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THE MIDDLE JURASSIC SAN RAFAEL GROUP AND RELATED ROCKS IN EAST-CENTRAL UTAH

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INTRODUCTION

The San Rafael Group of Middle Jurassic age is widely exposed in the uplands of the San Rafael Swell (fig. 1) and throughout much of the lowlands of the Green River Desert. Eastward from the Green River, the San Rafael Group is well displayed in high escarpments that form an almost continuous line of outcrop to Westwater Can yon. Between Courthouse Rock and Salt Valley the line of outcrop is interrupted and concealed by faulting. In the San Rafael Swell the group consists of five formations, in ascending order, Page Sandstone, Carmel Formation, Entrada Sandstone and the Curtis and Summerville Formations. In the Westwater Canyon area near the eastern border of Utah, the San Rafael Group is represented

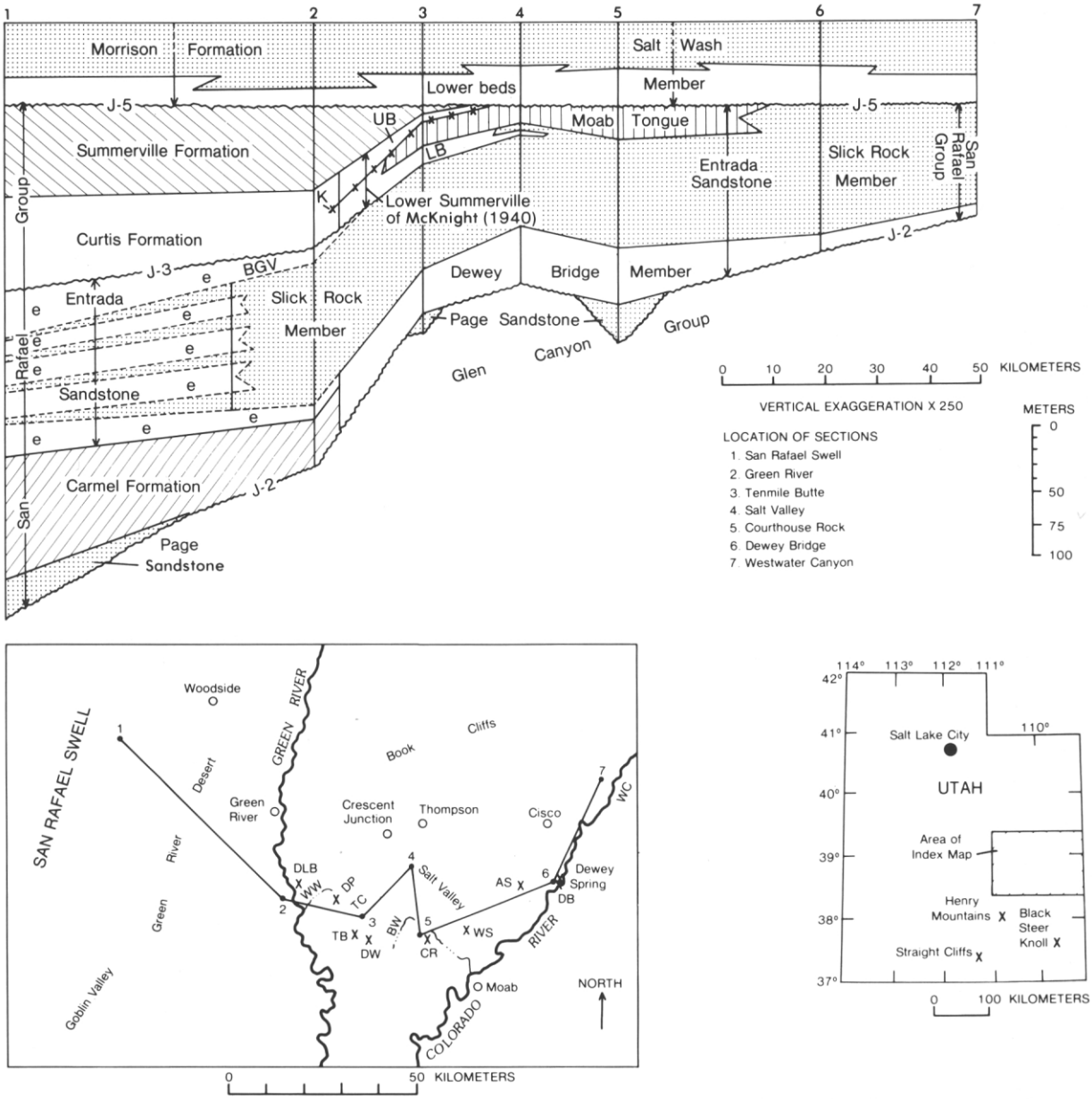


Figure 1. Index map and stratigraphic diagram showing correlation of San Rafael Group and related rocks. Symbols on diagram include: earthy facies of Entrada (E); bed at Black Steer Knoll (K); beds at Goblin Valley (BGV); and upper (UB) and lower (LB) beds of lower Summerville of McKnight (1940). Symbols on the map include: Auger Spring (AS); Bartlett Wash (BW); Courthouse Rock (CR); Dellenbaugh Butte (DLB); Dewey Bridge (DB); Dubinky well (DW); Duma Point (DP); Tenmile Butte (TB); Tenmile Canyon (TC); Willow Spring (WS); and White Wash (WW). J-2, J-3, and J-5 are unconformities discussed in the text.

solely by the Entrada Sandstone. Throughout the area the group is underlain by the Glen Canyon Group of Triassic and Jurassic age and is overlain by the Morrison Formation of Late Jurassic age.

