from the enclosing formations.

The series of red beds immediately beneath the Glen Canyon group, the Chinle formation, has yielded several groups of vertebrates as its most significant fossils. These vertebrates were for many years considered to constitute a single Upper Triassic fauna, because of resemblances to the fauna of the Keuper of Germany. Von Huene [39] in 1926, however, proposed to divide them into a Middle Triassic fauna and an Upper Triassic fauna, using in part stratigraphic position and in part the stage of evolution of certain species as the basis of separation. Branson [40] in 1927 and Branson and Mehl [41] in 1929 minimized the value of these Triassic vertebrates, as now known, for correlation and considered them to be an index of conditions rather than age. They considered Von Huene's conclusions not warranted. In the first paper cited Branson indicates Chinle as partly Middle and partly Upper Triassic. In the second paper the authors state that

> it seems logical to assume * * * that all of the bone-bearing beds of the Rocky Mountain Triassic are in a broad sense of the same age. That this age is Middle Triassic rather than Upper is indicated by the fact that all of the stegocephalian genera * * * are of the Metoposauridae, a family abundantly represented in the Lower Triassic of Europe but not appearing above the oldest Keuper.

Case [42] in 1928 likewise considered the Triassic vertebrate fauna of the southwest a single assemblage, though he viewed it as occurring in two zones separated by a widespread Shinarump conglomerate zone. He placed the whole in the Upper Triassic. Camp [43] in 1930 agreed with Von Huene in using the Triassic vertebrates for correlation and recognized two zones in the Chinle corresponding roughly to Von Huene's zones but placed them both in the Upper Triassic. Camp thought the Triassic vertebrates of Wyoming (†Popo Agie beds), especially studied by Branson and Mehl, to be Middle Triassic. It seems to the present writers that the weight of opinion regarding the Chinle fossils and the physical evidence favor the traditional age assignment of Upper Triassic for at least part of the Chinle, and that that is the more logical assignment for all of it. It is so regarded in this paper.

The beds that lie next above the Glen Canyon group, the Carmel formation, contain marine invertebrates that indicate an early Upper Jurassic age, as noted on page 7.

There was, therefore, between the Chinle and Carmel epochs an interval corresponding to possibly part of Upper Triassic time and certainly all of Lower and Middle Jurassic time. Into this interval the Glen Canyon group must be fitted, the part or parts to which it is to be assigned depending on individual interpretation of the physical evidence.

The Wingate, Kayenta, and Navajo formations of northern Arizona and southeastern Utah have been viewed by the later students of the region as intimately related, a belief expressed by associating the three units together under one name—†"La Plata group" (Gregory and others), "Wingate sandstone" (Emery), †"Zunian series" (Keyes), and "Glen Canyon group" (Gregory and Moore and others). That local unconformities occur within the group, particularly at the base of the Kayenta formation, is unquestioned, but all seem to be merely local features and of no general significance. The dominance of massive cross-bedded resistant sandstone with very little silt or clay materials, except in the thinner Kayenta formation, creates a strong impression that the differences between the formations, though obvious, are unimportant.

The impression of intimate relationship gained in northern Arizona and southeastern Utah is much weakened, however, if the whole area of occurrence of each of the formations of the group is considered, for then notable differences in distribution and some differences in lithology appear. The Wingate sandstone has a wide distribution in northern New Mexico and western Colorado not shared by the Kayenta formation and Navajo sandstone. It seems to lie in a basin whose main axis trends southeast (fig. 8).

On the other hand, the Navajo sandstone has a wide distribution in southwestern Utah and eastern Nevada not shared by the Kayenta formation and Wingate sandstone. It seems to lie in a basin whose main axis trends southwest (fig. 10). The Kayenta formation is recognized mainly in the region where both the Navajo and Wingate are present (fig. 9). Another notable difference is that the Wingate sandstone is persistently reddish and toward the margins of its area

[39] Von Huene, F. R., Notes on the age of the continental Triassic beds in North America, with remarks on some fossil vertebrates: U. S. Nat. Mus. Proc., vol. 69, art. 18 (no. 2644), pp. 1-5, 1926.

[40] Branson, E. B., Triassic-Jurassic "red beds" of the Rocky Mountain region: Jour. Geology, vol. 35, pp. 609-617, 1927.

[41] Branson, E. B., and Mehl, M. G., Triassic amphibians from the Rocky Mountain region: Missouri Univ. Studies, vol. 4, no. 2, p. 18, 1929.

[42] Case, E. C., Indications of a cotylosaur and of a new form of fish from the Triassic beds of Texas, with remarks on the Shinarump conglomerate: Michigan Univ. Mus. Paleontology Contr., vol. 3, no. 1, pp. 8-12, 1928.

[43] Camp, C. L., A study of the phytosaurs: California Univ. Mem., vol. 10, pp. 2-4, 1930.

of distribution is more and more divided into beds separated by soft silty sandstone and shale beds, whereas the Navajo is dominantly buff to white, remains massive and tangentially cross-bedded to its vanishing edge, and does not contain silt or shale. Again, the Wingate varies only moderately in thickness over much of its area of occurrence and does not show a single definite trend of change, whereas the Navajo increases steadily from a thin edge in the northeast toward the southwest until a thickness four or five times that of the known maximum of the Wingate is attained. A fourth item is that in the marginal areas the Wingate sandstone is suggestive of certain Chinle sandstones and the Kayenta formation is at places strongly reminiscent in color and constitution of certain facies of the Chinle formation, whereas the Navajo sandstone, on the other hand, is very strikingly imitated at many places by the light-colored facies of the Entrada sandstone and is wholly unlike any known facies of the Chinle. It therefore seems to the writers that, with the whole area of distribution of the formations taken into account, the Wingate and Kayenta formations are more closely related to the Chinle formation, and the Navajo is more closely related to the overlying Upper Jurassic. If the suggestion made elsewhere in this paper that the Nugget sandstone of the central Wasatch region is equivalent to the Navajo sandstone is true, the reported occurrence of *Trigonia* near the base of the Nugget would definitely place the Navajo in the Jurassic. Mathews [44] considered the Nugget to be Lower Jurassic and possibly lower Middle Jurassic, but the known distribution of Lower and Middle Jurassic marine waters on the American continent [45] makes it very unlikely that the Nugget contains any Lower Jurassic deposits.

Although the Wingate and Kayenta are apparently more closely related to the Chinle and the Navajo is more closely related to the overlying Jurassic, an age assignment on this basis is unsatisfactory. At present no one can with assurance exclude the possibility that the thick western Navajo and the thinner eastern Wingate and Kayenta are more or less contemporaneous deposits derived from different sources of material and representing somewhat though not greatly different conditions of deposition; that the material from the west with the passage of time extended farther and farther eastward into territory where originally the eastern material prevailed and partly covered it. To the writers this thesis seems on the available evidence unlikely to prove true, but it must be considered.

The lack of wide-spread, definitely marked unconformities between the Chinle formation and the Wingate sandstone, between the Kayenta formation and its two associates, and even between the Navajo sandstone and the Carmel formation, with its definite incoming of marine over nonmarine deposits, might lead to the assumption that sedimentation was continuous from the Upper Triassic into the Upper Jurassic and that conditions were extraordinarily stable during that long interval. There seem to be no decisive reasons, at least in theory, why such stability might not have prevailed and the accumulation of sediments might not have proceeded without important interruption from Triassic well into Jurassic time. In this case it would be nearly profitless to attempt to define any sharp planes of separation. It seems more probable, however, that no such stability existed, and that there were at least some breaks of noteworthy length which have not yet been located. In the past it has seemed to most geologists that the base of the Wingate sandstone is a persistent unconformity. In part this idea has been based on erroneous correlations and on the assumptions that the †La Plata group in Utah and Arizona and the †La Plata sandstone in Colorado are the same and that the unquestioned unconformity beneath the latter must extend westward, even though not everywhere obvious. In part it has been based on local but clean-cut unconformities (pl. 5, *B*) and on local sharp change in lithology at the base of the massive Wingate, though over the greater part of the Wingate area no sharp boundary can be seen, and in places even a thick zone of sediments is subject to dispute. The writers doubt that the base of the Wingate marks an important hiatus.

The identification by Eastman, Shimer, and Jackson [46] of possible early Jurassic fish, crustaceans, and an ammonite in Walcott's collections from Kanab, Utah, has led a number of investigators, including the writers, to examine the locality for further light on the matter, for there seemed to be offered there a chance to date a relatively early horizon. Little doubt remains now, as stated by Camp,[47] that the horizon is in the Triassic Chinle formation and the fossils all fresh-water species. The one genus of fishes definitely recognized occurs through a long range, and the crustaceans have little value for age determination. The reported ammonite, if real, was surely an accidental addition to the collection, perhaps in the 20 years or more during which it awaited examination. The record has little bearing on the present discussion.

Whatever may be the ultimate disposition of the Wingate sandstone, Kayenta formation, and Navajo sandstone, absolutely conclusive evidence as to their relationship to one another and to the enclosing formations is still lacking. In practice it is convenient to

[44] Mathews, A. A. L., Mesozoic stratigraphy of the central Wasatch Mountains: Oberlin Coll. Lab. Bull., new ser., no. 1, p. 42, 1931.

[45] Crickmay, C. H., Jurassic history of North America—its bearing on the development of continental structure: Am. Philos. Soc. Proc., vol. 70, no. 1, pp. 22–39, 80–84, 1931.

[46] Eastman, C. R., Shimer, H. V., and Jackson, R. T., in Cross, Whitman, The Triassic portion of the Shinarump group, Powell: Jour. Geology, vol. 16, p. 107, 1908. Cross, Whitman, and Howe, Ernest, Red beds of southwestern Colorado and their correlation: Geol. Soc. America Bull., vol. 16, p. 486, 1905.

[47] Camp, C. L., A study of the phytosaurs: California Univ. Mem., vol. 10, p. 12, 1930.

group them together as the Glen Canyon group, particularly in northern Arizona and southeastern Utah. For this group it seems the most logical course to maintain the more or less noncommittal age assignment of Jurassic (?), which has been used in several recent publications, though the Wingate and Kayenta formations may prove to be Triassic and the Navajo sandstone may prove to be Jurassic.

SAN RAFAEL GROUP

The formations of the San Rafael group have almost always been assigned to the Jurassic, both in the older and in the newer literature. The exceptions are so few that they may well be ignored. This agreement is due in large part to the presence in the group of the two fossiliferous marine units, the Carmel and Curtis formations, though in much of the literature no attempt was made to distinguish them. The fossils of the Carmel formation place it in the early Upper Jurassic (Callovian), and the fossils of the Curtis place it just below the middle of the Upper Jurassic (mainly Argovian). The Entrada sandstone can be assigned only as between them, and the Summerville only as a little later, perhaps late in Argovian time. The known distribution of Jurassic seas in North America, recently summarized by Crickmay,[48] shows that the waters withdrew from the interior region at about the end of the Argovian and that they did not return during the remaining portion of Jurassic time—the Kimmeridgian, Portlandian, and Tithonian of the European sequence.

MORRISON FORMATION

The age of the Morrison formation has for many years been a topic for debate, and the literature bearing on it has become extensive. Mook [49] in 1916 listed over 200 papers describing or discussing the formation, not including those of purely descriptive paleontology, and a considerable number have been added since 1916. In the earlier papers the general opinion was very strongly inclined toward an assignment to the late Jurassic, an opinion based in large part on comparisons of the dinosaur fauna with that of the British Wealden, then considered Jurassic. Somewhat later a few dissenting voices were heard suggesting that both Jurassic and Cretaceous deposits are included in the Morrison and a few suggesting that the Morrison should be placed entirely in the Cretaceous. The reasons for these newer assignments were varied and not always consistent with one another. The division of opinion, however, has continued, and in fairly recent writings may be found age assignments that include Jurassic, Jurassic(?), Cretaceous(?), Lower Cretaceous, and Upper Cretaceous.

It is necessary in considering the age of the Morrison to go farther afield than in considering that of the Glen Canyon group or the San Rafael group, for the Morrison is widespread, and no single region can supply sufficient evidence. Indeed, it is desirable to consider certain deposits in Europe and Africa as well as those of North America. Several summary discussions are available that deal with the matter in a comprehensive fashion. A symposium [50] held by the Geological Society of America at its meeting in 1914 affords a view of opinions then current; Mook [51] in 1916 brought together a detailed account of the history of opinion and much descriptive material; Schuchert [52] in 1918 again reviewed the whole matter, particularly as related to the age of the African Tendaguru deposits; Lee [53] in 1918 attempted a general discussion of the physical evidence; and Simpson [54] in 1926 reviewed the paleontologic data then available. It seems to the writers an opportune time to consider again very briefly the grounds advanced in the past for age assignments of the Morrison formation, to review the more recent contributions to the discussion, and to attempt an estimate of the present status of the problem.