STRATIGRAPHY

The distribution of the various parts of the San Rafael Group and their relationship to overlying and underlying rocks is shown on Figure 1. The stratigraphic diagram, as well as most of this report, is primarily a summary of two separate investigations (O'Sullivan, 1980 and 1981) describing Jurassic rocks from the Green River eastward about 74 km to Dewey Bridge. Some additional observations to the west in the San Rafael Swell and to the east near Westwater Canyon are included.

Sources of Data

The stratigraphic diagram (fig. 1) is derived from several sources. Most of the section in the San Rafael Swell (sec. 1) is from Wright and others (1979, p. 43-56) and was measured in secs. 3 and 4, T. 19 S., R. 12 E. The Page Sandstone in the San Rafael Swell (sec. 1) was measured by G. N. Pipiringos (oral commun., 1964) in sec. 18, T. 19 S., R. 11 E. The Carmel Formation and Entrada Sandstone in the composite section at the Green River (sec. 2) is from Wright and others (1962, fig. 2, no. 1 sec.) and was described from exposures in sec. 4, T. 24 S., R. 16 E. The upper part of the Green River section was measured by the writer near Dellenbaugh Butte in secs. 12 and 13, T. 23 S., R. 16 E. The Entrada Sandstone at Ten- mile Butte is from Craig and others (1959, no. 204 sec.) and was described in sec. 23, T. 24 S., R. 18 E. The upper part of the Tenmile Butte section was measured by the writer in secs. 1 and 12, and the Page Sandstone was measured in sec. 27, T. 24 S., R. 18 E. All the other measurements are by the writer and the locations of the stratigraphic sections are as follows: Salt Valley (sec. 4) in secs. 30 and 32, T. 22 S., R. 20 E.; Courthouse Rock (sec. 5) in secs. 20, 28 and 29, T. 24 5., R. 20 E.; Dewey Bridge (sec. 6) in sec. 7, T. 23 5., R.

24 E.; and Westwater Canyon (sec. 7) in secs. 9 and 16, T. 20 S., R. 25 E.

Unconformities

Three unconformities are associated with the San Rafael Group in east-central Utah. Two of these unconformities—termed J-2 at the base of the San Rafael and J-5 at the top—are also recognized throughout much of the Western Interior of the United States. The J-2 erosion surface is also informally termed the "chert pebble unconformity" because basal beds of the San Rafael Group nearly everywhere are characterized by ubiquitous chert pebbles and granules (fig. *2A).* An unconformity within the San Rafael referred to as J-3 at the top of the Entrada Sandstone is much less widespread and is difficult to recognize east of White Wash. The J-4 unconformity above the J-3 surface is truncated southward by the J-5 unconformity far to the north of Moab and is absent in east-central Utah. The unconformities and their regional stratigraphic significance are discussed more completely in a report by Pipiringos and O'Sullivan (1978).

Page Sandstone

The Page Sandstone (Peterson and Pipiringos, 1979, p. B20-B30) crops out primarily in a broad belt 65-80 km wide that trends about N. 15° E. and extends from the Straight Cliffs area of south-central Utah through the San Rafael Swell and into northern Utah. relatively small outliers of the Page Sandstone are recognized between the Green River and Salt Valley in east-central Utah. The Page is a light gray to reddish-tan fine-grained sandstone. In the San Rafael Swell, the Page is a highly crossbedded eolian sandstone (fig. *2B)* about 30 m thick. In the swell, the Page is very similar to the underlying Navajo Sandstone in bedding and lithology, because it was undoubtedly derived from the Navajo and deposited in a similar environment. Near Tenmile Butte (sec. 3) the Page is 10 m thick and consists of a series of interdune flat beds as much as 1.5 m thick alternating with eolian crossbedded units as much as 3 m thick. At Courthouse Rock (sec. 5), the gray Page Sandstone is locally at least 30 m thick and consists almost entirely of flat-bedded units (fig. *2C)* with only one crossbedded unit near the middle which is less than 1 m thick. Most of the Page of Courthouse Rock in all probability represents deposition in water. The Page Sandstone in east-central Utah appears to have been deposited in broad erosional depressions formed in the top of the Navajo Sandstone, possibly during the time the J-2 unconformity developed.

Carmel Formation

The Carmel Formation is of diverse lithology. In the stratigraphic section at the San Rafael Swell (sec. 1) about 75 percent of the Carmel Formation consists of greenish-gray and minor reddish-brown siltstone and shale in units as much as 10 m thick (Wright and others, 1979, p. 52-56): Limestone, sandstone and gypsum form a subordinate lithology. Gypsum is present in massive beds as much as 3.6 m thick, as a disseminated constituent and in veins and thin seams that cut other lithologies. Gypsum is most con-

Figure *2.* Views *of San Rafael Group and Morrison* Formation.

A Closeup *of pebbles on 1-2 unconformity near Courthouse Rock in NW¼,* sec. *28, T. 24 S., R. 20 E.*

B *Page Sandstone in San Rafael* Swell *in sec.* 18, *T. 19 S., R. 11 E.* Feet *of the* geologists are *on J-2 unconformity, which is basal unconformable* contact *of Page and underlying Glen Canyon Group. Photograph by G. N. Pipiringos.*

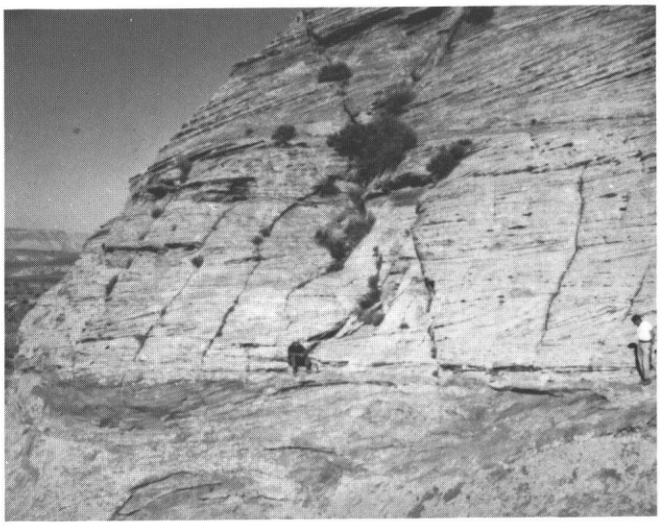
C *Lower part of Page Sandstone near Courthouse Rock in SWY,* sec. *28, T. 24 S., R. 20 E.*

D *Jurassic rocks near Duma Point in NW¼ sec. 30, T. 23, S., R. 18 E.* Top *of Slick Rock Member (SR) of Entrada Sandstone; lower Summerville* of *McKnight (1940) includes lower beds (LB), bed at Black Steer Knoll (K) and upper beds (UB); the basal red ledge (RL) of Summerville Formation; bed A (A) at base of Morrison Formation overlies the J-5 unconformity. The* lower *beds of the Salt Wash Member are 10.8 m thick and extend from the I-5 unconformity to the thick fluviatile sandstones* on upper *part of mesa. About 2.5 km to the east, the Moab* Tongue appears *beneath the bed at Black Steer Knoll.*

E *Lower beds* of *Salt Wash Member unconformably overlying Moab Tongue about 4.8 km west of Auger Spring in SWY,,SE% sec. 10, T.23 S., R. 22 E. Bed B (B) makes* ledge *at top of slope.* Compare *with fig.* 2D. *Strata at Duma Point from bed A through the bed at Black Steer Knoll have been removed by erosion along the 1-5 unconformity.*

F *Morrison Formation unconformably overlying Entrada Sandstone in SWY,,NW¼, sec. 8, T. 23 S., R. 24 E. near Dewey Spring. Bed A (A) makes ledges at top of Slick Rock Member; bed B (B) is* 0.5 m *thick at top* of *lower cliff. Lower beds of Salt Wash* are 30 *m thick and* extend from *base of bed A to base of thick fluviatile sandstone in upper part of cliff. J-5 unconformity is at base of bed A.*

A.



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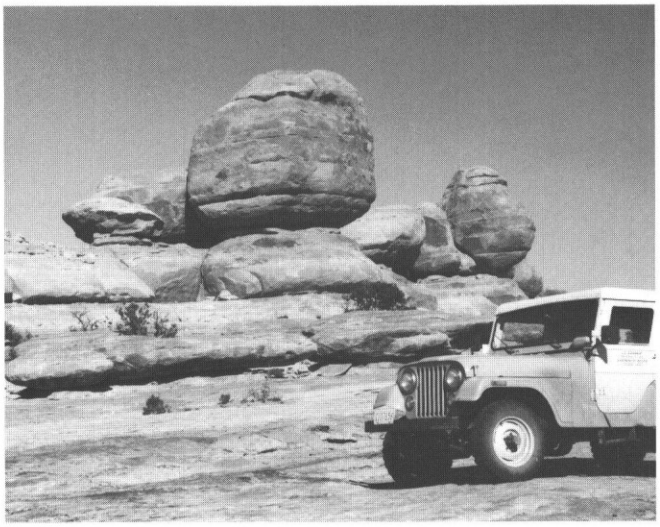

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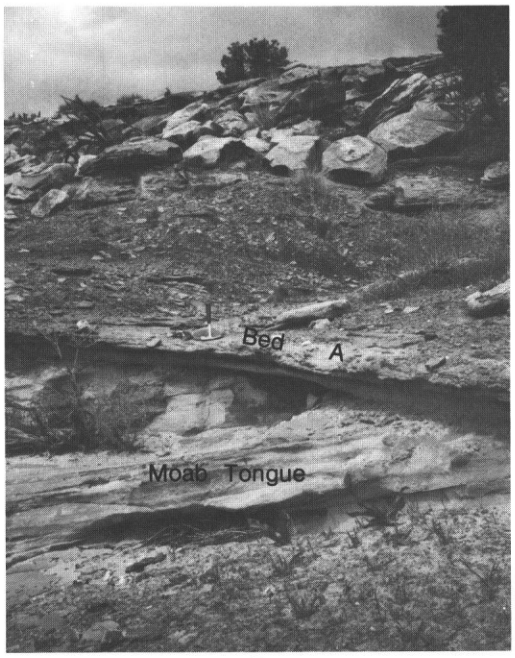

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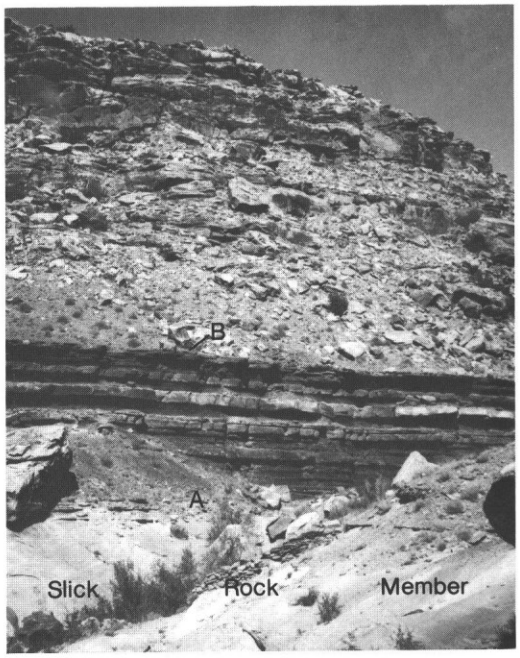

F.