The extreme limits of age possible for the Morrison are perhaps best fixed by the youngest marine formation beneath it and the oldest marine formation above it. As the interfingering Curtis and Summerville formations in the south and the Sundance formation in the north immediately underlie it, the Morrison cannot be older than late Argovian (middle Upper Jurassic). As the Purgatoire formation directly overlies it in southeastern Colorado [55] it cannot be younger than the earlier part of the Washita group, or Albian (late Lower Cretaceous). If the assignment of the flora of the Lakota sandstone to the Barremian [56] is accepted, a much lower limit in the Cretaceous than Albian is set, for the Lakota directly overlies the Morrison in the Black Hills region. The former assignment of the flora of the Kootenai formation to the Neocomian-Barremian [57] left even less of the Lower Cretaceous to contain the Morrison, for the Kootenai is recognized above a somewhat doubtful Morrison formation in southern Montana. Later assignments of the Kootenai, however, make it of the same age as the Lakota sandstone [58] or at most only a little older.[59] Whether the plants or marine invertebrates are used

[48] Crickmay, C. H., op. cit.

[49] Mook, C. C., A study of the Morrison formation: New York Acad. Sci. Annals, vol. 27, pp. 39-191, 1916.

[50] Papers by H. F. Osborn, W. T. Lee, C. C. Mook, R. S. Lull, E. W. Berry, and T. W. Stanton: Geol. Soc. America Bull., vol. 26, pp. 295-348, 1915.

[51] Mook, C. C., A study of the Morrison formation: New York Acad. Sci. Annals, vol. 27, pp. 39-191, 1916.

[52] Schuchert, Charles, Age of the American Morrison and East African Tendaguru formations: Geol. Soc. America Bull., vol. 29, pp. 245-289, 1918.

[53] Lee, W. T., Early Mesozoic physiography of the southern Rocky Mountains: Smithsonian Misc. Coll., vol. 69, no. 4 (Pub. 2497), 1918.

[54] Simpson, G. G., The age of the Morrison formation: Am. Jour. Sci., 5th ser. vol. 12, pp. 198-216, 1926.

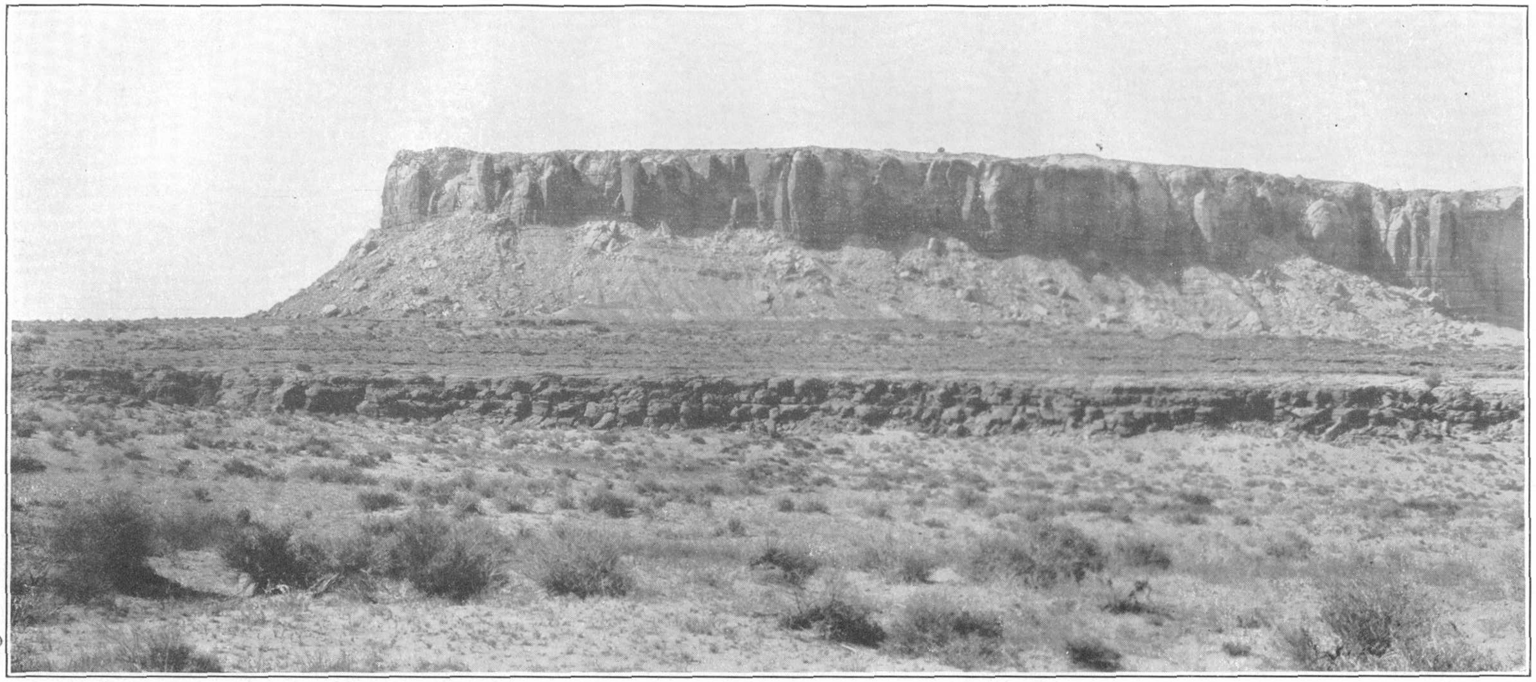
[55] Stanton, T. W., The Morrison formation and its relations with the Comanche series and the Dakota formation: Jour. Geology, vol. 13, pp. 657-667, 1905.

[56] Berry, E. W., The Kootenay and lower Blairmore floras: Canada Nat. Mus. Bull. 58 (Geol. ser., no. 50), p. 30, 1929.

[57] Berry, E. W., Lower Cretaceous floras of the world: Maryland Geol. Survey, Lower Cretaceous, pp. 118, 172, 1911.

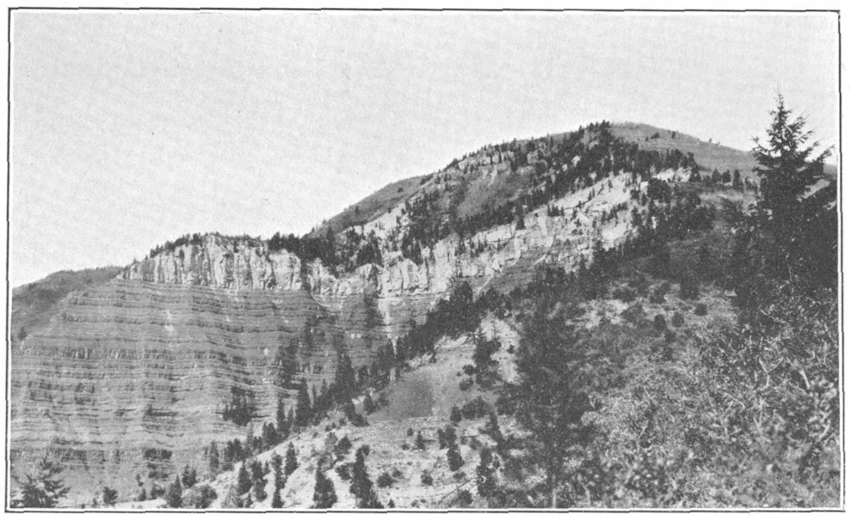
[58] Berry, E. W., Paleobotanic evidence of the age of the Morrison formation: Geol. Soc. America Bull., vol. 26, pp. 340-341, 1915.

[59] Berry, E. W., The Kootenay and lower Blairmore floras: Canada Nat. Mus. Bull. 58 (Geol. ser., no. 50), p. 30, 1929.



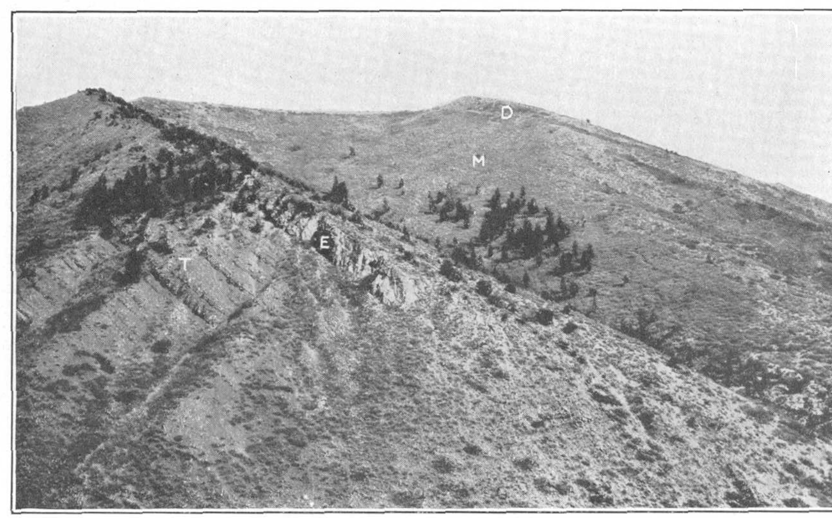
A. ENTRADA SANDSTONE AND THE LOWER PART OF THE MORRISON FORMATION NEAR THE MOUTH OF COTTONWOOD WASH, BLUFF, UTAH.

The low ledge in the foreground represents the complete thickness of the Entrada sandstone near the southern limit of the formation. The slope-forming beds and the massive ledge of sandstone ("Bluff sandstone") make up the lower part of the Morrison formation. Photograph by W. T. Lee.



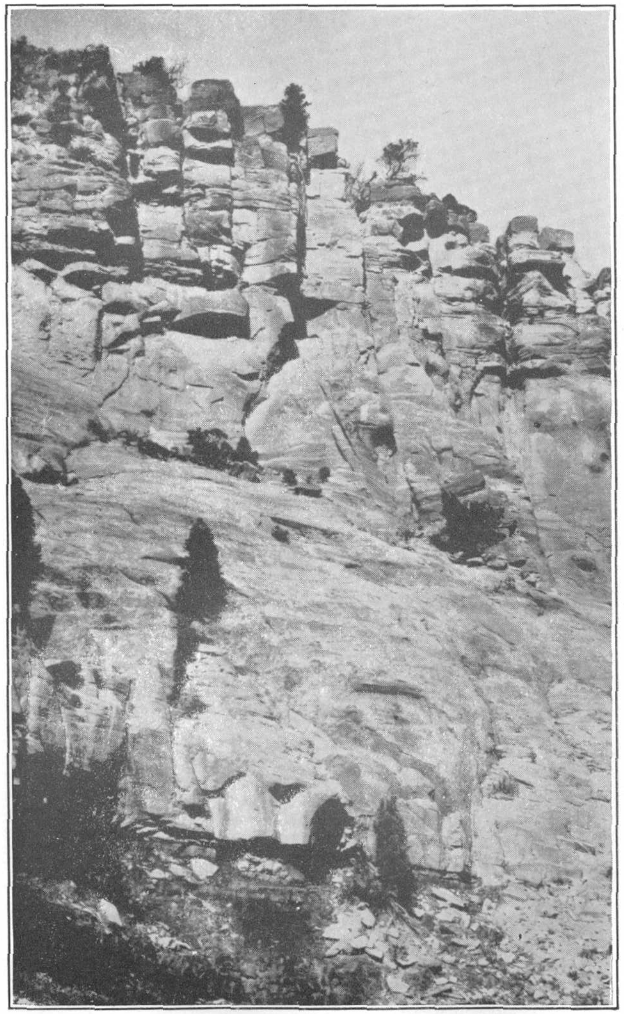
B. ENTRADA SANDSTONE 4 MILES EAST OF BASALT, COLO.

The Entrada sandstone rests upon red beds of Triassic age and is overlain by a thick limestone in the lower part of the Morrison formation. Photograph by J. B. Reeside, Jr.



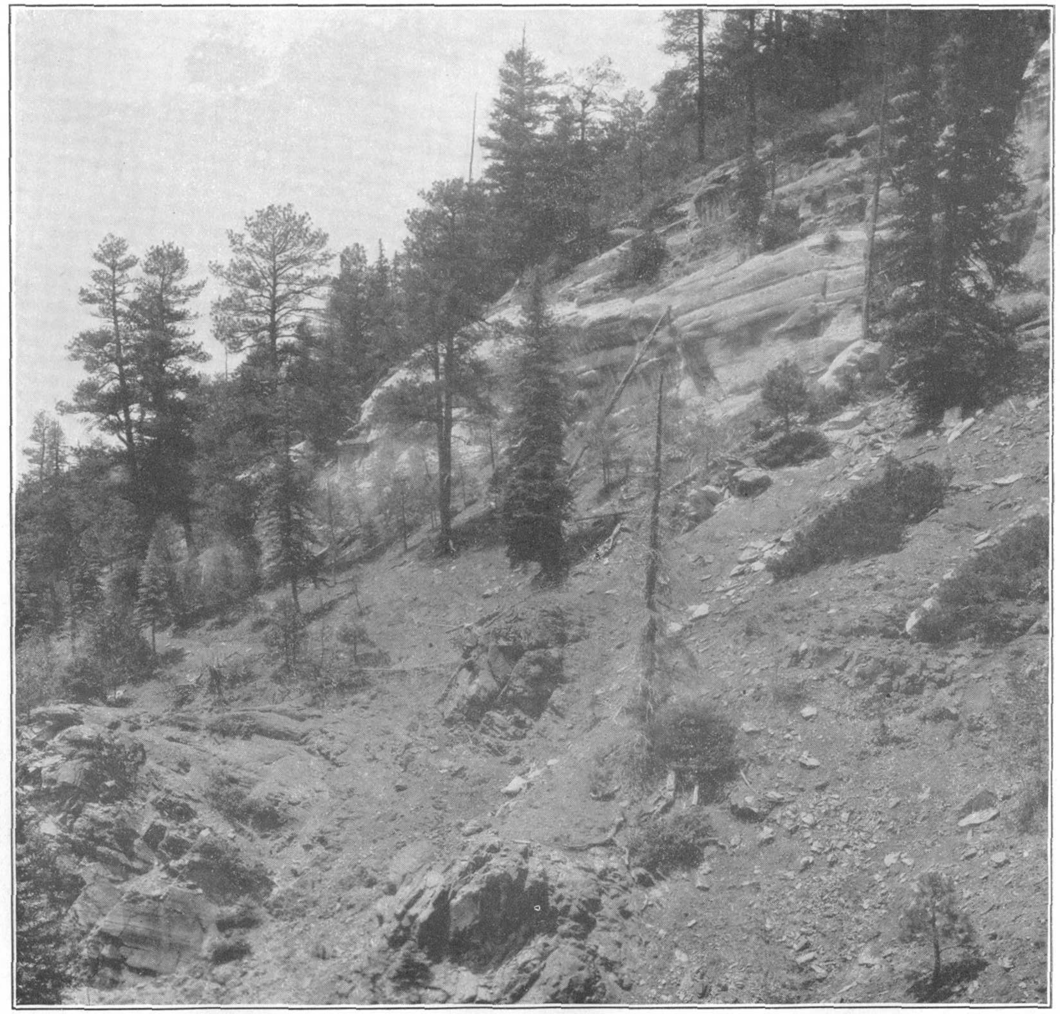
C. EXPOSURES IN SNOWMASS CANYON, COLO.

D, Dakota (?) sandstone; *M*, Morrison formation; *E*, Entrada sandstone; *T*, Triassic shales. A very thin representative of the Curtis formation, composed of shale and limestone, rests upon the Entrada sandstone and is overlain by a massive nonmarine limestone at the base of the Morrison formation. Photograph by J. B. Reeside, Jr.



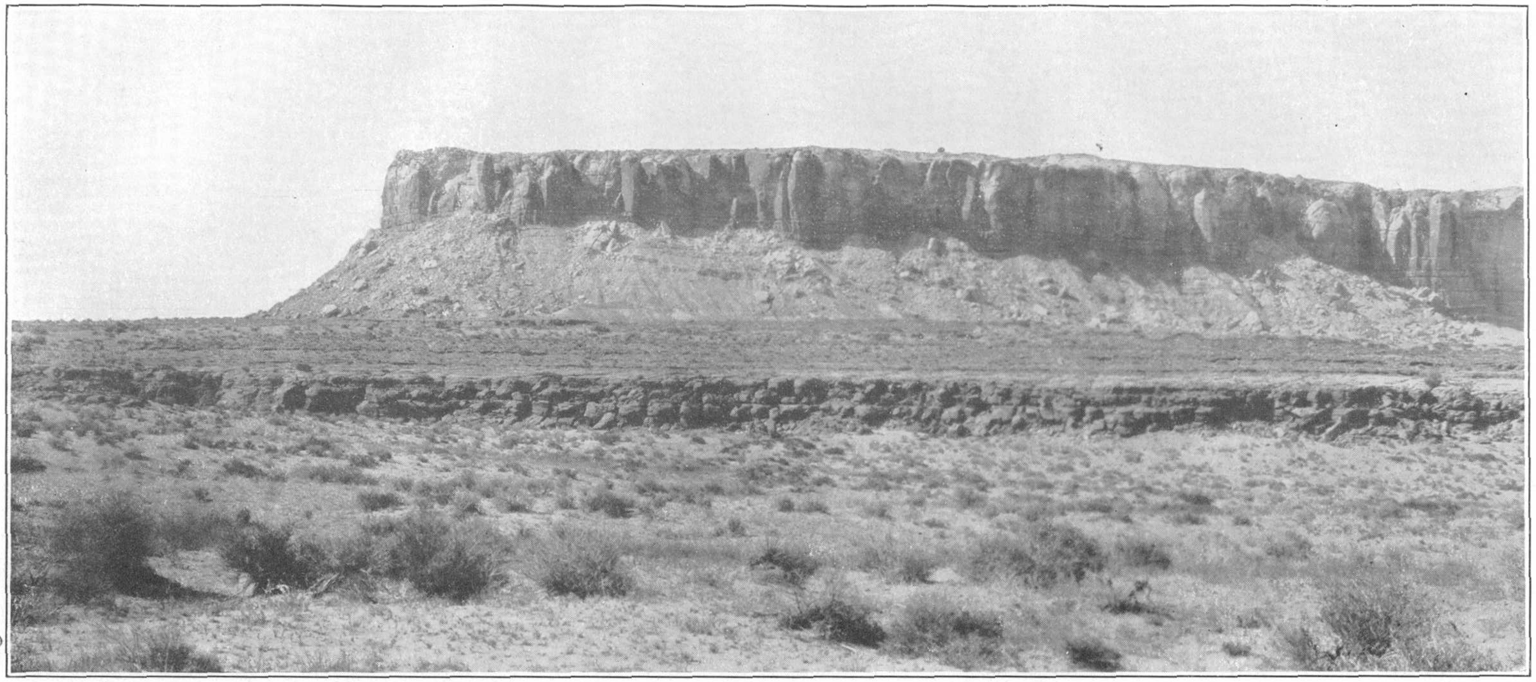
A. ENTRADA SANDSTONE AND CURTIS FORMATION NEAR THE COLORADO RIVER, 16 MILES ABOVE DOTSERO, COLO.

The massive Entrada sandstone rests upon beds of shale of Triassic age and is overlain by the blocky-weathering sandy marine limestone of the Curtis formation. Photograph by J. B. Reeside, Jr.



B. ENTRADA SANDSTONE RESTING ON SCHIST OF THE UNCOMPAHGRE FORMATION.

In the north bank of the Piedra River above the mouth of Wiminuche Creek, Colo. Photograph by Whitman Cross.



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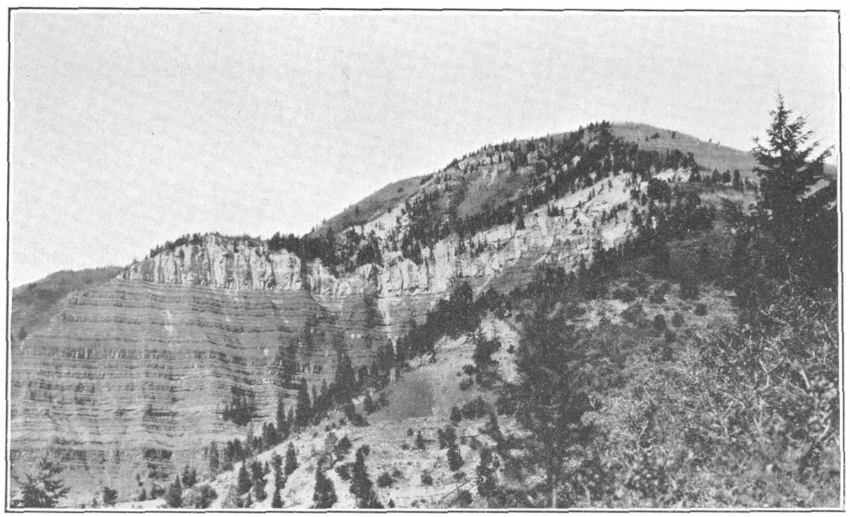

B. ENTRADA SANDSTONE 4 MILES EAST OF BASALT, COLO.

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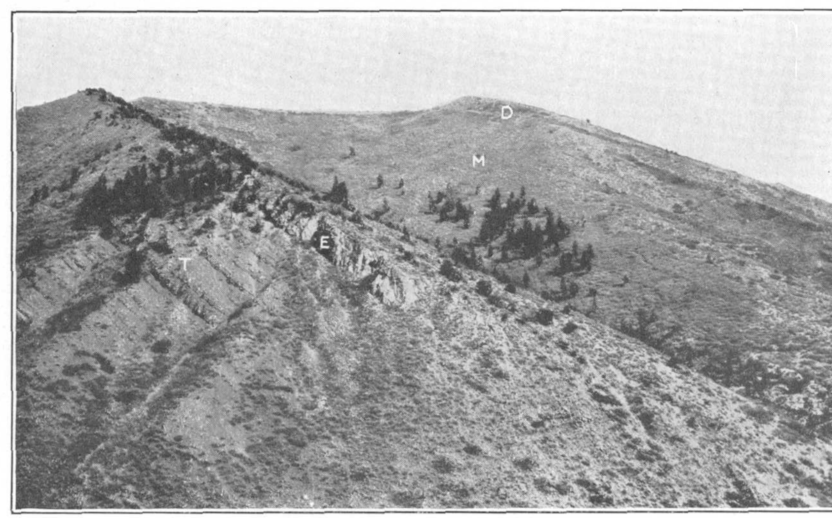

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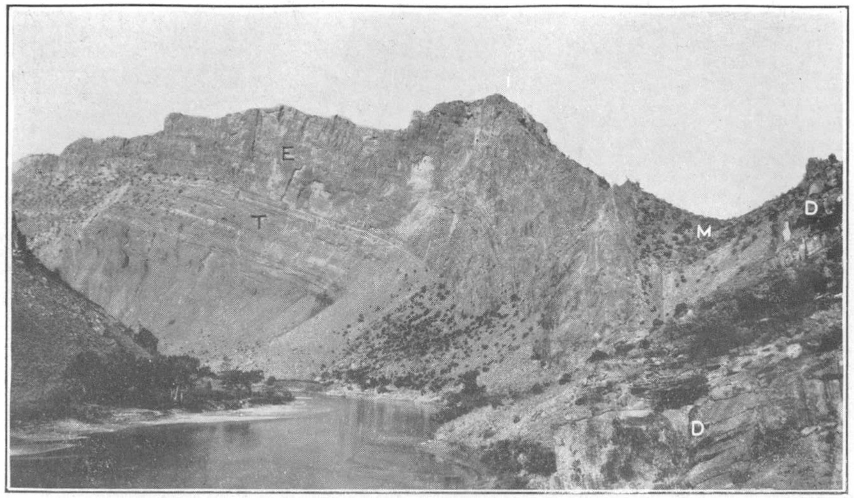
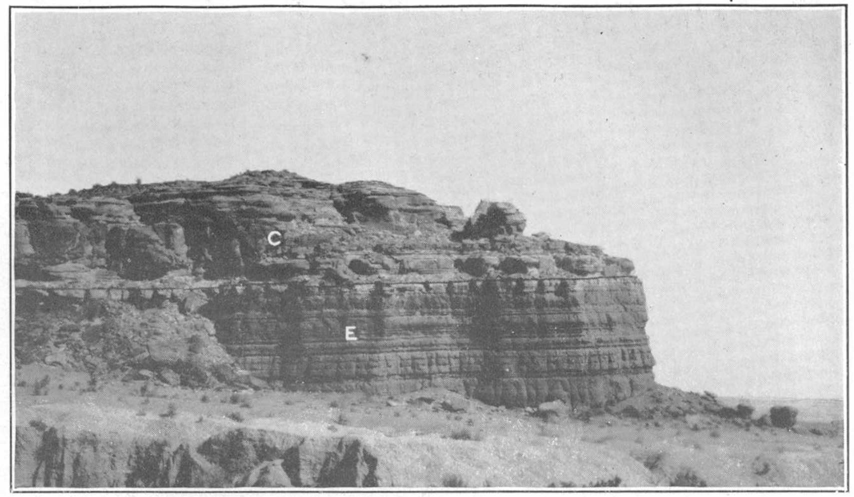


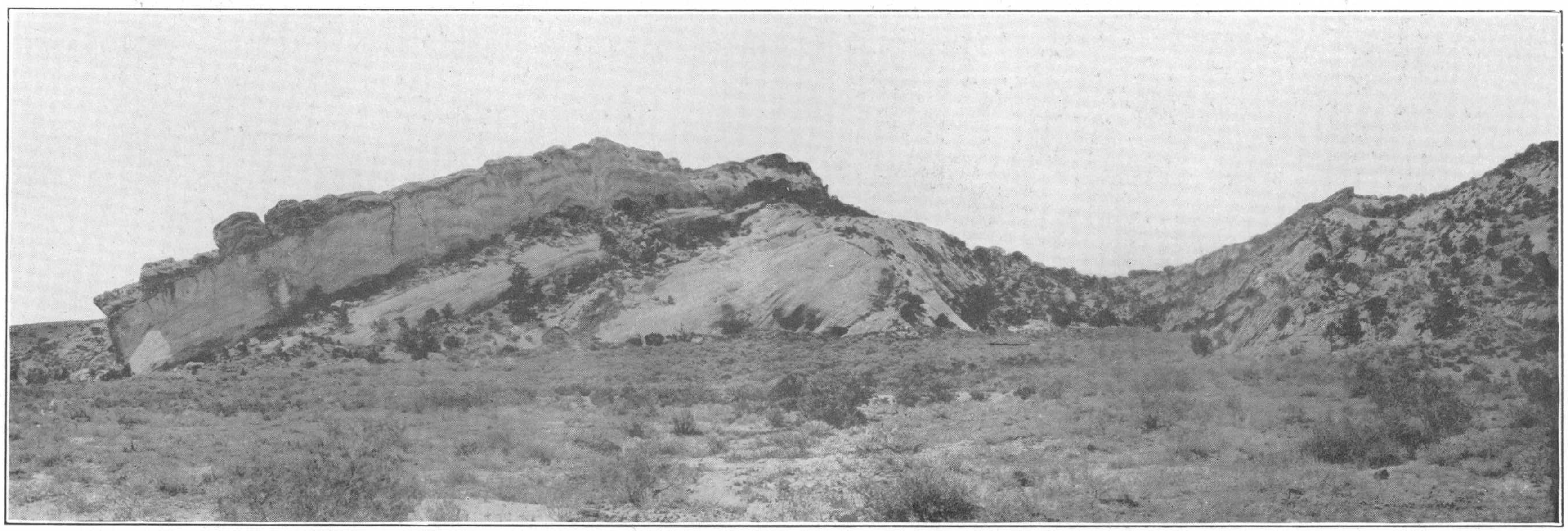
A. EXPOSURES IN FLAMING GORGE OF GREEN RIVER, UTAH.