Figure 2.

spicuous in the upper two-thirds of the formation. Gray, oolitic, ledge-forming limestone beds containing marine fossils are as much as 2.5 m thick. The limestone beds are found mainly in the lower one-third of the formation. Sandstone beds are commonly gray and as much as 2.5 m thick. Eastward from the San Rafael Swell, sandstone beds increase in abundance, and near the Green River (sec. 2) most of the Carmel consists of about equal amounts of sandstone and shale or siltstone (Wright and others, 1979, p. 83-87). Marine limestones and gray sandstone beds in the lower part of the Carmel disappear eastward towards the Green River by progressively onlapping the J-2 unconformity. The upper part of the Carmel Formation grades laterally into the lower part of the Entrada (Dewey Bridge Member) in a zone of transition extending from 3.2 to 8 km east of the Green River. The intergrading relationship of Carmel Formation and Entrada Sandstone are discussed in detail by Wright and others (1962, p. 2057-2062).

Entrada Sandstone west of the Green River

The Entrada Sandstone consists of siltstone and sandstone in differing proportions which vary regionally. In the San Rafael Swell (sec. 1), the Entrada Sandstone is mostly very fine grained sandstone to siltstone with only four clean partly crossbedded sandstone units, all less than 4.7 m thick (Wright and others, 1979, p. 49-51). The amount of siltstone diminishes eastward as succinctly described by Baker and others (1936, p. 7): "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. . . . Eastward from the San Rafael Swell this earthy facies passes into less earthy, irregularly bedded sandstone. . . 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 . . . with intricate cross bedding between horizontal bedding planes. . . ." The earthy facies of the Entrada Sandstone in the San Rafael Swell area is considered of nearshore marine origin (Baker, 1946, p. 80) marginal to marine rocks elsewhere in Utah.

Siltstone or earthy sandstone units near the base and top of the Entrada Sandstone are noteworthy. Over wide areas in an adjacent to the Green River Desert, siltstone beds at the top of the Entrada are referred to as the beds at Goblin Valley. Near the Green River (sec. 2), red siltstone in the lower part of the Entrada Sandstone can be traced eastward into the upper part of the Dewey Bridge Member (Wright and others, 1962, p. 2059).

The siltstone unit referred to as the beds of Goblin Valley has been discussed previously. McKnight (1940, p. 92) described these beds east of the Green River as ". . . a brownish-red muddy sandstone that weathers into rounded "rock baby" surfaces. The bedding is poor but appears to be largely horizontal. . . . This facies of the Entrada resembles the typical Entrada of the San Rafael Swell and is unlike anything developed to the east." In the Green River Desert, Baker (1946, p. 76) recognized the beds at Goblin Valley in the Entrada Sandstone as a ". . . zone of earthy sandstone 60 to 100 feet thick at the top of the formation . . . across the area. . ." At places in the Henry Mountains, Hunt (1953, p. 71) reported that ". . . the upper beds of the Entrada have eroded very irregularly and give rise to clusters of small grotesquely shaped buttes." In Goblin Valley, a locality southeast of San Rafael Swell, the beds at Goblin Valley are eroded into a particularly bewildering maze of spheroidal forms termed "hoodoos," "stone-babies," or "goblins." A part of the valley has been set aside as Goblin Valley State Park because of these interesting and peculiar erosional features.

Entrada Sandstone east of the Green River

East of the Green River, three formal subdivisions are recognized in the Entrada Sandstone. The Dewey Bridge Member at the base overlain by the Slick Rock Member are present throughout the area. The Moab Tongue at the top of the Entrada is found only over a more limited area (fig. 1).

Dewey *Bridge Member*

The Dewey Bridge Member over much of east-central Utah is the basal subdivision of the San Rafael Group. The member is a rather uniform dark-reddish-brown, very fine grained silty sandstone with a scattering of coarse grains particularly near the base. Throughout most of the area the basal part of the Dewey Bridge is a reworked zone, of variable thickness, which consists of nondescript, light- colored sandstone and intermixed chert pebbles associated with the J-2 unconformity. The member, particularly the upper part, tends to weather to rounded spheroidal forms known as hoodoos, stone babies or goblins. Here and there, the strata of the Dewey Bridge Member are deformed into convoluted folds of various dimensions. The Dewey Bridge is in part equivalent to, but is lithologically unlike the Carmel Formation. The member lacks the marine limestones, gypsum beds, green siltstone and shale units and gray sandstone beds typical of the Carmel Formation. The Dewey Bridge closely resembles the silty beds of the earthy facies of the Entrada in the San Rafael Swell and similarly is probably of nearshore marine origin.

Slick Rock Member

The Slick Rock Member is present throughout most of east-central Utah. The member is recognized to a point about 16 km west of Green River where much of it grades into earthy sandstone or siltstone (Wright and others, 1962, p. 2062). To the west over most of the Green River Desert and the San Rafael Swell, the Slick Rock is not differentiated and consequently the Entrada Sandstone is not subdivided into separate members. The Slick Rock Member consists of gray, reddish-tan and reddish-brown sandstone arranged in a series of crossbedded and massive or flatbedded units or beds separated by horizontal bedding planes. In the 4 sections at Salt Valley (sec. 4), Courthouse Rock (sec. 5), Dewey Bridge (sec. 6) and Westwater Canyon (sec. 7), where the entire Slick Rock was measured, the member consists of a total of 141 individual beds or units: of this total 78 are flatbedded units as much as 15.2 m thick averaging 2.02 m, and 63 are crossbedded units as much as 19.2 m thick averaging 2.64 m. The crossbedded units are of eolian origin and the flatbedded units represent interdune deposits.