T, Triassic shales; *E*, Navajo sandstone, Carmel formation, and Entrada sandstone; *M*, soft marine Jurassic shales and thin limestones of the Curtis formation and also the Morrison formation; *D*, Dakota (?) sandstone. Photograph by H. S. Gale.



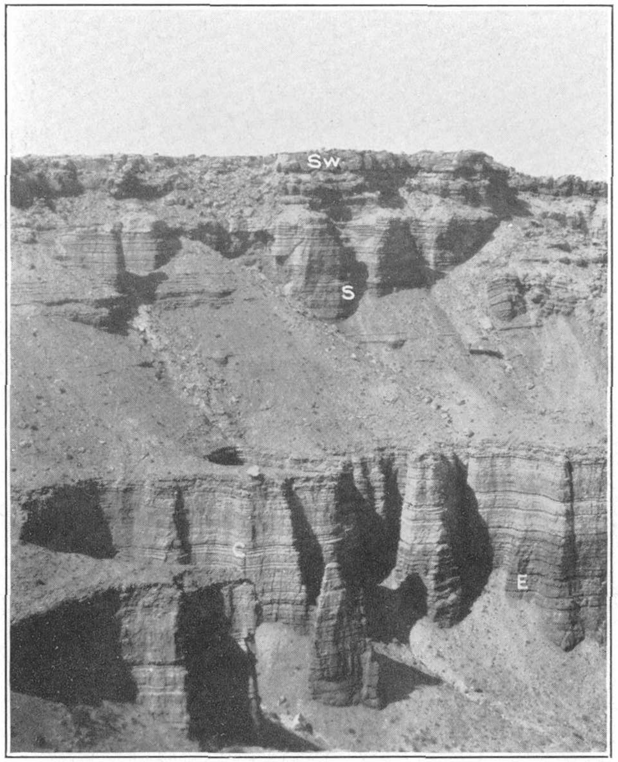
B. CLIFF AT MOUTH OF HORN SILVER GULCH, WEST FLANK OF SAN RAFAEL SWELL, UTAH.

Shows earthy facies of Entrada sandstone (*E*) overlain by sandstones at the base of the Curtis formation (*C*). Photograph by C. H. Dane.



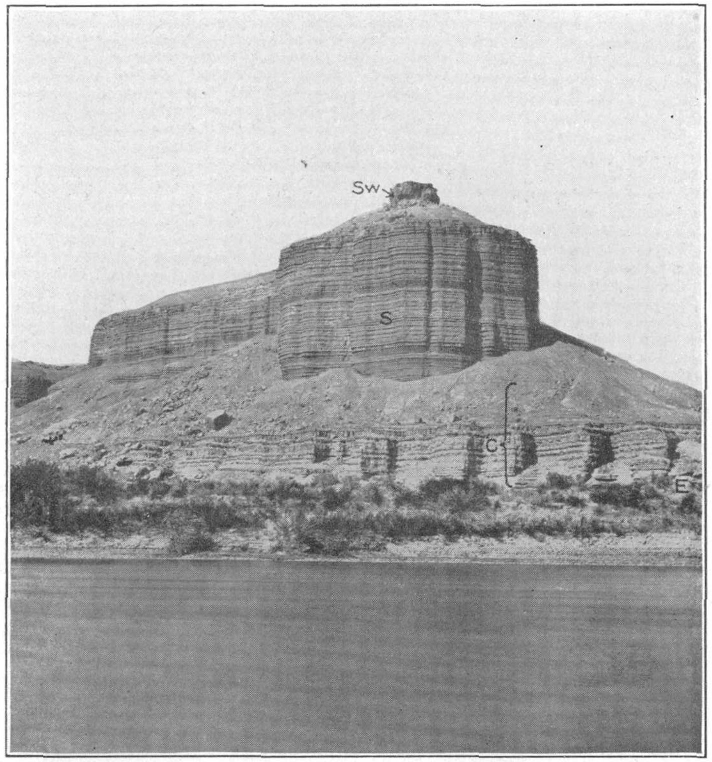
C. UNDIFFERENTIATED NAVAJO, CARMEL, AND ENTRADA FORMATIONS IN GAP OF SKULL CREEK.

Sec. 36, T. 4 N., R. 101 W., Colorado. Photograph by H. S. Gale.



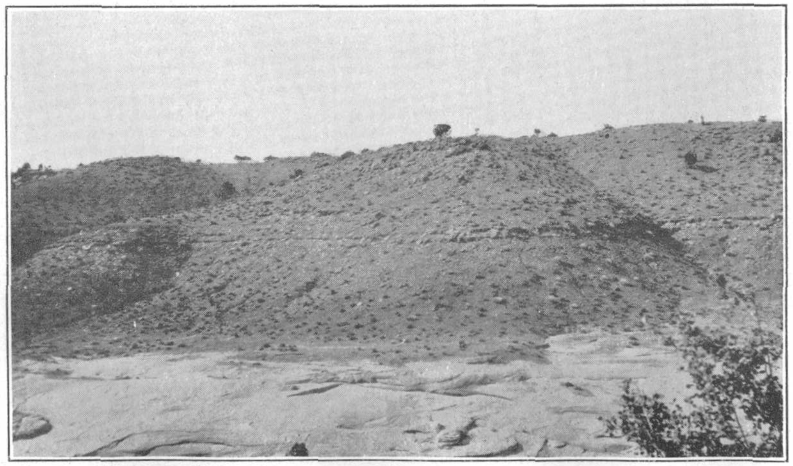
A. JURASSIC FORMATIONS EXPOSED IN THE NORTHWEST END OF BIG FLATTOP BUTTE, IN THE GREEN RIVER DESERT, UTAH.

Shows the similarity of the Entrada sandstone and the Curtis formation near the southeast margin of the Curtis and the thin regular bedding of the Summerville formation. *E*, Entrada sandstone; *C*, Curtis formation; *S*, Summerville formation; *Sw*, Salt Wash sandstone member of the Morrison formation. Photograph by A. A. Baker.



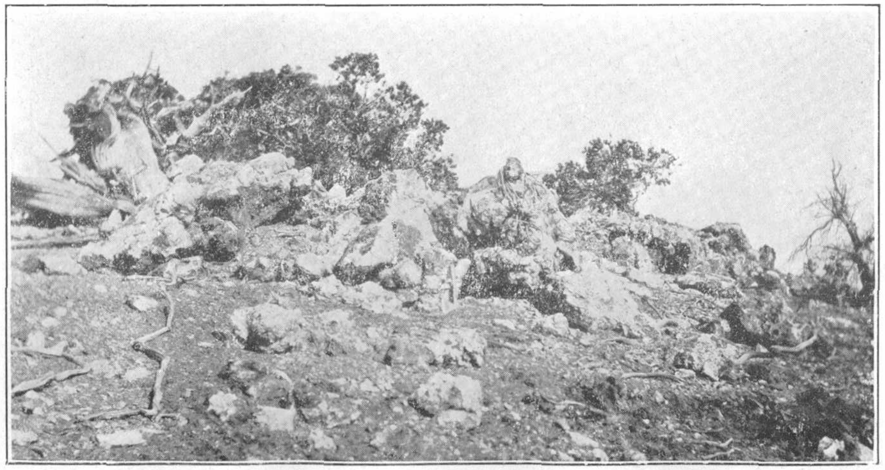
B. THIN REGULAR BEDDING IN THE SUMMERVILLE FORMATION IN DELLENBAUGH BUTTE, ON THE GREEN RIVER ABOUT 12 MILES SOUTHEAST OF GREEN RIVER, UTAH.

Shows the Entrada sandstone at the base of the cliff, the bedded character of the thin Curtis formation shortly before it wedges out east of Green River, and the thin regularly bedded Summerville formation. *E*, Entrada sandstone; *C*, Curtis formations; *S*, Summerville formation; *Sw*, Salt Wash member of the Morrison formation. Photograph by J. K. Hillers.



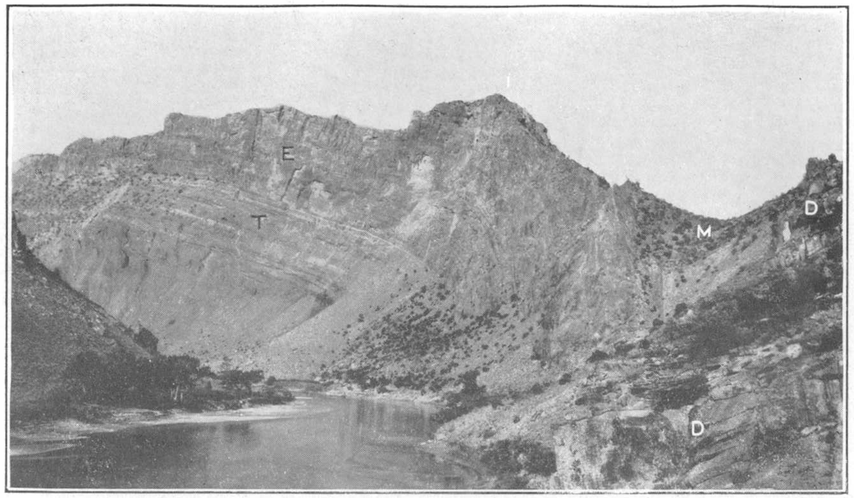
C. EXPOSURE OF SUMMERVILLE FORMATION 6 MILES SOUTHEAST OF CISCO, UTAH.

NE¼ sec. 12, T. 22 S., R. 24 E. White sandstone at the base of the picture is the Moab sandstone member of the Entrada sandstone. The sandstone at the top of the exposure is at or slightly above the base of the Morrison formation. Photograph by H. O. DeBeck.



D. MASSES OF CHERT WEATHERED FROM THE SUMMERVILLE FORMATION ON HATCH ROCK.

Sec. 1, T. 30 S., R. 22 E., Utah. Photograph by L. W. Clark.



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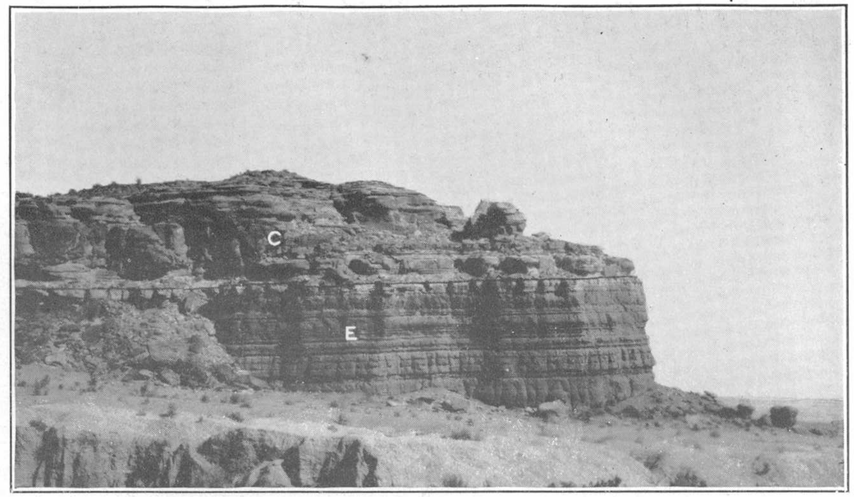

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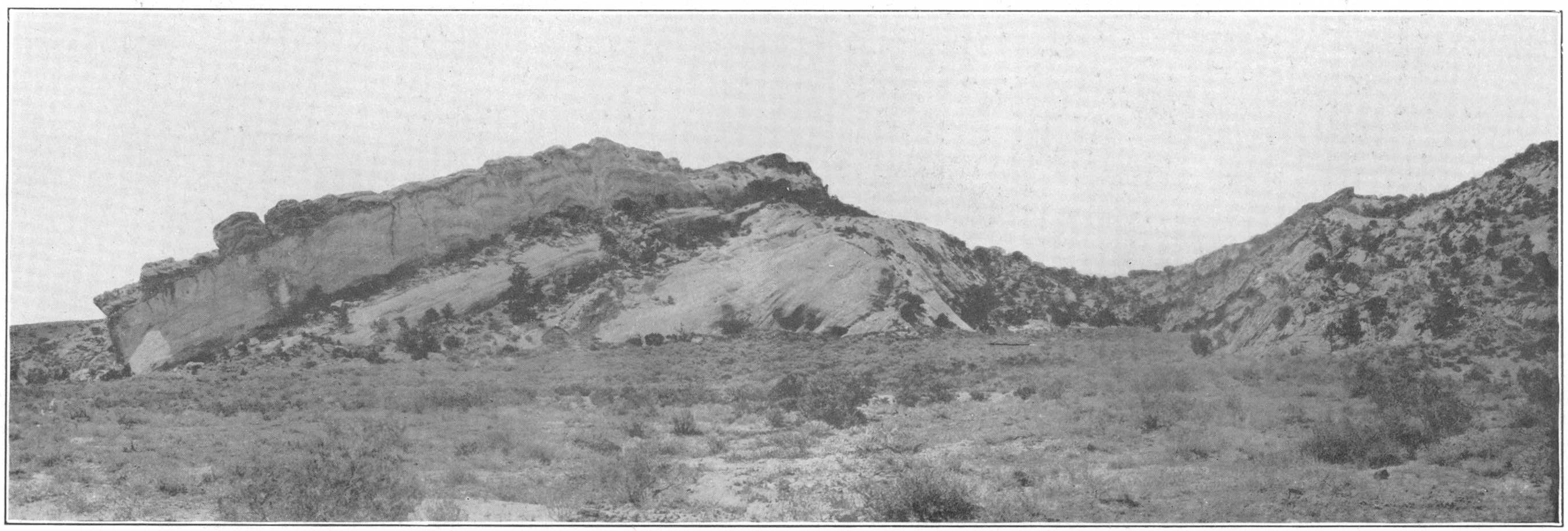

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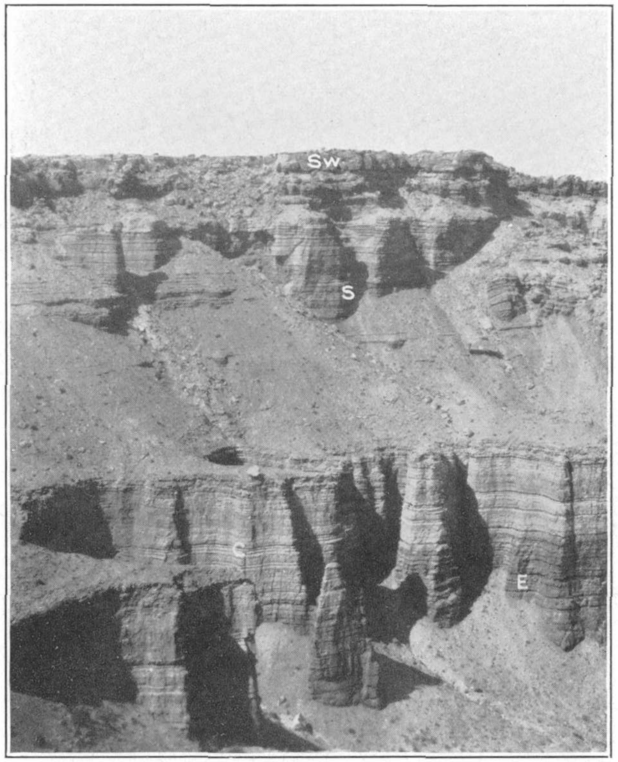

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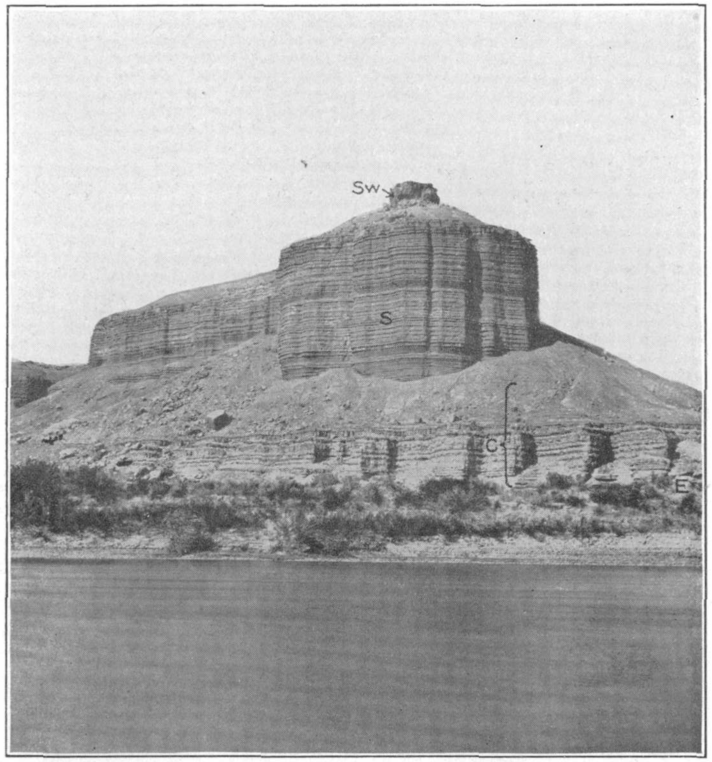

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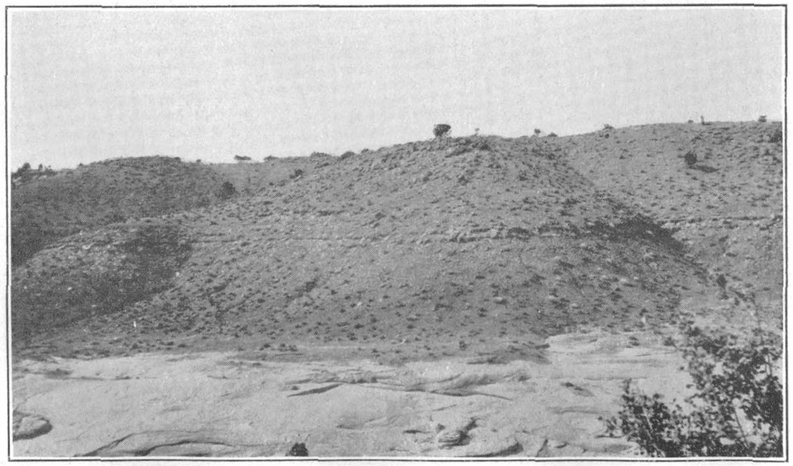

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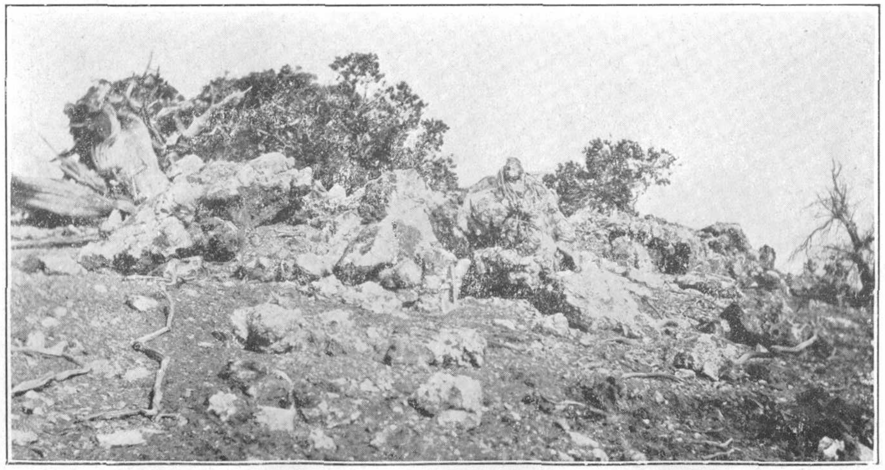

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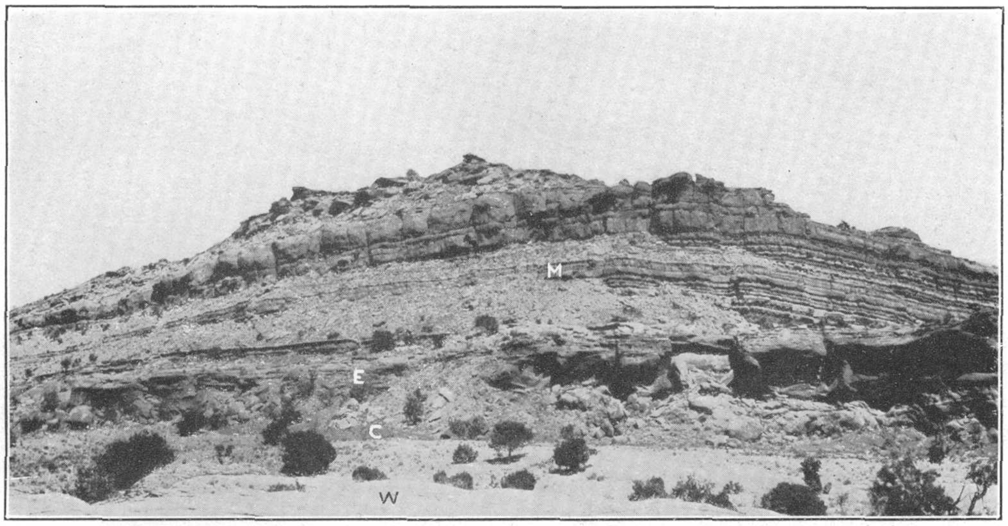
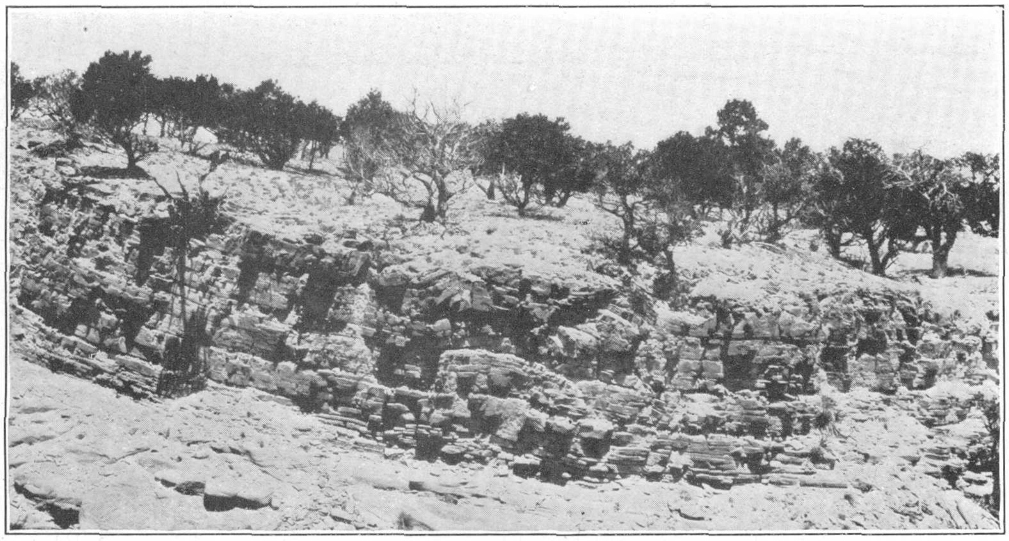


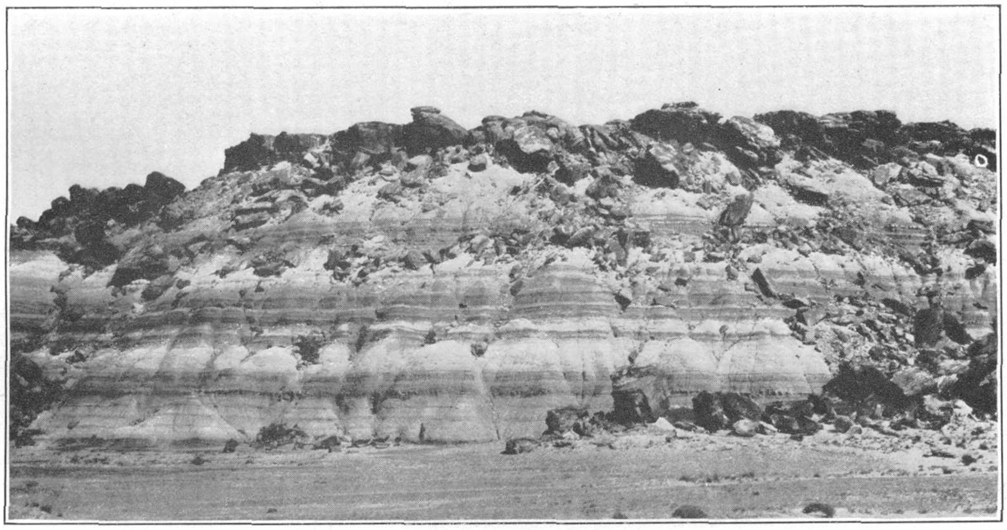
A. FORMATIONS OVERLYING THE WINGATE SANDSTONE AT BILTABITO, NEAR THE NORTHWEST CORNER OF NEW MEXICO.