Moab Tongue

The Moab Tongue is the youngest part of the Entrada Sandstone. At Courthouse Rock (sec. 5) and east of Salt Valley (sec. 4), the Moab Tongue rests directly on the Slick Rock Member, but the two units can be distinguished from each other by bedding characteristics. Near courthouse Rock (sec. 5) the Moab Tongue forms a single unit consisting solely of crossbedded eolian sandstone about 27 m thick that is unbroken by any flatbedded sandstone units. In contrast, the underlying Slick Rock Member consists of numerous flat and crossbedded units all of much lesser thickness. As thus defined, the Moab can be traced almost to Auger Spring, a locality about 30 km east of Salt Valley (sec. 4). At Auger Spring a

flatbedded unit lies within the sequence of beds that are laterally equivalent to the Moab Tongue. From Auger Spring eastward to Westwater Canyon, the strata between the Dewey Bridge Member and the J-5 unconformity are all assigned to the Slick Rock Member. It is obvious, however, that stratigraphic representatives of the Moab Tongue are in the upper part of the Slick Rock Member east of Auger Spring. The vertical jagged line on the stratigraphic diagram (fig. 1) that separates Moab Tongue from the Slick Rock Member indicates a lateral gradation and reflects the close affinity of the two units. The Moab Tongue as used herein joins the main body of the Entrada near Auger Spring; using different criteria Dane (1935, p. 94) and Wright and others (1962, p. 2067) traced the Moab from Auger Spring to Westwater Canyon. West of Bartlett Wash the bedding characteristics of the Moab are different. In the Tenmile Butte area (sec. 3), the Moab contains flatbedded sandstone units, but the tongue can be easily distinguished because it is separated from the Slick Rock Member by an underlying westward-thickening wedge of red beds. The flatbedded units in the Moab Tongue above the red beds reflect a lateral westward gradation into red beds. A short distance west of Tenmile Canyon the Moab Tongue cannot be differentiated. The intermixed flatbeds and crossbeds in the Moab west of Bartlett Wash record a progressive change from the thick eolian sandstone in the east to the marginal marine red beds in the west.

Curtis Formation

The Curtis Formation overlies the Entrada Sandstone. The formation consists principally of gray to greenish-gray fine- to very fine grained sandstone and interbedded green siltstone. Sandstone is generally glauconitic and is in beds less than 2 m thick which commonly are ripple marked or crossbedded. Conglomeratic sandstone beds are present sparsely thoughout the Curtis but generally are concentrated near or at the base of the formation and locally fill depressions cut into the top of the Entrada along the J-3 unconformity. Gypsum and sandy limestone in thin beds constitute a minor lithology. At Dellenbaugh Butte, 21 dark-reddish-brown to purple shales are interspersed through the Curtis Formation in beds all less than 100 mm thick. Similar clay beds occur elsewhere. Viewed from a distance, the Curtis shows two different weathering aspects; a lower ledge-forming part and an upper slope-forming part. Fossils in the Curtis formation indicate that it is of marine origin.

The Curtis Formation changes color where its outcrop crosses White Wash. E. T. McKnight mapped the Curtis eastward from the Green River and in his report states (McKnight, 1940, p. 98): "In the San Rafael Swell, the Curtis is a well-defined unit, differing from the Summerville not only in its light-greenish-gray to whitish color but also in its constitution, being more nearly a true sandstone as compared with the muddy sandstones and shales of the Summerville. In the area covered by this report, however, the distinction between the two is rather artificial and would never have been made had this area alone been considered. The Curtis here has about the same physical constitution as the Summerville, from which it differs in showing a general greenish-gray rather than reddish tone. All the Curtis sections east of the Green River show some red coloration, which gradually increases in amount to the east until the red color predominates, whereupon the Curtis loses its identity and becomes lower Summerville." McKnight (1940, pl. 1), for convenience, arbitrarily did not extend the Curtis Formation east of the NW% sec. 15, T. 23 S., R. 17 E., a locality on the west side of White Wash.

Lower Summerville of McKnight (1940)

Although the Curtis Formation is no longer recognized by McKnight east of White Wash, laterally equivalent strata are referred to as the lower Summerville of McKnight (1940). The lower Summerville of McKnight (1940), which is what the Curtis becomes, can be traced for some distance to the east of White Wash and consists of lower and upper beds separated by the bed at Black Steer Knoll. The lower Summerville of McKnight (1940) is undoubtedly a marginal marine deposit because of its position between the marine Curtis Formation to the west and the eolian Entrada Sandstone to the east.

Bed at Black Steer Knoll

The bed at Black Steer Knoll is a useful marker that is recognized over wide areas of east-central and southeastern Utah. The bed varies laterally somewhat in thickness, topographic expression, bedding structures, and lithology. Between White Wash and the Green River, it thins and passes westward into the Curtis Formation. From White Wash to Duma Point the bed at Black Steer Knoll generally weathers to a prominent double ledge of flatbedded sandstone and minor siltstone 1.2 m to 2.0 m thick, which can be visually traced for long distances. Farther east in the Tenmile Canyon area, the bed at Black Steer Knoll is as much as 3.8 m thick and is in part crossbedded. In the Bartlett Wash area, the bed at Black Steer Knoll is thinner than it is in the Tenmile Canyon area and is commonly well indurated with yellowish-gray limonitic cement.