Shows the thin units representing the Carmel formation and the Entrada sandstone near the southeast margin of these formations and the basal part of the Morrison formation. *W*, Wingate sandstone; *C*, Carmel formation; *E*, Entrada sandstone; *M*, Morrison formation. Photograph by A. A. Baker.



B. OUTCROP OF THE TODILTO LIMESTONE MEMBER OF THE MORRISON FORMATION ABOUT 4 MILES NORTH OF THE ATCHISON, TOPEKA & SANTA FE RAILWAY AT BLUEWATER, N. MEX.

Photograph by A. A. Baker.

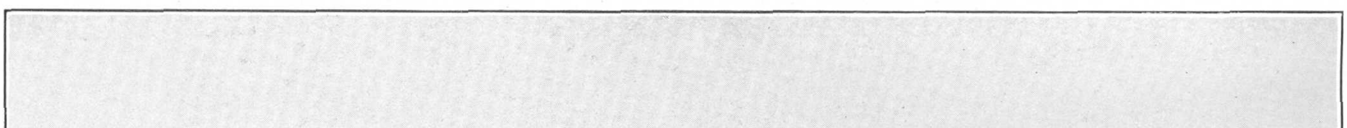


C. BANDED SHALE IN THE UPPER PART OF THE MORRISON FORMATION 13 MILES SOUTHWEST OF GREEN RIVER, UTAH.

Along the road from Green River to Hanksville. The ledge at the top of the slope is formed by a bed of siliceous sandstone near the top of the formation. Photograph by A. A. Baker.

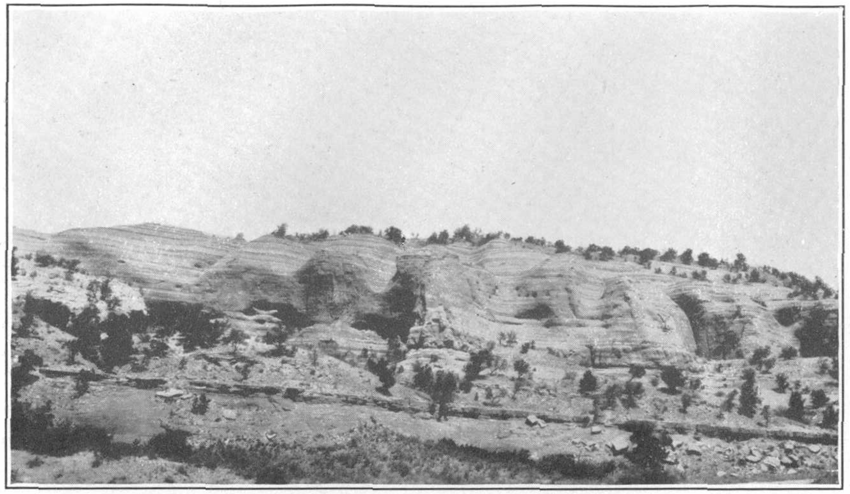
A. WINGATE SANDSTONE OVERLAIN BY GYPSUM AT THE BASE OF THE MORRISON FORMATION ON THE BANK OF THE GALLINA RIVER 30 MILES NORTHWEST OF ABIQUIU, N. MEX.

The wooded slope is Morrison shale. Photograph by N. H. Darton.



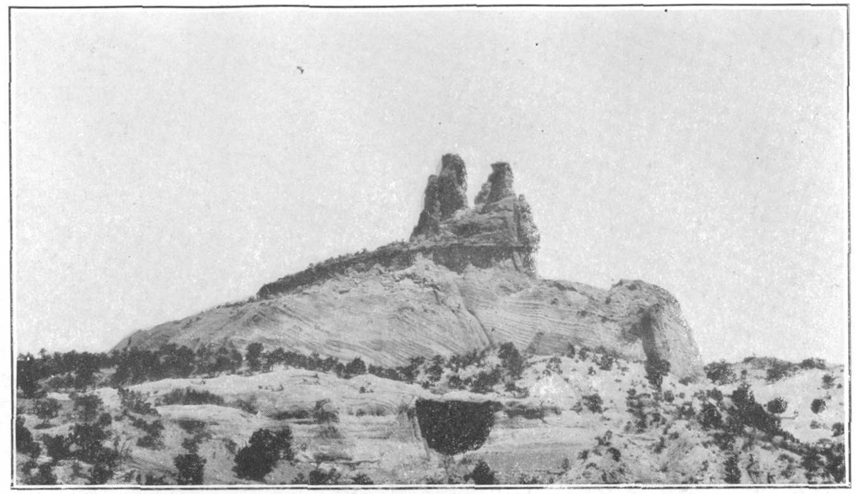
B. TODILTO LIMESTONE MEMBER OF THE MORRISON AND THE ASSOCIATED GYPSUM ALONG THE ATCHISON, TOPEKA & SANTA FE RAILWAY AT EL RITO, N. MEX.

Above the gypsum are sandy shales and sandstone of the Morrison formation. *T*, Todilto limestone member of the Morrison formation; *G*, gypsum overlying the Todilto limestone. Photograph by N. H. Darton.



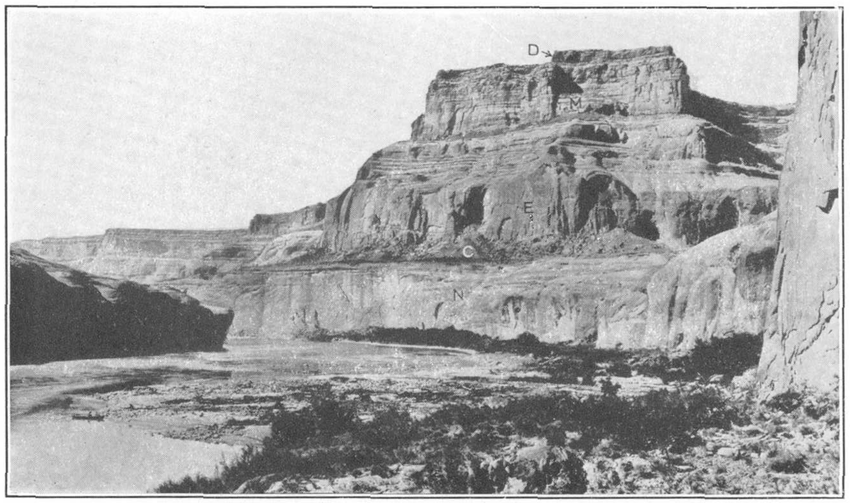
A. MORRISON FORMATION AT NAVAJO CHURCH, N. MEX.

Shows the banded sandstone in the lower part of the Morrison formation resting upon the Todilto limestone member, which overlies the Wingate sandstone. Photograph by A. A. Baker.



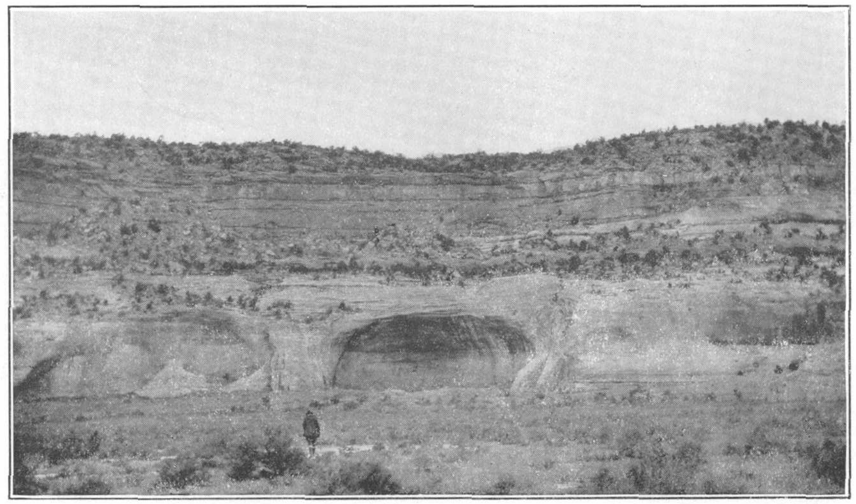
B. NAVAJO CHURCH, N. MEX.

Shows the cross-bedded sandstone in the upper part of the Morrison formation. Photograph by A. A. Baker.



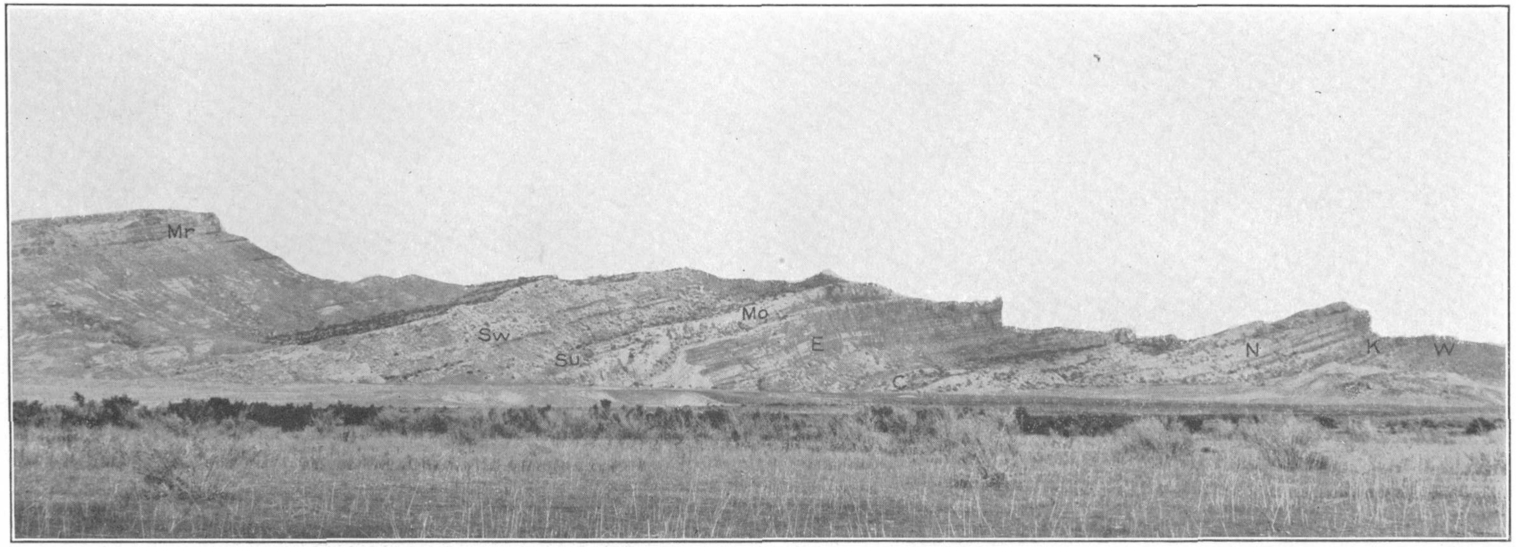
C. FORMATIONS EXPOSED ON THE COLORADO RIVER NORTHWEST OF NAVAJO MOUNTAIN, UTAH.

Shows the sandy character of the Morrison formation. *N*, Navajo sandstone; *C*, Carmel formation; *E*, Entrada sandstone; *M*, Morrison formation; *D*, Dakota (?) sandstone. Photograph by R. N. Allen.



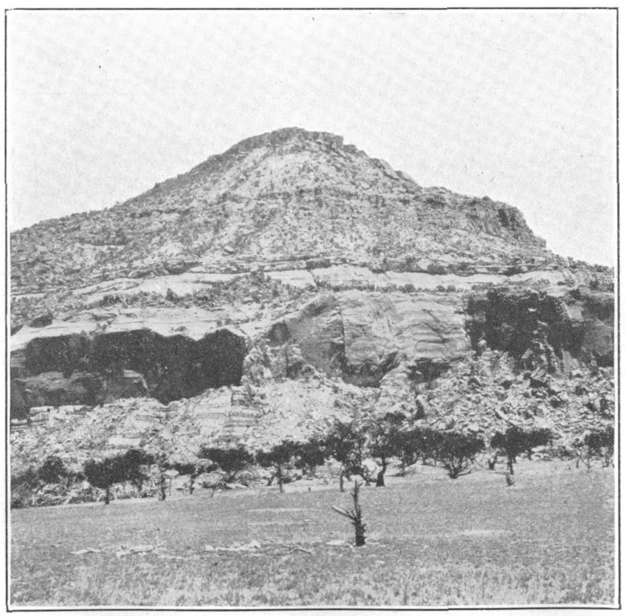
D. BEDDED SANDSTONES OF THE MORRISON FORMATION RESTING UPON THE MASSIVE WINGATE SANDSTONE NEAR LUPTON, ARIZ.

Photograph by W. T. Lee.



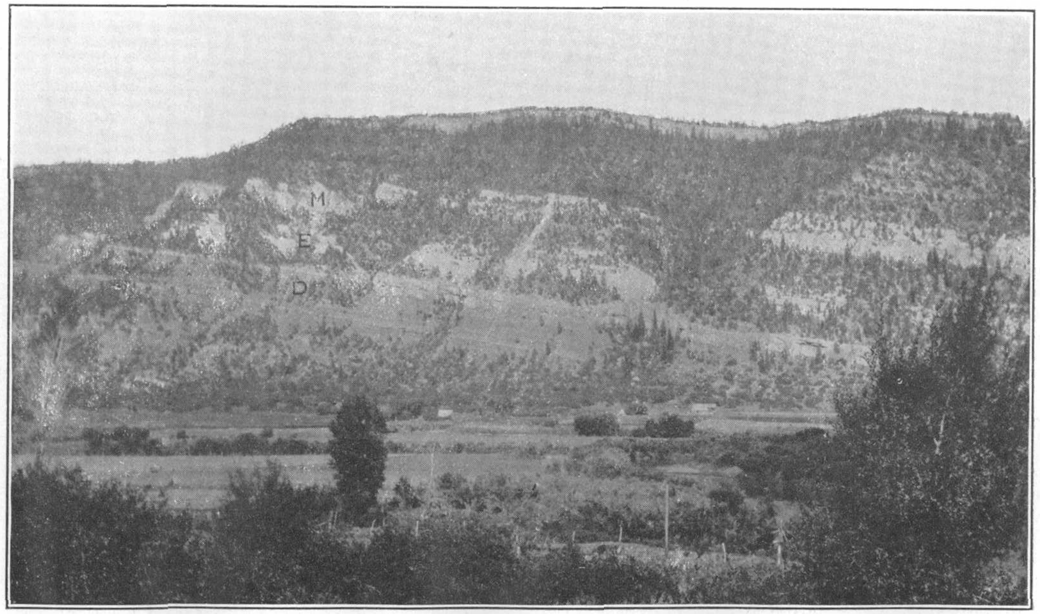
A. EAST WALL OF THE NORTH END OF SALT VALLEY ABOUT 7 MILES SOUTH-SOUTHWEST OF THOMPSON, UTAH.

The valley flat in the foreground is largely underlain by the Upper Cretaceous Mancos shale, dropped against the Jurassic formations of the valley wall by a large fault. *Mr*, Morrison formation; *Sw*, Salt Wash sandstone member of the Morrison; *Su*, Summerville formation; *E*, Entrada sandstone; *Mo*, Moab sandstone tongue of the Entrada; *C*, Carmel formation; *N*, Navajo sandstone; *K*, Kayenta formation; *W*, Wingate sandstone. Photograph by W. T. Lee.



B. MORRISON FORMATION OVERLAIN BY THE DAKOTA (?) SANDSTONE ABOUT 4 MILES NORTH OF THE ATCHISON, TOPEKA & SANTA FE RAILWAY AT BLUEWATER, N. MEX.

Shows the beds of massive sandstone in the lower part and the beds of shale in the upper part of the formation. Photograph by A. A. Baker.



C. ENTRADA SANDSTONE AND MORRISON FORMATION ON THE EAST WALL OF THE CANYON OF THE ANIMAS RIVER ABOVE DURANGO, COLO.

The Entrada sandstone rests upon the Dolores formation and is overlain by a thin discontinuous bed of limestone and sandstone beds in the Morrison formation. *D*, Dolores formation; *E*, Entrada sandstone; *M*, Morrison formation. Photograph by J. B. Reeside, Jr.

as a criterion, there is still available the post-Argovian part of the Upper Jurassic and an appreciable part of the Lower Cretaceous interval as a possible assignment for the Morrison.

It will be of interest to enumerate in generalized form the reasons given by various writers for the acceptance of an age assignment of the Morrison formation. Such a census has somewhat of a legalistic atmosphere, but it does offer a systematic basis for discussion. In addition, some of the reasons offered, entirely logical in their day, now seem like "straw men" set up to be knocked over. They are, however, needed to complete the story and are included. In the nature of the case—an effort to place a stratigraphic unit in a world-wide time scale—the paleontologic criteria must be the controlling factors. The more or less local physical criteria may add to or detract from the decisiveness of the interpretation adopted, but they can be of only secondary value.

The assignment of the Morrison to the Cretaceous, in entirety or in part, in the older literature has been based on the following criteria:

1. Assignment to the Cretaceous is more desirable because it places the physical break whose effects are recognized over the whole continent between two great time divisions rather than within one of them (S. F. Emmons, 1896).

2. The Morrison is said to be separated from the underlying beds by a profound unconformity which represents a long period of erosion; this erosion is especially shown by overlap on various older rocks down to the pre-Cambrian (W. T. Lee, 1915).

3. The Morrison is said to be essentially conformable with the overlying beds (W. T. Lee, 1915; C. C. Mook, 1916).

4. The Sundance sea was late Jurassic, and its withdrawal was effected by the final event of Jurassic time; the Morrison was the initial deposit when renewed sinking began slowly to outline the site of the Cretaceous marine invasion (W. T. Lee, 1915).

5. Where the Morrison is present the Comanche is absent, suggesting that these units may be equivalent (C. C. Mook, 1916).

6. The Morrison has been reported to pass directly into the Comanche by lateral change (W. T. Lee, 1903; N. H. Darton, 1904).

7. The Kootenai and Morrison may be two facies of the same period of sedimentation, one with plants, the other with land vertebrates (E. W. Berry, 1913; C. C. Mook, 1916).

8. The fauna of the Morrison is like that of the Arundel formation of Maryland, which has a Cretaceous flora (R. S. Lull, 1911; W. T. Lee, 1915; E. W. Berry, 1915; C. C. Mook, 1916).

9. The dinosaurs and other reptiles afford no evidence of age greater than Purbeck (latest Jurassic) and very little of age greater than Wealden (viewed as Cretaceous) (W. B. Scott, 1897, S. W. Williston, 1905; R. S. Lull, 1915; W. T. Lee, 1915).

10. The Morrison and the middle dinosaur zone at Tendaguru are related, and the latter is Cretaceous (R. S. Lull, 1915).

The assignment of the Morrison formation, in entirety or in part, to the Jurassic in the older literature has been based mainly on the following criteria:

11. The dinosaurs are like those of the European Jurassic, including beds as old as Callovian (early Upper Jurassic) but particularly the Wealden of England (then considered latest Jurassic) (E. D. Cope, 1884; O. C. Marsh, 1896; E. S. Riggs, 1901; J. B. Hatcher, 1903).

12. The mammalian fauna is like that of the Purbeck beds (latest Jurassic) of England (H. F. Osborn, 1888; F. B. Loomis, 1901).

13. The cycadeoid flora is like that of the Jurassic (L. F. Ward, 1900; J. B. Hatcher, 1903).

The definite assignment to both Jurassic and Cretaceous has been made (J. B. Hatcher, 1903; S. W. Williston via W. B. Scott, 1907; W. B. Scott, 1907; H. F. Osborn, 1915; C. C. Mook, 1916) principally on the thesis that it is entirely possible and would resolve the seeming conflict between various lines of evidence.

With respect to items 1 and 2, in the experience of the writers and as a matter of common record by others it is much more often the case, if the whole area of the Morrison is considered, that only an arbitrary lower boundary for the Morrison can be determined than that a satisfactory sharply defined boundary is discoverable. It is certainly true that at some localities an unconformity is present at what seems the most logical place on lithologic grounds to draw the basal boundary of the Morrison. In the San Rafael Swell, Utah, there is local angular discordance, particularly where the basal Morrison beds are gypsum. At other localities in the Swell, however, there is only erosional discordance, and at still others no sign of any discordance whatever. Within the underlying San Rafael group there are, furthermore, unconformities as striking as any at the base of the Morrison, and within the Morrison itself there are marked irregularities. The writers believe that the local angularity shown in the San Rafael Swell is more probably depositional and not due to folding and erosion, though there might conceivably have been slightly irregular uplift of the area of marine deposition, resulting in minor shallow folds. The truncation of these folds would not have involved much time. It is to be feared that, in a series of beds so variable as the marine Jurassic deposits and the Morrison formation, local unconformities at somewhat different horizons may be taken at distant localities as the same and regarded as representing a widespread and profound unconformity. The present writers are wholly unconvinced of a long pre-Morrison erosion interval and therefore of a widespread unconformity at the base of the Morrison formation. The existence of such an unconformity, as assumed in the older literature, seems to the writers a purely hypothetical matter. The field evidence for it has never been brought forward. The overlap of the Morrison on older beds down to the pre-Cambrian is in no sense a valid argument for unconformity between the marine Jurassic deposits and the Morrison. As Simpson [60] has pointed out, and others before him, the Sundance in Wyoming and the Entrada sandstone in northern and central

[60] Simpson, G. G., The age of the Morrison formation: Am. Jour. Sci., 5th ser., vol. 12, p. 201, 1926.

Colorado rest upon a persistent and notable erosion surface, and that observed at the base of the Morrison where the marine Jurassic beds are absent is perhaps more logically viewed as the same surface.

With respect to item 3, that the Morrison formation is conformable with the overlying beds (Lee said in 1915 "obviously conformable"), even a casual survey of the literature of the western interior region will show how few field geologists have noted this conformity and how many have found reason to recognize an unconformity at this horizon. Over large areas the Morrison is succeeded sharply by a conglomerate or conglomeratic sandstone which is associated with fossils wholly different from those of the Morrison and which is the basal unit of the next overlying formation (Dakota, Cloverly, etc.). Lee also in his latest papers [61] recognized a post-Morrison unconformity but considered it not to represent a long time. In the experience of the writers the top of the Morrison is sharply defined at many localities, in contrast with the relatively few at which the base is sharp. This, taken with a difference in fossils, seems to the writers to offer far better grounds for postulating a break than any pertaining to the basal boundary.

With respect to item 4, it has been a common error to underestimate the part of Jurassic time remaining after the completion of Sundance sedimentation and the withdrawal of the Sundance sea. The succeeding Morrison formation when viewed in its whole extent gives no physical evidence of a long lapse of time between Sundance sedimentation and Morrison sedimentation, and its fauna is said by all observers to be a uniform assemblage. There is no recorded evidence, so far as the writers know, of zones of markedly different age in the Morrison and therefore of accumulation at markedly different times at different places within its known area of distribution.

With respect to items 5 and 6, which are closely related, the oldest Comanchean rocks of Texas (Trinity group) are believed to be of late Aptian age (medial Lower Cretaceous), on the basis of their marine fossils; and they rest on various older rocks. Beds equivalent in age to the medial part of the Comanche epoch—that is, medial Albian—rest upon the Morrison in southeastern Colorado. It is hence not true that the units are mutually exclusive in distribution. Even if they were mutually exclusive it would indicate nothing about their relative ages. Lee [62] stated that the Morrison and Comanche beds grade laterally into one another in southeastern Colorado and the adjacent parts of Oklahoma and New Mexico, but Stanton [63] showed that this interpretation is erroneous and that the two formations are everywhere in the area sharply separated, with the Morrison below and the Comanche beds (Purgatoire) above.

With respect to item 7, the writers have been unable to find definite evidence that the Kootenai and Morrison are contemporaneous formations of differing facies. On the other hand, there do exist some data tending to show that they are not contemporaneous. The Kootenai formation in southern Montana [64] lies with apparent conformity upon beds that have been referred to the Morrison formation. This is rather weak evidence, for it remains to be determined whether the underlying formation is really Morrison and, if so, whether the conformity is real. The fresh-water invertebrate faunas,[65] though small and as a whole difficult to use in the present state of knowledge, have nothing in common. Insofar as they have a value, the species of the Kootenai are much more like those of the succeeding Upper Cretaceous than those of the Morrison are. No trace of the Morrison vertebrate fauna is known in the Kootenai, nor of the Kootenai plants in the Morrison. It seems to the writers that the amount of field work done on the Kootenai and Morrison formations to date would surely have turned up something common to these two nonmarine units if they were merely contemporaneous deposits of differing facies and not units of distinctly differing ages.

With respect to item 8, this has been the keystone of the whole structure of argument for a Cretaceous age assignment of the Morrison. There is general agreement that the Potomac group is Cretaceous, and the reptile-bearing Arundel formation in the midst of it was long correlated with the Morrison. Lull [66] in 1911 expressed the general opinion then current that the correlation on the basis of the reptilian fossils is absolute. However, the restudy of the Arundel fauna by Gilmore [67] has shown that it has only one doubtful genus in common with the Morrison fauna; that it has, in fact, much closer relations with Upper Cretaceous faunas than with that of the Morrison. With this conclusion Simpson [68] agrees and notes further that Matthew and Brown [69] confirm it in their study of the carnivorous dinosaurs. The Cretaceous age of the Arundel beds, therefore, does not prove a Cretaceous age for the Morrison. Indeed the comparison of the fauna of the Morrison with that of the Arundel serves only to show a considerably greater age for the Morri-

[61] Lee, W. T., Continuity of some oil-bearing sands of Colorado and Wyoming: U. S. Geol. Survey Bull. 751, pp. 1–22, 1923; Correlation of geologic formations between east-central Colorado, central Wyoming, and southern Montana: U. S. Geol. Survey Prof. Paper 149, pp. 17–20, 1927.

[62] Lee, W. T., Age of the *Atlantosaurus* beds [abstract]: Science, vol. 17, pp. 292, 293, 1903.

[63] Stanton, T. W., The Morrison formation and its relations with the Comanche series and the Dakota formation: Jour. Geology, vol. 13, pp. 657–669, 1905.