Upper and lower beds

The units referred to as the upper and lower beds of the lower Summerville of McKnight (1940) consist largely of reddish-brown siltstone to sandy siltstone. The beds generally crop out in steep covered slopes in which bedding structures are absent or obscured. Thin dark reddish-brown to purple clay beds are a lithologic feature of the lower Summerville of McKnight (1940) and are particularly abundant in the lower beds. These thin clay beds are the same as those in the Curtis Formation at Dellenbaugh Butte. At places east of White Wash, the upper beds contain one or more conspicuous white sandstone beds, which lithologically resemble sandstone beds in the Curtis Formation. These white sandstones in the upper beds of the lower Summerville of McKnight (1940) east of White Wash reflect an intermixing of lithology typical of the Curtis Formation to the west with equivalent red bed lithology to the east.

Summerville Formation

The Summerville Formation, overlies the Curtis Formation and is considered a marginal marine unit. The Summerville consists of red siltstone and lesser amounts of sandstone and shale, all in very thin beds. Gypsum is present in the upper part of the Summerville as thin beds, nodules, and seams, that cut across bedding. A noteworthy feature of the Summevil le described by many geologists is the thin even bedding. Near the type locality in the northern part of the San Rafael Swell, Gilluly (1929, p. 109 stated that ". . . the bedding is very even and continuous. . . ." In the Green River Desert, A. A. Baker noted that the Summerville is ". . . in very thin regular beds" and also noted the ". . . thin regular bedding of the Summerville . . ." (Baker, 1946, p. 84 and 86, respectively).

The selection of the base of the Summerville Formation is arbitrary. At Dellenbaugh Butte, the contact, for convenience, is placed at the rather abrupt color change from the gray Curtis Formation to the red Summerville Formation. Eastward from White Wash, the contact is placed beneath a unit recognized as the red

ledge (fig. *2D),* a prominent rough ledge that can be traced from White Wash to Bartlett Wash. The red ledge and overlying strata assigned to the Summerville Formation form an eastward thinning wedge of red beds.

In the region between the Green and Colorado Rivers, all the red beds of the upper part of the San Rafael Group terminate in the Dubinky well-Salt Valley area. The Summerville Formation and the upper beds of the lower Summerville of McKnight (1940) as well as the bed at Black Steer Knoll are truncated beneath the J-5 unconformity at the base of the Morrison Formation. The lower beds of the lower Summerville of McKnight (1940) pass laterally eastward into the Entrada Sandstone near Salt Valley (sec. 4).

Morrison Formation

The Morrison Formation unconformably overlies the San Rafael Group throughout east-central Utah and is mostly of terrestrial origin. The Morrison is about 156 m thick near Duma Point and 188 m thick near Dewey Bridge (Craig and others, 1959, no. 64, and 52 secs. respectively); only the basal part of the Salt Wash which is the lower member of the Morrison is discussed herein. The Salt Wash member consists of a sequence of light-colored sandstone ledges interbedded with slope-forming shale and siltstone. A unit termed the lower beds forms a red siltstone slope in the basal part of the Salt Wash Member. The lower beds lie between the lowest prominent, very light gray, ledge-forming channel sandstone, and the top of the San Rafael Group. Thin dense gray limestone beds typical of the Morrison Formation in other parts of Utah are common in the lower beds. Gray ledge-forming sandstones, in which bedding is absent or not apparent, crop out at many localities. The lower beds also contain rounded limestone nodules and chert in thin beds or nodules. Gypsum is also present in some abundance from the San Rafael Swell to the White Wash area. The lower beds from Salt Valley eastward to Westwater Canyon include a light-gray to reddish-tan ledge-forming sandstone termed bed B (fig. *2E* and *F).* Bed B is 0.1 to 3.5 m thick and lies 3.6 to 20 m above the base of the lower beds. Coarse grains and ripple marks are conspicuous features of bed B. East of the Dubinky well area, the lower beds wholly or in part have previously been correlated with the Summerville Formation (Gilluly and Reeside, 1928, pl. 15; Dane, 1935, p. 102-106; McKnight, 1940, p. 99-102; Stokes, 1952, p. 10-11).

Bed A

A thin widespread sandstone arbitrarily termed bed A everywhere immediately overlies the J-5 unconformity and marks the base of the lower beds. Bed A is light gray to yellowish gray locally banded reddish-brown; less commonly bed A is reddish tan. The bed throughout east-central Utah is generally less than 0.5 m thick but locally it is as much as 2.5 m. thick. Here and there the bed is ripple marked and commonly forms a resistant ledge (fig. *2E)* that overhangs underlying rocks. Coarse to very coarse grains of chert and quartz, ranging from 1.5 mm to 5 mm across, are a characteristic feature of bed A. Coarse grains are plentiful in bed A from the San Rafael Swell to Salt Valley, less plentiful from Salt Valley to Dewey Bridge and very sparse or absent east of Dewey Bridge. The largest clast noted is an isolated quartz pebble measuring 11.6 mm across at a locality 6.7 km northeast of Courthouse Rock in the NWIANWY$_4$SE$_1$/$_4$ sec. 12, T. 24 S., R. 20 E. Green clay galls are found in bed A at many places, but are particularly abundant at a locality 7.2 km east of Courthouse Rock near the center of sec. 19, T. 24 S., R. 21 E., where the road to Willow Spring crosses the outcrop of bed A.