[64] Fisher, C. A., Geology of the Great Falls coal field, Mont.: U. S. Geol. Survey Bull. 356, p. 22, 1909.

[65] Stanton, T. W., Invertebrate fauna of the Morrison formation: Geol. Soc. America Bull., vol. 26, pp. 343–348, 1915.

[66] Lull, R. S., The Reptilia of the Arundel formation: Maryland Geol. Survey, Lower Cretaceous, p. 178, 1911.

[67] Gilmore, C. W., The fauna of the Arundel formation of Maryland: U. S. Nat. Mus. Proc., vol. 59 (pub. 2389), pp. 589–594, 1921.

[68] Simpson, G. G., The age of the Morrison formation: Am. Jour. Sci., 5th ser., vol. 12, p. 207, 1926.

[69] Matthew, W. D., and Brown, Barnum, The family Deinodontidae with notice of a new genus from the Cretaceous of Alberta: Am. Mus. Nat. History Bull., vol. 46, pp. 367–385, 1922.

son. As the relations between the Arundel formation and the underlying Patuxent formation are said to be intimate and the Patuxent is assigned to a "Neocomian" (Valanginian-Hauterivian)-Barremian age, the evidence of the Potomac group would point to a Jurassic age for the Morrison rather than Cretaceous.

With respect to items 9 and 11 of the list given above, there is apparently general agreement today that the Wealden is Cretaceous. If, therefore, the Morrison reptilian fauna is to be correlated with that of the Wealden the Morrison must be placed in the lower part of the Lower Cretaceous. Marsh and others stoutly supported this correlation in several publications. Williston [70] in 1905 seemed to minimize the value of general comparison of the dinosaurs but arrived at the general conclusion stated in item 9. He thought certain elements in the fauna surely Cretaceous, but, as Schuchert [71] has indicated, these came from beds that are now given a post-Morrison assignment stratigraphically and are not relevant. Osborn [72] in 1915 indicated that the Wealden iguanodont dinosaurs were more specialized than those of the Morrison and that the Kimmeridgian forms were similar to those of the Morrison; that the sauropod dinosaurs of the Oxfordian were like the most primitive forms of the Morrison; that therefore part of the Morrison fauna is "truly Jurassic," though part may be "truly Lower Cretaceous." Lull [73] in 1915 cited two American genera of sauropods doubtfully identified in Europe but considered them of little comparative value. The stegosaurian dinosaurs of the Wealden, he says, include one group not represented in America until Lakota time, the other British stegosaurs of the Kimmeridgian and older horizons being close to those of the Morrison but perhaps less specialized. Simpson [74] has recently reviewed the reptilian faunas in the light of later studies in Europe and America. He finds the Sauropoda to have little value for correlation between Europe and America; the Theropoda to show strong evidence of Jurassic (pre-Wealden) age for the Morrison and Cretaceous age for the Arundel formation; the Ornithopoda to show strong evidence of Jurassic age for the Morrison and Cretaceous age for the Lakota sandstone; and the Stegosauria to show strong evidence for Jurassic age for the Morrison and Cretaceous age for the Lakota. The Reptilia other than the dinosaurs are in the main weak evidence, though they also indicate Jurassic age for the Morrison. Simpson concludes that the reptilian forms indicate a pre-Purbeckian (Kimmeridgian or Portlandian) age for the Morrison and not in any way a Wealden age.

With respect to item 10, the Tendaguru beds of the former German East Africa, now Tanganyika Territory, have been described or discussed in several publications, and their relations to one another and to deposits at other places have been much debated. The determination of these relations is of importance, for at Tendaguru there is an intimate association of marine beds and dinosaur-bearing beds. Schuchert [75] in 1918 reviewed the original German papers at some length and in 1934 some of the later publications. For the present purpose it is sufficient to use these able summaries. It is shown that at Tendaguru there are three zones containing dinosaur remains, each of which is followed by a marine zone. The German students originally considered the series continuous and extending from medial Upper Jurassic time into the Neocomian. The uppermost marine zone and the uppermost dinosaur zone were assigned to the Cretaceous; the four underlying zones were assigned to the Jurassic. Schuchert, adopting a suggestion by S. S. Buckman, proposed to consider the three dinosaur zones Jurassic, leaving only the upper marine zone in the Cretaceous. This suggestion seemed very plausible, for the middle and upper dinosaur zones are said to have almost indentical faunas, the middle marine zone contains ammonites that are assigned by everyone to the Jurassic, and the upper marine zone is assigned with equal unanimity to the Neocomian. Simpson [76] in 1926 considered the evidence briefly and agreed with Schuchert's interpretation. Kitchin [77] in 1926 discussed the Malone formation of Texas and incidentally the Tendaguru succession, and in 1929 [78] he described at some length the Tendaguru beds. He calls attention to the reported association in the Malone formation of undoubted Jurassic ammonites with pelecypods, particularly species of *Trigonia*, of types that have been considered purely Cretaceous wherever found, and to the presence in the middle marine zone at Tendaguru of a similar association. Kitchin proposed to place all these beds in the Cretaceous, assuming for the Malone formation that an unconformity had been overlooked and two distinct faunas mixed in collecting, and for the Tendaguru deposits that the Jurassic ammonites were reworked from some unknown source in Cretaceous time. It is certainly true that most, if not all, of the present records, other than the two cited, assign the particular

[70] Williston, S. W., The *Hallopus*, *Baptanodon*, and *Atlantosaurus* beds of Marsh: Jour. Geology, vol. 13, pp. 338-350, 1905.

[71] Schuchert, Charles, Age of the American Morrison and East African Tendaguru formations: Geol. Soc. America Bull., vol. 29, p. 262, 1918.

[72] Osborn, H. F., Close of Jurassic and opening of Cretaceous time in North America: Geol. Soc. America Bull., vol. 26, p. 298, 1915.

[73] Lull, R. S., Sauropoda and Stegosauria of the Morrison of North America compared with those of Europe and eastern Africa: Geol. Soc. America Bull., vol. 26, p. 330, 1915.

[74] Simpson, G. G., The age of the Morrison formation: Am. Jour. Sci., 5th ser., vol. 12, pp. 205-210, 1926.

[75] Schuchert, Charles, Age of the American Morrison and East African Tendaguru formations: Geol. Soc. America Bull., vol. 29, pp. 245-280, 1918 (references to the original German papers are given); The Upper Jurassic age of the Tendaguru dinosaur beds: Am. Jour. Sci., 5th ser., vol. 27, pp. 463-466, 1934.

[76] Simpson, G. G., The age of the Morrison formation: Am. Jour. Sci., 5th ser., vol. 12, p. 210, 1926.

[77] Kitchin, F. L., The so-called Malone Jurassic formation in Texas: Geol. Mag. vol. 63, pp. 454-469, 1926.

[78] Kitchin, F. L., On the age of the upper and middle dinosaur deposits at Tendaguru, Tanganyika Territory: Geol. Mag., vol. 66, pp. 193-220, 1929.

types of pelecypods in question to the Cretaceous, on indisputable evidence for at least some localities. Nevertheless it seems to the writers a remarkable thing that on two continents late Jurassic ammonites (Portlandian, according to Spath[79]) should be associated with similar peculiar pelecypods, and in both cases it should be necessary to call for extraordinary circumstances in explanation. With respect to the Malone formation, there is no warrant to assume an accidental mixture, and indeed field evidence indicates that the ammonites and the pelecypods are naturally associated.[80] Adkins[81] has recently discussed the Malone formation, postulating an "inferred unconformity" somewhere within it but not making very clear his idea of relationships of the disputed fossils. With respect to the Tendaguru beds it seems to the writer entirely gratuitous to assume the reworking of the ammonites. Indeed, Dietrich's restudy of the invertebrate material from Tendaguru, as reported by Schuchert, appears definitely to exclude any possibility of Cretaceous age for the middle marine zone, and to confirm an assignment to horizons older than upper Portlandian. No one questions the Jurassic age of the ammonites in the Malone and Tendaguru formations, and it would seem on general principles more reasonable to postulate uncertainty in our knowledge of the stratigraphic range of the debated types of pelecypods than to cast out the ammonites for a cause wholly unsupported by direct field evidence. A late contribution to the subject is that of Parkinson,[82] who follows essentially the German interpretation by putting the upper dinosaur zone at Tendaguru into the Wealden—that is, into the Cretaceous of most recent writers—and the four lower zones into the Jurassic Kimmeridgian and Oxfordian. He recognizes, however, very intimate relations between the upper and middle dinosaur zones and the middle and lower marine zones and in addition a disconformity between the upper dinosaur zone and the upper marine zone. Reck[83] has recently judged the flying reptiles of the Tendaguru beds to indicate a Jurassic age because of close relationship with the European Jurassic forms. He finds the same genera in the African deposits as in the American Morrison formation. To the writers the most reasonable view is still that of Buckman and Schuchert, reiterated in the latter's more recent review, that only the upper marine zone is Cretaceous.

The bearing of all this on the age of the Morrison is that the Morrison reptile fauna is very close to that contained in the upper and middle dinosaur zones at Tendaguru. Simpson says they are "practically identical." Even though the two areas of occurrence are remote and even though there may still be some difference of opinion as to the age of the African deposits, the writers believe the sum of the evidence to favor a Jurassic age assignment for them and therefore for the Morrison.

With respect to item 12, the mammals of the Morrison have been recently restudied by Simpson[84] and compared with the European faunas. He finds the older opinion completely substantiated. Three genera are common to the Morrison and the Purbeck, and others are closely comparable. The Wealden has only one mammal, and it is more advanced in type than its nearest relative in the Morrison.

With respect to item 13, the few plants of the Morrison are not now believed to be valuable for close age assignment, for very similar types occur in both Jurassic and Cretaceous beds. The Morrison flora is very small, consisting of cycadeoid trunks and of as yet unstudied silicified wood. The ascription of certain collections of Cretaceous plants from the Big Horn Basin, Wyo.,[85] and from Colorado[86] to the Morrison formation is no longer accepted. The first collection was said to have come from the very top of the formation, from beds lithologically similar to the overlying Cloverly formation; the second came from beds originally included in the Morrison but now considered unquestionably a part of the overlying Cretaceous deposits.

Lee[87] and others have advanced the idea that the thick gypsum deposits assigned in the present paper to the base of the Morrison could not have formed without an abundant supply of sea water. Certainly there are substantial beds of gypsum within the San

[79] Spath, L. F., On the Cephalopoda of the Uitenhage beds: South African Mus. Annals, vol. 28, pt. 2, pp. 135–136, 1930; The Jurassic ammonite faunas of the neighborhood of Mombasa, in Reports on geological collections from the coastlands of Kenya Colony: Hunterian Mus. Geol. Dept. Mon. 4, pp. 13–76, 1930.

[80] Stanton, T. W., oral communication.

[81] Adkins, W. S., The Mesozoic systems in Texas: Texas Univ. Bull. 3232, vol. 1, pt. 2, pp. 254–257, 1933.

[82] Parkinson, John, A note on the geology of the country around Tendaguru, Lindi district: Geol. Survey Dept. Tanganyika Terr. Short Paper 6, 1930; The dinosaur in East Africa, London, 1930.

[83] Reck, Hans, Die deutschostafrikanischen Flugsaurier, vorläufige Mitteilung: Centralbl. Mineralogie, 1931, Abt. B, Nr. 7, pp. 321–336.

[84] Simpson, G. G., American Mesozoic Mammalia: Yale Univ. Peabody Mus. Mem., vol. 3, pt. 1, 1929.

[85] Knowlton, F. H., Note on a recent discovery of fossil plants in the Morrison formation: Washington Acad. Sci. Jour., vol. 6, pp. 180–181, 1916.

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Rafael group and in close association with fossiliferous marine deposits, though the writers think that the discontinuous beds of gypsum associated with the Morrison do not demand sea waters as an essential to their formation. If Lee's thesis is accepted, the widespread occurrence of gypsum in the lower part of the Morrison, as understood in this paper, connects it intimately with the underlying marine Jurassic. Where limestones occur in association with these Morrison gypsum beds, as in northern New Mexico, fossils are ordinarily very scarce. Those found have been of fresh-water types, though it is conceivable that a coastal lagoon might at times receive fresh water and contain fresh-water organisms, although in the main it was receiving marine waters.

In summary, the Morrison formation must fall somewhere between late Argovian and Barremian time—that is, within the Kimmeridgian, Portlandian, or Tithonian of the Jurassic or the Valanginian or Hauterivian of the Cretaceous. The physical relations, as the writers see them, lend little strength to an argument for Cretaceous age, though they have been advanced in its favor. None of the correlations with American Lower Cretaceous formations are valid—particularly not that with the Arundel formation, so often cited. Past correlations with the Lower Cretaceous Wealden beds are no longer accepted, for the mammalian and reptilian fauna of the Morrison are closest to accepted late Jurassic faunas and are earlier than Wealden. The close faunal relationship with the African Tendaguru beds with their marine intercalations again argues for a Jurassic age. The writers, in brief, can see little basis for an assignment of the Morrison formation to the Cretaceous and much, especially the faunal evidence, for an assignment to the Jurassic, which is therefore made in this paper.

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