Tracks of dinosaurs are found in bed A at a locality about 0.5 km northwest of Courthouse Rock in the SW$_1$/$_4$NEIANEY, sec. 20, T.24 S., R. 20 E. The footprints heretofore were assumed to be in the Moab Tongue (McKnight, 1940, p. 94). The stratigraphic description of the track locality, however, clearly indicates that the footprints are in bed A. The footprints are described by McKnight (1940, p. 94) as ". . . in the very top of the Moab . . . preserved on a bedding plane that was either horizontal or else foreset at a very low angle." McKnight (1940, p. 97) further states that ". . . the track-bearing sand was deposited . . . beneath a red-bed series. . . ." The "red-bed series" referred to are the red siltstones of the lower beds of this report which immediately overlie bed A. Ripple marks present elsewhere in bed A indicate deposition in water. McKnight (1940, p. 97) in this regard states that "The tracks . . . prove that the sand in which they are imprinted was deposited by water. They could not have been preserved in dry wind-blown sand unless its surface had recently been wetted by rain, and such a surface would present a different appearance from the smooth, even bedding plane that is shown." The description just cited obviously applies only to bed A and not to the crossbedded eolian sandstone that makes up the entire Moab Tongue at the track locality. The footprints are on a slab of sandstone and McKnight (1940, p. 94) reports that "the trails of two or three animals are shown, the most perfectly preserved one of which records a bipedal creature with three functional toes, a 2 and one-half-inch foot, and an 8-inch stride.... Charles W. Gillmore, of the United States National Museum . . . reports that the animal making the tracks was probably an ornithopod dinosaur. . . .

The environment of deposition of Bed A is not completely understood. Ripple marks in bed A together with other bedding features obviously indicate currents in a body of water. The dinosaur foot prints were made under subaerial conditions after, probably soon after, the deposition of bed A. McKnight (1940, p. 97) discussed the implications of the conditions necessary to form and preserve the tracks and thought the necessary environment

.. would certainly prevail in fluviatile or delta deposits." Green clay galls in bed A suggest nearby source areas because the clay galls could not have survived a long transport cycle. The clay pebbles might have been derived from dried up mud in nearby terrestrial playa lakes. Clay galls also result from a process of fluviatile or tidal channel migration against clay banks. Although the conditions of deposition are uncertain, some geologists (L. C. Craig, oral commun., 1980) would exclude bed A and locally some overlying parts of the lower beds from the Morrison Formation because the strata seem more closely related to the San Rafael Group.

Base of the Morrison Formation

The lower boundary of the Morrison, as used herein, is at the J-5 unconformity. This is a minor downward change in the basal contact of the Morrison as used by many previous workers. According to L. C. Craig (written commun., 1980), some geologists place the base of the Morrison at the lowest indication of terrestrial deposition, a contact that lies at the base of the lowest channel sandstone, or lowest limestone, or lowest lenticular bed of sandstone, mudstone, or siltstone. In east-central Utah, this contact generally lies one or more meters above the J-5 unconformity. Locally however, channel sandstones are at or are very close to the J-5 unconformity. At a locality 8.8 km northeast of Dubinky well in the NWY$_4$NEX, sec. 23, T. 24, S., R. 19 E. a crossbedded fluviatile sandstone at least 1 m thick (the top is eroded) scours into the Moab Tongue. The fluviatile sandstone contains abundant green clay galls and shows as much as 0.6 m of relief in less than 3 m laterally.

At this locality the lowest channel sandstone coincides with the J-5 unconformity. At another locality 4.8 km southeast of Dubinky well in the NEIASEY, sec. 32, T. 24 S., R. 19 E., bed A is 1.5 m thick and consists of 2 parts. The lower 0.6 m is flat bedded and contains abundant clay galls; the upper 0.9 m is a crossbedded fluviatile sandstone with abundant green clay galls. Locally the upper crossbedded part of bed A interfingers with the lower flat beds indicating a close affinity of the 2 parts. However, at this locality, the lowest unequivocal terrestrial sandstone is 0.6 m above the J-5 unconformity. About 6.7 km northeast of Courthouse Rock in the SWY,NE$^{1}/_{4}$ sec. 12, T. 24 S., R. 20 E., the stratigraphic sequence above the Moab Tongue consists. of bed A 0.6 m thick overlain by 0.6 m of red siltstone in turn overlain by a crossbedded fluviatile sandstone 1 m thick. At this locality, 1.2 m separates the J-5 unconformity from the lowest undoubted terrestrial sandstone. The initial deposition of the Morrison Formation can be divided into two stages. During the time the lower beds of the Salt Wash Member were laid down, quiet water or sluggish streams must have prevailed as indicated by thin limestones and the fine-grained siltstone that make up much of the lower beds. Here and there a sporadic stream deposited thin fluviatile sandstones some near or on the J-5 unconformity. Later, after deposition of the lower beds, a well established stream system deposited thick, coarse fluviatile sandstones. The onset of the powerful stream system that characterized the later parts of Salt Wash time varied from place to place as shown by the intertonguing of the lower beds with overlying parts of the Salt Wash (fig. 1).

SUMMARY

Recent geologic investigations, briefly described herein, show some new and somewhat different interpretations of the stratigraphy of part of the Jurassic rocks of east-central Utah. The Page Sandstone is found as isolated lenses almost as far east as Moab. Tracing a key bed—the bed at Black Steer Knoll—reinforces the previous correlation of Moab Tongue with the Curtis Formation and additionally shows that the Moab is equivalent mainly to about the lower half of the Curtis. The Summerville Formation, which overlies the Curtis Formation, is completely truncated near Dubinky well and is therefore of much more limited extent than heretofore believed. Strata previously assigned to the Summerville Formation over large areas east and south of Dubinky well lie above the J-5 unconformity and are now recognized as part of the lower beds of the Salt Wash Member of the Morrison Formation. The J-5 unconformity forms a convenient—although not universally accepted—base of the Morrison Formation in east-central Utah. 95

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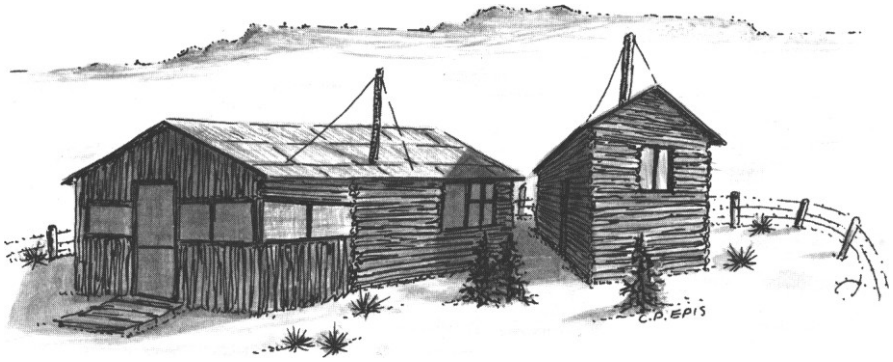

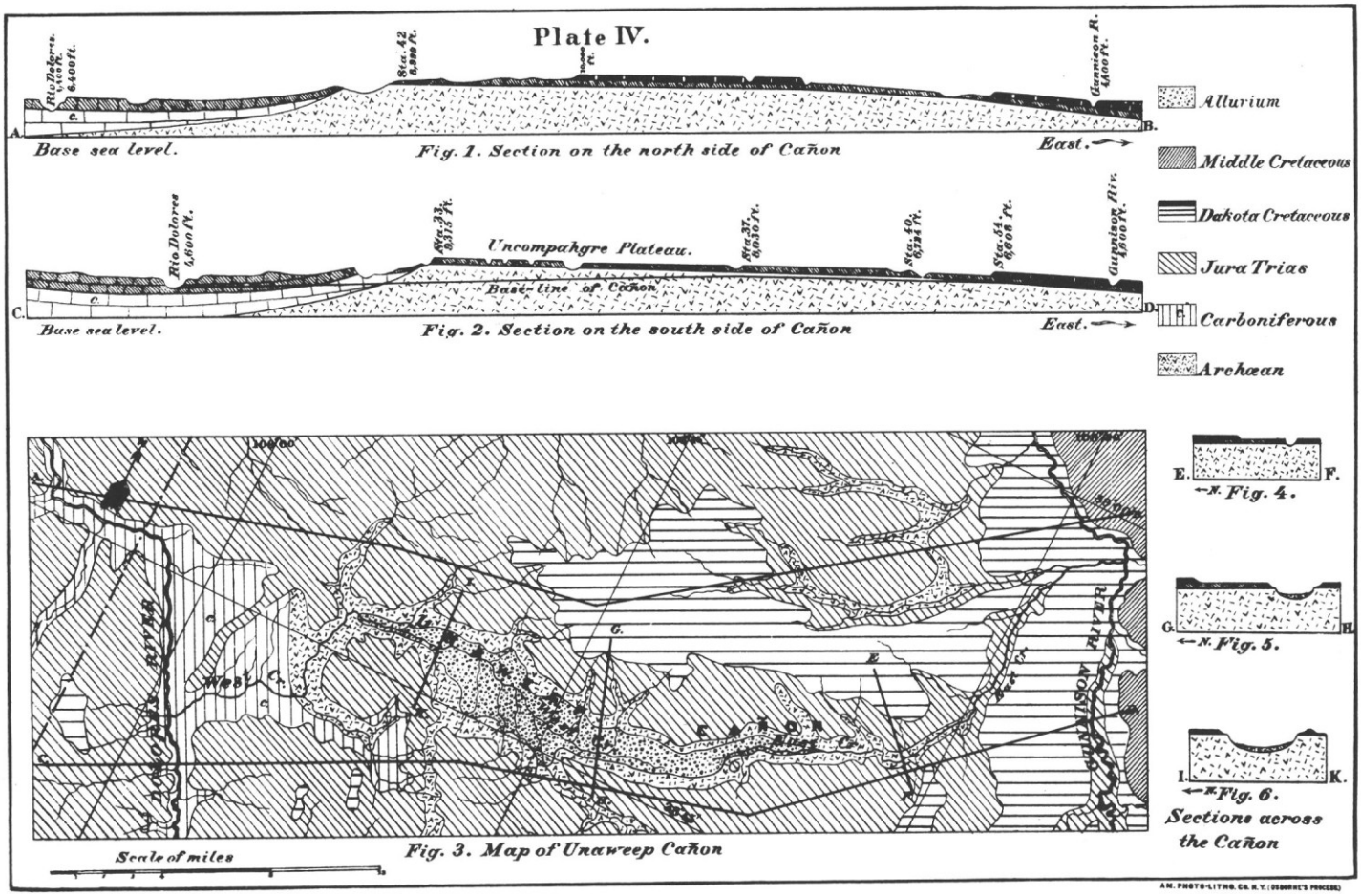

Geologic map and sections of Unaweep Canyon by A. C. Peale, Hayden Survey, 1874–75.